IMCA

Guidance for Diving Supervisors

International Marine Contractors Association

www.imca-int.com

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The International Marine Contractors Association (IMCA) is the international trade association representing offshore, marine and underwater engineering companies.

IMCA promotes improvements in quality, health, safety, environmental and technical standards through the publication of information notes, codes of practice and by other appropriate means.

Members are self-regulating through the adoption of IMCA guidelines as appropriate. They commit to act as responsible members by following relevant guidelines and being willing to be audited against compliance with them by their clients.

There are two core activities that relate to all members:

- Competence & Training
- Safety, Environment & Legislation

The Association is organised through four distinct divisions, each covering a specific area of members' interests: Diving, Marine, Offshore Survey, Remote Systems & ROV.

There are also five regional sections which facilitate work on issues affecting members in their local geographic area – Asia-Pacific, Central & North America, Europe & Africa, Middle East & India and South America.

IMCA D 022 Rev. 1

This document (formerly *The Diving Supervisor's Manual*) has been updated mainly to reflect changes in IMCA diving documentation.

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Date	**Reason**	**Revision**
May 2000	Initial publication	
May 2014	To reflect changes in IMCA diving documentation	Rev. 1
April 2015	Sections 9.13, 14.34.2 and 15.21 updated	Rev. 1
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Guidance for Diving Supervisors

IMCA D 022 Rev. 1 – August 2016

Introduction

1.1 The IMCA International Code of Practice for Offshore Diving[1]

The *IMCA international code of practice for offshore diving* (the Code), published in April 1998 and periodically revised, is intended to provide guidance and advice to diving teams, clients, contractors, vessel owners, installation and rig managers and safety personnel. It applies to all diving operations anywhere in the world which are:

- outside the territorial waters of a country (normally 12 miles or 19.25 kilometres from shore);
- inside territorial waters where offshore diving, normally in support of the oil and gas or renewable/alternative energy industries, is being carried out. Specifically excluded are diving operations being conducted in support of civil, inland, inshore or harbour works or in any case where operations are not conducted from an offshore vessel or floating structure normally associated with offshore oil and gas or renewable/alternative energy industry activities.

A number of countries in the world have national regulations and/or standards which apply to offshore diving operations taking place within waters controlled by that country and from vessels and floating structures registered in that country (flag state). In cases where the national regulations and/or standards are more stringent than this Code, they must take precedence over this Code and the contents of this Code should only be used where they do not conflict with the relevant national regulations/standards.

The contents include:

- duties, responsibilities and relationships;
- equipment;
- personnel;
- medical;
- operational planning;
- hyperbaric evacuation;
- emergency response and contingency plans;
- documentation/audits;
- country specific appendices.

1.2 IMCA Certification Schemes[2]

IMCA provides certification schemes for bell diving supervisors, air diving supervisors and life support technicians. The schemes comprise formal training courses followed by documented experience on the worksite. On completion of the relevant training and work experience the candidate, sponsored by a diving contractor member, will be put forward to sit the relevant IMCA examination. If successful, the candidate is awarded the appropriate IMCA certificate.

A bell diving supervisor will need to have passed both the air diving and bell diving modules of the certification scheme and be qualified and competent to supervise all surface and closed bell diving operations (including those in deck chambers).

An air diving supervisor will need to have passed the air diving module of the certification scheme and be qualified and competent to supervise all surface diving operations, including decompression in a deck chamber. The examination and training for an air diving supervisor does not included surface mixed gas diving techniques.

Possession of the certification does not necessarily imply that a supervisor is competent to carry out a specific operation. The diving contractor should be satisfied of the diving supervisor's competence before appointing him. Diving supervisors are to be appointed in writing by a letter of appointment from the diving contractor.

A diving superintendent or senior supervisor is an appropriately qualified diving supervisor who is in overall charge of an operation. Diving supervisors in charge of each part of the operation have direct responsibility for diving operations carried out under their control.

Life support technicians (LSTs) will need to have undergone an IMCA approved assistant life support technician (ALST) course; worked as an ALST for 2,400 panel hours; passed the LST module of the certification scheme; and be considered competent by the diving contractor.

Life support supervisors will need to have passed the LST module of the IMCA certification scheme. Only after having completed the requirements of the IMCA competence assurance and assessment guidelines and being considered competent by the diving contractor will they be considered qualified to supervise divers living in, or being compressed or decompressed in, a deck chamber.

Brief details of the IMCA offshore diving supervisor and life support technician schemes are given in Appendix 1. Full details can be found in IMCA D 013[2].

1.3 Qualification of Divers

All divers at work need to hold a suitable qualification for the work they intend to do. They will need to have the original certificate in their possession at the site of the diving project – copies should not be accepted.

IMCA only recognises two grades of diver under the Code. These are surface supplied divers and closed bell divers.

The list of certificates recognised by IMCA is constantly updated and the current list is available from IMCA.

1.4 The IMCA Competence Assurance and Assessment Guidelines[3]

IMCA's guidance on competence assurance and assessment has been developed to provide offshore contractors with a framework on which to build their own competence schemes, thereby giving the offshore industry, in general, confidence that all personnel appointed to safety-critical and other relevant positions can carry out their jobs in an effective manner.

It is not a qualification but a record of each person's qualifications, skills and ongoing development.

Within the diving team, safety-critical personnel in the scheme are superintendents, diving supervisors, divers, life support supervisors, LSTs, ALSTs, tenders, senior dive technicians and dive technicians.

Competence will be assessed by considering a range of criteria including qualifications, experience and technical skills.

Qualifications might include diving qualifications, IMCA certification, academic qualifications, medical certification or other vocational qualifications. Other skills will normally be assessed by approved in-house assessment.

The various competences for each job function, the knowledge and ability required to attain the competence and the method of demonstration are coded and tabulated in the guidance document.

For a bell diving supervisor, for example, the competence covering 'life support system operations' requires knowledge of the 'operation and hazards of life support and gas reclaim systems' and the ability to 'manage the safe operation of life support and gas reclaim systems'. The required knowledge and ability is demonstrated by 'completion of dive system familiarisation by company'; 'approved and documented in-service experience'; and 'assessment by approved company assessor'.

Full details and competence assessment tables for supervisors are given in IMCA C 003[3].

1 IMCA D 014 *IMCA international code of practice for offshore diving*
2 IMCA D 013 *IMCA offshore diving supervisor and life support technician certification schemes*
3 IMCA C 003 *Guidance document and competence tables: Diving Division*

Diving Physics

2.1 Units of Measurement

Two systems of measurement are commonly used in diving. The metric system, also known as the metre, kilogram, second (MKS) system or Système International (SI), is used by most companies. It is very easy to use as all of the units are based on a scale of 10 (European decompression tables, the Royal Navy tables and some other military tables are in metres).

The foot, pound, second (FPS) system is generally used by American companies and those using the US Navy tables. There are some differences between the imperial FPS system (still used in the UK) and US system which are noted below. On international worksites using FPS it is essential to have a clear agreement on the units being used.

2.2 The Metric System

Length	metres (m) 1,000 m = 1 kilometre (km) 100 centimetres (cm) = 1 m 10 millimetres (mm) = 1 cm
Velocity	metres/second, kilometres/hour (kph)
Area	square metres (m^2)
Volume	litres (ltr) or cubic metres (m^3) 1,000 ltr = 1 m^3
Weight or force	kilograms (kg) or tonnes (t) 1,000 kg = 1 t
Heat or energy	joules (J)
Temperature	degrees Celsius (°C) or Kelvin (°K)
Density	kilograms/litre (kg/l) tonnes/cubic metre (t/m^3)
Pressure	Pascals (Pa), millibars (mb), bar, metres of seawater (msw) 100,000 Pa = 1 bar 1,000 mb = 1 bar 10 msw = 1 bar

2.3 The FPS System

Length	foot (ft) 5,280 ft = 1 mile 6,080 ft = 1 nautical mile 12 inches (in) = 1 ft
Velocity	feet/second, miles per hour (mph), knot 1 knot = 1 nautical mile/hour
Area	square feet (ft^2)
Volume	cubic feet (ft^3) gallons (gal) 1 imperial gallon = 1.2 US gallons 1 US gallon = 0.83 imperial gallons
Weight or force	pounds (lb) or tons (ton) 2,240 lbs = 1 imperial ton 2,000 lbs = 1 US ton
Heat or energy	British thermal units (Btu) or therms 100,000 Btu = 1 therm
Temperature	degrees Fahrenheit (°F) or Rankin (°R)
Density	pounds/cubic foot (lb/ft^3)
Pressure	pounds per square inch (psi) atmospheres (atm), feet of seawater (fsw) 14.7 psi = 1 atm 33 fsw = 1 atm

2.4 Conversion Table

To convert from one unit to another, multiply by the number to the right. For example, to convert litres to US gallons, multiply by 0.264. To convert US gallons to litres, multiply by 3.79.

Although a conversion factor is given below, for most practical purposes, one bar can be considered equal to one atmosphere.

Unit	Conversion	Unit	Conversion	Unit
m	3.281	ft	0.305	m
metres/sec	1.944	knot	0.514	metres/sec
metres/sec	2.237	mph	0.447	metres/sec
m^2	10.765	ft^2	0.093	m^2
m^3	35.310	ft^3	0.02832	m^3
litre	0.035	ft^3	28.32	litre
litre	0.220	UK gal	4.546	litre
litre	0.264	US gal	3.79	litre
UK gal	1.201	US gal	0.833	UK gal
kg	2.204	lbs	0.454	kg
kg	0.000984	UK ton	1,017	kg
kg	0.0011	US ton	909	Kg
tonne	2,205	lbs	0.000454	tonne
tonne	0.984	UK ton	1.017	tonne
tonne	1.1	US ton	0.907	tonne
UK ton	0.893	US ton	1.12	UK ton
bar	0.987	atm	1.013	bar
bar	14.509	psi	0.069	bar
msw	3.3	fsw	0.303	msw
joule	0.000948	Btu	1,055.06	joule
°C	x 1.8 + 32	°F	-32 x 0.556	°C

2.5 Temperature

Temperature is measured in degrees Celsius (°C), degrees Fahrenheit (°F), degrees Kelvin (°K) or degrees Rankin (°R).

2.6 Celsius and Fahrenheit Scales

The Celsius and Fahrenheit scales are used for everyday temperature measurement.

The Celsius scale is named after Swedish scientist Anders Celsius who introduced it in the eighteenth century. It is based on the freezing and boiling points of water, which are respectively 0°C and 100°C. It is often known, incorrectly, as the centigrade scale.

The Fahrenheit scale is named after Daniel Gabriel Fahrenheit. He apparently based his scale on the lowest winter temperature he recorded, which he called '0°F' and on human body temperature, which he called '100°F' which proved impractical for calibration. It is now also defined according to the freezing and boiling points of water. These are respectively 32°F and 212°F.

To convert between the temperature scales:

°C =(°F - 32)/1.8 ***°F =(1.8 x °C) + 32***

2.7 Absolute Zero Temperature Scale

For gas calculations it is necessary to use an absolute scale of temperature. This is a temperature scale based on Absolute Zero.

Absolute Zero is the temperature when there is no heat energy left in a body. In other words, it is impossible to get any colder. It has been calculated as -273.16°C (-459.69°F) but this is a theoretical value and cannot be reached in practice.

Absolute temperature is the temperature measured from Absolute Zero. For degrees Celsius, the absolute temperature is in degrees Kelvin. For degrees Fahrenheit, it is in degrees Rankin.

Absolute temperature (°K) = temperature in °C + 273

Absolute temperature (°R) = temperature in °F + 460

2.8 Parts per Million (ppm)

Parts per million (ppm) is used for very small concentrations of gases. A chamber, for example, might contain 400 ppm of carbon dioxide.

ppm is treated in the same way as a percentage. The only difference is that ppm is parts per 'million', while percentage is parts per 'hundred'.

Calculations can be carried out directly in ppm, or by converting ppm to a decimal or to a percentage.

To convert ppm to a partial pressure, move the decimal point back six places, i.e. DIVIDE BY 1,000,000.

To convert ppm to a percentage, move the decimal point back four spaces, i.e. DIVIDE BY 10,000.

<u>*Example 1*</u>

400 ppm ÷ 1,000,000 = 0.0004 ppCO_2

650 ppm ÷ 10,000 = 0.065%

2.9 Calculations and Calculators

A calculator normally gives 10 digits in the answer. For example, it might give the answer to a partial pressure calculation as 0.4787468 bar. For partial pressures, two decimal places are usually adequate. In this case, it is rounded up to 0.48.

If the answer had been 0.4733468, it would have rounded down to 0.47.

If the following number is five or more, round up the number by one. If it is four or less, leave it as it is.

<u>*Example 2*</u>

1.23456 rounds to 1.23

1.23546 rounds to 1.24

The answers to the calculations in this book are generally rounded to two or three decimal places.

2.10 How to Convert Minutes to Hours and Minutes

If you have an answer in minutes and wish to convert it to hours and minutes, use the following method:

Example 3

A calculation shows that the diver can spend 283 minutes in the water. Convert this to hours and minutes.

Divide 283 by 60 to convert it into hours. You should get 4.7166666

Remember 4 hours. Subtract 4 from the answer leaving 0.7166666

Multiply by 60 to turn this decimal part back into minutes. Answer 43 minutes

The time is 4 hours and 43 minutes

2.11 Gauge Pressure and Absolute Pressure

Gauge pressure is the pressure shown on the gauge and is the pressure measured above atmospheric pressure. Commonly, it is termed as 'atmosphere (atm)' or sometimes referred to as 'atmosphere (ats)'.

Absolute pressure is the pressure including atmospheric pressure:

Absolute pressure (bar abs) = gauge pressure (bar) + 1 bar

$$\textbf{Absolute pressure (bar abs)} = \frac{\textbf{depth (msw)}}{10} + \textbf{1 bar}$$

Absolute pressure (ata) = gauge pressure (atm) + 1 (atm)

$$\textbf{Absolute pressure (ata)} = \frac{\textbf{depth (fsw)}}{33} + \textbf{1 atm}$$

Gauge pressure is used in gas volume calculations for gas quads. This gives the maximum volume that can be used, as there will always be one bar of gas left in the quad. Gauge pressure is used in gas volume calculations for chambers, as there is always one bar of gas in the chamber before pressurisation starts.

Absolute pressure must be used in all partial pressure calculations, all diver gas consumption calculations and all chamber temperature calculations. Absolute pressure is the pressure of the water or equivalent in a submersible decompression chamber (SDC) or deck decompression chamber (DDC), plus the one atmosphere surface pressure.

It is sometimes useful to work with the absolute pressure measured in msw or fsw. This is known as 'absolute depth':

Absolute depth (msw) = depth (msw) + 10 (msw)

Absolute depth (fsw) = depth (fsw) + 33 (fsw)

Some calculations may involve the use of gauge pressure values only, absolute pressure values only, or a combination of both gauge and absolute pressure values.

Example 4

Gauge Pressure Calculation Example

A DDC with a floodable volume of $6m^3$ is pressed from the surface to 30 msw. How much gas is used?

The DDC will of course be at surface pressure (1 bar) prior to pressurisation, but because the question asks only how much additional gas is required to pressurise the chamber to 30 msw there is no need to include this 1 bar surface pressure in the calculation i.e. gauge pressure should be used to work out the answer.

Note that 'free gas volume' is defined as the equivalent volume of compressed gas if expanded to atmospheric pressure at constant temperature.

Free gas volume (FGV) = pressure x floodable volume

$$\frac{30}{10} \text{ msw} = 3 \text{ bar gauge (bg)} \times 6m^3 = 18m^3$$

Example 5

Absolute Pressure Calculation Example

A DDC is at 30 msw with 6% oxygen showing on the surface analyser. What is the pO_2 at 30 msw?

In this example the pO_2 will depend on the pressure at 30 msw (gauge pressure) plus the extra 1 bar of pressure found on surface i.e. absolute pressure should be used to work out the answer.

$$\frac{30}{10} \text{ msw} + 1 = 4 \text{ bar absolute (bar abs)} \times \frac{6}{100} = 0.24\ pO_2$$

Example 6

Combination of Gauge Pressure and Absolute Pressure Calculation Example

A DDC is pressed from the surface to 30 msw using 6% oxygen. What will be the pO_2 at 30 msw?

First work out the pO_2 of the gas added to pressurise the chamber from surface to 30 msw.

$$\frac{30}{10} \text{ msw} = 3 \text{ bar gauge (bg)} \times \frac{6}{100} = 0.18\ pO_2$$

0.18 pO_2 is the pO_2 added to the DDC (using gauge pressure).

However, there is also the 1 bar of pressure at the surface to consider i.e. 0.21 pO_2 in air.

This must be added, which is: 0.18 pO_2 + 0.21 pO_2 = 0.39 pO_2.

0.39 is the pO_2 inside the chamber at 30 msw.

2.12 Gas Volumes

For gas consumption calculations, a commercial diver is calculated using 35 ltr (1.25 ft^3) of gas per minute.

Gas recovery systems, where the diver's gas is recycled, are calculated to have a loss of 5 ltr (0.18 ft^3) per minute.

For emergencies, it is usual to calculate using a breathing rate of 40 ltr (1.5 ft^3) per minute. This is to take into account the effects of cold shock (if the diver's heating system has failed) and apprehension. Some national legislation and companies may require a higher rate for calculations of emergency breathing (check your company manual).

The breathing rate is calculated by the volume of gas at surface pressure that the diver is breathing at a pressure of 1 bar. All gas volumes are measured at surface pressure.

If the diver is working at 30 msw (99 fsw), the absolute pressure is 4 bar abs. The free gas volume going through his lungs is now 4 x 35 l/min, or 140 l/min (5 ft^3/min).

Work rate normal gas consumption (metric) = absolute pressure (bar) x 35 l/min

Work rate normal gas consumption (imperial) = absolute pressure (ata) x 1.25 ft^3/min

Emergency gas consumption (metric) = absolute pressure (bar) x 40 l/min

Emergency gas consumption (imperial) = absolute pressure (ata) x 1.5 ft^3/min

$$\textit{Absolute pressure} = \frac{\textit{depth (msw)}}{10} + 1 \textit{ bar}$$

$$\textit{Absolute pressure} = \frac{\textit{depth (fsw)}}{33} + 1 \textit{ atm}$$

Example 7 (Metric)

A diver is working at 20 msw for 4 hours. What volume of gas will he use?

Absolute pressure	$= \frac{\text{depth (msw)}}{10} + 1$ *bar*
	$= \frac{20}{10} + 1$ *bar*
	= 3 bar abs
Gas consumption	*= absolute pressure x 35 l/min*
	= 3 x 35 l/min
	= 105 l/min

(Divide by 1000. Gas volumes are normally worked in cubic metres)

	= $0.105\ m^3/min$
In four hours, gas use	*=* $4 \times 60 \times 0.105\ m^3$
	= $25.2\ m^3$

The diver will use 25.2 m^3 of gas

Example 8 (Imperial)

A diver is working at 100 fsw for 30 minutes. What volume of gas will he use?

Absolute pressure	$= \frac{\text{depth (fsw)}}{33} + 1$ *atm*
	$= \frac{100}{33} + 1$ *atm*
	= 4.03 ata
Gas consumption	*= absolute pressure (ata) x* $1.25\ ft^3/min$
	= $4.03 \times 1.25\ ft^3/min$
	= $5.04\ ft^3/min$
In 30 minutes, gas use	*=* $30 \times 5.04\ ft^3$
	= $151.2\ ft^3$

The diver will use 151.2 ft^3 of gas

In offshore work, gas is usually supplied in gas racks (or quads). A quad is normally a rack of anything from 16 x 50 ltr bottles to 64 x 50 ltr bottles.

On the worksite, always check the number and volume of bottles in a quad when it is delivered as well as the pressure. Some quads only have 12 bottles and mistakes can happen. Some cylinders are not 50 ltr – internationally there is 40ltr/43ltr/45ltr, etc. It is important to check the capacity of the cylinder.

The volume of a 64 bottle quad is 64 x 50 ltr, which is 3,200 ltr or 3.2 m^3. This is known as the floodable volume (FV), because that is the volume of water that could be poured in.

The free gas volume that the quad can hold is found by:

Free gas volume = floodable volume x pressure

Example 9

A 64 x 50 ltr quad contains gas at a pressure of 100 bar. What is the total volume of useable gas in the quad?

Free gas volume $= \textit{floodable volume x pressure}$

$= 64 \times 50 \times 100 = 320{,}000\ ltr$

$= \dfrac{320{,}000\ ltr}{1000}$

$= 320\ m^3$

The total volume of gas in the quad is 320 m^3

2.13 Available Gas

A typical SCUBA bottle holds about 2.5m^3 or 88 ft^3 of gas when it is full. This, of course, is the free gas volume.

Calculations should be based on a realistic dive plan, which includes getting down to working depth, getting back safely and having enough gas to cope with a crisis.

Allowance for the ambient pressure and to 'drive' the regulator **must** be considered as an unavailable quantity.

Example: A dive is planned to 40 msw = 5 bar abs.

10 bar is required for regulator drive pressure, plus the absolute pressure of 5 bar means there is 15 bar that is unavailable to the diver. Therefore, if the bail-out is charged to 200 bar - 15 bar = 185 bar of pressure available to the diver.

Important note: The regulator drive pressure is only taken into consideration where there is a possibility that the diver could breathe the container to zero, i.e. bail-out bottles, emergency cylinders in dive baskets, onboard gas supplies and LP compressors.

Where the diver is breathing from a high pressure quad, the regulator drive pressure is not an issue as the quad is taken offline and replaced with a full quad well before he reaches the unavailable quantity of gas in the quad (determined by the ambient pressure of the dive and the drive pressure of the regulator at the quad or dive panel).

In practice, diving supervisors should allow a considerable margin of error and would normally change over to a new gas quad when the pressures drops to about 40 bar.

Example: 180 bar - 40 bar = 140 bar available pressure.

It is the **available pressure** that must be used in calculations.

For deeper dives, say 200 msw, the diving supervisor might change over a quad at 50 bar.

2.14 How Much Time is Available?

To find out how long the diver could work, use the following formula:

$$\textbf{\textit{Time available}} = \frac{\textbf{\textit{gas available}}}{\textbf{\textit{gas consumption}}}$$

Example 10

A diver is working at 80 msw, breathing from a 16 x 50 ltr quad at a pressure of 150 bar. How long could he work for (assume that the quad will be changed over at 40 bar)?

Floodable volume $= 16 \times 50\ ltr$

$= 800\ ltr$

Available pressure $= (150 - 40)\ bar$

$= 110\ bar$

Free gas volume	*= floodable volume x available pressure*
	= (16 x 50 ltr) x 110 bar
Gas available	*= 88,000 ltr*
Gas consumption	*= absolute pressure x 35 l/min*
Absolute pressure	$= \frac{\text{depth (msw)}}{10} + 1$ *bar*
	$= \frac{80}{10} + 1$ *bar*
	= 9 bar abs
Gas consumption	*= 9 x 35 l/min*
	= 315 l/min
Time available	$= \frac{\text{gas available}}{\text{gas consumption}}$
	$= \frac{88{,}000 \text{ ltr}}{315 \text{ l/min}}$
	= 279 minutes
	= 4 hours 39 minutes

The diver has enough gas available for 4 hours and 39 minutes

2.15 Calculating Gas Volumes by Proportion

Gas volumes are often given as free gas volumes when the container is full, like the volume of the bail-out bottle at the start of this section. The free gas volume is calculated in this case:

(When the floodable volume (FV) is unknown)

Free gas volume $= \frac{\textbf{available pressure}}{\textbf{pressure when full}} \times \textbf{volume when full}$

Example 11

A quad contains 5,800 ft^3 when it is at a pressure of 3,000 psi. How much gas does it contain when the pressure is 1,800 psi?

Volume when full	*= 5,800* ft^3
Available pressure	*= 1,800 psi*
Pressure when full	*= 3,000 psi*
Free gas volume	$= \frac{\text{available pressure}}{\text{pressure when full}} \times \text{volume when full}$
	$= \frac{1{,}800}{3{,}000} \times 5{,}800$
	= 3,480 ft^3

Example 12

A quad contains 5,800 ft^3 when it is at a pressure of 3,000 psi. How much gas is available to the diver if the quad was to be taken offline at a pressure of 1,800 psi?

Volume when full	*= 5,800* ft^3
Available pressure	*= 3,000 - 1,800 psi*
	= 1,200 psi
Pressure when full	*= 3,000 psi*
Free gas volume	$= \frac{\text{available pressure}}{\text{pressure when full}} \times \text{volume when full}$

$$= \frac{1,200 \times 5,800}{3,000}$$

$$= 2,320 \ ft^3$$

Note that in Example 11, the question was asking for the pressure left in the quad at 1,800 psi. Whereas, in Example 12, the question is asking how much gas is available to the diver, i.e. 3,000-1,800 = 1,200 psi.

Example 13

A diver is working at 250 fsw. He is breathing from a quad which contains 22,500 ft^3 of gas when it is at a pressure of 3,000 psi. It is now at 2,750 psi. How long could the diver work for (assume that the quad will be changed over at 500 psi)?

Available pressure = (2,750 - 500) psi = 2,250 psi

Free gas volume (when the FV is unknown) $= \frac{\text{available pressure}}{\text{pressure when full}} \times \text{volume when full}$

$$= \frac{2,250 \times 22,500}{3,000}$$

$$= 16,875 \ ft^3$$

Gas consumption = absolute pressure x 1.25 ft^3/min

Absolute pressure $= \frac{\text{depth (fsw)}}{33} + 1 \text{ atm}$

$$= \frac{250}{33} + 1 \text{ atm}$$

= 8.58 ata

Gas consumption = 8.58 x 1.25 ft^3/min

= 10.73 ft^3/min

Time available $= \frac{\text{gas available}}{\text{gas consumption}}$

$$= \frac{16,875}{10.73}$$

= 1,573 minutes

= 26 hours 13 minutes

The diver has enough gas available for 26 hours and 13 minutes

2.16 Surface Supply Compressors

High pressure (HP) and low pressure (LP) compressors are rated according to the volume of air that they take in each minute. This is the free gas volume of the air that is supplied to the diver.

In practice, the actual volume of air used by the diver will vary according to his work rate. These variations are dealt with by the reservoir on the compressor. However, for the calculations we use the specified breathing rates.

The supply pressure must, of course, be enough to get the air to the diver. At 50 msw (165 fsw), which is generally accepted as the maximum depth for air diving, the pressure is 6 bar absolute. Allowing 10 bar for the regulator, the supply pressure must be more than 16 bar absolute.

Always check the supply pressure of the HP and LP compressors to ensure they meet the delivery rate and supply pressure required.

Example 14

An LP compressor supplies 30 ft^3/min at 300 psi. The diver plans to work at 100 fsw. Is the air supply sufficient (allow 10 atm for the operation of the regulator)?

First check the pressure:

Absolute pressure $= \frac{\text{depth (fsw)}}{33} + 1$ *atm*

$= \frac{100}{33} + 1$ *atm*

= 4.03 ata

Allow 10 atm for the demand valve

Pressure required *= 4.03 + 10*

= 14.03 ata

= 14.03 x 14.7 psi

(there are 14.7 psi in 1 atm)

= 206 psi

The compressor delivers 300 psi, so the pressure is suitable

Gas consumption *= absolute pressure x breathing rate*

= absolute pressure x 1.25 ft^3*/min*

Absolute pressure *= 4.03 ata*

Gas consumption *= 4.03 x 1.25* ft^3*/min*

= 5.04 ft^3*/min*

The compressor delivers 30 ft^3/min, so the volume is suitable

Example 15

A lightweight LP compressor delivers 250 l/min at a pressure of 15 bar. Two divers are planning to work at 30 msw. Is the air supply sufficient?

First check the pressure:

Absolute pressure $= \frac{\text{depth (msw)}}{10} + 1$ *bar*

$= \frac{30}{10} + 1$ *bar*

= 4 bar abs

Allow 10 bar for the demand valve

(Note: the demand valve drive pressure is only added once, regardless of the number of divers)

Pressure required *= 4 + 10 bar*

= 14 bar

The compressor delivers 15 bar, so the pressure is suitable

Gas consumption *= absolute pressure (bar) x 35 l/min*

Absolute pressure *= 4 bar abs*

Gas consumption *= 4 x 35 x 2 (there are two divers)*

= 280 l/min

The compressor only delivers 250 l/min, so the volume is insufficient. This compressor is not suitable for the job and should not be used

2.17 Gas Use in an Emergency

The bail-out bottle is the diver's back-up in an emergency, but the deeper he is, the less time the air/gas in the bail-out cylinder will provide.

Example 16

A bail-out bottle has a floodable volume of 8 ltr. How much time has a diver got if his surface supply fails at 50 msw? The bail-out bottle is at a pressure of 200 bar.

At 50 msw, the pressure is 6 bar abs. Add on 10 bar for the regulator, and that equates to 16 bar he cannot use.

Available pressure	*= 200 - 16 bar*
	= 184 bar
Free gas volume	*= floodable volume x available pressure*
	= 8 x 184
	= 1,472 ltr

This is an emergency, so allow a consumption of 40 l/min. The absolute pressure is 6 bar

Gas consumption	*= absolute pressure x breathing rate*
Gas consumption	*= 6 x 40 l/min*
	= 240 l/min
Time available	$= \frac{\text{gas available}}{\text{gas consumption}}$
	$= \frac{1{,}472}{240}$
	= 6.13 minutes

The diver has just over six minutes of gas available

Example 17

A bail-out bottle has a floodable volume of 12 ltr. How much time has a diver got if his surface supply fails at 200 msw (660 fsw)? The bail-out bottle is at a pressure of 180 bar.

At 200 msw, the pressure is 21 bar. Add on 10 bar for the regulator, and that equates to 31 bar he cannot use.

Available pressure	*= 180 - 31 bar*
	= 149 bar
Free gas volume	*= floodable volume x available pressure*
	= 12 x 149
	= 1,788 ltr

This is an emergency, so allow a consumption of 40 l/min. The absolute pressure is 21 bar

Gas consumption	*= absolute pressure x breathing rate*
Gas consumption	*= 21 x 40 l/min*
	= 840 l/min
Time available	$= \frac{\text{gas available}}{\text{gas consumption}}$
	$= \frac{1788}{840}$
	= 2.12 minutes

The diver has just over two minutes of gas available

The bail-out should normally contain enough gas to allow the diver one minute of breathing for every 10 m (33 ft) of umbilical deployed. Therefore, in this instance, only 2 mins x 10 m = 20 m of umbilical could be deployed.

2.18 The Effect of Temperature

If a bail-out bottle was charged rapidly to 200 bar, the gas in the bottle would be hot. If this is then left to cool down, the pressure would fall in proportion to the absolute temperature drop.

Pressure varies directly with the temperature. The higher the temperature, the higher the pressure. Therefore, the cooler the temperature the lower the pressure.

Gas heats up when it is compressed into a bottle or quad. Assume the temperature rises to 30°C during filling. If the diver goes out into cold North Sea water, the temperature will drop to about 4°C and the pressure will drop accordingly.

Charles' Law

The amount of change in either volume or pressure is directly related to the change in absolute temperature.

$$\textbf{Final pressure} = \frac{\textbf{initial pressure x final temperature (absolute)}}{\textbf{initial temperature (absolute)}}$$

In the formula, temperatures are in °K or degrees Kelvin. To convert to °K just add 273 to the temperature in °C. This gives the temperature measured from Absolute Zero.

Example 18

After filling to 200 bar, a bail-out bottle is at a temperature of 30°C. What will the pressure be when the temperature drops to 4°C?

Initial pressure = *200 bar gauge*

Final pressure $= \frac{\text{initial pressure x final temperature (°K)}}{\text{initial temperature (°K)}}$

$= \frac{200 \times (4 + 273)}{(30 + 273)}$

$= \frac{200 \times 277}{303}$

Final gauge pressure = *183 bar gauge*

The temperature drop has caused a pressure drop of 17 bar which means 17 bar less in an emergency

In the FPS system, temperatures must be converted to °R or degrees Rankin. To convert to °R just add 460 to the temperature in °F. This gives the temperature measured from Absolute Zero.

Example 19

After filling to 3,000 psi a bail-out bottle is at a temperature of 100°F. What will the pressure be when the temperature drops to 40°F?

Final pressure $= \frac{\text{initial pressure x final temperature (°R)}}{\text{initial pressure (°R)}}$

Initial pressure = *3,000 psi*

$= \frac{3{,}000 \times (40 + 460)}{(100 + 460)}$

$= \frac{3{,}000 \times 500}{560}$

= *2,679 psi*

2.19 Partial Pressures

Air contains approximately 21% oxygen and 79% nitrogen. On the surface, the partial pressure of oxygen (ppO_2) is 0.21 x 1 bar abs = 0.21 bar abs or 210 mb (0.21 ata). The partial pressure of nitrogen (ppN) is 0.79 bar abs or 790 mb (0.79 atm).

At 30 msw, the absolute pressure is 4 bar abs. The partial pressure of oxygen is 0.21 x 4 bar abs = 0.84 bar or 840 mb (0.84 atm). The partial pressure of nitrogen is 0.79 x 4 bar = 3.16 bar.

0.84 + 3.16 = 4 bar

The partial pressures added together should equal the absolute pressure (use this as a rule). This is a consequence of Dalton's Law.

Dalton's Law

The total pressure exerted by a mixture of gases is equal to the sum of the pressures of each of the different gases making up the mixture with each gas acting as if it alone was present and occupied the total volume.

The formula is:

Partial pressure = absolute pressure x decimal percentage

The decimal percentage is the percentage divided by 100. Move the decimal point back two spaces. (15÷100 = 0.15) 15% is 0.15, (8÷100 = 0.08) 8% is 0.08, 0.4% is 0.04 and so on.

Example 20

A diver at 40 msw is breathing a 20/80 nitrox mix. What is the ppO_2 in his mix?

Partial pressure	*= absolute pressure x decimal percentage*
Absolute pressure	$= \frac{\text{depth (msw)}}{10} + 1$ *bar*
	$= \frac{40}{10} + 1$*bar*
	= 5 bar abs
Percentage	*= 20%*
Decimal percentage	*= 0.2*
Partial pressure	*= 5 x 0.2*
	= 1.0 bar

The ppO_2 is 1.0 bar

Example 21

A diver at 250 fsw is breathing a 15% mix. What is the ppO_2 in his mix?

Partial pressure	*= absolute pressure x decimal percentage*
Absolute pressure	$= \frac{\text{depth (fsw)}}{33} + 1$ *atm*
	$= \frac{250}{33} + 1$ *atm*
	= 8.58 ata
Percentage	*= 15%*
Decimal percentage	*= 0.15*
Partial pressure	*= 8.58 x 0.15*
	= 1.287 ata

The ppO_2 is 1.287 ata

In the metric system, partial pressures less than one bar are usually given in millibars. Using the metric system, an alternative formula as follows:

Partial pressure (mb) = absolute depth (msw) x percentage

Absolute depth (msw) is (depth+10) msw. And in this case, the percentage is the percentage, not the decimal percentage.

<u>*Example 22*</u>

In a chamber at 80 msw, the oxygen percentage reading is 4.5%. What is the ppO_2 in the chamber?

Partial pressure (mb)	*= absolute depth (msw) x percentage*
Absolute depth	*= depth + 10 msw*
	= 90 msw
Percentage	*= 4.5%*
Partial pressure	*= (90 x 4.5) mb*
	= 405 mb

The ppO_2 is 405 mb

Calculations of the partial pressure of carbon dioxide ($ppCO_2$) are often carried out using parts per million (ppm).

<u>*Example 23*</u>

The chamber is at 80 msw, the carbon dioxide reading (as read on the control room analyser) is 400 ppm. What is the $ppCO_2$ in the chamber?

An alternative way to calculate it is:

Partial pressure of CO_2 expressed as a percentage %	
400 ppm ÷ 10,000	*= 0.04% CO_2*
Absolute pressure	*= depth + 10 msw*
	= 90 msw
Partial pressure (mb)	*= 90 x 0.04*
	= 3.6 mb

The $ppCO_2$ is 3.6 mb

2.20 Choosing the Right Mix

A diver may use any of a variety of breathing gases including helium-oxygen mixture (heliox), a nitrogen-oxygen mixture (nitrox) or a mixture of three gases (trimix). A trimix usually consists of oxygen, helium and nitrogen.

The mix will be adjusted to supply a safe ppO_2 at the working depth. But there are also decompression considerations. The amount of inert gas dissolved in the diver's tissues and thus the decompression time, depend on the partial pressure of the inert gas. This is a consequence of Henry's Law.

Henry's Law

At a given temperature, the amount of gas dissolved in a liquid is directly proportional to the partial pressure of the gas.

In a heliox mix, for example, the lower the partial pressure of helium, the shorter the decompression. This means keeping the ppO_2 as high as possible. But if the ppO_2 were too high, the divers would suffer from chronic or acute oxygen poisoning.

Example 24

A diver at 125 msw is breathing a 4% mix. What is his ppO_2?

Partial pressure = *absolute pressure x decimal percentage*

Absolute pressure (bar) $= \frac{\text{depth (msw)}}{10} + 1$

$= \frac{125}{10} + 1$ *bar*

= *13.5 bar abs*

Percentage = *4%*

Decimal percentage = *0.04*

Partial pressure = *13.5 x 0.04*

= *0.54 bar*

His ppO_2 is 0.54 bar

As an alternative, use the other formula:

Partial pressure (mb) = *absolute depth (msw) x percentage*

Absolute depth = *depth + 10 msw*

= *125 + 10 msw*

= *135 msw*

Percentage = *4 %*

Partial pressure = *135 x 4*

= *540 mb*

His ppO_2 is 540 mb

Example 25

During a saturation dive at 600 fsw, divers require a ppO_2 between 0.5 and 0.8 atm. What is a suitable mix?

Partial pressure = *absolute pressure x decimal percentage*

In this case the percentage is required, so turn the formula round:

Decimal percentage $= \frac{\text{partial pressure}}{\text{absolute pressure}}$

Take the bottom end of the range:

Absolute pressure (atm) $= \frac{\text{depth (fsw)}}{33} + 1$

$= \frac{600}{33} + 1$

= *19.18 ata*

Decimal percentage $= \frac{0.5}{19.18} \times 100$

= *0.026 x 100*

= *2.6%*

The percentage at the bottom of the range would be 2.6%

Repeat for the top end of the range:

Decimal percentage $= \frac{0.8}{19.18} \times 100$

$= 0.042 \times 100$

$= 4.2\%$

The percentage at the top of the range would be 4.2%

Use anything between 2.6% and 4.2%. In practice, a 3%, 3.5% or 4% mix would probably be used.

Example 26

If the ppO_2 must lie between 1.2 and 1.6 bar, what is the greatest depth at which a 15% mix could be used?

Partial pressure = *absolute pressure x decimal percentage*

In this case it is the absolute pressure that is needed, so turn the formula round:

Absolute pressure $= \frac{\text{partial pressure}}{\text{decimal percentage}}$

The maximum depth is required, so partial pressure would be at the maximum, that is 1.6 bar

Absolute pressure $= \frac{1.6}{0.15}$ *bar*

= *10.67 bar*

To turn an absolute pressure into a depth, subtract one and multiply by 10

Maximum depth = *(absolute pressure - 1) x 10*

Maximum depth = *(10.67 - 1) x 10*

= *96.7 msw*

2.21 Equivalent Air Depth (EAD)

Nitrox diving shortens decompression times by using a lower partial pressure of nitrogen in the mix which reduces the body tissue absorption of the inert gas. For example, during a dive to 20 msw (66 fsw) on air, the diver would be breathing a ppN_2 of 2.37 bar. If he were breathing a 40/60 nitrox mix his ppN_2 would be only 1.8 bar.

Note that most company policies and the IMCA and UK HSE recommendations are for a maximum ppO_2 of 1.4 bar in a nitrox mix used for the diver's breathing medium in the water.

The decompression table to use for a nitrox dive is found by calculating the equivalent air depth (EAD). This is the depth on air that would give the same ppN_2.

On the metric system, the formula is:

$$\text{EAD} = \frac{(\text{nitrogen \% x absolute depth})}{(79)} - 10 \text{ msw}$$

On the FPS system, the formula is

$$\text{EAD} = \frac{(\text{nitrogen \% x absolute depth})}{(79)} - 33 \text{ fsw}$$

Note: Subtracting 10 msw or 33 fsw is the very last action of the calculation.

Example 27

A diver is breathing a 40:60 nitrox mix at 25 msw. What is the EAD?

$$\textbf{EAD} = \frac{\textbf{(nitrogen \% x absolute depth)}}{\textbf{(79)}} - \textbf{10 msw}$$

	nitrogen % = 60%
Absolute depth	*= (25+10) msw*
	= 35 msw
EAD	$= \frac{60 \times 35}{79} - 10$
	= 26.6 - 10
	= 16.6 msw

The EAD is 16.6 msw, so use the next deepest table

Example 28

A diver is breathing a 30/70 nitrox mix at 100 fsw. What is the EAD?

EAD	$= \frac{\text{(nitrogen \% x absolute depth)}}{79} - 33 \text{ fsw}$
Nitrogen %	*= 70%*
Absolute depth	*= (100+33) fsw*
	= 133 fsw
EAD	$= \frac{70 \times 133}{79} - 33$
	=117.8 - 33
	= 84.8 fsw

The EAD is 84.8 fsw, so use the next deepest table

2.22 Gas Mixing

Large worksites usually have gas recovery systems, gas blenders and pre-mix, but basic gas mixing skills may still be needed. The general gas mixing formula is:

$$\textbf{Pressure of mix 1} = \textbf{final pressure} \times \frac{\textbf{(\% final mix - \% mix 2)}}{\textbf{(\% mix 1 - \% mix 2)}}$$

When mixing two gases in an empty quad mix 1 and mix 2 are mixed together to give the final mix. The percentage of the final mix, of course, must lie between the percentages of mix 1 and mix 2. For example, it would be impossible to make 7% from 3% and 4%.

Mix 1 is the richer mix (most oxygen). As a general rule, the richer mix should be pumped first at the lower pressure. For mixes containing over 21% oxygen, there is a fire risk associated with high pressure pumping.

For some, the gas mixing triangle, based on the formula, is easier to remember and to use. Examples of both methods are given below.

Example 29 (Calculation Method)

You have an empty quad and you want to make 200 bar of 9%, using 2% and 12%. What pressure of each gas do you need?

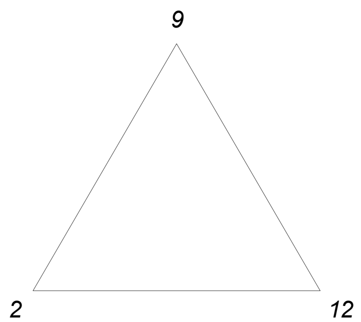
Pressure of mix 1	$= \text{final pressure} \times \frac{(\%\ \text{final mix} - \%\ \text{mix 2})}{(\%\ \text{mix 1} - \%\ \text{mix 2})}$
Final pressure	*= 200 bar*
% final mix	*= 9*
% mix 1	*= 12*
% mix 2	*= 2*
Pressure of mix 1	$= \frac{200 \times (9-2)}{12-2}$
	$= \frac{200 \times 7}{10}$
	= 140 bar of 12%

You need 140 bar of 12% and 60 bar of 2% to make 200 bar of 9%

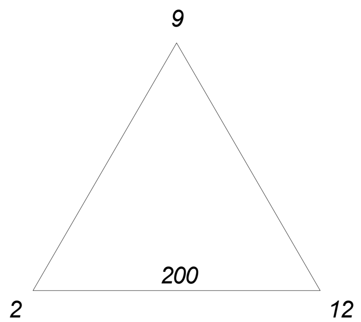
Example 30 (Triangle Method)

You have an empty quad and you want to make 200 bar of 9%, using 2% and 12%. What pressure of each gas do you need?

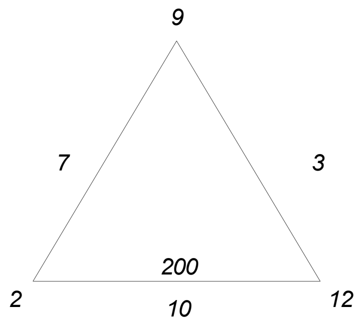
Begin by drawing a triangle and writing in the oxygen (O_2) percentages of the mix at each corner of the triangle. Always put the mix that you know the pressure of at the top. In this case, it is 9%. It does not matter where the other mixes go – the important fact is that the pressure must remain with the percentage it refers to, i.e. 200 bar of 9%.



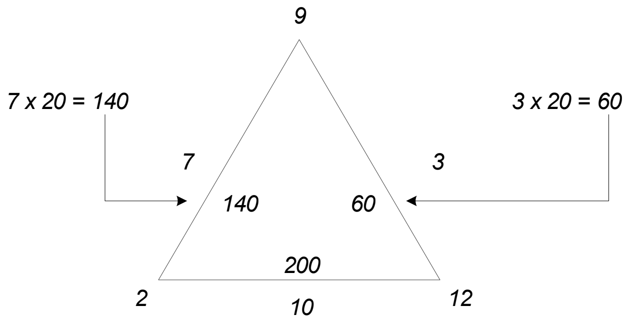
Write in the pressure that you know, inside the triangle opposite the mix with that pressure.



Subtract the small figure (%) from the larger figure (%) and write the answer between the same two percentages along each side of the triangle.



Divide the pressure by the figure underneath it. In this case that is 200 divided by 10 which equals a factor of 20. Multiply the factor by the other two figures as shown.



Write 140 inside the triangle. Do the same on the other side of the triangle (i.e. insert 60). Reading the opposite corners shows that you need 140 bar of 12% and 60 bar of 2%. Remember, the percentage figure at the corner of the triangle goes with the figure on the opposite side.

It is rare to have an empty quad and mixing usually involves pumping gas into a partially full quad. In this case, turn the formula round to calculate the final pressure.

$$\textbf{Final pressure} = \textbf{pressure of mix 1} \times \frac{(\%\ \text{mix 1} - \%\ \text{mix 2})}{(\%\ \text{final mix} - \%\ \text{mix 2})}$$

Mix 1 is whatever is in the quad and it may not be the richest mix. If it is actually the weakest mix, negative numbers will appear in the calculation. They will cancel out. If they don't cancel out, there is a mistake.

Example 31

You have 100 bar of 4% and you want to turn it into 10%, by pumping in 20%. What will the final pressure of the mixture be?

Final pressure $= \text{pressure of mix 1} \times \frac{(\%\ \text{mix 1} - \%\ \text{mix 2})}{(\%\ \text{final mix} - \%\ \text{mix 2})}$

Pressure of mix 1 = *100 bar*

% mix 1 = *4*

% mix 2 = *20*

% final mix = *10*

Final pressure $= \frac{100 \times (4-20)}{10-20}$

$= \frac{100 \times -16}{-10}$

(the minus signs cancel out) $= \frac{100 \times 16}{10}$

= *160 bar*

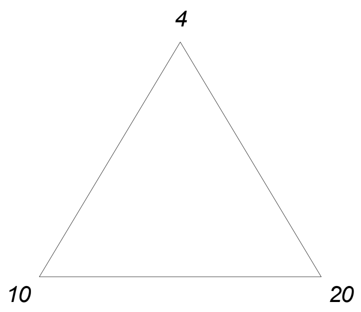
The final pressure is 160 bar.

Pump in 20% until the pressure reaches 160 bar (or a little over to allow for cooling)

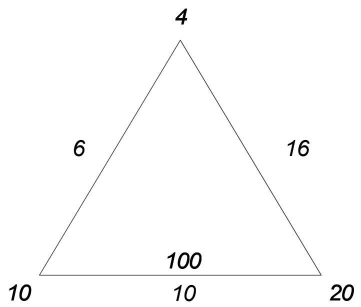
<u>*Example 32 (Triangle Method)*</u>

You have 100 bar of 4% and you want to turn it into 10%, by pumping in 20%. What will the final pressure of the mixture be?

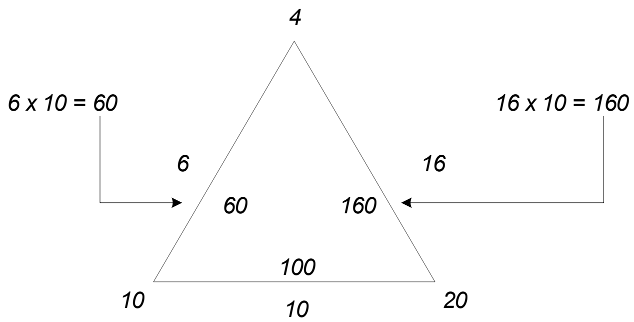
As before, write the mix that you know the pressure of at the top. In this case it's 4%. It does not matter where the other mixes go.



Write in the pressure that you know, inside the triangle opposite the mix.



Subtract the small figure (%) from the larger figure (%) and write the answer between the same two percentages along each side of the triangle. Divide the pressure by the figure underneath it. In this case that is 100 divided by 10 which equals a factor of 10. Multiply the factor by the other two figures as shown.



Write 60 inside the triangle. Do the same on the other side of the triangle. Reading the opposite corners shows that the pressure of 10% will be 160 bar. This is achieved by pumping 60 bar of 20% into the existing 4%.

2.23 Chambers and Bells

Pressurising an air chamber is quite straightforward. Air is blown into the required depth giving 21% oxygen, 79% nitrogen. The atmosphere is safe and breathable (except for nitrogen narcosis) to a depth of 50 msw (165 fsw). During decompression, there is no problem with low percentages or low partial pressures.

In a saturation chamber, heliox is blown in on top of the air that is already there. The final ppO_2 will depend on the ppO_2 in the air, and the ppO_2 added by the heliox.

The usual procedure is to start the pressurisation with a fairly rich mix, 16-20% oxygen, that is breathable at shallow depths. Compression then continues with a weak mix, usually 2%. For very deep dives, a weaker mix, perhaps 1%, could be used. Pure helium should not be used.

In theory, pressurisation could be started with a weak mix. The air that is already in the chamber gives a perfectly safe ppO_2. In practice, there is a risk that a leak (a door not sealing or a valve left open) might allow the chamber to flush with the weak mix, dropping the ppO_2 to dangerously low levels. Incidents like this have occurred causing some or all of the divers to become unconscious.

Some company procedures insist that a breathable mix is used to start pressurisation. Others allow a weak mix to be used, but the divers must breathe a safe mixture on the built-in breathing system (BIBS) until it is confirmed that the door is sealed, there are no leaks and the atmosphere is safe.

In all pressurisations, it is advisable to stop at 1 msw for a few minutes. If there is a significant leak, it will show immediately on the gauges.

2.24 Calculating the Depth of Rich Mix

To achieve the correct ppO_2 at living depth (typically about 0.4 bar), it is necessary to start with the correct depth of rich mix. If this depth is wrong, the final ppO_2 will be wrong and corrections will have to be made by adding oxygen or flushing.

The final ppO_2 will be made of the 210 mb already present in the air, the ppO_2 added in the rich mix and the ppO_2 added in the weak mix (usually 2%).

2.25 Pressurisation Calculations Using the Formula

Using the metric system the formula is as follows:

$$\text{Depth of rich mix (msw)} = \frac{(ppO_2 \text{ required (mb)} - ppO_2 \text{ present mb}) - (\text{depth msw} \times \%\text{ weak mix})}{(\%\text{ rich mix} - \%\text{ weak mix})}$$

There is usually a ppO_2 of 210 mb from the air in the chamber before pressurisation starts. To get a ppO_2 of 600 mb, O_2 added would be (600 - 210) mb = 390 mb.

Example 33

A chamber is to be pressurised to 90 msw, using 18% and 2%. The final ppO_2 must be 600 mb. What depth of 18% should be added to start the pressurisation?

$$\text{Depth of rich mix (msw)} = \frac{(ppO_2 \text{ required (mb)} - ppO_2 \text{ present mb})) - (\text{depth msw} \times \% \text{ weak mix})}{(\% \text{ rich mix} - \% \text{ weak mix})}$$

ppO_2 required	= 600 mb
ppO_2 present	= 210 mb
Bottom depth	= 90 msw
% weak mix	= 2
% rich mix	= 18
Depth of rich mix	$= \frac{(600 - 210) - (90 \times 2)}{(18 - 2)}$
	$= \frac{390 - 180}{16}$
	$= \frac{210}{16}$
	= 13.13 msw

Start the pressurisation by adding 13 msw of 18%, then carrying on to bottom depth (90 msw) with 2%

Using fsw, the formula as follows:

$$\text{Depth of rich mix (fsw)} = \frac{(3{,}300 \times (ppO_2 \text{ required (atm)} - ppO_2 \text{ present})) - (\text{bottom depth} \times \% \text{ weak mix})}{(\% \text{ rich mix} - \% \text{ weak mix})}$$

Note the double brackets in the first part of the equation. Minus the ppO_2s first, then multiply this figure by 3,300.

Example 34

A chamber is to be pressurised to 250 fsw, using 16% and 2%. The final ppO_2 must be 0.5 ata. What depth of 16% should be added to start the pressurisation?

$$\text{Depth of rich mix (fsw)} = \frac{(3300 \times (ppO_2 \text{ required (ata)} - ppO_2 \text{ present})) - (\text{bottom depth (fsw)} \times \% \text{ weak mix})}{(\% \text{ rich mix} - \% \text{ weak mix})}$$

ppO_2 required	= 0.5 ata
ppO_2 present	= 0.21 ata
Bottom depth	= 250 fsw
% weak mix	= 2
% rich mix	= 16
Depth of rich mix	$= \frac{((3300 \times (0.5 - 0.21)) - (250 \times 2)}{16 - 2}$
	$= \frac{(3300 \times 0.29) - 500}{14}$
	$= \frac{(957 - 500)}{14}$
	$= \frac{457}{14}$
	= 32.6 fsw

Start the pressurisation by adding 33 fsw of 16%, then carrying on to bottom depth (250 fsw) with 2%

2.26 Gas Volumes for Pressurisation

Free gas volume = chamber volume x pressure added

These are basically the floodable volume x pressure formulae used to work out how much gas there is in a quad. Remember to use gauge depth, not absolute depth for these calculations. If absolute depth is used, the air volume that was in the chamber before pressurisation would be included.

<u>*Example 35*</u>

A chamber system has a volume of $40m^3$. What volume of gas would it take to pressurise it to 150 msw?

Free gas volume	*= chamber volume x pressure added*
Chamber volume	$= 40\ m^3$
Pressure added	$= \frac{150}{10}$
	=15 bar gauge
Free gas volume	*= 40 x 15*
	$= 600\ m^3$

$600\ m^3$ of gas is required

<u>*Example 36*</u>

A chamber system has a volume of $1,200\ ft^3$. What volume of gas would it take to pressurise it to 500 fsw?

Free gas volume	*= chamber volume x pressure added*
Chamber volume	$= 1,200\ ft^3$
Pressure added	$= \frac{500}{33}$
	=15.15 ata
Free gas volume	*=1,200 x 15.15*
	$= 18,180\ ft^3$

$18,180\ ft^3$ of gas is required

<u>*Example 37*</u>

A chamber system has a volume of $30m^3$. It is to be pressurised to 90 msw, with 21 msw of 12% and 69 msw of 2%. What volume of each gas would be needed?

Free gas volume	*= chamber volume x pressure added*
Pressurisation on 12%	
Floodable volume	$= 30\ m^3$
Pressure added	$= \frac{21}{10}$
	= 2.1 bar gauge
Free gas volume	*= 30 x 2.1*
	$= 63\ m^3$
Pressurisation on 2%	$= \frac{69}{10}$
	= 6.9 bar gauge
Free gas volume	*= 30 x 6.9*
	$= 207\ m^3$

Pressurisation requires $63\ m^3$ of 12% and $207\ m^3$ of 2%

2.27 Aborting a Pressurisation

If a pressurisation is aborted it will be necessary to bring the divers back to the surface without causing decompression illness and preferably without subjecting them to a full saturation decompression.

Current procedures for aborting a pressurisation (such as those found in the latest revision of the US Navy Diving Manual) advise the following:

- for shallow aborts where the maximum depth and bottom time do not exceed the limits of the table use a suitable surface supplied HeO_2 decompression table to decompress the divers;
- for deeper emergency aborts beyond the limits of surface-supplied HeO_2 tables use a suitable saturation diving emergency abort procedure.

All personnel involved in managing aborts will need to be conversant with the full abort procedure requirements set down in company diving manuals or contained in selected suitable decompression tables.

2.28 Daily Gas Use

It is necessary to calculate daily gas use in the chamber. Gas losses caused by medical or equipment lock usage are significant. The formulae are familiar:

$$\text{Free gas volume} = \frac{\text{lock volume} \times \text{depth added (msw)}}{10}$$

$$\text{Free gas volume} = \frac{\text{lock volume} \times \text{depth added (fsw)}}{33}$$

To find the volume of the lock measure the length and diameter. Halve the diameter to get the radius. Measurements should be in metres (not centimetres) or feet. (If 'π' is not on your calculator, the value of π is 3.14.)

$$\text{Volume of lock} = \pi \times \text{radius}^2 \times \text{length}$$

Example 38

A medical lock is 0.8 m long and 0.3 m in diameter. The chamber is at 160 msw. How much gas is used when the lock is operated?

Volume of lock	$= \pi \times \text{radius}^2 \times \text{length}$
Length	= 0.8 metres
Radius	$= 0.3 \div 2$
	= 0.15 metres
Radius²	$= 0.15 \times 0.15$
	= 0.0225
Volume of lock	$= \pi \times 0.0225 \times 0.8$
	$= 0.057 m^3$
Free gas volume	$= \frac{\text{lock volume} \times \text{depth added}}{10}$
Depth added	= 160 msw
Free gas volume	$= \frac{0.057 \times 160}{10}$
	$= 0.912\ m^3$

When the lock is operated, 0.912 m^3 of gas is used.

Similar calculations may be carried out to estimate gas losses from other sources e.g. toilet flushes and analyser flows.

2.29 Adding Gas to the Chamber

Gas is added to the chamber on a regular basis, either to replace routine losses or to increase the chamber depth. If there is oxygen in the gas, as there almost always is, adding gas will increase the ppO_2.

These are the formulae. Both use the actual percentages, not decimal percentages.

ppO_2 added (mb) = depth added (msw) x percentage

$$ppO_2 \text{ added (atm)} = \frac{\text{depth added (fsw)} \times \text{percentage}}{3300}$$

2.30 Adding Oxygen to the Chamber

The divers in saturation are, of course, using oxygen metabolically all the time. Pure oxygen is added to the chamber atmosphere automatically or manually depending on the system, to maintain the correct ppO_2. If oxygen is to be added these rules apply:

10 cm of oxygen increases the ppO_2 by 10 mb

1 fsw of oxygen increases the ppO_2 by 0.03 atm

1 msw of oxygen increases ppO_2 by 0.1 bar

3 fsw of oxygen increases ppO_2 by 0.09 atm

2.31 How Much Oxygen is Needed?

On average, each diver in a chamber uses $0.72m^3$ ($25ft^3$) oxygen each per day. This is the amount of oxygen that they use metabolically, and it is not affected by depth.

The divers are not, of course, all in the chamber all of the time but it is easier to assume that they are. This also gives a safety margin to cover bad weather or other down time.

<u>*Example 39*</u>

Nine divers are in saturation for 5.5 days. How much oxygen will they use in the chamber?

Oxygen use $= 9 \times 5.5 \times 0.72$

$= 35.64\ m^3$

The divers will use 35.64 m^3 of oxygen metabolically

2.32 Oxygen and Decompression

On most tables, the ppO_2 is raised to a higher level before starting decompression. The required ppO_2 is then maintained during the decompression.

Every time gas is bled out of the chamber, oxygen is bled as well. The ppO_2 drops and more oxygen must be added. As the chamber gets shallower, the oxygen represents a higher percentage of the total volume, and the volume of oxygen coming out increases. Consequently, the volume that must be added increases.

The calculation of oxygen use during decompression is not used often but will be required. This is the formula:

Oxygen used during decompression = (Ln of the initial pressure) x ppO_2 (bar) x chamber volume

Initial pressure is the absolute pressure in the chamber at the start of the decompression. Ln is 'logarithm to the base e', a mathematical function found on most scientific calculators. The key might be labelled 'Ln' 'ln' or 'log e'. Press 'Ln', enter the initial pressure, and then multiply by the ppO_2 and chamber volume.

The ppO_2 is the ppO_2 used during the decompression. This is usually 400-500 mb (0.4-0.5 bar). In practice, no further oxygen additions are made after the percentage reaches a level between 21% and 23%. This formula does not take this into account and assumes that the ppO_2 will be kept at 500 mb all the way to the surface, so the answer will be slightly on the high side.

The metabolic oxygen use during the decompression must be added, together with any oxygen added to raise the ppO_2 to the level needed for decompression.

Example 40

A decompression from 95 msw takes two days, with a ppO_2 of 600 mb. There are two divers in the chamber, and the chamber volume is 10 m^3. How much oxygen is used?

Metabolic use:

Oxygen use	*= 2 x 2 x 0.72 m^3*
	= 2.88 m^3

Use during decompression:

Oxygen used	*= (Ln of the initial absolute pressure) x ppO_2 (bar) x chamber volume*
Initial pressure	*= 10.5 bar*
Ln (initial pressure)	*= 2.35 (from calculator)*
ppO_2	*= 0.6 bar*
Chamber volume	*= 10 m^3*
Oxygen used	*= 2.35 x 0.6 x 10 m^3*
	= 14.1 m^3
Total oxygen use:	*= (2.88 + 14.1) m^3*
	= 16.98 m^3

Example 41

Six divers are in saturation for eight days at 110 msw, with a ppO_2 of 400 mb. Before starting the decompression, the ppO_2 is raised to 600 mb. The decompression takes three days. The chamber volume is 15 m^3. How much oxygen is used?

As before, go one step at a time:

Metabolic use for the whole dive:

Dive time	*= 8 + 3*
	= 11
Oxygen use	*= 6 x 11 x 0.72*
	= 47.52 m^3

Oxygen required to make up the level to 600 mb:

Free gas volume	*= floodable volume x pressure added*

Raising the ppO_2 is basically the pressure x volume formula. It is the oxygen added that is important, not the total volume. The floodable volume is the chamber volume.

Floodable volume	$= 15\ m^3$
Pressure added	= *(600 - 400) mb*
	= *200 mb*
	= *0.2 bar (pressures in bar)*
Free gas volume	= *15 x 0.2*
	$= 3\ m^3$
Use during decompression:	
Oxygen used	= *(Ln of the initial absolute pressure) x* ppO_2 *x chamber volume*
Initial pressure	= *12 bar*
Ln (initial pressure)	= *2.48 (from calculator)*
ppO_2	= *0.6 bar*
Chamber volume	$= 15\ m^3$
Oxygen used	= *2.48 x 0.6 x 15*
	$= 22.32\ m^3$
Total oxygen use	= *47.52 + 3 + 22.32*
	$= 72.84\ m^3$

2.33 Temperature Changes

Chamber temperatures are always known accurately, and a temperature change will show as a change in chamber depth. It is possible to mistake a decrease in depth due to a temperature drop for a slow leak.

To calculate depth changes due to temperature changes, a variation of the temperature formula in Section 2.18 can be used:

$$\textbf{Final depth} = \frac{\textbf{Initial depth x final temperature (absolute)}}{\textbf{initial temperature (absolute)}}$$

If the temperature decreases the depth decreases, and if the temperature increases the depth increases.

Example 42

At the start of the shift, a chamber is at 145 msw and 32°C. During the shift, the temperature fell to 28°C. If the life support crew had not added gas to maintain depth, by how much would the depth have decreased?

Final depth	$= \dfrac{\text{initial depth x final temperature (°K)}}{\text{initial temperature (°K)}}$
Initial depth	= *145 msw*
Final temperature	= *28 + 273*
	= *301°K*
Initial temperature	= *32 + 273*
	= *305°K*
Final depth	$= \dfrac{145 \times 301}{305}$
Final depth	= *143 msw*
Depth decrease	= *145-143*
	= *2 msw*

The depth decrease would have been 2 msw

2.34 Venting the Chamber

When a chamber or bell is vented to a shallower depth, the percentages stay the same. If there was 4% oxygen in the chamber at the start of the vent, there will be 4% oxygen in the chamber at the new depth.

At 90 msw, 4% is 400 mb. On the surface, 4% is only 40 mb. This is not enough to support life. Anyone entering the chamber would collapse instantly and die quickly if they were not rescued.

If someone is unconscious in a chamber (or any enclosed space), rescue should not be attempted without breathing apparatus and, ideally, a lifeline. If the collapsed person cannot breathe, neither can the rescuer.

After a chamber has been vented to the surface, it should be flushed with air or allowed to ventilate until it is safe to enter. While it is flushing or ventilating, someone should remain at the entrance or the door should be closed and a warning notice posted.

If a chamber is vented, remember that percentages stay the same and work out the final ppO_2 accordingly.

Example 43

Chamber 1 is at 320 fsw, with a ppO_2 of 0.4 ata and a percentage of 3.74%. It is bled to 100 fsw. What is the ppO_2 at 100 fsw?

Percentages stay the same during a bleed.

Percentage at 100 fsw	= 3.74%
Partial pressure	= absolute pressure x decimal percentage
Absolute pressure	$= \frac{\text{depth (fsw)}}{33} + 1$ atm
	$= \frac{100}{33} + 1$ atm
	= 4.03 ata
Percentage	= 3.74%
Decimal percentage	= 0.0374
Partial pressure	= 4.03 x 0.0374
	= 0.15 ata

The ppO_2 at 100 fsw is 0.15 ata

Note: This ppO_2 would be unbreathable.

Oxygen would have to be added before or during the bleed to maintain the correct ppO_2.

2.35 Joining Chambers Together

If chambers are being joined, the chamber atmospheres will mix when the doors open. The final ppO_2 will depend on the total volume of oxygen in the system. Find the volume by using the familiar free gas volume formula. In this case, though, use only the partial pressure of oxygen, not the absolute pressure.

In a split level saturation, one set of chambers is at one depth, another set is at another depth. It may be necessary to blow down or bleed a chamber from one depth to the other.

Example 44

Chamber 1 is at 97 msw, with a ppO_2 of 400 mb. It is blown down to 130 msw, using 2%. What is the ppO_2 at 130 msw?

pO_2 increase = $\frac{\text{depth increase (msw) x decimal percentage}}{10}$

= $\frac{33 \times 0.02}{10}$

= *0.066 bar or 66 mb*

There was already 400 mb in the chamber

= *400 + 66 mb*

The ppO_2 at 130 msw is 466 mb

Example 45

After equalisation, Chamber 1 has a volume of $12m^3$ and a ppO_2 of 480 mb. Chamber 2 has a volume of $8m^3$ and a ppO_2 of 400 mb.

What is the final ppO_2 when the atmospheres are completely mixed?

Oxygen volume in Chamber 1:

Free gas volume	= *floodable volume x pressure*
Floodable volume	= $12m^3$
Pressure of oxygen (ppO_2)	= *480 mb*
	= *0.48 bar*
Oxygen volume	= *12 x 0.48*
	= $5.76\ m^3$

Oxygen volume in Chamber 2:

Free gas volume	= *floodable volume x pressure*
Floodable volume	= $8m^3$
Pressure of oxygen (ppO_2)	= *400 mb*
	= *0.4 bar*
Oxygen volume	= *8 x 0.4*
	= $3.2\ m^3$
Total oxygen volume	= *5.76 + 3.2*
	= $8.96m^3$
Total chamber volume	= *12 + 8*
	= $20m^3$

Turn the formula around:

Pressure = $\frac{\text{free gas volume}}{\text{floodable volume}}$

= $\frac{8.96}{20}$

= *0.448 bar*

= *448 mb*

The final ppO_2 is 448 mb

In practice, it might take a while for the atmospheres to mix.

2.36 Carbon Dioxide (CO_2) Removal

Carbon dioxide is removed from chambers using a chemical absorbent. The most commonly used chemical is soda lime or sodium hydroxide. Commercial products which remove carbon dioxide are usually made up of mixtures of sodium, potassium and calcium hydroxides. These absorbents are all commonly referred to as soda lime or sodasorb.

In the first stage of the process, carbon dioxide dissolves in water, present as vapour in the chamber atmosphere and in the absorbent, to form carbonic acid. The carbonic acid then reacts with the hydroxides to form carbonates and other chemicals, and regenerates the water. Heat is produced during the process.

If the absorbent is too dry, the first stage cannot take place and the process will be ineffective. If it is too wet, the absorbent will have a paste-like composition, which will close the pores and inhibit the reaction.

The absorption of carbon dioxide will be reduced if:

- the gas, or the absorbent, is too wet or too dry;
- the gas velocity is too high to allow the chemical reactions to take place;
- the temperature is too low;
- the absorbent is unevenly packed in the filter cylinder and the gas can tunnel through or bypass the absorbent;
- the absorbent is too tightly packed, restricting gas flow.

In practical terms, 1 kg of absorbent will absorb about 120 ltr of carbon dioxide. A diver in a chamber produces about as much carbon dioxide as the oxygen he uses. This is about 0.72 m^3 or 720 ltr per day, or 30 ltr per hour. Like metabolic oxygen use, carbon dioxide production is not affected by depth.

Assume 1 kg of absorbent will last a diver for four hours which means 6 kg of absorbent will last a diver for 24 hours.

Example 46

During a saturation dive, nine divers will live at 95msw for 10 days, including decompression. How much absorbent would they use?

Each diver needs 6 kg per day, regardless of depth.

absorbent used	*= 9 x 10 x 6*
	= 540 kg

540 kg would be used

This assumes that all the divers are in the chamber all the time. This gives a safety margin to cover bad weather or other down time. The actual dive plan, of course, would require considerably more absorbent to be onboard as a contingency.

2.37 Pressurising the Bell

Working depth is usually deeper than the living depth in the chambers and the bell will have to be pressurised by several metres at the start of each dive.

This can be done in two different ways. The same way as example 44 (joining chambers together) or as below. Both methods are shown.

Example 47

A chamber and bell are at 185 msw, with a ppO_2 of 400 mb. For the dive, the bell is separated from the chamber and blown down on 4% to a working depth of 200 msw. What is the ppO_2 in the bell at working depth?

pO_2 increase (mb)	*= depth increase (msw) x percentage*
Depth increase	*= 15 msw*
Percentage	*= 4*
pO_2 increase (mb)	*= 15 x 4*
	= 60 mb

The ppO_2 in the bell is (400 + 60) mb = 460 mb

Example 48

A chamber and bell are at 70 msw, with a ppO_2 of 500 mb. For the dive, the bell is separated from the chamber and blown down on 4% to a working depth of 90 msw. What is the ppO_2 in the bell at working depth?

pO_2 increase $= \frac{\text{depth increase (msw) x decimal percentage}}{10}$

$= \frac{20 \times 0.04}{10}$

= 0.08 bar or 80 mb

There was already 500 mb in the chamber

= 500 + 80 mb

The ppO_2 at 90 msw is 580 mb

2.38 Chemical Sampling Tubes

These are also known as colorimetric tubes, and are often called 'Dräger' tubes (named after one of the major manufacturers). A measured volume of gas is drawn through the tube and the chemicals inside change colour according to the concentration of the gas. The most widely used tubes are those for CO_2 detection. They are carried as standard in most diving bells.

The tubes give readings in either percentage or in parts per million, depending on the substance to be sampled and upon the scale to be used. They are calibrated for use on the surface. If they are used in a bell the reading must be adjusted accordingly.

Suppose a sample is taken in a bell at a depth of 110 msw (361 fsw). The scale reading shows 1%. Since the pressure is 12 bar absolute, 12 times the normal volume of gas has gone through the tube, and it is reading 12 times higher than it would on a surface analyser. This fact is very useful for the diving supervisor as the reading taken at depth by the diver in the bell is already a surface equivalent.

For example, if a chemical sample tube taken by the diver reads 0.4% and the company surface limit is 0.5%, the supervisor immediately knows that the CO_2 level is below the maximum allowed.

Important Notes:

1. The true percentage could also be called the true ppm or true partial pressure (pp) depending on the unit of measurement in use.

2. The true percentage (or ppm or pp) refers to the reading one would get from an analyser reading at surface in the control room.

In this case:

Example 49

A diver takes a chemical sampling tube reading of 0.4% in the bell at 110 msw. What will be the reading on the percentage surface analyser (i.e. the true percentage)?

$$\textbf{True percentage} = \frac{\textbf{scale reading}}{\textbf{absolute pressure}}$$

True percentage $= \frac{0.4}{12}$

$= 0.033\%$

Note: If the surface analyser was a ppm analyser, we would simply multiply the true percentage by 10,000 to convert the percentage to ppm. As stated earlier, this could be referred to as a true ppm.

It is often the partial pressure that matters, not the percentage. This can be found by dividing the scale reading (taken at depth) by 100 to give the partial pressure in bar or atm. For example, a scale reading of 0.4% in the bell is a partial pressure of 0.004 bar.

In the metric system, partial pressure in millibars can be found by multiplying the scale reading (taken at depth) by 10. For example, a scale reading of 0.4% in the bell is a partial pressure of 4 millibar.

2.39 Surface Equivalent Percentage (SEP)

Example 50

The bellman uses a chemical sampling tube to take a CO_2 reading in the bell. The scale reading is 1.4%. If the bell is at 400 fsw, give the true percentage of CO_2, the pCO_2 and the SEP.

True percentage $= \frac{\text{scale reading}}{\text{Absolute pressure}}$

Scale reading $= 1.4\%$

Absolute pressure (atm) $= \frac{\text{depth (fsw)}}{33} + 1 \text{ atm}$

$= \frac{400}{33} + 1 \text{ atm}$

$= 13.12 \text{ ata}$

True percentage $= \frac{1.4\%}{13.12}$

True percentage $= 0.107\%$

Partial pressure $= \frac{\text{scale reading}}{100}$

$= \frac{1.4}{100}$

Partial pressure $= 0.014 \text{ ata}$

The SEP is simply the scale reading, which is 1.4%

2.40 Total Gas Volumes

Calculating the weekly, monthly or total gas requirements for a diving operation is relatively straightforward but requires a systematic approach. This is some of the information required:

- volumes of the chamber system and bells;
- living depths and working depths;
- number of days diving;

- number of divers in saturation;
- how many pressurisations and decompressions are planned?
- is a gas recovery system being used for the dives?
- is a gas recovery system being used for the chambers?
- the treatment mixes needed for each depth range.

Carry out the calculations stage by stage, working through the planned operation, and keep a running total of the volumes of each gas mix. Calculations would include:

- gas volume to pressurise the system;
- metabolic oxygen consumption in the chamber;
- gas volumes for the operation of the medical and equipment locks;
- gas volumes for pressurisations to put new divers into saturation;
- oxygen volumes used during decompression;
- gas volumes for the bell bottles;
- gas volumes to pressurise the bell from living depth to working depth;
- gas volumes to pressurise the bell trunking;
- diver gas consumption;
- gas volumes for hyperbaric evacuation;
- gas reserves.

Gas reserves should be worked out according to company policy, but will probably be based on the IMCA guidance note IMCA D 050[1].

2.41 Heat Transfer

Heat is a form of energy and is measured in joules or calories in the metric system and British thermal units (Btu) in the Imperial system.

The specific heat capacity of a substance is the amount of heat needed to raise the temperature of 1 kg of the substance by 1°C. 1 kg of aluminium, for example, requires over seven times as much heat as 1 kg of lead to raise its temperature by the same amount.

Heat is transferred from one material, or part of a material, to another whenever there is a temperature difference. The rate of transfer depends on the temperature difference and the characteristics of the material.

Transfer takes place by conduction, radiation, convection or a combination of all three. Conduction is heat transfer by the direct transfer of energy from molecule to molecule. The materials must be in contact. A diver in cold water will lose most of his heat by conduction into the water.

Radiation is the transfer of heat by electromagnetic radiation. The materials do not need to be in contact. A chamber on a cold day (with no draught or wind chill) will lose most of its heat by radiation, since the surrounding air is a poor conductor.

Convection is the transfer of heat by the mass movement of liquid or gas. Inside a chamber, the heat generated by under floor heating will cause the gas to rise and warm the atmosphere by convection.

Conductivity is measured in joules per second per metre per °C. Water is 24 times more conductive than air so a diver's heat loss in water is 24 times what it would be on deck in air at the same temperature.

Conductive heat loss in water is increased considerably when a diver or swimmer is moving and circulating cold water over his body. In a survival situation in cold water it is best to keep as still as possible to minimise heat loss.

Helium is about six times more conductive than air, hydrogen about seven times more conductive, hence the very high respiratory heat loss in mixed gas diving. Every breath takes heat away from the diver.

In general, conductive heat loss can be reduced by some form of insulation, like a woolly bear and dry suit on a diver.

Radiant heat loss depends on the temperature and also on the surface of the body or material. A black surface, for example, has a higher radiant heat loss than a white or silver surface. The silver space blanket was designed to cut down radiant heat loss. It is effective in space, where there is no atmosphere and no conductive heat loss. It is less effective on the earth, where there can be a high conductive heat loss, especially in a strong wind.

Radiant heat loss is almost proportional to the fourth power of the surface temperature of the body. If the temperature doubled, the radiant heat loss would increase 16 times. If a chamber is insulated, the surface temperature will be lower and radiant heat loss reduced.

Convection is involved in many forms of heat transfer, but is not usually significant in diving operations.

2.42 Hot Water Suits

The amount of heat reaching the diver depends on the temperature of the water and the flow rate. A low temperature and a high flow rate transport as much heat as a higher temperature and a lower flow rate. If the water reaches the diver at temperatures in excess of 45°C, there is a risk of scalding.

In practical terms, it is easiest to measure the hot water temperature at the machine, but there can be a considerable heat loss in the umbilical. Most hot water machine manuals contain charts or tables to estimate the temperature drop and work out the expected temperature at the diver.

As a rough guide only, the following formulae may be used. They only apply in a sea water temperature of about 5°C (41°F), which could be expected in the temperate zones. Note the difference between UK and US gallons.

$$\textit{Temperature drop } (^\circ C) = \frac{\textit{Umbilical length (m)}}{\textit{Flow (litres/min)}}$$

$$\textit{Temperature drop } (^\circ F) = \frac{\textit{Umbilical length (ft)}}{4 \times \textit{Flow (UK gals/min)}}$$

$$\textit{Temperature drop } (^\circ F) = \frac{\textit{Umbilical length (ft)}}{5 \times \textit{Flow (US gals/min)}}$$

2.43 Buoyancy

The use of buoyancy bags is not an exact science. It is possible to calculate the weight of the object to be lifted and the amount of buoyancy needed. In practice, the object is often stuck in the mud and held by incalculable suction. See section 15.19 for safety precautions when using lifting bags.

There are two forces acting on an object in the water: its weight which tries to make it sink and the upthrust from the water which tries to make it float. If these forces are equal, the object stays where it is and it is said to be neutrally buoyant. If weight is greater than upthrust, it sinks. This is known as negative buoyancy. If upthrust is greater than weight, it floats up. This is known as positive buoyancy.

Upthrust = volume of water displaced x density of water

Seawater is denser than freshwater, so objects float better in seawater. If a boat sails from the sea into a freshwater canal or river, it will sink lower in the water as it progresses up river.

The density of seawater is 1.03 kg/l, or 1.03 t/m^3 or 64.38 lbs/ft^3. The density of freshwater is 1.00 kg/l, or 1.00 t/m^3 or 62.5 lbs/ft^3.

Example 51

A diving bell displaces 5 m^3 of sea water and weighs 4.8 tonnes. Is the bell positively buoyant?

Upthrust	*= volume of water displaced x density of water*
Volume of water displaced	$= 5\ m^3$
Density of sea water (There are 1000 kg in a tonne)	$= \frac{1030\ kg/m^3}{1000\ kg}$
	$= 1.03\ tonnes/m^3$
Upthrust	*= 5 x 1.03*
	= 5.15 tonnes

The bell weighs 4.8 tonnes, so its positively buoyant by (5.15 - 4.8) tonnes

Positive buoyancy = 0.35 tonnes

It would require at least 0.35 tonnes of additional weight to make the bell sink. The weights themselves will, of course, weigh less in the water because of the upthrust on them.

Example 52

A diving bell displaces 180 ft^3 of sea water and weighs 5.2 imperial tons. Is the bell positively buoyant?

Upthrust	*= volume of water displaced x density of water*
Volume of water displaced	$= 180\ ft^3$
Density of sea water	$= 64.38\ lbs/ft^3$
Upthrust	*= 180 x 64.38*
	= 11,588.4 lbs
(There are 2,240 lbs in an imperial ton)	$= \frac{11,588.4}{2,240}$
	= 5.17 tons

The bell weighs 5.2 tons, so it is negatively buoyant by (5.2 - 5.17) tons

Negative buoyancy = 0.03 tons

The bell will sink, although it would sink faster with additional weights. In practice, bell buoyancy tests include the weight of the divers and their equipment which is usually calculated as 150 kg per diver.

Example 53

A block of concrete, 2m x 2m x 3m, is lying on the seabed. The density of concrete is 2,400 kg/m^3. How much force is required to lift the block clear of the seabed?

Assume that the block is lying on a hard gravel bottom, so there are no suction problems.

The first step is to find the weight of the block:

Weight of block	*= Volume x density*
Volume	*= 2 x 2 x 3 m*
	= 12 m^3
Density	*= 2,400 kg/m^3*
Weight	*= 12m^3 x 2400*
(there are 1000 kg in a metric tonne)	*= 28,800 kg*
	= $\frac{28,800}{1,000}$
In air, it would take 28.8 tonnes to lift the block but in water there is an upthrust	*= 28.8 tonnes*
Upthrust	*= volume of water displaced x density of water*
Volume of water displaced	*= 12m^3*
Density of sea water	*= 1.03 tonnes/m^3*
Upthrust	*= 12 x 1.03*
	= 12.36 tonnes
Force required to lift the block	*= 28.8 - 12.36*
	= 16.44 tonnes

The block weighs 16.44 tonnes in the water. It will, however, weigh 28.8 tonnes if it is lifted out of the water

2.44 Summary of Depth and Pressure Formulae

Absolute depth (msw) = depth (msw) + 10
Absolute depth (fsw) = depth (fsw) + 33

Gauge pressure (bar) = depth (msw)/10
Gauge pressure (atm) = depth (fsw)/33

Absolute pressure = gauge pressure + 1
Gauge pressure = absolute pressure - 1

Depth (msw) = gauge pressure x 10
Depth (fsw) = gauge pressure x 33

Absolute depth (msw) = absolute pressure (bar) x 10
Absolute depth (fsw) = absolute pressure (atm) x 33

2.45 Summary of Gas Volume Formulae

Gas consumption = absolute pressure (bar) x 35 l/min

Gas consumption = absolute pressure (ata) x 1.25 ft^3/min

Free gas volume = floodable volume x pressure

Free gas volume = $\frac{\text{volume when full x available pressure}}{\text{pressure when full}}$
(when FV is unknown)

Time available = $\frac{\text{gas available}}{\text{gas consumption}}$

2.46 Summary of Temperature Formulae

°F = (1.8 x°C) + 32

°C = (°F- 32)/ 1.8

Absolute temperature (°K) = temperature in °C + 273

Absolute temperature (°R) = temperature in °F + 460

$$\text{Final pressure} = \text{initial pressure (abs)} \times \frac{\text{final temperature (absolute)}}{\text{initial temperature (absolute)}}$$

$$\text{Final depth} = \text{initial depth} \times \frac{\text{final temperature (absolute)}}{\text{initial temperature (absolute)}}$$

2.47 Summary of Partial Pressure Formulae

Partial pressure = absolute pressure x decimal percentage

Partial pressure (mb) = absolute depth (msw) x percentage

2.48 Gas Mixing

$$\text{Pressure of Mix 1} = \text{final pressure} \times \frac{(\text{\% Final Mix - \% Mix 2})}{(\text{\% Mix 1 - \% Mix 2})}$$

or

Use the gas mixing triangle (see Example 30)

2.49 Summary of Chamber Calculations

For depth of rich mix in initial pressurisation, use the trial and error method or one of the following:

$$\text{Depth of rich mix (msw)} = \frac{\text{(}ppO_2\text{ Req'd (mb) - }ppO_2\text{ present (mb) - (depth msw x \% weak mix)}}{\text{(\% rich mix - \% weak mix)}}$$

$$\text{Depth of rich mix (fsw)} = \frac{\text{(3,300 x (}ppO_2\text{ Req'd (atm) - }ppO_2\text{ present (atm)) - (bottom depth x \% weak mix)}}{\text{(\% rich mix - \% weak mix)}}$$

pO_2 increase (mb) = depth increase (msw) x percentage

$$pO_2\text{ increase (atm)} = \frac{\text{depth increase (fsw) x decimal percentage}}{33}$$

Free gas volume = chamber volume x pressure added

10 cm (0.1 msw) of pure oxygen will increase the ppO_2 by 10 mb

1 fsw of pure oxygen will increase the ppO_2 by 0.03 atm

1 msw of pure oxygen will increase the ppO_2 by 0.1 bar

3 fsw of pure oxygen will increase the ppO_2 by 0.09 atm

Oxygen used during decompression = (Ln of the initial absolute pressure) x ppO_2 (bar) x chamber volume

2.50 Summary of Chemical Sampling Tube Formulae

True percentage	$= \frac{\textit{scale reading}}{\textit{absolute pressure}}$
Partial pressure (bar or ata)	$= \frac{\textit{scale reading}}{100}$
Partial pressure (mb)	*= scale reading x 10*
SEP	*= scale reading*

2.51 Buoyancy Formula

Upthrust = volume of water displaced x density of water

2.52 Useful Numbers

Density of fresh water	1 kg/l 1 t/m^3 10 lbs/Imperial gal 8.3 lbs/US gal 62.5 lbs/ft^3
Density of sea water	1.03 kg/l 1.03 t/m^3 10.3 lbs/Imperial gal 8.6 lbs/US gal 64.38 lbs/ft^3
Diver gas consumption	35 l/min 1.25 ft^3/min
(Recovery systems)	5 l/min 0.18 ft^3/min

Diver gas consumption from a bail-out bottle or other supply source in an emergency

40 l/min
1.5 ft^3/min

Metabolic oxygen consumption in chambers

0.72 m^3/day or
0.5 l/min per diver
25 ft^3/day or
0.018 ft^3/min per diver

Absorbent use

1 kg absorbs 120 litres of carbon dioxide
1 kg lasts one diver for 4 hours
6 kg last one diver for 24 hours

Oxygen partial pressure limits (check company policy)

Therapeutic treatment	***1.6 to 2.8 bar***
Bounce dive	***1.2 to 1.5 bar***
Saturation (in water)	***0.5 to 0.8 bar***
Saturation (in chamber)	***0.35 bar to 0.5 bar***
Bail-out cylinder	***1.6 bar to 2.8bar***
Maximum for surface supplied diving	***1.4 bar***

Carbon dioxide partial pressure limits (check company policy).

Chamber	5 mb
	0.005 bar
	0.5%
	5,000 ppm
Bell (Maximum)	20 mb
	0.02 bar
	2%
	20,000 ppm

2.53 Self-Test Questions

Questions in italics are a repeat of the examples found in each section. Try them and if you have a problem look in the appropriate section and see how it should be done.

1. What is the absolute pressure at a depth of 254 msw?
2. What is the absolute pressure at a depth of 254 fsw?
3. A diver is working at 120 msw for 4 hours. What volume of gas will he use?
4. *A diver is working at 100 fsw for 30 minutes. What volume of gas will he use?*
5. Two divers are working out of the bell at 75 msw. What volume of gas will they use in 4 hours?
6. An air diver is working at 60 fsw for 20 minutes. What volume of air will he use?
7. *A 64 x 50 litre quad contains gas at a pressure of 100 bar. What is the total volume of gas in the quad?*
8. The quad in Question 7 will be changed over when the pressure falls to 40 bar. What volume of gas is available to the diver?
9. In Question 8, the diver is working at 130 msw. How long can he work for before the quad is changed over?
10. *A diver is working at 80 msw, breathing from a 16 x 50 litre quad at a pressure of 150 bar. How long could he work for? (Assume that the quad will be changed over at 40 bar.)*
11. A 64 x 50 litre quad is at a pressure of 205 bar. It can be used until the pressure falls to 30 bar. How much gas is available for use?
12. A 12 x 50 litre quad is at a pressure of 25 bar. What volume of gas will be needed to fill it to a pressure of 200 bar?
13. A bail-out bottle has a volume of 12 litres and contains gas at a pressure of 200 bar. If the diver is working at 100 msw, what volume of gas is available to him in an emergency?
14. A diver is working at 195 msw, breathing from a 16 x 50 litre quad at a pressure of 110 bar. The quad will be changed over at 40 bar. How long could he work for?
15. *A quad contains 5800 ft^3 when it is at a pressure of 3000 psi. How much gas does it contain when the pressure is 1800 psi?*
16. A quad contains 21650 ft^3 at a pressure of 2800 psi. How much gas does it contain when the pressure is 600 psi?

17. A quad contains 22,500 ft^3 at a pressure of 3000 psi. It can be used until the pressure drops to 450 psi. What volume of gas is available to the diver?
18. *A diver is working at 250 fsw. He's breathing from a quad which contains 22,500 ft^3 of gas when it is at a pressure of 3000 psi at the start of his dive. Just now, it is at 2750 psi. How much longer could the diver work for? (Assume that the quad will be changed over at 500 psi.)*
19. A diver is working at 380 fsw. He is breathing from a quad which contains 22,500 ft^3 of gas at a pressure of 3000 psi. The quad will be changed over at 450 psi. How long could the diver work for?
20. A quad contains 5400 ft^3 at a pressure of 2800 psi. It can be used until the pressure drops to 400 psi. What volume of gas is available to the diver?
21. *An LP compressor supplies 30 ft^3/min at 300 psi. The diver plans to work at 100 fsw. Is the air supply sufficient?*
22. *A lightweight LP compressor delivers 250 l/min at a pressure of 15 bar. Two divers are planning to work at 30 msw. Is the air supply sufficient?*
23. Two divers are planning to work at 60 fsw, using an LP compressor. What is the minimum delivery volume and pressure that they require?
24. *A bail-out bottle has a floodable volume of 12 litres. How much time has a diver got if his surface supply fails at 200 msw? The bail-out bottle is at a pressure of 180 bar.*
25. A bail-out bottle contains 100 ft^3 at 3500 psi. It is at a pressure of 3000 psi. If the diver's surface supply fails at 500 fsw, how long has he got to get back to the bell?
26. *After filling to 200 bar, a bail-out bottle is at a temperature of 30°C. What will the pressure be when the temperature drops to 4°C?*
27. After filling to 3500 psi, a bail-out bottle is at a temperature of 40°C. What will the pressure be when the temperature drops to 4°C?
28. *A diver at 250 fsw is breathing a 15% mix. What is the pO_2 in his mix?*
29. *In a chamber at 80 msw, the oxygen percentage reading is 4.5%. What is the pO_2 in the chamber?*
30. *A diver at 125 msw is breathing a 4% mix. What is his pO_2?*
31. A diver at 165 msw is breathing a 4% mix. What is the pO_2 in his mix?
32. A diver at 340 fsw is breathing a 6% mix. What is the pO_2 in his mix?
33. A diver at 60 msw is breathing an 18% mix. What is the pO_2 in his mix?
34. What is the pO_2 in a chamber at 50 fsw if the oxygen percentage is 23%?
35. The pO_2 in a chamber at 108 msw is 400 mb. What is the oxygen percentage?
36. The pO_2 in a chamber at 327 fsw is 0.42 ata. What is the percentage of oxygen in the chamber?
37. *During a saturation dive at 600 fsw, the divers require a pO_2 between 0.5 and 0.8 ata. What is a suitable mix?*
38. *If the pO_2 must lie between 1.2 and 1.6 bar, what is the greatest depth (in msw) at which you could use a 15% mix?*
39. During a bounce dive to 80 msw, the divers require a pO_2 between 1.2 and 1.6 bar. What is a suitable mix?
40. During a saturation dive at 208 msw, the divers require a pO_2 between 550 and 750 mb. What is a suitable mix?
41. Assuming that air contains 21% oxygen and 79% nitrogen, what is the pO_2 and pN_2 in air at 165 fsw?
42. A hydrox mix contains 1% oxygen. How deep could the diver go without exceeding a pO_2 of 750 mb?
43. *You want to make 200 bar of 9%, using 2% and 12%. What pressure of each gas do you need?*
44. You want to make 180 bar of 6%, using 2% and 18%. What pressure of each gas do you need?
45. You want to make 3000 psi of 23%, using 12% and 50%. What pressure of each gas do you need?
46. You want to make 2500 psi of 12%, using 2% and 18%. What pressure of each gas do you need?

47. *You have 100 bar of 4% and you want to turn it into 10%, by pumping in 20%. What will the final pressure of the mixture be?*
48. You have 45 bar of 2% and you want to turn it into 10%, by pumping in 18%. What will the final pressure of the mixture be?
49. You have 1800 psi of 1.5% and you want to turn it into 4%, by pumping in 16%. What will the final pressure of the mixture be?
50. You have 600 psi of 2% and you want to turn it into 6%, by pumping in 18%. What will the final pressure of the mixture be?
51. You have 50 bar of 2%, 40 bar of 4% and you want to mix them together and add 23% to make the mix up to 8%. What will the final pressure be? (Do this in two stages.)
52. You have 500 psi of 6%, 400 psi of 4% and you want to mix them together and add 16% to make the mix up to 12%. What will the final pressure be? (Do this in two stages.)
53. A chamber is to be pressurised to 90 msw, using 12% and 2%. The final pO_2 must be 600 mb. What depth of 12% should you add to start the pressurisation?
54. *A chamber is to be pressurised to 250 fsw, using 16% and 2%. The final pO_2 must be 0.5 ata. What depth of 16% should you add to start the pressurisation?*
55. You want to pressurise a chamber to 500 fsw, using 18% and 1%. The final pO_2 must be 0.6 ata. What depth of 18% should you add to start the pressurisation?
56. You want to pressurise a chamber to 120 msw, using 20% and 1.5%. The final pO_2 must not exceed 650 mb. What depth of 20% should you add to start the pressurisation?
57. *A chamber system has a volume of 40 m^3. What volume of gas would it take to pressurise it to 150 msw?*
58. *A chamber system has a volume of 1200 ft^3. What volume of gas would it take to pressurise it to 500 fsw?*
59. A chamber system has a volume of 38 m^3. What volume of gas would it take to pressurise it to 212 msw?
60. A chamber system has a volume of 875 ft^3. What volume of gas would it take to pressurise it to 355 fsw?
61. *A chamber system has a volume of 30 m^3. It is to be pressurised to 90 msw, with 21 msw of 12% and 69 msw of 2%. What volume of each gas would be needed?*
62. A chamber system has a volume of 1100 ft^3. It is to be pressurised to 620 fsw, with 39 fsw of 18% and 581 fsw of 1%. What volume of each gas would be needed?
63. A chamber system has a volume of 45 m^3. It is to be pressurised to 197 msw, with 7 msw of 16% and 190 msw of 1.5%. What volume of each gas would be needed?
64. *A medical lock is 0.8 metres long and 0.3 metres in diameter. The chamber is at 160 msw. How much gas is used when the lock is operated?*
65. An equipment lock is 4 ft long and 2 ft 6ins in diameter. The chamber is at 510 fsw. How much gas is used when the lock is operated?
66. *9 divers are in saturation for 5.5 days. How much oxygen will they use in the chamber? (Answer in m^3.)*
67. 6 divers are in saturation for 12 days. How much oxygen will they use in the chamber? (Answer in ft^3.)
68. *A decompression from 95 msw takes 2 days, with a pO_2 of 600 mb. There are two divers in the chamber and the chamber volume is 10 m^3. How much oxygen is used?*
69. A decompression from 180 msw takes 4 days, with a pO_2 of 600 mb. There are two divers in the chamber and the chamber volume is 10 m^3. How much oxygen is used?
70. *6 divers are in saturation for a total of 11 days including decompression at 110 msw, with a pO_2 of 400 mb. Before starting the decompression, the pO_2 is raised to 600 mb. The decompression takes 3 days. The chamber volume is 15 m^3. How much oxygen is used?*
71. During a saturation, the pO_2 in the chamber is maintained at 400 mb. Before starting decompression, the level is raised to 600 mb. If the chamber volume is 17 m^3, what volume of oxygen is required raise the pO_2?

72. 6 divers are in saturation at 275 fsw for a total of 12 days including decompression with a pO_2 of 0.4 ata. The pO_2 is raised to 0.6 atm for the decompression which lasts 2 days. The chamber volume is 500 ft^3. How much oxygen is used altogether?

73. *At the start of the shift, a chamber is at 145 msw and 32°C. During the shift, the temperature fell to 28°C. If the life support crew had not added gas to maintain depth, by how much would the depth have decreased?*

74. A chamber is at 345 fsw and 31°C. The temperature drops to 26°C. If the life support crew took no action, what would the depth decrease by?

75. *Chamber 1 is at 97 msw, with a pO_2 of 400 mb. It is blown down to 130 msw using 2%. What is the pO_2 at 130 msw?*

76. A chamber is blown down from 180 fsw to 210 fsw using 4%. If the pO_2 was 0.4 atm at 180 fsw, what is it at 210 fsw?

77. After a serious leak, a chamber is at 50 msw with a pO_2 of 180 mb. The chamber is blown back to the living depth of 125 msw using 5%. What is the pO_2 at living depth?

78. *Chamber 1 is at 320 fsw, with a pO_2 of 0.4 ata, percentage 3.74%. It is bled to 100 fsw. What is the pO_2 at 100 fsw?*

79. A chamber is at 186 msw, with an oxygen percentage of 2.1%. It is bled to 143 msw. What is the pO_2 at 143 msw?

80. *After equalisation, Chamber 1 has a volume of 12 m^3 and a pO_2 of 480 mb. Chamber 2 has a volume of 8 m^3 and a pO_2 of 400 mb. What is the final pO_2 when the atmospheres are completely mixed?*

81. Chamber 1 has a volume of 400 ft^3 and the pO_2 is 0.45 atm. Chamber 2 has the same volume, but the pO_2 is 0.38 atm. What is the final pO_2 when the chamber atmospheres are fully mixed?

82. Chamber 1 has a volume of 18 m^3 and the pO_2 is 420 mb. Chamber 2 has a volume of 12 m^3 and the pO_2 is 400 mb. Chamber 3 has a volume of 15 m^3 and the pO_2 is 600 mb. What is the final pO_2 when all the chamber atmospheres are fully mixed?

83. *A chamber and bell are at 185 msw, with a pO_2 of 400 mb. For the dive, the bell is separated from the chamber and blown down on 4% to a working depth of 200 msw. What is the pO_2 in the bell at working depth?*

84. Divers are being pressurised in a chamber using 2% straight from the surface. The pressurisation is aborted at 70 fsw when the oxygen percentage is 8%. The chamber is bled straight back to surface. What is the pO_2 on the surface? How do the divers feel about this?

85. *The bellman uses a chemical sampling tube to take a CO_2 reading in the bell. The scale reading is 1.4%. If the bell is at 400 fsw, give the true percentage of CO_2, the pCO_2 and the SEP.*

86. The bellman uses a chemical sampling tube to take a CO_2 reading in the bell. The scale reading is 2%. If the bell is at 145 msw, give the true percentage of CO_2, the pCO_2 and the SEP.

87. *A diving bell displaces 5 m^3 of sea water and weighs 4.8 tonnes. Is the bell positively buoyant?*

88. Would the bell in Question 87 be positively buoyant in fresh water?

89. *A diving bell displaces 180 ft^3 of sea water and weighs 5.2 imperial tons. Is the bell positively buoyant?*

90. A diving bell displaces 180 ft^3 of sea water and weighs 5.2 US tons. Is the bell positively buoyant?

91. A block of concrete, 1m x 1m x 1m, is lying on the seabed. The density of concrete is 2400 kg/m^3. How much force is required to lift the block clear of the seabed? (Ignore any suction.)

92. A welding habitat weighs 25 tonnes in air. It displaces 12 m^3. What does it weigh in sea water?

93. A closed length of pipe weighs 12 imperial tons (2240 lbs) and displaces 140 ft^3. How many 1 ton lifting bags would you need to lift it clear of the seabed? (Ignore suction.)

2.54 Answers to Self-Test Questions

1. 26.4 bar
2. 8.69 ata
3. 109.2 m^3
4. 151.2 ft^3 (see example 8)
5. 142.8 m^3
6. 70.45 ft^3
7. 320 m^3 (see example 9)
8. 192 m^3
9. 6 hours 32 minutes
10. 4 hours 39 minutes (see example 10)
11. 560 m^3
12. 105 m^3. It is only a 12 bottle quad!
13. 2.15 m^3
14. 1 hour 18 minutes
15. 3480 ft^3 (see example 11)
16. 4639 ft^3
17. 19125 ft^3
18. 26 hours 13 minutes (see example 13)
19. 20 hours 22 minutes
20. 4629 ft^3
21. Yes (see example 14)
22. No (see example 15)
23. 7.04 ft^3 per minute, 188 psi (12.82 ata)
24. 2.1 minutes or 2 minutes 7 seconds (see example 17)
25. 3.1 minutes or 3 minutes 6 seconds
26. 183 bar gauge (see example 18)
27. 3097 psi
28. 1.287 ata (see example 21)
29. 405 mb (see example 22)
30. 540 mb (see example 24)
31. 700 mb
32. 0.678 ata
33. 1.26 bar
34. 0.578 ata
35. 3.39%
36. 3.85%
37. Anything between 2.6% and 4.2% (see example 25)
38. 96.7 msw (see example 26)
39. Anything between 13.3% and 17.78%
40. Anything between 2.52% and 3.44%
41. 1.26 ata, 4.74 ata

42. 740 msw
43. 140 bar of 12% and, 60 bar of 2% (see examples 29 and 30)
44. 135 bar of 2%, 45 bar of 18%
45. 2132 psi of 12%, 868 psi of 50%. Be careful with the 50%!
46. 938 psi of 2%, 1562 psi of 18%
47. 160 bar (see example 32)
48. 90 bar
49. 2175 psi
50. 800 psi
51. 121 bar
52. 2453 psi or 2450 psi exactly if using the triangle method
53. 21 msw
54. 33 fsw (see example 34)
55. 46.3 fsw
56. 14 msw
57. 600 m^3 (see example 35)
58. 18180 ft^3 (see example 36)
59. 805.6 m^3
60. 9413 ft^3
61. 63 m^3 of 12%, 207 m^3 of 2% (see example 37)
62. 1300 ft^3 of 18%, 19367 ft3 of 1%
63. 31.5 m^3 of 16%, 855 m^3 of 1.5%
64. 0.912 m^3 The answer may vary slightly, depending on the value that you use for π. This answer uses 3.1415927, straight off the calculator. If you use 3.14 you get 0.905 m^3 (see example 38)
65. 303.44 ft^3. As above, answers may vary. 3.14 gives 303.3 ft^3
66. 35.64 m^3 (see example 39)
67. 1800 ft^3
68. 16.98 m^3 (see example 40)
69. 23.4 m^3
70. 72.84 m^3 (see example 41)
71. 3.4 m^3
72. 2569 ft^3. You need 100 ft^3 to make up the pO_2 to 0.6 ata, 1800 ft^3 in total for metabolic use and 669 ft^3 for the decompression
73. 2 msw (see example 42)
74. 6.2 fsw
75. 466 mb (see example 44)
76. 0.436 ata
77. 555 mb
78. 0.15 ata (see example 43)
79. 321 mb
80. 448 mb (see example 45)
81. 0.415 ata

82. 474 mb. Just like the others. Find the total volume of oxygen and divide by the total chamber volume.
83. 460 mb (see example 47)
84. 0.08 ata, the divers are probably unconscious
85. True percentage 0.107%, pCO_2 0.014 ata, SEP 1.4% (see example 50)
86. True percentage 0.13%, pCO_2 20 mb, SEP 2.0%
87. Yes, the upthrust is 5.15 tonnes (see example 51)
88. Yes, the upthrust is 5 tonnes
89. No, the upthrust is 5.17 imperial tons (see example 52)
90. Yes, the upthrust is 5.79 US tons (did you use 2000 lbs = 1 ton?)
91. 1.37 tonnes
92. 12.64 tonnes
93. You need a lift of 7.98 tons. That is, 8 lifting bags.

1 IMCA D 050 *Minimum quantities of gas required offshore*

Diving Medicine and First Aid

3.1 Directional Terms

In medicine and first aid, directions are always given from the patient's point of view. This is unlikely to cause a problem when dealing with limbs, but it is easy to make a mistake when examining the trunk. The left upper quadrant of the abdomen, for example, refers to the patient's left.

Anterior means to the front of the body, *posterior* is to the back. The midline is an imaginary line down the centre of the body. *Medial* means towards the midline, *lateral* is away from the midline.

Superior means towards the top of the body, *inferior* towards the bottom. *Proximal* means closer to, and *distal* means further away from a point of reference. These terms are used when referring to the arms and legs, and the points of reference are the shoulders and hips respectively.

Knowledge of these terms is useful when transmitting medical data, but not essential. It is always better to give a clear description rather than use a word when you are uncertain of its meaning.

3.2 Cell Function

The cell is the basic unit of life and the human body contains many millions of individual cells. Each cell has a limited life, and cells are continually dying and being replaced. During a human lifetime, every cell is replaced many times.

Each cell is a complex and highly organised unit that contains all the genetic information necessary to build all the body tissues and organs.

Cells are supplied with nutrients and oxygen by the bloodstream, which also removes waste products. In diving terms, the most important of these waste products is carbon dioxide, which is carried in the bloodstream as carbonic acid.

The breathing reflex is not normally triggered by a lack of oxygen, but by a raised carbonic acid level in the bloodstream. In other words, it depends primarily on carbon dioxide accumulation rather than an oxygen lack.

Repeated deep breaths (known as hyperventilation) will flush carbon dioxide from the lungs. This in turn lowers the carbonic acid level in the blood and the breathing reflex will not be triggered during breath holding. This can cause death while breath-hold diving. Low oxygen levels will eventually trigger the breathing reflex (but the carbon dioxide trigger is far more sensitive). Obviously drowning will results if this happens in breath-hold diving.

Rapid shallow breathing, in contrast, allows carbon dioxide to accumulate in the lungs and raises carbonic acid levels in the blood. This stimulates breathing, which becomes even faster and shallower. The cycle continues and can cause collapse from carbon dioxide poisoning (hypercapnia). This condition can occur in divers (see section 3.47).

Oxygen will only pass into the bloodstream if the pO_2 (partial pressure or tension of oxygen) in the lungs' alveoli is higher than the pO_2 in the blood in the capillaries in contact with the alveoli.

Similarly, oxygen will only pass from the bloodstream into a cell if there is pressure gradient. The pO_2, partial pressure or tension of oxygen in the blood must be higher than that in the cell.

Similarly, carbon dioxide will only pass from the cell into the blood if the pCO_2 in the cell is higher than that in the blood and from the blood into the lung if the pCO_2 is higher in the blood than in the gas in the alveoli.

If a diver breathes a pure inert gas, such as pure helium, the pO_2 in the blood will be lower than that in the cells. The partial pressure gradient is reversed and oxygen flows from the cells into the bloodstream. The cells are rapidly depleted of oxygen, collapse is immediate and death follows very quickly.

The exchange of oxygen and carbon dioxide at cellular level is known as internal respiration. The exchange of oxygen and carbon dioxide in the lungs is known as external respiration.

Inadequate oxygenation of the cells is known as hypoxia and produces the symptoms of shock. It may be caused by a low concentration of oxygen in the breathing gas, poor circulation, serious dehydration, toxicity or a variety of other causes.

Complete lack of oxygen in the cells is known as anoxia.

3.3 Body Systems

Cells are combined to build tissues, which in turn are combined to make up the various organs of the body. A system is a group of organs arranged to perform complex functions.

There are eleven organ systems in the body. Those that are of particular importance to diving are:

- skeletal;
- respiratory;
- circulatory;
- nervous.

3.4 Skeletal System

The skeleton provides a rigid framework which supports and gives shape to the body and protects the internal organs. The bones are linked by cartilage or ligaments to allow various degrees of movement depending on the type of joint.

In broad terms, it consists of the skull, spine, rib cage, collar bones and shoulder blades, pelvis, the long bones of the arms and legs and the small bones of the hands and feet.

In all there are 206 separate bones. The skull, for example, consists of 28 bones ranging from the flat bones which form the dome of the skull to the small auditory ossicles which function in hearing.

The spine consists of 26 vertebrae separated by disks of cartilage which act as shock absorbers and prevent the vertebrae from rubbing together.

The top seven vertebrae, which make up the neck, are known as the cervical vertebrae and this section of the spine is known as the c-spine. It is particularly vulnerable to injury from impact and whiplash (see section 3.18).

The long bones in the arms and legs act as levers operated by the muscles which are attached to them. Muscles are joined to bones by tendons; bones are joined to bones by ligaments.

The joint surfaces in the arms and legs are covered with a layer of smooth hard cartilage lubricated by sinovial fluid. Rapid pressurisation can cause discomfort or even pain in the joints. This condition is known as compression arthralgia and is probably caused by small pressure differences in the joints (see section 3.40).

Blood cells are created in the marrow of the long bones which has a high blood flow. A broken femur, or thigh bone, consequently results in serious internal bleeding inside the leg.

There is some evidence that osteonecrosis, or areas of dead bone, is found in divers and compressed air workers more frequently than in the rest of the population. When extensive offshore diving first started, it was believed that this would be a major problem. Extensive studies in the 1970s and 1980s, however, showed that this is not the case.

There are five principal body cavities contained within or supported by the skeleton.

The cranial cavity, inside the skull, houses the brain. The skull also contains the sinuses, cavities in the forehead and cheekbones. The sinuses serve to lighten the heavy mass of facial bone, and give resonance to the voice. They are connected by tubes to the back of the nose. If these tubes are blocked, the diver will suffer from sinus squeeze (see section 3.26).

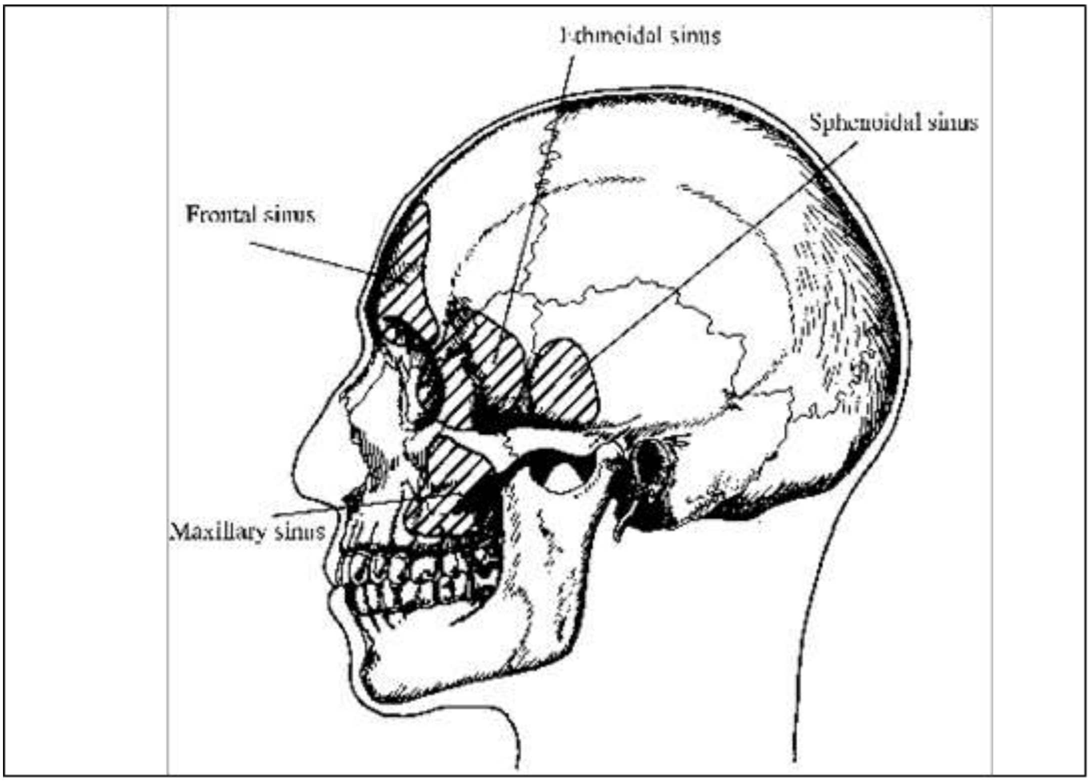


Figure 3-1 – The sinuses

The spinal cavity, inside the spine, carries the spinal cord.

The thoracic cavity, or chest cavity, protects the lungs, heart and the major blood vessels. It is separated from the abdominal cavity by the diaphragm at the base of the rib cage. The diaphragm is a sheet of muscle.

Air or gas entering the thoracic cavity from a damaged lung or from an external injury is known as pneumothorax (see section 3.33).

The abdominal cavity extends from the diaphragm to the rim formed by the pelvic bones. It contains the liver, stomach, gall bladder, pancreas, spleen, small intestine and most of the large intestine. Unlike all the other cavities, it is not protected by bones and the organs are extremely vulnerable to impact.

Damage to the diaphragm, which may be caused by impact or underwater explosion, can allow abdominal organs to be forced into the thoracic cavity. This may cause compression of the lungs or heart with associated difficulties in breathing or circulation.

The pelvic cavity, surrounded by the bones of the pelvic girdle, contains the bladder, part of the large intestine and the internal reproductive organs. A broken pelvis can result in serious bleeding into the pelvic cavity.

3.5 Respiratory System

The respiratory system includes both internal and external respiration. Internal respiration is described above (see section 3.2). External respiration is concerned with gas exchange in the lungs.

Under normal conditions, air is taken in through the nose. The nasal cavities are lined with mucous membrane which warms and moistens the air and helps to filter out dust particles. The sinuses are connected to the nasal cavities. Divers, who breathe mainly through the mouth, lose the protective benefits of the mucous membrane.

Air passes down the pharynx, or throat, and into the larynx. The larynx is commonly known as the voice box. The Adam's apple is part of the larynx.

The section of the airway above the larynx is known as the upper airway, the section below as the lower airway.

In a conscious person, food and liquids are normally prevented from entering the lower airway by a flap called the epiglottis which closes over the larynx when swallowing. In an unconscious person, this reflex may not be present and solids and liquids, like vomit, could be inhaled into the lungs.

Below the larynx is the trachea, or windpipe. It is a stiff tube, supported by rings of cartilage. The trachea is about 10 cm long, and then divides into the left and right bronchi, which carry the air into the left and right lungs.

The right bronchus is shorter and wider than the left and continues in an almost straight line from the trachea. For this reason, solid objects that are inhaled tend to lodge in the right bronchus.

Each bronchus continues to branch, each branch containing less cartilage and increasing amounts of muscle, until there is no cartilage left. At this stage, the tubes are about 1mm in diameter and are known as bronchioles.

The muscles in the bronchioles are sensitive to various hormones in the bloodstream and can contract forcefully, restricting airflow. This is what occurs during an asthma attack. These hormones and 'chemicals' are released in the blood stream by stimuli such as pollen, some food such as nuts, cold air and exercise – to name but a few.

The bronchioles continue to branch, eventually terminating in grape-like clusters of tiny, hollow air sacs known as alveoli. The repeated branching in the lungs makes an enormous area available for gas exchange in the alveoli. In an adult male this area is about 70 m^2.

The alveoli are covered in a network of fine blood vessels called capillaries. The membrane separating the bloodstream from the gas in the lungs is only one cell thick and it is across this membrane that gas exchange takes place.

Because the membrane is so thin, it is extremely vulnerable to pressure differences. If it is ruptured and gas enters the bloodstream directly as bubbles, the casualty can suffer from the extremely serious condition known as arterial gas embolism (see section 3.34).

There are about 300 million alveoli and the lungs appear as large spongy organs. Each lung is conical in shape, with its base resting on the diaphragm. Each lung is covered by a double layer of membranes called the pleura. The outer layer lines the chest wall.

The two layers of the pleura are so close together that they are virtually in contact with each other. They are separated only by a thin layer of fluid called the pleural fluid. The pleural fluid acts as a lubricant to allow the pleural membranes to slide over each other during respiration.

If there is damage to the lung or to the chest wall, the space between the pleural membranes may become filled with gas (pneumothorax) or blood (haemothorax). This will cause partial or complete collapse of the lung (see section 3.33).

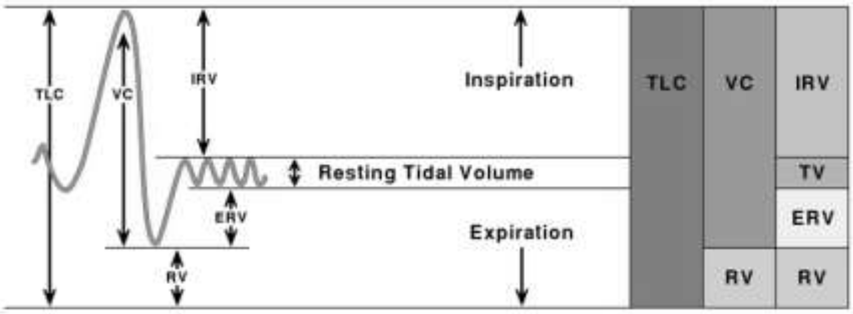
Deoxygenated blood is carried to the lungs by the pulmonary artery. Oxygenated blood is carried from the lungs back to the heart by the pulmonary vein (see section 3.6).

The act of breathing is triggered in the brain by raised carbonic acid levels (due to increasing CO_2 production in the cells) in the bloodstream. The chest expands drawing gas into the lungs. The movement is caused by the muscles between the ribs and the contraction of the diaphragm. This increase in respiration causes the reduction of carbonic acid to 'normal levels'.

When the chest is fully expanded, nerve receptors in the chest wall send signals causing the muscles to relax and the chest contracts expelling the gas.

In normal air breathing, we inhale approximately 21% oxygen and our exhaled gas contains about 16% oxygen which is sufficient for mouth to mouth resuscitation of an unconscious non breathing person, who is thus hypoxic.

The average adult male takes about 12 breaths per minute at rest, moving about 500 ml of gas during each breath (tidal volume). The total lung capacity is about 6000 ml and in very deep breathing about 5000 ml of gas can be moved. This is known as the vital capacity of an individual.



Key

TLC	Total Lung Capacity
VC	Vital Capacity
IRV	Inspiratory Reserve Volume
TV	Tidal Volume
ERV	Expiratory Reserve Volume
RV	Residual Volume

Figure 3-2 – Lung volume schematic

During normal respiration at rest, the body uses about 250 ml of oxygen per minute. During exercise oxygen use can be 1000 ml per minute or more. For calculations involving divers in saturation, IMCA D 050[1] recommends using a consumption of 500 ml per minute. This figure is for metabolic use and does not depend on depth.

Normal production of carbon dioxide at rest is about 200 ml per minute. This is slightly less than the normal oxygen consumption, but for all practical calculations carbon dioxide production can be taken to be as the same as oxygen use.

During respiration, the upper airway, the trachea and parts of the bronchi constitute a dead space where no gas exchange takes place. During normal breathing about 150 ml of gas remains in the dead space. Oral nasal masks and snorkels add to this dead space.

During rapid shallow breathing, most gas movement takes place in the dead space and there is only a small amount of gas exchange. This leads to carbon dioxide accumulation in the lungs.

Confusingly, the term ‘hyperventilation’ is applied both to this type of breathing and to repeated deep breaths which flushes carbon dioxide from the lungs.

3.6 Circulatory System

Blood vessels extend throughout the body carrying blood to and from all the tissues. Arteries carry blood away from the heart, veins return blood to the heart. Blood is pumped from the heart through large arteries which repeatedly branch into smaller arterioles and finally into capillaries where gas exchange with the tissues takes place.

Blood then flows from the capillaries into small veins, which progressively join together and increase in size, to return to the heart.

There are two circulation circuits. The systemic circulation supplies all the body tissues except for the lungs which are supplied by its own specific circuit. The pulmonary circulation passes only through the lungs.

In the systemic circulation blood pumped away from the heart through the arteries is oxygenated and bright red in colour. Blood returning to the heart through the veins has given up oxygen to the tissues and is dark red. Almost every case of bleeding involves the systemic circulation.

In the pulmonary circulation blood pumped away from the heart through the pulmonary artery is going to the lungs to be oxygenated and is dark red. Blood returning to the heart from the lungs through the pulmonary vein has been oxygenated and is bright red in colour.

3.7 The Blood

Blood carries oxygen and nutrients to the tissues and transports carbon dioxide and other waste products. It also carries hormones, protects the body from bacteria and other harmful substances, and helps to maintain temperature and fluid balance.

An important constituent of blood is haemoglobin (in red cells) which carries oxygen to the tissues. Haemoglobin carries about 95% of the oxygen with the remainder dissolved in the plasma. The blood also contains leucocytes (white cells) which protect the body against invading micro-organisms and remove dead cells and other debris, and platelets which cause the blood to clot.

These constituents are carried in a fluid called plasma. When the breathing gas contains a high pO_2, a significant amount of oxygen is carried dissolved in the plasma. This is important in the hyperbaric treatment of carbon monoxide poisoning.

If bubbles form in the bloodstream as a result of decompression illness, platelets may activate and clots may form around the bubbles.

3.8 The Heart

The heart lies in the centre of the chest, although two thirds of its mass is to the left of the midline. It is about the size of a fist and consists of four ‘chambers’ and two main muscular pumps. The right heart receives blood from the systemic circulation which has a low oxygen content and a high carbonic acid level and pumps it through the pulmonary circulation. Here, in the lungs, the carbonic acid is released as carbon dioxide into the alveoli and transported out of the body in the exhaled gas. At the same time oxygen is picked up.

The more powerful left heart receives the oxygenated blood from the lungs and pumps it through the systemic circulation to supply all the body tissues and then back to the right heart.

One-way valves in the heart ensure that the regular contractions pump the blood in the right directions.

Blood pressure is usually measured in millimetres of mercury (mm Hg). Systolic blood pressure is the pressure exerted against the walls of the arteries when the heart is contracted. For adult males it is roughly 100 mm Hg plus the patient’s age. Diastolic blood pressure is the pressure when the heart is relaxed. It is normally between 65 and 90 mm Hg.

Blood pressure may fall because of blood or fluid loss, various conditions which dilate the blood vessels and increase the volume available for circulation, problems with the heartbeat, or some other medical condition.

Capillary refill gives a quick indication of blood pressure in a casualty. Squeezing the bed of a fingernail or pinching a fold of skin in the forehead stops circulation to that point and the tissue becomes pale. When the pressure is removed, the colour should return to pink almost instantly. If the refill takes more than 2 seconds, there may be cause for concern.

The heart muscle is stimulated to beat regularly by a series of electrical impulses. Various circumstances such as electric shock, hypoxia, severe hypothermia, electrolyte imbalance caused by near drowning, trauma and a variety of medical conditions can cause this rhythm of electrical impulses to become chaotic.

This condition is known as ventricular fibrillation and stops the heart beating. The casualty can be sustained using CPR, but it may be possible to re-start the heart using a portable defibrillator.

The normal heart rate may be anything from below 40 beats per minute in a very fit individual to over 80 beats. During hard exercise it may rise as high as 200 beats.

The heart rate can be counted easily by feeling the pulses in the neck (carotid), wrist (radial) or inner thigh (femoral). The most reliable pulse in a casualty is the carotid.

If the casualty's systolic blood pressure has dropped below 80 mm Hg, the radial pulse will not be detectable. Below 70 mm Hg the femoral pulse will not be detectable; below 60 mm Hg the carotid pulse will not be detectable.

3.9 Nervous System

The nervous system transmits information rapidly from one body area to another by means of nerve impulses.

Although there is a single, continuous nervous system it is convenient to subdivide it into the central nervous system and the peripheral nervous system.

3.10 Central Nervous System (CNS)

The CNS consists of the brain and spinal cord, both of which are encased in and protected by bone. The spinal cord is continuous with the brain.

The organs of the central nervous system are covered by layers of membrane known as the meninges. Cerebro-spinal fluid circulates around brain and spinal cord under the meninges. It is similar to plasma and acts as a protective cushion around the CNS.

The principal parts of the brain are the cerebrum, cerebellum and brain stem.

The cerebrum is the largest part of the brain and controls all the higher functions such as thought, speech and voluntary movement. It also exercises unconscious control over many of the body's functions.

It is split into two hemispheres and different areas of the brain are involved in different activities. The left hemisphere of the brain controls movement on the right side of the body. The right hemisphere controls movement on the left. Damage to one side of the brain is indicated by symptoms and signs down the other side.

The cerebellum lies beneath the cerebrum and is of similar shape but considerably smaller. It exerts unconscious control over a variety of basic functions.

The brain stem links into the spinal cord and also controls the operation of the heart and lungs.

Damage to the brain is indicated by symptoms down one side of the body. Damage to the right side of the brain might show, for example, as loss of control or feeling in the left arm and left leg.

The spinal cord runs through the spinal cavity and is protected by the spinal column. It transmits nerve impulses to and from the brain. Bundles of nerves to various parts of the body branch out from the spinal cord at various levels down the spinal column.

Damage to the spinal cord is indicated by symptoms below the point at which damage has occurred. It might show, for example, as loss of control or feeling in both legs.

If the spinal cord is damaged, it will not repair itself, although over a period of time nerve impulses may re-route themselves.

3.11 Peripheral Nervous System (PNS)

The PNS collects information from various sensors both inside and on the surface of the body and transmits it to the CNS. It then passes information from the CNS to the various parts of the body.

There are 12 cranial nerves which carry information about vision, hearing, smell, taste, heart rate, and head, shoulder and tongue movements. The neurological assessment in cases of decompression illness includes tests of the functioning of the cranial nerves.

There are 31 pairs of spinal nerves, each of which can be related to a specific area of body surface.

The PNS can be separated into those nerves which carry information from the sensory organs to the CNS and those which carry information from the CNS to organs such as muscles and glands which will perform specific actions.

The latter can be further divided into two groups. The somatic system, broadly speaking, involves those organs that are under conscious control, like the muscles of the arm. The autonomic system involves organs that are not under conscious control, like the muscle of the intestines.

3.12 The Ear

The ear is particularly vulnerable to pressure differences and damage to the eardrum can be painful and have serious consequences for a diver.

The outer ear, leading from the outside to the eardrum, has specialised sweat glands which produce wax to protect the eardrum against dust. A wax blockage in the outer ear can lead to a reversed ear during diving (see section 3.25).

In saturation diving, the outer ear becomes extremely vulnerable to bacterial and yeast infections.

The eardrum separates the outer ear from the middle ear. The eardrum is a delicate skin membrane which transmits sound vibrations to the linkage of small bones called ossicles in the middle ear.

The middle ear is connected to outside atmosphere via the Eustachian tube which connects to the back of the throat. If the Eustachian tube is blocked by swelling or mucus, the diver is unable to equalise pressure in the middle ear (see section 3.26).

The ossicles transmit the vibrations to the cochlea in the inner ear. The cochlea contains the hearing sense organ, which transmits the information to the brain via the auditory nerve.

Also in the inner ear are the fluid filled semi-circular canals which control balance. In rare cases, decompression illness may be caused by bubble formation in the inner ear.

The brain can identify the direction from which a sound comes by noting the time difference in the arrival of the sound at each ear. In water, sound travels much faster than in air, and the brain is unable to make this distinction. The diver is, therefore, unable to locate the source of a sound underwater.

3.13 General Principles of First Aid

All divers have some first aid training and the *IMCA international code of practice for offshore diving* requires that at least two team members are diver medics. At least one diver medic must be available on the surface or in the saturation chamber at all times. This means that in theory a diver medical technician (DMT) in a sat system should not be diving without another DMT in the system.

The principles of first aid apply when dealing with diving injuries, as with all other injuries. There are many excellent books and courses and this section merely summarises the steps of the primary survey of a casualty.

Studies show that the survival of a seriously injured casualty depends to a large extent on the time it takes to get specialised help. Always summon help immediately.

Before approaching any casualty, in the water or on deck, first ensure that it is safe to do so.

Thereafter, the steps of the primary survey can be remembered by the mnemonic ABCDE – Airway, Breathing, Circulation (and c-spine), Disability, Expose and Examine.

Recommendations from medical organisations concerning initial actions can change from time to time. The information below is generic and you should follow the practices taught by your training provider and observe possible regional-specific requirements.

3.14 Safety

Is it safe to approach the casualty?

Hazardous situations might include a diver unconscious in a chamber, bell or other enclosed space, a casualty in contact with a live high voltage cable or a diver unconscious in the water because of a contaminated air supply.

If the diver is unconscious in the water it will be extremely difficult to check airway and breathing or start resuscitation. He should be brought onto the deck or into the bell as rapidly as possible.

3.15 Airway

Is the casualty's airway clear?

Approach the casualty and, if possible, hold the casualty's head before asking "Are you all right?" Holding the head prevents movement which could aggravate any c-spine injury (see section 3.18).

If the casualty is conscious and in no obvious difficulty the airway is clear and other injuries can be dealt with.

If the casualty is unconscious, summon help immediately, before or while checking the airway.

The airway must always be checked first, regardless of other injuries. Casualties have died of suffocation while enthusiastic rescuers applied pressure and bandages to serious wounds.

The airway may be blocked by vomit, debris, dentures, damaged teeth or tissue or a swallowed tongue. A swallowed tongue is typically found after an oxygen convulsion. In most cases blockage can be removed with the fingers.

3.16 Breathing

Call for a medic (or ambulance if the vessel is docked).

If the casualty is not breathing, open the airway by using a head tilt or chin lift and look, listen and feel for signs of breathing for 10 seconds. Use a chin lift if spinal injury is suspected.

If the casualty is breathing and there is no reason to suppose spinal injury, place in the recovery position and monitor his condition until he is transported to a medical facility.

If the casualty is not breathing give two effective inflations, either mouth to mouth or using resuscitation equipment. Make sure the airway is open and watch for lung inflation.

Inflations will be of no benefit if the casualty has no circulation and this must be checked before continuing.

3.17 Circulation

Spend 10 seconds looking for movement, swallowing, profuse bleeding (as an indication of circulation), checking capillary refill or pulse.

To check capillary refill, squeeze and release the nail bed on any finger or a fold of skin on the forehead. The nail or skin should appear white for a moment, as the blood supply is restricted, and then regain its colour as the capillaries refill. If there is no refill, there is no circulation.

Always check the carotid pulse in the neck. The radial pulse (in the wrist) may not be detectable.

Capillary refill and pulse may be difficult to assess if the casualty is hypothermic.

If there is no circulation, or you are unsure, start CPR at a rate of 30 compressions to 2 breaths.

If there is circulation, continue rescue breathing at a rate of 10 breaths per minute and monitor circulation.

If available, a portable automatic defibrillator may be used to re-start the heart. This very useful piece of equipment literally talks the user through the procedure and can be used with the minimum of training. It should be increasingly available on offshore worksites.

Once breathing and circulation are assured, stop any serious bleeding, by bandaging or direct pressure.

Internal bleeding is associated with broken bones, especially the femur (thigh bone) or pelvis, abdominal injuries or the effects of an underwater explosion.

Internal bleeding as a result of a fracture can be reduced by splinting and stabilising the injury.

3.18 C-Spine Injury

After any accident involving a fall, impact or whiplash, suspect injury to the c-spine. These are the vertebrae in the neck and injury can lead to serious and incapacitating damage to the spinal cord.

Detecting symptoms in an unconscious casualty is impossible and a conscious casualty may not experience any initial symptoms. Always handle such casualties with care, avoid moving the neck and fit a neck collar as soon as possible.

Neck collars still allow sufficient movement to cause damage and even after a collar is fitted, continue to hold the casualty's head.

Damage to the spinal cord causes a variety of symptoms including numbness and tingling in the extremities and paralysis. These symptoms are, of course, also symptoms that might be present in serious DCI (decompression illness).

If there is reason to suspect DCI the casualty should be pressurised on the appropriate therapeutic table, while continuing any other first aid procedures. However, it may be necessary to weigh up priorities – if CPR is essential and severe bleeding needs to be addressed, this may take priority over the need to recompress in cases of less serious DCI.

3.19 Disability

This is a quick check of the casualty's consciousness level to establish a baseline for monitoring his progress.

Use the AVPU scale of consciousness:

A – Alert

V – Responds to Verbal stimulus

P – Responds to Painful stimulus

U – Unresponsive.

3.20 Expose and Examine

Exposing the casualty's body surface will reveal any further injuries, which can be dealt with in order of importance.

It may be necessary to cut off a diver's suit to carry out the examination. Note that a tight fitting wetsuit or undersuit may act both to reduce bleeding and to restrict blood flow into the limbs, thus maintaining blood pressure in the brain. Cutting or removal of the suit may cause a serious blood pressure drop. However, it is inevitable that the suit will have to be removed (cutting off if necessary) to get access to the arteries (to assess BP and pulse), veins (to get IVs in), urethra (to insert urinary catheters) and to perform examinations.

3.21 Monitoring the Casualty

Once the casualty is stable, monitor his condition by checking and recording the vital signs every five minutes until he is handed over to a medical facility.

The vital signs are:

- pulse;

- blood pressure;
- respiration;
- skin colour and temperature;
- pupil size.

Check the carotid pulse, note the rate and whether it is weak, strong, bounding or irregular.

Assess blood pressure (BP) by checking the other pulses or by noting the capillary refill time. If the BP is below 80 mm Hg, the radial pulse will not be detectable. Below 70 mm Hg the femoral pulse will not be detectable, below 60 mm Hg the carotid pulse will not be detectable.

Count the breaths per minute and note whether breathing is shallow, deep, rapid or noisy.

Note whether the skin is pink, pale or bluish in colour, hot, warm, cold or moist.

Pupils should be equal in size, round and react to light. If a small light is shone into the eye, the pupil should contract.

Recording this information provides valuable data for medical staff dealing with the casualty.

3.22 Casualty Handling

Casualty handling is an important part of first aid. In general, the casualty should be handled gently, keeping the head and spine stable and paying attention to any broken limbs.

There has been little research or practice into handling an injured diver in the water. The priority is usually to get him quickly to the surface or into the bell.

If spinal injury is suspected, attempts should be made to stabilise the diver's head as he is brought to surface. The weight of the head and helmet will cause the head to swing sharply.

If sea conditions permitted, and the diver was clearly breathing and in no danger of vomiting into his helmet, it would be possible to float a spine board under his body. This would be used to stabilise his c-spine before lifting him from the water.

This method has been used successfully on injured swimmers who have suffered c-spine injuries from board diving in swimming pools.

Helmet removal must be done with extreme care, maintaining traction and supporting the head and neck.

3.23 First Aid Equipment

There must be a minimum amount of first aid equipment at the diving site. This will depend on the type of diving, but a standard list has been agreed and can be found in DMAC 15[2] and DMAC 28[3].

Much of the equipment listed is intended for a doctor coming to the site to attend a serious emergency. It is not all intended for first aid use.

Regular checks must be made to see that drugs are properly stored and still in-date.

Bell and chamber kits and resuscitation equipment should be checked before every dive and all members of the diving team should know how to use the equipment.

3.24 Barotrauma – Introduction

Barotrauma, or 'pressure injury', is injury caused by pressure differences between the various cavities in the diver's body and his environment.

It is most likely to occur close to the surface where the proportional changes in pressure are greater. If a diver descends from the surface to 10 msw, the pressure will double. If he descends from 90 msw to 100 msw the pressure will only increase by one tenth.

The effects range from minor irritation to serious, sometimes life threatening, conditions.

3.25 Aural Barotrauma

Aural barotrauma, or barotrauma affecting the ears, is probably the most common diving problem. Pain is caused by a pressure difference across the eardrum.

Under normal conditions, pressure equalises through the Eustachian tube, which connects the middle ear to the back of the throat. If the Eustachian tube is blocked, usually by mucus, pressure cannot equalise and the eardrum is forced in as the diver descends.

Divers are familiar with 'clearing the ears'. This procedure, known medically as the Valsalva manoeuvre, simply equalises pressure through the Eustachian tube.

A blocked Eustachian tube can sometimes be cleared by the use of nose drops or sprays, but these may have adverse side effects which prohibit diving. Refer to the instructions and advice of the company's medical adviser.

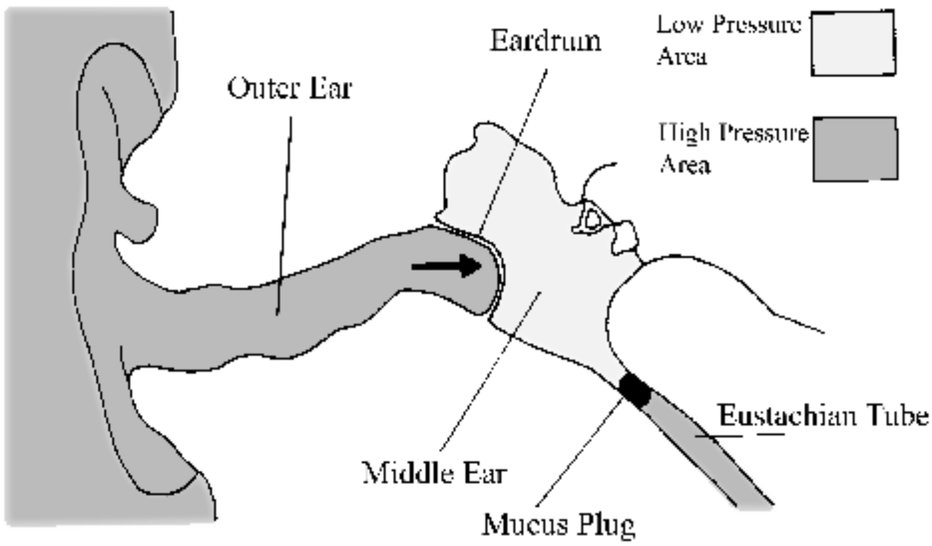


Figure 3-3 – Aural barotrauma – blocked Eustachian tube

Reversed ear occurs when the Eustachian tube is clear, but the outer ear is blocked by a wax plug or sometimes a tight fitting wet suit hood. Pressure cannot equalise in the space between the eardrum and the wax and the eardrum is forced outwards.

In both cases, only a very small pressure difference can cause severe pain. Continuing the descent will rupture the eardrum. This can allow water to enter the middle ear, causing disorientation and nausea and raise the chances of infection.

A diver should not dive if he is unable to clear his ears. If the diver has an inflamed eardrum or bleeding from the ears after a dive seek medical advice.

3.26 Sinus Squeeze

The sinuses are cavities in the forehead and cheekbones which are connected directly to the back of the nose. If the connecting tubes become blocked by mucus, pressure in the cavities cannot equalise on descent. The blood supply to the lining of the sinuses will be at a higher pressure than the cavity and small blood vessels will rupture. The diver suffers pain and bleeding from the nose. If he is unable to clear his sinuses, he should abort the dive. Problems with equalising the maxillary sinus will often result in pain in the upper teeth.

If the sinuses block while the diver is underwater, gas will be trapped under pressure in the cavities. The diver will suffer increasing pain on ascent and the pain will continue for some time after the dive.

Pressure usually equalises gradually, but the mucus plug may be forced explosively down the nose. Nasal decongestants may help but must be used with care and following consultation with the company's diving medical adviser.

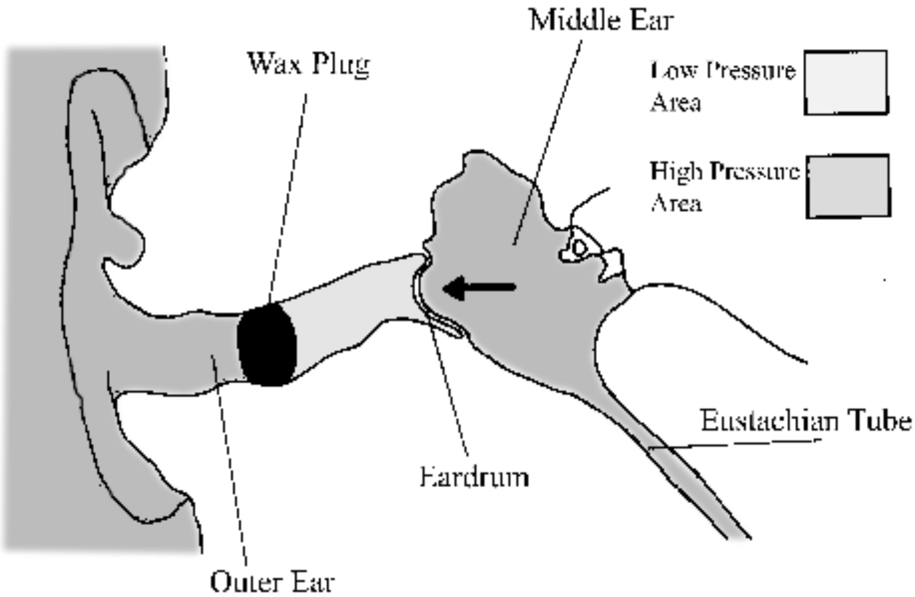


Figure 3-4 – Aural barotrauma – reversed ear

3.27 Dental Barotrauma

Minor, but painful, problems may occur if there is a cavity beneath a filling in a tooth. The diver will suffer pain on descent. This may ease after he reaches working depth if the pressure in the cavity equalises.

If gas is trapped in the cavity at depth, the filling may be forced out by the pressure on ascent. In some cases, the tooth itself has shattered. These problems can be avoided by good dental care. Divers should consult a dentist for a check-up every 6 months

Pain occurring in all the top teeth may be associated with sinus squeeze rather than dental barotrauma.

3.28 Mask Squeeze

Mask squeeze occurs in diving when pressure in a face mask is less than the surrounding pressure. It occurs when the diver fails to equalise pressure in the mask through his nose.

Symptoms are discomfort, nosebleed, bulging and bloodshot eyes. The condition occurs during descent and can be easily remedied by equalising pressure through the nose or returning to surface.

3.29 Nips

Nips only occur when using a dry suit without suit inflation. As the pressure increases, the suit is compressed around the body, trapping folds of skin in the material of the suit. This produces minor, but painful, bruising, often in a linear fashion and may be confused with skin DCI.

3.30 Helmet Squeeze

Helmet squeeze is usually associated with standard gear divers. It is very rare these days, although a mild case did occur in the 1980s whilst divers were using a gas recovery system.

The injury occurs when there is a relative pressure drop inside the diver's helmet. In hard hat diving, this used to occur if the diver fell into deeper water and his compressor was unable to cope with the rapid pressure increase. The pressure in his helmet and lungs would be less than the surrounding pressure. The lungs would be compressed and in extreme cases the rib cage would be crushed, and there would be severe internal haemorrhaging. The condition could be fatal.

In the very early days of diving before non-return valves were fitted to helmets, squeeze occurred if the diver's compressor failed, or his umbilical was broken. The pressure in the diver's helmet and lungs would fall to surface pressure, or to the pressure at the broken end of the umbilical.

All helmets now have a non-return valve to prevent this type of pressure loss.

The modern diver is neutrally buoyant and unlikely to be subject to sudden rapid descents. His air or gas supply is far more efficient and the seals on helmets and masks are soft enough to allow flooding if there should be a pressure drop.

The only potential hazard is in gas recovery systems where the diver's exhaled gas is returned to the surface for recycling. He is able to exhale to a pressure lower than helmet pressure through an exhaust valve. In theory, failure of the exhaust valve could have serious consequences. In practice a chain of safeguards is built into the system and gas recovery systems have an excellent safety record.

Treatment depends on the severity of the squeeze. In all cases, medical advice should be sought.

3.31 Pulmonary Barotrauma of Ascent

This typically occurs when the diver is subject to a rapid, uncontrolled ascent, either in the water or in a chamber or bell blow up. It is rare in commercial diving and usually occurs among inexperienced sports divers. The few commercial diving accidents appear to have been caused by equipment failure.

During a rapid ascent, the diver must exhale forcibly. If he fails to do so, or if the ascent is too fast, the pressure in his lungs will exceed the surrounding water pressure.

Only a very small pressure difference is needed to damage the delicate membranes and blood vessels in the lungs. Gas can then escape from the lungs into other body tissues or cavities, or enter the bloodstream directly in the form of bubbles, leading to cerebral artery gas embolism.

As in all cases of barotrauma, the most dangerous time is close to the surface where proportional pressure changes are greatest. The volume of gas in the lungs doubles in the last 10 msw. If a blow up can be stopped before the last 30 msw, the potential for injury can be reduced considerably.

Note that in any mixed gas blow up, the diver will also be suffering from hypoxia. As the ambient pressure falls so will the pO_2 (see section 2.19).

The diver may also be suffering from decompression illness. If a diver suffering from pulmonary barotrauma has to be recompressed, he should not be decompressed without medical advice. There may be complications associated with the barotrauma (see section 3.24).

There are three common conditions associated with pulmonary barotrauma of ascent: interstitial emphysema, pneumothorax and arterial gas embolism. They may be present individually or together.

3.32 Interstitial Emphysema

The escaping gas travels through the tissue layers into the space between the lungs (the mediastinum), or below the skin under the arms or at the base of the neck. Gas bubbles can sometimes be felt and seen under the skin.

The diver may feel pain behind the breastbone and a sensation of fullness in the throat. His voice may be hoarse. He will normally be treated in hospital. If this happens in sat, the decompression profile may need to be altered to cope with expansion of gas.

3.33 Pneumothorax

This literally means 'air in the chest'. Gas escapes from the lungs into the space behind the ribs.

Under normal conditions, the lungs adhere to the back of the ribs by suction. The escaped gas breaks the suction, allowing all or part of a lung to collapse. In very mild cases, the victim may not notice any symptoms and the condition can only be identified by X-ray.

In more serious cases, the victim will feel pain in the chest in the area of the collapse and may have breathing difficulties. His chest will move unevenly when breathing and, because the collapsed lung restricts circulation, the blood vessels in the neck may be swollen. His breathing rate may increase.

If the victim is under pressure in a chamber, he must not be decompressed without medical assistance. As the decompression proceeded, the volume of gas in the chest would expand, collapsing the lung further. Collapse of both lungs is, of course, fatal.

A doctor, or suitably trained medic, can equalise pressure by inserting a hollow needle between the ribs (thoracocentesis). The lung is normally re-inflated in hospital.

3.34 Arterial Gas Embolism (AGE)

This is one of the most serious pressure related injuries. Gas from the lungs enters damaged blood vessels in the form of bubbles. Because the damage occurs during a blow up, the ambient pressure is reducing rapidly and the bubbles increase in size as they travel though the bloodstream.

They are carried first to the heart and then through large blood vessels to the brain. They lodge in the smaller vessels supplying the brain, restricting circulation and causing serious damage to the central nervous system.

The diver may suffer from paralysis, visual disturbance, loss of balance, convulsion or collapse. The symptoms are rapid in onset, usually occurring within five minutes of surfacing and the condition is often fatal.

The only effective treatment is immediate pressurisation. The exact depth of pressurisation will be given in the company manual. This will compress the bubbles and allow the circulation to re-establish itself. CPR may be necessary during transport to the chamber and during pressurisation.

No attempt should be made to decompress the diver without medical advice. He may require several days to stabilise and there may be other complications such as pneumothorax (see section 3.33).

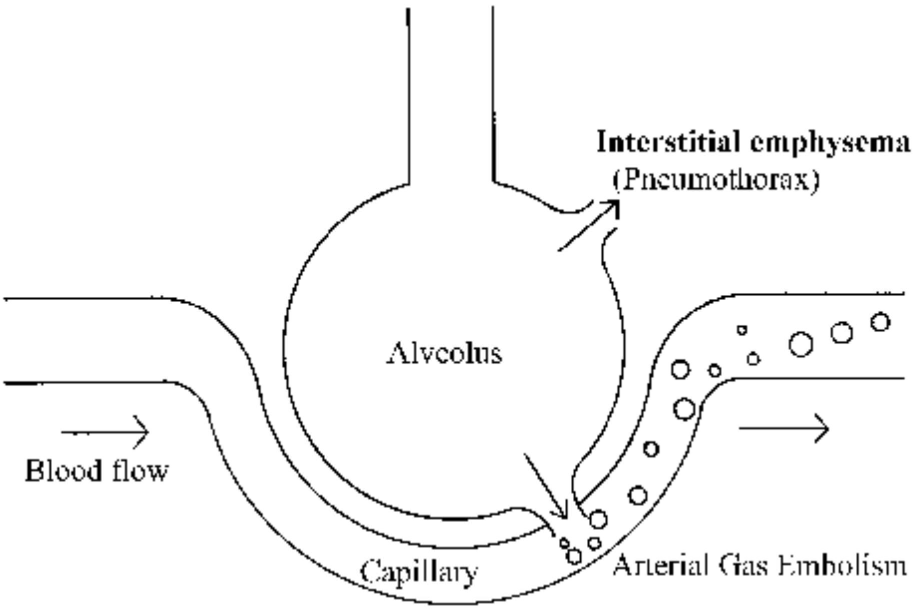


Figure 3-5 – The mechanisms of pulmonary barotrauma

3.35 Decompression Illness (DCI)

During a dive, the inert gas in the diver's breathing mixture is absorbed into his tissues. The mass of gas absorbed depends on the partial pressure of the gas (Henry's Law), the type of tissue and the time. After a specific time, which depends on the type of gas and the pressure, the diver's tissues become saturated with gas and no more is absorbed.

Breathing air on the surface at a pressure of 1 bar, the body is saturated with about 1 litre of nitrogen. The body of an air diver under a pressure of 2 bar contains about 2 litres of nitrogen, when saturated, under a pressure of 4 bar, 4 litres when saturated and so on.

Slightly less than half of the nitrogen is dissolved in water in the body, slightly more than half in fat. Fat only makes up about 15% of normal body weight, but nitrogen is five times more soluble in fat than in water.

Typically, nitrogen dissolving in the water of the body reaches saturation in about one hour. Nitrogen dissolving in the fat takes several hours. Fat requires much more nitrogen to become saturated and has a relatively poor blood supply.

When the partial pressure of the inert gas decreases, it starts to come out of solution. If it comes out of solution too quickly, it forms bubbles which lodge in the tissues, causing a variety of symptoms.

The partial pressure of the inert gas may be reduced by an overall pressure drop during ascent or by a change in gas mixture at the same depth. During bounce dive decompressions, for example, divers used to transfer from a bell filled with heliox mix to an air filled chamber. Although the overall pressure remained constant, the partial pressure of helium had fallen to zero and helium started to diffuse rapidly from the divers' tissues. Under these conditions, there is a risk of DCI.

Similar problems could occur if chamber reclaim gas, containing a high proportion of nitrogen, was used to pressurise a chamber.

In general, DCI is avoided by the correct use of decompression tables. The longer and deeper the dive, the longer the decompression will take. Even if the decompression table is followed exactly, however, there is still a risk of DCI. The tables are for an 'average' diver. Individual susceptibility can depend on age, fitness, obesity, cold, fatigue, local restrictions to circulation and even emotional stress.

After a successful decompression, the bloodstream is still full of very small 'silent' bubbles, detectable only by ultrasonic techniques. Hard exercise after the decompression can cause the bubbles to coalesce and cause DCI.

If an air diver ascends from 10 msw to surface, about 65% of the dissolved nitrogen will have left his body in the first hour and about 90% after six hours. He will not, however, be completely free of the excess gas for 12 hours.

In surface supplied diving, the incidence of DCI drops if the length of time that a diver spends at a particular depth is limited. Many companies therefore impose a time limit. Historically this was typically done by limiting dives to the US Navy Tables 'O' repetitive group. In many parts of the world, such as the North Sea, either governments or clients may impose specific depth and time limits. IMCA's maximum bottom time limitations for surface decompression (SD), in-water decompression and transfer under pressure (TUP) decompression diving are shown in Appendix 2.

Historically two types of DCI were generally recognised – Type 1 or pain only DCI and Type 2 or serious DCI. The latter affects the central nervous system and is far more dangerous, although the symptoms may seem trivial. There is a current school of thought that does not differentiate between type 1 and type 2 DCI. All DCI is caused by insult to the body through gas release; the extent, location and duration will determine the nature and severity of the resulting symptoms.

Some companies maintain the Type 1 and Type 2 categorisation of DCI.

The only satisfactory treatment is recompression and eventual decompression using a therapeutic table. This always includes treatment with a high partial pressure of oxygen.

It is usual to treat all cases as serious DCI since some are often masked by pain. A case of pain-only DCI can develop into serious DCI.

A full neurological check should be carried out, using the checklist supplied by the company.

Nerves and tissues are damaged by DCI and it is important to start treatment promptly. Cases treated within 30 minutes have a 90% success rate. A delay of 5 hours reduces the success rate to only 50%. If the delay is over 12 hours the success rate is low.

Delays sometimes occur because the diver is unwilling to report his symptoms. This may be due to inexperience, a reluctance to return to the chamber or even a fear of missing a crew change. Pain is often described as a sore, pulled or stiff muscle. The only way to check is to pressurise the diver. If the symptoms disappear, it is DCI.

Although the mechanism is different, arterial gas embolism is categorised as DCI. The injury occurs during decompression and the symptoms are identical to those of a serious DCI.

3.36 Pain Only DCI

Pain only DCI is likely caused by bubble formation in muscles or joints. Pain, which is often severe, occurs at the site of bubble formation.

Skin bends are caused by bubble formation in the fat layers under the skin. The diver will experience an itching sensation and a rash may develop.

Minor pains or twinges are often described as 'niggles'. They are, nevertheless, DCI and must be treated accordingly.

3.37 Serious DCI

Serious DCI is caused by bubble formation in the central nervous system (CNS). The symptoms may be minor – pins and needles or a slight numbness – but they must be treated with the utmost seriousness. Serious DCI is often difficult to differentiate from arterial gas embolism especially if it comes on quickly. Consideration must be given to gas load, rate of ascent, potential for pulmonary barotraumas, speed of onset of symptoms and so on.

Spinal DCI, for example, is caused by bubble formation in the spinal cord or in the sheath covering the cord. Typical symptoms are numbness or tingling in the extremities, pain around the waist, loss of bladder or bowel control, a feeling of weakness in the legs or paralysis below a certain level.

If the condition is untreated, a portion of the spinal cord will be permanently damaged. Although the nervous system may be able to bypass the damage and restore the functions, its capacity for repair is reduced. Next time, the diver may face permanent loss of sensation or permanent paralysis.

If bubbles lodge in the brain, the diver can display symptoms ranging from simple irritability to hallucination or paralysis down one side of the body. Any unusual behaviour may be a symptom of cerebral DCI and a full neurological check must be carried out.

Vestibular DCI is caused by bubble formation in the inner ear. The symptoms are loss of balance, nausea and vertigo. There is often a ringing or roaring noise in the ears. This type of DCI is sometimes associated with a change from helium-oxygen mixtures to air, or deep excursions from saturation.

Although the CNS is not involved, the condition known as 'chokes' is included as serious DCI because it is immediately life threatening. The diver is unable to breathe properly because large numbers of bubbles have formed in the pulmonary circulation.

Chokes are rarely seen in modern diving and are usually associated with a blow up, or rapid decompression. Breathing difficulties may also occur if bubble formation is interfering with the breathing reflex in the brain.

3.38 Dysbaric Osteonecrosis

Osteonecrosis, or patches of dead bone, is found in the general population but some evidence suggests it occurs more frequently in divers and compressed air workers. It is probably caused by a restriction of circulation to the bone, during repeated decompressions over a long period.

When large scale diving started in the North Sea, regular checks were carried out on all divers to assess the long term effects. Although necrosis does occur, it is generally restricted to the shafts of the long bones and has no disabling effect. Damage to a joint occurred only in a very small number of cases. It is no longer considered a serious hazard.

3.39 High Pressure Nervous Syndrome (HPNS)

If divers are compressed too rapidly, to depths in excess of 100 msw (330 fsw), they may suffer from tremors and loss of co-ordination and show changes in their brain-wave patterns.

The condition worsens with depth and can become disabling. The symptoms disappear on decompression. It can be avoided by slow, planned pressurisation for deep dives.

3.40 Compression Arthralgia

Rapid or deep pressurisation can also cause discomfort and pain in the joints. This may be associated with clicking noises when the joints are moved.

It is thought to be caused by small pressure differences in the joints. Like HPNS, it can be avoided by following a safe pressurisation schedule

3.41 Gas Toxicity

Although it is possible to give approximate partial pressure limits for the toxicity of various gases, these are only guidelines. Susceptibility varies from person to person and day to day.

Gases routinely encountered in diving usually have straightforward partial pressure limits. Other gases, like welding gases, may have limits expressed as occupational exposure limits (OEL), or threshold limit values (TLV) which are based on regular exposure during a normal working week.

On the worksite always adhere to the limits laid down in the company manual.

3.42 Chronic Oxygen Poisoning

Pulmonary or chronic oxygen poisoning develops after long exposure to a pO_2 in excess of 0.6 bar. This could occur if divers were living in saturation chambers for extended periods, or if a diver were breathing oxygen for a long period as part of a therapeutic decompression. The following table shows the approximate amount of damage that might be expected after breathing various pO_2s.

pO_2 (bar)	**Time to cause 10% lung damage**	**Time to cause 20% lung damage**
2.0	9 hours	15 hours
1.5	13 hours	20 hours
1.0	23 hours	Several days
0.8	Several days	
0.6	No damage	

In an attempt to assess the risk from breathing various partial pressures for various times, the unit pulmonary toxic dose (UPTD) has been defined as the effect of breathing oxygen at a pressure of 1 bar for 1 minute. Doubling the partial pressure, however, more than doubles the UPTD and the UPTD is normally calculated by referring to a table.

Unfortunately, UPTD calculations cannot take into account the differences between people, the effects of previous oxygen breathing and the recovery period during air breaks.

During chronic oxygen poisoning, the lungs become congested, there is a fluid build-up and damage to the capillaries. The first symptom is a mild tickling, or irritation in the lungs and a slight cough.

The irritation progresses to a severe and constant burning sensation, aggravated by breathing, and a persistent cough. If the diver were to continue to breathe a high pO_2 his lungs would suffer permanent damage.

Other symptoms include extreme fatigue, muscle aches, headaches, dizziness, tingling and numbness in the fingers and toes.

Chronic poisoning is avoided by careful monitoring of the pO_2. Divers in a saturation chamber normally breath a pO_2 of about 0.4 bar. In the water, saturation divers breathe a pO_2 of about 0.7 bar.

Serious cases of DCI may require long periods of oxygen treatment. A certain amount of chronic poisoning must be accepted if the alternative is damage to the brain or spinal cord.

3.43 Acute Oxygen Poisoning

Acute oxygen poisoning can occur if the pO_2 exceeds 1.6 bar. The oxygen affects the brain directly, causing visual disturbance (usually tunnel vision), hearing problems, nausea, twitching of the facial muscles, irritation and dizziness, followed by a violent convulsion and coma. The victim may swallow his tongue . Unless he is recovered promptly, he may suffocate or drown.

The warning symptoms can be remembered by the mnemonic VENTID:

- Vision;
- Ears;
- Nausea;
- Twitching;
- Irritation;
- Dizziness.

The onset of the convulsion is, however, often very fast giving little if any time to react.

If the diver is breathing a high pO_2 in the chamber, his tolerance is higher. This is probably because CO_2 accumulation in his body during a dive makes him more susceptible in the water.

For DCI treatment in a chamber, the diver can breathe a pO_2 as high as 2.8 bar for a defined time/ intervals before breathing chamber atmosphere. He will do so only under observation by an attendant, who will remove his breathing mask if any VENTID symptoms are seen.

Convulsions may still occur after oxygen breathing has been stopped. If a convulsion should occur, the attendant will prevent the diver from damaging himself and check his airway and breathing. The diver will normally recover from the coma unharmed.

Mouth gags are usually provided to prevent the convulsing diver biting his tongue. The priority, however, must be to stop him damaging his head in the confined space of the chamber. Immobilising his head and not his body could cause neck injuries, so the attendant should merely attempt to prevent his head hitting anything.

No attempt should be made to decompress a diver during a convulsion, even if a move is due. He will be unable to exhale and may suffer pulmonary barotrauma.

Convulsions occur in chambers only rarely. In the water, poisoning is only likely if the diver is supplied with the wrong gas mix. Some divers may show increased susceptibility to the higher concentrations of oxygen used in nitrox diving. The dive supervisor must remain alert and watch for possible signs of oxygen toxicity during such dives. By following procedures and analysing the gas on-line to the diver the risk should be reduced.

3.44 Anoxia

Anoxia is a complete lack of oxygen. It has occurred in diving operations when the diver has been supplied with pure helium instead of the correct gas mix.

If a diver breathes pure helium, the normal pressure gradient in the lungs is reversed. The pO_2 in the breathing gas is lower than that in the diver's body. Instead of oxygen passing from the lungs into the bloodstream, it passes from the bloodstream into the lungs, removing oxygen rapidly from the body. Collapse is almost instantaneous and death follows quickly. CPR should be started immediately, preferably using a high pO_2.

Pure helium is not carried offshore in order to avoid this type of accident. It is standard practice to analyse gas before it goes to the diver and always have an on-line analyser, with audio alarms turned on.

3.45 Hypoxia

Hypoxia is a shortage of oxygen. This is generally considered to occur when the pO_2 is less than 160 mb (0.16 atm). A completely inactive person can survive for a time on less than 100 mb (0.1 atm).

In the water the pO_2 should never get this low. The minimum is usually 450-600 mb.

If the pO_2 is very low, the effect is identical to anoxia. If the pO_2 is only slightly below the limit, there will be a gradual onset of symptoms. The victim is confused and has a pale skin with a bluish tinge. He will gradually lapse into unconsciousness and death. If he is working hard in the water, the onset will be faster.

Treat by removing to a safe atmosphere and resuscitating if necessary.

3.46 Nitrogen and Hydrogen Narcosis

The narcotic effects of deep air breathing have been familiar to divers since the nineteenth century, but it was only in the 1940s that nitrogen was identified as the toxic element.

The effects are similar to drunkenness and can occur whenever the partial pressure of nitrogen (pN_2) exceeds approximately 3.2 bar. In air diving, this starts to occur at depths in excess of about 30m (100 fsw) and is dependent on individual susceptibility. Supervisors must remain alert to signs of the onset of narcosis.

Divers learn to cope with the effects of narcosis by a series of 'work up' dives, increasing the depth a little each time. A deep mixed gas diver is not necessarily competent to cope with narcosis on a deep air dive and should go through a series of work up dives.

Hydrogen which has been used for very deep dives also shows a narcotic effect but at much greater partial pressures.

3.47 Hypercapnia

The symptoms of hypercapnia or carbon dioxide poisoning are headache, sweating and increased respiration usually accompanied by feelings of apprehension.

Almost all cases of CO_2 poisoning in the water occur when the diver loses control of his breathing rhythm. This may be caused by stress or by hard physical work.

His breathing becomes rapid and shallow and his lungs are not flushed adequately. CO_2 levels rise in his lungs, increasing the carbonic acid level in his bloodstream. This, in turn, stimulates his breathing. His breathing becomes faster and shallower and he is caught in a dangerous cycle with the CO_2 in his body rapidly reaching toxic levels. Collapse can follow very quickly without any other symptoms. The diver can avoid the situation by taking regular slow breaths.

The diving supervisor should always monitor the diver's breathing rate and tell him to slow down, or calm down, if it starts to increase.

Carbon dioxide can accumulate in chambers, bells or gas recovery systems, but the build-up is usually slow and can be dealt with easily. Gas recovery systems include a CO_2 analyser with audio and visual alarms.

The maximum pCO_2 limits in chamber and bell are usually 5-10 mb.

3.48 Carbon Monoxide

Carbon monoxide is typically found in the air supply from a faulty compressor or a compressor with a badly placed air intake. It may also be encountered in habitat welding operations.

A partial pressure that would be safe on the surface may be lethal at 30 msw (99 fsw), where the partial pressure is four times greater. Air supplies must be analysed on a regular basis.

The haemoglobin, which normally carries the oxygen in the bloodstream, binds strongly to carbon monoxide. The oxygen carrying capacity of the blood is seriously reduced and the victim will collapse from lack of oxygen. He will have a cherry red complexion, because of the bright red colour of the carboxy-haemoglobin in his blood.

Treatment is difficult because it is very hard to remove the carbon monoxide from the bloodstream and restore its oxygen carrying capacity. Resuscitate and give the casualty oxygen or an oxygen rich mix. Treatment with hyperbaric oxygen is beneficial since additional oxygen will be carried to the tissues dissolved in the plasma.

3.49 Hydrogen Sulphide

Hydrogen sulphide may be found in association with oil based mud which may be carried back into the bell or chamber on divers' suits. The gas will then be given off in the bell or chamber.

The gas has a distinctive 'bad egg' smell, but this is not a reliable guide since toxic levels of the gas destroy the sense of smell.

In low concentrations it causes irritation of the eyes, breathing difficulties and a severe headache. At high levels it causes unconsciousness and death.

Contamination can be avoided by the use of disposable oversuits which are dumped outside the bell. If hydrogen sulphide (H_2S) is suspected, regular checks of bell and chamber atmosphere should be made using chemical sampling tubes and there should be immediate flushing if any gas is detected. Portable detectors are available and have been used in diving bells.

3.50 Hydrocarbons

Benzenes and other hydrocarbons may be present in oil based mud. These can be released into the bell atmosphere from the divers' contaminated suits and umbilicals. Precautions include thorough cleaning of the umbilical before pulling it into the bell, the use of disposable oversuits which are ditched before entering the bell and the use of analyser equipment in the bell (see IMCA D 021[4]).

Another likely source of hydrocarbon contamination is oil spray in the breathing supply. This is commonly caused by a badly maintained air compressor.

Symptoms are narcosis, nausea and possible lung infection. The affected diver should have a full medical check.

Oil in the gas supply may be detected by spraying the gas onto a sheet of clean white paper. Any oil traces will be clearly visible.

3.51 Cleaning Fluids

Accidents have been caused by cleaning fluids such as Freon being left in pipework or gas mixing tanks. When diving started, the fluid was carried into the diver's lungs. Water in pipework or bail-out bottles has also caused problems.

All cleaning should be logged and all gas supply systems should have drain valves at low points (see IMCA D 031[5]).

3.52 Solid Particles

Solid particles may be carried into a bell or chamber atmosphere if scrubbers are incorrectly used or inadequately maintained.

3.53 Hypothermia

Divers must be maintained in thermal balance to avoid excessive heat or cold affecting their health, safety and efficiency.

Hypothermia, or cold exposure, is a danger faced by all divers in cold water. The danger is considerably greater for mixed gas divers because of the very high thermal conductivity of helium. The respiratory heat loss can be enormous.

Divers breathing heliox mixtures must have some form of active heating and, below 150 msw (492 fsw), they must have a heated gas supply. If the heating system fails, the diver must return to the bell immediately.

If a bell is stranded on the seabed, the risk of death from cold outweighs the risk of oxygen lack or carbon dioxide accumulation. All bells carry survival suits and thermal regenerators or heat sponges, which recycle the heat from the divers' exhaled breath.

Normal body temperature is about 37°C. Shivering starts to occur at about 36°C and is an attempt to warm the peripheral tissues. Shivering stops as the core temperature falls and the body attempts to conserve energy. Note that not all people shiver and some can become hypothermic without any warning symptoms.

As the core temperature continues to fall, the body shuts down circulation to the cold outer layers. The casualty becomes irritable, confused and begins to lose co-ordination. There is a fall in heart rate and blood pressure. Collapse normally occurs when the core temperature drops below about 30°C and death occurs at about 25°C.

Approximate core temperature	Symptoms
37°C	Normal body temperature.
35-36°C	Increased metabolic rate. Uncontrollable shivering (in most people).
34°C	Impaired judgement. Slurred speech.
31°C	Shivering decreases and is replaced by muscular rigidity. Movement becomes erratic and jerky.
28°C	Irrational behaviour. Stupor. Muscular rigidity. Pulse and respiration slowed.
27°C	Unconsciousness. Loss of reflexes. Fixed and dilated pupils. Low or undetectable pulse. Ventricular fibrillation may occur.
25°C	Failure of cardiac and respiratory centres. Ventricular fibrillation. Death.

Many of these symptoms may not be apparent to the diver in the water and hypothermia can be very rapid in onset if heating systems fail during a heliox gas dive. A heating system failure may not be apparent on the surface. A hot water hose, for example, may not be properly connected to a diver's suit.

The diving supervisor should take any indications like slurred speech, irritation or difficulty in performing simple tasks as possible symptoms of hypothermia and ask the diver to return to the bell or to the surface.

The clinical phases of progressive hypothermia can be classed as follows:

1. *Mild* body core temperature 35-34°C
2. *Moderate* body core temperature 33-30°C
3. *Severe* body core temperature < 30C

Casualties with mild hypothermia should be re-warmed gradually. Serious cases should be re-warmed under medical advice. Rapid re-warming can cool the blood as it flows though the cold outer tissues and cause a fatal temperature drop as it returns to the core.

If breathing and pulse are no longer detectable, do not start CPR unless it can be continued until re-warming starts under medical advice.

Never assume that a hypothermic victim is dead. The rule is 'Not dead until warm and dead'.

3.54 Hyperthermia

Heat illness is relatively rare, but may occur in very warm waters or in chambers in hot weather if there has been a failure of the cooling system. It may also be caused by heat of compression if excessive pressurisation rates are used.

It has also been found in divers using hot water suits, who have worked for a long period with high water temperatures. Dressed-in standby divers in hot climes must be alert to the dangers of over-heating and should ensure adequate hydration.

Hyperthermia is considered to occur when the body temperature exceeds 39°C. In its mild form, heat exhaustion, the casualty will feel lethargic and have a raised pulse rate. Treat with a cold bath or shower and salty drinks.

Heat stroke is a serious and life threatening condition where the body's temperature control mechanism has failed and body temperature rises rapidly. The casualty should be cooled as rapidly as possible and medical aid called. Resuscitation may be necessary. Heat stroke is only likely to occur if the warning signs of heat exhaustion are ignored.

3.55 Drowning

Drowning occurs when the victim starts to inhale under water. This may be because he can no longer hold his breath, or because the shock of sudden cold immersion causes an involuntary gasping. This will only occur to a diver if his mask or helmet is lost or damaged, or if a bell is flooded.

As long as the victim is conscious, the epiglottis will close off the airway and only small amounts of water will enter the lungs. Most of it will go into the stomach.

The victim will collapse from the combined effects of hypoxia and carbon dioxide poisoning. In theory, irreparable brain damage and death occur in 4-5 minutes. In practice, survival times may be considerably greater in cold water drowning.

If the victim is rescued quickly, resuscitation has a high chance of success. Oxygen, which is always available on a diving site, can assist recovery.

If a diver has been brought to the surface unconscious, he may have been unable to exhale and may be suffering from AGE. He may also, of course, be suffering from DCI. Pressurisation in a chamber should be routine. The higher pO_2 will be of benefit in any case.

After resuscitation, secondary drowning may occur. This is caused by fluid shifts within the lung tissue. The revived casualty should be evacuated as rapidly as possible, even if there are no symptoms. His condition may deteriorate rapidly.

Cold water drowning may trigger the so called mammalian diving reflex which lowers the heart rate and breathing rate often to undetectable levels.

The rule, as for hypothermia, is 'Not dead until warm and dead'.

3.56 Water Jet Injuries[6] [7]

Water jet injuries may appear insignificant and give no indication of the extent of tissue damage below the surface. Internal organs may be injured and infection may be carried deep into the wound. More serious symptoms may develop over the subsequent four or five days and include fever and a rising pulse rate and deep tissue infection.

It is essential to arrange for surgical examination as quickly as possible. In the interim, first aid is confined to wound dressing and monitoring the condition of the casualty.

3.57 Electrocution[8]

Electrocution may occur on deck, in the water or in a bell or chamber. The shock may stop the heart, cause burns and also cause impact injuries if the casualty is thrown against a bulkhead or equipment.

Once the electric current has been isolated or the casualty removed from the source of electricity, follow normal procedures for an unconscious casualty.

Do not touch the casualty while he is still in contact with the live source of current.

3.58 Blast Injuries[9] [10]

Explosions may occur underwater in association with oxy-arc cutting or operations involving explosives. There is only a small risk of injuries caused by seismic surveying work.

Blast injuries in the water include damage to internal organs, collapsed lung or ruptured eardrums. Damage to the helmet may also lead to drowning.

The casualty should be resuscitated and evacuated to hospital as soon as possible.

Sonar transmissions may cause discomfort and disorientation but injury is unlikely.

3.59 Communications

Once the immediate crisis is over, it may be necessary to seek further medical assistance by telephone or radio. It is essential to have all the relevant facts before making the call. There must be a pre-arranged method of transmitting medical information from the worksite to a doctor. Companies may provide their own checklists, or use DMAC 01[11].

3.60 Reporting of Injuries

All injuries, whether diving related or not, should be reported to the company on the appropriate accident report form.

In most countries, there is also a legal requirement to report certain types of injury to the appropriate authorities.

1 IMCA D 050 *Minimum quantities of gas required offshore*
2 DMAC 15 *Medical equipment to be held at the site of an offshore diving operation*
3 DMAC 28 *The provision of emergency medical care for divers in saturation*
4 IMCA D 021 *Diving in contaminated waters*
5 IMCA D 031 *Cleaning for oxygen service: Setting up facilities and procedures*
6 IMCA D 049 *Code of practice for the use of high pressure jetting equipment by divers*
7 DMAC 03 *Accidents with high pressure water jets*
8 IMCA D 045 *Code of practice for the safe use of electricity under water*
9 DMAC 12 *Safe diving distance from seismic surveying operations*
10 DMAC 06 *The effect of sonar transmissions on commercial diving activities*
11 DMAC 01 *Aide-mémoire for recording and transmission of medical data to shore*

Environmental Conditions

4.1 Consideration of Environmental Conditions during the Risk Management Process

Serious consideration should always be given to managing the risks arising from prevailing and foreseeable environmental conditions when planning diving projects – and when carrying out pre-dive checks during the course of diving operations.

There have been a number of major accidents involving divers that seem, in large measure, to have been caused by failures to anticipate and plan for the serious impacts that adverse environmental conditions can have on offshore diving operations. In such cases, had environmental operating conditions been properly considered in advance, then appropriate risk control measures could have been put in place and disaster may have been averted.

This section describes a broad range of environmental conditions that need to be considered during the diving project risk management process.

4.2 Terminology and Classification

The Beaufort scale of wind force was devised by the British Admiral, Francis Beaufort, in 1805. It was intended to be a simple way of describing wind speed and is based on the visible effects of the wind. Actual wind speeds were not included until the system was standardised internationally in 1926.

The Beaufort scale and the terminology used in English language weather forecasts are shown in Appendix 3.

In wave forecasts, maximum wave height is defined as the greatest wave height observed in a 10 minute period. Significant wave height is the average height of the largest one third of all waves observed in a 10 minute period.

Precipitation is a general term covering drizzle, rain, sleet, hail and snow.

The classification of clouds is based on a system introduced by the British scientist, Luke Howard, in 1803. He recognised three basic types of clouds: cirrus, cumulus and stratus. Cirrus are high, streaky clouds (from the Latin for hair). Cumulus are heaped clouds (Latin for a pile). Stratus are layers or sheets of clouds (Latin for a layer). They can be further described by adding the term nimbus to indicate a cloud producing precipitation, or altum meaning high.

These descriptions are combined as necessary. Cumulo nimbus, the typical thunder cloud, is a heaped cloud producing precipitation. Nimbo stratus is the continuous layer of grey cloud associated with steady rain. Cirro cumulus are high streaky clouds starting to heap together. There are further classifications based on height and more specific descriptions, but the basic terms are adequate for everyday use.

4.3 Weather Systems

Although advances in technology have made it possible for work to continue in relatively harsh conditions, all offshore operations are ultimately weather dependent. The diver is the most vulnerable member of the offshore workforce and the diving supervisor will rely on weather forecasts and his own observations of the weather.

All weather systems are driven by the heat received from the sun. The sun heats the earth's surface, which in turn heats the atmosphere. This produces an unstable system, with hot air close to the surface continually rising into the atmosphere.

In general terms, air pressure is low at the equator where the air is hotter and less dense, and high at the poles. This pressure difference sets up an overall air flow from the poles to the equator. There, the air rises and returns to the poles at a high altitude.

This overall flow is complicated by a large number of factors: the circulation of the earth, ocean currents, the periodic El Niño event, the uneven heating of the continental land masses, the greenhouse effect, catastrophic events like large volcanic eruptions and long term effects like changes in solar activity and changes in the tilt of the earth.

At present, the general circulation is driven by alternating bands of high and low pressure which give the familiar pattern of prevailing winds:

- easterlies in the polar regions;
- westerlies in the temperate regions;
- easterlies in the tropical regions.

Because of their importance in world trade, the tropical easterlies which carried European sailing ships across the Atlantic are still referred to as the trade winds. There are also two calm zones – the Doldrums at the equator and the warm sunny high pressure areas in the tropics.

Superimposed on this pattern are the regional and seasonal weather systems: depressions, anticyclones, monsoons, hurricanes, tornadoes and all the winds and fogs that are governed by local conditions.

Winds blow into low pressure systems and out of high pressure systems, but are deflected by the rotation of the earth. In the northern hemisphere, if you stand with your back to the wind, the centre of low pressure is to your left. In the southern hemisphere it is to your right.

Most of the bad weather in temperate regions is caused by lows or depressions, which are compact and mobile low pressure systems. A typical temperate zone depression has a diameter of about 1,600 km (1,000 miles). Associated with most depressions are warm and cold fronts. A warm front is the leading edge of a mass of relatively warm air and a cold front is the leading edge of a mass of relatively cold air. The temperature difference between the warm and cold air masses may only be a few degrees.

An approaching depression, with warm and cold fronts, shows a well defined sequence of weather:

- high cirrus clouds are driven ahead of the storm by high altitude winds. The sky remains clear and visibility is often exceptionally good. Pressure begins to fall slowly and there may also be the onset of a long swell, originating from the storm;
- the clouds thicken and become lower. Initially, the cloud layer is translucent and there is often a halo around the sun or moon;
- the wind freshens and backs and there is a slow temperature rise, which may only be noticeable with a thermometer. Wave height increases;
- the clouds become low and dense and steady drizzle, rain or snow starts to fall;
- as the warm front passes, the wind slackens and veers. The rain or snow decreases or stops and the clouds become higher and thinner. Visibility is generally poor;
- as the cold front approaches, the wind backs and becomes squally. Clouds thicken and become heavy and towering cumulo nimbus;
- the passage of the cold front is characterised by squally, unstable conditions, cumulo nimbus clouds, heavy rain, sleet or snow showers and sometimes thunder.

The rate at which these changes occur depends on the speed at which the depression is moving. If the centre of the depression passes directly over the worksite, pressure will fall and then rise again and there will be a period of calm as the centre passes over. The pressure is unlikely to fall lower than about 980 mb in the centre. Wind speeds around a depression are typically 40-50 knots.

Hurricanes are small areas of low pressure with very high wind speeds that form only over warm seas, where there is a layer of warm moist air close to the surface. A typical hurricane has a diameter of only 160 km (100 miles) and a pressure of 950 mb in the centre. The centre of the hurricane is calm and wind speeds around the hurricane are 100 knots or more.

The highest wind speeds are found in tornadoes, which have a diameter of only 100 m (330 ft), pressure at the centre as low as 800 mb and wind speeds of up to 300 knots. Tornadoes are land based and are a regular hazard in the mid-west of the United States.

The sea borne equivalent of the tornado is the waterspout. This is a rapidly gyrating vortex which descends from cumulus or cumulo nimbus clouds, whipping up the sea and sucking up a column of water which may be anything from 1 m up to 300 m in diameter. Waterspouts rarely last more than half an hour but the strong peripheral winds, disturbed sea state and the descending water all pose considerable hazards.

Monsoons are a seasonal occurrence on the Indian sub-continent. During winter, the land mass is relatively cool and the sea is warm, causing gentle offshore winds. In summer the land heats up, producing a huge zone of low pressure and drawing strong winds in from the sea. It is these damp winds which cause the associated heavy rainfall. The onset of the monsoon can be forecast with some accuracy and is usually associated with disturbed sea states.

High pressure systems are stable and slow moving with clear skies and low wind speeds. In summer they are typified by bright sunshine and calm seas. In winter the temperature is low because of the absence of insulating cloud cover and there is often fog or poor visibility. Pressure may be up to 1,010 mb.

4.4 Local Weather

Thunderstorms may occur in the cold sector of a depression or may develop locally during warm weather. The development occurs when a mass of air is heated from below. Powerful convection currents are established and the air mass becomes turbulent.

A pre-thunder sky is characterised by dense cirrus clouds, associated with banks of altocumulus and sometimes cumulus. Thunder clouds have a huge vertical development with a rapid development and expansion at higher altitudes. The top of the cloud is often blown out into a characteristic anvil shape by high altitude winds.

Below the thunder clouds are squalls, violent gusts of wind and heavy falls of rain or hail. The thunder clouds typically collapse quickly to be replaced by others. A thunder sky shows a confused mass of dense clouds, building, collapsing and re-forming.

Close to land, winds may be influenced by the difference in heating between land and sea. During the day, the land heats more rapidly than the sea, and the air heats and rises and cool air is drawn in from the sea. At night, the land cools but the sea retains its heat. Air rises over the sea and is drawn in from the land. Onshore winds during the day and offshore winds during the night are typical in otherwise clear, stable conditions.

Powerful local winds occur in many parts of the world. They may be generated by the topography of the local land mass but their effects can be felt far out to sea. The Mistral, for example, the well known Mediterranean wind, is produced by the funnelling effect of the Rhone valley.

Fog forms when warm air blows over a cold surface. This may occur along a coast or where warm and cold ocean currents meet. The haar, or sea fog, along Scottish North Sea coasts is caused by warm sea air in contact with the cold land. The famous San Francisco fog is caused by warm air from the land meeting the cold California current. The fog off Newfoundland occurs where the cold Labrador current meets the warm Gulf Stream.

4.5 Sea State

Most waves are wind generated, although they may also be caused by currents, seabed features or exceptional events like earthquakes, volcanic eruptions or surface or subsea landslips.

The dimensions of a wave are its height, from crest to trough, its wavelength, the distance between crests and the depth to which its movement can be felt.

Wavelength is always much greater than height and if the ratio of height to wavelength becomes greater than about 1:13, the wave breaks. If the wave moves into shallow water it will slow down, but the wave height increases rapidly. It will start to break when the water depth is equal to about half its wavelength.

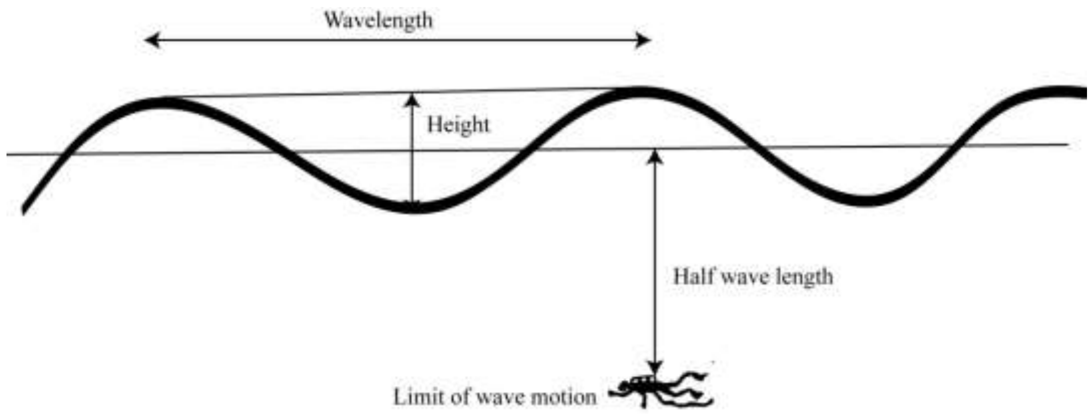


Figure 4-1 – Wave length and height

Although waves can move at considerable speed and transmit enormous amounts of energy, there is very little forward movement of water. The water in a wave moves vertically in a circle. An object apparently being moved horizontally by the waves is either windblown or subject to a wind generated current (see section 4.6) or other current. Only when the wave breaks does the water start to move forward.

The height of a wind generated wave depends on the wind speed, the time that the wind has been blowing and the fetch. The fetch is the distance of open water that the wind has been blowing over. Wave height is also affected by the height and direction of existing wave trains.

The distance that the waves will travel depends on their wavelength. Long wavelengths travel furthest and it is common to experience a long wavelength swell generated by a wind many miles away.

Under normal conditions, the wave pattern is a combination of one or more wave trains. A local wind, for example, may generate waves on top of a remotely produced swell. The interference between the wave trains can produce considerable variation in wave height.

Where peaks of one train coincide with troughs of the other, wave heights will decrease. When peaks coincide with peaks, wave heights will increase. For example, the wave trains are usually out of phase and peaks may only coincide every fifth wave. This can establish a fairly regular pattern of changing wave heights and is the origin of the belief that the 'seventh wave' is larger than the others.

In general, wave movement can be felt by the diver down to a depth equal to about half the wavelength. A typical wavelength is 20 m (66 ft), with the turbulence felt down to 10 msw (33 fsw). A diver close to the surface will be badly affected by even a moderate swell. In all sea conditions, however, the consideration is not whether the diver can work, but whether he can be safely removed from the water.

In addition to the risk of being flung against the structure, the shallow air diver may be subject to considerable variations in pressure as the crests and troughs of waves pass overhead. This may affect his decompression if he is carrying out shallow stops in the water and in extreme cases may cause aural or pulmonary barotrauma.

Mixed gas divers will only be affected by the heave on the bell. The bellman may be subject to uncomfortable pressure changes if the heave compensation is inadequate.

For both air and gas diving safe maximum conditions are hard to define. Many factors such as wave type and wave period and the behaviour of the vessel must be considered. DP vessels may vary considerably in their sea keeping capabilities.

4.6 Tide and Current

Tides are caused by the combined gravitational effects of the sun and the moon. When the sun and moon are aligned, at full moon and new moon, the effect is at its maximum and the tidal range is at its greatest. These are known as spring tides. When the sun and moon are at 90° to each other, at first and last quarters, the effect is at its minimum and the tidal range is at its lowest. These are known as neap tides.

The tidal range is the difference in height between low tide and high tide. It depends on the phase of the moon, the bottom and the shape of the coastline. Neighbouring harbours may have quite different tidal ranges.

The times and heights of tides are given in tide tables. They can be affected considerably by strong winds. Before the Thames Barrier was built, for example, the coincidence of a spring tide and a storm in the English Channel would have caused a tide high enough to cause serious flooding in London.

The greatest tidal range, of about 18 m (60 ft) occurs in the Bay of Fundy between New Brunswick and Nova Scotia. The time for the tide to travel up the inlet coincides roughly with the rise and fall of the tide in the open sea and the resonance effects produce the large range. A similar effect occurs in the Bristol Channel in England, where there is a tidal range of 15 m (50 ft).

On average, the tide rises for six hours and twelve minutes. This is the rising, or flood tide. At the top of the flood, the level remains constant for a short period. This is the high water slack. The falling or ebb tide then runs for about six hours and twelve minutes until low water slack. The cycle then begins again. In some areas (like the English Channel), flood and ebb tides may run for considerably less than six hours.

The change in water depth caused by the tide will clearly affect dive times and duration. In some cases, there may also be legal implications. Most legislation imposes a maximum depth for air diving, usually about 50 msw (165 fsw). Working depth may be less than 50 msw at low tide, more than 50 msw at high tide.

Tidal streams are the currents associated with flood and ebb tides and change direction accordingly. Currents may run in different directions at different depths. During tidal diving, the identification of slack water is essential and tide tables are not reliable because of local variations. Tide meters should be used to measure current.

The greatest rate of rise or fall, and consequently the fastest tidal stream, occurs halfway through the tide in open water. The bigger the range, the faster the tidal stream is. Tidal streams can also increase in speed around headlands and in narrow channels. In some areas they can be as fast as 10 knots.

The 'twelfths rule' is used to estimate the amount of rise or fall in each of the six hours.

Hour 1	1/12 of range
Hour 2	2/12 of range
Hour 3	3/12 of range
Hour 4	3/12 of range
Hour 5	2/12 of range
Hour 6	1/12 of range

Currents may also be produced by wind, by river flow close to an estuary or by major ocean currents. Tidal current will be superimposed on these currents. It may increase or decrease the speed and may produce turbulence.

The speed of a wind generated current is usually about 3% of the wind speed. A Force 7 wind, therefore, will generate a surface current of about one knot. A Force 5 wind will generate a surface current of 0.6 knots.

Because of the earth's rotation, the direction of a wind generated current is about 45° to the wind direction. As depth increases, the current decreases and the direction turns further away from the wind. At 10 msw (33 fsw) it is about 90° to the wind direction and the speed is usually negligible.

River currents are often associated with poor visibility caused by sediment carried by the river. The major ocean currents are normally slow moving and unlikely to affect the diver.

The force exerted on a diver and his equipment by the current is proportional to the water velocity squared. If the velocity doubles, the force increases four times.

The diver's umbilical is subject to considerable drag. If he is working from a bell or wet bell, with a short umbilical aligned with the current, he will suffer far less than a surface supplied diver. Other considerations for diving in currents are:

- the ability of the surface crew to recover the diver safely after the dive. Conditions on the surface and at the worksite should be taken into account. Surface current could be strong enough to carry a bell underneath a vessel and hinder recovery, although the current at working depth may pose no problem;
- the ability of the standby diver to reach the diver in an emergency;
- the physical strength and endurance of the diver;
- the type of equipment being used;
- the type of work being carried out;
- whether the work is being carried out mid-water or on the seabed;
- whether both hands are required to carry out the task;
- changes in strength and direction of the current;
- the possibility of using an underwater tender, swim lines, etc. Note that if the diver is working in the lee of a structure he may not be aware of an increase in current.

AODC 047[1] suggests the following restrictions on working in currents, but notes that conditions vary enormously and the restrictions should be applied flexibly, taking into account diver feedback and operational requirements.

<table>
<tr><th>Current (Knots)</th><th>0.0</th><th>0.8</th><th>1.0</th><th>1.2</th><th>1.5</th><th>1.8</th><th>2.0 and beyond</th></tr>
<tr><td>Surface supply in mid water</td><td>Normal work</td><td>Observation</td><td>See Note 1</td><td colspan="4">See Note 2</td></tr>
<tr><td>Surface supply on bottom</td><td>Normal work</td><td>Light work</td><td>Observation</td><td>See Note 1</td><td colspan="3">See Note 2</td></tr>
<tr><td>Bell or wet bell in mid water</td><td colspan="2">Normal work</td><td>Light work</td><td>Observation</td><td>See Note 1</td><td colspan="2">See Note 2</td></tr>
<tr><td>Bell or wet bell on bottom</td><td colspan="3">Normal work</td><td>Light work</td><td>Observation</td><td>See Note 1</td><td>See Note 2</td></tr>
</table>

Note 1: Diving by means of this method in these currents should not be a routine operation. The diving supervisor should consult with the divers involved and any other person he judges necessary about the best way to conduct such an operation.

Note 2: Diving by means of this method in these currents should not be considered unless the operation has been pre-planned taking account of the presence of high current from the early stages of the project. Special solutions involving equipment, techniques and procedures should have been evolved to overcome or protect the diver from the effects of current and provide contingencies for foreseeable emergencies.

Tide meters provide accurate information on current at different depths and can be used to assess diving conditions[2].

4.7 Solitons

These are eddies or whirlpools which may occur subsurface at any depth, or at the surface. These cannot be forecast and occur seemingly at random, usually for a very short duration amounting to only a few seconds, or minutes. The effect can be as severe as completely rotating a DP vessel whilst trying to hold station, or washing a diver into a subsea structure, all without warning.

The soliton is a phenomenon which occurs in known areas such as offshore Shekou in China, Trinidad and others. The only precautionary measure is to be aware that the phenomenon may occur and have procedures in place to cover the eventuality.

Surface breaking solitons may be visible from the vessel bridge as eddies or unusual localised currents and may also show up on radar.

In mathematics and physics, a soliton is a self-reinforcing solitary wave (a wave packet or pulse) that maintains its shape while it travels at constant speed. Solitons are caused by a cancellation of nonlinear and dispersive effects in the medium. 'Dispersive effects' refer to dispersion relations between the frequency and the speed of the waves. Solitons arise as the solutions of a widespread class of weakly nonlinear dispersive partial differential equations describing physical systems. The soliton phenomenon was first described by John Scott Russell (1808–1882) who observed a solitary wave in the Union Canal in Scotland, UK. He reproduced the phenomenon in a wave tank and named it the 'Wave of Translation'.

- the waves are stable, and can travel over very large distances (normal waves would tend to either flatten out, or steepen and topple over);
- the speed depends on the size of the wave, and its width on the depth of water;
- unlike normal waves they will never merge – so a small wave is overtaken by a large one, rather than the two combining;
- if a wave is too big for the depth of water, it splits into two, one big and one small.

A single, consensus definition of a soliton is difficult to find. Drazin and Johnson (1989) ascribe three properties to solitons:

1. they are of permanent form;
2. they are localised within a region;
3. they can interact with other solitons and emerge from the collision unchanged, except for a phase shift.

Some types of tidal bore, a wave phenomenon of a few rivers including the River Severn in the UK, are 'undular': a wavefront followed by a train of solitons. Other solitons occur as the undersea internal waves, initiated by seabed topography, that propagate on the oceanic pycnocline.

Rogue waves (also known as freak waves, monster waves, killer waves and extreme waves) are relatively large and spontaneous ocean surface waves that are a threat even to large ships and ocean liners. In oceanography, they are more precisely defined as waves whose height is more than twice the significant wave height (SWH) which is itself defined as the mean of the largest third of waves in a wave record. Therefore rogue waves are not necessarily the biggest waves found at sea; they are, rather, surprisingly large waves for a given sea state.

4.8 Visibility[3]

Close to the surface, in-water visibility is affected by the amount of daylight and the angle at which sunlight strikes the surface. When the sun is low, in winter in the higher latitudes or in the early morning or late evening, the sun strikes the surface at a low angle and a large proportion of the light is reflected. If the sea is rough, reflection in the surface layer is increased.

After the diffused light has entered the water it is absorbed, scattered and reflected. The various wavelengths of light are absorbed as the light passes through the water. At about 10 msw (33 fsw) only green and blue wavelengths remain and the diver is effectively colour blind without artificial light.

Scattering and reflection depend on the turbidity of the water. This is a measure of the number of fine particles suspended in the water. These particles may be sediment, plankton or any solid material.

There may be seasonal or daily variations in turbidity. Plankton growth is greatest in the summer. The amount of sediment may vary with the strength and direction of the tidal current, or variations in the flow of a large river. The diver's work, water jetting for example, can also affect turbidity. There are also, of course, variations with depth.

The visibility of an object to the diver depends on the amount of light reaching his eyes and the contrast of the object with its background. In monochromatic conditions, where the diver has no artificial light to assist him, contrast depends solely on the relative brightness of object and background.

Experiments on divers working in poor visibility have shown error levels as high as 30% in work involving measurement or inspection. Diver performance is closely related to field dependency. This is a standard psychological measure of the subject's flexibility in assessing and dealing with a situation. In general, those who performed poorly in the visibility tests had higher field dependency, that is, they were less flexible in their approach.

In addition to the practical difficulties of bad visibility, some divers may become apprehensive and more likely to react badly in a crisis.

Visibility on the surface is also an important consideration. Visibility needs to be good enough to locate a diver on the surface who may have cut his umbilical in an emergency, or had it cut by accident. It should also be possible to locate and recover any deck crew who may fall into the water. Most installations stop all over-the-side work when visibility is poor.

As with most diving safety requirements, it is a matter of judgement by the senior diving supervisor on site to decide when diving should stop due to reduced surface visibility.

Although such situations are very rare, the visibility should also be good enough to locate and recover a diving bell that has surfaced in an emergency.

Diving may also be stopped by the master of a vessel if fog or mist significantly increases the risk of collision.

Mobile/portable surface supplied diving should only be used in good visibility and only in daylight unless the small craft has a suitable generator to supply lighting. It should be equipped with the normal marine emergency equipment of torches, flares, etc.[4].

4.9 Temperature

Sea temperatures in the shallow surface layers vary according to location and season. Overall, temperature decreases with depth until a depth is reached where the temperature remains stable all year at about 4°C (39°F). The depth at which this occurs depends on the location.

The temperature decrease with depth is not regular. The water lies in layers with a clear change of temperature in each layer. On a sunny day in temperate zones, for example, there is a marked temperature drop at a depth of 1-2 msw (3-7 fsw).

The boundary between layers, known as a thermocline, is often clearly visible to the diver. Warm layers lie on top of cold layers in a very stable configuration in contrast to the turbulent situation in the atmosphere.

Each layer acts as a self-contained system and may be moving independently of the layers above and below. During his descent, the diver may pass through several layers, each with a different temperature, current and visibility.

Divers may be subject to thermal stress caused by excessive heat or cold. The heat loss when living in or breathing a helium atmosphere is considerable and divers need to be provided with active heating of their gas supply below 150 msw (660 fsw)[2].

Except in an emergency, like a stranded bell, the potential hazard lies in gradual temperature changes. If the diver's hot water supply is not quite hot enough, he faces a slow drop in core temperature in the course of a long dive. This will affect his working performance, increase the possibility of errors and make his response to an emergency less effective.

His heart rate and blood pressure drop and he may collapse on leaving the water. While he is vertical in the water the hydrostatic pressure on his legs maintains the blood flow to the brain. When he comes out of the water, the hydrostatic pressure is removed and blood pressure drops in the brain, causing unconsciousness.

If the hot water supply is too hot, the diver may suffer from heat illness. This is generally considered to be more dangerous than cold exposure. A core temperature rise of only a few degrees can be fatal, while the body can survive a drop of over 15°C. Generally, the diver will feel ill and return to the surface or bell without further incident.

Like the cold diver, he may collapse on leaving the water. His surface blood vessels will be dilated and, when the hydrostatic squeeze is removed, blood pressure will drop in the brain as flow through the legs increases.

If the diver's helmet or mask is broken or lost in cold water, he may suffer from cold shock. This causes an involuntary gasping reflex which can cause drowning as water is sucked into the airway.

He may also experience the 'diving reflex'. This reflex is found in diving mammals. Sudden immersion of the face in cold water shuts down many of the body systems to conserve oxygen. In man, this may be fatal. It may also account for some of the remarkable survivals after long periods of cold water immersion.

Extreme heat or cold can have an adverse effect on the standby diver on the surface. He should be provided with shelter, kept at a comfortable temperature and provided with liquids to prevent dehydration in hot conditions.

4.10 Sound Transmission

The velocity of sound in air is 330 m per second (742 mph). In water it is 1,440 m per second (3,240 mph). Sound also travels considerably further underwater. These differences make it difficult for a diver to judge both the direction and distance of a sound source.

The assessment of the direction is based on the small difference in the arrival time of the sound at each ear. Since sound travels much faster in water, the arrival time difference is much smaller and does not relate to the direction.

This inability to assess direction and range can make diving in the vicinity of seismic surveying operations distracting and unsettling for the diver. DMAC 12[5] provides guidance on diving in the vicinity of seismic operations but notes that the noise of the explosions will interfere with the diver's concentration long before they pose any physical danger.

Sonar transmissions may have audio-vestibular effects on the diver, causing disorientation. Because of the attenuating effects of the helmet, divers with helmets are safe from any known sonar transmissions with frequencies above 500 Hz, although hooded and non-hooded divers may be at some risk. The neoprene hoods normally worn by divers do afford some attenuation. A 3 mm neoprene wet suit hood provides some hearing protection from sound frequencies between 400 and 500 Hz at shallow depths (<10 msw)[6].

4.11 Hazardous Marine Life[1]

Fish are generally frightened by the size of the diver and the noise of his breathing apparatus. The noise made when the diver exhales is composed of low frequencies where fish have been shown to be most sensitive. Cod, for example, can hear a diver at distances up to 1 km away.

If dives are carried out regularly on the same site, the fish will become accustomed to the diver. They may, in fact, start to be attracted by the noise of the breathing apparatus. This may be because the diver's activities stir up sediment and increase the food supply. Some divers have been troubled by fish that became too friendly.

In areas like the North Sea, there are some fish that appear intimidating. A conger eel can be up to 2 m long and monkfish can reach 1.5 m – both species have impressive teeth.

In warmer waters, there are various types of marine life that are potentially dangerous. They range from stinging jelly fish and corals to stone fish, lion fish, sea snakes and sharks. The dive plan should identify these hazards and include contingency and emergency plans[2]. These might include briefing the divers on the appearance of the hazardous marine life and holding suitable antidotes for any toxins on the worksite. It may be suggested as a precautionary measure that any divers stung or bitten subsea should be recovered to the bell or basket and removed to the system or surface for observation in case they suffer from anaphylactic or toxic shock and possible collapse.

Statistically, marine life does not represent a serious hazard to the diver and there are few cases of divers coming to harm.

1 AODC 047 *The effects of underwater currents on divers' performance and safety*
2 IMCA D 014 *IMCA international code of practice for offshore diving*
3 AODC 034 *Diving when there is poor surface visibility*
4 IMCA D 015 *Mobile/portable surface supplied systems*
5 DMAC 12 *Safe diving distance from seismic surveying operations*
6 DMAC 06 *The effect of sonar transmissions on commercial diving activities*

Communications

5.1 Introduction[1 2 3]

Good communication is fundamental to the safety of any operation. 'Communication' is a broad term that includes hard wire systems, sound powered systems, radios and emergency back-up systems; computer systems; alarm, warning and indicator lights and audio alerts; closed circuit television (CCTV); word of mouth; hand signals and other visual signals; rope signals and tapping codes; toolbox talks and post operation debriefing. Also see section 6.

English is the international language of communication, used at sea and in the air. In a multinational diving team the common language may be the language of the majority. Another language, perhaps English, may be used to bridge gaps in understanding. Whichever language is in use, people tend to revert to their own language in a crisis.

Even if speakers are fluent in another language, cultural differences can lead to misunderstanding and even offence. To a South American, a Northern European may appear unfriendly, indifferent or even unaware of a problem. The Northern European may see the South American as over-excited or even panicking about a small incident. In reality, both are fully competent and in control of the situation. Cultural awareness is as important as the language.

The diving supervisor is directly responsible for communications with the diver. He needs to have voice communication and be able to monitor the diver's breathing pattern at all times.

Historically, the only person who has been in direct communication with divers while they are in the water is the diving supervisor. This has resulted in a very high degree of trust being established between the diver in the water and the supervisor on the surface.

In recent years, particularly while carrying out inspection work, it has become increasingly common for personnel other than the supervisor to wish to talk directly to the diver. In some circumstances this can be hazardous and set out below are a number of fundamental rules which should ensure the continued safety link between diver and supervisor.

1) At no time must the supervisor pass over the total communications responsibility to anyone, other than another properly appointed and qualified diving supervisor.

2) At all times, the diving supervisor must be able to hear the diver's voice communications and breathing pattern, even if another person is joined into the communications link.

3) In any communications system the diving supervisor must be able to disconnect all other personnel immediately so that the direct link between diver and supervisor is uninterrupted.

CCTV may be used to transmit hand signals or written messages when audio communication has failed.

When a remotely operated vehicle (ROV) is in use, the diving supervisor has overall responsibility for the safety of the whole operation. Close communication with the ROV supervisor is vital. There should be a dedicated communications link and a repeat video monitor showing the same picture seen by the ROV pilot. See section 15.20.

5.2 General Communications on the Vessel or Installation

The diving supervisor needs to have reliable communications with everyone involved in the operation and needs access to all of the communications of the vessel or installation. Communications include all available systems: word of mouth, documentation, radio, telephone, fax, etc.[4].

It is useful to provide a clear, graphic description of all the communications available in the form of a communications matrix. This is a grid listing of all the relevant communication systems available on the vessel with contact telephone numbers or radio channels as appropriate. IMCA D 046/M 205[3] contains an example of a communications matrix.

Typically the bridge/dive control system will include hard wired voice communications, with back-ups, to the following areas:

- bridge/DP (dedicated open line from dive control);
- engine control room;

- dive control/bell dive control (dedicated open line);
- ROV launch/control (dedicated);
- crane (dedicated open line from crane during crane ops);
- work deck/riggers/deck crew;
- saturation chamber/control (dedicated from dive control);
- cabins of key personnel;
- other vessels/platforms/units.

Where dedicated, these communications should be backed up by the ship's telephone system and/or hand held radios operating on specified channels.

Non-diving personnel like crane drivers and riggers need to be made aware of the hazards facing the diver, the importance of clear communications and the time lag in communications being relayed to or from the diver.

Adequate time should be allowed for the testing of all communications systems likely to be used during the diving operation.

5.3 Voice Communication

Voice communication is used to pass clear, complete and accurate information in plain language. Since English is the internationally accepted language, voice procedure and phonetic codes are based on English.

The basic rules of good communication are as follows and should be made clear to the entire diving team:

- on a multinational worksite agree communications language and procedure before the operation starts. Have written aides-mémoire at each communications site;
- only speak if it is necessary. If you do not have anything to say, do not say anything;
- think before you speak, and speak slowly and clearly;
- say who you are speaking to and where you are speaking from;
- ensure that the recipient of the message repeats all instructions back to verify them;
- use the standard words and phrases correctly. If in doubt, use plain English;
- let the other person know when you have finished speaking, usually by saying 'over';
- have a procedure to deal with communications breakdown. In most cases, you will carry out the last instruction received and then stop the operation. Alternative methods of communication can then be used.

After establishing contact, communications often open with a readability check. The standard phrase is 'how do you read?' The reply is usually given as 'loud and clear', 'broken', 'distorted' or 'faint'.

If all crew members are familiar with the system, the standard readability scale is more precise: 1 – unreadable; 2 – readable but with difficulty; 3 – readable now and then; 4 – readable; 5 – perfectly readable. The response to 'how do you read?' would be, for example, 'reading you strength 4'.

The following words and phrases are widely used in voice communication:

Acknowledge	I understand your message
Affirmative	Yes, or you are clear to proceed
All stop	Stop the action and wait for further instructions
Come up or down	Lift or lower, on a winch or crane
Correction	An alteration to the previous message
Easy	Lift or lower slowly on a winch or crane. ('Slowly' is also used)
Go ahead	Proceed with your message
How do you read?	How are you receiving me?

I say again	Repetition of a message
Negative	No, or you are not clear to proceed
Over	Message ended and waiting for a reply
Out	Message ended and no reply expected
Read back	Repeat the message as received
Repeat	Similar to 'say again' but usually used to emphasise a word or phrase: 'do not, repeat do not, come up on the winch'
Roger	I have received all of your last transmission. (This is probably the most misused phrase in voice communication.)
Say again	Repeat your message
Say again from	Repeat your message from
Slowly	Lift or lower slowly on a winch or crane. ('Easy' is also used)
Speak slower	Self explanatory
Standby	Wait for another message
That is correct	Self explanatory
Verify	Confirm the accuracy of your last message
Wilco	I have understood your message and will carry out the instructions. (Only use this after you have verified the instructions by repeating them.)

Avoid the use of ambiguous words like 'may', 'might', 'should', 'could' or 'can'. The following examples are from IMCA D 046/M 205[3]:

May

Do Not Say:	'May divers enter the water?'
Say:	'QUESTION. Do divers have permission to enter the water?' *[Or e.g. '... is it safe for divers to enter the water?']*
Do Not Say:	'Divers may enter the water.'
Say:	'ANSWER. Divers have permission to enter the water.' *[Or e.g. '... it is safe for divers to enter the water?]*

Might

Do Not Say:	'Divers might enter the water.'
Say:	'INTENTION. Divers will enter the water.'

Should

Do Not Say:	'You should use the ten tonne crane.'
Say:	'ADVICE. Use the ten tonne crane.'

Could

Do Not Say:	'You could be using the wrong shackle.'
Say:	'WARNING. Check the shackle is correct.'

For spelling out words, it is preferable to use the phonetic alphabet. It is intended for unambiguous international use, as is the pronunciation of the numbers. If there is any difficulty in remembering the phonetic alphabet, other suitable words can be used.

A	Alpha	N	November
B	Bravo	O	Oscar
C	Charlie	P	Papa
D	Delta	Q	Quebec
E	Echo	R	Romeo
F	Foxtrot	S	Sierra
G	Golf	T	Tango
H	Hotel	U	Uniform
I	India	V	Victor
J	Juliet	W	Whisky
K	Kilo	X	X ray
L	Lima	Y	Yankee
M	Mike	Z	Zulu
0	Zero	5	Fiver
1	Wun	6	Sixer

2	Too	7	Sev-en
3	Thuh-ree	8	Ait
4	Fow-er	9	Niner

Numbers always need to be given with care. It is very easy to confuse the numbers 30 and 13, for example.

- always specify the units of measurement – metres, feet, tonnes, kilograms, pounds;
- always say a number twice, once by name once as individual digits – '13, that is wun, thuh-ree' or '30, that is thuh-ree, zero';
- always request a confirmation of the number;
- try to avoid using fractions. It is better to say 'fow-er point fiver' than 'fower and a half'. If fractions must be used, describe the fraction as well, to avoid confusion 'wun third, that is, wun over thuh-ree'.

5.4 Voice Communication with the Diver

There needs to be two-way voice communication with the diver at all times[4]. Voice communications are made more difficult by the noise of the diver's breathing and other noises, e.g. water jetting, burning, hydraulic tools, etc. Communications from the surface should, as far as possible, be fitted around these noises. It is time-wasting and tiring to try to talk over a loud noise.

If there is an urgent need to talk to the diver, most underwater tools and equipment can be switched off at the surface to reduce noise, provided there is no hazard to the diver.

Do not talk to the diver during lifts, lowers or other operations where he may need to warn the surface urgently of any problems.

Plan all tasks so that they involve the minimum amount of voice communication.

Before the dive starts, agree names for the tools, equipment, locations and procedures that will be involved. Sending down the wrong tool can waste an hour. Two or three syllable names are clearer than single syllable names.

Keep messages short and simple. Break a long message down into sections. The diver may have to turn off his free flow or stop breathing to listen.

Be aware of the time lag in the chain of communication. An instruction from the diver may take 30 seconds or more to reach the crane driver via the diving supervisor, and more time before the instruction is acted upon.

Ensure that the divers know the procedures for lost communications. See section 10.

Record all voice communications starting with the pre-dive checks. The recording needs to be kept until it is clear that there have been no problems during or following the dive. It is recommended that recordings are kept for at least 24 hours[4]. If an incident or accident occurs, the recording should be kept in a safe place for the investigation.

Rope and hand signals may be used routinely for tender to diver and diver to diver. Different signals may be used by divers trained in different countries. Signals must be standardised on a multinational crew.

5.5 Hand Signals on Deck

Hand signals are frequently used to control lifts and lowers on winches and cranes. The signals given below are generally accepted, but should be confirmed with everybody involved.

Lift	Point one finger up and rotate it
Lower	Point one finger down and rotate it
Left	Point left
Right	Point right
Stop	A clenched fist

5.6 Emergency Communications

In addition to rope and hand signals, guidance notes and company manuals contain various emergency communication procedures for maintaining contact with the divers. See section 10.

In any diving emergency, the diving supervisor needs to have full access to all communication systems available to seek advice and transmit information to the shore. DMAC 01[5] is an aide-mémoire for transmitting medical information. Company manuals may include similar forms for transmitting other information about diving incidents.

1 AODC 031 *Communications with divers*
2 AODC 032 *Remotely operated vehicle intervention during diving operations*
3 IMCA D 046 *Guidance on operational communications* (also IMCA M 205)
4 IMCA D 014 *IMCA international code of practice for offshore diving*
5 DMAC 01 *Aide-mémoire for recording and transmission of medical data to shore*

Documentation

6.1 Introduction

Almost all documents used in diving operations are subject to document control. Both on the document and also in a centrally held document register it will state who the document has been circulated to, which individual or department prepared the document and who is allowed to modify it.

In general, all modifications to documents will be carried out through some central point to allow all circulated copies to be updated. This system should always be followed. It is designed to prevent unofficial, and possibly unsafe, procedures being developed and to ensure that out-of-date documents do not remain in circulation.

Documents should not be photocopied unless it is specifically authorised. Photocopies will not be on a circulation list and will not receive updates. Many businesses now run intranet systems where the most up-to-date versions of company documents may be accessed by staff.

6.2 Documentation on Site

Operating procedures will consist of the company's standard procedures, together with any site or task specific procedures (based on risk assessments), contingency and emergency plans.

There must be a clearly defined work scope and a list of resources, personnel and equipment required to carry out the programme, a mobilisation plan, a question and answer summary and a logistics plan.

For every diving operation, the following documents must also be on-site[1]:

- company operations manual;
- safety management system (SMS);
- management of change procedure;
- bridging document (interface document between clients' and companies' SMS);
- risk assessments;
- in date system audit document;
- technical manuals and spares inventory for the equipment on site;
- planned maintenance system;
- repair and maintenance records;
- diving project plan;
- diving operations logbook;
- dive records sheets;
- pre and post dive checklists;
- use of equipment checklists;
- incident investigation documentation.

The diving supervisor should also be familiar with the relevant legislation for the area in which the operation is taking place and other relevant guidance notes and advisory publications. These include:

- national guidance or advisory notes;
- OGP Diving Recommended Practice;
- IMCA D 014[1];
- AODC and IMCA guidance notes;
- DMAC guidance notes;
- IMO Code of Safety for Diving Systems;
- IMO Guidelines and Specifications for Hyperbaric Evacuation Systems.

6.3 Individual Documentation

Every individual will normally be required to have the following documents:

- passport;
- logbook and record of competence;
- letter of appointment (if applicable);
- job description (legally required in some countries);
- training or qualification certificates;
- certificate of medical fitness;
- offshore survival certificate (if applicable).

Logbooks, which includes the IMCA record of competence (see section 1.4), are required for:

- diving supervisors;
- divers;
- inspection divers;
- life support technicians;
- dive technicians;
- diving tenders (record of training and assessment).

Logbooks should be completed daily and signed by the logbook holder and countersigned by the relevant supervisor. This is particularly important for the diver's logbook. The record of the dive may be of considerable importance if there are any subsequent medical problems.

Logbooks are supplied by IMCA, but any logbook is suitable provided that it contains all the required information. The minimum information required in the diver's logbook for each dive is[1]:

- name of diver;
- the name and address of the diving contractor;
- the date to which the entry relates (an entry must be completed daily for each dive carried out by the diver);
- the name or other designation and the location of the installation, worksite, craft or other place from which the diving operation was carried out;
- the name of the supervisor who was in control of a diving operation in which the diver took part;
- the maximum depth reached on each occasion;
- the time the diver left the surface, the bottom time, and the time the diver reached the surface on each occasion;
- where the dive includes time spent in a compression chamber, details of any time spent outside the chamber at a different pressure;
- the type of breathing apparatus and mixture used by the diver;
- any work done by the diver on each occasion, and the equipment (including any tools) used in that work;
- any decompression schedules followed by the diver on each occasion;
- any decompression illness, discomfort or injury suffered by the diver;
- any other factor relevant to the diver's safety or health;
- any emergency or incident of special note which occurred during the dive.

The entry needs to be dated and signed by the diver and countersigned by the supervisor.

6.4 Diving Operations Logbooks

There needs to be a daily record of all activities carried out during a diving operation.

There is no specific format that this document should take. However, the following is the minimum information which should be recorded:

- name and address of the diving contractor;
- date to which entry relates (an entry must be completed daily by each supervisor for each diving operation);
- location of the diving operation, including the name of any vessel or installation from which diving is taking place;
- name of the supervisor making the entry and date on which the entry is made;
- names of all those taking part in the diving operation as divers or other members of the dive team;
- any codes of practice which apply to the diving operation[1];
- purpose of the diving operation;
- breathing apparatus and breathing mixture used by each diver in the diving operation;
- bail-out pressure and content;
- decompression schedule containing details of the pressures (or depths) and the duration of time spent by divers at those pressures (or depths) during decompression;
- emergency support arrangements;
- maximum depth which each diver reached;
- times at which the divers leave atmospheric pressure and return to atmospheric pressure plus their bottom times;
- any emergency or incident of special note which occurred during the diving operation, including details of any decompression illness and the treatment given;
- any defect recorded in the functioning of any plant used in the diving operation;
- particulars of any relevant environmental factors during the operation such as partial pressure oxygen, CO_2, water temperature as appropriate;
- toolbox meetings and job safety analyses carried out;
- management of change applied offshore to revise a procedure;
- near-miss and incident reporting;
- any other factors likely to affect the safety or health of any persons engaged in the operation.

6.5 Chamber Logbooks

The chamber logbook is effectively part of the diving operations logbook. It will normally contain:

- the name of the life support supervisor (LSS);
- the names of the LSTs;
- the names of divers under pressure, their bell team, chamber and bunk location;
- the date and time of pressurisation and the pressurisation procedure;
- gases on-line to the control panel and details of any changes;
- hourly records of oxygen, carbon dioxide, temperature and humidity in each chamber (and in the bell on some systems);
- times of calibration of analysis equipment;
- details of transfer under pressure (TUP) operations;
- details of chamber activities such as medical lock operations, showers, divers' meals, filter changes;
- decompression details;
- any cases of decompression illness (DCI) or other illness or injury and treatment details;
- any other factors likely to affect the safety or health of the divers.

The life support team will normally complete gas use and gas stock logs.

6.6 Reporting

In addition to keeping the diving operations log, the diving superintendent or supervisor is normally responsible for a variety of reports, which may include:

- daily report;
- near miss, incident and accident reports;
- key performance indicators that have been agreed as project benchmarks;
- medical log;
- shipping records and shipping returns;
- equipment failures and damage reports;
- monthly summary of emergency drills and exercises;
- gas quantities reports/status;
- minutes of safety meetings.

The daily report may be distributed by fax or e-mail. The diving superintendent or supervisor may delegate the completion of parts of the report to other team members, although he carries the final responsibility. The LSS, for example, often completes details of chamber operations and gas and consumables. The report will normally include details of:

- personnel on board (POB);
- personnel movements;
- divers pressurised in the last 24 hours, in the chamber or undergoing decompression;
- work carried out including the number of dives;
- any extra work;
- weather conditions;
- consumables stocks;
- gas stocks and gas use;
- equipment;
- quality and health, safety and environment items, e.g. number of total bottom times (TBTs), inductions, incidents, etc.;
- any near misses, incidents or accidents;
- work planned for the next 24 hours;
- any client comments.

6.7 Checklists

Checklists are normally prepared as part of the planning for the diving operation. The person carrying out the checks may also be required to sign the completed checklist. Checks include[1]:

- a visual and touch inspection before any power is turned on;
- an examination of the system for cracks and dents, loose parts, unsecured wires and hoses, oil spots, discolouration, dirty camera lens, etc.;
- a function check of each component. Even if a valve is in the position required by the checklist, it should be operated and returned to the correct position (subject to any safety considerations);
- loose bolts or couplings should be tightened or, if necessary, replaced;
- all mechanical parts should be kept clean and lubricated;
- areas of potential corrosion should be examined and any necessary preventative or corrective measures taken;
- major mechanical components should be regularly checked for alignment and abrasion;

- the handling system should be checked for structural damage;
- electrical lines and connections should be examined and any hydraulic systems inspected for leaks and abrasions. Fluid levels should be regularly checked;
- a function test should be performed on all brakes and latches.

6.8 Certification and Maintenance[1]

IMCA guidance (for example IMCA D 011[2] and IMCA D 018[3]) contains advice on the planned inspection and maintenance of diving systems and equipment.

The planned maintenance system will be set up by the diving contractor. It may be paper based, but is commonly set up on a computer system.

Maintenance may be based on time, hours operated, manufacturer's recommendations or previous experience. The system should state the frequency with which each maintenance task must be undertaken and who is qualified to carry out the work. The person responsible should complete a record of work, either on paper or on the computer.

There should be an equipment register, listing all equipment on site with copies of all certificates of examination and tests, together with information such as design limitations or restrictions on use.

Verification of certification and the planned maintenance system should normally be carried out at least annually using the relevant IMCA Diving Equipment Systems Inspection Guidance Note (DESIGN) audit document as a checklist. There are currently DESIGN audit documents for air (IMCA D 023[4]), closed bell (IMCA D 024[5]), surface supplied mixed gas (IMCA D 037[6]), mobile/portable diving systems (IMCA D 040[7]) and for the hyperbaric reception facility forming part of a hyperbaric evacuation system (IMCA D 053[8]). As well as certification, the documents cover type and suitability of equipment.

6.9 Accident and Incident Reporting

All companies and some national legislation require incident reporting. Near miss and incident reporting ensures that steps can be taken to stop the incident occurring again and prevent an accident. All members of the diving team should be encouraged to make incident reports.

Non-conformance reports are reports of occurrences which do not cause a near miss or other incident, but do not conform to laid down procedures or standards. They may affect safety or quality and have the same importance as incident reports.

All companies, and most national legislation, require all accidents to be reported. An accident is anything that causes injury, however minor. The information may be required for legal, medical, insurance, social security, statistical and safety purposes.

Reports should be completed on the forms supplied and, where possible, should include witness statements.

Accidents and incidents should also be reported to the master of the vessel or offshore installation manager (OIM) of the installation where the event took place.

1 IMCA D 014 *IMCA international code of practice for offshore diving*
2 IMCA D 011 *Annual auditing of diving systems*
3 IMCA D 018 *Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment*
4 IMCA D 023 *DESIGN – Diving equipment systems inspection guidance note for surface orientated (air) systems*
5 IMCA D 024 *DESIGN for saturation (bell) diving systems*
6 IMCA D 037 *DESIGN for surface supplied mixed gas diving systems*
7 IMCA D 040 *DESIGN for mobile/portable surface supplied diving systems*
8 IMCA D 053 *DESIGN for the hyperbaric reception facility (HRF) forming part of a hyperbaric evacuation system (HES)*

Management and Planning

7.1 Duties and Responsibilities

There should be one company clearly in overall control of any diving operation. This is normally the company employing the divers.

If there are two or more companies employing divers on the same operation, there needs to be a written agreement stating which company is in overall control.

The company in overall control is referred to as the diving contractor.

7.2 Diving Contractor

In all diving operations, the name of the diving contractor should be displayed and all those involved in the operation, as clients, employees, sub-contractors, vessel or installation owners, etc. need to know who the diving contractor is.

The diving contractor will assemble the diving team and appoint supervisors and other management personnel. The management structure should be clearly defined in writing. It should include arrangements for any handover of supervisory responsibility at various stages during the operation.

The diving contractor should ensure that the following are in place[1]:

- a diving project plan;
- an overall quality management system which includes a safety management system;
- appropriate insurance policies;
- risk assessments for mobilisation/demobilisation, the operation of the equipment and work tasks to be undertaken and the contingency/emergency plans;
- a management of change procedure;
- a safe and suitable place from which operations are to be carried out;
- suitable plant and equipment supplied, audited and certified in accordance with the relevant IMCA Diving Equipment Systems Inspection Guidance Note (DESIGN) documents, other Diving, Remote Systems & ROV and Marine Division guidance notes and International Maritime Organization (IMO) documents, including equipment supplied by diving personnel;
- plant and equipment correctly and properly maintained;
- a suitable plan which includes emergency and contingency plans;
- sufficient personnel of the required grades in the diving team;
- personnel holding valid medical and training certificates and qualified and competent in accordance with the IMCA training, certification and personnel competence tables[2];
- suitable site-specific safety and familiarisation training provided to all members of the dive team;
- adequate arrangements to ensure that the supervisor and dive team are fully briefed on the project and aware of the content of the diving project plan and the dive plan;
- project records kept of all relevant details of the project, including all dives;
- a procedure for near-miss and incidents/accidents reporting, investigation and follow-up;
- adequate arrangements for first aid and medical treatment of personnel;
- clear reporting and responsibility structure laid out in writing;
- diving supervisors and life support supervisors appointed in writing and the extent of their control documented;
- the latest approved version of the diving contractor documents and plans at the work site are being used;
- all relevant regulations/standards complied with.

7.3 Diving Team

The size and composition of the diving team depends upon a number of factors, but always needs to be such that the diving operation can be conducted safely and effectively.

Factors to be considered include:

- tasks to be carried out;
- type of equipment (air, saturation, etc.);
- deployment method;
- location;
- water depth;
- special conditions (for example, strong tide or current);
- operational period (12 or 24 hours per day);
- contingency and emergency planning – handling of any foreseeable emergency situations;
- national legislation;
- client policy.

For each operation, team sizes and competence should be decided after completion of a risk assessment. It is the absolute responsibility of the diving contractor to provide a well balanced, competent team of sufficient numbers to ensure safety at all times[1].

There should be suitable arrangements for first aid and medical treatment of personnel[1]. Each team should include one or more personnel qualified in advanced first aid as a diver medic. He need not necessarily be a diver, but needs to be fit and competent to enter a chamber and carry out treatment under pressure. If the diver medic is a diver, he should not dive unless there is another diver medic on the surface.

The team may also include trainees, such as trainee diving supervisors or ALSTs.

The absolute minimum for a surface supplied air/nitrox diving operation under the *IMCA international code of practice for offshore diving* is five, consisting of:

- air diving supervisor;
- working diver;
- standby diver;
- tender for working diver;
- tender for standby diver.

The absolute minimum number of personnel required to carry out an offshore surface supplied mixed gas dive is six. This is made up of one supervisor (who does not dive) and five personnel who are qualified to dive[3].

The absolute minimum team size to support divers during a closed bell diving operation and 24 hours' life support operations under the *IMCA international code of practice for offshore diving* is nine, consisting of:

- closed bell diving supervisor;
- two life support supervisors;
- two life support technicians;
- two divers in the bell;
- surface standby diver;
- tender for surface standby diver.

Provision should also be made for a relief diving supervisor to be available. In practice, diving teams are usually considerably larger to allow round the clock working. They also normally include deck crew and technicians.

Ideally, all the support personnel should be employed by the diving contractor and be familiar with the special requirements of a diving operation.

If sub-contract personnel are used, their competence and suitability should be carefully considered. They could pose a hazard both to themselves and to the rest of the diving team.

Staff employed by a diving support vessel (DSV) or installation owner to maintain a permanently installed diving system may become part of the diving team.

In all cases, the precise arrangement, including responsibilities and chain of command, needs to be agreed in writing.

7.4 Duties and Responsibilities of Others

In an offshore operation the divers may be affected by the actions of personnel in the immediate vicinity or by the actions of personnel on installations many miles from the dive site.

The actions of all other parties involved in the diving operation can have an effect on the safety of the diver. These include the client, main contractor, offshore installation manager (OIM) and master of the vessel.

Onsite representatives appointed by the client or main contractor needs to have the necessary knowledge and experience to be competent for the task.

Duties and responsibilities of others involved include[1]:

- Agreeing to provide facilities and extend all reasonable support to the diving supervisor and contractor in the event of an emergency. Details of the matters agreed should form part of the planning for the project;
- Considering whether any underwater or above water items of plant or equipment under their control may cause a hazard to the diving team. Such items include:
  - vessel/floating structure propellers and anchor wires
  - underwater obstructions
  - pipeline systems under pressure test or with a pressure lower than the pressure at the diver work location
  - subsea facilities
  - water intakes and discharge points causing suction or turbulence
  - gas flare mechanisms that may activate without warning, or equipment liable to start operating automatically
  - appropriate isolations and barriers (mechanical, electrical, optical, hydraulic, instrumentation isolations and barriers);
- The diving contractor will need to be informed of the location and exact operating details of such items in writing and in sufficient time to account for them in risk assessments[4];
- Ensuring that sufficient time and facilities are made available to the diving contractor at the commencement of the project in order to carry out all necessary site-specific safety and familiarisation training;
- Ensuring that other activities in the vicinity do not affect the safety of the diving operation. They may, for example, need to arrange for the suspension of supply boat unloading, overhead scaffolding work, etc.;
- Ensuring that a formal control system, e.g. a permit to work system, exists between the diving team, the installation manager and/or master;
- Providing the diving contractor with details of any possible substance likely to be encountered by the diving team that would be a hazard to their health, e.g. drill cuttings on the seabed, possible bell atmosphere contaminants etc. They will also need to provide relevant risk assessments for these

substances, based on the material safety data sheets (MSDS). This information will need to be provided in writing and in sufficient time to account for them in risk assessments;

- Providing the diving contractor with information about any impressed current system on the worksite or in the vicinity and details of the system;
- Keeping the diving supervisor informed of any changes that may affect the diving operation, e.g., vessel movements, deteriorating weather, etc;
- In addition, the client should ensure, as far as is reasonable, that the diving contractor has all the necessary plant, equipment, personnel and operating procedures to meet national and other relevant regulations;
- When diving from DP vessels, arrangements must be made to inform the diving supervisor of any change in station keeping capability. See section 8.

7.5 Job Descriptions

It is advisable, and in many countries a legal obligation, to provide a written job description for all personnel describing their duties and responsibilities.

In general, all personnel should:

- be suitably qualified;
- have a suitable in-date medical certificate;
- comply with legal requirements;
- follow company safety and operational procedures and those of the vessel or installation;
- work to a satisfactory standard;
- only carry out tasks for which they have received appropriate instruction or training;
- look after their own safety and the safety of others;
- keep up-to-date with safety information;
- advise the diving supervisor of any potential hazards, near miss incidents or accidents;
- not take drink or drugs before or during an operation.

Job descriptions vary from company to company and the following job descriptions are for illustration only.

7.6 Diving Superintendent

Also known as a senior supervisor or subsea manager. If appropriately qualified as an IMCA diving supervisor (see section 1) and appointed in writing by the company, he may act as a diving supervisor. Duties and responsibilities include:

- managing all operational activity;
- ensuring that the operation is carried out safely in accordance with national legislation, company policy and other relevant standards;
- ensuring that the permit to work system is followed;
- ensuring that all work is carried out to the appropriate quality standards;
- ensuring that all personnel are competent, qualified and familiar with the work plan, diving system, diving procedures, safety and emergency procedures, etc.;
- liaising with the client, master of the vessel, OIM, etc. as appropriate;
- ensuring that the maintenance programme is carried out and that documentation is up to date;
- preparing daily reports and other reports as required by the company;
- passing on safety information via shift briefings or monthly or weekly meetings according to company policy;
- reporting potential hazards, near miss incidents or accidents to the company;

- implementing any safety measures required by the company.

Much of this work will be delegated but the diving superintendent has overall responsibility.

7.7 Diving Supervisor

He needs to be an appropriately qualified IMCA diving supervisor (see section 1) and must be appointed in writing by the company. Duties and responsibilities include:

- liaising with the diving superintendent;
- ensuring the health and safety of the diving team;
- ensuring that diving is carried out from a safe and suitable place and in accordance with national legislation, company policy and the *IMCA international code of practice for offshore diving*;
- ensuring that plant and equipment are properly maintained, suitable for the task and meet legal requirements;
- ensuring that the diver's equipment is properly maintained and checked before diving;
- ensuring that the diver is medically fit and competent to carry out the task. For hazardous or complex tasks, it may be necessary to carry out additional training before the operation starts;
- ensuring that the diving team is fully aware of the dive plan and contingency and emergency plans;
- ensuring that he has direct, clear and reliable voice communications with the diver, all personnel and all locations under his supervision and any other personnel involved in the operation. These include, for example, DP operators and crane operators;
- ensuring that he is able to see divers in the bell or chamber, either by viewports (on the surface) or by video link. As far as possible, he should aim to have video links to all locations under his control which he cannot see directly;
- de-briefing the diving team after the dive;
- maintaining the diving operations logbook and all other required documentation;
- reporting any equipment faults, other potential hazards, near misses or accidents;
- signing divers' logbooks after each dive and maintaining his own logbook;
- briefing his opposite number at shift changeover.

7.8 Trainee Supervisor

A trainee diving supervisor can only supervise a dive in the presence of a diving supervisor. He cannot supervise a dive alone and cannot be used as a relief for meal breaks, etc.

7.9 Diver

He needs to be appropriately qualified (see section 1). Duties and responsibilities may include:

- undertaking dives and other duties as required by the diving supervisor;
- informing the diving supervisor if there is any medical or other reason why he cannot dive;
- ensuring that his personal diving equipment is working correctly and is suitable for the planned dive;
- ensuring that he fully understands the dive plan and is competent to carry out the planned task;
- knowing the routine and emergency procedures;
- reporting any medical problems or symptoms that he experiences during or after the dive;
- reporting any equipment faults, other potential hazards, near misses or accidents;
- checking and putting away personal diving equipment after use;
- keeping his logbook up to date and presenting it for signing by the diving supervisor after each dive.

7.10 Life Support Supervisor (LSS)

He needs to be qualified under the IMCA scheme and be appointed in writing by the company. He reports to the diving superintendent or to the diving supervisor, according to company policy. In all cases, he liaises closely with the shift supervisor. He needs to know the company's diving and medical and emergency procedures. Duties and responsibilities include:

- managing the life support crew including life support technicians, tenders and gasman;
- ensuring the health and safety of the divers in the chamber and the members of the life support team;
- storing and maintaining medical and first aid supplies and equipment;
- managing gas and consumables;
- ensuring that all chambers and chamber equipment are in-date;
- checking and maintaining the hyperbaric lifeboat;
- supervising gas mixing;
- supervising chamber checks and ensuring that forbidden items are not allowed into the chamber;
- ensuring the safe and efficient running of the chamber system and the maintenance of comfortable living conditions for the divers in the chamber system;
- ensuring that daily chamber logs are correctly completed and kept up to date;
- ensuring that divers follow personal and chamber hygiene routines;
- carrying out and logging medical treatments as required;
- reporting any equipment faults, other potential hazards, near misses or accidents;
- assisting the diving supervisor as required during a hyperbaric evacuation;
- maintaining his own logbook.

7.11 Life Support Technician (LST)

He needs to be qualified under the IMCA scheme. He reports to the life support supervisor or diving supervisor. He needs to know the company's diving and medical and emergency procedures. Duties and responsibilities include:

- carrying out chamber checks;
- carrying out pressurisations and decompressions;
- supervising medical and equipment lock operations;
- assisting during TUP;
- maintaining the chamber environment within the limits specified by the company;
- calibrating analysis instruments;
- gas mixing;
- reporting any equipment faults, other potential hazards, near misses or accidents;
- assisting during any emergency procedures;
- maintaining his own logbook.

7.12 Assistant Life Support Technician (ALST)

He should have attended an IMCA approved ALST course or hold an IMCA recognised closed bell certificate issued prior to 1 November 2006.

He assists with all chamber operations under the direct supervision of the LSS or LST. When he has logged 2,400 panel hours he may be nominated by his company to sit the LST exam.

If the ALST has a closed bell certificate and has sat and passed an examination set by an approved training establishment and has demonstrated competence as an offshore closed bell diver in accordance with IMCA C 003[2], he can become eligible to sit the exam after 360 panel hours.

Passing the exam indicates that the ALST has the theoretical knowledge to become an LST, but he should only be promoted if his company is satisfied with his competence in accordance with the provisions of the IMCA guidance on competence assurance and assessment.

Note: *At least half of the required panel hours should have been obtained in the two years prior to the application to sit the examination being made.*

IMCA D 013[5] sets out how time on a simulator can count towards gaining panel time for both trainee diving supervisors and assistant life support technicians.

7.13 Tender

Provides general surface support for the diving operation. The diving supervisor or life support supervisor needs to ensure that he is competent to carry out all the tasks that he is required to undertake. These may include:

- umbilical handling;
- assisting with medical and equipment lock operation;
- assisting during TUP;
- cleaning divers' equipment;
- operating winches or tuggers.

7.14 Senior Dive Technician

Supervises the technical team and reports to the diving superintendent. He has overall responsibility for the equipment maintenance and certification programmes and the repair of equipment.

No work should be carried out on any part of the diving system without the authority of the diving supervisor.

7.15 Dive Technician

Reports to the technical supervisor or diving supervisor.

No work should be carried out on any part of the diving system without the authority of the diving supervisor.

7.16 Deck Crew

The deck crew will normally consist of qualified divers, together with non-diving specialists like riggers or technicians. There may be a deck supervisor or rigging supervisor. All members of the deck crew should:

- be briefed on the work being carried out by the diver;
- be made aware of the physical limitations of diving work;
- understand ways in which equipment can be prepared on deck to assist the diver;
- be aware of the delays in communicating with the diver and the effect this has on lifting and other operations;
- be familiar with good rigging practice and seamanship and know about safe working loads and safety factors;
- wear suitable footwear, clothing, helmets, buoyancy aids, safety lines as appropriate.

7.17 Training and Familiarisation

The diving supervisor needs to be satisfied that all members of the diving team and any other personnel involved in the operation are competent to carry out the tasks required of them.

A diver's competence can normally be assessed from his logbook. If there is any doubt about his competence for a specific task, the diving supervisor should discuss the procedures in detail with the diver to assess his level of knowledge.

If the operation involves any unfamiliar or complex tasks, it may be necessary to arrange training before the operation commences. This would normally be carried out in shallow water. For simpler tasks, a pre-dive description of the task might suffice.

Newly qualified divers may only have a small amount of experience in basic diving tasks and may be unwilling to admit it. Divers who are gaining experience and competence require support and assistance from the diving team and from the diving supervisor.

Members of the deck crew, especially those who are non-divers, may require briefing or even a formal training session before the operation commences.

Specific safety training for all personnel includes[1]:

- courses on survival, first aid and firefighting;
- an installation- or vessel-specific safety induction course on the hazards to be found at work and while responding to emergencies;
- further task-specific training outlining any special hazards associated with the tasks being carried out;
- refresher training at regular intervals.

7.18 Safety Meetings

Most companies make arrangements for safety meetings or briefings on a regular basis. They may also be required under national legislation or the rules of the installation or vessel.

These meetings may take place on a weekly or monthly basis, or be informal briefings at the start of a shift.

Items discussed should be minuted and the minutes should be displayed.

7.19 Work Periods

In general, work should be planned so that each person works a maximum of 12 continuous hours followed by 12 continuous hours of rest.

Longer work periods may be required from time to time, but these should be exceptional and not form a planned part of the operation.

Under the *IMCA international code of practice for offshore diving*:

- if a member of the diving team is asked to work for more than 12 hours, he needs to have had at least eight hours off in the previous 24 hours;
- The longest period a member of the diving team will be asked to work, and only in exceptional circumstances, will be 16 hours before being given eight hours of unbroken rest;
- in saturation diving, bell runs will not last more than eight hours from seal to seal and the divers must then have 12 hours of unbroken rest;
- no person will be expected to work for more than 12 hours without an intermediate meal break taken away from their place of work.

Under normal conditions there will also be toilet and refreshment breaks. There must be competent and qualified personnel to act as reliefs during these breaks.

The diving superintendent may be the only person able to stand in for the diving supervisor. In some operations, it may be possible to plan breaks around tide and current conditions or other interruptions to diving.

7.20 The Dive Plan

The dive plan, which must be in place before any diving takes place, consists of:

- the diving contractor's standard rules and procedures;
- procedures based on the tasks to be performed and risk assessments of these tasks;
- procedures based on site-specific risk assessments;
- contingency and emergency procedures.

All diving supervisors need to have a copy of the dive plan and details should be passed on to the diving team.

The following issues may be considered in the dive plan. This is not intended to be a comprehensive list:

- diving procedures, the techniques to be used, length of divers' umbilicals (see section 10.3), duration of bell runs and lock outs, TUP procedures[6 7 8];
- the depth and exposure limits for various mixes, volumes of gas to be held on-board, gas handling procedures[9 10 11 12];
- the support location. There are different considerations for fixed installations and for the different types of vessel. DP vessels present particular hazards;
- launch and recovery procedures;
- worksite hazards such as water intakes or discharges, anchor cables, taut wires, debris or overhead working. Control systems must be agreed with the client or installation owner;
- divers working in the vicinity of ROV operations;
- safe use of tools and other equipment;
- environmental hazards such as tide, current, water temperature, weather, sea state, poor surface visibility;
- communications – with the divers and diving team and with any person who may have any effect on the diving operation;
- emergency and contingency plans.

Details of procedures and control of the various hazards are given in sections 10 and 15.

7.21 Management Skills

A diving team generally comes together for a fairly short time to carry out a specific task.

Since the team is built around the task, the diving supervisor will normally manage the team on this basis. It is commonly described as task-centred management.

7.22 The Task

The diving supervisor is there to manage and should not generally get involved in hands-on work. A diving supervisor who takes over gas mixing, for example, is showing either a lack of confidence in his team or a lack of confidence in his management skills.

He needs to have a thorough knowledge of all aspects of the operation, the support location and the diving system. Without this knowledge he will not have the confidence of the diving team.

He needs to follow the progress of the task and identify and deal with problems. These may be technical problems or the more difficult problems of personality.

7.23 The Diving Team

The diving team needs to have confidence in the diving supervisor and there needs to be good communications with the team. Some of the ways in which these objectives can be achieved are by:

- ensuring that every individual in the team understands the task to be carried out;
- ensuring that everybody in the team knows the standard of work expected. This includes everything from coming on shift on time to following complex procedures;
- ensuring that everyone knows the consequences of failing to maintain standards. In most cases this will be just a few words from the diving supervisor;
- ensuring that everyone knows the disciplinary procedures and that if they are required they are applied fairly and seen to be applied fairly;
- sharing work fairly between members of the team having regard to their qualifications, competence and experience;
- knowing who work well together and who do not;
- dealing with any grievances promptly and fairly;
- consulting with those who are experienced or qualified in relevant areas before making difficult decisions;
- keeping the team fully informed. Lack of information is one of the most common complaints from any workforce;
- consulting the team about any proposed changes which may affect work routines, income or other personal aspects;
- encouraging feedback from the team.

7.24 The Diving Supervisor and Individual Team Members

Every team member should feel that he is performing well and receiving recognition for his work. The diving supervisor should try to ensure that:

- every individual knows his own tasks and responsibilities;
- these tasks and responsibilities are within the range of his abilities. A task that is too easy or too hard will cause frustration.

The diving supervisor should know who can work unsupervised and who needs regular checks. Whenever possible he should take a walk round the worksite. It lets him see what's going on and lets each individual know that he's being considered.

Finally, the diving supervisor should get to know each individual in his team and be aware of his strengths and weaknesses. The diving supervisor should never pry into people's personal lives, but if he hears of any problems he may need to take them into account.

1 IMCA D 014 *IMCA international code of practice for offshore diving*
2 IMCA C 003 *Guidance document and competence tables: Diving Division*
3 IMCA D 030 *Surface supplied mixed gas diving operations*
4 AODC 055 *Protection of water intake points for diver safety*
5 IMCA D 013 *IMCA offshore diving supervisor and life support technician certification schemes*
6 IMCA D 015 *Mobile/portable surface supplied systems*
7 IMCA D 010 *Diving operations from vessels operating in dynamically positioned mode*
8 IMCA D 033 *Limitations in the use of SCUBA offshore*
9 IMCA D 050 *Minimum quantities of gas required offshore*
10 IMCA D 043 *Marking and colour coding of gas cylinders, quads and banks for diving applications*
11 DMAC 04 *Recommendations on partial pressure of* O_2 *in bail-out bottles*
12 DMAC 05 *Recommendation on minimum level of* O_2 *in helium supplied offshore*

Support Locations

8.1 Introduction

Divers may work from a variety of locations ranging from very small boats, using mobile portable equipment to large fixed installations or purpose built diving support vessels (DSVs).

Consideration should be given to the effect that each location will have on the safety and efficiency of the diving operation. Items to be considered might include station keeping capability, deck strength, location of dive stations on the vessel, access to the water, external supplies and emergency evacuation. IMCA D 035[1] provides guidance on selecting vessels of opportunity for diving projects.

8.2 Small Work Boat, Supply Boat or Standby Vessel

The smallest type of vessel used in offshore diving operations is a small craft for mobile or portable surface supplied systems. IMCA D 015[2] makes recommendations about the equipment and crewing of such craft.

In all cases, these craft will be working from a larger support vessel or support location and should remain within close vicinity and in line of sight at all times. They are restricted to operating in good weather and good visibility. Sea conditions should be such that the diver can safely enter and leave the water and such that the craft can be safely launched and recovered by the support vessel.

Small work boats, supply boats or standby vessels may be used in certain operations. These vessels are not specifically designed for diving operations and have a number of limitations:

- lack of manoeuvrability;
- low grade navigation systems and no, or poor, position keeping ability;
- minimal deck space;
- no, or limited, crane or lift facilities;
- low electrical power reserves;
- unsuitable propeller guards;
- limited bad weather capability for overside operations;
- no, or poor, helicopter access;
- limited personnel accommodation;
- limited crew experience with diving operations.

These limitations should be taken into account when considering the work scope and location of the vessel.

8.3 Small Air Range DSVs and Larger Supply Boats

These vessels may suffer from some or all of the limitations listed above, but dedicated DSVs may have several advantages:

- diving systems and facilities are built in;
- the ship's engineers are experienced in working on diving systems;
- the ship's crew is familiar with diving operations.

8.4 Larger Monohull and Multihull DSVs

Although expensive to operate, these vessels are the best available for diving support. Multihulls provide exceptional stability, all systems are built in and the ship's crew is experienced in diving operations. There is often a permanent diving team, which ensures a close working relationship with the ship's crew.

The vessel typically provides facilities for mixed gas and air diving as well as ROVs. Some of these vessels also carry out year round maintenance on particular fields and may also have a firefighting capacity.

8.5 Fixed Platforms and Temporarily Fixed Platforms

Fixed platforms are immobile structures, either of steel jacket or concrete construction built from the seabed.

Temporarily fixed platforms are mobile structures fixed in one location on a short or long term basis. These include tension leg platforms (TLPs), moored production platforms, drilling rigs, crane barges and accommodation barges. They may be kept on location by DP or anchor systems. Specific hazards for divers include anchor cables and submerged pontoons.

The following problems may be associated with operating from fixed or temporarily fixed platforms:

- space restrictions on the installation of the diving system;
- difficulty of access to certain parts of the structure from a fixed diving system location;
- compliance with zoning requirements related to hydrocarbon safety;
- additional safety and training requirements placed on the diving team;
- the height between the platform and sea level;
- the possibility of a power shut down due to a preferential trip operation;
- hazards from intakes and outfalls on the installation;
- hazards from other work being carried out on the installation.

8.6 Specialist Locations

These include multi-support vessels, lay barges, trenching barges and any other specialised vessel. Each such location should be carefully considered at the planning stage and subjected to a full risk analysis.

8.7 DP Systems – Introduction

Much of the information in the following sections is taken from IMCA M 103[3] and IMCA D 010[4].

A DP system consists of all the equipment necessary to maintain the position keeping ability of the vessel. The system can be divided into five sections – power, propulsion, control, reference and sensors.

The power system consists of power generation distribution and power management system. The propulsion system consists of the propulsors such as tunnel and azimuth thrusters and main engines. The control system consists of the power management system and the position control system. The reference system includes the position measuring systems that provide information about the vessel's position such as hydroacoustic systems, laser radars and taut wires. The sensor system consists of those devices which measure attitude and movement and the environmental conditions such as wind sensors and vertical reference units.

An excursion is any change of position or heading, either intentional or unintentional. It can range from many metres to less than a metre.

As far as possible, the system is designed to avoid common single point failures. These are failures without a back-up or redundant system, or where the failure affects both the main and back-up systems. If single point failure cannot be avoided, units should be designed to fail safe. If a thruster control unit failed, for example, it could be hazardous if the thruster went to full power or provided thrust in an unwanted direction. The unit is therefore designed to fail as set, fail to zero thrust or trip the drive motor or engine. As a final back-up, every thruster should have a manually operated emergency stop, normally sited close to the main DP control station.

During proving trials, the system is tested in all normal modes of operation and failure modes are simulated. On the basis of the trials, calculations of station keeping capability are made for various situations, including the maximum number of thrusters and/or power units that could be operational after the worst single failure.

The results of these calculations are presented in a polar plot form for various current, wind and wave conditions. They provide an initial basis for estimating safe working limits. They are checked during trials and in the first year of DP operations.

Capability plots show the likely environmental limits within which the vessel will effectively return to the wanted position, when an excursion takes place caused by normal external forces. Excursions during normal operations within the safe working limits are recorded to develop a footprint for the vessel. This is the expected range of movement under normal conditions.

A fully operational DP system should reliably keep a vessel in position in such a way that the maximum excursion from vessel motions and position keeping will not be more than half the critical excursion for the work being carried out.

A critical excursion means an excursion where, because of the speed and/or extent of the movement, personnel could be injured and/or substantial damage could be sustained.

For every location and operation safe working limits should be defined. These are environmental limits within which a critical excursion caused by a single fault is very unlikely, either because there is adequate control and power remaining or because the environmental loads are small.

The determination of safe working limits for a diving operation needs to include the time taken for the divers to return to the bell or basket on a yellow or red alert, the likely speed of position loss and the increased position excursion after the worst failure mode.

IMO recommends that every DP vessel built after July 1994 should be assigned to an equipment class. In the definitions below 'single fault' includes an inadvertent act by any person on-board the vessel.

- equipment class 1 – loss of position may occur in the event of a single fault;
- equipment class 2 – loss of position should not occur from a single fault of an active component, such as a generator or thruster, but may occur after failure of a static component such a cable, pipe or manual valve;
- equipment class 3 – loss of position should not occur from any single failure, including a completely burnt fire sub-division or flooded watertight compartment.

The class of vessel required, critical excursion, safe working limits and other factors will be decided during the risk assessment. All DP DSVs should be at least equipment class 2.

DP vessels may be subject to mutual interference when working close to each other. Problems might include thruster wash, interference with position reference sensors and intermittent shielding from wind and waves. These factors should be taken into account during planning.

There are at least three DP alert levels on every vessel:

- green – normal operational status. Adequate equipment is on-line to meet the required performance within the safe working limits;
- yellow – degraded operational status. In general it is the condition where one or more items of redundant DP equipment has failed, safe working limits are being exceeded or an excursion of heading or position is likely but will not be critical;
- red – DP emergency status. There is a loss of position, or loss of position is inevitable.

8.8 DP Power Systems

The power system is generally diesel electric, with diesel generators supplying electric thrusters.

The system design and operational planning should consider the effect of the sudden failure of one diesel engine or of a fire in the engine room. Classification societies normally require class 2 systems to have at least one redundant engine which will come on-line automatically. In the event of a fire, fire detection systems should give sufficient warning for the recovery of the divers before the power is lost.

Class 3 systems should have two independent engine rooms. The design should be such that smoke from a fire in one engine room could not be drawn into the other, activating the smoke alarms and making the situation appear worse than it is.

For diving operations, the power distribution system should be so arranged that a fault on any switchboard section separated by bus ties would not cause the loss of the whole switchboard. This must be the case for every working combination of generators and thrusters.

As far as possible, the thrusters should have independent cable routes and control power so that in the event of a fault, fire or flooding no more than one thruster would be lost.

8.9 DP Propulsion Systems

The propulsion systems of these vessels normally consist of thrusters, azimuth and tunnel, and main engines. The thrusters are so arranged so as to give the vessel position and heading control and are normally diesel electric. The thrusters also operate either at constant pitch and variable speed or variable pitch and constant speed. Other types of thruster found on these vessels include gill jet and Voith Schneider.

8.10 DP Control Systems

Power management and position control both affect thrust for position keeping. The power management system should be able to switch smoothly to redundant systems. On vessels that use substantial amounts of power for other activities, such as cranes or fire pumps, the power management system should also be able to shed or reduce load to maintain power to the thrusters.

Almost all DP vessels use computers and/or microprocessors for position control. It is essential that there should be a period of stabilisation after position is first established or after a major move, heading change or change in environmental conditions. This will initially be at least 30 minutes.

Most systems combine an automatic and a manual system. The minimum control requirement for diving operations is for two automatic fully redundant control systems providing, on the loss of one, a smooth transfer to the other which would be unnoticed by the divers. There should also be a joystick for manoeuvring, which can either be separate from or an integral part of the DP control system.

Class 3 vessels should have an additional DP control room, in case the main control room is put out of action by fire or flood. On class 2 vessels, the design should consider the risk and the impact of fire on the control room, cables and associated systems.

At least one computer needs to be uninterrupted by the worst power loss failure possible and be able to continue operating with associated equipment for at least 30 minutes.

8.11 DP Position Sensors

The position reference sensors are designed to measure the position of the vessel as accurately as possible. For diving work at least three position references need to be on-line and at least two should be of different types.

Replumbing a taut wire (see section 8.12) when it is one of the three position sensors is not a violation of this requirement, provided the action is completed as quickly as is safe and sensible and the station keeping was stable when the taut wire was deselected before replumbing.

The position references selected should be chosen according to the situation. Some considerations are water depth, open water and the proximity to other installations or vessels. No single factor should affect more than one position reference.

Position references should have independent power supplies and cable routes should be separate. They should all be designed so that they cannot give an unchanging position when data is lost and the vessel is moving.

At present the types of position sensor in common use are taut wire, hydroacoustic position reference (HPR), differential global positioning systems (DGPS), laser radar systems such as FanBeam and CyScan and FM radar systems such as RADius and RadaScan.

8.12 Taut Wire Systems

A constant tension wire runs via a davit to a weight on the seabed. The wire runs through a wire measuring device, along the davit, through a sensor head pulley and down to the weight. As the vessel moves, the changing wire length and the angle of the wire to the vertical give the vessel's position relative to the weight.

Vertical taut wire systems are usually placed close to the centre of the vessel to reduce the effects of the vessel's pitch and yaw. Horizontal taut wire systems can be attached to a fixed structure or even a second vessel. This requires a separate surface taut wire system.

Taut wire systems, whether vertical or horizontal, need to be designed so that they cannot fail in a way which will provide a constant position signal because of a fouled wire, inadequate bottom weight or faulty head sensors.

The weight is very heavy, typically several hundred kilos. It needs to be deployed carefully to avoid damage to subsea structures. If the vessel is close to a platform, the weight should be deployed at a safe distance from the platform. Because the platform is wider at the base than at the top, there is a risk that the weight might damage cross members or be lowered inside the structure.

The taut wire has a maximum safe angle of operation. Before the maximum angle is reached, the weight should be moved. This should only be done after consultation with the diving supervisor, who will ensure that the divers and bell are safe. A moving weight presents a hazard to divers on the seabed.

In deep water, the vessel may move a considerable distance before the maximum angle is reached. In shallow water, it can move only a short distance. There is thus a minimum depth at which a taut wire system can be used.

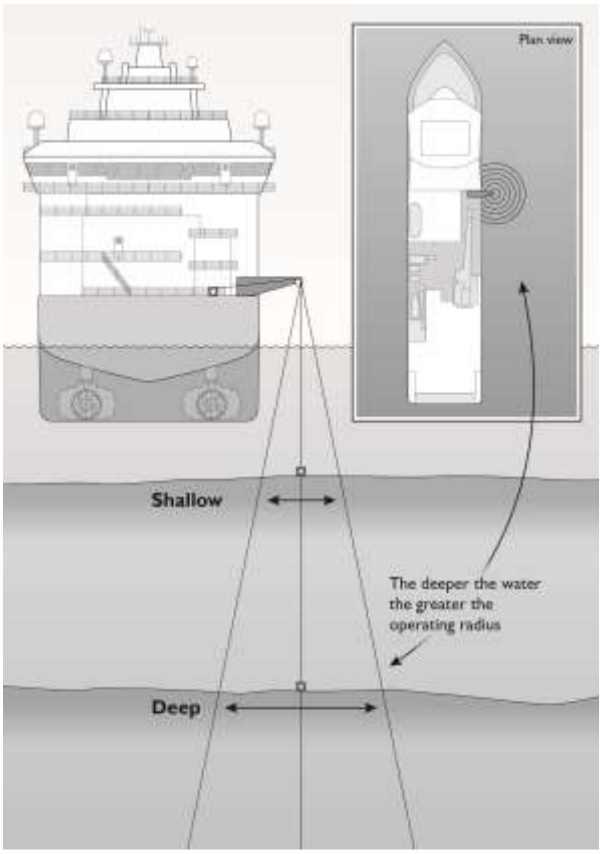


Figure 8-1 – DP vessel – operating radius

The taut wire itself looks very similar to a tugger wire. An incident occurred when a diver mistook it for a tugger wire and attempted to move it. The DP system followed the taut wire and the diver, causing a serious drive-off or move off station under power.

The taut wire should be clearly marked, usually with fluorescent tape or light sticks, to distinguish it from any other wires or cables. Ideally the weight itself should be painted white.

Problems may occur if there is contact between the bell cable, umbilical or crosshaul and the taut wire. In one incident, during a planned move, a taut wire snagged on a crosshaul shackle and moved with the bell, remaining vertical. The DP system was unable to register any movement and the vessel continued to move. It was in open water with no visual references and moved over 100 m before the error was discovered.

The taut wire may also be snagged by ROV umbilicals. AODC 032[5] recommends that the ROV launching position should be a reasonable distance from the area of taut wire deployment.

If there is any snagging of the taut wire, the system is effectively offline and there will be a yellow alert.

In heavy seas, the taut wire winch may be unable to follow the vessel's movement and the weight may be lifted clear of the seabed. This could cause a drive-off.

8.13 Hydroacoustic Position Reference (HPR)

Acoustic signals are transmitted from transponders placed on the seabed and received by a transducer beneath the hull of the vessel. The signal pulses are at regular, pre-set intervals. By noting the time between each pulse a distance can be calculated. This is combined with a bearing to give a position.

Several transponders may be deployed at once. In addition to the seabed transponders, one may be attached to the taut wire weight and one to the outside of the diving bell. The bell transponder will be in addition to the emergency bell location beacon.

When setting up on DP at a new location, divers may place additional acoustic transponders as required. Before leaving a location they may be asked to recover transponders.

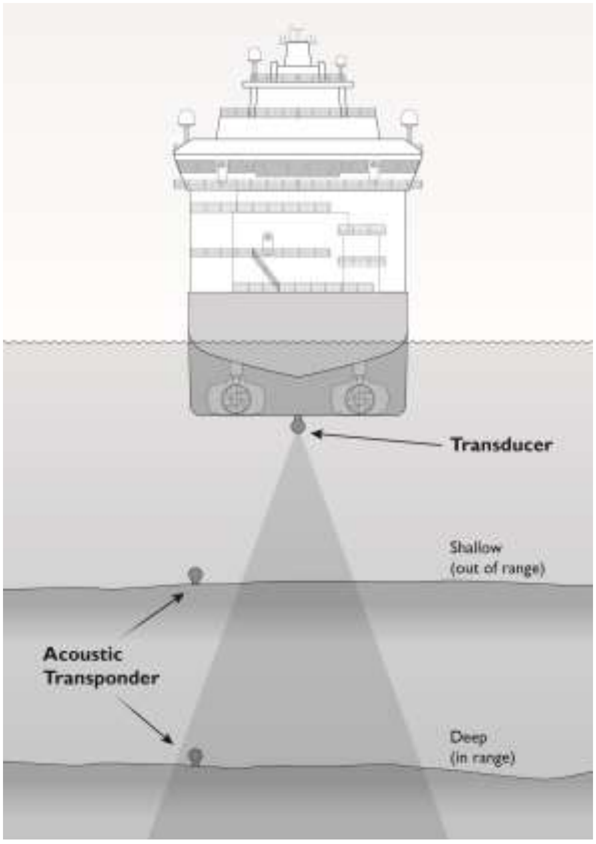


Figure 8-2 – DP vessel – HPR range

An HPR system should be designed so that it cannot accept any signal that is not intended to be used for position information. Possible sources of interference might be other transponders, water jetting equipment, thrusters or the diver's breathing exhaust gas bubbles.

The pattern of hydroacoustic transmissions from the seabed is cone shaped. In shallow water, the cone is very narrow and it is possible for the vessel to miss the transponder signal and overshoot the position. As with taut wire systems, there is a minimum operating depth.

If there is only one transducer on the vessel, the acoustic system can only count as one reference system, regardless of the number of transponders on the seabed.

8.14 Differential Global Navigation Satellite System (DGNSS)

Satellite based global positioning systems are not in themselves accurate enough to give a useable position for the vessel. This can be achieved by the use of differential correction signals from one of the number of suppliers of these signals, which are transmitted to the vessel via medium frequency, high frequency or satellite radio link.

To achieve an acceptable level of redundancy when using more than one DGNSS, the equipment and differential correction signals should come from different suppliers. Furthermore, signals from different correction stations should be used.

Two major causes of problems with DGNSS are scintillation – the effect of solar activity on the DGNSS signals – and shadowing of antenna by nearby structures.

8.15 Laser Radar Systems

Both FanBeam and CyScan are laser range and bearing systems.

8.15.1 FanBeam

Because of the difficulty of targeting a single laser beam, FanBeam uses a system that produces a laser beam in a 20° vertical fan. By scanning this fan horizontally a fixed target can be tracked from a moving vessel and its bearing, relative to the vessel's heading and range, can be determined. Range is found by measuring the time taken for a pulse of laser light to travel from the laser source to the target and back to the detector. Depending on the system used, the maximum range is 2,000 m.

The target may be reflective tape or a retro prism. Reflective tape should be mounted on a vertical cylinder to allow viewing from all angles. The cylinder should be 150-250 mm in diameter and 1,000 mm long. It is effective for ranges up to 150 m. Retro prisms are required for greater ranges. Each prism gives reflections up to 30° on either side of the prism centre line. For 360° working, a minimum of eight prisms is recommended. For ranges between 1,000-2,000 m, a stack of six prisms is required.

In all cases, the target should be the best reflector in the vicinity.

The system has the following limitations:

- the operating range is reduced in fog, snow and heavy rain. Typically the operating range is 35-50% better than the human eye in poor visibility;
- the system will not operate, or at best suffer from degraded performance, if the sun is shining directly into the lens;
- targets need to be located clear of other reflective surfaces, like reflective tape on lifeboats, lights, etc. The system software can overcome most problems, but a better reflective surface close to the target is hard to suppress.

As with the Artemis system, problems could occur if the target were accidentally moved or obscured.

8.15.2 CyScan

Another laser radar system is CyScan which operates on the principle of infrared laser 'time-of-flight' to pre-positioned retro-reflective targets, using a rotating scanner head design (as with a conventional microwave radar scanner) which gives a continuous 360° panoramic view of the vessel's surroundings and possible target locations. It rotates at 360° per second while the laser pulses at 30 kHz thereby giving a potential of 80 measurements for every 1° of rotation.

The operating range is up to 400 metres in the majority of environments. Ranges in excess of 1000 metres can be achieved with a sophisticated optical prism reflector.

This system has the following limitations:

- operating range is greatly reduced in fog, snow and heavy rain although the operational range is still 30% to 50% better than the human eye in poor visibility;
- care is required in selecting optimum target locations. Particular care should be taken to ensure unequal spacing of multiple targets and that line of sight is maintained throughout the operation. Permanent location of targets is recommended;
- optimum performance requires the use of manufacturer's own targets.

For both these, problems could occur if the target were accidentally moved or obscured.

8.16 Frequency Modulated Microwave Radar Systems

Both RADius and RadaScan are FM radar systems.

8.16.1 RADius

RADius utilises radar principles in short range and direction monitoring. This system, like other similar systems, is designed to operate close by structures and other vessels. The use of identifiable transponders minimises the risk of tracking false echoes.

RADius consists of one or several interrogators typically located on a moving vessel and one or several transponders which are deployed on the target which the vessel will approach. The RADius system measures the distance and bearing between the interrogators on the moving vessel and the transponders. All deployed transponders at the target have unique identities, thus multiple transponders can be utilised for integrity and high availability.

The range of operation depends upon the transponders used, typically being up to 350 m for 500 series and up to 1000 m for 600 and 700 series transponders.

8.16.2 RadaScan

RadaScan is a low power (3 Watt) frequency modulated continuous wave radar sensor operating over a 100 MHz bandwidth in the licence-free 9.25 GHz maritime radiolocation band. The sensor picks up reflections from retro-reflective transponders which are placed on the installation. The transponders are totally passive in nature and introduce a unique code into the reflection to allow unambiguous identification and robust tracking.

The sensor contains a 360° rotating antenna which scans continuously at 1 Hz and so aids unrestricted vessel manoeuvrability. Because the sensor operates in the same frequency region as conventional X-band radars, consideration needs to be given to sensor installation position with regard to other radar units.

This system has the following limitations:

- operational range is limited to 1000m;
- care is required in selecting optimum transponder locations and that line of sight is maintained throughout the operation;
- permanently located transponders are recommended;
- requires the use of manufacturer's own transponders;

- multi-target operation requires horizontal angular separation of more than 7° between transponders.

8.17 Artemis Surface Reference System

The Artemis system consists of a fixed antenna unit and a mobile antenna unit. The fixed antenna unit is battery powered and is mounted on a fixed installation. The mobile antenna unit is mounted on the vessel. Microwave transmissions between the two antennas are used to give an extremely accurate distance and bearing.

Artemis units are safe for Zone 1 use, but should be switched off during radio silence, for wireline or explosive work. This should only be done after consultation with the DP operator and diving supervisor.

Artemis is limited to line of sight use and any obstruction can cause a system error. Signal distortion or interruption will occur if the fixed antenna battery is low. Interference could be caused by the fixed antennas of other DP vessels operating in the vicinity or by radar transmissions. Systems should therefore be designed so that they will only accept signals unique to the DP vessel on which they are being used.

It is usual to mount the fixed antenna unit on a corner of the structure so that Artemis can be used on two faces without having to relocate the unit. Vessels may have two fixed antenna units to avoid unnecessary delay when moving from one side of a structure to another.

Fixed units have been subject to interference by personnel on the structure. Personnel have removed batteries for use in other equipment, the whole unit has been moved or objects have been placed in front of the unit. Objects causing interference have been as small as a scaffolding tube or as large as a container. Units have been switched off by safety officers unaware that they are safe for Zone 1 use.

8.18 Environmental and Vessel Sensors

Additional sensors are required to measure wind speed and direction, heading, pitch, roll and yaw. Wind speed and direction are measured by anemometers (or wind sensors), heading by gyro compasses and other movements by a vertical reference unit (VRU) or a more sophisticated motion reference unit (MRU).

The anemometers may give false readings because of turbulence around a structure or helicopter downdraught.

For diving operations, there needs to be at least two anemometers, preferably in different locations with separate supplies and cable routes. There should be at least two vertical reference sensors with separate supplies and cable routes. The DP control should give a warning if any unit fails. Because of the importance of heading control there should be at least three gyro compasses.

All vessel sensors need to be in separate locations, so that redundant units are unlikely to suffer from the same fire, flood or other physical damage.

8.19 Communications

There must be a dedicated voice communication system, with a back-up system, between the diving supervisor and the DP control room. There should be a similar dedicated communication system, with back-up, linking all the other control centres of the vessel with dive control, e.g. ROV control, crane control, etc.

Information which should be passed regularly from the diving supervisor to DP control includes:

- bell and diver status;
- intention to use and use of water jetting equipment;
- intention to release high volumes of compressed air underwater;
- possibility of divers, bell or equipment blanking or moving acoustic reference transponders;
- the status of all downlines;

- requests to move the vessel;
- any situation which is unusual or may need a change to agreed procedures;
- any other operation which may affect the operation of the DP system. This will be identified in the risk assessment.

Information which should be passed regularly from DP control to the diving supervisor includes:

- intention to move the vessel or change heading;
- changes in operational status affecting position control;
- any forecast or actual significant changes in the weather;
- other vessel movements in the vicinity;
- intention to handle any downline, including re-positioning of the taut wire weight;
- relevant platform information;
- any situation which is unusual or may need a change to agreed procedures;
- any other operation which may affect the safety of the divers. This will be identified in the risk assessment.

Similar information also needs to be exchanged with any ROV supervisor and with the platform. The platform needs to keep the vessel informed of planned ship and helicopter movements, crane lifts, over the side working, waste discharges, weather information and details of any acoustic beacons or transponders which may be in the area.

8.20 Vessel Movements

A DP vessel can move to a new position or heading automatically if the new co-ordinates are entered into the system. It may also be moved under manual control using the joystick. **However, joystick control is not acceptable during diving operations.**

A change of heading involves rotation of the vessel about a specific centre. If the divers are not at the centre of rotation, they will experience a change of position and the consequences must be considered before any heading change is made. Under normal conditions, only small changes of heading should be made with divers in the water. If it is necessary to make a more significant heading change, the divers should be recovered to the bell initially, followed by an assessment of the situation to be made whether to recover them to surface while changing the heading.

If the vessel is under stable DP control, position or heading may be changed without recalling the divers to the bell or basket, provided that all personnel have been informed and the diving supervisor and DP operator are satisfied that:

- the move can be executed safely;
- umbilicals and other diving-related work lines are clear and will remain so during the move;
- the divers understand the move and are not endangered by it;
- the divers can easily reach the bell or basket;
- three position references will be on-line during the move;
- the move will not exceed the scope of any of the three position references;
- the move will be stopped if one position reference has to be re-positioned and this results in only two references being on-line;
- the DP operator will verify the move input before carrying it out;
- the move is made at low speed and can be stopped at any time;
- changes of heading and position are not made simultaneously;
- due account has been taken of the selected centre of rotation when the heading is to be changed;
- any movements in distance is carried out in steps of 5 m.

If the DP operator, the diving supervisor or the divers have any concerns about the safety of the move, the move should be stopped immediately and the divers should return to the bell or basket.

The movement of moored vessels that are acting as dive platforms can also impact upon the safety of divers in the water. Therefore a similar level of caution should be exercised when moving conventionally moored vessels on anchors. If the vessel is stable, position or heading may be changed without recalling the divers to the bell or basket, provided that all personnel have been informed and that the diving supervisor and master are satisfied that:

- the move can be executed safely;
- umbilicals and other diving-related work lines are clear and will remain so during the move;
- the divers understand the move and are not endangered by it;
- the divers can easily reach the bell or basket;
- the move is made at low speed and can be stopped at any time;
- changes of heading and position are not made simultaneously;
- due account has been taken of the selected centre of rotation when the heading is to be changed;
- any movements in distance is carried out in steps of 5 m.

If the master, the diving supervisor or the divers have any concerns about the safety of the move, the move should be stopped immediately and the divers should return to the bell or basket.

8.21 DP Alerts

DP status lights should be displayed in dive control rooms and are often also displayed in saturation control, on deck and in the ROV control room. Yellow and red alerts are accompanied by audio alarms sounding in dive control rooms. Sometimes alarms also sound in the master's cabin, diving superintendent/senior supervisor's cabin and generally over the PA system. DP alerts are operated from the DP control room.

The diving supervisor will have contingency plans for each alert condition. Every worksite is different and it is not possible to produce standard plans. Diving team members should be fully briefed on their duties. If more than one diving operation is being carried out from the same vessel, the respective diving supervisors should ensure that their planned actions will not conflict.

On a yellow alert the following actions should be taken:

- the diving supervisor should instruct the diver to move to a safe location. This may be the bell weight, bell or basket;
- as far as is practical, the divers should make safe any work or items of equipment that could pose a hazard;
- after consultation with the DP operator, the diving supervisor will decide whether to continue or abort the dive. If he has any doubts, he should abort the dive.

On a red alert the diving supervisor should recover the divers as rapidly as possible, having due regard to any hazards posed by downlines (note: all downlines should have a weak link attachment) or subsea structures. During the emergency, the DP operator will use all available means to maintain position whilst ensuring the safety of surface divers who may be adversely affected by resulting thruster wash.

8.22 Umbilical Handling on DP Vessels[6]

A full discussion of this subject appears in IMCA D 010[4].

8.22.1 Umbilical Lengths

The working divers' umbilicals must be securely tended at all times during routine operations and during any foreseeable emergency intervention. Where an excursion is planned such that the diver could be brought within range of any physical hazard identified by the risk assessment (such as vessel thrusters, propellers, water intakes, etc.), that diver's umbilical must be physically restrained to prevent it from coming within five metres of such hazards.

The reach or length of the bellman/standby diver's umbilical should be two metres greater than that of the working diver's umbilical to provide manoeuvrability. At the same time it must also be restrained to prevent it coming within three metres of any identified hazard. This rule should apply whether the standby diver is located on the surface, in mid-water, or in a diving bell.

In Figure 8-3, the distance c to the thruster can be found by $c^2 = a^2 + b^2$.

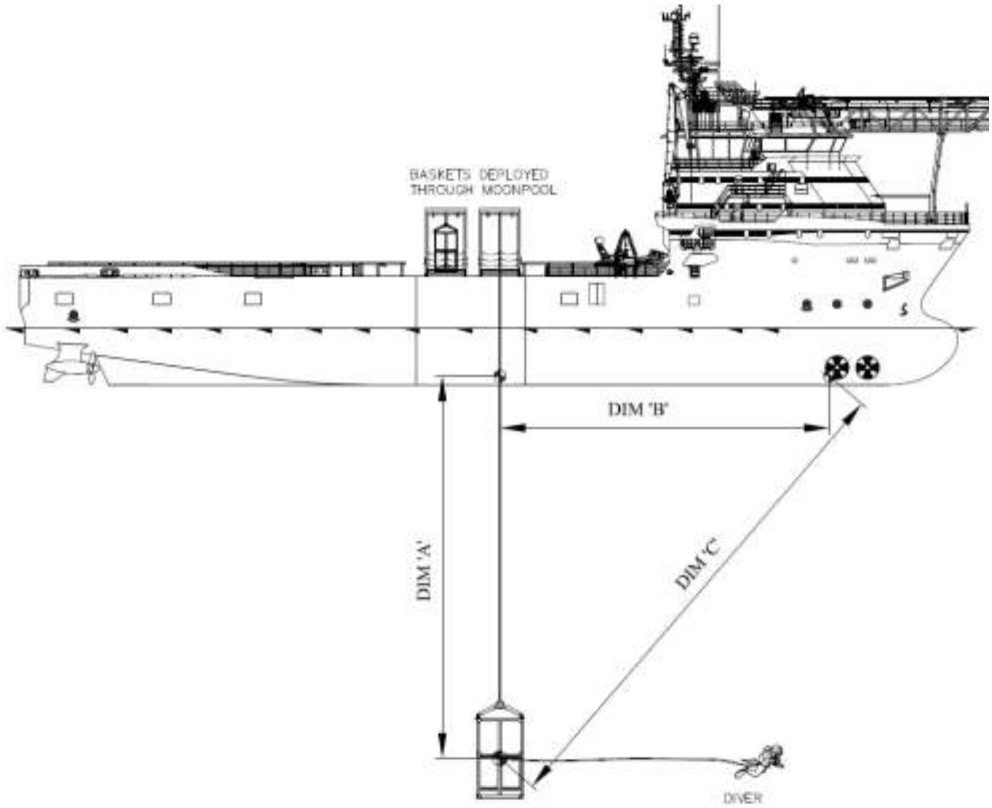


Figure 8-3 – DP vessel – Basic hazard range calculation

In certain circumstances, where the deployment of the standby diver and the working diver are from different locations, consideration must be taken (as in Figure 8-3) of the proximity of hazards to these locations when calculating safe umbilical lengths. It should be noted that such considerations may impose additional restrictions on the length of the working diver's umbilical.

It should also be noted that a basket or bell deployed over the side (rather than through a moonpool at the centreline of the ship) may cause a significant offset which must be accounted for in the precise calculation of safe umbilical lengths for the divers, i.e. the 3D nature of the true situation must be recognised. By measuring from the centre-point of the basket or bell to the closest hazard at wherever the launch point is actually located, then the true distance from the closest hazard will always be recorded.

8.22.2 Additional In-Water Tender

Where an in-water tender is deployed in addition to a bellman, his umbilical must also be prevented from coming into contact with any identified hazard during a foreseeable emergency rescue. In addition, the project risk assessment should consider the relative functions of the bellman and the in-water tender in the event of an emergency.

8.22.3 Points of Tending

The tending point is defined as the surface or in-water point from which the diver's excursion umbilical can be securely tended.

Tending can be achieved safely by employing:

- a tender located on the vessel from which the working diver is deployed;
- a tender located in an additional device deployed from the DSV, either on or above the surface, such as a stage or gondola;
- a tender/bellman located in the deployment device from which the working diver is deployed;
- an in-water tender located mid-water or near the seabed in a separate device deployed from the vessel, in addition to the bellman. This tending point must be able to hold position relative to the vessel if DP failure occurs;
- an unmanned in-water tending point, provided that the criteria set out in section 8.25 can be met.

When the depth of the worksite puts the diver beyond physical hazards identified by the risk assessment and no restriction on umbilical length is necessary, other than consideration of bail-out capacity, then an in-water tending point may be considered to enhance the safety of a working diver who is using an extended umbilical, accessing a structure or working within a jacket structure or manifold.

Where the standby diver is located on the vessel and he is deployed in the water in an additional device, procedures should be in place to maintain his umbilical to prevent it from coming within three metres of the nearest hazard.

8.23 Deployment of the Excursion Umbilical

The length of umbilical deployed should be kept to a minimum to prevent it becoming snagged and to permit easier recovery of a diver in an emergency, particularly when currents are present. At the same time, allowance should be made for vessel movement within the DP footprint.

In order that the length of umbilical deployed can be monitored, the umbilical should be marked at appropriate intervals.

In certain circumstances, a diver may secure himself underwater in order to achieve stability. In such cases, a recommended 'weak link' should be used. The means by which the diver's umbilical is prevented from coming into contact with a hazard should not be dependent on this weak link.

The working diver, tender and bellman should each monitor the marking and relative position of the umbilical, and immediately inform the supervisor of any concern regarding its safety.

In some surface supplied diving operations, the diver's point of entry may be some way from the deck (either in terms of distance or elevation). In such cases, it may be appropriate, subject to suitable risk assessment, to position a tender at an intermediate point on or above the waterline by means of a basket, light craft or other appropriate means. If this form of intermediate tendering is employed, the device containing the tender should be monitored and effective communications maintained.

8.24 Use of Negatively Buoyant Umbilicals

The use of negatively buoyant umbilicals may provide an inherently safer operation in some circumstances.

8.25 Deployment of Divers Using In-Water Tending Points

When access to certain work sites is restricted it may be necessary to deploy a diver/divers beyond the pre-determined safe umbilical length as determined from the distance between the deployment device and the nearest hazard, e.g. thruster.

Typical restrictions may be platform overhangs, flare towers, lifeboats, bridges and such like.

Access can be safely achieved using active and passive diver tending. This can be carried out in either saturation or air diving mode and utilises a device (basket, hoop, rectangular frame or similar) suspended from the cherry picker, crane or working platform on the vessel. It is preferred but not essential that a basket be deployed on a man riding lifting device.

Tending with active and passive methods utilises different operating techniques as set out below.

A diver access study will determine the length of umbilical required and contribute to the assessment process to decide which method of umbilical management should be used.

This document details two preferences that may be considered:

i) Active tending, where the task or diving conditions warrants enhanced umbilical management;

ii) Passive tending, where there is a requirement to utilise one or two divers at the worksite.

An unmanned in-water tend point often takes the form of a large metal hoop or rectangular frame lowered from a crane, although other methods may be used. Figure 8-4 shows a rectangular frame in use as an unmanned in-water tend point. The diver leaves the bell or dive basket and goes through the frame to reach the task. The umbilical is effectively held at the frame, preventing the diver from coming too close to the nearest hazard.

For example, the basket/bell may be 17m away from the nearest thruster. If the task were 18m from the basket/bell, the diver's umbilical would allow him to reach the thruster. By lowering a frame into the water between the basket/bell and the task, perhaps 8m from the basket/bell and 20m from the thruster, the diver is safeguarded. He needs only 8m of umbilical to reach the frame, thus maintaining a safe distance from the thruster. Once he is through the frame, the umbilical is restrained at the frame and he requires only 10m to reach the task. He is kept a safe 10m from the thruster.

The position of the bell or basket and frame are governed by the following rules:

- The distance from the frame to the diver must not exceed (the distance from the bell or basket to the nearest hazard - 5) metres. Referring to Figure 8-4, this can be expressed as $C_{max} = (A - 5)$

OR

- The distance from the frame to the diver must not exceed (the distance from the frame to the nearest hazard - 5) metres. Referring to Figure 8-4, this can be expressed as $C_{max} = (D - 5)$

  whichever is shorter

AND

- The distance from the frame to the diver must be at least 2m longer than the distance from the bell or basket to the frame, i.e. Distance B is always less than Distance C by at least 2m.

Referring to Figure 8-4, this can be expressed as $C_{min} > B + 2$.

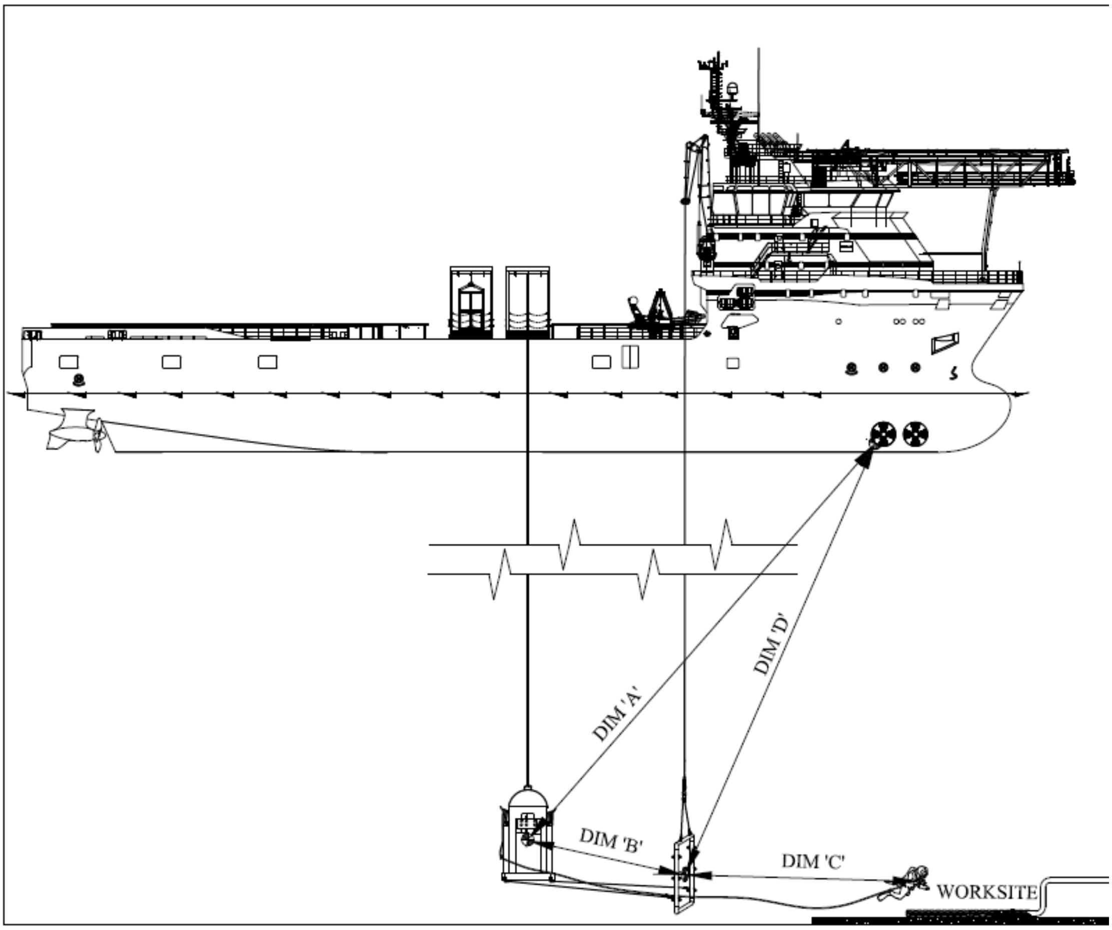


Figure 8-4 – Extended umbilical diving from a DP vessel; single diver; unmanned in-water tend point

Tending can be achieved using active (manned) or passive (unmanned) tending at the in-water tending point provided the criteria in sections 8.25.1 and 8.25.2 are met.

8.25.1 Active Tending at the (Manned) In-Water Tending Point

Active tending at the in-water tending point enables enhanced umbilical management in situations similar to those described above.

Where the planned excursion using active tending at the in-water tending point is undertaken the following criteria are to be met. In the event of the tender becoming incapacitated, the working diver should have available to him sufficient length of umbilical to allow his direct return to the deployment device without the disconnection of his umbilical from the swim line. This is addressed by ensuring that at all times his maximum allowable excursion beyond the in-water tending point meets the greater than 'B' requirement shown in Figure 8-5.

- The tending point is held in position relative to the vessel;
- The length of the working diver's umbilical must be restrained in such a way that it cannot reach to within five metres of any physical hazards (such as thrusters, propellers etc.);
- The reach of the in-water tender and bellman/standby diver umbilicals is restrained such that each is two metres longer than that of the working diver's umbilical, to provide manoeuvrability but cannot reach to within three metres of any physical hazard;
- Where the working diver and standby diver are deployed from different locations, this should be taken into account when calculating safe umbilical lengths;
- A swim line is fixed between the deployment device and the manned in-water tending point;
- The working diver's umbilical is secured to the swim line between the deployment device and the manned in-water tending point at the maximum allowable excursion distance from the in-water tending point;
- The bellman's/in-water tender's umbilical and that of any standby diver is secured to the swim line between the deployment device and the manned in-water tending point at the calculated maximum excursion distance for the working diver from the in-water tend point plus two metres;
- A task-specific risk assessment is carried out and, where appropriate, additional measures identified are provided;
- Suitable procedures should be in place, based on the particular circumstances of the diving operation, to permit recovery of a diver in an emergency;
- Consideration should also be given to the safe recovery of the diver to the surface.

For active (manned) in-water tending the following constraints apply to the safe working distance for the working diver's umbilical:

C_{max} = D – 5 metres

OR

C_{max} = A – 5 metres, depending which distance is shorter

AND

B is always less than C by at least 2 metres i.e. $C_{min} > B + 2$

(This is to allow, in the event of an emergency, direct recovery of the diver to the deployment device.)

where:

A = distance from the deployment device to the nearest physical hazard

B = distance from the deployment device to the in-water tending point

C = distance from the in-water tending point to the diver

D = distance from the in-water tending point to the nearest physical hazard

See Figure 8-5.

8.25.2 Passive Tending at the (Unmanned) In-Water Tending Point

Passive tending at the in-water tending point, utilising one or two working divers at the worksite, can be carried out provided the following criteria are met:

- The tending point is held in position relative to the vessel;
- The length of any working diver's umbilical must be restrained in such a way that it cannot reach to within five metres of any physical hazards (such as thrusters, propellers etc.);
- The reach of the bellman/standby diver's umbilical is restrained such that it is 2 metres longer than that of the working diver's umbilical to provide manoeuvrability but cannot reach to within three metres of any physical hazard;
- Where the working diver(s) and standby diver are deployed from different locations, this should be taken into account when calculating safe umbilical lengths;
- A swim line is fixed between the deployment device and the unmanned in-water tending point;
- An appropriate method or procedure must be in place to ensure that any working diver's umbilical is restrained at its maximum allowable excursion distance at the unmanned in-water tending point;
- The bellman's umbilical and that of any standby diver is secured to the swim line between the deployment device and the unmanned in-water tending point at the calculated maximum excursion distance for the diver from the in-water tending point plus two metres;
- A task specific risk assessment is carried out and, where appropriate, additional measures identified are provided;
- If a problem begins to arise when two divers are on passive tending, then one diver should return to the tend point and revert to active tending;
- Suitable procedures should be in place, based on the particular circumstances of the diving operation, to permit recovery of a diver in an emergency;
- Consideration should also be given to the safe recovery of the diver to the surface.

For passive (unmanned) tending the following constraints apply to the safe working distance for the working diver's umbilical:

C_{max} = D – 5 metres

OR

C_{max} = A – 5 metres, depending which distance is shorter

AND

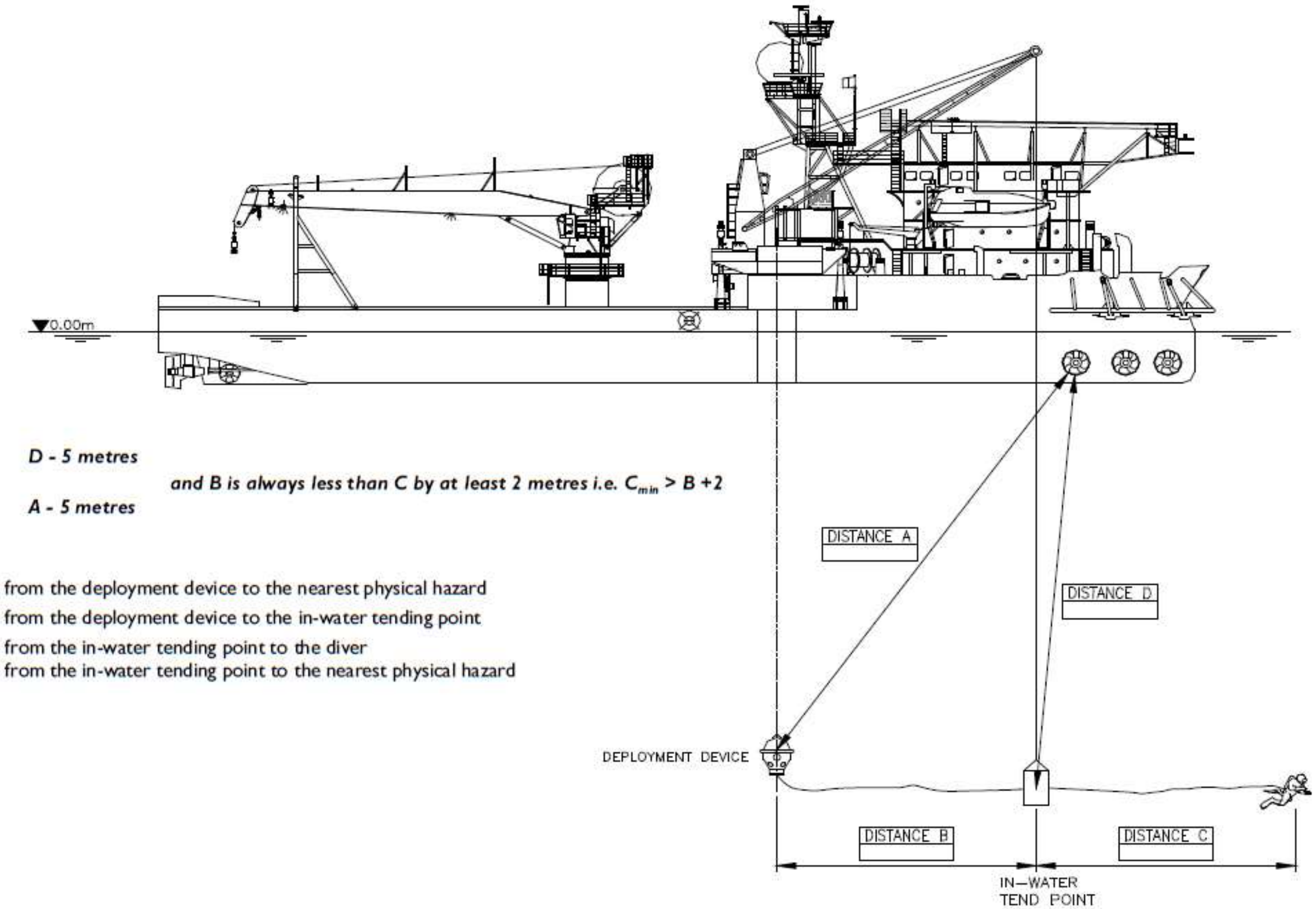
B is always less than C by at least 2 metres i.e. $C_{min} > B + 2$

(This is to allow, in the event of an emergency, direct recovery of the diver to the deployment device.)

Where:

A = distance from the deployment device to the nearest physical hazard
B = distance from the deployment device to the in-water tending point
C = distance from the in-water tending point to the diver
D = distance from the in-water tending point to the nearest physical hazard

See Figure 8-5.



C_{max} = *D - 5 metres*

OR

C_{max} = *A - 5 metres*

and B is always less than C by at least 2 metres i.e. $C_{min} > B + 2$

where:

A = distance from the deployment device to the nearest physical hazard

B = distance from the deployment device to the in-water tending point

C = distance from the in-water tending point to the diver

D = distance from the in-water tending point to the nearest physical hazard

Figure 8-5

8.25.3 Calculation Examples for the Deployment of Extended Umbilical Divers Using In-water Tending Points

Example 1

Suppose the distance from the basket/bell to the thruster (Distance A) is 17m and from the in-water tend point to the thruster (Distance D) is 20m. Because it is shorter than Distance D, Distance A (17m) is selected to calculate C_{max}. The distance from the in-water tend point to the diver (Distance C) must not exceed (17 - 5)m, or 12m. This, of course, is shorter than (D - 5).

The distance from the basket/bell to the in-water tend point (Distance B) is 8m, so the distance from the in-water tend point to the diver (Distance C) must be at least (8 + 2)m, or 10m. Distance C, therefore, must be between 10 and 12m.

These criteria are based on considerations which include the possibility that the hoop may be moved or lifted during emergency diver recovery.

Example 2

Suppose the distance from the basket/bell to the thruster (Distance A) is 25m and from the in-water tend point to the thruster (Distance D) is 20m. Because it is shorter than Distance A, Distance D (20m) is selected to calculate C_{max}. The distance from the in-water tend point to the diver (Distance C) must not exceed (20 - 5)m, or 15m. This, of course, is shorter than (A - 5).

The distance from the basket/bell to the in-water tend point (Distance B) is 10m, so the distance from the in-water tend point to the diver (Distance C) must be at least (10 + 2)m, or 12m. Distance C, therefore, must be between 12 and 15m.

8.26 Identification of Hazards and the Preparation of Vessel Hazard Diagrams

Diagrams specific to each vessel should be provided in both DP and dive control to enable the DP operator and the diving supervisor to visualise the relative position of the vessel, the deployment device[1] and the divers in relation to the worksite, and to plan operations accordingly. These diagrams should also be available in other appropriate areas. They should be prepared using up-to-date and accurate vessel General Arrangement drawings, and they should include:

- a thruster configuration diagram showing the deployment device at various depths, at 10 metre increments, and distance to the nearest thruster;
- illustrations of all other hazardous areas into which umbilicals (main and excursion) must not be allowed to stray, e.g. propellers, seawater intakes, and any subsea hull obstruction that could affect the safety of diving operations;
- the position of nearby mooring lines, if appropriate;
- the height of subsea structures above the seabed.

Typical vessel hazard diagrams are included as Appendix 4 to this document.

In DP control, the position of ground-based reference systems and their status should also be displayed.

In dive control and, where appropriate, in ROV control, there should also be an indication of the reference systems used and the various diving-related working lines that have been deployed, e.g. deployment devices, downlines, cranes, winches, hydraulic and electric lines, taut wires and acoustic transponder locations. The supervisor should have a method for maintaining a status record of deployment devices. For the benefit of tenders operating from the deck the transverse position of thrusters should be painted on the hull above the water line and on the deck, and, if possible, on the bulwark or handrail.

[1] Where there is more than one diver deployment location on a vessel there should be diagrams for each location.

8.27 DP Operations in Shallow Water

In shallow water, the safety of the diver may be affected by the proximity of thrusters, water flow from the thruster affecting visibility and the fact that some position reference sensors are less reliable. Escape routes for the vessel in an emergency may be restricted by adjacent shallow water.

In general, the shallower the water, the smaller scope there is for movement before seabed position reference sensors need relocation.

- the scope of taut wires is greatly reduced, depending on the height of the reference point;
- HPR is more susceptible to interference from the vessel;
- the maximum natural excursion of the vessel can exceed the scope of a seabed position reference.

There should always be at least three position references, one of which should be a radio or surface position reference. Surface reference systems may offer greater reliability because they are not susceptible to water depth. They may have other limitations, however, and these should be assessed: for example, the range of microwave radar systems may be too limited for accurate bearing information; laser radar systems may only be used within fairly close proximity (1000 m) to a platform or other structure on which the reflector or transponder is placed; DGNSS signal may be lost whilst working in close proximity to a platform under the shadow of a helideck.

Planning and risk assessment should also consider the following:

- the appropriate clearance between the bell or basket and the keel or lowest thruster must be determined, taking into account tide, weather, subsea obstructions, etc.;
- thruster proximity may be a concern for bell diving as well as surface oriented diving;
- umbilicals should be negatively buoyant wherever practical;
- vessel noise may affect the diving operation;
- higher thruster and generator loads can be expected than for the same weather conditions in deeper water, causing operations to be stopped earlier;
- shallow waters are often associated with strong tidal currents and poor underwater visibility. This may affect the diver's ability to identify and avoid taut wires, etc.

8.28 Diving within Anchor Patterns

Diving within an anchor pattern restricts vessel movements and may expose the diver to additional hazards such as umbilical snagging. Taut wires could be snagged on mooring lines, causing a loss of seabed position reference.

The positions of all anchors must be confirmed by the moored vessel and the position of the mooring lines established by two independent means, one of which may be by calculation. If the calculations place the mooring lines more than 250 m from the diver's bell or basket, a second means of identification is not needed.

If the vessel returns to the same location, there is no need to check the positions again, unless the moored vessel has moved or the moorings have been moved or adjusted.

The moored vessel must not move or adjust mooring tension or position without informing the DP vessel master. The DP vessel master should also be informed if draught changes affect the catenary of the mooring lines.

The DP operator must be able to monitor the moored vessel at all times, either with radar or by radio. If radar and radio contact is lost, the diving operations must be stopped immediately.

There must be a reporting procedure and a permit to work procedure to ensure that the moored vessel reports any mooring line adjustments, dumping of potentially harmful substances (such as drill mud), other vessels in the area or any other operation that could pose a threat to the divers.

In general there should be at least 50 m between the bell or basket and any mooring line. There may be an additional safety margin if wind or current could carry the vessel towards the mooring line. If it is considered necessary to work closer than 50 m to a mooring line the following must apply:

- the position of the mooring line must be plotted and remain traceable throughout the operation. This can be achieved by an ROV mounted transponder or other suitable means;
- the time spent closer than 50 m to the mooring line should be minimised;
- where twin bell systems are in use, emergency provision for the loss of one or both bells should be considered during planning.

Risk assessment should include the fact that movement at the touchdown of the anchor is inevitable and can cause poor seabed visibility, with the resultant risk of umbilical snagging or other hazard to the diver.

The thruster configuration diagram (see plan view of vessel) should show the position of mooring lines. There should also be a diagram on the vessel showing touchdown points and catenaries for various mooring line tensions.

8.29 Subsea Structures and Wellheads[3 4]

The lack of visual references on the surface makes diving from a DP vessel on to or close to a subsea structure potentially hazardous.

The location of subsea structures should be recorded and displayed (see section 8.22) and consideration should be given to providing a reference point to verify their positions, such as an ROV or marker buoys.

After risk assessment and planning, the location of the bell or basket should take into account the environmental conditions, the height of the structure, the diver's entry point (if applicable), the vessel footprint, available position reference systems and the diver's upward and downward excursion limits.

If the diver is entering an enclosed structure, he should be tended at the entry point by a second diver. This should be considered in the risk assessment and included in the dive plan.

In the risk assessment, consideration should also be given to other potential hazards. These might include leakage of hydrocarbons or other harmful substances from a wellhead. The location of the bell or basket, and the diver's approach could be arranged to ensure that the prevailing current carries the substances away safely.

1 IMCA D 035 *The selection of vessels of opportunity for diving operations*
2 IMCA D 015 *Mobile/portable surface supplied systems*
3 IMCA M 103 *Guidelines for the design and operation of dynamically positioned vessels*
4 IMCA D 010 *Diving operations from vessels operating in dynamically positioned mode*
5 AODC 032 *Remotely operated vehicle intervention during diving operations*
6 AODC 058 *Diver attachment to structures by means of a 'weak link'*

Gas Handling

9.1 High Pressure (HP) Gas Handling

Gas handling is a skilled procedure and poor gas handling has caused injuries and fatalities. Personnel may be injured directly by explosion or fire, by clamps or doors opening under pressure or by hose ends whipping under pressure. Divers may be killed if they are supplied with the wrong gas mixture. A blast of HP gas can cause blindness or deafness. Regular exposure to the noise of venting gas can seriously impair hearing.

Gas may be stored in single cylinders (typically 40 to 50 litres floodable volume), quads (typically 12, 16, 48, 54, 56, or 64 cylinders), or a single large cylinder like a kelly or 'Torpedo' (typically 1 to 2 m^3 floodable volume).

Only personnel nominated by the diving supervisor should handle gas and procedures should be in place and followed at all times. Responsibility for gas may be delegated to the life support supervisor, or dedicated 'gasman', but the diving supervisor should make regular checks of the system.

All personnel handling gas should take the following precautions:

- never operate any valve or carry out any operation on the gas system without checking with the diving supervisor or life support supervisor;
- on some installations, a hazardous operations work permit may be needed when transferring gas through flexible hoses;
- never connect a supply without analysing the gas at the quad or kelly before connection. On a worksite where mixed gas and air diving operations are taking place, the gas supply from HP air quads must be analysed before connection;
- never put a gas on-line without analysing it at the control panel;
- never put a gas on-line to the diver without an on-line oxygen analyser with an audio hi-lo alarm;
- always use the correct fittings;
- always check that hoses are correctly rated for the task, of the correct length and free from dirt and rust;
- check the condition of all hoses and fittings before use. Hose end fittings may show fatigue cracks and should be replaced;
- tie hose end connections to a strong point with rope or whip checks to prevent whipping in the event of a fitting failure;
- route all hoses safely;
- open all valves slowly at arm's length, looking away from the valve. When the valve is fully open, close it by half a turn. This leaves the valve handle free to move, indicating clearly that it is open;
- never over-tighten valves in the closed position. This will cause damage to the seats;
- when venting gas, wear ear defenders to prevent long term damage to hearing;
- never play games with HP gas.

9.2 Low Pressure (LP) Gas Handling

Although there is often a tendency to underestimate the risks associated with LP gas, it has the same capacity as HP gas to injure or kill. It should be treated with respect and handled according to the same procedures as HP gas.

Typically, accidents occur whilst removing clamps on LP filters. A clamp can fly open with sufficient force to kill if it is released under only a few bars of pressure. It is vital to ensure that any pressure vessel, including medical locks and chamber trunkings, is fully vented before any attempt is made to open it.

Medical locks should normally have baffles on the internal vent to prevent items being sucked in and blocking the exhaust line. Consideration should also be given to the possibility that exhaust or pressure gauge lines may be blocked by freezing during deep operations.

If there is any difficulty in opening the clamp, this may indicate that there is still pressure in the container, regardless of pressure gauge readings or interlocks. The situation should be assessed before proceeding.

Divers in a chamber face a risk of suction injury from exhaust valves. This hazard is normally avoided by fitting T-pieces or sections of drilled pipe to the valves.

9.3 Gas Storage[1 2 3 4 5]

Gas may be contained in a single free standing cylinder, quad, kelly, bail-out bottle, cylinders attached to a diving basket, bell or habitat or an air reservoir on a compressor.

All cylinders need to be correctly marked. Colour coding alone is not sufficient and a system of labelling must be used which indicates precisely what the content of each cylinder is. This should show the types and percentages of gases it contains, with the oxygen percentage given first. Regardless of colour coding and labelling all gases need to be analysed before connection.

Air and mixed gas quads should be stored in separate areas to minimise the risk of wrong connections.

The following colour coding system is widely used, and conforms to ISO and IMO standards. Other colour coding systems may be used and the diving supervisor must ensure that the system complies with a recognised and agreed standard[6].

Gas	**Symbol**	**Cylinder/quad**	**Cylinder/quad shoulder or top**
Helium	He	Brown	Brown
Diving oxygen	O_2	Black	White
Heliox	He/O_2	Brown	Brown/white quarters
Nitrogen	N_2	Grey	Black
Oxygen/helium/nitrogen mixtures	$O_2/He/N_2$	Brown	Black/white/brown in one-third sections
Argon	Ar	Dark blue	Dark blue
Air (breathing)	AIR	Grey	Black/white quarters
Carbon dioxide	CO_2	Black	Grey
Calibration gases	As appropriate	Pink	Pink

The European standard EN1089 specifies the same colours for the shoulders of gas cylinders, but notes that the cylinder body may be any colour that does not cause confusion in relation to the shoulder colours. If there are two colours, they may be painted in quarters or bands. A fuller discussion of this subject appears in IMCA D 043[1].

Single cylinders are normally used to supply zero or calibration gas for analysis equipment. They must be fixed securely, either in an upright or horizontal position. If a single cylinder falls over, the pillar valve could be broken off, releasing the HP gas and propelling the cylinder like a rocket. The force is reputedly sufficient to allow the cylinder to penetrate a steel bulkhead.

Quads and kellys may be stored below deck, perhaps built into a hold, or stored on deck. The gas storage area should be adequately protected by, for example, the provision of fire deluge systems and guards against dropped objects[6]. There should be no smoking in a gas hold. Oxygen must never be stored in a confined space.

Damage to valves and fittings on quads has occurred during lifting and transport. Exposed valves and fittings on quads should be protected from damage by fitting an appropriate lattice, which must allow access to the valves. See IMCA D 009[5].

All quads need to be secured to prevent movement in a heavy sea. Even a small movement may be sufficient to break hose connections. A large gas leak from quads stored in a confined space could lead to the space being flooded with gas with a low oxygen content, with a danger of hypoxia for anyone entering the hold.

As a precaution, an oxygen analyser with an audio and visual hi-lo alarm should be placed in the gas hold.

Each cylinder in the quad may not be colour coded but the quad frame should be painted in the relevant colour(s). If the cylinders are completely encapsulated, so that the shoulders are not visible, IMCA D 043[1] states that there should be a round 'flag' of at least 20 cm (8") in diameter painted according to the table above, on all cylinders on each face of the bank.

In large banks of cylinders, different cylinders may contain different gases and each should be colour coded accordingly with 'flags' as necessary.

9.4 Cylinders Used Underwater

Bail-out bottles, cylinders attached to a diving basket, bell or habitat and any other cylinders that are used underwater are more susceptible to water ingress and may suffer from internal corrosion.

Bail-out bottles may be placed in a tank of water whilst charging to prevent heating during compression.

There are three main areas of concern about water in bail-out bottles:

- the reduced capacity of the bottle (because of the presence of water) to contain sufficient gas to adequately supply the diver in case of emergency;
- the possibility that water, rather than gas, may be fed to the diver;
- the potential for serious or fatal injury to personnel if the bottle should explode during charging due to accelerated corrosion.

Water may enter bell on-board gas cylinders via the charging manifold (AODC 064[4]). The manifold incorporates an isolation valve or non-return valve which is closed before venting the charging whip. After the whip is disconnected, a plug or blank is fitted to the manifold to prevent dirt or water ingress. The space between the plug and the isolation valve contains air at atmospheric pressure. At depth, the ambient pressure may be sufficient to force water into this space. This water can then be carried into the cylinders next time the charging manifold is used. To minimise this risk, AODC 064 makes these recommendations:

- the design of the charging manifold should allow the minimum possible volume behind the blanking plug, have provision for venting before the plug is removed and ensure that the section between the plug and isolation valve points downwards so that it is self-draining;
- consideration should be given to using O-ring seal hand connectors to ensure watertight integrity;
- if there is no non-return valve in the manifold, it should be vented back before connecting the charging whip. If there is a non-return valve, the portion between the non-return valve and the plug should be self draining;
- after re-fitting the plug, the isolation valve should be opened to pressurise the space between the valve and the plug. The plug should be suitable for the maximum working pressure;
- if there is an unexpectedly low pressure reading before charging cylinders, consideration should be given to the possibility that water may have entered the cylinder.

Bail-out bottles and other cylinders used underwater should be examined on a regular basis. IMCA D 018[7] and AODC 037[3] recommend that bail-out bottles are checked every six months by removing the pillar valve and checking for moisture or rust or other corrosion particles. If there is any such evidence of corrosion the bottle should be returned to base for testing. A similar test should be carried out on bell on-board gas cylinders and other fitted cylinders, but only if there is any suggestion that water may have entered them.

9.5 Testing and Certification

All cylinders require testing and certification according to the regulations in force and according to IMCA D 018[7]. Certification is required every two years for cylinders that go underwater and every five years for cylinders that remain on the surface. Cylinders subject to a six monthly check still require testing and certification.

Reservoirs on air compressors are pressure vessels and also require testing and certification. They need to be fitted with a suitable relief valve.

All pipework and hoses should be safely routed and secured, marked and colour coded as appropriate. Special considerations for oxygen are shown below. Connections to dive control panels are covered in section 9.

9.6 Oxygen Handling[8 9]

Pure oxygen under pressure, or any gas mix containing over 25% oxygen, has the potential to generate a serious fire or explosion. Almost all materials will ignite easily and burn rapidly in high pressure oxygen. If oxygen flows rapidly into a pipe, for example, the heat of compression can raise the temperature sufficiently to ignite traces of dirt or grease, which in turn will ignite the metal. Combustion occurs with the speed of an explosion and there have been numerous accidents involving serious burns and fatalities.

Any gas mixture containing more than 25% oxygen by volume should be handled like pure oxygen[6].

Flexible hose should be kept to a minimum in oxygen systems and rigid pipework used as far as possible. Stainless steel pipe or fittings should not be used, in accordance with IMCA D 012[9].

Quarter turn valves should not be used. They can be opened quickly, allowing a rapid gas flow which can generate enough heat of compression to cause ignition. Needle valves should be used, which can only be opened slowly.

Quarter turn valves may be in-line as emergency shut off valves. They should be labelled as such and lightly taped open to prevent routine use.

Normal practice is that quarter turn valves should not be used if gas containing more than 25% oxygen is at a pressure higher than 15 bar. However, it is recognised that there are safety benefits in having quarter turn valves on the diver's gas control panel as this allows the diving supervisor to easily identify if a particular valve is open or closed and also to isolate a leak quickly.

When diving using nitrox the gas supply to the diver(s) may need to be up to 20 bar in order to provide sufficient pressure to the helmet at deeper depths. If quarter turn valves are to be used on the control panel then a risk assessment should be carried out to consider the desirability of having them set against the small increase in risk of fire and explosion at this pressure.

Sealants should be used sparingly and only oxygen compatible PTFE tape or paste or oxygen compatible liquid sealants should be used. A loose end of Teflon (PTFE) tape inside a pipe can ignite easily and will burn to produce the toxic gas phosgene. Common liquid thread sealants, like Loctite, are not safe for use in pressurised oxygen until they are fully cured. This may take several days in cold conditions.

All pipework, hoses, valves and other fittings used in the oxygen system must be oxygen clean, according to procedures laid down in the company manual. All cleaning should be logged and precautions should be taken to ensure that cleaning fluids are not left in the system (see section 9.7).

Equipment received directly from suppliers cannot be considered oxygen clean and should be cleaned according to the procedures.

To minimise the fire risk, oxygen pressure should be reduced at the quad to the lowest suitable pressure, normally with a maximum of 40 bar[9]. Higher pressures may, however, be used for operational reasons. Even at reduced pressures there is still a risk and all personnel should follow safe handling procedures.

Oxygen or any gas mix containing more than 25% of oxygen should never be stored in a confined space. There would be a fire risk arising from oxygen leakage into the space, and the consequences of an explosive fire in the confined space would be extremely serious. Cylinders should be stored on deck in a safe area.

Vented oxygen can accumulate in clothing and pose a serious fire hazard. Smoking or going near someone who is smoking or near any naked flame can cause the clothing to ignite.

In addition to the normal gas handling procedures, the following precautions should be taken when handling oxygen:

- ♦ no smoking or naked flames;

- ensure that all fittings, pipework and hoses are oxygen clean;
- open all valves slowly. Do not open and close a valve rapidly to clear particles of dirt before connecting a hose. This can cause ignition. If necessary, clean the valve with a suitable cleaning material;
- do not pump oxygen. If oxygen is used for gas mixing, decant it at the lowest possible pressure and do so slowly. Recreational diving agencies commonly recommend nitrox and oxygen fill rates of 5 to a maximum of 7 bar per minute (the slower the better).

9.7 Cleaning of Pipework and Fittings[8]

All fittings for oxygen service should be properly cleaned onshore before installation or delivery offshore. This cleaning should be carried out in a controlled area, an area where cleanliness control procedures create an environment free of oil, grease and dust.

Cleaning is typically carried out with naturally based biodegradable biological agents. Volatile chlorinated cleaning agents are now banned under the Montreal Protocol, because of the impact on the ozone layer.

Packing should not contaminate the cleaned component and it is important that all packing materials are free of contaminants. They should be inspected prior to use.

Cleaning for oxygen service on site should only be carried out if there is a suitable controlled environment.

All internal cleaning of pipework, hoses and fittings should be carried out according to procedures and properly logged. Logging should include the date, personnel involved, sections of system or items cleaned, cleaning fluids used and procedures and should be signed by a competent person.

In addition to logging, the system of fittings may also have a label carrying the date of cleaning and the signature of the person carrying out the cleaning.

Hoses should only be cleaned with liquids approved by the manufacturer. There is a risk that cleaning fluid can be left in the system and carried through to the diver. Gas flushing of the system is not adequate and only short sections of pipework, or small parts of the system, should be cleaned at a time. Aqueous based solutions will tend to flow to the lowest points of the gas system and drain points should be fitted.

9.8 Inert Gas Handling[10]

The accidental supply of pure inert gas to divers has resulted in several fatalities. Inhaling pure inert gas flushes oxygen from the diver's tissues, causing immediate collapse followed quickly by death. The chance of successful resuscitation is small.

This type of accident appears to result from a failure to follow procedures for gas connection and on-line analysis. Because of the serious consequences of such failures, DMAC 05[11] recommended that pure inert gas should be replaced on the worksite with a mixture containing 2% oxygen for depths from 50-150 msw (165-495 fsw), with lower percentage mixes at greater depths.

At 50 msw (165 fsw) a 2% mix gives a ppO_2 of 0.12 bar which would probably cause unconsciousness, but not death. At 150 msw (495 fsw) the ppO_2 would be 0.32 bar which would not even cause unconsciousness.

At depths less than 50 msw, where the inert gas could be helium or nitrogen, 2% is not sufficient and AODC 038[10] notes that a higher percentage of oxygen should be added to the inert gas. The minimum oxygen percentage in inert gas will normally be stated in the dive plan (and as stipulated in company manuals).

In general, pure inert gas should not be carried on worksites. Helium used within the scope of the *IMCA international code of practice for offshore diving* must contain a minimum of 2% percentage oxygen[6].

Pure inert gas may be needed in exceptional circumstances, perhaps for very deep saturation pressurisations. If this is the case, there must be strict procedures in place for all transport, analysis, connection, and use of the inert gas. Procedures might include the following:

- the diving contractor should have a policy which only allows the ordering of pure inert gases by a specified individual, usually the safety officer;
- the safety officer needs to be give written authorisation for the use of pure inert gas on the worksite;
- the provision of inert gas should be discussed with the diving superintendent and he needs to be aware of the potential risks;
- the inert gas needs to be signed for on delivery by the diving superintendent;
- the gas volume, content, colour coding and labelling must be checked and logged by the life support supervisor;
- the gas should be secured against improper use. This may be done by hard piping all the quads to the point of use, securing quads in a locked compartment, fitting a locking device to each valve or using the gas immediately. The method used should be logged and signed by the life support supervisor or diving superintendent;
- after connection to the point of use, safe connection should be verified, logged and signed by the diving superintendent;
- after use, the gas should be returned to a secure status, as above, returned to shore or vented. This should be verified, logged and signed by the diving superintendent.

9.9 Gas Analysis – Introduction

Gas analysis is fundamental to the safety of a diving operation. An air diving supervisor should make regular checks on air purity, normally using chemical sampling tubes. The presence of oil droplets in the air can be checked for easily by venting the air on to a sheet of clean white paper. Oil will leave traces on the paper.

All air chambers should have an oxygen analyser to check for raised oxygen levels during oxygen breathing[12]. If no carbon dioxide analyser is available, the chamber should be flushed on a regular basis as required. It is also usual to carry chemical sampling tubes in the chamber (see section 9.12).

During mixed gas diving, oxygen and carbon dioxide levels are routinely monitored. In specialised operations it may be necessary to check other gases. This may be done using chemical sampling tubes or more sophisticated equipment like spectrometers or chromatographs. The diving supervisor normally delegates most gas analysis to the life support team, although he will monitor the diver's breathing gas.

Most analysis equipment actually measures the partial pressure of the gas concerned, although the reading may be given as a partial pressure, percentage or part per million. Chemical sampling tubes, however, are calibrated specifically to give a percentage or ppm (parts per million) reading at surface pressure and a correction must be applied if they are used under pressure.

Every analyser should be calibrated on a regular basis, according to national regulations, manufacturers' instructions or company procedures. Calibration must be carried out according to the manufacturer's instructions, but the following general procedures apply:

- as far as possible, calibrate the instrument in the position in which it will be used. A change of angle or local electromagnetic fields may affect readings;
- with power off, set the mechanical zero, usually using a screw on the face of the dial. This does not apply to digital instruments;
- switch the instrument on and allow it to warm up if necessary;
- check in-line filters. Most instruments require a dry gas sample and should have a silica gel filter or similar in-line. Analysis for unusual gases may require additional filters;
- use a zero gas (pure helium or pure nitrogen) to carry out any setting up checks and set the zero. Use the correct flow rate for the sample gas;
- use a calibration or scale gas to set a scale reading. Air may be used as a scale gas on most oxygen analysers, and the scale should be set at 20.9%. If air is used, the sample must be taken from outside. The oxygen percentage in a closed control room can be as low as 18%.

9.10 Oxygen Analysis

Oxygen analysis may be carried out using a fuel cell analyser or a magneto-dynamic cell. Fuel cell analysers are produced by a number of manufacturers, magneto-dynamic analysers are produced by Servomex and are commonly known by this trade name. Fuel cell analysers are more widely used because they are robust, lightweight and suitable for remote readings.

A fuel cell is a battery which generates electricity in proportion to the ppO_2. The cell may be fitted inside or outside the analyser with the gas sample flowing over it, or placed in a chamber and connected to the analyser in the control room.

A fuel cell analyser is calibrated with a zero gas and scale gas, as described above. If the fuel cell is placed in a chamber, it can only be calibrated when the chamber is on the surface, or by reference to another analyser sampling the gas on the surface.

A fuel cell in the chamber can only be used as a guide to the ppO_2. Errors may be caused by condensation on the fuel cell, changes in chamber temperature, changes in the temperature of the wires carrying the signal to the analyser and radio transmissions and other electromagnetic fields.

Since the fuel cell is a battery, it will run out, normally in about six months. This is indicated by erratic readings. Cells are expensive and some companies require cells to be returned to base where they can be reconditioned.

Magneto-dynamic cells rely on the fact that oxygen is one of the few paramagnetic gases and the molecules are attracted by a magnetic field. The cell consists of a small quartz dumb-bell suspended in a strong non-uniform field. When the sample gas enters the cell, oxygen molecules are attracted to the strongest part of the field, changing the forces acting on the dumb-bell and causing it to rotate. The rotation is measured by the movement of a beam of light across a split photocell and converted to an electric current.

Although delicate, the cell is surprisingly robust. It will be distorted by high flow rates of the sample gas, which can move the dumb-bell excessively. The angle at which the analyser is placed affects the suspension of the dumb-bell and it must be calibrated in situ.

9.11 Carbon Dioxide Analysers

Carbon dioxide analysers rely on the fact that each gas absorbs specific wavelengths of radiation. Equal infra-red beams of the appropriate wavelength are shone onto two cells. One cell contains a reference gas, the other cell contains the sample gas.

The sample gas absorbs radiation in proportion to its carbon dioxide content and heats up. By comparing the temperature rise with the temperature of the reference cell, the proportion of carbon dioxide can be measured.

Calibration normally requires a zero gas and scale gas. Some analysers require a set up procedure which should be repeated at regular intervals according to the manufacturer's instructions or if it becomes impossible to calibrate the instrument. Because measurement depends on temperature, it is essential that the analyser warms up to a stable temperature before use. Readings are commonly given in parts per million.

9.12 Chemical Sampling Tubes

The most widely used chemical sampling tubes are probably those manufactured by Dräger and all tubes are commonly described as Dräger tubes. They are also known as colorimetric tubes. They are widely used for carbon dioxide analysis in the diving bell and to test LP air supplies for contaminants.

The glass tube contains a chemical which changes colour in proportion to the amount of the sample gas drawn through the tube. The tubes are usually calibrated in percentage or parts per million, for use on the surface, but actually measure the partial pressure of the gas. If a chamber or bell atmosphere is sampled using a tube on the surface, there is no need to make any correction to the reading.

If the tube is used under pressure, a correction needs to applied. For a true percentage or parts per million, divide the scale reading by the absolute pressure in bars. For a true partial pressure, regardless of depth, divide a percentage scale reading by 100 or a parts per million scale reading by 1,000,000 (see section 2.38).

Some companies use percentage surface equivalent (PSE) or surface equivalent percentage (SEP). This is simply the scale reading and companies provide a table of safe PSEs for each depth. To convert a surface reading from a bell or chamber to a PSE, simply multiply the surface reading by the absolute pressure.

To use a tube, follow the manufacturer's instructions. In general, the procedure is as follows:

- check that you have the correct tube for the gas to be analysed and that it is in-date;
- note the number of pumps needed. This is normally indicated on the tube as for example N = 5. There may be more than one scale on the tube for different numbers of pumps;
- check that you have the correct pump. The volume of gas drawn through the tube is critical;
- check the pump by fitting the unbroken tube into the pump and exhausting the bellows. The pump should not re-inflate. If it does, it is leaking and the reading will be inaccurate;
- break the ends off the glass tube and fit it into the pump with the arrow pointing towards the pump. Gas is drawn through the tube;
- exhaust the bellows and allow them to re-fill completely at their own speed. The chain on the pump must be tight before exhausting the bellows again;
- if the tube shows adequate colouration after one pump, take a reading from the one pump scale. If not, carry on for the maximum number of pumps shown;
- if there is no discolouration at all, some tubes can be sealed with the rubber caps provided and re-used up to two more times. Check the manufacturer's instructions.

9.13 Air and Gas Purity

Possible sources for the contamination of gas supplies include:

- impurities in pipework;
- improper location of compressor air intakes;
- oil leakage in compressors;
- degassing of paints or resins;
- overheating or burning of electrical insulation or other materials;
- electrical arcing;
- contaminants associated with the diving operation.

This section is concerned only with the purity of air from a compressor and gas from suppliers. It is not concerned with chamber or habitat atmospheres or gas recovery systems (see sections 9.14, 14, and 15).

Most contractors specify that the purity of air supplies should conform to a particular standard. If national legislation requires stricter standards, these need to be adhered to. The British and European standard BS EN 12021 specifies the following maximum levels of contaminants in compressed air for breathing apparatus:

Carbon monoxide	5 ppm
Carbon dioxide	500 ppm
Oil	0.5 mg/m^3
Water	25 mg/m^3 (at compressor outlet)
Water	50 mg/m^3 (at cylinder outlet, pressure 40-200 bar)
Water	35 mg/m^3 (at cylinder outlet, pressure over 200 bar)

The air shall be free from unsatisfactory odour or taste

BS EN 12021 also specifies that 'compressed gas for breathing shall not contain contaminants at a concentration which can cause toxic or harmful effects' and that 'all contaminants shall be kept to as low a level as possible'. Contaminants that are not specifically listed in the standard may also be present for various reasons; including leakage of ambient contaminants into the helmet or face mask.

As the compressed air will be breathed at all depths within the air range, it is vital that the toxic contaminant limits consider both a partial pressure effect and that in some cases the effects of these contaminants could be additive to, or even considerably greater than, the sum of their individual effects.

BS EN 12021 therefore specifies that for breathing air only the limit for all contaminants (including those not listed) 'shall be less than one sixth of a national 8 h exposure limit'.*

Under BS EN 12021, the dew point of the air shall be sufficiently low to prevent condensation and freezing. Where the apparatus is used and stored at a known temperature, the pressure dew point shall be at least 5°C below the likely lowest temperature. Where conditions of usage and storage of the compressed air supply is not known, the pressure dew point shall not exceed -11°C.

Air samples from compressors should be analysed on a regular basis according to company procedures. This is normally every three or six months, after any repair or modification to the compressor and after any incident or accident. There should be a separate certificate for each analysis.

Purchased gas should be provided with an analysis certificate and should be free of contaminants. Acceptable levels of impurities are normally based on national occupational exposure limits. Impurity levels in purchased gases are normally well below this level.

9.14 Gas Recovery Systems

Diver gas recovery systems filter the diver's exhaled gas to remove moisture, solid particles, carbon dioxide, trace gases and bacteria. Oxygen is added to the filtered gas to maintain the correct ppO_2 and it is pumped to a suitable pressure in a volume tank for re-use.

The bellman and/or the diving supervisor should be able to switch over instantly to a conventional gas supply if there is a failure in the recovery system. This should be in addition to the normal back-up provided by the bell on-board supply and the diver's bail-out bottle.

Potential hazards of a diver gas recovery system are:

- failure of the exhaust line which could cause a pressure drop in the diver's helmet and a squeeze. Exhaust valves and back-up systems are generally reliable;
- excessive levels of contaminants in the recovered gas. This is only likely to occur in a poorly maintained system. The diver's gas supply needs to be monitored by a carbon dioxide analyser with an audible and visual alarm to indicate excessive levels of the gas;
- unsafe ppO_2. The diver's gas supply needs to be monitored by an oxygen analyser with an audible and visual hi-lo alarm.

In a chamber gas recovery system, all gas from the chambers and medical locks is exhausted into large gas bags. When the bags are full, the gas is automatically pumped through a filtration system and returned to HP quads for re-use.

There is a risk of bacterial contamination in the gas bag and the planned maintenance system should include regular sampling.

During decompression, gas is normally exhausted to atmosphere at depths less than about 20 msw (66 fsw). The oxygen percentage is too high for re-use and exhausting gas into the bags may be very slow.

Since the chamber contained air before pressurisation, the recovered gas contains nitrogen and should not be reused in the chamber. If it is used for chamber pressurisation, there will be increased nitrogen levels in the chamber. The nitrogen level will stabilise over successive pressurisation-recovery cycles, but recovered gas containing nitrogen should only be used according to company procedures.

* Note that BS EN 12021 contains a National Foreword for the UK. This allows the UK to take a more conservative approach than other countries. The National Foreword specifies that in the UK all toxic components in air (except carbon monoxide which is defined as 5 ppm in the main standard) should be less than one tenth of the national 8 h exposure limit, not less than one sixth as per the main standard.

Some chamber recovery systems incorporate molecular filters which remove nitrogen.

Gas samples from all recovery system compressors should be analysed on a regular basis according to company procedures. IMCA D 024[13] recommends that testing is carried out every six months, after any repair or modification to the compressor and after any incident or accident. There should be a separate certificate for each analysis.

9.15 Managing Gas Supplies

Gas supplies are normally managed by a dedicated gasman or a life support technician. They are normally under the overall responsibility of the life support supervisor. Control of a diver gas recovery system may remain with the diving supervisor.

The content, pressure, volume and location of every quad should be shown on the gas board, which is updated at least once per shift. There should also be a gas log, recording all deliveries, despatches, gas transfer or gas mixing. Gas volumes are included in the daily report to base.

When gas arrives on-board, the gas must be analysed and the pressure and volume noted in the log. The content must be clearly marked on the quad. When a quad is empty, it needs to be clearly marked as empty.

Gas supplies should not be connected or disconnected without the authority of the life support supervisor or diving supervisor. Gas should not be connected without analysing the gas at the quad or kelly. It should not be put on-line without analysing the gas at the control panel.

There should always be sufficient gas in reserve, at a suitable pressure, to meet the requirements of IMCA D 050[14]. See sections 11.3 and 14.32.

1 IMCA D 043 *Marking and colour coding of gas cylinders, quads and banks for diving applications*
2 AODC 010 *Gas cylinders used in conjunction with diving operations in areas governed by UK regulations*
3 AODC 037 *Periodic examination of bail-out bottles*
4 AODC 064 *Ingress of water into underwater cylinders charged by means of a manifold system*
5 IMCA D 009 *Protective guarding of gas cylinder transport containers (quads)*
6 IMCA D 014 *IMCA international code of practice for offshore diving*
7 IMCA D 018 *Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment*
8 IMCA D 031 *Cleaning for oxygen service: Setting up facilities and procedures*
9 IMCA D 012 *Stainless steel in oxygen systems*
10 AODC 038 *Guidance note on the use of inert gases*
11 DMAC 05 *Recommendation on minimum level of O_2 in helium supplied offshore*
12 IMCA D 023 *DESIGN – Diving equipment systems inspection guidance note for surface orientated (air) systems*
13 IMCA D 024 *DESIGN for saturation (bell) diving systems*
14 IMCA D 050 *Minimum quantities of gas required offshore*

General Diving Procedures

10.1 Introduction[1 2 3]

National legislation normally has specific requirements and depth limitations for different types of diving and these take precedence over the *IMCA international code of practice for offshore diving* where their requirements are more stringent.

All diving operations require a dive plan which should include a risk assessment of the diving techniques to be employed and the site-specific hazards. See section 12.3 for risk assessment and section 8 for specific information on diving from DP vessels.

All plant and equipment should be checked annually[4] according to the appropriate IMCA DESIGN audit, as follows:

- IMCA D 023[5] – *DESIGN – Diving equipment systems inspection guidance note for surface orientated (air) systems*;
- IMCA D 024[6] – *DESIGN for saturation diving (bell) systems*;
- IMCA D 037[7] – *DESIGN for surface supplied mixed gas diving systems*;
- IMCA D 040[8] – *DESIGN for mobile/portable surface supplied diving systems*;

There should always be enough personnel to allow the diving operation to be conducted safely and effectively (see section 7).

Team members may carry out more than one duty, provided that they are competent to do so and that their different duties do not interfere with each other. Duties and responsibilities need to be clearly defined in the dive plan to avoid confusion.

Trainees often form part of the team, but under normal conditions will not be allowed to take over the functions of the person training them. A trainee diving supervisor, for example, can only work under the direct control of the diving supervisor.

The divers and standby diver all need to be medically fit to dive and clear of any decompression penalties. They may be unfit to dive for a variety of reasons, including colds or flu, ear infections and stomach upsets.

The appointed diving supervisor is in control of the operation at all times and needs to be in direct two-way voice contact with the diver. The bell diving supervisor should have control of the bell blow-down (which can also be used to vent the bell) at all times (see information note IMCA D 02/10 – *The control of bell blow-down facility during saturation diving*) for the following reasons:

- The bell diving supervisor is ultimately responsible for the safety of the divers during the course of the bell run;
- If the bell occupants should become incapacitated, the bell diving supervisor would be powerless to intervene if he was without control of the blow-down/vent of the bell;
- This is particularly important should the bell atmosphere become contaminated. Without control the bell diving supervisor would be unable to flush the bell;
- In the event of rapid bell internal pressure loss, the combination of loss of internal vision through vaporisation and increased noise in the bell would exacerbate the emergency. Without surface control, the bell diving supervisor would be powerless to intervene.

The appointed diving supervisor should be able to monitor the diver's breathing pattern at all times. He should not hand over communication to any other person except another properly appointed and qualified diving supervisor.

All voice communications with the diver need to be recorded and the recording should be kept until it is clear that there have been no problems during or following the dive. It is recommended that recordings are kept for at least 24 hours[9].

As far as possible, the standby diver or bellman should listen in to the communications with the diver. The more he knows, the more effectively he can respond in an emergency.

The diver's breathing equipment needs to supply him with a suitable gas, at a suitable rate of flow, at a suitable temperature in all foreseeable conditions, including emergencies.

There should be means to maintain the diver in safe thermal balance. On some worksites he may need a hot water suit or other type of heated suit. In warmer water, wet suits or cotton overalls may be adequate. For most heliox diving, heated suits are essential, though in warm waters when using surface gas, wet suits may be adequate. The gas supply should be heated below 150 msw (495 fsw)[9].

If dry suits are used, suit inflation should be from the main gas supply, or from a separate bottle, and never from the bail-out bottle.

If the diver is not using a helmet and working in the splash zone, or in any other area where he may be subject to significant water movement close to a structure, consideration should be given to head protection.

Before any dive, in addition to items on checklists, the diving supervisor should check the following points:

- Is the permit to work (or other documentation) in order?
- Have all relevant people been informed that the dive is to take place?
- Have all those taking part in the operation been fully briefed on the task, potential hazards and emergency procedures?
- Has all machinery (including underwater fittings on vessels e.g. sea chests, rotating shafts, thrusters, propellers etc.), valves or other items of equipment whose operation could endanger the diver been properly and securely isolated so that start-up or unsafe movement cannot occur during the course of the dive? See information note IMCA D 13/09 – *Diving from, on or in close proximity to merchant vessels – protocol for isolating machinery systems*;
- Are the minimum amounts of gas and air, at suitable pressures, and minimum amounts of other consumables available?
- Are the weather conditions suitable and likely to remain so for the duration of the dive?
- If relevant, are the correct flags, shapes or lights being displayed from the ship?

After decompression, the divers will normally be required to stay close to the chamber for a period specified in the dive plan, in case they suffer from decompression illness. Restrictions on flying after diving will be stated in the dive plan.

DMAC 07[3] gives the following restrictions for flying after diving without decompression illness:

	Time before flying at a cabin altitude of	
	600 m (2000 ft)	**All other flights**
No-stop air dives, with less than 60 minutes under pressure in the previous 12 hours	2 hours	8 hours* (24 hours)
All other air, nitrox, heliox and mixed gas diving (less than 4 hours under pressure)	12 hours	24 hours
Heliox saturation (more than 4 hours under pressure)	12 hours	24 hours
Air or nitrox or trimix saturation (more than 4 hours under pressure)	24 hours	48 hours

* *8 hours applies to short flights. For longer flights, as for example intercontinental flights, the time is extended to 24 hours*

Following treatment for DCI, advice should be sought from a diving medical specialist. The times given below are minimum times:

	Time before flying at a cabin altitude of	
	600 m (2000 ft)	**All other flights**
Immediate and complete resolution of symptoms on first recompression	24 hours	48 hours
Cases without immediate response or with residual symptoms must be decided on an individual basis by a diving medical specialist. Generally wait as long as possible	Consult a diving medical specialist	

Consideration should be given for 100% oxygen during flight. Following landing, the diver should be assessed by a competent diving doctor.

Emergency procedures should be included in the dive plan and the emergency procedures given in this chapter are intended for guidance only.

10.2 Launch and Recovery Systems[10]

Baskets, wet bells and closed bells are all man-riding systems and all elements of the handling system must meet the testing and certification requirements for man-riding equipment.

All lift wires, whether intended for routine or back-up lifting, should be non-rotating, have an effective safety factor of 8:1 and be as compact as possible to minimise the space requirements for their operating winches. Certification requirements are given in IMCA D 018[11].

Winches, whether hydraulically or pneumatically operated, need suitable braking systems. They are not to be fitted with a pawl and ratchet gear in which the pawl has to be disengaged before lowering[9]. Winches when used to launch and recover the diver should be rated as man riding and have suitable documentation stating 'fit for purpose as man riding service' by the manufacturer or competent person.

Lift wires suffer from frequent immersion in salt water, shock loading from waves and frequently pass over multiple sheaves. They can suffer from rapid deterioration if they are not properly maintained and special maintenance procedures should be followed[9 12].

Hydraulic motors should be kept running to maintain the system at operating pressure, even when the winch is stopped during lifting and lowering operations. A mechanical brake should be applied automatically during any such stop.

Baskets, wet bells and closed bells should be designed and equipped to prevent spinning or tipping.

The bell umbilical may have its own winch or simply run over sheaves for storage in a basket. Sheaves should be designed with a diameter and groove profile that will support the umbilical adequately and not allow any part of the umbilical to become trapped or damaged. The umbilical length should be monitored to prevent bights forming.

If members of the diving team are involved in bell or umbilical handling close to the side of the installation, they should wear helmets, work vests or safety lines and follow the installation's procedures for over-the-side working. For umbilicals that are recovered into a basket, the diving team/tenders should not be permitted to enter the basket at any time.

If there is a failure of the main winch or cable additional means of recovery are required. Every system should have a back-up power supply for the main winch and a secondary winch system.

Guide wires should be capable of lifting the bell. See section 13.5.

A cross-haul winch and its rigging may be capable of recovering the bell. However, to move the bell back to its mating position may be a complex task and contingencies will need to be carefully prepared[13].

The umbilical may be strong enough, or may incorporate a strength member, to allow it to be used to recover the bell at least to the air diving range. If the umbilical is used for secondary recovery there is always a risk of damage to the umbilical and this method should only be used if other methods cannot.

For additional information on closed bell handling see section 13.5.

10.3 Divers' Umbilicals[14]

10.3.1 Length of Divers' Umbilicals – Surface Oriented Diving

In general, the excursion length of the umbilical should be as short as possible.

Factors which should be considered when deciding on the length of surface oriented divers' umbilicals are:

- The distance of the job from the proposed entry point or diver deployment device (basket or wet bell);
- The duration of the diver's bail-out bottle at the depth. In the event of loss of gas supply, the diver must be able to return to a place of safety (e.g. a wet bell) or to the surface using his bail-out bottle alone, and this may dictate the maximum length of his umbilical;
- The size of any wet bell in relation to the storage of the diver's and bellman's umbilicals;
- The type of umbilical, its bulk and buoyancy. A long length of negatively buoyant umbilical will act to drag a diver down, while a bulky umbilical in current may have a similar effect;
- The condition of the worksite, including debris, rocks or other obstructions which could hinder the diver's return to a place of safety or to the surface;
- The unforeseen safety factor needed for particular situations such as DP incidents, loss of diver heating or trapped umbilicals.

Each operation should be considered on its merits and the length of diver's umbilical determined on the above and other factors relevant to the particular circumstances.

If the dive is likely to bring the diver within range of any hazard, such as thrusters or water intakes, the umbilical should be tied off, or otherwise physically restrained, to stop the diver coming within 5 m (16 ft) of the hazard. Length restrictions should be detailed in the dive log.

The standby diver's umbilical should be 2 m (7 ft) longer than the diver's umbilical to allow him to reach the diver in an emergency. IMCA D 010[14] gives further recommendations about umbilical handling when diving from DP vessels.

10.3.2 Length of Divers' Umbilicals – Closed Bell Diving

The question of what is the acceptable and safe length of umbilical which a diver can use from a closed diving bell has been considered on MANY occasions and different answers have been produced. The true answer is that the safe length will be influenced by a number of factors and that no specific all-embracing answer can be given.

A figure of 100 ft (30 m) was established by custom and practice and this became the norm for many closed (and indeed wet) bell diving operations. While this is a reasonably practical figure it should not be construed that 25 m is always safe, or that 35 m is unsafe, as the selection of 30 m was entirely arbitrary, based on the average from a number of operations. As with surface oriented diving, the excursion length of a closed bell umbilical should be as short as possible.

Factors which should be considered when deciding on the length of a closed diving bell umbilical are:

- The distance of the job from the proposed closed bell location;
- The duration of the diver's bail out bottle at the depth. In the event of loss of gas supply, the diver must be able to return to the closed bell using his bail out bottle alone and this may dictate the distance he can be away from the bell. The diameter of the bell manway must be considered when sizing the bail out bottle, as this will dictate the diver's ease of entry into the bell;
- The size of the closed bell in relation to the storage of the diver's and bellman's umbilicals;
- The type of umbilical, its bulk and buoyancy. A long length of negatively buoyant umbilical will act to drag a diver down, while a bulky umbilical in current may have a similar effect;
- The condition of the worksite, including debris, rocks or other obstructions which could hinder the diver's return to the closed bell in an emergency;

- The unforeseen safety factor needed for particular situations such as DP incidents, loss of diver heating or trapped umbilicals.

Each operation should be considered on its merits and the length of diver's umbilical determined on the above and other factors relevant to the particular circumstances.

If the dive is likely to bring the diver within range of any hazard, such as thrusters or water intakes, the umbilical should be tied off, or otherwise physically restrained, to stop the diver coming within 5 m (16 ft) of the hazard. Length restrictions should be detailed in the dive log.

In an emergency the bellman may need to pay out more umbilical than the pre-determined maximum length and for this purpose, 'spare' umbilical inside the bell, but lightly tied off to prevent routine use, is desirable.

In all operations the bellman's umbilical should be at least 2 m (7 ft) longer than the diver's umbilical to allow him to reach the diver in an emergency. IMCA D 010[14] gives further recommendations about umbilical handling when diving from DP vessels.

10.3.3 Marking of Divers' Umbilicals

Umbilicals should be marked at least every 10 m and are often marked every 5 m. Many companies use a colour coded system of marking. The system below, for example, uses a turn of red tape for every 5 m and a turn of black tape for every 10 m. If the different coloured tapes are also of different widths, it is possible to check umbilical length by touch in poor visibility.

Length (metres)	Black tape	Red tape
5		1 turn
10	1 turn	
15	1 turn	1 turn
20	2 turns	
25	2 turns	1 turn
30	3 turns	
35	3 turns	1 turn
40	4 turns	
45	4 turns	1 turn
50	1 broad turn	

10.3.4 Properties of Divers' Umbilicals

The umbilical may be positively, neutrally or negatively buoyant and any implications of the umbilical buoyancy should be included in the risk assessment. The umbilical also acts as a lifeline and should be strong enough to lift a fully equipped diver from the water.

10.3.5 Examination, Testing, Certification and Maintenance of Divers' Umbilicals

Divers' umbilicals are used in harsh offshore conditions and are frequently immersed in seawater for extended periods of time. They are often dragged across submarine structures covered in sharp and abrasive marine fouling. When handling divers' lines all dive team members, including the divers and tenders, should make every effort to protect the umbilicals from harm. The aim should be to minimise degradation or damage both in the water and on deck. Surface crew should be strongly discouraged from standing on coiled umbilicals (an all too familiar sight).

All diving plant and equipment, including diver umbilicals, require regular inspection, maintenance and testing to ensure every item is fit for purpose and safe to use, e.g. that it is not damaged or suffering from deterioration. Regular maintenance is an important factor in ensuring the safe operation of diving equipment. The diving contractor will need to have an effective system for planned maintenance and should have on site an adequate supply of spares for all plant and equipment.

IMCA D 018 contains comprehensive guidance on the frequency and extent of examination, testing and certification required for all items of diving plant and equipment used in a diving project, together with the levels of competence required of those carrying out the work. Specific guidance on the examination, testing and certification of divers' umbilicals is set out in IMCA D 018 detail sheets 11 *Electrical Equipment* and 28 *Umbilicals – Hose Components only; including end terminations and fittings but excluding electrical components*.

See also section 6.8.

10.4 Heating Systems

Almost all body heating for divers is provided by hot water suits. Electrical heating systems were used in the past, but were not in general very successful.

The amount of heat reaching the diver depends on the hot water flow rate and temperature at which the hot water reaches the diver. A lower temperature and a higher flow rate can transport as much heat as a higher temperature and a lower flow rate. A higher temperature will transfer this heat more effectively to the diver, but increases the risk of scalding.

Water temperature is measured at the machine on deck, but there is a considerable temperature drop in the umbilical. This temperature drop depends on the temperature at the machine, umbilical length, flow rate and sea temperature. It can usually be found from charts or tables in the hot water machine operating manuals.

If the water reaches the diver at temperatures in excess of about 45°C (113°F) there is a risk of scalding, blistering and hyperthermia. Scalding typically occurs at wrists and ankles. If the temperature or flow rate is too low there is a risk of hypothermia.

Whilst the supply to the diver is of vital importance the supply to the bellman should also be considered. If the diver gets too much heat the bellman may get too little.

The diver's respiratory heat loss increases with depth, as the density of the breathing gas increases. There needs to be gas heating for divers deeper than 150 msw (495 fsw)[9]. At 200 msw (660 fsw), for example, gas should be supplied at a temperature of about 24°C (75°F).

Gas is normally heated in a heat exchanger supplied by hot water. Although the gas may be heated effectively at the heat exchanger it will lose heat in the hose and pipework leading to the demand valve. There will be a further heat loss when the gas expands after passing through the demand valve. The total temperature drop may be as much as 15°C (27°F).

For efficient operation the gas heater should be as close to the demand valve as possible and all pipework on the helmet should be insulated.

The diver himself is not a reliable judge of temperature. After some time in the water he may start to suffer from what has been described as 'thermal confusion'. In other words he may not be able to assess his heating requirements adequately. He may ask for more heat to deal with a cold spot in his suit and scald himself elsewhere or he may not realise that his body temperature is dropping and become hypothermic. Respiratory heat loss is particularly hard to detect because the body only has temperature sensors in the skin, not in the lungs.

Both hyperthermia and hypothermia are gradual in onset and will not be noticed by the diver. Symptoms that might be noticed by the diving supervisor are signs of fatigue or confusion, or changes in breathing pattern.

The diving supervisor needs to have a display showing the temperature of water being supplied to the diver and visual and audible alarms which operate in the dive control room if the outlet temperature moves outside pre-set limits [5 6 7 8].

If the diver asks for more heat it is generally better to increase the flow rather than raise the temperature, to avoid scalding.

10.5 Gas Supplies[15 16]

The diver's gas supply should be so arranged that if his umbilical is cut, it will not deprive any other diver, including the standby diver, of his gas supply. It should be fitted with an in-line oxygen analyser with an audible hi-lo alarm in dive control. The alarm should be provided for air as well as for mixed gas dives[9].

Every diver needs to carry a bail-out bottle which contains enough gas to allow him to reach a place of safety if his main supply fails. If mixed gas or nitrox is on site, the oxygen content of all bail-out bottles and cylinders carried in a basket, wet bell or portable system needs to be checked before each dive.

In surface supplied diving, a standard bail-out bottle will normally provide sufficient gas for the diver to reach safety. In bell diving, the diver may require two cylinders or a rebreather bail-out system. In either case, the minimum gas supply in the bail-out is commonly based on one minute's duration for every 10 m (33 ft) of umbilical deployed.

The breathing rate in an emergency is normally taken as about 40 litres (1.5 ft^3) per minute to allow for the effects of cold shock and apprehension. Some companies use, and some national legislation uses, an even higher emergency breathing rate. The calculation should also take into account the available pressure of gas in the bail-out bottle after deductions for depth and working pressure of the regulator (see section 2.16).

DMAC 04[15] suggests that mixed gas bail-out bottles should contain a mix giving a high ppO_2 of up to 2.8 bar at the working depth. This is considerably higher than the normal safe maximum but will not be breathed by the diver for long enough to cause poisoning. This has the advantage of increasing the reserves of oxygen in the diver's bloodstream and tissues and extending his survival time if he becomes unconscious. The recommendation is that for most dives, serious consideration should be given to standardising the bail-out mix to 20% oxygen. The maximum ppO_2 of 2.8 bar would not be reached until 130 msw.

During closed bell diving operations there should be an emergency supply of breathing gas carried on board sufficient to support each working diver plus the bellman outside the bell for a minimum of 30 minutes at a breathing rate of 40 litres/minute at the maximum depth of the diving operation.

10.6 Water Intakes and Discharges[17]

If there is any risk of suction injury to the diver, the dive plan needs to consider:

- the maximum safe length of the diver's umbilical (see section 10.3);
- any other means of physically protecting the diver, such as guards over intake points;
- the identification and isolation of all equipment that could endanger the diver if it were operated;
- a detailed briefing of the diver, identifying hazards and any specific emergency or contingency plans;
- procedures to inform everyone who may operate the equipment that there is a diver in the water and to make them aware of the risk;
- the inclusion of these measures in the permit to work system;
- contingency plans to deal with any emergency that may arise if a valve were inadvertently opened.

10.7 Underwater Obstructions

Underwater obstructions include subsea structures, down lines, taut wires, ROV umbilicals, anchor cables, etc. Provision for dealing with these obstructions should be in the dive plan, and they should be mapped in dive control (see section 8.21).

The principal risk to the diver comes from a snagged umbilical. If there is strong current, or in shallow water with a heavy swell, the diver may be carried into the obstruction and injured.

10.8 Restricted Spaces

A diver who is working in any restricted space, such as a pipeline, a vertical pipe or pile or a complex structure may face difficulties if he has to return to surface or the bell in an emergency.

If he is engaged in cutting or welding operations, there may be an additional risk of explosive gases accumulating in the space.

The dive plan should include specific procedures to deal with these operations. These will commonly include a second diver, outside the structure, to tend the umbilical and to act as an additional standby.

1	AODC 038	*Guidance note on the use of inert gases*
2	AODC 048	*Offshore diving team manning levels*
3	DMAC 07	*Recommendations for flying after diving*
4	IMCA D 011	*Annual auditing of diving systems*
5	IMCA D 023	*DESIGN – Diving equipment systems inspection guidance note for surface orientated (air) systems*
6	IMCA D 024	*DESIGN for saturation (bell) diving systems*
7	IMCA D 037	*DESIGN for surface supplied mixed gas diving systems*
8	IMCA D 040	*DESIGN for mobile/portable surface supplied diving systems*
9	IMCA D 014	*IMCA international code of practice for offshore diving*
10	AODC 019	*Emergency procedures – provisions to be included for diving bell recovery*
11	IMCA D 018	*Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment*
12	IMCA M 194	*Guidance on wire rope integrity management for vessels in the offshore industry*
13	IMCA D 032	*Cross-hauling of bells*
14	IMCA D 010	*Diving operations from vessels operating in dynamically positioned mode*
15	DMAC 04	*Recommendations on partial pressure of O_2 in bail-out bottles*
16	IMCA D 028	*Guidance on the use of chain lever hoists in the offshore subsea environment*
17	AODC 055	*Protection of water intake points for diver safety*

Surface Supplied Air Diving

11.1 Introduction

This section covers all air and nitrox diving operations that do not use a closed bell, including surface supply, mobile/portable systems and wet bell systems. Where necessary the word 'nitrox' may be substituted for the word 'air' when reading this section. Surface supplied mixed gas diving is covered in section 12.

IMCA D 033[1] reiterates the IMCA (and earlier AODC) guidance that SCUBA is an inappropriate technique for use in offshore diving operations. The principal reasons are lack of an adequate gas supply, poor surface communication, the risk of losing the demand valve and the need for the diver to carry out his own in-water decompression.

11.2 Diving Team

The minimum team size for surface supplied air diving is five: diving supervisor, working diver, standby diver, tender for the working diver, tender for the standby diver. In practice, most diving teams will be much larger.

For umbilicals tended from the surface, there must be one tender for each diver. For umbilicals tended from a basket or wet bell, one tender is required for every two divers in the water.

There must be a standby diver in immediate readiness to dive whenever there is a diver in the water. He need not be wearing his mask or helmet, but it must be to hand. There must be at least one standby diver for every two divers in the water.

11.3 Air and Gas Supplies

Air or nitrox should not be used below 50 msw (165 fsw)[2]. At this depth, the ppO_2 in air is about 1.25 bar. Higher levels of ppO_2 can be tolerated in the water, but there are complex inter-relationships between the effects of oxygen, nitrogen and carbon dioxide on the diver. For this reason, a maximum ppO_2 in nitrox diving of 1.4 bar is recommended. Company or legal limits may be lower.

This limit should only be applied after taking into account possible errors in analysis equipment and depth measurement. For example, the maximum ppO_2 might be calculated for a depth 5 msw (16 fsw) below the planned dive depth to allow for any errors or unexpected depth changes.

The recommended minimum quantities of air required are given in IMCA D 050[3]:

- Sufficient compressed air must always be available for two emergency dives to the full intended diving depth as a reserve. This air must either be stored in containers or else be supplied by two totally independent sources;
- Sufficient compressed air must be available to pressurise both locks of the deck decompression chamber to the maximum possible treatment depth plus sufficient air for three complete surface decompression cycles. This air must be stored in containers or else be supplied by two totally independent dedicated sources;
- 90 m^3 (3,200 ft^3) of breathing oxygen must be available for emergency treatment procedures.

Two totally independent sources could be two separate compressors operating from different power supplies (rig electric supply and diesel for example) or one compressor and an HP air quad. Rig air is not suitable. It is not a dedicated supply and may not be available in the quantity or to the quality required.

If an air compressor is used, the checklist should include a check on the location of the air intake. Machinery that may have been placed near it or the wind direction or ship's heading may have changed.

11.4 Surface Supplied Air Diving

Surface supplied diving air systems should conform to the requirements of IMCA D 023[4].

Divers must be able to enter and leave the water safely and there must also be a safe means of access and egress for the standby diver. Jumping into the water is hazardous and divers should always be lowered into the water in a basket or enter by a fixed ladder. If a basket is used, there must be a second basket for the standby diver. If a ladder is used, it should extend at least 2 m below the surface and the diver should have to climb no more than 2 m above the water surface[2].

Arrangements must be in place to recover an injured or unconscious diver to the deck. In most cases this would not be practicable with only a ladder.

When a basket is used, emergency breathing gas cylinders should be provided in the basket in a standard layout, to allow the divers to access the cylinders rapidly in an emergency[2]. AODC 039[5] recommends that the cylinders should be fitted with a first stage regulator and then a double connection. One side should go to a normal demand valve, the other to an obvious and easily accessible valve connected to a length of hose rigid enough to be pushed up inside the neck seal of a helmet. There should also be a contents gauge and preferably a half mask for use with the demand valve.

The diver should keep the diving supervisor informed about his position and the progress of the task. He must report any depth changes. Although the diving supervisor is able to monitor the diver's depth with his pneumo, he cannot look at the depth gauge constantly. If he is not informed, he may miss short excursions which would affect the decompression.

The umbilical tender should be able to feel the movements of the diver and adjust the amount of slack accordingly. He must not let slack accumulate, or it may snag. He must be governed at all times by the maximum safe length of umbilical established in the dive plan and the umbilical should be tied off accordingly.

11.5 Mobile/Portable Surface Supplied Systems[6]

Mobile/portable surface supplied systems (SRU – SCUBA replacement unit) are systems that may be moved to different locations on an installation or mounted on a small boat operating from a support vessel. Mobile/portable systems should conform to the requirements of IMCA D 040[7].

The system would generally be used for air or nitrox diving at depths less than 30 msw (100 fsw) with no decompression required. It could be used up to a maximum depth of 50 msw (165 fsw), but only in exceptional circumstances and after a careful risk assessment.

IMCA D 015[6] recommends that the system should consist of at least two horizontally mounted cylinders, each with a minimum floodable volume of 46 litres (1.6 ft^3) and a working pressure of not less than 150 bar (2175 psi). The cylinders must be manifolded through the dive control panel so that the diver and standby diver each have a dedicated supply. A third cylinder should be provided which can be switched on to either supply.

A standard design of dive control panel should be used, with separate circuits (including pneumo) for each diver. There should be two full sets of diving equipment, including appropriate harnesses to aid diver recovery.

Risk assessment should include the following:

- the weather forecast for the period of remote operation. Consideration should be given to the launch and recovery of the small craft by the support vessel;
- the maximum time for recovery of a diver to the decompression chamber;
- the minimum diving team size;
- life saving apparatus and personal protective equipment. This might include immersion suits, work vests, etc.;
- the availability of a second small craft, to assist the first if necessary;
- other vessels such as infield crew boats, supply boats, etc. operating in area;
- surface visibility restrictions due to fog/heavy rain/darkness;
- contingency and emergency plans including suitable means for recovery of a casualty from the deployment craft/point, to the recompression chamber.

The system should not be used if there is any risk of the diver or his umbilical becoming fouled, or where immediate recovery of the diver cannot be achieved.

If the system is operated from a small boat, the boat should always be in line of sight of the support vessel. There should be a lookout on the support vessel and reliable and continuous communication between the diving supervisor and the lookout.

The boat should carry all normal marine emergency equipment for a boat of its size and safety equipment for all personnel on board. This will include work vests, survival suits, life saving apparatus, etc. It must be able to display the international signals indicating that diving is underway.

Any equipment identified as necessary for the safe completion of the dive must be able to continue operating in the event of loss of the vessel's primary power. This may be by the use of batteries, connection to an emergency generator, the use of stored energy (compressed air), etc.

The boat should have a propulsion system that will allow fast and efficient return of the diver to the support vessel and, as a general guide, should be no more than 15 minutes away. There must be a reliable means of transferring an incapacitated diver to the decompression chamber. A second recovery craft should be identified and available at the support vessel to assist the small craft in the event of a problem with the small craft.

Any propellers should be fitted with suitable guards to prevent injury to the diver.

11.6 Wet Bell

Wet bell systems should conform to the requirements of IMCA D 023[4].

Note that a dive basket fitted with a dome is not a wet bell. A wet bell requires a dome and main supply umbilical from the surface providing (as a minimum) air to a manifold inside the wet bell and diver excursion umbilicals terminated at the wet bell.

The wet bell provides a safe means of entry to the water, a working base under the water and a safe means of exit from the water. It must be located on deck in such a way that the divers can enter and exit easily and also to allow an unconscious diver to be removed safely.

It should be able to carry at least two divers without cramping and must have chains or a gate at the entry point to prevent the divers falling out. There must be internal handholds for the divers and suitable means for supporting an unconscious diver with his head in the air space.

The system should be designed to prevent spinning or tilting[2] and be suitably protected against impact. The wet bell should remain negatively buoyant when the dome is fully filled with air.

There should be two (or more) correctly colour coded air cylinders fitted to the wet bell and securely mounted. Sufficient sources of air, of breathing quality, must be available and suitably arranged so that if the on-line supply to the diver fails, an alternative supply can be immediately switched on. Each of the sources should be able to provide adequate pressure and flow rates to all divers that they may be required to supply at the maximum depth of the intended diving operation. The air supply to each diver must be arranged so that if one line fails then this does not significantly interfere with another diver's gas supply.

There should be a primary air supply for each diver plus a secondary supply. Note: The diver's bail-out is not the secondary supply. In a wet bell it is acceptable that the secondary supply is provided from the onboard cylinders, provided that there is either one diver remaining in the wet bell to switch the supplies over manually or else that the switchover is automatic (for example a shuttle valve).

The onboard supply should be able to provide adequate pressure and flow rates to all divers that it may be required to feed at the maximum depth of the intended diving operation. Cylinders should be valved and connected up in such a way that this onboard air supply is available to the divers as back-up or for blowdown of the enclosed top section.

The bell should not be lowered into the water until all members of the diving team are ready and the entrance to the bell has been secured. Members of the deck crew handling the bell should wear safety helmets and life jackets or safety lines.

The main umbilical should be monitored for length to prevent bights forming and the diving supervisor should keep a check on umbilical tension.

If the water depth exceeds the planned maximum dive depth, there should be a system for preventing the wet bell falling below this level in the event of a winch failure. This may be done by means of a guide wire system or by the use of a snubber line.

The divers' umbilicals should be tied off in the bell to prevent the safe maximum being exceeded (see section 10.3).

As well as maintaining contact with the diver, the diving supervisor should make regular contact with the bellman.

At the end of the dive the diving supervisor should not lift the bell until the divers have confirmed that the umbilicals are stowed and the safety chains/gate is in place. Trailing umbilicals may snag. The divers may undergo in-water decompression stops in the wet bell, or undergo a surface decompression.

11.7 Decompression Procedures

The duration of the dive may depend upon decompression limits or it may be governed by tidal currents or operational requirements on the installation. In all cases, timing is vital and the supervisor must ensure that the diver starts his ascent when planned, even if only a small amount of work is required to complete the task.

The diver should never be asked to carry out any work during decompression stops and should avoid hard physical effort after decompression, which may initiate DCI.

Decompression will be carried out according to the tables provided by the company. It is common to select a table deeper or longer than the actual dive to provide a margin for error. If in-water stops are planned, there should be a contingency plan to deal with aborted decompression due to emergency or deteriorating weather conditions.

Contingency plans should also include a procedure for safely recovering a diver who has been accidentally delayed for a bottom time in excess of that shown in the table.

If surface decompression is planned, the deck crew must be briefed on their duties and the procedures to ensure that the divers can enter the chamber as rapidly as possible. It is usual to have the main chamber already pressurised and blow the divers down in the outer lock. The outer lock should then be brought back to surface in case it is required for an emergency.

11.7.1 Exposure Limits for Air and Oxy-nitrogen Diving

Diving carries an inherent risk of decompression illness (DCI). In surface supplied diving the incidence of DCI drops if the length of time a diver spends at any particular depth is limited.

It is recommended that diving using air should be organised in such a way that the planned bottom times do not exceed the limits outlined in Appendix 2.

If a nitrox breathing mixture is being used, the maximum exposure can be found by entering the equivalent dive depth (EAD) of the maximum dive depth in the table.

It should be remembered that any subsequent dive within 12 hours of surfacing (repetitive diving) may not be allowed by some decompression tables and will be restricted in others[8].

11.8 Emergency and Contingency Plans

The dive plan should include plans to deal with foreseeable emergencies, taking into account both general hazards and worksite specific hazards. Only general principles of emergency procedures are given below.

The diving supervisor and dive team should be ready to deal with an emergency at any time and there should be regular drills for all anticipated emergencies.

If the standby diver or bellman is sent to the assistance of the diver, procedures must be in place to ensure that he and his umbilical remain clear of all hazards identified in the risk assessment.

11.8.1 Loss of Communications – Surface Supply

If voice communication to the diver is lost, contact should be established using line signals and the diver should return to surface. The supervisor may be able to assess the situation using an ROV. Contact may be established by flashing the diver's light or flashing video or ROV lights.

The diver can reply by line signals or by hand signals to a video camera. He should return to surface prepared to undergo surface decompression if required.

If contact cannot be established, or there is any doubt about the diver's condition, the standby diver should be sent in immediately.

11.8.2 Loss of Communications – Wet Bell

If voice communication to the diver is lost, the diving supervisor may establish communications by flashing lights, as above, or the bellman should be asked to establish contact using line signals. If contact cannot be established, or there is any doubt about the diver's condition, the bellman should recover the diver as necessary.

If voice communication to the bellman is lost, the diver should be asked to return to the bell.

If there is a complete loss of voice communications to the bell, contact will be established using an agreed procedure and signalling methods. Typically, the diving supervisor will signal the bell by flashing the bell lights and the divers will signal by operating the blow-down valve.

If these methods cannot be used, the diving supervisor may be able to assess the situation using on-board video or an ROV, if available. He may consider sending the standby diver in, although if the bell is deeper than 50 msw (165 fsw) he may wish to try to lift the bell above this depth before doing so. (Under the IMCA International Code a wet bell may be used to a depth of 75 msw (248 fsw) using mixed gas (see section 12).)

11.8.3 Loss of Hot Water

If the diver is using a hot water suit and the hot water supply fails, the situation should be assessed and if the problem cannot be resolved immediately the dive should be aborted. There should be no delay in aborting the dive and the back-up heating system should be put on-line as rapidly as possible.

11.8.4 Loss of Gas Supply – Surface Supply

If the gas supply fails on the surface, the diving supervisor should switch over to the emergency supply and inform the diver. If the emergency supply can be maintained, the diver should be brought to surface following the appropriate decompression procedure. If the supply cannot be maintained, he should be brought immediately to surface for a surface decompression.

If the gas supply fails at the diver, he should turn on his bail-out supply and inform the diving supervisor. He should then make a controlled return to the surface and carry out a surface decompression as required.

If a basket is used, the diver should return to the basket and use the emergency gas cylinder (see section 11.4).

If the diver is able to push his pneumo under his neck seal, the diving supervisor may also turn on the gas to the pneumo as a secondary supply.

11.8.5 Loss of Gas Supply – Wet Bell

The diver should use his bail-out supply to return to the bell. The bellman will turn on the on-board supply. The dive should be aborted.

11.8.6 Snagged Umbilical

A snagged or entangled umbilical is potentially very hazardous and the diver must stop what he is doing and deal with the situation immediately. If necessary, the standby diver may be sent to assist.

11.8.7 Diver Recovery – Surface Supply

If the diver is unconscious, or apparently unconscious, the diving supervisor should immediately switch over to the emergency gas supply and send in the standby diver. After assessing the situation, the supervisor may instruct the tender to start to pull the diver up on his umbilical.

The standby diver must keep the diving supervisor informed of his actions. He should recover the diver to the surface or to the basket. Once the diver's head is clear of the water he must remove his helmet and the diver's helmet, check for breathing and start resuscitation if necessary.

On deck, the diver medic and installation medic should be alerted. The chamber may be needed for decompression, treatment of arterial gas embolism or simply to provide hyperbaric oxygen.

11.8.8 Diver Recovery – Wet Bell

The procedures are similar to those for surface supplied diving, but the bellman recovers the diver to the bell. He should be able to carry out resuscitation inside the canopy of the bell.

The wet bell must not be lifted until the bellman has confirmed that the diver's and bellman's umbilicals are stowed safely. A trailing umbilical could snag and turn an incident into a serious accident.

11.8.9 Diver Adrift on the Surface

A diver adrift on the surface will have cut his umbilical in an emergency, or had it cut accidentally. He may have had to jettison his helmet and bail-out bottle and may be injured.

If he cannot be recovered immediately, the diving supervisor must alert the installation's safety boat and standby vessel. On a large field, there may be in-field helicopters which could also assist.

Members of the diving team should keep the drifting diver in sight for as long as possible and note his direction of drift. It can be extremely difficult to locate a person in the water in even a moderate swell.

11.8.10 Lift System Failures

Recovery procedures in the event of a lift system failure should be included in the company manual. The diving supervisor and dive crew should be familiar with the procedures and recovery drills should be carried out.

There should be back-up power supplies for the main winch for a basket or wet bell. In the unlikely event of a main cable failure on a basket, the diver should be able to return to surface having due regard for any hazards, such as thrusters.

If the wet bell main cable fails, the bell can normally be recovered using the guide wires.

11.8.11 Fire in the Control Room

The bridge or installation control room should be informed and attempts should be made to fight the fire without putting any personnel at risk.

The diving supervisor should put on a breathing apparatus (BA) set if necessary and recall the divers to surface, warning them of a possible loss of gas supply. He may need to use line signals if the communications have been damaged.

The divers should undergo surface decompression if necessary. If the chamber or gas supply has been damaged in-water stops may be required. In some areas, it may be possible to make provision for rapid transport of the divers to another installation.

11.8.12 DP Emergencies

See section 8. If there is a yellow alert, diving should stop immediately and the divers should be recovered to surface or move to a safe location as defined in the dive plan. The safe location may, for example, be the wet bell.

After assessing the situation, the diving supervisor should recover the divers to surface or continue the dive. If there is any doubt, the divers should be recovered.

If there is a red alert, the divers must be recovered as rapidly as possible. The bell must not be recovered until the divers have confirmed that the umbilicals are safely stowed.

1 IMCA D 033 *Limitations in the use of SCUBA offshore*
2 IMCA D 014 *IMCA international code of practice for offshore diving*
3 IMCA D 050 *Minimum quantities of gas required offshore*
4 IMCA D 023 *DESIGN – Diving equipment systems inspection guidance note for surface orientated (air) systems*
5 AODC 039 *Emergency air bottles in diving baskets*
6 IMCA D 015 *Mobile/portable surface supplied systems*
7 IMCA D 040 *DESIGN for mobile/portable surface supplied diving systems*
8 IMCA D 048 *Surface supplied diving operations using nitrox*

Surface Supplied Mixed Gas Diving

12.1 Introduction

This section covers all mixed gas diving operations that do not use a closed bell, except for nitrox diving. Surface supplied air and nitrox diving are covered in section 11.

Surface supplied heliox diving can be used to increase the range or duration of surface diving operations without the use of saturation techniques. The technique is not, however, intended to be used as an effective alternative to saturation diving.

Because of the restricted bottom time in deeper dives the technique is only suitable for a limited range of work, such as short duration inspection dives or simple tasks such as disconnecting a wire[1].

Surface supplied diving mixed gas systems should conform to the requirements of IMCA D 037[2]. Procedures should conform to IMCA D 030[1].

Many of the general and emergency procedures are the same as those for air or nitrox supplied wet bell diving (see section 11). This chapter describes the important differences.

12.2 Limitations

Due to the inherent risks involved, this type of diving should only be conducted within the following parameters:

- it must only be carried out using a properly equipped wet bell. Note that a dive basket fitted with a dome is not a wet bell. A wet bell requires a main supply umbilical from the surface providing (as a minimum) air to a manifold inside the wet bell and diver excursion umbilicals terminated at the wet bell;
- maximum depth should be limited to 75 m;
- for depths between 0 and 50 m, the bottom time should be limited such that the in-water decompression required is less than 100 minutes;
- for depths between 50 and 75 m, the bottom time should be limited to a maximum of 30 minutes.

12.3 Risk Assessment

Because of decompression constraints, the immediate recovery of a diver is not always possible. Even using emergency schedules, in-water decompression could be 60 minutes or more. For this reason, the results of a risk assessment may preclude the use of surface supplied mixed gas techniques.

For the same reason, any equipment failure could have serious consequences and suitable back-up systems must be in place.

Consideration should also be given to the need for the provision of adequate supplies for hot water (taking into account the ambient water temperature) in the event of an emergency, particularly if long in-water decompression times are planned. Similarly heating or cooling for the chamber may be required during decompression in extreme ambient temperatures.

The risk assessment should consider:

- the dive depth;
- the diving platform being used (fixed installation, anchored barge, etc.);
- the specific hazards involved in working from a DP vessel. The divers do not have the same ready access to a pressure-controlled environment as they would if a closed bell were in use. In-water decompression from a vessel that has lost position-keeping ability may not be possible;
- predictability of weather conditions, where the vessel may be subject to sudden squalls or unpredictable sea conditions endangering the wet bell in the water;
- tidal conditions, e.g. where dives are limited to periods of slack water;
- visibility;
- diver recovery in the event of a vessel or platform emergency, particularly if long in-water decompression is planned;

- evacuation of a diver undergoing decompression in the surface chamber if an emergency arose such as a vessel/installation fire;
- working on, or in the vicinity of, offshore installations; in particular any obstructions or items that could snag an umbilical, causing equipment damage or over run of bottom time;
- the duration of the diver's bail-out bottle at maximum anticipated depth. This should be estimated to allow the diver one minute's duration for each 10 m of horizontal distance he is away from the safe refuge (the wet bell). The breathing rate in an emergency is normally taken as about 40 litres (1.5 ft^3) per minute. The calculation should also take into account the available pressure of gas in the bail-out bottle after deductions for depth and working pressure of the regulator;
- the amount and types of emergency gas carried on the wet bell;
- water temperature. Cold water adds an additional element of risk; the water temperature (cold water or warm water) may cause problems during long in-water decompression stops;
- where the standby diver is located and the length of time it would take him to reach an incapacitated diver;
- nature of work to be performed.

12.4 Diving Team

The minimum team size for surface supplied mixed gas diving is six, one more than is required for surface supplied air diving. The team consists of a diving supervisor and five suitably qualified divers. In practice, most diving teams will be much larger. Consideration may be given to having extra personnel available to assist with umbilicals or similar in an emergency.

This team will allow one dive with one working diver in the water (Note: There may also be an in-water standby diver). After that dive is complete, once the diver and, where appropriate, the in-water standby diver have been fully decompressed and are able to take their places as members of the diving team on the surface, it may be possible to carry out another dive using one of the other divers as the working diver (and one as the in-water standby if appropriate). This assumes the dive team still have adequate time available to carry out a second dive before they require a rest period.

If it is planned to carry out more than one working dive in the day then a larger team (normally at least eight) will be required.

The use of an in-water standby diver in the wet bell may increase the team size required for a surface supplied mixed gas diving operation from the minimum required for a normal such operation.

The provision of additional adequate and suitable personnel in the dive team will need to be carefully considered during the planning of this type of diving operation, for example whether a dedicated system technician and/or dedicated winch operator is required.

In addition to a suitable surface supplied qualification, divers should have logged surface supplied deep diving experience and be familiar with the use of a wet bell. They should have received adequate familiarisation training in the use of this technique. In-house familiarisation training should be carried out with content, date and performance recorded. This training should only be carried out by those familiar with, and experienced in, the running of such operations.

In general the working and standby divers should meet the following criteria (this does not include dives during diver training):

- a minimum of 200 logged offshore surface supplied dives (air or mixed gas) to depths greater than 30 m;
- logged verification of at least 10 previous dives completed from a wet bell.

The diving supervisor should be an experienced surface supplied air diving supervisor, with previous experience of surface supplied mixed gas diving operations either as a diver or as a supervisor.

It should not be assumed that all supervisors holding an IMCA bell diving supervisor certificate will be familiar with surface supplied mixed gas diving or that they will have the training, knowledge or experience required for running such an operation.

There are a wide variety of tables in use, many of which involve frequent changes of gas mixtures, and these need to be clearly understood by the supervisor in addition to the normal responsibilities that a supervisor has for the safe execution of a diving operation.

All supervisors should have received adequate familiarisation training in the use of the technique and the decompression tables to be utilised. In-house familiarisation training should be carried out with content, date and performance recorded. Since surface supplied mixed gas diving differs from saturation diving, such training should only be carried out by those familiar with, and experienced in, the running of such operations.

12.5 Air and Gas Supplies

The wet bell must have adequate supplies of all breathing mixtures used during the course of the dive (including bottom mix in the event of a trapped diver). This will normally require separate gases supplied by a surface umbilical coupled to a suitable manifold system, with gas in sufficient quantities for the decompression periods involved.

Careful consideration needs to be given to the total amount of each gas to be provided taking into account the provision of gas for an emergency.

The importance of adequate supplies of onboard gas fitted to the wet bell is highlighted because the diver's bail-out will contain only one of the breathing mixtures utilised (normally bottom mix) and will not be sufficient for emergency decompressions. This could have an impact on the size/weight of the wet bell and the handling spread.

As a minimum, there should be 7 m^3 of both bottom mix and compressed air for each diver at the maximum depth planned.

12.6 Equipment

Essential equipment for a safe surface supplied mixed gas dive is:

- a dive panel and gas distribution system that has been purpose-designed for surface supplied mixed gas diving and is clearly marked to provide for suitable diver (and surface or in-water standby) supply and the proper switch of gases in accordance with the contractor's diving tables;
- sufficient and suitable oxygen analysers fitted with audio/visual alarms;
- a wet bell and deployment system, properly fitted out with adequate onboard gas supplies in the event of failure of the surface supply. Note that there is normally no requirement for high pressure oxygen to be fitted to the wet bell. This should ensure that pure oxygen cannot be accidentally supplied to the diver;
- a secondary recovery system sufficient to manage the controlled ascent of the bell in the event of failure of the main system. The secondary recovery system should be adequate to provide for the in-water decompression stages that many tables call for.

As many tables may require the use of high oxygen content gases to be administered during in-water decompression stops, all equipment should be subject to a frequent and thorough oxygen cleaning regime. There should also be a suitable means to ensure that this supply cannot be accidentally supplied to the diver.

Consideration should also be given to the provision of adequate equipment to maintain the diver's body temperature both during time on helium-based mixtures and during long staged decompression. Diver exposure and body temperature requirements should be addressed as part of the detailed risk assessment, including potential failure of any hot water system.

12.7 Umbilical Handling

As noted in section 11.6 a dive basket fitted with a dome is not a wet bell. A wet bell requires a main supply umbilical from the surface providing (as a minimum) air to a manifold inside the wet bell and diver excursion umbilicals terminated at the wet bell.

During surface supplied mixed gas diving operations, particularly at deeper depths, it is vital that the diver is always able to return to his safe refuge (the wet bell) as easily as possible. In the past divers using umbilicals coming from the surface carried out surface supplied mixed gas diving operations either by passing their umbilicals through a running shackle arrangement mounted on the wet bell or by swimming into the wet bell and exiting through the side opening such that their umbilicals always led back to the wet bell.

The exclusive use of diver excursion umbilicals terminated at the wet bell means that such arrangements are now unnecessary for wet bell divers. However, if a surface standby diver is employed then the diving contractor should consider the advisability of putting in place arrangements to ensure that his umbilical always leads back to the wet bell should he be required to dive beyond it.

The dive team should be familiar with the particular method in use for the surface standby diver on any specific work site and a written record should be maintained (preferably signed by each person) that this is the case.

12.8 Decompression Procedures

Normal decompression after a surface supplied mixed gas diving operation requires the use of a deck decompression chamber (DDC) after the diver has returned to the surface. Such a chamber is also needed for any possible emergency or therapeutic treatments required.

For surface supplied mixed gas diving the minimum requirements for the chamber are:

- two compartments;
- minimum internal diameter of 1.37 m (54") if only one diver in the water and only one diver requiring decompression at any one time;
- minimum internal diameter of 1.5 m (60") if more than one diver in the water or more than one diver requiring decompression at any one time;
- as a minimum there should be one mattress such that an injured diver can be given medical treatment while lying prone in the main compartment;
- in a 1.5 m diameter (or larger) chamber there must also be at least one fixed bunk a minimum of 1.8 m long;
- a means of ensuring the chamber occupants are maintained in thermal balance. This could be by fitting heating/cooling inside the chamber or by siting the chamber in an area where the whole chamber can be maintained at a suitable temperature.

Note that any chamber manufactured after 1 January 2015 should have a minimum internal diameter of 60 inches if using imperial measurements or 1500 mm if using metric measurements. Chambers manufactured before that date do not need to meet this size requirement.

Decompression illness occurring as a result of a surface supplied mixed gas dive may require deeper therapeutic decompression than would normally be used for air diving. Procedures should clearly state the provisions made for treatment of decompression illness which does not respond to treatment on standard tables. There must be sufficient quantities of therapeutic gas mixtures on board, in addition to the minimum quantities of medical oxygen, to carry out two full treatments.

Consideration should be given to the possibility that a diver may require saturation techniques for treatment of serious decompression illness. This may be addressed in either of two ways:

- provision of a system to transfer a diver under pressure into a saturation diving system;
- use of a two-compartment chamber (with adequate working depth) which would allow therapeutic treatment in saturation conditions. This would require the provision of an environmental control unit and sanitary facilities.

12.9 Recovery of an Injured Diver

The location of the standby diver (the primary method of rescue) should be considered in detail at the time of the risk assessment. The standby diver will then either be based on the surface or will tend from the wet bell itself. Some of the matters to be considered in the risk assessment are:

- if the secondary supply is provided from the on-board cylinders and switchover is not automatic, then one diver will have to remain in the wet bell to switch the supplies over manually if this becomes necessary. This person can act as in-water tender and standby diver;
- the time taken for a surface standby to reach the diver. As the working depth increases, this factor will become more relevant. In general at depths shallower than 50 m, the standby diver is likely to be located at the surface;
- some decompression tables involve switching gases during descent; this practice may not favour emergency procedures involving a surface based standby diver;
- strong currents, poor visibility or snagging hazards that could delay a surface standby from descending;
- access to the water by a surface standby diver;
- the exposure of a diver acting as standby diver in a wet bell to possible lengthy decompression.

In addition to a standby diver located inside the wet bell, a surface standby diver may well be considered as a secondary means of providing assistance, particularly during in-water decompression at shallower depths.

The wet bell should have a securing mechanism for attachment to the diver's harness to ensure that the head of an unconscious or injured diver can be kept in the gas bubble of the wet bell dome.

Consideration should be given to the size and layout of the wet bell, particularly with regards to the umbilical stowage space (if relevant), as well as the space required for an unconscious diver plus the standby diver in the event of the standby diver having to rescue the working diver.

1 IMCA D 030 *Surface supplied mixed gas diving operations*
2 IMCA D 037 *DESIGN for surface supplied mixed gas diving systems*

Closed Bell Diving

13.1 Introduction

This section covers diving operations using a closed bell. The breathing medium is generally heliox.

13.2 Diving Team

The absolute minimum team size to support divers during a closed bell operation and 24 hours' life support operations is nine: diving supervisor, two life support supervisors, two life support technicians, two divers in the bell, standby diver on the surface, tender for the standby diver[1]. In practice, the team will generally be much larger.

In saturation diving, no diver should spend more than six hours in water out of the bell. After two hours' work he should be given the opportunity to return to the bell for a drink and perhaps a light snack[1].

A bell run should not last more than eight hours from seal to seal. The divers should then have at least twelve hours of unbroken rest[1]. For round-the-clock diving, therefore, there must be at least three teams of divers in the chamber.

The diving project plan (which consists of the company's standard operating procedures together with site or task specific procedures) should also state the maximum period that the divers will remain in saturation. This is normally 28 days including decompression. In exceptional circumstances it may be appropriate to consider a brief extension, but only with the written agreement of the company's medical adviser, the divers and the diving supervisors. To maintain continuity during a long contract, it is usually better to change out the divers one team at a time. At the start of the contract, for example, Team 1 may reach surface after 21 days, Team 2 after 24 days and Team 3 after 28 days. Thereafter, all teams will spend 28 days in the chamber.

Legislation or company manuals may specify a maximum number of days per year that an individual diver may spend in saturation.

The diving superintendent will generally delegate management of the life support team to the life support supervisor (see section 7).

13.3 Diving Bell[2 3]

A closed bell is sometimes referred to as a submersible decompression chamber (SDC) and the hull valves are essentially the same as those on a chamber. The bell umbilical provides for gas, hot water, power, communications, video, emergency communications, internal and external depth measurement and gas analysis.

All external valves, except those carrying oxygen at more than 15 bar absolute, should be fitted with a quarter turn valve and are normally open. The oxygen lines should, of course, be fitted with needle valves which are normally open.

Internally, the circuit supplying the diver's gas should be fitted with a non-return valve. Other gas and water connections, with the exception of oxygen lines, should generally be fitted with quarter turn valves.

All valves should be clearly labelled externally as well as internally, in case emergency connections have to be made to the bell. The diving supervisor should have control of the bell blow-down supply to the bell at all times.

In emergency situations, such as damage to the main umbilical, divers have occasionally failed to close off all necessary valves. Divers should be given time to familiarise themselves with the valve layout and carry out appropriate emergency drills.

AODC 009[3] recommends that every bell carries an emergency waterproof checklist of all valves that must be closed to ensure pressure integrity in the bell and all those valves that must be kept open. A duplicate should be kept in dive control and the contingency plan should contain a procedure for completing this checklist and confirming the operation with the diving supervisor via through water communications. Photographs of all internal and external bell valves should be available in dive control[4].

The onboard gas supply is designed to supply the diver if the surface supply fails. It is normally arranged to come on-line automatically if the surface supply pressure drops below a set level. It usually incorporates an audible and visual indication that the changeover has occurred, to warn the bellman to recall the diver and inform the diving supervisor.

There must be an emergency supply of breathing gas carried on board sufficient to support each working diver plus the bellman outside the bell for a minimum of 30 minutes at a breathing rate of 40 litres (1.5 ft^3) per minute at the maximum depth of the diving operation. This is to allow the diver(s) to return safely to the bell, allow the bellman to recover any injured divers or allow a diver to clear debris if the bell is fouled.

Sufficient oxygen must be available for metabolic consumption by the maximum number of divers at 0.5 litres/minute per diver for at least 24 hours at the end of a bell run. It must be possible to operate the oxygen add system easily from inside the bell, even if the divers are suffering from fatigue or hypothermia.

The bell atmosphere should be analysed on the surface and may also be analysed in the bell. It is normal to carry an oxygen analyser and chemical sampling tubes to measure the pCO_2 in the bell. The oxygen add system is designed to add a fixed amount of oxygen to the bell atmosphere and, under normal conditions, oxygen should only be added on the instructions of the diving supervisor. Carbon dioxide levels are normally controlled by the bell scrubber, but the bell may also be flushed.

Consideration should be given to providing a means of monitoring the bell atmosphere for hydrocarbons and H_2S.

Seat belts are provided in the bell and for use during bell movements.

When the bell is working at an intermediate depth, consideration should be given to the operating position of the door so as to prevent flooding in the event of an uncontrolled descent[2] (see information note IMCA D 12/08 – *The use of bell outer doors during saturation diving operations*).

13.4 Emergency Equipment in the Bell[5]

Every bell should contain lifting equipment suitable for lifting an injured or unconscious diver into the bell. The divers should be familiar with this equipment and carry out drills in its use. It is recommended that such drills should only end with successful closure of the bell inner door.

The diving project plan should specify the equipment required and the procedures to recover the bell if the lifting cables and umbilical are accidentally severed. It should be equipped with a location transponder using the internationally agreed frequency of 37.5 kHz and an internationally agreed common manifold block for attachment of an emergency umbilical. Cable cutters should be provided to allow the divers to clear severed cables if necessary.

A lost bell can be located using a locator deployed from a surface vessel, a diver hand-held locator or a locator mounted in an ROV. The transponder and locators should be checked and tested regularly.

There should be a means of keeping the bell door clear of the seabed to allow the divers to leave the bell. A bell side door is not considered a suitable means of exit in emergency.

Onboard gas supplies and survival systems need to be capable of sustaining the stranded divers for at least 24 hours[1]. Personal survival equipment should be provided for each diver. It normally consists of an undersuit, hooded insulation suit and personal carbon dioxide scrubbers which incorporate thermal regenerators. These consist of wire gauze, which is heated by exhaled gas and then warms the inhaled gas. High energy food should also be provided.

Under normal conditions, the ppO_2 in the bell is about 0.5 bar and, even without further oxygen adds, the divers could survive for many hours without suffering from hypoxia. Without adequate supplies of absorbent soda lime, however, the $ppCO_2$ would reach dangerous levels quite quickly.

The stranded divers should be able to communicate using through water communications. Through water communications should be tested at the end of every dive, in preparation for the next dive, and recorded as a pre-dive check. Testing should be carried out before the first dive in accordance with the manufacturer's instructions[6].

In extreme circumstances communication can be by using the internationally agreed tapping codes. Cards listing the codes should be carried in the bell and affixed to the outside for the benefit of rescuers. The divers may also be able to communicate by hand signals or written messages via a viewport.

The recovery of stranded divers can be achieved in a number of ways, depending on the location:

- wet transfer of the divers to another bell, in areas where there are other DSVs close enough to render rapid assistance. On two-bell systems, emergency planning should consider the possibility that DP failure may prevent the use of the second bell;
- the use of an ROV to attach an emergency lifting cable and umbilical. If this is included in the planning, the system must be specifically engineered and tested;
- release of bell weights and recovery on the surface.

AODC 061[5] considers that the release of the bell weights is the least desirable option. The ascent of the bell could be impeded by debris or severed cables and it might strike a surface vessel. Once on the surface it may be difficult to locate and weather conditions could make fixing a lifting cable very difficult.

If releasable weights are used, the following criteria should be applied:

- at least two independent actions must be required to release the weights;
- no single component failure should allow the weights to release;
- the weights must not release accidentally if the bell is tilted, and must still be capable of release if the bell is tilted;
- if hydraulic or pneumatic release systems are used they should be so designed that they cannot be accidentally activated by pressure differences or the maximum pressure to which the bell is likely to be subject.

The release system needs to be inspected and tested on a regular basis by a competent person.

Divers should be familiar with the company's emergency procedures and how they are initiated.

AODC 019[2] recommends that all worksites should carry up-to-date internal and external photographs of the bell to provide information to those attempting to rescue the divers if the bell becomes lost or stranded.

In any emergency involving a stranded bell the diving supervisor should immediately alert any DSVs in the area which may be able to render assistance.

13.5 Closed Bell Handling Systems

The bell handling system should allow the bell to be locked off the chamber system, lowered safely through the splash zone without undue spinning or swinging and positioned accurately at working depth. It should maintain the bell at working depth without undue movement and allow it to be recovered safely to deck and locked onto the chamber system.

The main elements of the handling system are:

- A-frame or trolley and cursor;
- winch, main cable and guide wires;
- umbilical handling system;
- heave compensation gear (if fitted);
- cross haul system (if fitted);
- secondary recovery systems.

The bell is normally handled on deck using a trolley or A-frame. The trolley may run overhead, with the bell suspended underneath, or be a sliding platform on deck. The system used should be able to locate the bell accurately on the chamber trunking, even in a heavy sea. Excessive movement of the bell when it is on deck poses a hazard to the deck crew as well as the divers.

The cursor is designed to guide and stabilise the bell on its passage through the splash zone. It runs on guide rails which end a few metres below the surface. The cursor may be active or passive.

An active cursor has its own winch, separate from the bell winch, and during deployment and recovery through the vessel moonpool the bell is locked inside the cursor. The cursor winch takes the weight of both the bell and the cursor. A passive cursor simply rests on the bell and moves with it up or down the guide rails. It is held in contact with the bell only by its own weight. The bell winch takes the weight of both the bell and the cursor.

Heave compensation gear is designed to cancel out the effects of the vessel's motion on the bell main cable. It usually includes a system to maintain the correct tension on the guide wires. Although widely used, it is not essential in most operations. A failure of the system will generally result in inconvenience rather than hazard.

Cross haul systems are a means of moving the bell to a location which is not immediately below the deck installation. This may be done by angled guide wires fixed to the structure or by using cables to pull the bell from the vertical. Any cross haul cables should be strong enough to use for secondary recovery[7].

See section 10.2 for information on other elements of the handling system.

13.6 Gas Supplies

IMCA D 050[8] recommends that for all mixed gas diving there must be sufficient gas available to allow every diver in the chamber 4 hours breathing on the BIBS in case the chamber atmosphere becomes contaminated.

For saturation diving there should be:

- sufficient mixed gas to carry out the intended bell run, plus the same quantity as a reserve. This gas is in addition to the gas requirements in the following paragraphs. Bell onboard gas must not be included in these calculations;
- sufficient mixed gas to pressurise all deck chambers required for the operation to the maximum intended storage depth, plus at least an equal amount in reserve. During the operation, the reserve of gas sufficient to completely re-pressurise the chambers must be maintained. As well as providing a safety reserve against major leaks, this gas is also available for pressurising any hyperbaric rescue chamber;
- sufficient gas to allow a full decompression from the storage depth to the surface twice, allowing for the normal daily consumption of gas due to leakage, medical lock, toilet flushing, etc.;
- sufficient oxygen to allow for metabolic consumption by each diver plus that required to maintain the ppO_2 during decompression. This quantity to be doubled for safety reasons.

These gas volumes should all be available at a pressure high enough for immediate use. Gas at a pressure too low to supply the diver or go into the chamber should not be included. Gas reserves for the diver should be based on the assumption that any gas recovery system is not operating.

13.7 Transfer Under Pressure (TUP)

Every stage of a TUP procedure involves the divers in the bell, the divers in the chamber, the diving supervisor, the life support supervisor and the deck crew. An error by any of these personnel could have serious and perhaps fatal consequences. Good communication and correct procedures are essential.

The doors to the bell trunking should stay closed at all times unless divers are moving between bell and chamber. Doors to the transfer lock should stay closed at all times unless divers are entering or leaving the lock. Both the diving supervisor and the life support supervisor should routinely check the status of the doors.

During the actual transfer the chamber system should be safeguarded by having a diver in the transfer lock controlling the trunking door and by ensuring that all doors to the transfer lock remain closed.

It is, of course, good practice for all chamber doors to be normally closed, in case of pressure loss in any compartment.

All systems need to have pressure interlocks to prevent the trunking being opened under pressure[1].

It must be made absolutely clear to all members of the diving team that they should never attempt to remove the trunking clamp unless:

- they have received direct orders from the diving supervisor;
- they have checked that the pressure gauge on the trunking is reading zero;
- they have opened the bleed valve on the trunking to check the pressure. Gauges can be faulty.

The diving supervisor is directly responsible for the control of the TUP operation, though this can depend on who has physical control of the pressurisation valve. The supervisor, divers and life support supervisors need to be completely familiar with their company and the dive system procedures.

13.8 Saturation Dives

Ideally, the divers should be pressurised in the chamber and may be given a rest period before starting to dive. The rest period is generally longer for deeper dives. See section 7.19.

Divers may be pressurised in the bell and dive immediately. If this procedure of 'bouncing into sat' is used, it is advisable to use a breathable mix to start the pressurisation. There may be a maximum depth specified for this procedure since the divers forego any rest period before diving.

Procedures for aborting a saturation pressurisation and for emergency saturation decompression are in sections 2.27 and 14.32.

There should be a surface standby diver who is able to intervene if the bell can be lifted to a safe depth. He need not be dressed, but his equipment should be checked and ready.

Gas and consumable stocks should be checked on a daily basis, usually by the life support supervisor or gasman. Chamber checks need only be carried out before the pressurisation of a chamber, or after any operation of the chamber skin valves. The remaining checks must be carried out before every bell run.

The ppO_2 in the diver's mix will normally be in the range of 0.6-0.9 bar. The ppO_2 in the chamber will normally be about 0.4 bar.

The following checks should be carried out:

- gas and consumable stocks;
- chamber checks (see section 14);
- dive control room checks;
- bell checks;
- standby diver checks;
- DP checks (if applicable, see section 8).

13.9 Checklists

The following items may be included in the dive control room checklist:

- presence of necessary documentation and associated items including contingency and emergency procedures, tables, logbook, work schedule, stop watch, pens, emergency torches, etc.;
- medical and first aid kits;
- fire extinguisher and BA sets;
- power supplies;
- communications to all necessary locations on the installation;
- video monitors;

- the status of all valves on the dive control panel;
- the pressures of all gases on the control panel;
- calibration of gas analysis equipment;
- analysis of all gases on the panel;
- hi-lo alarms on the divers' gas supply;
- gas recovery system checks;
- bell handling equipment checks;
- hand held bell locator;
- any special equipment required for the operation.

The following items may be included in the bell external checklist:

- pressure and contents of all on-board gas bottles;
- external lights and TV camera;
- condition of viewports;
- security and operation of weight release system (if applicable);
- the status of all external valves;
- equipment required in the bell basket.

The following items may be included in the bell internal checklist:

- internal lights;
- communications and emergency communications;
- condition of viewports, O-rings, etc.;
- operation of the heater and scrubber (refill if necessary);
- spare absorbent, e.g. sodasorb;
- analysis equipment;
- hot water system;
- operation of the BIBS;
- main gas supplies to diver's and bellman's helmets;
- communications to diver's and bellman's helmets;
- emergency gas supplies to diver's and bellman's helmets;
- operation of automatic changeover to emergency gas supply;
- pressure and contents of bail-out bottles;
- operation of bail-out bottles;
- pressure gauges;
- bell tool kit checklist;
- divers' individual equipment as required;
- the status of all internal valves;
- emergency equipment including procedures, checklists, emergency communications card, stop watch, torch, spare O-ring, first aid kits, bell survival kits, emergency scrubbers, emergency tool kit.

The standby diver's equipment needs to be checked fully before each dive and maintenance should not be carried out on it during the dive.

13.10 Emergency and Contingency Plans

The dive plan should include plans to deal with foreseeable emergencies, taking into account both general hazards and worksite specific hazards. Only general principles of emergency procedures are given below.

The diving supervisor and dive team should be ready to deal with an emergency at any time and there should be regular drills for all anticipated emergencies.

If the standby diver or bellman is sent to the assistance of the diver, procedures need to be in place to ensure that he and his umbilical remain clear of all hazards identified in the risk assessment.

13.10.1 Lost Communications – Diver

The diver should respond to any umbilical signals from the bellman and return to the bell immediately. It may also be possible to attract the diver's attention by flashing video or ROV lights. If the diver fails to respond, the bellman needs to be instructed to start diver recovery procedures (see section 13.10.6).

13.10.2 Lost Communications – Bell

Attempts should be made to establish contact using the emergency telephone or through water communications.

If this is not successful, contact may be made by flashing bell light, signals on the pressurisation-line or hand or written signals via the video monitor or ROV camera. Copies of any signalling methods and codes used should be held in the bell and in the dive control.

As soon as the divers indicate that they have a seal, the bell should be returned to surface.

13.10.3 Loss of Hot Water

If the hot water system fails the diver should start his return to the bell immediately. If he is breathing heliox he could start to suffer from hypothermia in a matter of minutes.

While he is returning to the bell he should be adequately supplied by the head of water in the umbilical and by water remaining in the boiler. This may need to be mixed with cold water manually to supply water at the correct temperature. The surface crew should meanwhile be switching over to a back-up heating system or back-up machine. Back-up heating may be provided by on-board steam.

13.10.4 Loss of Gas Supply – Diver

The diver should start to return to the bell immediately. Before turning on his bail-out he needs to check that there is no risk of losing his gas through a free flow. The diving supervisor will be monitoring the diver's breathing and if he notices any significant changes he should alert the bellman.

If the problem has arisen in the diver's gas supply to the bell, the bellman should be warned by the changeover valve switching over to the on-board supply. He should notify the diver and diving supervisor and the diver should return to the bell.

13.10.5 Loss of Gas Supply – Bell

The diving supervisor should change over to the back-up supply and inform the diver. The diver should return to the bell immediately and, if the problem cannot be resolved immediately, the bell should return to surface.

13.10.6 Diver Recovery

If a diver's breathing stops, or if he fails to respond to voice communication or umbilical signals, it should be assumed that he requires assistance. If the bellman cannot pull the diver back into the trunking by his umbilical he will need to lock out and recover him. He should keep the diving supervisor informed of all his actions, but not waste time waiting for a reply.

The bellman should be well trained in the rescue procedure, but may forget important points. If he makes a serious error the diving supervisor can correct him. The diving supervisor should monitor the bellman's breathing closely. Any nervous, shallow breathing or excessive exertion could lead to carbon dioxide accumulation and unconsciousness.

An ROV can provide a useful view of the operation, but it should not be allowed to add to the difficulties by getting too close to the diver or bellman or snagging umbilicals.

The general procedure for the bellman is as follows:

- FIRST ACTION: Change to the on-board gas supply. Bad gas might be the cause of the problem;
- lower the hook of the manlift well below the trunking;
- open the gas supply to his helmet or mask and put it on. Turn on his hot water supply;
- push his umbilical out of the trunking and open the flood up valve;
- leave the bell and follow the diver's umbilical;
- open the diver's freeflow and if necessary supply him by pushing his pneumo into his helmet;
- drag the diver back to the bell along the line of his umbilical. Taking a more direct route might snag the umbilical;
- hook the manlift onto the appropriate D-ring on the diver's harness. The bellman and divers should be exercised in the advantages and disadvantages of using different D-rings;
- enter the bell and lift the diver in. The bellman should keep his helmet on to allow him to see what is happening underwater if the diver's equipment snags;
- remove the diver's helmet and start CPR. CPR should be carried out according to company procedures. This will either be with the diver on his back with his legs up the bell wall or suspended from the manlift with his body in the water. If the latter method is used it is essential that the diver's body remains in the water. Water pressure is needed to keep the blood supply in the upper body and head;
- as soon as the diver is breathing the bell should return to surface. Even if the diver has apparently recovered, medical aid must be called;
- if the diver has been injured on the seabed but is still breathing comfortably he should be recovered as carefully as possible to avoid aggravating his injuries.

13.10.7 Loss of Bell Pressure – At Depth

If the bell cannot be lifted without loss of pressure, likely causes are valves left open or a damaged O-seal on the bell door. Every bell should carry a valve closure checklist and a spare O-seal.

If the problem cannot be dealt with, the divers should await a wet transfer (see section 13.10.11). If necessary they should put on survival equipment.

If the pressure loss only starts to occur after the bell has been lifted, it may be lowered back to working depth to allow the diving supervisor and divers to assess the situation.

13.10.8 Loss of Bell Pressure – Surface

If the bell is on the surface, the diving supervisor should attempt to maintain pressure while the bell is locked onto the chamber. The deck crew may be able to identify the source of the leak.

The divers in the chamber should be alerted. They should ensure that the trunking door is free to open and that all doors to the transfer lock are closed. The divers should transfer from the bell as quickly as possible and close the trunking door.

13.10.9 Umbilical Failure

The diver should return to the bell and the internal valves should be closed according to the valve closure checklist. Communications should be established as in section 13.10.2.

If the umbilical has parted, the divers and an ROV (if available) should assess the situation before attempting to lift the bell. The umbilical may have become snagged.

The bell should be lifted slowly. The standby diver should be deployed when the diving supervisor is satisfied that the bell is within air range and it is appropriate for the diver to assess the situation and remove the damaged umbilical if necessary.

The divers should put on survival equipment as soon as possible. If the bell cannot be lifted, they should await intervention to free the bell or a wet transfer (see section 13.10.11).

13.10.10 Lifting Gear Failures

Every company and system has specific procedures for dealing with lifting gear failures. These include adequate back-up power supplies for winches and the possibility of bell recovery by guide wires or cross haul cables.

The divers and an ROV (if available) should normally assess the situation before attempting to lift the bell.

If the bell cannot be lifted, the divers should await intervention to free the bell or a wet transfer (see section 13.10.11).

13.10.11 Wet Transfer

This method has been used successfully on several occasions. The rescue bell should be lowered as close as possible to the stranded bell. The proximity will depend on the station keeping abilities of the vessels involved and is weather dependent.

The number of divers in the rescue bell will depend on the personnel and equipment available and the condition of the stranded divers.

In principle, a rescue diver carries a spare helmet and umbilical to the stranded bell and brings the stranded divers back one at a time. If there is a long swim or a current he may rig a swim line between the bells.

If the stranded divers are suffering from hypothermia, they should be re-warmed gradually. Connecting them directly to the hot water supply could lead to collapse.

13.10.12 DP Emergencies

See section 8. If there is a yellow alert, the diver should return to the bell weights. After assessing the situation, the diving supervisor should recover the bell to surface or continue the dive. If there is any doubt, the bell should be recovered.

If there is a red alert, the bell should be recovered as rapidly as possible.

1 IMCA D 014 *IMCA international code of practice for offshore diving*
2 AODC 019 *Emergency procedures – provisions to be included for diving bell recovery*
3 AODC 009 *Emergency isolation of gas circuits in the event of a ruptured bell umbilical*
4 IMCA D 024 *DESIGN for saturation (bell) diving systems*
5 AODC 061 *Bell ballast release systems and buoyant ascent in offshore diving operations*
6 IMCA D 008 *Testing of through water communications*
7 IMCA D 032 *Cross-hauling of bells*
8 IMCA D 050 *Minimum quantities of gas required offshore*

Chambers

14.1 Introduction

The *IMCA international code of practice for offshore diving*[1] states that no diving operation is to be carried out unless a two-compartment chamber is at the worksite, or in its close vicinity, to provide suitable therapeutic recompression treatment.

Air chambers are normally defined as those which are not intended for continuous occupation, but the main chamber should be large enough to allow two divers to lie down comfortably. Note that any air diving chamber manufactured after 1 January 2015 should have a minimum internal diameter of 60 inches if using imperial measurements or 1500 mm if using metric measurements. Air chambers manufactured before that date do not need to meet this size requirement.[2]

Chambers used for surface supplied mixed gas diving should have the following specifications[3]:

- if only one diver in the water and only one diver planned to be requiring decompression at any one time, the minimum diameter is 1.37 m (54");
- if more than one diver in the water and more than one diver planned to be requiring decompression at any one time, the minimum diameter is 1.50 m (60");
- in a 1.5 m (or larger) diameter chamber there must be at least one fixed bunk, a minimum of 1.8 m long.

Saturation chambers should be large enough to stand up in and provide a healthy and safe environment for a lengthy occupation. Note that any surface compression chamber used for saturation diving and manufactured after 1 January 2015 should have a minimum internal diameter of 72 inches if using imperial measurements or 1800 mm if using metric measurements[4]. Note also that the Diving Medical Advisory Committee (DMAC) recommends a minimum diameter of 1.8m (72") but preferably 2.15m (84") for any saturation chamber within which medics may have to work.[5]

Chambers and fittings must be included in the planned maintenance system[1]. They also require periodic examination and testing, according to national legislation and insurance requirements[6].

Other useful guidance notes are listed below and information may also be found in the standards published by the certification societies. The main certification societies are DNV GL, Lloyd's, ABS, Bureau Veritas, and the US Coast Guard.

- AODC 059[7] – *Pressure gauges and other forms of pressure monitoring equipment used in conjunction with diving operations*
- IMCA D 011[8] – *Annual auditing of diving systems*
- IMCA D 018[6] – *Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment*
- IMCA D 023[2] – *DESIGN – Diving equipment systems inspection guidance note for surface orientated (air) systems*
- IMCA D 024[4] – *DESIGN for saturation diving (bell) systems*
- IMCA D 037[3] – *DESIGN for surface supplied mixed gas diving systems*
- IMCA D 047[9] – *Acrylic plastic viewports*

14.2 Fire Hazard in Chambers and Habitats

If a fire occurs inside a chamber the occupants will be at risk both from the fire itself and from the toxic fumes which will be given off by the burning materials. Even if ignition does not occur an overheating electrical cable, for example, could give off toxic fumes.

Fire requires fuel, heat and oxygen. It will not start or continue unless all three are present.

The normal fuels which might be found in a saturation chamber environment are paint on the chamber walls, clothing, bedding, books and newspapers, food packaging materials, sugar and other foodstuffs. The remains of meals, bacon fat for example, may provide fuel.

Because of the higher oxygen percentage the fire hazard is far greater in an air chamber than in saturation and no inflammable material should be taken in.

Items which have been found in chambers, in spite of company restrictions, are aftershave lotion, aerosols and various forms of oil and grease. Oil and grease may be taken in deliberately, hair oil for example, or be there because of poor maintenance and cleaning procedures.

Heat, or the source of ignition, could be provided by a faulty electrical supply, a battery, or at high oxygen levels by a static discharge or simply by friction. Astonishingly, fatal fires in air chambers have been caused by divers smoking.

The ease with which fire will start depends both on the percentage of oxygen and on the ppO_2. In an air atmosphere at 24 msw (80 fsw), where the percentage is 21% but the ppO_2 is over 700 mb, a grinding spark is sufficient to ignite cotton overalls. In contrast, in a heliox environment the minimum oxygen percentage for combustion is 6%. Where the oxygen percentage is below 6%, regardless of partial pressure, fire will not start.

The rate at which a fire will burn depends only on the ppO_2. A fire occurring at a raised ppO_2 could be a flash fire which almost constitutes an explosion. Fatal fires which have occurred in air chambers have all been flash fires, associated with high oxygen levels, poor maintenance and failure to take common-sense precautions.

An assessment of fire risk must take into account oxygen concentration, the flammability of materials in the chamber and likely sources of ignition.

The highest fire risk probably occurs in air range habitat welding operations. There is both a high oxygen percentage and a high partial pressure and several sources of ignition. The lowest fire risk probably occurs in saturation chambers where the oxygen percentage is below 6% for most of the time. In saturation diving chambers it is only during initial compression to depth and during the final stages of decompression that there may be a risk. The following extract from the US Navy Diving Manual (Revision 6) gives additional information and a formula for working out the fire zone depth.

15-17 FIRE ZONE CONSIDERATIONS

Every effort shall be made to eliminate any fire hazard within a chamber. When oxygen percentages are elevated as during the later stages of decompression, a fire will burn rapidly once started, perhaps uncontrollably. As a result, special precautions are necessary to protect the diver's safety when in the fire zone. The fire zone is where the oxygen concentration in the chamber is 6 percent or greater. Using standard saturation diving procedures (oxygen partial pressure between 0.44 and 0.48 ata), fire is possible at depths less than 231 fsw. Thus, during a saturation dive the divers will be in the fire zone during initial compression to depth and during the final stages of decompression.

Example. The chamber atmosphere is 0.48 ata ppO_2. The minimum oxygen percentage for combustion is 6 percent. Compute the fire zone depth.

The fire zone depth is computed as follows:

$$\text{Fire zone depth (fsw)} = \frac{ppO_2 \times 33}{O_2\,\%/100} - 33$$

$$= \frac{0.48 \times 33}{0.06} - 33$$

$$= 231 \text{ fsw}$$

Although the design of the DDS minimizes fire potential, personnel must remain vigilant at all times to prevent fires. Appropriate precautions for fire prevention include:

- Fire-suppression systems, if available, must be operational at all times when in the fire zone.
- Chamber clothing, bed linen, and towels shall be made of 100% cotton. Diver swim trunks made of a 65% polyester–35% cotton material is acceptable.
- Mattresses and pillows shall be made of fire-retardant material when in the fire zone.
- Limit combustible personal effects to essential items.
- Limit reading material, notebooks, etc., in the fire zone.

- All potential combustibles shall be locked in only with the permission of the Diving Supervisor.
- Whenever possible, stow all combustibles, including trash, in fire-retardant containers, and lock out trash as soon as possible.
- Being thoroughly familiar with all emergency procedures (EPs) regarding fire inside and outside the Deep Diving System.

In general, whenever the oxygen percentage is 21% or above there is fire risk and extra precautions should be taken. The percentage should never be allowed to rise above about 23%. The precise level will be stated in the company manual.

Every chamber should have a suitable means of firefighting. This may range from portable hyperbaric fire extinguisher in an air chamber to sophisticated sprinkler systems in saturation chambers.

A portable hyperbaric fire extinguisher consists of a container holding some non-toxic extinguishing agent and a cylinder pressurised with a suitable gas. The pressure in the cylinder should be checked regularly and the extinguishing agent should be replaced at the intervals recommended by the manufacturer. The maintenance and refilling of extinguishers should be logged.

14.3 Air Chambers

Under the IMCA guidelines all air chambers should be two-compartment. The smaller outer lock is principally used for rapid pressurisation during surface decompression. It also provides access to the main chamber without loss of pressure.

The chamber is normally controlled by operating the chamber hull valves directly or through a control panel mounted on the chamber. There are two sets of identical valves and controls, one set for the main chamber and one set for the outer lock.

There are two separate sources of air for pressurisation, both on-line to the chamber to provide main and back-up supplies. There are usually two exhaust valves (a main exhaust and a fine bleed), an analysis line and a separate line to the depth gauge.

There should be voice communication with the main chamber and outer lock and viewports close to the control panel to allow the operator to see the divers.

The main chamber and outer lock have pressure relief valves, set to operate at slightly below the safe working pressure of the chamber and sump drain valves. There are equalisation valves linking the main chamber and the outer lock internally. The quarter turn valve in the main chamber (if fitted) is normally open and the quarter turn valve in the outer lock is normally closed. This allows equalisation from the outer lock if the divers in the main chamber are incapacitated.

Internal fittings include lights, communications, CO_2 scrubbers, heating or cooling systems and the appropriate number of BIBS masks. External lights, shining through the ports, are fitted in some chambers.

Chamber doors can be dogged or locked in the closed position, normally using a handle that can be operated from either side of the door. It must always be possible to open a chamber door from the outside to allow access to the chamber. It is normal to remove the dogs as soon as the door is sealed.

See section 14.8 and the subsequent paragraphs for valves and hull penetrations. See section 14.15 for medical locks. See section 9 for information on analysis equipment.

14.4 Gas Supplies for Air Chambers

The main air supply is usually from an LP compressor with a back-up supply provided from an HP air quad. As a minimum, oxygen must be available for supply to the BIBS.

Back-up gas requirements will be stated in the company manual, but the minimum quantities for air chamber use are laid down in IMCA D 050[10]. These quantities are in addition to those required for planned use.

The guidance note states:

- Sufficient compressed air needs to be available to pressurise both locks of the deck decompression chamber to the maximum possible treatment depth (normally 50 metres) plus sufficient air for three complete surface decompression cycles. This air should either be stored in containers or else supplied by two totally independent dedicated sources;
- $90m^3$ (3200 cu ft) of breathing quality oxygen needs to be available for emergency treatment procedures.

"Two totally independent dedicated sources" could be two separate compressors, one of which is connected to the rig or vessel emergency electric power or separate power source (e.g. diesel) or one compressor plus compressed air storage containers.

Rig air should not be considered as a dedicated air supply for diving as it is principally provided for other purposes and may not be available to the quality, or in the quantity or at the pressures required.

14.5 General Procedures for Air Chambers

No one should enter a chamber without removing footwear and dirty overalls. Pockets should be checked for boxes of matches, lighters or other forbidden materials before entering a chamber. Even experienced divers may forget what they are carrying. This applies even if personnel are only entering a chamber to clean it or carry out maintenance. A lighter, for example, could be dropped and remain undetected during pressurisation.

The chamber should be cleaned after every use and kept clean. When it is not in use, the door should be dogged.

HP air and gas pressures should be checked on a regular basis, even if the chamber is not in use, and volumes kept at least at the minimum levels specified in IMCA D 050[10].

Full internal and external checklists should be carried out before every dive, even if use of the chamber is not planned. It is always on standby for therapeutic or emergency use.

During surface decompression procedures, the main chamber should be pressurised to the required depth before the dive so that the diver can be pressurised quickly in the outer lock.

No one should undergo therapeutic treatment without an attendant in the chamber. The attendant should know the symptoms and treatment of acute oxygen poisoning and be competent to carry out neurological checks following a checklist.

During the breathing of oxygen rich mixes on the BIBS, the chamber oxygen percentage should be monitored and the atmosphere should be flushed if levels approach the maximum specified in the company procedures. The chamber should be flushed on a regular basis, usually every 15 or 20 minutes. There should be oxygen analysis[2].

14.6 Saturation Chambers

Saturation chambers are linked together in what may be an extensive system. Chambers may be at different depths and some may be in use for decompression while others are used for pressurisation.

The complexity of a system, and the potential for error, increases rapidly as the number of chambers increases. A four-chamber system with a transfer lock, for example, has nearly 200 valves, up to four environmental control units, up to 10 monitors and a range of analysis equipment.

In addition to the life support technicians, the diving team and the divers in the chambers must have a good knowledge of the system. A basic lack of knowledge by divers in the chamber has been a contributory cause in several incidents.

A chamber is usually categorised as a living chamber, wet chamber for showers and toilets or transfer chamber linking to the bell. The transfer chamber normally functions as a wet chamber.

In the following text 'chamber' may refer to a one-compartment chamber or one compartment of a two-compartment chamber. Divers under pressure should always have access to at least two chambers or compartments to provide an escape route in an emergency.

Each living chamber has a medical lock and there may be a large equipment lock on the transfer chamber (see section 14.15).

14.7 Chamber Connections

Connections from the chamber control to the chamber may be rigid piping, HP hose or a combination. If rigid piping is used for the main run of pipework, a short section of hose at the chamber will help to damp out any noise or vibration.

Gas lines should be marked at regular intervals along their length for easy identification.

All chamber hull penetrations must have a valve on both sides to allow the valve to be closed off in an emergency or during maintenance. These valves may be known as hull valves or skin valves.

Most penetrations are in the same rectangular area, usually in the centre of the chamber. Exceptions are overpressure relief valves, sump drains, toilet valves and equalisation valves between compartments.

The location of certain valves is important. The analysis valve must be placed where it will give an accurate sample of the chamber atmosphere. If the exhaust valve is immediately next to the pressurisation valve flushing of the chamber atmosphere will be less effective. Prominent and vulnerable fittings such as silencers should not be placed where they could cause an obstruction in the chamber or be easily damaged.

Chamber checklists include a check on the status of all valves and should also include a function test. The valve should be operated every time to ensure that it does not become seized.

During saturation the status of external valves should be checked at the start of every shift in case maintenance has been carried out on the previous shift and the valves have not been reset. Internal valves are designed as far as possible to be foolproof.

Electrical penetrators (internal) should be used only for the purpose intended – no ad hoc/home-made pigtails to be used for DVD players/PSP/Notebook computers.

14.8 Pressurisation Valves

The pressurisation connection normally has a quarter turn valve on the outside and a non-return valve or quarter turn valve and silencer on the inside. If there is a quarter turn valve on the inside, it should be taped open to prevent accidental closure but allow emergency closure.

The valve and the connecting pipework must have a large enough diameter to pressurise the chamber at a suitable rate. If the internal diameter is too small, icing may occur.

A check on the internal condition of the silencer may be included in the checklist. Some silencers are not capable of being dismantled. Dirt particles and, in an air chamber, oil particles may accumulate and block the silencer causing a risk of explosion during pressurisation.

14.9 Exhaust Valves

Exhaust connections have quarter turn valves inside and outside. There should be a T-piece or drilled section of pipe on the inside to prevent suction injuries to the divers and prevent small objects being sucked into the exhaust line.

There may be two separate exhaust lines, for fast bleed and fine bleed, or a single line separated at the chamber control panel.

The internal diameter of the valve and connecting pipework must be large enough to handle the gas flow associated with stage decompression. It is often difficult to maintain the correct rate of decompression during a bleed from 3 msw (10 fsw) to surface in an air decompression.

14.10 Depth Gauge Connections

An error in a depth gauge reading, or the misreading of a depth gauge can lead to a serious incident or accident.

Errors can occur if a gauge is incorrectly labelled or connected to the wrong chamber, if the internal or external chamber valve is closed or if it is part of a crossover system and switched to the wrong chamber.

Crossover systems, in which one gauge serves two chambers and is switched between them, are potentially very dangerous and must never be used. It is easy to misread a chamber depth and pressurise or exhaust the wrong chamber. Crossovers should not be found on any system. If they appear as an unauthorised modification they must be replaced immediately.

All gauges should be clearly labelled. On a new system, or after maintenance, chamber connections should be verified by pressurising each chamber to 1 msw (3 fsw). The reading should appear on the correct gauge and only on the correct gauge.

It is advisable to have both internal and external chamber valves taped lightly open to avoid accidental closure. To prevent serious pressure loss in an emergency, small bore valves are used or a small diameter fitting is put on the internal valve.

14.11 Analysis Connections

Like the depth gauge connection, the analysis valves are usually small bore and lightly taped open. Errors from closed valves are, however, less likely because many analysis lines and most analysers have flow meters fitted. On saturation systems (but not on air chambers), O_2 analyser hi-lo alarms will usually sound if the flow is stopped and air diffuses into the equipment.

Unlike depth gauge connections, crossover systems are widely used on analysis lines on saturation systems, with one analyser switched between several chambers. All connections should be correctly labelled and a check carried out on a new system or after maintenance, as for depth gauge connections.

14.12 Built in Breathing Systems (BIBS)

In an air chamber, the BIBS supplies only oxygen or a rich oxygen mix. It is principally used for surface decompression or therapeutic treatments. When not in use, the external and internal BIBS and dump valves are normally closed. Leakage of oxygen into the chamber could pose a serious fire hazard.

In a saturation system, the BIBS can supply oxygen, an oxygen rich mix or bottom mix. They are, however, principally used as an emergency breathing supply and a suitable bottom mix should be connected at all times. The external and internal BIBS and dump valves should be open. If there are minor leaks, either through the masks or dump valves, the internal valves may be closed. They can be opened quickly by the divers in emergency.

Under normal conditions, only bottom mix should be connected to the BIBS to prevent the accidental supply of a toxic oxygen mix. A rich mix should only be connected for treatment purposes. The oxygen percentage of the mix would be specified in the tables.

There should be suitable stowage for the BIBS masks inside the chamber. They must be immediately available without causing undue inconvenience to the divers. Divers have removed masks which they felt caused further constriction in an already small bunk space.

BIBS masks and dump valves should be regularly checked and maintained and be oxygen clean[11].

14.13 Water Supply and Sump Drain

The chamber water supply may be put under pressure by using a pump or by using a pressurised water container.

Pressurised containers are normally supplied with 2% or bottom mix via a regulator piloted to the chamber pressure. There must be a pressure relief valve on the container. There must be non-return valves on the mains water supply to prevent accidental pressurisation of the water system. Pressurised containers may also be used to supply fire sprinkler systems.

In an air chamber, the sump drain valve is usually fitted in the bottom of the chamber with a quarter turn valve on an elbow internally and a quarter turn valve on the outside. It is rarely required.

In a saturation chamber, the sump drain is either a rigid pipe or a flexible hose running under the floor plates from a quarter turn or spring loaded valve on the chamber wall. The sump drain is used regularly after showers.

A flexible hose is usually more effective since it can be moved about by the diver to suck up water. Whichever system is used, the inlet to the hose or pipe should be narrower than the main bore to trap any particles that could block the system. Blockages are commonly caused by particles of soda lime. If a hose is used there must be additional vent holes drilled in the end to act as a diffuser.

Internal and external skin valves are normally closed and only opened to drain the sump. Good communications between divers and surface are essential and the divers should be warned to keep their feet and fingers clear of the suction.

14.14 Toilet Valves

Toilets are designed with several valves, often with interlocks, to ensure that they cannot be accidentally flushed whilst in use. There must always be a gap between the toilet seat and the toilet bowl to prevent any potentially lethal suction accidents. On many systems, the toilet seat must be closed before flushing can take place.

Flushing the toilet and emptying any holding tanks requires the operation of several valves and co-ordination between divers and surface. Both must follow the correct procedures which should be posted internally near toilet and externally near exhaust valves.

Internal holding tanks allow the divers to flush the toilet several times without calling surface. External tanks help to prevent a serious pressure loss if there is any error or malfunction in the operation on the hull valves.

During and after decompression, pressure in the holding tanks may be greater than chamber pressure. Tanks should always be vented before opening the toilet valve to prevent unpleasant incidents.

14.15 Medical and Equipment Locks

Medical locks and equipment locks are the only part of a chamber system where doors are closed against pressure. Internal doors should be kept closed and dogged when not in use and, as far as possible, locks should remain at surface pressure with outer door closed and clamped.

The internal doors of large equipment locks, which are commonly in the transfer chamber, are sometimes left unsecured after preparations for a dive and bell lock-off. The life support technician should always check the status of the door after use using the video monitor.

Medical locks may be pressurised by the divers in the chamber by opening the door valve or by personnel outside the chamber operating equalisation valves. Large equipment locks are normally pressurised from chamber control to prevent any drop in chamber pressure.

All medical and equipment locks must have pressure gauges visible to the person operating the lock and a safety interlock system must be fitted to the clamping mechanism securing the outer lock door. This interlock must make it impossible to open the clamp if there is still pressure inside the lock and impossible to obtain a gas tight seal on the lock if the clamp is not properly closed[1]. They should have baffles on the internal vent to prevent items being sucked in and blocking the exhaust line.

Locks should only be operated by personnel with the required competence. The full procedure and precautions to be taken must be made clear to all personnel operating the lock. Written operating procedures should be posted externally near each lock.

14.16 General Procedures for Operating Medical and Equipment Locks

The lock must never be used, by divers or surface, without confirmation from chamber control.

Chamber control must check with both surface and the divers before allowing the lock to be operated. The LST must monitor chamber pressure during lock operations.

Neither side should operate the lock without knowing what is inside. Some items, such as used light bulbs, have exploded during decompression or shortly after reaching surface. Sensitive equipment or materials may be damaged by rapid pressurisation or decompression.

Containers must have their tops removed or pierced. Containers completely full of liquid, like fruit juice cartons, can be compressed safely.

The lock should not be overfilled. The connection to the pressure gauge may be blocked or food or other material may be sucked into the exhaust valve.

The inside of the silencer on the exhaust valve can accumulate dirt, in the form of food particles etc., very quickly and should be checked regularly if possible.

When the tender is venting the lock he must stand by until the lock reaches surface pressure. He should operate the valve at arm's length, looking away. The sound of escaping gas will normally indicate whether or not the lock is decompressing normally.

Before opening the lock he should check that gas is no longer escaping from the valve and that the pressure gauge reads zero.

If he has any unusual difficulty in opening the door he should assume that there is still pressure in the lock. It is possible for gauge, exhaust valve and interlock pressure connections to be blocked. In this case, the door should be properly secured and the lock pressurised and checked.

The external door should either be clearly open or clearly closed. The practice of leaving the door with the clamp only half tightened is potentially dangerous. The lock should never be left unattended until the lock is secure.

When the external door has been closed, the tender must stand by until the lock has been safely pressurised. He must immediately inform the divers and the control room if there is a leak.

The divers must pressurise the lock slowly to avoid overturning containers.

Playing games with the medical lock, or any pressurised container, is potentially dangerous and should not be allowed.

14.17 Viewports

The condition of chamber viewports should be checked as part of the chamber checklist. Mechanical damage may show as chips, scratches or crazing and must be reported and dealt with. Damage could also be caused by an overheating light bulb in an external chamber light shining through a viewport. Such damage shows as a distortion in the viewport.

Acrylic plastic viewports start to decompose after a period. The process is accelerated in bright sunlight. Ten years is a normal safe working life and viewports should be replaced after this time, even if they have been in storage, i.e. complete renewal is necessary within 10 years of fabrication[4].

Viewports are subject to certification and the test date and details should be marked on the circumference of the viewport. This marking will often not be visible when the viewport is fitted into the chamber. If the serial number or other identifying mark for each viewport is not visible when fitted in situ then it should be prominently marked on the outside of the chamber adjacent to each viewport. Viewports must not be used without evidence of testing.

They must be mounted in the correct size of housing with the correct size of O-rings or other sealing gaskets. Fittings of the wrong size will cause undesirable stresses in the viewport.

IMCA D 047[9] also contains information about testing of viewports using polarised light.

14.18 Environmental Control Units

Environmental control in an air chamber is usually limited to a carbon dioxide scrubber and a heating or cooling system.

Environmental control units (ECUs) for saturation systems circulate the atmosphere to maintain safe, healthy and comfortable levels of oxygen, carbon dioxide, temperature and humidity in the chamber for an extended period.

Oxygen is usually added automatically into the circulating system to ensure proper mixing into the chamber atmosphere.

Carbon dioxide is removed by soda lime and trace gases and odours are removed by Purafil or activated charcoal in the soda lime filter. Moisture is extracted by cooling the gas which is then re-heated, if necessary, to the required temperature. Water must be drained from the system at regular intervals.

Soda lime works more efficiently when damp and the chamber gas is always circulated through the soda lime filter before passing though the cooling coils. Some systems incorporate water sprays for the soda lime filter to dampen the soda lime if required.

ECUs may be internal or external units. Internal systems are compact and only require low power to circulate the gas. They can be difficult to maintain under pressure and the divers may have to be woken up to change filters.

External systems require large bore external pipework and pressure vessels to contain filters and other units. They require more deck space and more power to operate, but are easier to maintain and filter changes can be made without disturbing the divers.

The large bore chamber penetrations have a non-return valve on the inlet and flow reducing valves on the outlet. These will close in an emergency if the gas flow exceeds a certain rate.

Internal carbon dioxide scrubbers are provided, in case the ECU fails. They can also be used to assist mixing of the chamber atmosphere during pressurisation.

14.19 Chamber Control

The chamber controls for a saturation system are normally in a chamber control room which may be remote from the chambers.

Chamber control has voice communication with each chamber and often has individual communications systems for each bunk in the chamber. There should also be voice communications with dive control and with medical and equipment locks, the gas storage hold, bell trunking and the diving superintendent.

There should be video monitors showing the inside of every chamber, unless the inside can be viewed easily by the life support personnel through the viewports. If possible, there should also be monitors showing the outside of medical and equipment locks and the bell trunking.

Chamber control should be equipped with one or more sets of breathing apparatus to allow LSTs to continue operating if the control room were to become filled with fumes. They should have comms[2] also but in reality most systems have BA masks with comms that plug directly into supplies from panels.

There must be a separate control panel and separate depth gauge for each chamber. Apart from analysis lines, there should be no crossover connections. All important valves and reducers on the panel must be arranged so that it is possible to isolate any valve and use an alternative in the event of failure.

The control panel allows the life support supervisor to supply a variety of mixes to the chamber for pressurisation and for the BIBS. If several mixes are connected to a common pressurisation-line at the control panel, non-return valves and vents must be fitted to prevent accidental leakage between mixes.

Oxygen is often added automatically, but the automatic valve should have a manual by-pass in case of failure.

14.20 Gas Supplies and Consumables for Saturation Systems

Back up gas requirements will be stated in the company manual but the minimum quantities for saturation diving use are laid down in IMCA D 050[10]. These quantities are in addition to those required for planned use.

The guidance note states that before commencing saturation diving operations there should be:

- sufficient gas, in the event that the chamber atmosphere becomes contaminated, to allow each diver four hours' breathing on BIBS masks at the deepest storage depth in addition to other gas reserves;
- sufficient quantities of treatment gas for the depths involved to carry out any foreseeable treatments as detailed in the company's rules;
- sufficient mixed gas available to be able to pressurise the system (all deck chambers/HES involved in the saturation) required for the envisaged operation to the maximum intended storage depth, plus at least an equal amount as a reserve. During the operation, the reserve of mixed gas, sufficient to completely repressurise the system, should be maintained at all times;
- sufficient oxygen to allow for metabolic consumption by each diver, any oxygen make-up prior to decompression, plus that required to maintain the ppO_2 during decompression. This quantity should be doubled for safety reasons and held in two separate banks;
- sufficient quantities of calibration and zero gas to provide a minimum of three weeks' supply for the analysers. This reserve needs to be maintained during the saturation.

In addition,

- sufficient mixed gas should always be available at the start of a bell run to carry out the intended bell run, or for both intended bell runs if conducting bottom turn-rounds/continuous diving, plus the same quantity of gas should be held as a reserve. This gas will be in addition to the gas requirements in the above paragraphs. Gas carried onboard the bell or hyperbaric evacuation system (HES) in cylinders should not be included in these calculations.

Back-up supplies must be immediately available. For chamber use this means that they must be at sufficient pressure to go directly into the chamber. Gas at a pressure of less than 20 or 30 bar cannot be considered as part of the reserve.

Minimum quantities of other consumables like soda lime and Purafil will normally be specified in company manuals. Typically, they will be sufficient to continue operations for about two weeks without further supplies being received.

14.21 Chamber Hygiene[12]

The warm, damp, crowded saturation chamber environment is ideal for the spread of all kinds of infection. Gram negative bacilli commonly cause ear infections and wound infections. Various types of fungal growth cause ear infections and skin infections. Both gram negative bacilli and fungi can be detected using swabs. Viral infections cause respiratory tract diseases and gastro-enteritis.

Infection may be passed in from outside the chamber, or may be already present in the divers' bodies. Bacteria which cause ear and skin infection, for example, are normally resident in the bowel.

Procedures specifically for dealing with ear infections are shown in section 14.22. The following general procedures should be followed:

- the divers in the chamber and all surface crew who are passing food or equipment into the chamber must maintain a high standard of personal hygiene. Infection could be passed into the chamber by dirty hands;
- the inside of the medical lock must be kept clean;
- the area around the chambers must be kept clean and tidy;
- rubbish must be passed out of the chamber every day;
- divers should not share diving gear or chamber headsets;
- even minor injuries must be treated immediately;

- chamber bedding must be laundered on a regular basis, usually every three days, but daily if there is infection in the chamber;
- the divers must not share towels or soap. Towels should be passed out of the chamber immediately after showering;
- the divers should not use strong or aggressive detergents or soaps which may aggravate the skin and allow infection to become established;
- ideally all chamber laundry should be washed in a dedicated washing machine. Washing should be carried out at the highest suitable temperature;
- disinfectant, suitable for a hyperbaric environment, should be poured into the toilet bowl after use;
- the chamber must be cleaned thoroughly on a daily basis with a suitable disinfectant, used according to the manufacturer's instructions;
- chamber sumps must be kept dry and any internal ECU systems must be drained frequently;
- chambers may be swabbed to check for infection. Areas and items to be swabbed include toilet, sink, walls, sumps, shower heads, ECU drip tray, helmet liners, suits, bedding, headsets. The frequency of swabbing should be specified in the company manual;
- if a chamber gas reclaim system is used, the reclaim bag should be swabbed on a regular basis.

14.22 Ear Infections

Under normal conditions, the ear contains a variety of harmless bacteria. In saturation, the high humidity and other factors kill these bacteria and make it possible for other more harmful infections to colonise the ear.

The bacteria which cause these infections are normally resident in the human body and are very easily carried to the ear. Divers in saturation should not put their fingers or anything else into their ears, except sterile swabs or ear drops. Cotton buds and other types of swab which are available over the counter are not sterile and should not be put into the ear.

The chances of infection are reduced considerably by the use of preventative, or prophylactic, ear drops. These are usually a silver acetate, salicylic acid or aluminium acetate solution which makes the ear canal too acidic for the bacteria. Drops should be taken on a regular basis as instructed, usually every eight hours.

One bottle must be provided for each ear, and labelled accordingly, to prevent cross infection from one ear to the other. If the drops cause itching it is usually best to stop using them. Itching causes scratching which can induce infection.

Swabs are sometimes taken from the divers 24 hours before pressurisation and the use of preventative ear drops started at this time.

If a diver suffers an ear infection, he should be given treatment ear drops and, if necessary, a suitable pain killer. Preventative drops must be discontinued. He requires one labelled bottle of drops for each ear, even if he has symptoms in only one ear. He should also take ear swabs to allow the infection to be identified.

If two or more divers show symptoms, it may be advisable to carry out regular swabbing of all the divers' ears. Under normal conditions, regular swabbing is not advisable because it can cause damage to the ear canal and increase the risk of infection.

All use of ear drops, swabs and chamber cleaning should be checked and logged by the life support supervisor.

14.23 Saturation Pressurisation

Before pressurisation, chambers must be cleaned and checked using checklists. Gas volumes must be checked and the required gases connected to the control panel. Gases must be analysed at the quad before connection and at the control panel after connection. Stocks of other consumables, such as soda lime, must be checked.

It is usual to put essential items into the chamber while it is on the surface. These include bedding, towels, soap, toilet rolls, cleaning materials, mugs, spoons and basic foodstuffs like tea, coffee, sugar, biscuits, jams, sauces, etc. Although the fire risk is small, sugar lumps are preferable to granules. All containers must have their tops removed or punctured. Cellophane or plastic wrapping, typically round packets of biscuits, must be removed or punctured.

The divers may all have taken ear swabs before going into the chamber to check for any infections. They should be issued with preventative ear drops and checked for allergies to any common medicines such as aspirin or penicillin.

It is essential to ask the divers to check their pockets and personal belongings for any forbidden items before they go into the chamber. Even a highly experienced diver may forget what he has in his bag. Lists of forbidden items are in company manuals and include batteries and many battery operated items[13].

The depths of various mixes to start the pressurisation may be given in the company manual or can be calculated using the formulae in section 2.24.

If the initial pressurisation mix is not breathable on the surface, there is always a risk that a leaking door seal or some other leak (typically an exhaust valve left open at the end of a decompression and not checked properly) will allow the chamber to flush and drop the ppO_2 to dangerous levels.

Some companies insist that the first few metres of pressurisation must be carried out using a breathable mix. If this is not the case and a breathable mix is not used, the following precautions must be taken:

- the divers must be on BIBS for at least the first 10 msw (33 fsw);
- the pressurisation must be stopped at about 1-3 msw (3-10 fsw) to check for leaks.

Reclaimed gas should not be used for pressurisation unless the nitrogen content is within safe limits specified in the company manual. A high ppN_2 in the chamber could have an adverse effect on the decompression.

The ECU and scrubber should be running during pressurisation to assist mixing of the chamber atmosphere. The process can be assisted by asking the divers to make their beds or wafting towels.

In the early stages of a pressurisation, divers should not lie on their bunks. They should sit or stand so that the LST can see clearly that they are well and conscious.

BIBS mixes must be changed during pressurisation to ensure that there is always a breathable mix on-line.

Pressurisation rates are specified in company manuals and must not be exceeded. For deep saturations, there may be a stop during pressurisation and a rest period at living depth before diving takes place.

In some circumstances, divers may be pressurised in the bell and carry out a dive before returning to the chamber. This procedure will normally be carried out by the diving supervisor from dive control. Precautions should taken to ensure that the bell cannot be accidentally flushed with low ppO_2 gas mix and that the correct gases are on-line before diving starts.

14.24 Daily Routines in Saturation

See section 13.7 for TUP procedures and section 9 for gas handling and analysis.

Environmental parameters will be specified in the company manual, but typical values for a heliox saturation are:

- oxygen – about 400 mb (0.4 atm);
- carbon dioxide – equal/less than 5 mb (0.005 atm);
- nitrogen – less than 1000 mb (1 atm);
- temperature – 25-33°C (77-92°F);
- humidity – 50% to 70%;
- depth – within 0.3 msw (1 fsw) of the specified depth.

With the exception of nitrogen, these parameters should be checked and logged every hour. The oxygen analysers should have hi-lo alarms with an audible and visual alarm. Temperature should be maintained at a level comfortable to the divers. This will vary according to depth and humidity. Analysers should be calibrated before every sat and every shift change thereafter or as indicated in company manuals.

All events should be logged. These include bell lock on and lock off, medical and equipment lock operations, calibration of analysers, chamber cleaning, taking of swabs, medical treatments, etc.

It is the responsibility of the life support team to have equipment ready to go into the chamber for each dive and to deal with the divers' meals, laundry, mail and all their other daily requirements.

14.25 Split Level Saturations

In some saturations, it may be necessary to maintain chambers at different living depths. On a two-bell system there are few problems, but on a single bell system the bell and transfer chamber depths will need to be changed regularly to match each living depth.

Before separating any chambers, the system should be checked for any risk of accidental equalisation. This might occur through connections on the control panel, crossovers on external ECU connections, pressurised shower systems, sprinkler systems, etc. Separation between chambers should be ensured by bleeding the trunking between the chambers to surface.

If access to the transfer chamber is being switched between living chambers, the atmosphere must be checked after each depth change, before the doors are opened to the living chamber.

Depth changes in living chambers, either an intermediate pressurisation or decompression, must be carried out according to the company manual, with rest periods as necessary.

14.26 Saturation Decompression Procedures

Decompression must be carried out according to the company manual. It may be a stage decompression, or a continuous bleed and there may be a rest or stabilisation period, especially after a deep excursion.

If several decompressions are underway, at different depths and different rates, timers with audio alarms for each chamber will reduce the risk of error.

After decompression, the divers should be checked and debriefed. It is advisable for them to avoid physical work for at least twelve hours and avoid very hot showers or saunas.

They should stay close to a chamber for 12 hours, and not fly above 600 m (2,000 ft) for 24 hours. Flights below 600 m (2,000 ft) are allowed after 12 hours[14]. Most companies also impose a restriction on any further diving for a period of at least 48 hours.

If an empty chamber is bled straight back to the surface, the atmosphere will be hypoxic (see section 2.34). Precautions must be taken to ensure that no one enters the chamber until it has been fully ventilated and the atmosphere is safe to breathe.

14.27 Chamber Fires

If fire starts in a chamber, the chamber must be evacuated immediately. The doors must be closed and the chamber bled back to surface. In a saturation system, the divers must have an evacuation procedure. Escape in the wrong direction could leave them isolated from the rest of the system, possibly in a small lock, for an extended period.

If evacuation is not possible during saturation, all divers in the system should go onto the BIBS immediately and attempt to extinguish the fire or pass the burning material out through the medical lock. Electrical power to the chamber should be turned off and the chamber should be flushed.

If evacuation is not possible in an air chamber, the BIBS supply should be turned off and the chamber flushed. The BIBS gas will be oxygen, or an oxygen rich mix, and presents a serious hazard. The divers should attempt to extinguish the fire or pass the burning material out through the medical lock. Electrical power to the chamber should be turned off.

If a flash fire occurs in a chamber the accident will almost invariably be fatal. This is only likely to occur in an air chamber, or in a saturation chamber close to the surface during decompression, as a result of poor maintenance or procedures.

14.28 Chamber Pressure Loss

If there is a rapid pressure loss in the chamber the divers will be liable to suffer from decompression illness, barotrauma and hypoxia as the ppO_2 drops. There will also be considerable noise and communication with the affected chamber will be impossible. Misting will occur as the temperature drops and it will be impossible to see where the divers are. Doors between chambers may seal.

The life support technician should put gas into the system in an attempt to maintain pressure and other members of the surface crew should attempt to locate the leak.

The divers should attempt to evacuate the leaking chamber and close the door. They should go onto the BIBS. The chamber atmosphere maybe hypoxic or even hyperoxic if rich mixes have been used to maintain pressure. They may need to evacuate to the bell or to a hyperbaric rescue vessel.

When the leak has been contained, the divers may be incapacitated and members of the surface crew should enter the chamber as soon as possible. The life support technician must check the chamber atmosphere and restore a normal ppO_2 as quickly as possible.

14.29 Unbreathable Atmosphere

The chamber atmosphere may become unbreathable because of toxic fumes or because it has become hypoxic after a pressure loss or during pressurisation. See section 14.28 for pressure loss.

Typical sources of toxic fumes are oil-based mud on diving equipment, which can give off hydrocarbons and hydrogen sulphide, or welding fumes carried back in the bell from a lock-on habitat. Fumes could also be caused by overheating electrical cables or fire. Most companies now have bell Hypergas analysers.

In most cases there will be some warning of the problem. The divers should evacuate the chamber and close the doors. They should go onto BIBS immediately in the new chamber.

The whereabouts of all the divers in the system should be checked and an analysis made of all the chamber atmospheres. A saturation system should carry a variety of chemical sampling tubes for this purpose.

The types of sampling tubes carried will depend on the type of diving operation, but may include carbon dioxide, carbon monoxide, hydrogen sulphide, benzene and hydrocarbons.

If it is impossible to evacuate the chamber the divers should go onto BIBS until the chamber atmosphere has been thoroughly flushed. According to IMCA D 050[10], there should be enough gas on-board to keep all the divers in the chamber supplied on BIBS for a minimum of four hours.

Hypoxia during pressurisation may occur because of inadequate mixing or because of accidental flushing.

If only some of the divers are affected, the others may be able to render assistance. They should all go onto BIBS until the atmosphere is returned to normal.

If all the divers are incapacitated, the life support technician should flush the chamber with a rich oxygen mix and get members of the surface crew into the chamber as quickly as possible.

Personnel entering the chamber should take precautions to avoid being overcome by hypoxia. This type of incident will normally occur very close to the surface.

14.30 Failure of ECUs

In almost all cases, an ECU can be repaired in a very short period and long-term failures are rare. If this should occur, the following methods may be used to maintain the environmental parameters:

- oxygen – rig a gas line from the oxygen connection to the base of the back-up carbon dioxide scrubber to ensure mixing and add manually;
- carbon dioxide – use the back-up scrubber;
- temperature – use external electric heaters and insulate the chambers or in hot conditions arrange a cold water sprinkler system over the chambers. Additional bedding can be supplied in cold conditions;
- humidity – minimise the use of showers. If available, silica gel could be added to the soda lime in the back-up scrubber, but would require frequent changing.

If there were no power at all, the divers would have to use personal carbon dioxide scrubbers and perhaps bell survival equipment.

14.31 Fire in the Chamber Control Room

Sets of breathing apparatus must be available in the chamber control to allow life support crew to continue operating if the room becomes filled with fumes. All members of the life support crew must be trained in the use of the equipment.

If it becomes necessary to evacuate the control room it may be possible to continue operations through the bell from dive control. All gas supplies to chamber control should be closed off at the quads.

If the chamber system itself is threatened, follow hyperbaric evacuation procedures.

14.32 Emergency Decompression

In a potentially hazardous situation an accelerated decompression from saturation might be considered preferable to a hyperbaric evacuation.

Some companies provide accelerated decompression tables. If they are used, provision should be made to transport the divers rapidly to a chamber in a safe location as soon as they reach surface. Accelerated decompression is usually only an option for shallow saturations. See DMAC 31[15] for more detailed guidance.

14.33 Emergency Medical Treatment

Every offshore worksite should carry suitable medical equipment[16]. The diving company should also have a documented medical plan, prepared in conjunction with its medical adviser, to provide initial first aid requirements and contact specialist medical advice as required[5]. Initial treatment should be provided by a diver medic, who is part of the dive team onboard.

DMAC 28[5] recommends that every saturation system should provide a facility where an injured diver can be given medical treatment while under pressure. This can be accomplished by designating one chamber as the chamber in which medical treatment can be carried out. It should have the following minimum specifications:

- a minimum internal diameter of 1.8 m (6 ft) but preferably 2.15 m (7 ft) or more;
- the ability to remove, or move out of the way, bunks and other equipment normally fitted to the chamber but not needed directly for a medical emergency;
- a bunk for the patient which should:
  - be waist high
  - have access from at least one side and one end have a firm base (such as a permanent or easily fitted metal base) be able to tilt the patient to 30° both at the foot and head ends;
- a tray or working surface for medical instruments;

- a means for suspending IV drips overhead the patient (hooks or similar);
- a convenient medical lock of at least 300 mm diameter;
- a good communications system with connections in a suitable location for personnel beside the casualty;
- suitable extra lighting for the area of the casualty. This may be the normal bunk lights fitted with long leads to reach the treatment area;
- sufficient additional gas and electrical hull penetrations (in order to ensure that in an emergency appropriate gas and electrical supplies can be rapidly connected) as agreed with the specialist medical adviser.

Good communications are extremely important. Ideally a doctor onshore should be able to talk directly to the person inside the chamber who is treating the diver. In practice, however, this may be difficult or impossible, and the usual procedure is for the LSS to relay information as required.

The diving company and the medical adviser should agree a list of specialist equipment to be taken offshore by an emergency medical support team. This will clearly depend on the offshore facilities available and may be site specific.

14.34 Hyperbaric Evacuation of Saturation Divers[17] [18] [19]

In an emergency, divers in saturation cannot be evacuated by the same methods as other crew members. Methods of hyperbaric evacuation that could be considered, depending on conditions, are:

- wet transfer;
- crane lift off in a dedicated hyperbaric chamber to another vessel; or
- evacuation to sea in a dedicated hyperbaric chamber or lifeboat.

If the evacuated divers are placed in the sea in a dedicated hyperbaric chamber or lifeboat, they face problems of thermal stress, seasickness, dehydration and the difficulty of location and recovery. This should be an action of last resort.

The following conclusions are based on actual incidents:

- the diving supervisor and topside support technicians will try to remain at their posts during an emergency, until the divers under pressure can be evacuated;
- if circumstances are suitable, evacuation by wet transfer at depth is proven and in many cases will be the preferred method;
- in a sudden disaster, any form of hyperbaric evacuation is unlikely to work. Examples include sudden capsize or sinking of a ship, major explosion, fire or adverse weather. Under such circumstances, conventional ships' lifeboats for the surface crew will probably not be useable either;
- hyperbaric evacuation should only be considered as a last resort, and only when the diving supervisor is certain that the divers under pressure will come to more harm if they remain in the diving system. In most incidents, divers have been safer remaining inside the diving system;
- hyperbaric evacuation is unlikely to be necessary even in an emergency and will only be used infrequently;
- the method of hyperbaric evacuation which is most suitable for any emergency will depend entirely on the surface facility, the reason for evacuation, the conditions prevailing at the time and the number of divers in saturation. No one method is suitable for all eventualities.

14.34.1 Provision of a Hyperbaric Evacuation System (HES)

For all saturation diving operations a hyperbaric evacuation system (HES) needs to be provided that, in the event of a vessel or fixed/floating installation evacuation, is capable of evacuating the maximum number of divers that the dive spread is capable of accommodating, to a designated location where the divers can be decompressed in a safe and comfortable manner, taking in consideration the geographical location and weather conditions.

The HES includes the whole system set up to provide hyperbaric evacuation. It includes the planning, procedures, actual means of evacuation, reception facility, contingency plans, possible safe havens and anything else involved in a successful hyperbaric evacuation[18].

The equipment that supports the hyperbaric evacuation arrangements includes:

- hyperbaric rescue unit (HRU) – this can be a self-propelled hyperbaric lifeboat (SPHL) or hyperbaric rescue chamber (HRC);
- life support package (LSP);
- hyperbaric reception facility (HRF), if applicable.

Note: It is not acceptable to plan from the outset of a project to use a diving bell as a hyperbaric rescue unit.

The HRU should be capable of maintaining the divers at the correct pressure and with life support for a minimum of 72 hours (see *IMO Guidelines and Specifications for Hyperbaric Evacuation Systems Resolution A.692(17)*).

There are four distinct phases from the decision to launch the HRU until safe decompression of the divers, which are as follows:

Phase A – transfer of the divers into the HRU and make it ready for launch (with a maximum time to undertake this – 15 minutes);

Phase B – the launch of the HRU and for it to be 100 m clear of the vessel/installation being evacuated (with a maximum time to undertake this – 30 minutes – the time starting when the instruction to launch the HRU is given);

Phase C – the transit of the HRU to the reception site

The time taken to get the HRU to a safe haven should be as soon as possible and planning should be based on arrival at the safe haven within 75% of the HRU designed endurance

The safe haven is where the HRU arrives on completion of transit. This can be the reception site, or the point at which the HRU is loaded onto transport and taken to the reception site;

Phase D – safe decompression of the divers

The reception site is where the HRU will be taken for the safe decompression of the divers to be completed. The site can be the location for the LSP where the decompression can be carried out (or completed) in the HRC or SPHL using the LSP, or transfer into a portable HRF (which system is in place will have been agreed by the client), or a permanent HRF.

A vessel with a single HRU should, when alongside a fixed or floating structure, barge, vessel or in port, not be positioned with the HRU such that it may get damaged or cannot be launched when required.

14.34.2 Evacuation Planning, Procedures and Equipment

The decision to decompress the divers in the HRU using an LSP or providing an HRF into which the divers can be transferred, decompressed and receive medical treatment should be based on a risk assessment directly involving the client. The items to be considered are amongst others:

- working/storage depth;
- prevailing weather and sea conditions;
- distance and duration to a safe haven/reception site;
- HRC or SPHL;
- medical aspects during transit and anticipated medical treatment requirements.

As part of the planning the availability and level of support should be ascertained, which can be provided by the client or others near the location where the saturation diving work is going to take place.

Each saturation system should have project specific hyperbaric evacuation and rescue plans and procedures, which have been risk assessed, for the location(s) and water depth where the work is planned to be carried out.

Guidance on the elements to be considered for the planning and execution of a hyperbaric evacuation and subsequent decompression, including, training and risk assessment can be found in IMCA D 052[18].

The HRU, LSP and HRF will need to comply with the requirements contained in IMCA D 024[4] and IMCA D 053[19] as well as *IMO Guidelines and Specifications for Hyperbaric Evacuation Systems Resolution A.692(17)*.

In an emergency, it is possible that the HRU will be recovered by personnel without experience of diving systems. To ensure that the rescuers provide appropriate assistance and do not take any actions hazardous to the divers, the International Maritime Organisation (IMO) has agreed on a standard set of warning instructions and other markings to be permanently displayed on every HRU (see IMO Resolution A.692(17)). The warning instructions will normally be shown in at least two separate locations. These warning instructions and other markings must be clearly visible when the HRU is floating.

All equipment and the documentation required for the efficient management of hyperbaric evacuations should be risk assessed and audited.

Hyperbaric rescue drills should be included in the regular on-board fire and boat drills, after agreement with the ship's captain or OIM. HRCs and SPHLs should have a practice deployment and recovery every six months to check that all systems operate and that personnel know their duties. Other worksite hyperbaric evacuation/rescue drills and exercises (excluding launch and recovery of the HRU) should be carried out regularly[18].

Bell diver rescue drills should be done early in the sat period (first two to three bell runs) and every 14 days thereafter. It is recommended that such drills should practice the recovery of a completely incapacitated saturation diver to the interior of the bell and that the drill should only end when the door inside the bell has been successfully closed.

14.34.3 Accelerated Emergency Decompression from Saturation[15]

There may be circumstances where the HRU is out of action, the weather conditions may prohibit launch of the HRU or reception facilities may be not available. In any of those circumstances emergency decompression from saturation may offer the best opportunity of the divers' survival. DMAC guidance on emergency decompression[15] is available.

1	IMCA D 014	*IMCA international code of practice for offshore diving*
2	IMCA D 023	*DESIGN – Diving equipment systems inspection guidance note for surface orientated (air) systems*
3	IMCA D 037	*DESIGN for surface supplied mixed gas diving systems*
4	IMCA D 024	*DESIGN for saturation (bell) diving systems*
5	DMAC 28	*The provision of emergency medical care for divers in saturation*
6	IMCA D 018	*Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment*
7	AODC 059	*Pressure gauges and other forms of pressure monitoring equipment used in conjunction with diving operations*
8	IMCA D 011	*Annual auditing of diving systems*
9	IMCA D 047	*Acrylic plastic viewports*
10	IMCA D 050	*Minimum quantities of gas required offshore*
11	IMCA D 031	*Cleaning for oxygen service: Setting up facilities and procedures*
12	DMAC 26	*Saturation diving chamber hygiene*
13	IMCA D 041	*Use of battery operated equipment in hyperbaric conditions*
14	DMAC 07	*Recommendations for flying after diving*
15	DMAC 31	*Accelerated emergency decompression (AED) from saturation*
16	DMAC 15	*Medical equipment to be held at the site of an offshore diving operation*
17	IMCA D 051	*Hyperbaric evacuation systems (HES) interface recommendations*
18	IMCA D 052	*Guidance on hyperbaric evacuation systems*
19	IMCA D 053	*DESIGN for the hyperbaric reception facility (HRF) forming part of a hyperbaric evacuation system (HES)*

General Safety Requirements

15.1 Risk Assessment

The diving contractor's responsibilities include provisions to ensure that a risk assessment has been carried out[1]. Risk assessments will normally have been carried out for all the routine diving procedures and the results included in the company manual. The project manager, diving superintendent and diving supervisor may, however, be involved in carrying out site- or task-specific risk assessments.

The basis of risk assessment is task analysis, sometimes called job analysis or job safety analysis. The aim is to break each task down into steps and identify the significant risk associated with each step. Procedures are then devised to reduce or remove the risk.

Most companies provide some type of risk assessment form to ensure a systematic approach. Headings include:

- a full description of the task broken down into steps;
- an identification of the hazards involved in each step;
- the hazard ratings (see section 15.2);
- a list of all personnel likely to be involved or affected. This may include personnel who are not part of the diving team and personnel on different vessels or installations;
- controls to be implemented (training, procedures, protective equipment);
- the hazard ratings after the controls are implemented;
- monitoring procedure to ensure that the controls are implemented and effective;
- review procedures.

If it is not possible to reduce the risk to an acceptable level, then an alternative must be found.

Risk assessments should be based on the actual activities on the worksite, not on the written procedures. If personnel are not following procedures properly, additional risks can be introduced.

As far as possible, the assessment should consider the effects of unusual or infrequent events. Accidents frequently occur when non-routine activities are taking place or when there are interruptions to routine activities.

It should consider personnel who might be particularly at risk or subject to special risk. These might include new or inexperienced members of the diving team or team members who are not fluent in the language in common use on the worksite.

There may be a number of different hazards associated with each step of a task and each one must be assessed and controlled.

Once the controls are in place, they must be monitored to see if they are effective. Procedures must be in place to carry out regular reviews and to make changes on the basis of feedback from the worksite and changes in the tasks.

Offshore experience has shown that many major incidents occur when changes are made to procedures, equipment, activity or approved practice without re-evaluation of potential impacts with reference to established procedures. An organisation's procedure for the effective management of change (MoC) should include the specification of criteria which personnel at all levels may use to identify, evaluate and request a change.

Each diving contractor should have in place an MoC procedure which describes what actions should be taken if there is a need to revise an existing approved design, fabrication or work/installation procedure and how to manage change associated with unplanned events that may arise during the offshore works.

Normally a formal review of the change should take place to ensure that safety is not compromised.

When an offshore risk assessment is required senior personnel, typically the diving superintendent/offshore manager, vessel master, diving supervisor, project engineer and client, should carry out this risk assessment. The contractor's management of change procedure needs to describe clearly the process to be followed, including the requirement for offshore and onshore reviews and risk assessments and who needs to give approval offshore and onshore both from the contractor and the client, for any revision or change[2].

All personnel should be encouraged to report potential hazards, incidents and near misses to the diving supervisor. It has been estimated that there are about 400 near misses for every fatality. That is 400 warnings that have been ignored.

15.2 Hazard Rating

Risk is usually rated according to the seriousness of an accident and the probability of the accident taking place. An air crash, for example, is a serious and usually fatal accident but is very unlikely. Thus flying has a low hazard rating. In a game of rugby football minor injuries are quite possible and this has a medium hazard rating.

Various methods have been devised to carry out a systematic risk measurement. The simpler methods, which are adequate for physical risk management, evaluate only the probability and the seriousness of the accident. More sophisticated methods, which may be carried out using specially designed software, also include the frequency of exposure to the hazard and consider financial as well as physical risk.

The probability of an accident occurring can be rated on a scale of 1 to 5:

1	*Extremely Improbable*. An accident could only occur under freak conditions. This should be the normal status on the worksite.
2	*Improbable*. An accident might occur if other factors were present but the risk is minimal. Examples might include a cracked electrical plug or worn taping on an umbilical.
3	*Possible*. The accident may occur if an additional event takes place. This additional event is a specific action, or failure to act, not a random event. An example might be failure to analyse gas at the quad before connection. If there is a further failure to analyse the gas at the control panel, an accident could occur.
4	*Probable*. The accident could be precipitated by wind, vessel movement, vibration or human carelessness. Examples might include an unsecured ladder or a poorly secured single gas cylinder.
5	*Highly Probable*. If work continues there will almost certainly be an accident. Examples might include an exposed electrical conductor, a hatch left open on a walkway or an LP fitting used on an HP system.

There is often some discussion before categorising an item. It could be argued, for example, that an unsecured ladder would almost certainly lead to an accident and should therefore be given a rating of 5 rather than 4.

The seriousness of an accident can be rated in a similar way:

1	*Trivial injury*. The injury can be treated on site and does not prevent the casualty from working.
2	*Minor injury*. Injury or disease that keeps the casualty off work.
3	*Serious injury*.
4	*Major injuries*. Serious injuries to a number of people.
5	*Death to one or more people*.

On the basis of the probability and severity ratings, a risk matrix can be constructed to give a hazard rating:

Severity → **Probability ↓**	**1**	**2**	**3**	**4**	**5**
1	Low	Low	Low	Low	Low
2	Low	Low	Medium	Medium	Medium
3	Low	Medium	Medium	Medium	High
4	Low	Medium	Medium	High	High
5	Low	Medium	High	High	High

If, for example, a transfer lock door were left open, an accident might occur if the trunking door were also left open and an attempt was made to remove the trunking clamp under pressure. The chances of this happening are small and the probability rating would be 2. If such an accident did occur, however, it would result in fatalities, giving a severity rating of 5. From the matrix, leaving the transfer lock door open has a medium hazard rating.

There may be other hazards associated with leaving the door open. An unsecured door could swing in a heavy sea causing injury or damage to valves or fittings. In some operations there may also be a risk associated with gases from a contaminated bell atmosphere.

The risk assessment should also consider the hazards of keeping the door closed. What, for example, are the risks associated with the divers being trapped in their chamber if the door seals?

It is not necessary to carry out risk assessment to a very detailed level and list every trivial hazard. Common sense will usually show how far to go.

Further guidance on the risk management process and on preparation of diving project plans is contained in section 7 of IMCA D 014[1].

15.3 Approaches to Safety

Almost all accidents are avoidable and frequently caused by a failure to follow procedures. Even equipment failure can usually be attributed to incorrect use or inadequate maintenance.

The responsibility for safety rests with the diving supervisor. He must ensure that procedures, training and maintenance programmes are followed, safety equipment is used and that the diving team adopts a safe attitude to work.

He can instil a safe attitude into the team by clearly adopting a safe attitude himself. Whilst he will always be under pressure to get the job done he must put safety first and be seen to put safety first.

Many companies use regular shift meetings or toolbox briefings to raise safety issues and allow feedback from the team. Other personnel who are not members of the diving team may also be involved in the diving operation. They should be briefed and allowances must be made for their lack of diving knowledge.

Every member of the team must follow the procedures laid down and should also understand why they are following them. After a period of time, when the team has become completely familiar with procedures, there is sometimes a tendency to become casual. This is typically seen in the use of checklists. Items are ticked off without being properly checked. It is at this stage that accidents may happen.

Good communication, in the broadest sense, is fundamental to safety. It includes correct voice procedure during a dive, clear briefings and instructions, incident reporting and the freedom and willingness of team members to raise safety points with the diving supervisor.

Experienced team members should be encouraged to pass on their experience to beginners and beginners should feel free to ask questions. The diving supervisor should keep the team up to date on all safety notices, company procedures and legislation.

During dives the whole team should be in the habit of keeping each other informed about what is going on. In some operations both efficiency and safety depend on several groups of people, often in different parts of the vessel, remaining in close contact.

Particular care must be taken in passing over information at shift changes. Every team member should have a clearly defined opposite number to hand over to.

15.4 Personal Protective Equipment (PPE)

The type of PPE required for any task will be identified in the risk assessment. The diving supervisor must ensure that the appropriate PPE is worn, make the necessary equipment available and ensure that it is suitable for use. Personnel should not be expected to wear scratched and opaque safety glasses, torn and dirty gloves or oil soaked work vests.

For work on deck, basic PPE consists of helmet, overalls, working gloves and safety boots. Some installations require personnel to wear safety glasses at all times on deck. There may also be a specific requirement for orange or brightly coloured overalls to aid the location of anyone who falls overboard. A work vest or safety line must be worn if working over the side.

Anything which interferes with the ability to see or hear can contribute to accidents. Problems may be caused by large hoods which interfere with peripheral vision or sunglasses in poor light. MP3 players or other personal music systems are distracting and seriously interfere with hearing.

There are specific hazards associated with gas handling. There may be a requirement for personnel to wear safety glasses, gloves (even if working below decks) and ear defenders. The noise of venting gas does not have any short term effect on the hearing but may have serious long term effects.

PPE may also be required in the water. Divers using a band mask in the splash zone, or any area where there is a risk of head injury, should be provided with a suitable protective helmet.

Other in-water PPE includes gloves, barrier cream, disposable oversuits and totally enclosed diving suits for work in heavily contaminated water[3]. In all cases, the standby diver must be provided with the same type of PPE as the diver.

15.5 Good Housekeeping

Good housekeeping, or basic tidiness, is synonymous with safety. A dirty and untidy deck increases the risks of slipping or falling. Badly maintained equipment carries its own hazards and difficulty in finding equipment will certainly slow down the operation and may cause serious problems in an emergency.

The diving supervisor should:

- provide proper stowage for tools and equipment and make sure they are put away after use;
- make sure that personnel using tools and equipment pass them on to their opposite numbers at shift changes;
- have a properly organised stores system. If numbers allow, have one person per shift in charge;
- provide plenty of rubbish bags or bins, make sure people use them and make sure somebody empties them;
- delegate somebody on each shift to keep the deck clear of rubbish. It should be disposed of according to installation procedures;
- delegate someone on each shift to clean floors and ensure that cleaning materials are available;
- ensure that oil or chemical spills are cleaned up immediately;
- never allow anyone to remove gratings or hatch covers without roping the area off. Even if a hatch is only open for a minute, someone could fall down it;
- ensure that all cables and hoses are run safely and, as far as possible, kept clear of gangways;
- ensure that any head height obstruction, such as a cable tray, is painted to make it clearly visible. A yellow background with red or black stripes is commonly used;
- provide adequate lighting in all workplaces;

- ensure that all gas quads and liquid containers are clearly marked with their contents;
- ensure that, as far as possible, all hoses, pipes and cables are colour coded;
- ensure that emergency equipment, such as BA sets, fire extinguishers and shut off valves and emergency exits are not obstructed by other equipment or rubbish;
- ensure that any special handling procedures are followed for items such as hazardous chemicals or explosives.

15.6 Wire Ropes and Slings

Most wire ropes are constructed from six strands laid around a fibre core. The core allows the strands to bed in and take up their natural positions when the rope bends or stretches. It also acts as an absorbent for lubricating oil.

The strands are made up of single wires, each running the full length of the rope. The number of wires in a strand depends on the application. A large number of small diameter wires gives the rope flexibility, a smaller number of large diameter wires gives the rope resistance to wear at the cost of some flexibility. Galvanised wires, or in some cases stainless steel wires, are used for resistance to corrosion.

Ropes stretch under load. Permanent constructional stretch occurs when the rope is first used and the strands settle and the core compresses. It is irreversible and the rope may be pre-stretched during manufacture. Elastic stretch occurs during normal use and, if the elastic limit is not exceeded, the rope will return to its normal length when the load is removed.

The size of a wire rope is normally given as its greatest diameter. (The size of fibre rope is normally given as its circumference.) It may also be classified according to the number of wires and strands. A 6 x 19 (12-6-1) rope consists of 6 strands, each with 19 wires laid 12 around 6 around one central wire.

For general working, a wire rope should have a safety factor of 5. In other words, the rope or sling should not be used for loads that are greater than one-fifth of its breaking strain. The large safety factor is necessary to allow for errors of judgement, shock loading and the unforeseen. No equipment should ever be used for a load greater than its SWL.

For wire ropes used for man-riding, the safety factor should be 8[1]. The SWL for ropes may be shown on the rope or contained in the documentation.

Wire ropes must be stored on drums or in coils to avoid kinking. To remove a wire rope from a drum, put a bar through the centre of the drum and support it securely so that the drum can rotate freely. Pull the rope off straight ahead. Have someone control the rotation of the drum so that the rope remains tight and loose coils do not form on the drum.

To unroll a coil, roll it along the deck leaving the rope straight behind. If it is too heavy to roll, it should be placed on a turntable and pulled out. Place a cross piece on top to stop loops jumping free and kinking.

A single part sling is made from a single length of rope with an eye splice round a thimble at each end. A double part sling is made from a loop with thimbles fitted into the end of the loop. The loop may be made by splicing the ends of a length of rope or be constructed directly from laid rope.

The SWL of a made up wire sling is usually stamped on the collar. This applies in normal use, but if the sling is subject to extra strain by running over a hook or shackle the SWL will be reduced.

Multi-legged slings should ideally be used with the legs at less than 90° to each other and never with the legs at more than 120°. The SWL with legs between 90° and 120° is about 0.7 of the SWL with the legs at less than 90°.

If a rope or sling shows any sign of damage or deterioration it should not be used. It should be returned to a responsible person to ensure that it is taken out of commission.

The SWLs of all shackles and hooks must also be checked. The rigging system is only as strong as its weakest component.

Homemade rigging, such as eyes made in slings with bulldog grips, brackets or clamps welded on site, etc. should not be used.

Particular care has to be taken when lowering loads into the water. Crane hooks should have a secured lock, to prevent the load lifting as it enters the water and twisting the sling off the hook. Note that a simple latched hook is not sufficient[4].

15.7 Winches and Tuggers

The way in which a wire rope is spooled onto a winch or tugger drum depends on the lay of the rope. If the rope is incorrectly spooled, the coils tend to separate when the load is removed and may overlap and crush when the load is re-applied. A correctly spooled rope causes the coils to pack when the load is removed.

The fleet is half the length of the drum and is the distance moved by the rope from the centre to the edge of the drum as it winds or unwinds.

If the rope leads from the drum to a fixed sheave, there will be abrasion on the sides of the sheave and the drum as the rope travels across the drum. To minimise this abrasion, the maximum angle of the rope at the sheave, known as the fleet angle, should not exceed 1.5°.

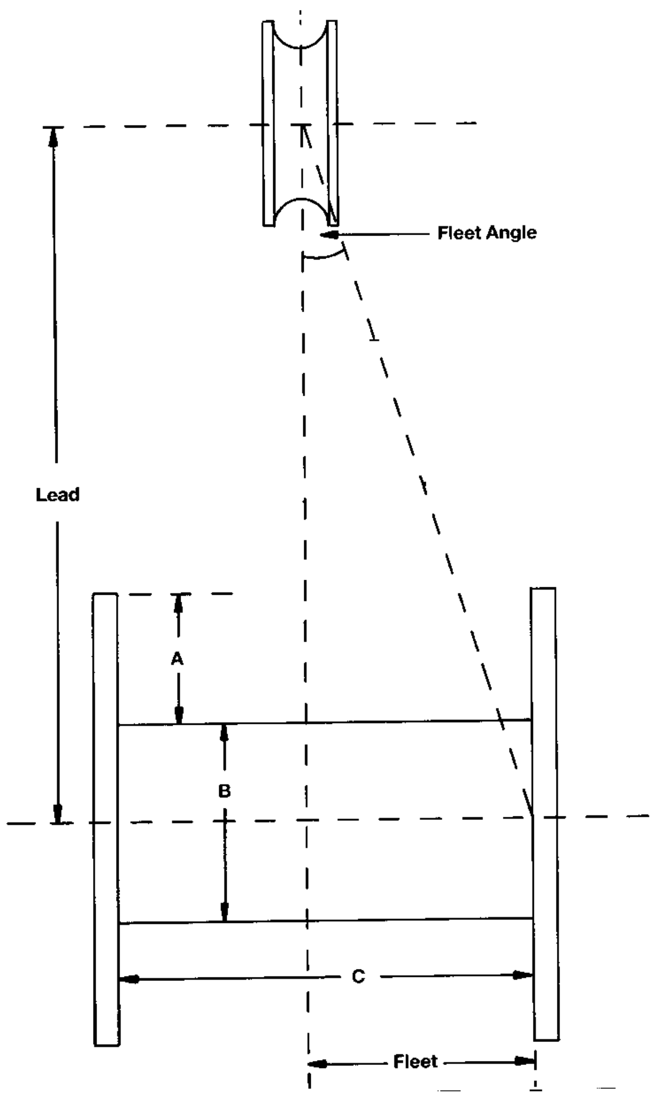


Figure 15-1 – Winches – lead and fleet

In practical terms, the fleet angle is measured by comparing the fleet with the lead, the distance from the centre of the drum to the centre line of the sheave shaft. There must be at least 38 m of lead for every metre of fleet.

The following general rules should be followed when operating winches:

- make sure that the person operating the winch is well briefed and trained in the use of the equipment, has attended the toolbox talk and is fully conscious of the task to be undertaken;
- there must be voice communication with the winch operator;
- check the winch and cable before use. In particular check the SWL and the length of cable on the drum. There should be enough cable to carry out the work and leave at least five turns on the drum;
- the drum should not be overloaded with cable. Normally there should be about 2.5 times the diameter of the winch wire between the outside of the top layer of the wire and the edge of the drum flange;
- make sure that rotating parts are covered by guards and keep the surrounding deck clean and clear of rubbish or obstructions;
- do not allow excessive side loading on the cable and make sure that the cable will not cause any danger when it tightens;
- do not allow the winch to be left unattended with power on;
- ensure that operating instructions are clearly displayed;
- follow the maintenance schedules.

There are specific requirements for winches for bells and diving baskets. See sections 10.2 and 13.5.

15.8 Lifting Loads[5 6]

An inexperienced person frequently underestimates the forces involved in rigging and lifting. Typical accidents include trying to stop a heavy swinging load and having the hand, or body, crushed against a bulkhead, or trying to straighten a tugger cable while the drum is rotating and having fingers trapped. At the other extreme, an inexperienced person may injure himself by attempting to lift a weight which is too heavy for him.

The following points give general guidance for good practice in lifting loads:

- establish an effective system of communication;
- ensure that you use a well understood and uniform code of signals;
- ensure that there is only one designated signaller. A stop signal should, however, be obeyed by the crane driver regardless of who gives it;
- check that the area is clear before lowering a load;
- the signaller must never give the signal to lift until he has clearance from the person slinging the load;
- nobody must ride on loads;
- awkward loads, like pipework, should be given a trial lift to check for stability;
- always use the correct slings;
- do not attach slings to bands, strops or fastenings on packages unless they are specifically designed for lifting;
- protect slings and edges against abrasion with strips of softwood or other suitable material;
- always use four-legged slings on trays or pallets, and fix a net if necessary to stop items falling off;
- use the correct slings with spreaders on long loads;
- always raise and lower loads smoothly and lower immediately if the load shows signs of slipping;
- do not lift loads over personnel or get underneath loads;

- never leave winches or cranes unattended with loads slung.

When a crane is being used in diving operations the diving supervisor should have a primary (dedicated and preferably hard wired) and secondary means of voice communication with the crane driver.

IMCA's main guidance on lifting operations may be found in IMCA M 187[5].

There are specific requirements for lifting bells and diving baskets. See sections 10.2 and 13.5 of this document.

15.9 Hand Tools

Many accidents are caused by badly maintained or incorrectly used hand tools. Injuries typically occur to the hands or eyes and people other than the user may be affected. The commonest faults are:

- split hammer shafts;
- loose hammer or pick heads;
- damaged or missing file handles;
- worn spanner jaws;
- using the wrong tool for the job. Using a spanner as a hammer, for example.

Injuries may also be caused by tools that are dropped by personnel working overhead.

It is the responsibility of the diving supervisor to ensure that members of the dive team use the correct tools for the task, and that the tools are well maintained and fit for use.

15.10 Electrical Power Tools on Deck

Electrical power tools should be used with care in the wet and only if they are designed for this purpose. They should never be used if the cable, plug or socket is damaged or if they run intermittently or blow fuses on a regular basis. These are all conditions which can lead to a serious electric shock. In all cases, operation should be protected by an earth leakage circuit breaker (ELCB).

Power tools should only be used for the purpose for which they are intended and safety devices should never be overridden nor should triggers be tied back.

Electrical power tools should only be used where they are of a suitable, safe voltage, typically 110 volts. The transformer used to reduce the voltage provides protection.

All cables should be run securely to avoid damage and trip hazards.

15.11 Electrical Equipment in the Water[7]

Repair or maintenance of electrical equipment should only be carried out by properly trained and competent personnel. No person should work alone on high voltage equipment[1].

The following precautions should be taken when using electrical equipment in the water:

- ensure that all equipment and connections are in good condition. Pay particular attention to earth connections;
- use the lowest possible voltage;
- use DC in preference to AC wherever possible as the shock hazard is lower;
- pay attention to any insulation monitoring equipment fitted to topside units. It will warn of any deterioration in the condition of the insulation;
- if an ELCB, nowadays more commonly called a residual current device (RCD), trips it indicates that there may be an earth fault on the equipment. The fault must be investigated and RCDs (ELCBs) must never by bypassed;

- take special precautions if power is turned on to the equipment when it is still on deck. A man handling the equipment on a wet deck may be at a greater risk than a diver in sea water;
- do not attempt to modify any electrical equipment;
- do not remove electrical equipment which is normally bolted onto a bell, habitat or other structure. The bolts may provide the earth connection.

If the diver is working on impressed current anodes the dive plan will require precautions to be taken against electric shock. These may require the current to be turned off.

IMCA D 041[13] lists electrical items that are prohibited in chambers because of the risk of electric shock, fire or toxic fumes.

15.12 Oxy-Arc Cutting[8]

Always investigate the use of cold cutting techniques (diamond wire cutting; drilling; powered hacksaw, etc.) before resorting to oxy-arc cutting.

During oxy-arc cutting operations there is a risk of electric shock. Further problems may be caused by the electrolytic effect of the current, which produces hydrogen and oxygen. If the gases collect in an enclosed space, forming a gas pocket, they may detonate with sufficient force to injure or kill the diver. Increasing depth increases the density of the gas in a gas pocket, increasing the potential energy and the force of any explosion.

The assessment of the explosion hazard should play a key role in the risk assessment. If it is concluded that there is a significant risk of explosion, an alternative method must be found.

Gas pockets may occur in the following situations:

- material to be cut in contact with earth or mud – oxygen from the cutting torch may jet into the earth or mud beyond the metal being cut, creating cavities which may trap gas;
- material encased in concrete – when cutting a concrete coated pipeline, gas may track between the pipe and the coating, forming laminar gas pockets;
- annular spaces – when cutting pile guides, for example, gas will travel up inside the annular space. Normally it should escape, but if the exit is blocked by mud or debris, gas pockets could form;
- flat and horizontal surfaces – flat surfaces overhead may trap large volumes of gas in 'flat' bubbles;
- large mass of material being cut – burning large bolts or nuts from below will, if the burn is directed towards the centre, create mini-cavities in the molten metal and explosions will be inevitable. Cutting should start at the edge and progress at a tangent.

Blow backs are explosions at the cutting point. They are generally of low intensity but have been large enough to cause equipment damage. They appear to be caused by hydrogen generated inside the rod in the short time interval between energising and striking an arc. Flushing the rod with oxygen before energising should minimise the risk.

Explosions may also occur because of explosive or inflammable materials on the worksite. These include hydrocarbons inside a pipeline or structure, or in the mud, paint or bitumastic coatings and some light alloys such as those used in sacrificial anodes.

Before cutting into an enclosed space like a pipe, tank or tubular, a vent hole must be cut open in the upper part in order to allow gases that may be present, as well as cutting gases, to evacuate. If necessary, the gas trap above the vent hole should be vented or flushed with inert gas or its contents pumped out through the vent hole during the whole of the cutting activity.

If the presence of a flammable gas is suspected in the enclosed space, the cutting of the vent hole should be carried out using cold cutting techniques. Note also that if there is a pressure differential between the inside of the enclosed space and the surrounding water, there is a danger of pressure release or of suction.

If the diver places himself between the torch and the earth clamp the same electrolytic process will cause rapid corrosion of the metal valves on his helmet. The associated electromagnetic field may also cause sparking between fillings in the diver's teeth.

The polarity should always be tested. Connections may be incorrectly labelled or the generator may be incorrectly wired. Place an electrode in the torch head. Immerse the torch and earth clamp in a bucket of salt water, making sure that they do not touch. If the polarity is correct small bubbles will flow from the electrode when the power is on.

The following precautions should be taken:

- the equipment should be connected and used according to the manufacturer's instructions and the procedures in the dive plan;
- ensure that the diver is aware of the hazards involved and is properly trained and competent in the use of the equipment;
- any excess cable should be uncoiled and laid out on the deck. Electromagnetic forces in a coiled cable will reduce the efficiency of the power supply;
- a polarity check should be made on deck and a test cut made to ensure the equipment is functioning correctly;
- the metal surface should be cleaned to give good electrical contact when the earth clamp is connected. The clamp should be fixed as close as possible to the planned cut. Never use the ship or support vessel as earth, and do not hang the earth in mid-water;
- ensure that the diver wears rubber gloves when cutting;
- ensure that the diver is placed securely and that he is not between the torch and the earth clamp or standing in a bight of cable;
- ensure that the diver is placed to one side of the area to be cut and not directly in front of it. This should ensure that if an explosion does occur the blast energy is not directed straight at the diver's helmet and faceplate. The supervisor should check the diver's location constantly throughout the operation;
- ensure that the torch is sent down to the diver with the power off;
- ensure that the diver checks for any potential gas pockets;
- ensure that the diver checks below him to ensure that molten slag will not drop on to him, his umbilical or other equipment;
- never turn the power on unless the diver asks for it and is ready to start cutting immediately;
- ensure that the diver never has the power on when he is changing electrodes, when he leaves the worksite, returns to the bell or comes to the surface;
- never allow the diver to point a torch at anybody, whether the power is on or off.

To minimise the risk of blow back, the procedure for striking an arc is as follows:

- check that the diver is in a suitable position to start cutting (see above);
- ask the diver to flush the torch with oxygen and maintain the flow;
- on the diver's request, energise the torch;
- the diver should strike the arc and begin cutting;
- if the diver fails to strike an arc or has difficulty maintaining the cut, the torch must be flushed with oxygen again before resuming.

15.13 Wet Welding

The following precautions should be taken in addition to those listed for oxy-arc cutting:

- only use an underwater welding torch of approved design;
- ensure that the diver uses a welding visor to protect his eyes;
- never allow damaged electrodes to be used;
- ensure that the electrodes are kept dry until use.

15.14 Power Tools in the Water

All power tools should have a dead-man handle, an on-off lever which must held in the on position during operation. It should be impossible to lock the handle in the on position and it should never be tied back.

Ideally, the power supply should be controlled from the surface. The diver should ask for 'power on' when he starts to use the tool and 'power off' each time he stops using it. This prevents any accidental operation by the diver.

Before supplying power to the diver the diving supervisor should check that he is securely placed, that his umbilical is clear and that he is clear of any other cables or downlines. A rotating tool will tend to rotate the diver, possibly with dangerous consequences.

Any power tool that becomes defective in the water should be changed out immediately.

There are particular hazards in the use of cutting and grinding disks. Some countries require personnel who fit or operate abrasive disks to have completed an approved training course. This also applies to disks used underwater.

The adhesive used in disks tends to degrade underwater and the dive plan should ensure that only dry disks that have not previously been exposed to water are used and that only enough disks for each dive are taken underwater at a time[1].

The following precautions should be taken:

- ensure that the rotational speed of the power tool is no greater than the safe maximum speed stamped on the disk;
- ensure that disks have the correct arbor size and the correct centre fitting. The centre of the disk will be either flat or dished;
- ensure that the correct tool is used for fixing the disk;
- ensure that disks are only fitted or removed with the main power supply off;
- ensure that the choice of disk for a specific job is based on the manufacturer's recommendations. Underwater conditions may affect the efficiency of a disk.

15.15 HP Water Jet[9] [10]

Even an apparently minor jetting injury can be very serious and medical aid must be called immediately. The jet will have carried infection deep into the body tissues and the casualty's condition may deteriorate rapidly in the next few hours. Typical sites for water jet injuries are the arms and legs. A jetting injury in the chest could be immediately fatal.

To avoid the risk of injury, a water jet should never be used when there are two divers in close proximity in the water. Special care should be taken when working from a DP vessel since the noise may interfere with acoustic reference systems.

Procedures will be in the dive plan and should include the following:

- check that the working pressure of the compressor does not exceed that of the gun and hoses;
- check the condition of all hoses, hose couplings and connections, nozzles and lances;
- ensure that whip checks are fitted to all hose connections;
- check the operation of all valves, triggers and safety catches;
- check that the diffuser tube on the retro jet is secure;
- check that all safety valves on the compressor are pre-set and sealed. Check the condition of the seals. A missing seal may mean an incorrectly set valve that would not release pressure in an emergency;
- on diesel driven units check that the power take off clutch will engage and disengage freely;

- before supplying high pressure to the gun, check that the diver is placed securely and is holding the gun firmly with both hands;
- only supply high pressure to the gun when requested by the diver. The gun must never be lowered to the diver on load or returned to surface on load;
- do not allow the diver to tie back or wedge the trigger;
- if the gun fails to shut off completely when the trigger is closed it is defective and the operation should stop until it has been repaired or replaced;
- after use, shut down the compressor and release the pressure from the system by operating the gun.

15.16 Hazardous Materials

The diving crew may encounter a variety of hazardous materials, either used as part of a procedure or unavoidably present during a procedure. In all such cases, contact with hazardous materials must be included in the risk assessment. Data is normally obtained from a material safety data sheet (MSDS) but expert assistance may also be required.

The risk assessment should consider the effects on the divers in the water and the deck crew, and the effects of the hazardous material being carried into a chamber. The effects and the preventative measures may be different in each case. Preventative measures may include:

- the use of barrier cream on unprotected areas of skin by all divers and deck crew likely to come into contact with the material;
- disposable coveralls and rubber working gloves for all divers and deck crew likely to come into contact with the material;
- a separate downline for all equipment associated with the material. This downline should not be used for any other equipment;
- procedures to prevent contaminated equipment or clothing being taken into a bell or chamber. In some cases, very small amounts of contamination can cause significant problems, even in a large chamber.

The supervisor must be fully aware of the hazards, the symptoms of toxicity and the associated emergency and medical procedures. Typically, the affected person should be removed to an uncontaminated environment and medical advice should be sought. The onshore doctor will need full details of the hazardous material from the MSDS, and the type and length of exposure.

15.17 Explosives

An underwater explosion causes a much more powerful shockwave than an explosion in air. Divers have been injured and killed both underwater and on the surface. There may also be a risk to surface vessels. In an area of intense diving activity consideration should be given to divers on other worksites. Even a small charge can have effects at a distance of one nautical mile.

Explosives should never be detonated until the divers are clear of the water and all vessels are in safe locations.

On deck, the explosives should only be handled by trained personnel. They should only be placed underwater under the direct supervision of the diving supervisor, acting with the advice of an explosives engineer.

15.18 Radioactive Sources and Dangerous Substances

Dangerous substances must only be used under the supervision of a qualified and designated person and should be securely stored in a properly marked container. Any door or hatch giving access to the place where the substance is stored should also be clearly marked.

Any person working with radioactive sources, or X-ray equipment, must be briefed on the risks involved and should be provided with a dosimeter or film badge.

15.19 Lifting Bags[11]

Lifting bags are a major piece of lifting equipment and should be treated as such. The manufacturer should supply information about safety factors, SWL, testing, maintenance and the uses for which the bag has been designed.

The bag and all its individual components should each be marked with a unique serial number and the SWL. Components include strops, rings, shackles, etc. and a list of component parts should be supplied with the bag. A bag should not be used if it has modified or replaced components not approved by the manufacturer.

Records should be kept for each bag and it should be included in the planned maintenance system. Examination and test criteria are given in IMCA D 016[11].

Air bag lifts are segregated into two general categories – static and dynamic:

- **Static lift** – this is where an air lift bag is secured by hold-back rigging and used as a single lift point, commonly known as a 'skyhook'. The air lift bag has very positive buoyancy, but it is directly restrained to anchor points, therefore, the lift bag is fixed and the load is free to move vertically with the use of a suitably approved lifting device;
- **Dynamic lift** – the air lift bag is used to lift the load directly, and used typically for the movement of loads between locations. The air lift bag and the load tends to be neutrally buoyant with a system of restraints in place. In such instances the lift bag and load are moved together.

Parachute bags should be fitted with a suitable attachment point at the top to allow an inverter line to be fitted to the bag. For all dynamic lifts the inverter line must be long enough to attach to the load and invert and spill the gas from the bag if there is a failure on any part of the rigging and the bag breaks free and starts an uncontrolled ascent. The line should be strong enough to resist the snatch load caused by a rapidly ascending bag, bearing in mind that a longer inverter line will allow the bag to achieve a greater upwards velocity and, hence, will create a larger snatch load. For this reason the slack in the inverter line should be minimised (no more than one foot of slack is recommended).

There should also be a restraining line (usually known as the 'hold-back line') from the load to a suitable anchor point. Commonly, a dead man anchor (DMA) is used. It must be strong enough to prevent the uncontrolled ascent of the load if the lifting bag or bags are over-inflated.

It is important to be clear about the different purposes of these two lines:

- The inverter line is in place to invert and spill the gas from the bag if there is a failure on any part of the rigging between the bag and the load and the bag breaks free and starts an uncontrolled ascent i.e. its purpose is to invert the bag if it becomes detached from the load being lifted. The inverter line is not intended to invert the parachute bag when it is still attached to the load and its rigging is still under tension. For all dynamic lifts the inverter line should always be attached to the load being lifted by the parachute bag[1];
- The hold-back line is provided to restrain or hold-back the positive buoyancy of the lift bag. It should be attached in such a way as to prevent an uncontrolled ascent of the load being lifted. It should be fitted between the load being lifted and a suitable fixed point.

Inverter lines and hold-back lines are vitally important safety control measures for lifting operations that involve the use of underwater air lift bags. A suitable inverter line should always be used with parachute type bags. In normal circumstances hold-back rigging should be attached to an independent anchor point. A risk assessment needs to be conducted if, for any reason, it is proposed that this attachment is omitted. Figure 15-2 illustrates the correct usage of inverter and hold-back lines with parachute lifting bags during a complex dynamic lift.

[1] If an inverter line is attached to a DMA it cannot (and should not) be expected to act as a secondary means to ground a buoyant lift bag and load that is heading for the surface. In such circumstances the tension on the lift bag exerted by the load will make it very difficult or impossible for the inverter line to invert and empty the bag from the crown. The most likely scenario is that the inverter line will come under great tension and simply part. Inverter lines should never be attached to anything but the crown of the bag and the load itself during dynamic lifts. It is the hold-back line that is used to prevent an uncontrolled ascent of the load being lifted, not the inverter line.

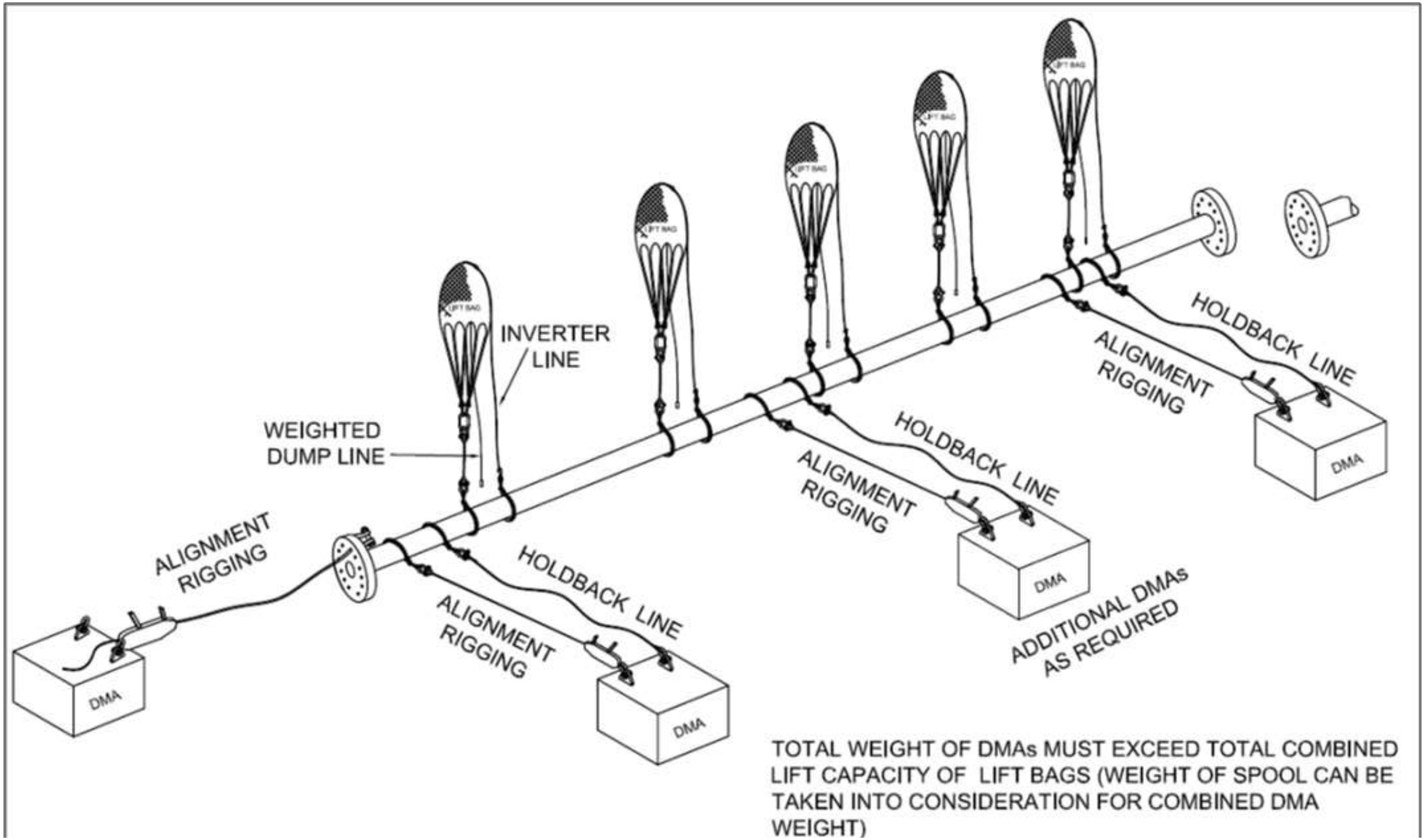


Figure 15-2 – Multiple air bag lift – dynamic

Parachute bags should also have a dump valve, which can be operated by a line, usually running down inside the bag, which can be easily reached by the diver and operated from a safe location. The dump valve line and the inverter line should ideally be of different materials and sizes so that they can be easily distinguished.

Totally enclosed bags must have relief valves. These should be tested before use and must be set to maintain an internal pressure sufficient to fully inflate the bag. They are designed to be used in the horizontal position and should never be rigged so that they are vertical or can rotate to a vertical position.

Since they cannot be over-inflated, bags cannot lift loads greater than their designed SWL. The associated rigging may, however, be subject to additional snatch loads under the following conditions:

- when the bag is used in shallow water it may be subject to wave action;
- when the bag lifts the load to the surface it may be exposed to wave motion;
- when the bag is incorrectly rigged or becomes snagged and breaks free;
- when the lift is assisted by a crane and changes in dynamic loading are caused by vessel movement.

Incorrect rigging can also cause the SWL to be exceeded on individual components, by allowing all the load to fall on a single strop, for example. If two bags are attached to a single lift point, the bags will be in contact. This may affect the buoyancy and loading.

Before lifting bags are used, a full assessment of the task must be carried out. It should include:

- calculations of the weight to be lifted or moved and the size and type and number of bags required;
- calculations, where possible, of the centre of buoyancy and centre of gravity of the object to be lifted, so that plans can be made to stop the object tipping or rotating;
- the positioning and attachment of the lifting bags;
- calculations of all safety factors involved.

If the weight of the object to be lifted or moved is unknown or the object is buried in mud, the load can only be estimated. Precautions should be taken before the lift bags are attached, to ensure that when they are inflated control of the load is not lost. The inverter line from the top of the bag is secured to the load itself and will perform its function (provided it is strong enough to resist the snatch load) should the lift bag attachment fail. It would not, however, prevent the load from going up in an uncontrolled fashion if the bag was accidentally over-inflated. For this reason, hold-back rigging should normally be connected to a suitable independent anchor point.

Before use, do the following for each bag:

- check the serial numbers of all components against the certificate;
- check the test date of the certificate;
- visually inspect all components, strops and stitching on the bag, even if the bag is new;
- check the operation of the dump valve on parachute bags, and the correct attachment and operation of the line operating the dump valve;
- check the attachment of the inverter line on parachute bags;
- check the operation of the relief valve on totally enclosed bags.

A spreader bar may be used to provide an even distribution of lift points. The spreader bar must have a test certificate and the SWL must be marked on the bar.

The inflation sequence should ensure that the number of partially filled bags at any one time is minimised. In general, each bag should be filled completely before starting on the next. The air hose used to fill the bag must not be tied off to the bag during inflation.

If two divers are in the water, procedures must be in place to ensure that bags are not inflated or deflated unless both divers have been informed and each knows the position of the other, and their umbilicals, in relation to the task. Poor visibility, current and surface swell may also be additional hazards.

In addition to theoretical knowledge acquired in diver training, all personnel involved in the use of lifting bags should receive training in their storage, examination, deployment, rigging, cleaning and maintenance.

15.20 Working with ROVs

For all operations where divers are working in the water with ROVs[2], the risk assessment must include all hazards associated with simultaneous operations. In all cases, the diving supervisor must have authority over the ROV supervisor or pilot whilst divers are in the water.

There should be close liaison with the ROV team and only experienced ROV pilots should be used. Inexperienced or trainee pilots should only be used on non-diving work

The following problems may occur when working with ROVs:

- diver and ROV umbilicals can become entangled;
- bell wire or umbilical and ROV umbilical can become entangled;
- the ROV and its umbilical could impede the diver's return to the bell in an emergency;
- the ROV could foul a taut wire or transponder and cause a DP malfunction;
- larger ROVs could injure the diver by collision or by their thrusters;
- ROVs are electrically powered and constitute an electric shock hazard.

There must be direct communication between the diving supervisor and the ROV supervisor or pilot. The diving supervisor should have a monitor which shows him what the ROV pilot sees.

The ROV launch system must be sited at a safe distance from the bell, wet bell, basket or taut wire.

All thrusters should be fitted with securely fixed guards to prevent the ingress of a diver's fingers, umbilical or equipment.

During operations the following procedures are recommended:

- there should be a clear chain of command understood by all concerned;
- operational procedures should be set up in advance and only changed with proper authority;
- emergency diving procedures should be understood by ROV personnel;
- emergency recovery procedures for the ROV should be established and made clear to the diving and ROV supervisors;
- all members of the diving and ROV teams should be aware of the potential hazards;
- the ROV should only be deployed or recovered during diving with the authority of the diving supervisor and precautions should be taken against fouling;
- current should be continuously monitored to assess the risk of the ROV or garage becoming entangled with the bell or diver's umbilical;
- the diver should always leave the worksite first;
- the ROV should always stand off unless given permission by the diving supervisor to move in;
- if the ROV becomes entangled the diver may assist in its recovery, under instructions from the diving supervisor. Electrical power to the ROV must be turned off;
- if the ROV loses orientation the pilot must inform the diving supervisor immediately.

15.21 Emergency Drills[12]

The diving supervisor must be fully aware of all his company's documented contingency plans and emergency procedures, both generic and those referring specifically to the diving operation and worksite. He must ensure that all members of the dive team are also aware of the procedures.

On an air diving site these should include getting the diver (including a completely incapacitated diver) out of the water or out of the chamber with due regard for decompression. If decompression is not possible contingency plans must be made for evacuation to a chamber.

On a saturation diving site plans must be made for hyperbaric evacuation. Boat and fire drills for the diving team should include these evacuation procedures.

Emergency drills should be carried out on a regular basis. These include diver recovery drills, basket or bell recovery drills and chamber emergency drills.

Bell diver rescue drills should be done early in the sat period (first two to three bell runs) and every 14 days thereafter. It is recommended that such drills should practice the recovery of a completely incapacitated saturation diver to the interior of the bell and that the drill should only end when the door inside the bell has been successfully closed.

Any lessons learnt during the drills should be discussed. Additional training should be provided as required and where applicable, emergency procedures should be modified.

15.22 Managing an Emergency

The dive plan should contain plans and procedures to deal with all reasonably foreseeable emergencies[1]. All members of the diving team should be familiar with these procedures.

If an incident occurs, the diving supervisor must assess the situation and implement the immediate action laid down in the procedures. This may be initiating a failed communications procedure, sending in the standby diver or preparing a chamber for hyperbaric evacuation. The standby diver should not be committed if he would be put at risk.

If there is any doubt, the diving supervisor should assume the worst. It is far better to send in a standby diver unnecessarily than it is to fail to send him in when he is needed.

As soon as the situation permits, the diving supervisor should inform the master of the vessel or the OIM. He should also inform the client's representative and contact his company, even if the situation is apparently under control. He may require specialist advice as he continues to manage the incident.

He should maintain a log of events and keep in close touch with all parties concerned until the emergency is over. If the incident involves a fatality or serious injury, there may be an investigation and steps should be taken to preserve and gather evidence. This may include:

- leaving all plant and equipment as it is, unless it is unsafe to do so;
- noting the position of the valves on all gas cylinders and then closing them to keep the contents for analysis (the number of turns required to close gas cylinders should be recorded);
- noting the position of all valves on the control panels;
- photographing or sketching equipment;
- getting signed and dated statements from all those involved;
- securing the dive log, voice recordings, video recordings, ship's log, maintenance records and any other relevant records.

The diving supervisor should not speculate about the causes of the incident or attempt to apportion blame before the investigation is underway. The investigation may be carried out by the diving company, client, insurance investigators, health and safety inspectors or police.

1 IMCA D 014 *IMCA international code of practice for offshore diving*
2 IMCA S&L 001 *Guidance for the management of change in the offshore environment*
3 IMCA D 021 *Diving in contaminated waters*
4 AODC 018 *Attachment of loads to lifting hooks during diving operations*
5 IMCA M 187 *Guidelines for lifting operations*
6 IMCA D 046 *Guidance on operational communications* (also IMCA M 205)
7 IMCA D 045 *Code of practice for the safe use of electricity under water*
8 IMCA D 003 *Guidelines for oxy-arc cutting*
9 IMCA D 049 *Code of practice for the use of high pressure jetting equipment by divers*
10 DMAC 03 *Accidents with high pressure water jets*
11 IMCA D 016 *Underwater air lift bags*
12 IMCA C 013 *First aid and other emergency drills*

IMCA Certification Schemes

The following information is taken from IMCA D 013[1].

1.1 Trainee Diving Supervisor

This refers to a diver who has satisfactorily completed a diving supervisor training programme (designed to comply with this scheme) but who is gaining offshore experience prior to passing the IMCA theory examination(s) and subsequent formal appointment as a diving supervisor.

Initially, a trainee diving supervisor should only be allowed to supervise for short periods and always with a properly appointed diving supervisor present. As his experience increases, these periods may be extended. However, a diving supervisor should remain in charge of the diving operation at all times and should not delegate his responsibility to the trainee.

1.1.1 Trainee Air Diving Supervisor

To qualify as a trainee air diving supervisor, a candidate must meet the following minimum criteria:

a) Hold an IMCA-recognised surface supplied diving qualification as set out in the current information note *Diver and diving supervisor certificates*. Anyone who has comparable training and experience may be referred to the IMCA Certification Schemes Co-ordinator for a decision by the Assessment Panel;

b) Have demonstrated competence as an offshore air diver in accordance with Job Category D05 of IMCA C 003[2] and have completed 100 offshore commercial dives;

c) Have satisfactorily completed an IMCA-approved Trainee Air Diving Supervisor training course which meets the Terminal Objectives of this scheme (see IMCA D 013[1]) and have passed the course examination. **Candidates are not eligible to attend such courses until they have complied with criteria a) and b) above.**

1.1.2 Trainee Bell Diving Supervisor

To qualify as a trainee bell diving supervisor, a candidate must meet the following minimum criteria:

a) Hold an IMCA-recognised closed bell diving qualification as set out in the current information note *Diver and diving supervisor certificates*. Anyone who has comparable training and experience may be referred to the IMCA Certification Schemes Co-ordinator for a decision by the Assessment Panel;

b) Have demonstrated competence as an offshore bell diver in accordance with Job Category D04 of IMCA C 003[2] and have completed 400 lockout hours;

c) Have satisfactorily completed IMCA approved Trainee Air and Bell Diving Supervisor training courses which meet the Terminal Objectives of this scheme (see IMCA D 013[1]) and have passed the course examinations. **Candidates are not eligible to attend such courses until they have complied with criteria a) and b) above.**

1.2 Diving Supervisor

This is the main grade and covers qualified and experienced personnel, the main responsibilities of which are summarised in section 7 of this guidance and elsewhere (IMCA D 014[3]; IMCA D 013[1]). The duties and responsibilities of diving supervisors may also be defined in law for the area of operation.

1.2.1 Air Diving Supervisor

Having qualified as a trainee in accordance with 1.1.1 above, personnel must additionally fulfil the following minimum requirements before being appointed in writing by a diving contractor as an air diving supervisor:

a) Have logged at least 200 panel hours (under direct supervision) offshore on a minimum of 100 surface dives over a minimum period of 60 days (not necessarily consecutive) working as a trainee air diving supervisor.

   Up to 60 panel hours and 30 surface dives can be gained by 30 hands-on hours' experience on a class A simulator or up to 40 panel hours and 20 surface dives can be gained by 20 hands-on hours' experience on a class B simulator working as a trainee air diving supervisor;

b) Have demonstrated competence as an offshore air diver in accordance with IMCA C 003[2] and have completed a minimum career total of 200 offshore commercial air dives;

c) Have been recommended by a company following satisfactory offshore reports confirming competence in accordance with the IMCA guidance on competence assurance and assessment;

d) Have passed IMCA Air Diving Supervisor examination:

   The examination must be within one year of the application approval or the candidate will be required to reapply. Note: Application to sit the examination must be made within three years of successful completion of the training course and at least half the required panel hours should have been obtained in the two years prior to the application being made.

1.2.2 Bell Diving Supervisor

Having qualified as a trainee in accordance with 1.1.2 above, personnel must additionally fulfil the following minimum requirements before being appointed in writing by a diving contractor as a bell diving supervisor:

a) Have acted as a trainee air diving supervisor on at least 10 offshore commercial air dives.

   If a class A simulator is used, 10 hours need to be gained on the simulator as a trainee air diving supervisor in addition to acting as a trainee diving supervisor on at least 5 offshore commercial dives. One of the simulator dives must include the emergency recovery of a closed bell within the air range;

b) Have logged at least 350 panel hours (under direct supervision) offshore on a minimum of 50 bell runs over a minimum period of 90 days (not necessarily consecutive) working as a trainee bell diving supervisor.

   Up to 105 panel hours and 15 bell runs can be gained by 53 hands-on hours' experience on a class A simulator or up to 70 panel hours and 10 bell runs can be gained by 35 hands-on hours' experience on a class B simulator;

c) Have logged at least 360 panel hours at any time working either as an LST or as an assistant LST;

d) Have been recommended by a company following satisfactory offshore reports confirming competence in accordance with the IMCA guidance on competence assurance and assessment;

e) Have passed IMCA Air Diving Supervisor and Bell Diving Supervisor examinations:

   The examinations must be completed within one year of application or the candidate will be required to reapply. Note: Application to sit the examinations must be made within three years of successful completion of the training courses and at least half the required panel hours should have been obtained in the two years prior to the application being made.

1.2.3 Air Diving Supervisor to Bell Diving Supervisor

A qualified air diving supervisor who has demonstrated competence in accordance with IMCA C 003[2] and supervised a minimum of 100 offshore air dives and who wishes to progress to bell diving supervisor does not have to resit the IMCA Air Diving Supervisor examination, but must fulfil the following minimum requirements before being appointed in writing by a diving contractor as a bell diving supervisor:

a) All aspects of 1.1.2;

b) Have logged at least 150 panel hours (under direct supervision) offshore on a minimum of 20 bell runs over a minimum period of 45 days working as a trainee bell diving supervisor.

   Up to 45 panel hours and 6 bell runs can be gained by 22 hours' hands-on experience on a class A simulator or up to 30 panel hours and 4 bell runs can be gained by 15 hands-on hours' experience on a class B simulator;

c) Have logged at least 360 panel hours at any time working either as an LST or as an assistant LST;

d) Have been recommended by a company following satisfactory offshore reports confirming competence in accordance with the IMCA guidance on competence assurance and assessment;

   Have passed IMCA Bell Diving Supervisor examination. Note: Application to sit the examination must be made within three years of successful completion of the training course and at least half the required panel hours should have been obtained in the two years prior to the application being made.

1.3 Senior Diving Supervisor or Diving Superintendent

This is the most senior grade and is a qualified diving supervisor with considerable experience. He is appointed by the diving contractor to be in control of a major diving operation with at least one other diving supervisor reporting to him. He has the authority to forbid the start and to order the termination of any diving operation for safety reasons.

He may only order the start of a diving operation if he is acting as the diving supervisor.

He may act as a diving supervisor for part of the operation but otherwise he normally has overall responsibility, whilst any diving supervisor on duty is legally responsible for the operation for which he has been appointed.

1.4 Assistant Life Support Technician

This is the most junior grade and refers to a person gaining experience.

Divers holding an IMCA-recognised closed bell diving qualification who completed diver training prior to 1 November 2006 can be appointed assistant LSTs. Closed bell divers who trained after 1 November 2006 must pass the training establishment Assistant Life Support Technician examination before they can be appointed assistant LSTs.

Before being sent offshore as an assistant LST, all other entrants must:

a) undergo an IMCA approved basic course to the Terminal Objectives set down in IMCA D 013[1], either at a training school or in a company; and

b) produce documentary evidence of satisfactorily completing such a course.

An assistant LST should not be allowed to carry out any tasks unless properly supervised.

After working for at least 2400 logged panel hours as an assistant LST, a person may be nominated by his company to sit the IMCA Life Support Technician examination. Up to 720 panel hours can be gained by 144 hands-on hours' experience on a class A simulator or up to 480 panel hours can be gained by 96 hands-on hours' experience on a class B simulator.

Closed bell divers with IMCA-recognised certificates who have sat and passed an Assistant Life Support Technician examination set by an approved training establishment would only be required to log 360 panel hours, provided that they produce signed logbooks verifying their diving experience and have demonstrated competence as an offshore closed bell diver in accordance with IMCA C 003[2]. Where a simulator is available, up to 108 panel hours can be gained by 22 hands-on hours' experience on a class A simulator or up to 72 panel hours can be gained by 15 hands-on hours' experience on a class B simulator.

Passing the IMCA Life Support Technician examination will indicate that an assistant LST has the basic theoretical knowledge necessary for promotion to LST, but he should only be promoted if his company is satisfied as to his competence in accordance with the provisions of the IMCA guidance on competence assurance and assessment. Note: At least half the required panel hours should have been obtained in the two years prior to the application to sit the examination being made.

1.5 Life Support Technician

This is the main grade and covers qualified and experienced personnel.

An LST should have demonstrated his practical capabilities as an assistant LST (as in 1.4 above) and should have passed the IMCA Life Support Technician examination.

He is able to carry out all the normal tasks of a life support nature, but there should always be a diving or life support supervisor on duty and in control.

1.6 Life Support Supervisor

This is the most senior grade. Before becoming eligible for promotion to life support supervisor, an LST should, since having qualified as such, have demonstrated competence as a life support technician in accordance with IMCA C 003[2], have logged at least 2400 panel hours working as an LST, and have received training in aspects of leadership.

He should be appointed in writing by his company on the basis of his experience, character and ability to accept responsibility. A bell diving supervisor is also qualified to act as a life support supervisor, although he may not have previously worked as a life support technician.

He should have specific responsibility for the control of the saturation complex.

Dependent on national regulation and the management structure of the company, he may be subject to direct supervision by a more senior person.

1.7 Onshore-Based Life Support Personnel

An assistant LST who has only worked in an onshore hyperbaric centre may be considered eligible to sit the IMCA Life Support Technician examination provided that he has completed at least 90% of the required 2400 panel hours (i.e. 2160 hours) in operation of an occupied chamber when under pressure (with at least 50% mixed gas experience).

Only those life support personnel who have experience using mixed gas will be eligible to sit the IMCA Life Support Technician examination.

1 IMCA D 013 *IMCA offshore diving supervisor and life support technician certification schemes*
2 IMCA C 003 *Guidance document and competence tables: Diving Division*
3 IMCA D 014 *IMCA international code of practice for offshore diving*

Maximum Bottom Time Limitation

Maximum bottom time limitations applicable to a single dive for surface decompression (SD), in-water decompression and transfer under pressure (TUP) decompression diving.

Depth		**Bottom Time* Limits (minutes)**	
Metres	**Feet**	**TUP**	**SD and in water**
0-12	0-40	240	240
15	50	240	180
18	60	180	120
21	70	180	90
24	80	180	70
27	90	130	60
30	100	110	50
33	110	95	40
36	120	85	35
39	130	75	30
42	140	65	30
45	150	60	25
48	160	55	25
51	170	50	20

* Bottom time is the total elapsed time from when the diver is first exposed to a pressure greater than atmospheric i.e. (a) when leaving the surface with an open device; (b) on the start of pressurisation when a closed device is employed in the observation mode, to the time (next whole minute) that the diver begins decompression (measured in minutes).

When breathing oxy-nitrogen mixtures with oxygen percentages higher than in natural air, the equivalent air depth should be established. It is this equivalent air depth which should be used to establish bottom time limits.

Weather Terminology and Classifications

Wave heights given in Table 3-1 are those that might be expected in the open sea and there is usually a time lag between the increase in wind speed and the increase in wave height. In enclosed water, the waves will normally be lower, but steeper. See section 4.5.

Beaufort Scale	**Wind Speed (knots)**	**Description**
0	0	Calm, sea like a mirror
1	1-3	Light air, ripples only
2	4-6	Light breeze, small wavelets (0.2m), crests have a glassy appearance
3	7-10	Gentle breeze, large wavelets (0.6m), crests begin to break
4	11-16	Moderate breeze, small waves (1m), some white horses
5	17-21	Fresh breeze, moderate waves (1.8m), many white horses
6	22-27	Strong breeze, large waves (3m), probably some spray
7	28-33	Near gale, mounting sea (4m) with foam blown in streaks downwind
8	34-40	Gale, moderately high waves (5.5m), crests break into spindrift
9	41-47	Strong gale, high waves (7m), dense foam, visibility affected
10	48-55	Storm, very high waves (9m), heavy sea roll, visibility impaired. Surface generally white
11	56-63	Violent storm, exceptionally high waves (11m), visibility poor
12	64 and over	Hurricane, 14m waves, air filled with foam and spray, visibility bad

Table 3-1 – The Beaufort scale

The following tables give terms that are used in United Kingdom and most English language weather forecasts.

Wind direction	Indicates the direction from which the wind is blowing
Wind becoming cyclonic	Indicates that there will be considerable change in wind direction across the path of a depression within the forecast area
Veering	The changing of the wind in a clockwise direction e.g. SW to W
Backing	The changing of the wind in an anti-clockwise direction e.g. SE to NE

Table 3-2 – Wind

Fog	Visibility less than 1000m
Poor	Visibility between 1000m. and 2 n.miles
Moderate	Visibility between 2 and 5 n.miles
Good	Visibility more than 5 n.miles

Table 3-3 – Visibility

Gale	Winds of at least Beaufort force 8 (34-40 knots) or gusts reaching 43-51 knots
Severe gale	Winds of force 9 (41-47 knots) or gusts reaching 52-60 knots
Violent storm	Winds of force 11 (56-63 knots) or gusts of 69 knots or more
Hurricane force	Winds of force 12 (64 knots or more). Note the term is Hurricane Force: the term hurricane on its own is only used to imply a true tropical cyclone
Imminent	Expected within 6 hours of time of issue
Soon	Expected within 6 to 12 hours of time of issue
Later	Expected more than 12 hours from time of issue

Table 3-4 – Gale warnings

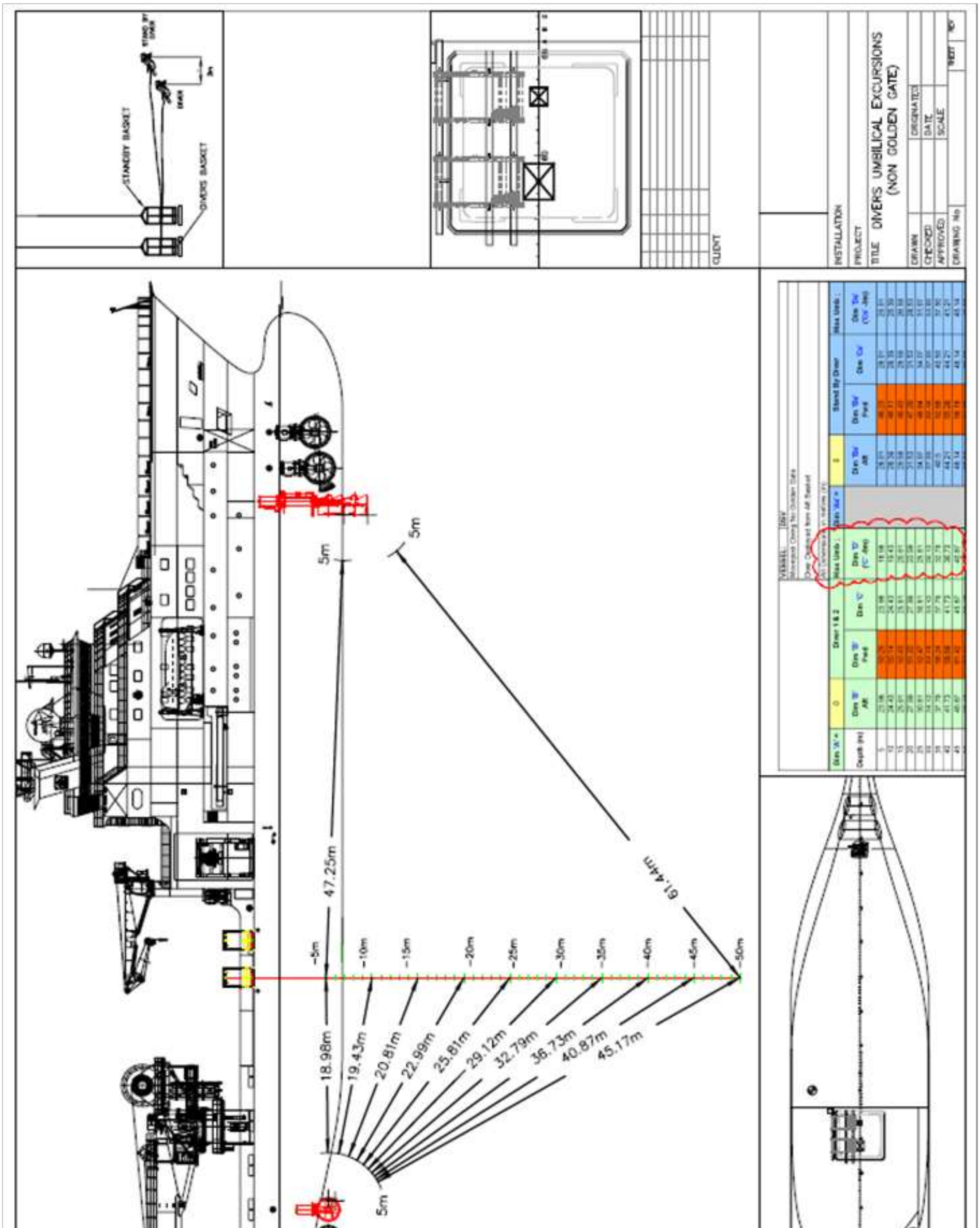
Slowly	Moving at less than 15 knots
Steadily	Moving at 15 to 25 knots
Rather quickly	Moving at 25 to 35 knots
Rapidly	Moving at 35 to 45 knots
Very rapidly	Moving at more than 45 knots

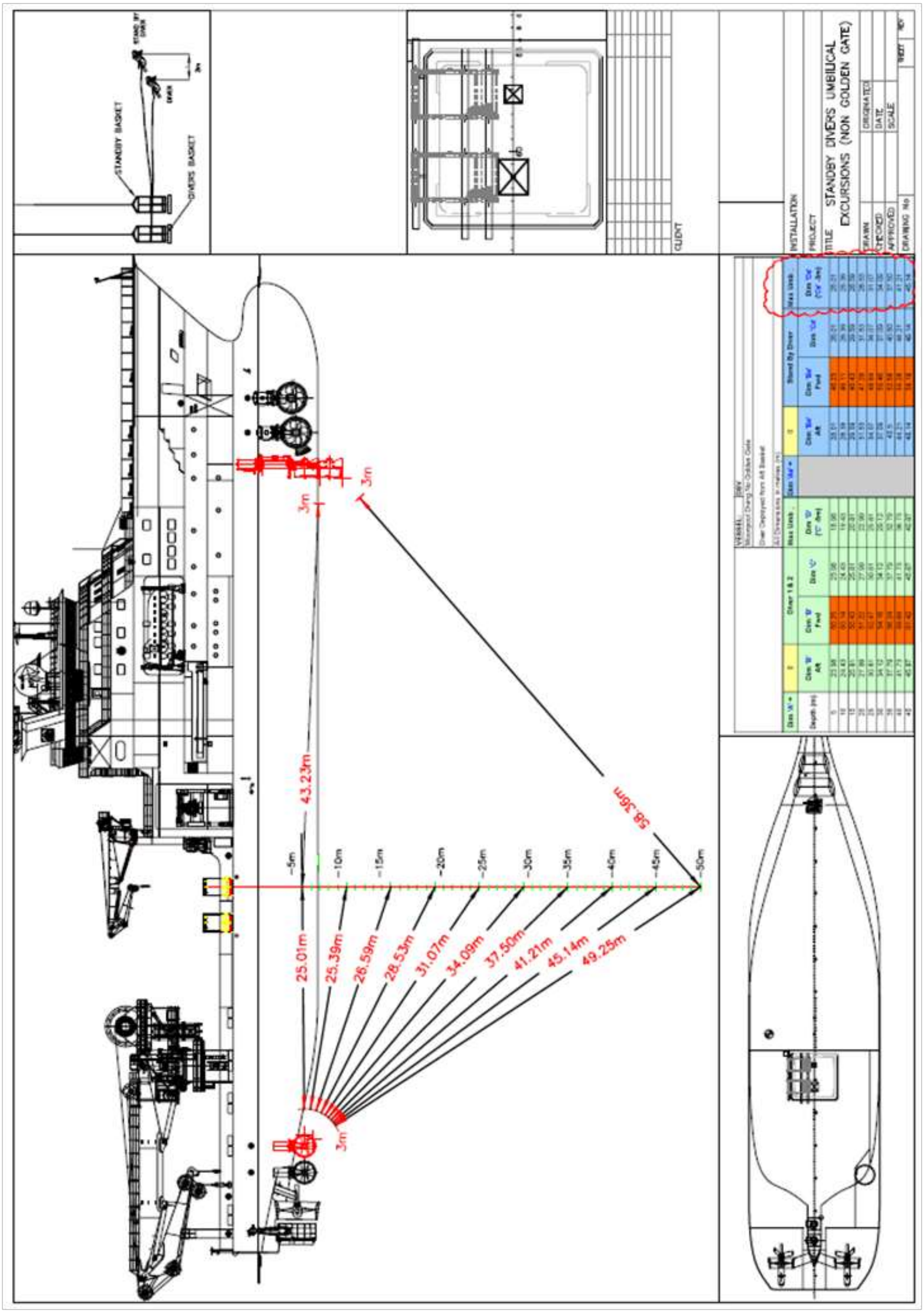
Table 3-5 – Movement of pressure systems

Rising (or falling) slowly	Pressure change of 0.1 to 1.5 mbar in the preceding 3 hours
Rising (or falling) slowly	Pressure change of 1.6 to 3.5 mbar in the preceding 3 hours
Rising (or falling) quickly	Pressure change of 3.6 to 6.0 mbar in the preceding 3 hours
Rising (or falling) very rapidly	Pressure change of more than 6.0 mbar in the preceding 3 hours
Now rising (or falling)	Pressure has been falling (rising) or steady in the preceding 3 hours, but at the time of observation was definitely rising (or falling)

Table 3-6 – Pressure tendency in station reports

Vessel Hazard Drawings


DIVERS UMBILICAL EXCURSIONS
(NON GOLDEN GATE)
INSTALLATION
PROJECT
TITLE
CLIENT
DRAWN
CHECKED
APPROVED
DRAWING No
ORIGINATED
DATE
SCALE
STANDBY BASKET
DIVERS BASKET
47.25m
61.44m
18.98m
19.43m
20.81m
22.99m
25.81m
29.12m
32.79m
36.73m
40.87m
45.17m
5m
5m
5m
-5m
-10m
-15m
-20m
-25m
-30m
-35m
-40m
-45m
-50m


STANDBY BASKET
DIVERS BASKET
STAND BY DIVER
DIVER
CLIENT
INSTALLATION
PROJECT
TITLE
STANDBY DIVERS UMBILICAL
EXCURSIONS (NON GOLDEN GATE)
DRAWN
CHECKED
APPROVED
DRAWING No
ORIGINATED
DATE
SCALE
43.23m
58.36m
3m
25.01m
25.39m
26.59m
28.53m
31.07m
34.09m
37.50m
41.21m
45.14m
49.25m
-5m
-10m
-15m
-20m
-25m
-30m
-35m
-40m
-45m
-50m