CCO Ltd

Diving management studies
Study No 7

History & evaluation of IMCA D 050 rev. 1.1 "Minimum quantities of gas required offshore"

04 March 2024

CCO Ltd *Diving consulting*

52/2 moo 3 tambon Tarpo
65000 Phitsanulock
Thailand

Contacts: Tel: +66 857 277 123
+66 900 314 585
E mail: info@ccoltd.co.th

Important Note

This study is written with the sole purpose of informing people interested in diving activities whether the document discussed is suitable for commercial diving.

Christian CADIEUX

Document history

June 2021	Initial study
August 2021	Publication to the general public
March 2024	Modified the document according to the revision made in December 2023 by the publisher: - Text modifications and improvements - Added comments on the additional topics of the revision

CCO Ltd Diving consulting

52/2 moo 3 tambon Tarpo
65000 Phitsanulock
Thailand

Contacts: Tel: +66 857 277 123
+66 900 314 585
E mail: info@ccoltd.co.th

Tables of contents

Page left blank intentionally

I - Purpose

1.1 - Purpose of this study

IMCA published an update of the Diving Guidance D 050 "Minimum Quantities of Gas Required Offshore" in December 2023, replacing the version published in April 2021, which I commented on in the Diving Management Study #7 in August 2021. However, the IMCA authors state that this new update only includes changes to the headers, footers, document map, and the introduction of references and a glossary, previously missing. Therefore, there is no change in content, which remains strictly similar to the April 2021 edition that replaced the May 2012 edition.

Note that the study of the April 2021 edition provided an opportunity to recall the purpose of these guidelines and their evolution since their first publication by the AODC in July 1983, and also to verify whether it was an improvement over the May 2012 edition and suitable for commercial diving operations. Since the December 2023 edition (Revision 1.1) contains no changes to the text of the previous edition, this review of Study #7 only contains textual improvements and comments on the two newly added sections.

Clarification: *The people who have written this document for IMCA are called "The authors" in this study.*

1.2 - Purpose of these guidelines and history.

Every diver knows that a lack of breathing gas or an inappropriate mix may result in asphyxia and possibly one or multiple fatalities. Also, it is well known that accidents such as pulmonary barotraumas and decompression sickness should be treated by recompression in a chamber. Therefore, it is essential to ensure that minimum reserves of appropriate gases are present on the worksite and immediately available during the diving operations. It must be noted that gases are consumable, so what has not been used on a worksite will be used one day on another project. There is, therefore, no reason not to provide more gas than the minimum to ensure that any unplanned situation regarding this point can be adequately covered.

However, the calculation of these minimum levels is difficult as they are heavily dependent on circumstances such as breathing mixtures used, decompression schedules used, depth of dive, work rate, environmental conditions, the physical condition of the divers, and their metabolism that differ from one person to another, etc.

To answer the problems above and simplify their operational procedures, some of the early diving contractors had set up minimum gas reserves to be carried on the worksites and below which the operations had to be stopped or not be started in their company manuals. For example, COMEX, a pioneering company no longer involved in commercial diving, published the following minimum quantities of therapeutic gases to be carried on-site in its medical books:

Air/nitrox bounce diving worksites

Maximum depth	*O2*	*50/50 heliox*	*20/80 heliox*
50 m	90 m^3	90 m^3	90 m^3

Air/nitrox saturation worksites

Maximum depth	*O2*	*50/50 heliox*
45 m	90 m^3	90 m^3

Heliox bounce diving or heliox saturation worksites

Maximum depth	*O2*	*50/50 heliox*	*20/80 heliox*	*10/90 heliox*	*5/95 heliox*	*3/97 heliox*
40 m	90 m^3	90 m^3				
110 m	90 m^3	90 m^3	220 m^3			
210 m	90 m^3	90 m^3	220 m^3	400 m^3		
360 m	90 m^3	90 m^3	220 m^3	400 m^3	650 m^3	
450 m	90 m^3	90 m^3	220 m^3	400 m^3	650 m^3	800 m^3

Note that 90 m^3 comes from the 9-bottle / 50-litres quads at 200 bar used on all COMEX worksites that subsequently became a reference unit that other companies have adopted.

It is, therefore, natural that the Association of Offshore Diving Contractors (AODC), one of the forerunners of IMCA, which was founded in 1972, issued document AODC 14 in 1983 to establish the minimum gas levels to be maintained on sites. This document was used as a reference until 2012, when it was replaced by IMCA D 050.

Note that IMCA was formed in 1995 through the merger of the Association of Offshore Diving Contractors (AODC), and the Dynamically Positioned Vessel Owners Association (DPVOA). Most AODC guidelines were still in force after the formation of the association and have been gradually replaced by IMCA documents. For information, the latest AODC guidelines have been converted to the IMCA label in 2023.

2 - Guidelines developed in AODC 14 and the initial publication of IMCA D 050

2.1 - AODC 14

2.1.1 - Description

This document provided guidelines for two types of operations:
"Surface orientated (air) diving", and "mixed gas diving". Mixed gas diving guidelines were separated into three parts: "General", "bounce diving", and "saturation diving".

This document has set up procedures that are still in force in the latest version of IMCA D 050. Moreover, the texts have not evolved much since this first publication.

- The document established the following rules for "surface orientated (air) diving":
  1. *"Sufficient compressed air must always be available for two emergency dives to the full intended diving depth as reserve. This air must either be stored in containers or else supplied by two totally independent dedicated sources"*
  2. *"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".*
  3. *"90 m3 (3200 cu ft) of breathing oxygen must be available for emergency treatment procedures".*

  The document said that this air had to be stored in containers or supplied by two totally independent dedicated sources (Two separate compressors, one connected to the vessel emergency electric power or separate power source (e.g., diesel) or one compressor plus compressed air storage containers).
  These guidelines are still in force today.

- Regarding "mixed gas diving", the document said the following:
  1. In point "general", the guideline explained the particularities of helium and particularly the fact that this gas easily leaks due to the small size of its atoms.
     The guideline already explained that the chamber atmosphere can become contaminated, and for this reason, a built-in breathing system (BIBS), designed with a dumping system to the outside of the chamber, should always be available with an appropriate mix and sufficient reserve to allow each diver 4 hours breathing during the time the chamber atmosphere is cleaned or flushed out. This procedure is also still in force today.
     The guidance also said that for both bounce and saturation diving, *"Sufficient quantities of treatment gas had to be available to carry out any foreseeable treatments as detailed in the company's Rules for the depths-involved".*
     In addition, the guidance reminded the reader that in case evacuation of a casualty was planned by helicopter, the gas for the pressurization of the portable chamber had to be considered and available in the gas reserve of the worksite.
  2. In point "bounce diving' the document established the following guidelines still used as references today:
     - *"Sufficient mixed gas must be available for the divers in the water or bell to carry out their planned work, plus additional gas to allow a complete dive to be made to the maximum depth as an emergency".*
     - *"Sufficient mixed gas and/or air must be available to pressurize the deck chamber to the transfer depth twice.*
     - *If atmospheric control in the chamber is to be achieved by flushing, then sufficient gas or air must be available for the necessary flushing for two complete decompressions from the intended transfer depth".*
     - *"Sufficient helium or mixed gas must be available to pressurise the deck chamber to maximum diving depth and then carry out a full saturation decompression in the event of emergency medical treatment being required. In this case, sufficient oxygen must be available to allow for metabolic consumption by each diver plus that required to maintain PO_2 during decompression.*
  3. In point "saturation diving" it was said that *"Before the start of a saturation, there must be sufficient mixed gas available, to be able to pressurise all deck chambers 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 chambers must be maintained"* It was also said that this gas must be fitted to the system to prevent a safety reserve against major leak.
     It was also said that sufficient gas to allow a full decompression from the storage depth to the surface, allowing for the normal daily consumption of gas due to leakage, toilet flushing, etc., and sufficient oxygen to allow for metabolic consumption by each diver plus that required to maintain PO2 during decompression were to be calculated and that the quantities found had to be doubled.
     Regarding the organization of bell runs, the guideline said that sufficient mixed gas must always be available to carry out the intended bell run plus the same quantity of gas as a reserve. Also, that this gas

should be in addition to the gas requirements in the previous paragraphs and that the onboard gas of the bell is not to be included in these calculations.

2.1.2 - To conclude on AODC 14

When AODC published this guideline in 1983, the association had not yet edited documents indicating gas consumption calculation methods. The procedures used were those taught in diving schools and published in documents such as the US Navy manual or the equipment manufacturers' guidelines. That was corrected in May 2000 with the publication of IMCA D 022 "Guidance for diving supervisors", which has standardized simple methods of calculation and officially set up the consumption rates of a diver at work (35 l/min) and in an emergency (40 l/min) agreed by the association. Although they are based on empirical calculations, these values are still used by IMCA today.
It must be noted that the calculation of therapeutic gases was based on the US Navy procedures in force during this period. For this reason, the minimum quantities of heliox 50/50 and 20/80 to be used with the COMEX therapeutic table Cx 30, which is today used by a lot of doctors, were not mentioned in the recommendations for air diving. It was also the case of the calibration gases.

However, despite these omissions, AODC 14 had the merit of establishing the following prevention principles regarding the management of gases on worksites.

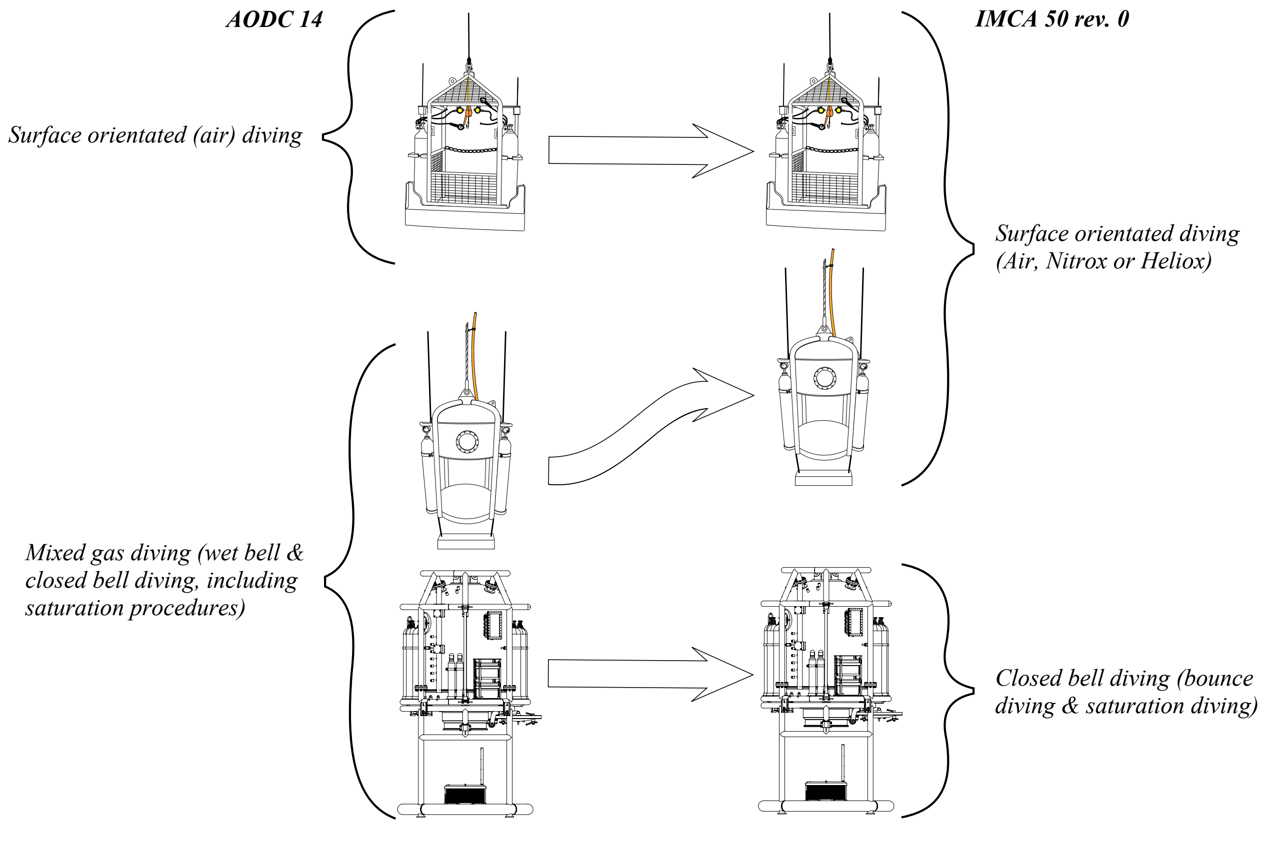
- There must be sufficient gas reserves to perform the planned dives.
- There must be sufficient gas reserves to manage unplanned events. That includes sufficient reserves of appropriate therapeutic gases.
- The gases above must be available at all times
- Onboard gases of bells, baskets, and evacuation systems must not be included in these calculations. That suggested that these reserves must always be filled to their maximum capacity.

Thus, we can say that this guidance was a good base that has probably contributed to saving lives during the 29 years it has been considered the AODC/IMCA reference. Also, we will see in the next evolutions of the guideline that most of its texts have been kept and are still considered valid references.

2.2 - The initial edition of IMCA D 050

2.2.1 - Description

This document introduced some changes regarding the classification of the types of dives: AODC 14 previously classified the diving operations into "Surface orientated (air) diving", and "Mixed gas diving". As a result, wet bell diving operations using heliox were classed with closed bell operations (bounce dives and saturation procedures). IMCA 50 revision 0 classified the diving procedures into two main categories: “Surface Orientated Diving (Air, Nitrox or Heliox)” and “Closed Bell Diving”. As a result, heliox diving operations with wet bells below 50 m were classified with air diving operations, and bounce diving operations with closed bells were classified with saturation diving operations.



This classification appeared more logical than the previous one, as air diving teams often undertake wet bell diving operations.

The guidelines given in "Surface Orientated Diving (Air, Nitrox or Heliox)" were those previously in use in AODC 14 for "surface Orientated (air) diving" with only a few words that were changed:

1. For the 1st rule, AODC 14 said: *"Sufficient compressed air must always be available for two emergency dives to the full intended diving depth as reserve. This air must either be stored in containers or else supplied by two totally independent dedicated sources"*.
   IMCA D 050 rev 0 said: *"Sufficient compressed gas always needs to be available for two emergency dives to the full intended diving depth and time. This gas is to be kept as a reserve. This gas should either be stored in containers or else supplied by two totally independent dedicated sources"*.
2. The 2nd rule of "surface Orientated (air) diving" of AODC 14 said: *"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 either be stored in containers or else supplied by two totally independent dedicated sources"*.
   IMCA D 050 rev 0 said: "*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"*.
3. For the third fundamental rule, AODC 14 said: *"90 m3 (3200 cu ft) of breathing oxygen must be available for emergency treatment procedures"*.
   IMCA D 050 rev 0 said: *"90 m3 (3200 cu ft) of breathing oxygen must be available for emergency treatment procedures"*.

The guidelines given for "closed bell diving" were presented in the same manner as those of "mixed gas diving" AODC 14. Thus, divided in the 3 points "General", "Bounce diving", and "Saturation diving". We can also see the the texts were the same or only slightly modified as shown in the example below:

1. In point "General" :
   - AODC 14 said: *"Helium and helium gas mixtures, due to the extremely small size of the helium atom, leak from storage cylinders even when precautions are taken to tighten fittings". "Due allowance must always be made, therefore, for leakage when calculating minimum quantities of gas required at the start of a diving operation":* These sentences were exactly the same in IMCA D 050 revision 0.
   - AODC 14 said: *"In either mixed gas, bounce, or saturation diving, there is always the possibility of the deck chamber atmosphere becoming fouled due to smoke or other contaminant. In such circumstances the chamber occupants should use the built-in breathing system (BIBS), dumping the exhaust overboard while the main chamber atmosphere is cleansed or flushed out. Sufficient gas should always be available to allow each diver 4 hours breathing on BIBS masks in addition to other gas reserves".* This phrase is also strictly the same in IMCA D 050 rev. 0.
   - AODC 14 said: *"The composition and use of therapeutic or treatment gases varies from company to company, dependent on their detailed operating procedures and treatment tables used. Sufficient quantities of treatment gas must be available to carry out any foreseeable treatments as detailed in the company's Rules for the depths-involved. This applies to both bounce and saturation diving".* This sentence is also not changed in IMCA D 050 rev. 0.
   - Note that the guideline regarding helicopter rescue chambers was withdrawn.
2. Three guidelines were provided in point "Bounce diving" that were word for word those of AODC 14.
3. The guidelines in point "saturation diving" were also those of AODC 14:
   - AODC 14 said that *Before commencing diving certain quantities of gas should be available as below. If the gas supplies fall to a level such that the remaining gas only satisfies paragraphs "b" to "d", then decompression must be started"*.
     This text was identical in IMCA D 050 rev. 0, except that the paragraphs were 1 to 4 of point 3.3.
   - The text of paragraph A of AODC 14 said the following: *"Sufficient mixed gas must always be available to carry out the intended bell run plus the same quantity of gas as a reserve. This gas will be in addition to the gas requirements in the following paragraphs. Gas carried onboard the bell in cylinders must not be included in these calculations"*.
     Paragraph 1 of IMCA D 050 said: *"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 following paragraphs. Gas carried onboard the bell or hyperbaric evacuation system (HES) in cylinders should not be included in these calculations"*.
   - Paragraph 2 of IMCA D 050 rev 0 corresponded to paragraph B of AODC 14 with some small modifications.
     AODC 14 said the following: *"Before the start of a saturation there must be sufficient mixed gas available, to be able to pressurise all deck chambers 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 chambers must be maintained - As well as providing a safety reserve against major leaks in the system this gas can also be used to pressurise any hyperbaric rescue chamber which may be fitted to the system".
IMCA D 050 rev 0 said: *"Before the start of a saturation, there needs to be 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".*

- Paragraph C of AODC 14, that said that there must be 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, food-lock use, toilet flushing etc. had been withdrawn in IMCA D 050.
- Paragraph 3 of IMCA D 050 rev 0 corresponded to paragraph D of AODC 14 with also some small modifications.
  AODC 14 said: *"Sufficient oxygen to allow for metabolic consumption by each diver plus that required to maintain PO_2 during decompression. This quantity to be doubled for safety reasons".*
  IMCA D 050 rev. 0 said: *"There should be sufficient oxygen to allow for metabolic consumption by each diver, any oxygen make-up prior to decompression, plus that required to maintain the PPO2 during decompression. This quantity should be doubled for safety reasons and held in two separate banks".*
- In paragraph 4 of IMCA D 050, it was said that there should be a minimum of three weeks' supply of calibration and zero gas for the analysers before starting the saturation dive, and that the reserve of calibration gases had to be maintained during the saturation. As discussed previously, this guideline was missing in AODC 14.

In addition to these texts which were a revision of those of AODC 14, IMCA 50 Rev 0 introduced some elements of gas calculation from IMCA D 022 such as:

- The breathing gas consumption rates *(Consumption rate at surface pressure x Depth)*
- The open circuit breathing value of divers at work *(35 litres / min)*
- The open circuit breathing value of divers in an emergency *(40 litres / min)*
- The consumption using reclamation systems *(5 litres / min)*
- The equation to provide an approximate value for the minimum quantity of oxygen required to maintain the desired oxygen partial pressure levels in a system during decompression *((Natural logarithm (Ln) initial pressure) x PPO2 in bar x chamber volume in M3).*
- The formula to calculate the volume of a domed ends chamber *((π(D/2)2 x L) + 4/3 πr3)*
- The oxygen metabolic consumption in chambers *(0.5 litres/minute per diver)*
- The built-in breathing system (BIBS) gas consumption *(20 litres/ min)*

Displaying these elements of calculation in this guideline was useful, as the reader had not to look for them in another document.

2.2.2 - To conclude on the initial edition of IMCA D 050

This first edition of IMCA D 050 was a good evolution of AODC 14:

- The relevant texts of AODC were conserved.
- It provided a more logical classification of the diving procedures to take into account.
- It also introduced the principle that calibration gases are to be taken into account in the minimum reserve of gases.
- In addition, some useful clarifications regarding the methods of calculations were provided.

Nevertheless, a lot of precisions were not explained in this guidance:

- The document still did not indicate the minimum quantities of therapeutic mixes other than oxygen, such as heliox 50/50 and 20/80 used with the COMEX therapeutic table Cx 30, which was already used by a lot of doctors.
- The guidance recognized that more stringent open-circuit breathing values in emergencies were in force but did not adopt them.
- The elements to take into account were not detailed. Thus, as with AODC 14, the guideline provided principles to be in place for the calculation of minimum gas reserves but did not detail them.
- Note that domed chambers are very rare and that the document did not provide the equation for calculating an ellipse. The document also did not indicate that every pressure vessel is normally fitted with an identification plate that indicates its volume in addition to the information regarding its construction process.

3 - IMCA D 050 revision 1 and 1.1

3.1 - Description

IMCA D 050 revision #1 was published in March 2021. As mentioned in the introduction of this study, its presentation was slightly modified in December 2023 (revision 1.1), and a glossary and references have been added. According to the authors, these two revisions aim to provide more comprehensive advice on appropriate minimum quantities for all the sources of gas required to support a diving project across a range of industry-recognized diving methods. Also, new guidelines on minimum requirements for decompression, therapeutic, BIBS, calibration, metabolic, escape, Life support package (LSP), and Hyperbaric Rescue Facilities (HRF) gas stocks are now included.

3.1.1 - Introduction of the document

This part of the document develops topics such as its scope, its objectives, its application, the variations that may be encountered in the gas calculations, the calculation errors, the useable gas quantities, the problems arising from helium leakage, the management of the stocks (gas status), and the operational losses.

- In point "Scope," the authors remind the reader of the reasons for the guideline, which are those that were explained in AODC 14 and the first edition of IMCA D 050 (May 2012):
    - Indicate the minimum amounts of breathing medium needed before starting any diving operation. Regarding this matter, the authors clearly indicate that it is impossible to define appropriate minimum quantities for all the sources of gas required to support a diving project in a generic document due to the large number of variables involved.
    - Also, provide advice on how to calculate the minimum gas quantities required.

  The authors also say that these minimum gas quantities should be specified within the diving project plan.
- The elements in point "Objectives" complete what is said in "scope" and indicate the document aims to:
    - Assist the diving contractor for the preparation of the diving project plan.
    - Ensure that the amounts of emergency breathing medium have been adequately evaluated and are displayed in the dive and saturation/chamber control rooms.
    - Ensure that diving operations are not started or are stopped if the reserves of gas are below the minimum stated.

  This point also says that the document is designed to provide operational guidance that highlights the need for an adequate safety management system, an appropriate and efficient risk assessment system, and a failure mode & effect analysis (FMEA) system.

  Note that apart from the need for FMEA, the texts displayed in this point are strictly identical to those of the initial IMCA D 050 (revision 0).
- In point "Application", the authors say that this guidance is intended to apply worldwide, but if more stringent laws are in force, they will take precedence over this guideline. It must be noted that this practice is in force in companies for a long time.
  The text displayed is not exactly the same as the initial version, but says the same thing.
- Point "Variations" indicates that formalize minimum gas reserves is difficult as they depend on elements such as the configuration of the dive system, the composition of the mixes, the decompression process, the depth and the environmental conditions, the charge of work, etc.
  It is said that the guideline provides only the "absolute minimum levels of gas to be on the worksite". It is also said that *"These minimum levels do not account for the gas supplies required for carrying out any operational tasks"*. Apart this last sentence, the texts are identical to what was said in the previous revision.
  However, It would have been interesting to add that if the gas reserves fall below these levels, the dives must be interrupted and decompression must be started. This guideline would have reinforced the texts above.
  Nevertheless, we recognize that a similar one is published in the next point "gas status".
  The authors also say that manufacturers' guidelines should be followed and a risk assessment process implemented. These elements are often neglected by the teams, so it is good to remind them.
- Point "Calculation Error" is used to explain to the reader that the calculations are based on the "ideal gas law", which results are not fully exact, but that the margins in place minor the variations of the calculations.
  This text is strictly identical to the one of the previous revision. Regarding this topic, we can say that the "ideal gas law" allows for rapid and easy calculations and gives sufficiently accurate results. Calculations would be more complicated if using Avogadro's Law, Van der Waals equation, and the compressibility factors of gases.
  Note that Avogadro, Van der Walls, and the compressibility factors of gases are described in point 2.2.3 of book #2, "Gas supplies and chambers management" of the "Saturation diving handbook" Diving and ROV Specialists.
- In point "Useable Gas Quantities" the authors remind the reader that the gas quantities shown in the document relate to the surface equivalent volume of gas which must be available to the divers. It is also explained that whilst the effects of depth are calculated, the losses due to the system (regulators and pipework), and the gas

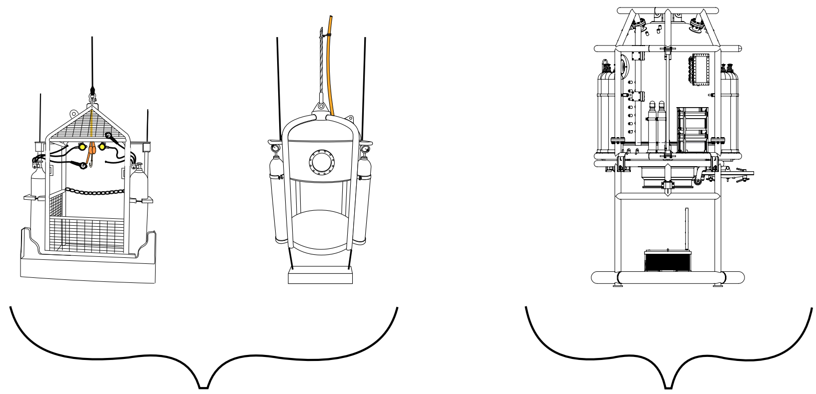
remaining in gas containers, must be assessed and added to the calculated values.

- Point "Helium leakage" reminds the reader of the problems arising from the fact that helium is a light gas. As a result, this gas leaks easily despite precautions, and for these reasons, these leakages must be taken into account. Note that this text was present in AODC 14 and the initial version of IMCA D 050 (May 2012).
- The point "Gas Status" was not present in the revision of IMCA D 050 published in 2012 (revision 0). It says that the reserves of gas should be separated into two parts:
  1. What the authors call "Reserve gas" are gases mainly used for safety applications, such as bailouts contents or therapeutic gases that remain unused until the conditions require their use. The authors indicate that diving operations may continue while the "Reserve gas" is equal or above its minimum.
  2. What the authors call "Consumable gas" are the gases provided for ongoing use that vary in quantity according to their use and the re-supply. In fact, they are the gases consumed during the operations. The authors also indicate that "Consumable gases" require continuous monitoring, and the diving operation should be stopped, and the decompression started if these gas levels are equal or below the minimum values.

  The fact that diving operations have to be stopped when the gas reserves fall below the minimum level was already highlighted in AODC 14 and the 1st publication of IMCA D 050. However, these previous editions did not separate the gas status in "Reserve gas" and "Consumable gas".
- In Point "Operational losses", the authors set up the operational gas loss of "consumable gas" to 10%, which is the value commonly applied by Life surface Technicians (LST) in their calculations.
  This clarification is also added to the previous edition.

3.1.2 - Guidelines for diving operations

There is no change with the first edition of IMCA D 050 (May 2012) regarding the classification of the diving operations. Thus the authors have kept the operations into two main categories: "Surface Orientated Diving (Air, Nitrox or Heliox)" and "Closed Bell Diving"



Surface orientated diving (Air, Nitrox or Heliox)

Closed bell diving (bounce diving & saturation diving)

3.1.2.1 - Surface Orientated Diving (Air, Nitrox or Heliox)

The three main guidelines of paragraph 2.1 of the 1st version of IMCA D 050 have been kept. However, numerous topics have been added to provide more clarifications. Also, the authors have used the classifications "consumable type" and "reserve type" described above in their description of the needs.

- In point 2.1 "General", the authors say: *"This section addresses the gas required for surface diving operations and provides minimum limits on gas to have on-site, either in quantity or on how it can be calculated depending on the circumstances"*. They also explain that surface diving consists of short periods under pressure and that can be quickly stopped. For this reason, the gas requirements for surface-orientated diving are set during the planning and recorded in the diving project Plan.
  The authors also say that if the required gas is not present the dive cannot start. These elements are those suggested in the previous versions. Nevertheless, they are more developed.
- Point 2.2, "operational in water gases (classified 'consumable')", did not exist in the previous version of the guideline. It explains that the minimum operational gas requirement cannot be set out in a generic document due to numerous variables. For this reason, the study of the project planning is necessary to evaluate the needs for the operations. The authors also say: *"There must, however, be the following minimum gas supplies available, in addition to any gas requirements to carry out the work tasks, in order to allow a diving program to commence"*. Thus, I understand that the minimum levels of gas available are described in the next paragraph. The authors also say that the dives must be stopped if the minimum gas levels are not available, as previously said in AODC 14 and the initial edition of IMCA D 050.
  However, in my opinion, this text does not clearly explain the methods that can be used to evaluate the gas consumption during the operations. I understand that the team has to calculate the consumption for each planned

dive. But it could have been interesting to list the variables and remember that gas at a pressure of less than 20 or 30 bar cannot be considered as part of the reserve (IMCA D 022). Also, it would be suitable for consistency to suggest a rule similar to the one indicated for closed bell diving that says that sufficient gas should be available at the start of a bell run to carry out the intended bell run plus the same quantity of gas as a reserve.

- In point 2.3, "Divers Personal gas reserve - Bailout - (classified 'reserve')", the authors indicate that all working divers must carry a personal gas reserve to provide sufficient endurance to allow the diver to return to a place of safety. This is the text already displayed in section 10.5 of IMCA D 022. It is indicated that the capacity must be calculated to allow breathing for 1 minute for every 10 metres of excursion umbilical deployed at a rate of 40 litres minutes. Regarding this rate, I consider that it is not scientifically calculated. For this reason, I suggest the reader considering the UK HSE study RR 1073 "The provision of breathing gas to divers in emergency situations", which concludes that a breathing rate between 50 l/min or 75 l/min might be appropriate (62.5 l/min is the middle value).
    - In point 2.3.1, "Surface Tended Excursion Umbilicals", and point 2.3.2, "Wet bell excursion umbilical", the authors say that the umbilical's excursion distance of divers deployed with surface tended umbilical (thus the tender at the surface), is the length of umbilical deployed from the tending point at the surface. Also, that for divers deployed from a wet bell supplied by a main umbilical and with the diver's excursion umbilical connected to the onboard bell panel, the excursion distance is the length of the excursion umbilical deployed.
    These two points give suitable clarifications of the initial text of IMCA D 022 that says: *"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"*.
- Point 2.4 is an evolution of the text in point 2.1 in the initial version of IMCA D 050 and AODC 14. It was said: "*Sufficient compressed gas always needs to be available for two emergency dives to the full intended diving depth and time. This gas is to be kept as a reserve. This gas should either be stored in containers or else supplied by two totally independent dedicated sources"*. The new version says: *"Sufficient compressed gas always needs to be available for two thirty-minute rescue dives by the standby rescue diver to the full intended diving depth with the diver breathing at 40 l/min"*. We can see that the duration of the dive and the consumption rate are indicated in the new version, which gives more precise information regarding these matters. Unfortunately, the authors have removed the information regarding the gas sources.
- In point 2.5, "Diver Deployment System Gas (classified 'reserve')", the authors describe the minimum reserves of gas to be calculated for a basket or a wet bell. Note that the initial version of IMCA D 050 did not discuss precisely this point.
Regarding baskets, the authors suggest fitting them with sufficient gas reserve to recover the divers to the surface without missing decompression stops in case of main gas supply failure. They also suggest that a bottle with a volume of 44.4 litres and a pressure of 150 bar minimum should be sufficient. Regarding this topic, I suggest calculating the necessary volume using breathing rates in an emergency, as the divers may be stressed, and considering the maximum decompression time. Also, B 50 litres bottles at 200 bar are today more used than the model indicated in the text (The breathing rates I suggest are those of the UK HSE study RR 1073).
Regarding wet bells, the authors suggest as a minimum a gas reserve that allows recovering the divers to the surface without missing decompression stops in the event of the main gas failure, taking into account the provision of suitable PPO2. The breathing rate indicated in this point is the one used in an emergency. The authors also say: *"If the onboard gas is also one of the alternative gas sources for the working diver this gas volume will require to be enhanced accordingly"*.
- Point 2.6, "In Water decompression gas (gas type 'consumable')" was also not a part of the previous version of IMCA D 050. It discusses in-water decompression gases such as oxygen, and says that there must be enough quantities immediately available for decompressing all the working divers in the water at the same time before starting the dive if such a method of decompression is planned. It also says that a generic calculation cannot be provided because the necessary amount of gas will depend on the parameters of the dives (depth, bottom time, and sea conditions). For this reason, these calculations should be part of the diving project plan.
However, in addition to this reminder, it would have been suitable to specify the normal respiratory rates at rest (20 to 25 l/min), indicate that gases at a pressure of less than 20 or 30 bar cannot be considered as part of the reserve (IMCA D 022), and to provide a rule such as the one for metabolic oxygen in chambers, discussed in point 3.62 of the document, where it is said that the O2 quantity should be doubled. Such a rule allows to cover unforeseeable adverse situations, and increase the consistency of the guidelines.
- Point 2.7 discusses "Surface decompression gases - Non-therapeutic (classified 'consumable')" and reuses and reinforces a rule already in force in the previous version of IMCA D 050 and AODC 14.
The authors say: *"Sufficient compressed air needs to be available to pressurise both locks of the deck decompression chamber to the maximum decompression depth (normally ≈ 15 metres) plus sufficient air for three complete surface decompression cycles"*. The authors also say that sufficient oxygen must be available for the planned periods.
In the previous edition, this text included therapeutic treatments, and the following was said: *"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". Note that oxygen was not taken into consideration in the initial edition.
As for in water decompression, it would have been interesting to indicate the respiratory rates, that the content of the cylinders will not be fully used, and indicate that more oxygen than calculated should be provided.

- Point 2.8 is another additional topic to the previous edition of IMCA D 050 that gives recommendations regarding "Calibration gases (classified 'consumable')".
Regarding analysers used for air & nitrox diving, it is explained that a lot of models can be calibrated with air but that some devices may require the use of a calibration gas.
Regarding the analysers used with heliox mixes, the authors recommend to use calibration gases such as 100% helium (zero gas) and a mix with 20% oxygen. They say the following regarding quantities of calibration gas: *"No minimum quantity of calibration gas is set as there is no commitment of the divers to depth requiring the analysers to be recalibrated. If the analysers cannot be calibrated prior to the dive then the dive cannot be carried out. Sufficient quantities of calibration gases should be carried to complete the anticipated project scope*". They also say that two sources of each calibrations gas should be organized onsite and that for short mobilizations two small bottles can be provided rather than a large one.
Regarding this topic, it is, of course, positive to indicate that calibration gases have to be taken into account. However, it would have been interesting to indicate that the need for calibration depends on the system of analyzer used (Fuel cell, Magneto-dynamic, Photo-acoustic, Acoustic, Thermal conductivity detection, etc.) which manufacturers usually give the recommended frequencies of calibration. Also, I consider that indicating gas percentages to be used is outside the topic. In addition, these suggested mixes should be justified and not imposed without explanations. Thus why using these calibration mixes instead of others?

- Point 2.9 discuss of "Therapeutic gases (classified 'reserve')" and reuse some texts previously published in AODC 14 and the 1st edition of IMCA D 050:
    1. The authors say: *"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"*.
    The text of AODC 14 and the first edition of IMCA D 050 was: *"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"*.
    We can see that the text conforms with the 1st edition. However, because the text published in point 2.7, "Surface decompression gases", indicates already that there must be sufficient gas for 3 surface decompression cycles, there is a doubt regarding the purpose of these 3 surface decompressions cycles (underlined in the text) that need to be clarified. Obviously, medical personnel transferred into the chamber may have to be decompressed, and some gas must be stored for this purpose. But in this case, we do not use a surface decompression procedure that consists of performing the in-water stops up to 9 metres and then transfer the diver to the chamber to complete the rest of the decompression. Thus, we can consider that this part of the sentence results from a bad copy-paste of the original text from AODC 14.
    Note that the COMEX medical manual provided a specific table for the decompression of medical personnel that can be found in the manuals CCO Ltd and Diving & ROV Specialists.
    2. Regarding therapeutic gases, the authors provide the following clarification that was not included in AODC 14 and the 1st edition of IMCA D 050: *"There should be sufficient quantities of therapeutic gases to carry out treatment of a DCI during normal decompression based on the contractor's tables"*.
    This sentence suggests that gases such as heliox 50/50, used with the medical table COMEX Cx 30, must be considered when calculating the gas reserves, which solves this missing highlighted in the previous version of IMCA D 050. However, oxygen is considered a therapeutic gas, which results that this text conflicts slightly with the text below. It would have been a good idea to re-write a text considering all therapeutic gases. Note that the COMEX medical manual recommends 90 m3 of heliox 50/50 and 90 m3 of heliox 20/80 in addition to 90 m3 of oxygen for air/nitrox bounce diving (see in point 1.2).
    3. Regarding the provision of oxygen, the new text says: *"90 m3 (3200 cu ft) of breathing quality oxygen needs to be available for emergency treatment procedures at each decompression chamber which may be used for therapeutic purposes within the Diving Project Plan"*.
    The text of the previous guidelines was: *"90 m3 (3200 cu ft) of breathing quality oxygen needs to be available for emergency treatment procedures"*.
    This text has been reinforced as it indicates that 90 m3 of oxygen must be ready for use for each chamber.

- Point 2.10, "Operational personnel escape gases (classified 'reserve')" which the authors say that they have to be included in the gas calculations of the diving project plan, is also added to the initial texts of IMCA D 050.
In this part of the document, the authors say that sufficient compressed air must be available for the diving support crew to safely recover the divers to surface pressure and make their way to the vessel's muster stations. The authors also say that the breathing rate for the calculation should be 40 l/minute and that this requirement applies to the team members assigned to the diving station to recover the divers to the surface during a vessel alarm. The authors also say that this supply may be umbilical fed or a Breathing Apparatus (BA) set, and if the supply is umbilical fed, a BA set must also be provided for each member of the support crew to provide a means of escape once the divers are safe.
It is obvious that respiratory means allowing the surface support team to recover the divers and then escape

during a vessel emergency are of primary importance, so these gas reserves must always be taken into account and available. However, it would be more suitable to adopt the breathing rates of the UK HSE report RR 1073. Also, note that BA sets that can be connected to an external supply source and then disconnected exist and would avoid the personnel breathing polluted or deadly gas when changing from an umbilical supplied breathing apparatus to a bottle supplied one. For example, Dräger, a well-known manufacturer, proposes an “Automatic Switch Over Valve” that is designed to automatically connect from the external supply to the bailout if this supply fails and allows for the disconnection of the umbilical when escaping the area.

- Point 2.11, “Diver Transfer Oxygen (classified ‘reserve’) was also not discussed in the previous version of IMCA D 050. In this point, the authors explain that if the divers have to be transferred from a stricken vessel to a standby chamber situated in another place without being adequately decompressed, sufficient portable oxygen sets are required to allow these divers to breath 100% oxygen during their evacuation process and until they are being re-pressurized in the standby chamber. The transfer durations and gas consumptions should be calculated and be introduced in the Diving Project Plan.
  Considering that many contractors forget to implement this procedure, I think that adding it to gas reserve calculations is a good reminder. However, the authors do not indicate the suitable respiratory rate for the calculation that should be an emergency rate due to the divers' apprehension.

Note that the authors have not retained the following texts that were present in the initial D 050 edition:

1. *“Two totally independent (air) 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”.*
2. *“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”.*

Diving operations from rigs are scarce today as ROVs have replaced divers for most of the tasks. However, it would have been interesting to modify these texts to indicate that air from industrial compressors is not suitable for breathing unless a specific filtration system is installed. It would have also been interesting to keep in the text the principle of the two separated gas sources, and when these gas sources are compressors, they must not be connected on the same power supply.

3.1.2.2 - Closed bell diving

- Point 3.1, “General”, describes closed bell operations that can be bounce dive and saturation diving and say that the necessary gases must be set up during the organization phase. The readers are reminded of the safety principle that if the minimum gas levels are not available, the dive must not start. Also that the decompression must be started immediately if any of the consumable gas stocks are reduced to the minimum allowable levels. These guidelines are those previously explained in AODC 14 and the first edition of IMCA D 050.
- In point 3.2 “Operational In Water Gases (classified ‘consumable’)”, the authors say: *“Sufficient mixed gas should always be available at the start of a bell run to carry out the intended bell run plus the same quantity of gas should be held as a reserve. This gas will be in addition to the gas requirements in the following paragraphs. Gas carried onboard the bell or hyperbaric evacuation system (HES) in cylinders should not be included in these calculations”.*
  This text is the same as in the previous version of IMCA D 050, except the text related to continuous diving is removed (see the text underlined below). This removal does not denature the validity of the guideline that remains similar. The previous text was: *“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 following paragraphs. Gas carried onboard the bell or hyperbaric evacuation system (HES) in cylinders should not be included in these calculations”.*
- In point 3.3, “Divers Personal gas reserve - Bailout (classified ‘reserve’)”, the authors say: *“All working divers must carry a personal gas reserve to provide sufficient endurance to allow the diver to return to a place of safety”*. This is the text already displayed in point 2.3, and in point 10.5 of IMCA D 022. As above, it is indicated that the capacity must be calculated to allow breathing for 1 minute for every 10 metres of excursion umbilical deployed at a rate of 40 litres minutes (again, I suggest considering the UK HSE study RR 1073).
  The authors also promote the use of rebreathers, which I recommend for dives below 60 m. *Note that such equipment is described in point 2.3.7 “Bailout systems” of the document ”Description of a saturation system” published by “Diving and ROV Specialists”.* In addition to increasing the duration of breathing time, these systems reheat the breathed gas, which is not possible with a classical bottle. However, the authors say that the breathing rate does not need to be considered for rebreathers. It is true that a rebreather recycles the breathed gas. Nevertheless, they should have considered that oxygen and soda-lime (that removes the CO2 from the breathed gas) have to be renewed as oxygen will be consumed by the diver, and the soda-lime saturated with CO2. Also, the systems currently in use require to have their mix adjusted to the depth of intervention, and changing the mix will be the source of gas loss. In addition, mixes may have to be stored if the divers are planned to change of working depth during the saturation project.
  The elements indicated in this point were not present in the previous edition of IMCA 050.
- In point 3.4, “Surface Rescue Diver Gases (classified ‘reserve’)”, the authors say: *“Dive systems relying on*

surface deployed diver intervention for emergency bell recovery require to have sufficient compressed gas available for two thirty-minute rescue dives to the full intended diving depth with the diver breathing at 40 l/min. This gas is to be kept as a reserve". This guideline that was not included in the initial version of IMCA D 050 and AODC 14, clarifies the gas reserve for the intervention of rescue divers deployed from the surface (as said previously breathing rates of the UK HSE report RR 1073 are more suitable).

- Point 3.5, "Closed bell onboard gas", discusses the oxygen and the working diver's gas reserve.
  - Regarding oxygen, the authors explain that the onboard oxygen is used for supplying the bell during the bell run and maintain the metabolic consumption of the divers for 24 hours in an emergency (emergency includes events such as lost bell or loss of gas supplies). As a result, the authors provide these two rules:
    1. *Enough oxygen must be provided at the start of a bell run for both requirements and the bell run must be aborted if the oxygen levels reduce to the reserve minimum required 24 hour emergency survival time level.*
    2. *Sufficient oxygen must be available for metabolic consumption by the maximum number of divers at 0.5 l/min (surface equivalent volume) per diver for at least 24 hours at the end of a bell run.*

    These two laws were suggested in the initial version of IMCA D 050, but not clearly written.
    The authors also say that elements such as the design of the dive system, the volume of the cylinders, the characteristics of the regulators, the operating pressure, the number of divers, must be taken into account to calculate the oxygen reserve, and that the result of these calculations must be included in planned gases of the diving project plan
  - Regarding the gas reserve of the working diver the authors provide the following rule:
    "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 l/min at the maximum depth of the diving operation".
    The authors also say the the calculation of this gas reserve is to be done taking into account the elements indicated in the previous point (Design of the dive system, number of divers in the bell, gas cylinders' volume, characteristics of the regulators, and operating pressure), and that the result of this calculations must be included in planned gases of the diving project plan.
    Note that a breathing rate at the lowest values indicated in the UK HSE report RR 1073 may be appropriate in this case as the divers have normally passed the 1st emotional shock that may happen if deprived of gas during the dive and be obliged to use the bailout.
- Point 3.6, "Dive System Chamber Gases" provides guidelines on the gases necessary for pressurization, the metabolic consumption of oxygen, and the emergency supplies (BIBS).
  - Regarding the gas necessary for pressurization (classified consumable), the text provided in this new revision is similar to text #2 of point 3.3 of the first version of IMCA D 050.
    The text of the previous edition said: *"Before the start of a saturation, there needs to be 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*".
    The new text says the following (Only the part underlined between brackets is changed):
    "Before the start of a saturation, there needs to be sufficient mixed gas available to be able to pressurise the system <u>(including all deck chambers, bells and Hyperbaric Evacuation System (HES) components required for the envisaged operation)</u> 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 re-pressurise the system, should be maintained at all times".
  - The authors have also reused the text of the previous edition regarding "metabolic and decompression oxygen (consumable)" however, they have added some useful clarifications. The text of the initial version of IMCA D 050 said: *"There should be sufficient oxygen to allow for metabolic consumption by each diver, any oxygen make-up prior to decompression, plus that required to maintain the PPO2 during decompression. This quantity should be doubled for safety reasons and held in two separate banks".*
    Then the authors indicated that the minimum metabolic consumption of oxygen is 0.5 litres/minute per diver (30 litres/hour) and that the formula for the calculation of the oxygen to be added during the decompression is explained in the appendix.
    There is no comment to make regarding this text that has been adequately reinforced.
    For information, these formulas are also explained in Book #2 of the saturation handbook published by "<u>Diving & ROV specialists</u>".
  - Regarding "Living chamber emergency breathing supply (classified 'reserve')", the following text was displayed in point "general" in the previous version of IMCA D 050: *"In mixed gas, bounce or saturation diving, there is always the possibility of the deck chamber atmosphere becoming fouled, due to smoke or other contaminant. In such circumstances the chamber occupants should use the built-in breathing system (BIBS), dumping the exhaust overboard while they transfer to another chamber or the main chamber atmosphere is cleansed or flushed out. Sufficient gas should always be available to allow each diver four hours' breathing on BIBS masks at the deepest storage depth in addition to other gas reserves".*
    The new text has been adapted to saturation diving only and says: *"In saturation diving, there is always the*

possibility of the deck chamber atmosphere becoming fouled, due to smoke or other contaminants. In such circumstances the chamber occupants should use the built-in breathing system (BIBS), dumping the exhaust overboard while they transfer to another chamber or the main chamber atmosphere is cleansed or *exhaust overboard while they transfer to another chamber or the main chamber atmosphere is cleansed or* *flushed out. Sufficient gas quantity should always be available to allow each diver four hours breathing on BIBS masks (ppO2 400mbar –1400mbar) at the deepest depth".* The authors say that this minimum value depends on parameters such as the design of the dive system and the number of divers.
They also say that some mixes can be used for gas supply in emergency and therapeutic treatment.
An example of mixes that can be used is provided and based on the following percentages and consumption by diver:

- 20%, to be used from the surface to 60 msw (the authors calculate a consumption between 5 and 34 m³, depending on the depth with a breathing rate of 20 l/min).
- 10% for depths from 30 to 130 msw (with a consumption planned between 20 and 68 m³, based on the parameters above)
- 7 % for depths between 48 and 190 msw (with a calculated consumption between 28 and 96 m³ also based on 20 l /min breathing rate).
- 2% for depths between 190 to 300 msw (with a consumption planned between 96 and 150 m³).

Regarding this topic, I think it would have been interesting to highlight the fact that other mixes than those selected for this example can be used. Many companies use what they call "standard mixes" and what they call "alternative mixes" that are unused mixes from previous operations that can be put online instead of being remixed to provide a standard mix. Also, it would have been interesting to write that it is important that the mixes prepared to be online must be organized to cover every depth from the storage depth to the surface without a gap between two depths. In addition, it is a good practice to organize the mixes with overlaps to pass from one depth to another during an ascent smoothly. As a result, 3% is more appropriate than 2% as it allows depths between 123,3 m and 456 m and thus allows to pass from this mix to the next one quietly when a mix 2% O2 obliges to transfer to 7% at 190 m imperatively.
Also, it would have been interesting to insist on the fact that these mixes should be ready for use at any time in the eventuality that an emergency decompression is to be started.

- Point 3.7 discusses of "calibration gases (consumable)" The authors suggest the following calibration for gases that are common in the industry:

  Above 100 msw:
  - 100% Helium
  - 10% O_2 and 1000 ppm CO_2 (balance He)
  - 20% O_2 & 4000 ppm CO_2 (balance He).

  For operations up to 300 m
  - 100% Helium
  - 5% O_2 & 500 ppm CO_2 (balance He)
  - 10% O_2 & 1000 ppm CO_2 (balance He)
  - 20% O_2 & 4000 ppm CO_2 (balance He).

  The authors say that the quantity of calibration gas depends on the design and the size of the diving system. In addition to what is said, it should be interesting to say that this quantity also depends on the system of analyzer used (Fuel cell, Magneto-dynamic, Photo-acoustic, Acoustic, Thermal conductivity detectors, etc.), and the recommended frequencies of calibration that are usually given by the manufacturers.
  The authors also say that two sources of each calibrations gas should be organized on site, and that two small bottles can be provided rather than a large one for short mobilizations, as previously indicated for surface orientated diving. Regarding small bottles, it should be remembered that the needs for calibrations are more elevated with a saturation system than a surface-orientated diving system.

  Note that the authors have withdrawn the sentence saying that a minimum of three weeks supply of calibration gas and zero gas is mandatory, which was present in the previous edition of IMCA D 050. Also, I consider that indicating gas percentages to be used is outside the topic. In addition, these suggested mixes should be justified and not imposed without explanation. Thus why these calibration mixes and not others?

- "Therapeutic gases" are discussed in point 3.8 and classified as 'reserve gases'. The authors have kept the sentence of the previous version of IMCA D 050 and AODC 14, which says that the composition and use of therapeutic gases depend on the operating procedures and treatment tables used by the companies and that sufficient quantities of treatment gas for the depths involved need to be available to carry out any foreseeable treatments as detailed in the company's manuals.
  The authors also say that there should be sufficient quantities of therapeutic gases to carry out treatment of a decompression illness during normal decompression. This guideline is reinforced by an example of organization of therapeutic gases with PP O_2 from 1.5 to 2.5 bar. This example is calculated for 6 divers undertaking 4 periods of 30 minutes alternating with 5 minutes chamber atmosphere breaks using the following mixes:
  - 100 % oxygen, from the surface to 15 m (the authors plan for 36 m³)
  - 60 % oxygen, from 15 to 31 msw (the authors plan for 60 m³)
  - 37.5% oxygen from 30 to 56 msw (the authors plan for 96 m³)
  - 24 % oxygen from 53 to 94 msw (the authors plan for 150 m³)

- 15 % oxygen from 90 to 156 msw (the authors plan for 240 m³)
- 10 % oxygen from 140 to 240 msw (the authors plan for 360 m³)
- 7 % oxygen from 205 to 300 msw (the authors plan for 447 m³)

As already discussed for the emergency breathing mixes, the authors do not insist enough on the fact that therapeutic mixes prepared to be online must be organized to cover every depth from the storage depth to the surface without a gap between two depths.
Also, it would have been suitable to explain the principle of “standard” mixes that are the preferred mixes of the company and “alternative mixtures” that are unused mixes from previous operations that can be put online instead of being remixed to provide a standard mix.
In addition, and as explained previously in emergency breathing gases, it is a good practice to organize the mixes with overlaps to smoothly pass from one depth to another during an ascent. The example below shows various mixes that can be selected to organize therapeutic mixes with suitable PPO2 and overlaps. Note that the maximum PPO2 of 2.8 bar (or ATA) is commonly used by decompression table designers. For this reason, the authors should have explained why they have selected a lower maximum value in their example. Also, insisting on a particular percentage can be seen outside the topic of this guidance, which is the “minimum quantities of gas required offshore”, and not the "optimal composition of gases”.

Depths with 2.8 bar and 1.5 bar PPO_2 for various oxygen percentages

Percentage oxygen	*Depth in metres with 1.5 bar PPO2*	*Depth in metres with 2.8 bar PPO2*		*Percentage oxygen*	*Depth in metres with 1.5 bar PPO_2*	*Depth in metres with 2.8 bar PPO_2*
100 %	5	18		***13 %***	105	205
70 %	11	30		***12 %***	111	223
60 %	15	36		***11 %***	126	244
50 %	20	46		***10 %***	140	270
40 %	27	60		***9 %***	156	301
30 %	40	83		***8 %***	177	340
20 %	65	130		***7 %***	204	390
15 %	90	179		***6 %***	240	456
14 %	125	190		***5 %***	270	550

- Point 3.9. “Operational Personnel Escape Gases (reserve)”, provides the same guidance as in Point 2.10, of Surface orientated diving “Operational personnel escape gases (reserve)” in which the authors say that they have to be included in the gas calculations of the diving project plan. As previously discussed, this topic is added to the initial version of IMCA D 050.
  My comments are those displayed in point 2.10.
- In point 3.10, “Diver transfer oxygen (reserve)”, the authors say that if the divers have to be transferred from a stricken vessel to a standby chamber situated in another place without being adequately decompressed, sufficient portable oxygen sets are required to allow these divers to breath 100% oxygen during their evacuation process and until they are being re-pressurized in the standby chamber. The transfer durations and gas consumptions should be calculated and be introduced in the Diving Project Plan (DPL). This is what is said in point 2.11 of Surface orientated diving “Diver transfer oxygen (reserve)”.
  Regarding this topic, it would have been suitable to indicate that such an event may happen after an accelerated decompression (See the document DMAC 31) as returning saturated divers to the surface without decompression will result in explosive decompression. My other comments are those discussed for point 2.11.
- Point 3.11, “Hyperbaric reception facility (HRF) requirements” describes what is an hyperbaric reception facility (a saturation complex that is situated in a strategic place onshore or offshore, into which the divers are transferred from the Hyperbaric Rescue Unit (HRU) to perform their decompression).
  The authors say that the HRF must comply with the gas requirements they have discussed in the following points:
  - 3.6 – Dive System Chamber Gases – except for a reduced quantity of BIBS gas where only one hour for each diver in the HRF is required. The quantities in Table 3.1 of the new guidance may then be adjusted accordingly.
  - 3.7 – Calibration Gases.
  - 3.8 – Therapeutic Gases.
  - 3.9 – Operational Personnel Escape Gases.

  My comments are those previously provided in these points.
- Point 3.12, “Life Support Package (LSP) (reserve)”, describes what this system is, and the minimum gas to provide to use it safely. Note that today Life Support Packages (LSP) are mainly used to maintain optimal living

conditions of the divers during the transfer to the place where the decompression facility has been installed.
The authors say that when the life support package is used to increase the autonomy of the Hyperbaric Rescue Unit (HRU) for interim support at a safe-haven or Hyperbaric Reception Facility (HRF) location with no planned decompression, the guidance on what should be considered is as listed below. However, that the exact quantities are driven by HRU volume, depth, manning, and location.

- Minimum recommended quantities for interim support pressurisation gas and BIBS:
  1 x 200 bar 16 rack of 98%/2% Heliox
  1 x 200 bar 16 rack of Heliox (PPO_2 200 – 1400 mbar).
- Minimum recommended quantities for interim support metabolic oxygen:
  1 x 200 Bar 16 rack of diving quality O_2
- Minimum recommended quantities for interim support calibration gases (50 litres bottles):
  1 x 100% Helium – 200 bar
  1 x 20% O_2 & 4000 ppm CO2 (balance He) – 200 bar.

The authors also say that where the objective for the LSP is to give primary support for HRU decompression on a vessel of opportunity or at a designated safe haven, the requirements of 3.6.2 are calculated in accordance with Appendix 1, Section 2, "Maintenance of Oxygen Partial Pressure During Decompression", utilising the HRU floodable volume (FV):

Minimum quantity of oxygen required = (Ln initial pressure) x PPO2 (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" or "natural logarithm", a mathematical function found on most scientific calculators where "e" equals the approached value of 2,71828.
  The key might be labelled 'Ln' 'ln' or 'log e'. Press 'Ln', enter the initial pressure, then multiply by the ppO_2 and chamber volume.

In addition, the authors say that it may not be practical or possible for the LSP to contain all of the required gas and consumables for a full decompression or for unforeseen events and that in such a circumstance, the equipment and gas supplies need to be managed to ensure that they will arrive at the desired location rapidly.

Regarding therapeutic gases, the authors say that these gases are important for decompression as the stresses, both physical and mental, of the evacuation process leave the divers more prone to decompression accidents. For this reason, they say that the therapeutic mix package should comply with section 3.8.

Regarding comments that can be made on the fact that Hyperbaric Rescue Units (HRU) are used for decompression of saturated divers, note that in the document "Saturation diving handbook" published by "Diving and ROV specialists" it is said in point 4.5.1.8 "Decompression in the Hyperbaric Rescue Unit" that Hyperbaric Rescue Units (HRU) are not designed to perform optimal decompression. As a result, safety organizations and most clients require that the decompression is organized in the Hyperbaric Reception Facility, which is designed for this purpose. Note that one day is necessary to ascent from 16 metres and 11 days from 301 metres using the decompression procedure NORMAM 15. Thus, such long decompressions are not to be envisaged with people nailed on their seats and should be considered only when an undesirable event results that the Hyperbaric Reception Facility is no more available.
Also, it is not suitable to say that decompression gas supplies need to be managed to ensure that they will arrive at the desired location rapidly. In my humble advice, gases planned for decompression should be available on site before starting the diving operations. It is also what most clients request.

- Point 3.13 discusses "Air/Nitrox Transfer Under Pressure (TUP) Diving". Note that Heliox Transfer Under Pressure (TUP) Diving procedures have been withdrawn.
  The authors explain that Air/nitrox TUP diving is an amalgamation of surface orientated diving and closed bell diving where the divers are deployed in a closed bell and then transferred to the chamber where they complete their decompression through a trunk to which the chamber is connected.
  They also say: *"The composition and use of therapeutic or treatment gases varies from company to company, dependent on their detailed operating procedures and the therapeutic tables used. This document is based on treatment using US Navy therapeutic table 6 with oxygen breathing periods. Companies using other therapeutic tables should ensure they have sufficient quantities of therapeutic gas for the depths involved to carry out any foreseeable treatments as detailed in the company's rules"*.
  Regarding this sentence, the purpose of this guidance is to provide companies advice on how to design company rules. So sending the readers to their company rules appears not really suitable! Also, I can understand the use of a particular procedure in the demonstration of a principle. However, what is said does not give a real guideline on how to calculate the gases used by a therapeutic table! Thus, it would be more suitable to explain the principle of calculation for such tables that are all based on the same system.
  They also say that Air/nitrox TUP diving needs to comply with the following sections of this document:
  3.2 - Operational In Water Gases, except the breathing gas will be air/nitrox:
  "Sufficient mixed gas should always be available at the start of a bell run to carry out the intended bell run plus the same quantity of gas should be held as a reserve. This gas will be in addition to the gas requirements in the following paragraphs. Gas carried onboard the bell or hyperbaric evacuation system (HES) in cylinders should not be included in these calculations".
  3.3 - Divers Personal Gas Reserve (Bailout)
  "All working divers must carry a personal gas reserve to provide sufficient endurance to allow the

diver to return to a place of safety"

3.4 - Surface Rescue Diver Gases:
"Dive systems relying on surface deployed diver intervention for emergency bell recovery require to have sufficient compressed gas available for two thirty-minute rescue dives to the full intended diving depth with the diver breathing at 40 l/min. This gas is to be kept as a reserve"

3.5 - Closed Bell System Gas Reserve - Oxygen - Metabolic oxygen makeup during air diving is to be carried out by flushing the bell. The oxygen requirements in this section are for 24 hour survival in a trapped or lost bell scenario: *"Sufficient oxygen must be available for metabolic consumption by the maximum number of divers at 0.5 l/min (surface equivalent volume) per diver for at least 24 hours at the end of a bell run"*.
Also, closed bell system gas reserve for working diver: *"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 l/min at the maximum depth of the diving operation*".

2.7 - Surface Decompression Gases - with the addition of air for pressurising the closed bell and trunks:
"Sufficient compressed air needs to be available to pressurise both locks of the deck decompression chamber to the maximum decompression depth (normally ≈ 15 metres) plus sufficient air for three complete surface decompression cycles. Sufficient breathing quality oxygen needs to be available for the full number of oxygen breathing cycles for each working diver under pressure"

2.8. - Calibration Gases:
"Calibration gases may not be required for air or nitrox diving as it may be possible to calibrate analysers with well-ventilated standard ambient air. Some analysers however may require calibration mixes, which should be verified as suitable for the analysers in use".

2.9 - Therapeutic Gases:
"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) <u>plus sufficient air for three complete surface decompression cycles</u>".
"There should be sufficient quantities of therapeutic gases to carry out treatment of a DCI during normal decompression based on the contractor's tables".
"90 m3 (3200 cu ft) of breathing quality oxygen needs to be available for emergency treatment procedures at each decompression chamber which may be used for therapeutic purposes within the Diving Project plan"

3.9 - Operational Personnel Escape Gases
"Sufficient compressed air at a minimum availability of 40 l/min needs to be available for the diving support crew to operate in a vessel emergency situation to safely recover the divers to surface pressure and to make their way to the vessel's evacuation stations within the vessel's allotted abandonment time frame. This requirement applies to each member of the diving support crew required to remain at their operational station at a vessel muster alarm".

3.10 - Diver Escape Oxygen, where the authors say that if the divers have to be transferred from a stricken vessel to a standby chamber situated in another place without being adequately decompressed, sufficient portable oxygen sets are required to allow these divers to breath 100% oxygen during their evacuation process and until they are being re-pressurized in the standby chamber. The transfer durations and gas consumptions should be calculated and be introduced in the diving project plan.

My comments regarding these text are previously indicated in the points indicated by the authors.
Note that the guidelines of point 3.2 "bounce diving" in the previous version of IMCA D 050 have been withdrawn or adapted in the texts above. That demonstrates that IMCA has banished the use of closed bells for heliox bounce diving.

Important:
Soda lime and Purafil are not taken into account in the texts. Saturation procedures cannot be organised without these consumables, , because they are essential to absorb the CO_2 and other contaminants (The average consumption of a diver is 6 kg soda-lime/day). Soda lime is also used in bells and chambers' scrubbers and must be regularly renewed according to their usage.
Also, cartridges for systems "Gaspure" (replacement every 2830 m³ of gas) and "Helipure" must be taken into account as they are part of the gas recycling systems.

3.1.3 - Conclusion of the authors

In this point, the authors reuse the conclusion of the previous version of IMCA D 050, and say the following regarding the purpose of this document. Thus, it confirms only what is explained in the introduction and throughout the document:

- It provides guidelines as to when diving operations should not start due to insufficient gas reserves.
- It provides guidelines as to when decompression of saturation operation should start due to insufficient gas reserves.
- That the quantities referred to are for guidance only and are the absolute minimum.
- That a risk assessment should be undertaken for the diving project. It is likely to result in much greater quantities of gas required to be maintained on board to cover all eventualities.

3.1.4 - Appendix 1: Gas calculations

In this point, the authors provide element of calculation that are provided in Chapter 2 of IMCA D 022 “Guidance for diving supervisors”.

They explain that breathing gas consumption rates are usually quoted as respiratory minute volumes (RMV) with the Formula “Free gas volume = Consumption rate at surface pressure x Depth”

They also provide the diver’s gas consumption in the water: 35 l/min for a diver at work, 40 l/min for a diver in an emergency (I suggest using the rate of the UK HSE report RR 1073 instead of this rate), and five litres/minutes using reclamation system. However, the authors say that certain global regions, regulatory authorities and company policies may stipulate or recommend other work and emergency breathing rates, i.e. 45 l/min, 62.5 l/min, etc.. Also that the diving contractors should ensure, through risk assessment and regional compliance, that they are using appropriate breathing rates.

The formula for the maintenance of oxygen partial pressure during decompression is also explained:

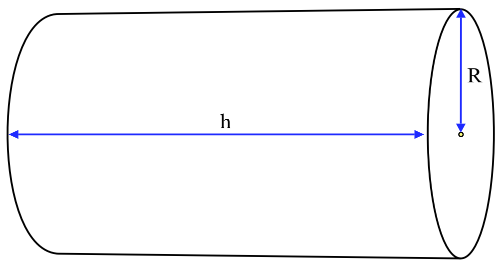
Minimum quantity of oxygen required = (Ln initial pressure) x PPO_2 (bar) x chamber volume

- “Initial pressure” is the absolute pressure in the chamber at the start of the decompression.
- Ln is “logarithm to the base e” or “natural logarithm”, a mathematical function found on most scientific calculators where “e” equals the approached value of 2,71828.
  The key might be labelled ‘Ln’ ‘ln’ or ‘log e’. Press ‘Ln’, enter the initial pressure, then multiply by the ppO_2 and chamber volume.

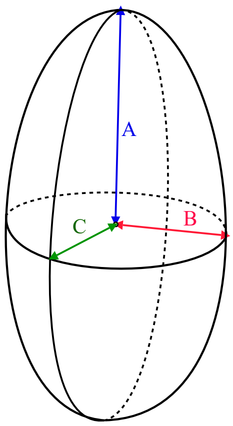
The oxygen metabolic consumption (05 litres/min) and BIBS respiratory rate (20 l/min) are provided

The method for the calculation of the volume of chambers previously published in the 1st edition of IMCA D 050 is kept: Vol. chamber = (π(D/2) x L) + 4/3 πr3, where the domed ends of the chamber are true spheres (in this case r = D/2).
As I have said previously, chambers with domed end are very rare and I think more suitable to take into account the texts and formulas below from the “Saturation diving handbook” Published on the website “Diving & ROV Specialists”:
Every pressure vessel is normally fitted with an identification plate that, in addition to information regarding its construction process, indicates its volume. The manufacturer is also required to indicate the volume of the elements that compose the dive system in a document that should be accessible to the people in charge. Thus, the Life Support Supervisor should have all information to calculate the volume of the system.
In the improbable case that the volume of a chamber or a lock has to be calculated, the following method and formulas can be used:

- *For medical locks of pressure vessels with a similar shape, the formula to apply is the one for the calculation of the volume of a cylinder: Vol. = $\pi R^2 h$*



- *In the case of a chamber with rounded ends, which are today very rare, the volume of the item is equal to the volume of the cylinder + the volumes of the two half spheres at the extremities. As two half spheres equal a sphere, the formula for the calculation of the volume to be used is: Vol. = $4/3\ \pi R^3$, where R is the radius of the sphere.*
- *Most chambers are provided with oblate spheroid ends, which can be considered ellipsis. In this case, the following formula can be applied: Vol. = 4/3 π x A x B x C (see A, B, C in the scheme below). This volume is to be added to the volume of the cylinder to give the volume of the chamber.*
  Note that when A = B = C, the ellipsis is a sphere.



- *To find the volume of the pipes, the formula for the volume of a cylinder can be applied.*

3.1.5 - Appendix 2: Gas Requirements check sheets

In this point, the authors provide examples of forms which may be used to plan for minimum diving gas requirements . My advice is that it would have been more appropriate to provide theses sheets at the end of each topic discussed, because that provide summaries of he points discussed.

Each list provides the following information:

- Gas function
- The reference point of the gas function discussed
- The classification of the gas ("Consumable" or "Reserve")
- The minimum required
- The calculated quantities (to be calculated)
- The quantities on site (to be indicated)
- Notes (to be filled if necessary)

These sheets summarize recommendations to calculate gas quantities for the following points:

1. Surface Orientated Air or Nitrox Diving
    - Operational in-water gas - See point 2.2
    - Divers personal gas reserve (bailout) - See point 2.3
    - Diver rescue gas - See point 2.4
    - Wet bell/basket gas - See point 2.5
    - In-water decompression gas - See point 2.6
    - Surface decompression gas - See point 2.7
    - Calibration gas - See point 2.8
    - Therapeutic gas - See point 2.9
    - Dive crew evacuation gas - See point 2.10
    - Diver transfer oxygen - See point 2.11
2. Surface Orientated Mixed Gas Diving
    - Operational in-water gas - See point 2.2
    - Divers personal gas reserve (bailout) - See point 2.3
    - Diver rescue gas - See point 2.4
    - Wet bell gas - See point 2.5
    - In-water decompression gas - See point 2.6
    - Surface decompression gas - See point 2.7
    - Calibration gas - See point 2.8
    - Therapeutic gas - See point 2.9
    - Dive crew evacuation gas - See point 2.10
    - Diver transfer oxygen - See point 2.11
3. Gas Check Sheet - Closed Bell Air/Nitrox TUP Diving
    - Operational in-water air - See point 3.2
    - Divers personal air reserve (bailout) - See point 3.3
    - Diver rescue air - See point 3.4
    - Closed bell oxygen - See point 3.5.1
    - Closed bell onboard air - See point 3.5.2
    - Chamber BIBS - See point 3.6
    - Chamber pressurization air - See point 2.7
    - Calibration gas - See point 2.8
    - Therapeutic gas - See point 2.9
    - Dive crew evacuation gas - See point 2.10
    - Diver transfer oxygen - See point 2.11
4. Gas Check Sheet - Saturation Closed Bell Diving
    - Operational in-water gas - See point 3.2
    - Divers personal gas reserve (bailout) - See point 3.3
    - Diver rescue gas - See point 3.4
    - Closed bell onboard oxygen - See point 3.5.1
    - Closed bell onboard gas reserve - See point 3.5.2
    - Chamber pressurization gas - See point 3.6
    - Chamber metabolic oxygen - See point 3.6
    - Chamber decompression oxygen - See point 3.6
    - Chamber BIBS - See point 3.6
    - Calibration gas to 100 msw - See point 3.7
    - Calibration gas to 300 msw - See point 3.7

- Therapeutic gas - See point 3.8
- Dive crew evacuation gas - See point 3.9
- Diver transfer oxygen - See point 3.10

5. Gas Check Sheet - Hyperbaric Reception Facility
   - Chamber pressurization gas - See point 3.6
   - Chamber metabolic oxygen - See point 3.6
   - Chamber decompression oxygen - See point 3.6
   - Chamber BIBS - See point 3.6
   - Calibration gas to 100 msw - See point 3.7
   - Calibration gas to 300 msw - See point 3.7
   - Therapeutic gas - See point 3.8
   - Dive crew evacuation gas - See point 3.9
6. Gas Check Sheet - Life Support Package
   - Hyperbaric Rescue Unit (HRU) pressurization gas - See point 3.12.1
   - Hyperbaric Rescue Unit (HRU) metabolic oxygen - See point 3.12.2
   - Calibration gas - See point 3.12.3
   - HRU decompression gas - See point 3.12.4
   - Therapeutic gas - See point 3.12.5

Note that the gases and soda-lime of the Hyperbaric Rescue Units (HRU) and other elements are missing in these sheets. For this reason, it is recommended to refer to the texts indicated in the various points, and refer to other sources.

3.1.6 - Appendix 3 – Therapeutic gas for saturation diving

In this appendix, the authors provide tables of oxygen partial pressures for the therapeutic heliox mixes taken as an example in point 3.8, "Therapeutic gases" from the surface to 300 m. Another table provides the same calculations in feet (surface to 1000 fsw).
The authors say that diving contractors are responsible for selecting the diving tables they use for decompression and decompression illness treatments. They also say the following:
" It should be noted that it is not IMCA's intention, in this appendix or elsewhere, to specify a maximum ppO2 limit for therapeutic breathing gases used in saturation or in surface diving operations. A range of 1.5 bar ppO2 to 2.5 bar ppO2 has been adopted in this appendix to illustrate that, using the selected heliox mixtures, it is possible to maintain oxygen partial pressures between 1.5 and 2.5 bar throughout the entire range of depths covered by the charts".
In addition, the authors say that contractors may select procedures with different PPO2, such as US Navy procedures, which are based on PPO2 between 1.5 and 2.8 ATA. However, why selecting these mixes instead of those from existing procedures and publishing full tables in metric and imperial where a more reduced example would have been sufficient for explaining the principles discussed? I see here the hided intention to impose these values!
The tables published are designed as follows:

Saturation Diving Therapeutic Gas ppO_2 Values (MSW)

	O_2 %						
Depth	7	10	15	24	37.5	60	100
MSW	ppO_2 value			<1.5bar	1.5 to 2.5 bar		>2.5bar
0	0.1	0.1	0.2	0.2	0.4	0.6	1.0
1	0.1	0.1	0.2	0.3	0.4	0.7	1.1
2	0.1	0.1	0.2	0.3	0.5	0.7	1.2
3	0.1	0.1	0.2	0.3	0.5	0.8	1.3
4	0.1	0.1	0.2	0.3	0.5	0.8	1.4
5	0.1	0.2	0.2	0.4	0.6	0.9	1.5
6	0.1	0.2	0.2	0.4	0.6	1.0	1.6
7	0.1	0.2	0.3	0.4	0.6	1.0	1.7
8	0.1	0.2	0.3	0.4	0.7	1.1	1.8
9	0.1	0.2	0.3	0.5	0.7	1.1	1.9
10	0.1	0.2	0.3	0.5	0.8	1.2	2.0
11	0.1	0.2	0.3	0.5	0.8	1.3	2.1
12	0.2	0.2	0.3	0.5	0.8	1.3	2.2
13	0.2	0.2	0.3	0.6	0.9	1.4	2.3
14	0.2	0.2	0.4	0.6	0.9	1.4	2.4
15	0.2	0.3	0.4	0.6	0.9	1.5	2.5
16	0.2	0.3	0.4	0.6	1.0	1.6	2.6
17	0.2	0.3	0.4	0.6	1.0	1.6	2.7

A similar table to this example can be easily done using a spreadsheet with these percentages or other percentages. It is the case with the table displayed on the next page.
In addition to quickly doing calculations, the advantage of spreadsheets is that they allow visualization of the continuity and overlaps of the mixes selected. Note that the partial pressures between 1.5 & 2.5 bar are in green in this example, and those between 2.5 & 2.8 bar are in yellow. Note that 2.5 bar PPO2 is indicated to comply with the example above.

		Oxygen %						
Depth	**Abs pressure**	**7**	**10**	**15**	**24**	**37.5**	**60**	**100**
0	1	0.07	0.10	0.15	0.24	0.38	0.60	1.00
1	1.1	0.08	0.11	0.17	0.26	0.41	0.66	1.10
2	1.2	0.08	0.12	0.18	0.29	0.45	0.72	1.20
3	1.3	0.09	0.13	0.20	0.31	0.49	0.78	1.30
4	1.4	0.10	0.14	0.21	0.34	0.53	0.84	1.40
5	1.5	0.11	0.15	0.23	0.36	0.56	0.90	1.50
6	1.6	0.11	0.16	0.24	0.38	0.60	0.96	1.60
7	1.7	0.12	0.17	0.26	0.41	0.64	1.02	1.70
8	1.8	0.13	0.18	0.27	0.43	0.68	1.08	1.80
9	1.9	0.13	0.19	0.29	0.46	0.71	1.14	1.90
10	2	0.14	0.20	0.30	0.48	0.75	1.20	2.00
11	2.1	0.15	0.21	0.32	0.50	0.79	1.26	2.10
12	2.2	0.15	0.22	0.33	0.53	0.83	1.32	2.20
13	2.3	0.16	0.23	0.35	0.55	0.86	1.38	2.30
14	2.4	0.17	0.24	0.36	0.58	0.90	1.44	2.40
15	2.5	0.18	0.25	0.38	0.60	0.94	1.50	2.50
16	2.6	0.18	0.26	0.39	0.62	0.98	1.56	2.60
17	2.7	0.19	0.27	0.41	0.65	1.01	1.62	2.70
18	2.8	0.20	0.28	0.42	0.67	1.05	1.68	2.80
19	2.9	0.20	0.29	0.44	0.70	1.09	1.74	2.90
20	3	0.21	0.30	0.45	0.72	1.13	1.80	3.00
21	3.1	0.22	0.31	0.47	0.74	1.16	1.86	3.10
22	3.2	0.22	0.32	0.48	0.77	1.20	1.92	3.20
23	3.3	0.23	0.33	0.50	0.79	1.24	1.98	3.30
24	3.4	0.24	0.34	0.51	0.82	1.28	2.04	3.40
25	3.5	0.25	0.35	0.53	0.84	1.31	2.10	3.50
26	3.6	0.25	0.36	0.54	0.86	1.35	2.16	3.60
27	3.7	0.26	0.37	0.56	0.89	1.39	2.22	3.70
28	3.8	0.27	0.38	0.57	0.91	1.43	2.28	3.80
29	3.9	0.27	0.39	0.59	0.94	1.46	2.34	3.90
30	4	0.28	0.40	0.60	0.96	1.50	2.40	4.00
31	4.1	0.29	0.41	0.62	0.98	1.54	2.46	4.10
32	4.2	0.29	0.42	0.63	1.01	1.58	2.52	4.20
33	4.3	0.30	0.43	0.65	1.03	1.61	2.58	4.30
34	4.4	0.31	0.44	0.66	1.06	1.65	2.64	4.40
35	4.5	0.32	0.45	0.68	1.08	1.69	2.70	4.50
36	4.6	0.32	0.46	0.69	1.10	1.73	2.76	4.60
37	4.7	0.33	0.47	0.71	1.13	1.76	2.82	4.70
38	4.8	0.34	0.48	0.72	1.15	1.80	2.88	4.80
39	4.9	0.34	0.49	0.74	1.18	1.84	2.94	4.90
40	5	0.35	0.50	0.75	1.20	1.88	3.00	5.00
41	5.1	0.36	0.51	0.77	1.22	1.91	3.06	5.10

To calculate the absolute pressure enter the formula "= A3/10+1" in the cell B3, then drag the formula downward .

B3 fx =A3/10+1

	A	B	C	D	E	F	G	H	I
1			Oxygen %						
2	Depth	Abs pressure		10	15	24	37.5	60	100
3	0	1	0.07	0.10	0.15	0.24	0.38	0.60	1.00
4	1	1.1	0.08	0.11	0.17	0.26	0.41	0.66	1.10
5	2	1.2	0.08	0.12	0.18	0.29	0.45	0.72	1.20

Click on this small square and drag downward

To calculate the PP O2 of 7% enter the formula "= B3*7/100" in the cell C3, then drag the formula downward. Proceed similarly with the other percentages

C3 fx =B3*7/100

	A	B	C	D	E	F	G	H	I
1			Oxygen %						
2	Depth	Abs pressure	7	10	15	24	37.5	60	100
3	0	1	0.07	0.10	0.15	0.24	0.38	0.60	1.00
4	1	1.1	0.08	0.11	0.17	0.26	0.41	0.66	1.10
5	2	1.2	0.08	0.12	0.18	0.29	0.45	0.72	1.20

3.1.7 - Elements added in the revision 1.1: References and Glossary

A reference section and a glossary have been added to Revision 1.1, which were not present in Revision 1.
However, these two elements are unnecessary in their current presentation, as the information they provide is insufficient and could be included in the texts.

- The only reference provided is *"IMCA D063 Diving Equipment Systems Inspection Guidance Note – DESIGN for Hyperbaric Rescue Unit (HRU) Life Support Packages (LSP)"*, which is extremely poor and conforms to the "circular reasoning" many authors of IMCA guidelines have.
  For information, "circular reasoning" is a method of thinking where the proposition is supported by the premises, which are supported by the proposition, creating a circle in reasoning where no useful information is shared. In other words, X is true because of Y, and Y is true because of X. So, the only references provided by IMCA are IMCA references.
  It would have been interesting to indicate documents published by other organizations such as the UK HSE, the US Navy, COMEX, and the DMAC (in which IMCA is involved), in addition to a selection of scientific studies such as those stored in our database, to justify the procedures promoted in this document instead of trying to impose them without explanations.
- The glossary is provided on page 22 of the paper, which is surprising as authors usually offer it at the beginning of the document they write. Also, the information provided by the authors is limited to the translation of acronyms, which can be done within the various texts, as I often do in the documents I provide. So, a glossary is interesting when it gives definitions that are too long to be included in the texts, such as, for example, the one of a "Breathing Apparatus (BA)", a "Built-In Breathing System (BIBS)", or a "Diving System Inspection Guidance Note (DESIGN)". Thus, definitions of elements the reader may not be familiar with.

3.2 - Summary of the comments regarding revisions 1 and 1,1 of IMCA D 050

IMCA D 050 revisions #1 and 1.1 add positive elements to the initial edition. However, they are far from perfect for the reasons discussed in the previous texts and summarized here.

Regarding the positive elements, we must admit that some clarifications regarding the elements to consider are useful guides the readers can follow to provide gas reserves and consumables to working sites.
Also, the topics discussed are based on the principles already implemented in AODC 14 and the initial version of IMCA D 050, from which most texts have been reused and reinforced. Additional topics have been added to reinforce the explanations. Among the topics reinforced or added, we can note the following:

- Operational in-water gas: These guidelines are those previously explained in AODC 14 and the first edition of IMCA D 050.
- Diver rescue gas: The duration of the dive and the consumption rate are indicated in the new version.
- Divers personal gas reserve (bailout): This topic was not clearly discussed in the previous edition. Also, the authors promote rebreathers for saturation diving.
- Wet bell/basket gas: The initial version of IMCA D 050 did not discuss precisely this point.
- In-water decompression gas: Oxygen is taken into consideration and was not in the previous editions.
- Surface decompression gas: Oxygen is taken into consideration and was not in the previous editions.
- Operational personnel escape gases: Not included in the previous versions.
- Therapeutic gases: These texts have been reinforced. Also, other gases than oxygen are considered.
- Calibration gases: They are taken into consideration in this new version. It was not the case before.
- Closed bell oxygen: This topic is added. It was only suggested previously.
- Closed bell onboard gas: This topic is added. It was only suggested previously.
- Chamber pressurization gas: The text of the previous versions is reused and reinforced.
- Metabolic oxygen: The text of the previous versions is reused and reinforced (added the consumption rates).
- Chamber decompression oxygen: This topic was not discussed in the initial publications.
- Chamber BIBS: The previous text is re-employed and adapted to saturation diving only.
- Hyperbaric Rescue Unit (HRU) pressurization gas: This topic was not present in the previous versions.
- Hyperbaric Rescue Unit (HRU) metabolic oxygen: This topic was not present in the previous versions.
- HRU decompression gas: This topic was not present in the previous versions.

As a result, revision #1 of IMCA D 050, published in April 2021, comprised 38 pages, the current revision, 52 pages, while the initial one, published in 2012, was only seven.
The lists and examples for gas calculations provided in the appendix provide useful complements to the texts.
Also, it is said that the guideline provides only the "absolute minimum levels of gas to be on the worksite", and that

“These minimum levels do not account for the gas supplies required for carrying out any operational tasks".

Regarding the elements that can be improved, note the following list that summarizes the main comments previously provided in the texts:

- IMCA continues to use a breathing rate of 40 litres per minute for divers in an emergency, despite most competent bodies use higher rates. Also, the UK HSE report RR 1073, “The provision of breathing gas to divers in emergency situations”, is a scientific study published in 2015 that concludes that a breathing rate between 50 l/min or 75 l/min might be appropriate (62.5 l/min is the middle value). It cannot be ignored by IMCA personnel who say that more stringent breathing rates than those they use exist. The reasons IMCA is not changing this rate are unclear. It will indeed oblige the organization to review a lot of publications. I remember that the association wanted to organize experiences regarding this matter a few years ago, and then nothing has happened. Does the association keep this breathing rate because the more stringent rates have been the fact of other structures, or does the association keep it because it allows for less gas?
- The text of “operational in-water gas” does not clearly explain the methods used to evaluate the gas consumption during the operations. It could have been interesting to list the variables and remember that gas at a pressure of less than 20 or 30 bar cannot be considered as part of the reserve (IMCA D 022). Also, it would be suitable for consistency to suggest a rule similar to the one indicated for closed bell diving that says that sufficient gas should be available at the start of a bell run to carry out the intended bell run plus the same quantity of gas as a reserve.
- The text describing gas reserves of “Wet bell/basket gas”, suggests that a bottle of 44.4 litres with a minimum of 150 bar may be sufficient. However, the text should say that calculating the necessary volume using the breathing rates of the divers in an emergency and the maximum decompression time is the most suitable method. Note that, B 50 litres bottles at 200 bar are today more used than the model indicated in the text.
- In the text for “in-water decompression gas” it would have been suitable to specify the normal respiratory rates at rest (20 to 25 l/min), indicate that gases at a pressure of less than 20 or 30 bar cannot be considered as part of the reserve (IMCA D 022), and to provide a rule such as the one for metabolic oxygen in chambers, discussed in point 3.62 of the document, where it is said that the O2 quantity should be doubled. Such a rule allows to cover unforeseeable adverse situations, and increase the consistency of the guidelines.
- Regarding calibration gases, it would have been interesting to indicate that the need for calibration depends on the system of analyzer used and that the manufacturers usually give the recommended frequencies of calibration. Note that the previous edition recommended calibration gases for at least 3 weeks to support a saturation project. Also, I consider that indicating gas percentages to be used is outside the topic. In addition, the authors should explain the reason particular mixes are suggested instead of others.
- Regarding the preparation of deck Decompression Chambers, the texts for “surface decompression gas reserve and therapeutic gases”, which were grouped in the same paragraph in the previous editions of the guideline, have been separated in this revision. In the new text about “Therapeutic gases”, it is said that gas provision for three surface decompression dives is necessary, which is unclear. Obviously, medical personnel transferred into the chamber may have to be decompressed, and some gas must be stored for this purpose. But in this case, we do not use a surface decompression procedure that consists of performing the in-water stops up to 9 metres and then transfer the diver to the chamber to complete the rest of the decompression. Thus, we can consider that this part of the sentence results from a bad copy-paste of the original text from AODC 14.
- Regarding the equipment provided for “surface support personnel escape from the diving station” in case of an emergency, the authors forget to indicate that new breathing apparatus sets that can be connected to an external supply source and then disconnected exist and avoid the personnel breathing polluted or deadly gas when changing from an umbilical supplied breathing apparatus to a bottle supplied one as suggested in the text.
- Regarding the rebreathers described in “Bailout systems for saturation diving”, the authors say that the breathing rate does not need to be considered for rebreathers. It is true that a rebreather recycles the breathed gas. However, the authors should have considered that oxygen and soda-lime (that removes the CO2 from the breathed gas) have to be renewed as oxygen will be consumed by the diver, and the soda-lime saturated with CO2. Also, the systems currently in use require to have their mix adjusted to the depth of intervention, and changing the mix will be the source of gas loss. In addition, mixes may have to be stored if it is planned to change the working depth during the saturation project.
- The text in the previous editions related to air sources has been removed. It would have been interesting to keep and modify this text which says that air from industrial compressors is not suitable for breathing. It would have also been interesting to keep the text explaining the principle of two separated gas sources and that when these gas sources are compressors, they must not be connected to the same power supply.
- Regarding living chamber emergency breathing mixes and therapeutic mixes, even though the authors say that other mixes than those selected in their examples are suitable, insisting on a particular percentage by providing full tables where a more reduced example would have been sufficient to illustrate explanations of the texts, can be considered the intention of imposing these values, which is outside the topic of this guidance that is supposed to be discussing the “minimum quantities of gas required offshore”, instead of “optimal composition of gases”. It would have also been interesting to explain the principle of “Standard mixes”, which are the preferred mixes of the company, and “Alternative mixes” that are available mixes from previous operations or the gas supplier

that can be put online instead of being remixed to provide a standard mix. Also, it would have been suitable to explain that mixes prepared to be online must be organized to cover every depth from the storage depth to the surface without a gap between the two depths. The principle of mixes overlapping that facilitates passing from one depth to another would also have to be explained more.

- In the text describing the gas need for a Life Support Package (LSP), the authors suggest that such equipment can be used for decompression. It is what was in procedures 30 years ago when Hyperbaric Reception Facilities (HRF) were scarce. However, this procedure is not suitable today, except for extremely shallow dives. Thus, such decompression should be considered only if the transfer to the reception facility is not possible.
  The text that says *"it may not be practical or possible for the LSP to contain all of the required gas and consumables for a full decompression or unforeseen events and that in such a circumstance, the equipment and gas supplies need to be managed to ensure that they will arrive at the desired location rapidly"*. It is not suitable for managing emergencies because it is obvious that gases for decompression must be onsite in sufficient quantities before starting the project. It must be considered that places of the world where diving gases can be easily found and quickly transferred to offshore or sheltered places are rare.
- In many texts, instead of providing guidelines, the authors suggest the readers to refer to their company rules. However, the purpose of this guidance is to provide companies advice on how to design their rules. So sending the readers to their existing company rules appears not really suitable!
- The authors have forgotten to consider the needs for Soda-lime, Purafil which are consumables that are essential in saturation and a minimum of which should be indicated. The provision of cartridges for filtration systems such as Divex Gaspure and Helipure essential for gas reclaiming should also be indicated.
- The gases and soda-lime of the Hyperbaric Rescue Units (HRU) are also not clearly discussed and are not in the check lists (see appendix 2)
- In the text for "in-water decompression gas" it would have been suitable to specify the normal respiratory rates at rest (20 to 25 l/min), indicate that gases at a pressure of less than 20 or 30 bar cannot be considered as part of the reserve (IMCA D 022), and to provide a rule such as the one for metabolic oxygen in chambers, discussed in point 3.62 of the document, where it is said that the O2 quantity should be doubled. Such a rule allows to cover unforeseeable adverse situations, and increase the consistency of the guidelines.
- Regarding calibration gases, it would have been interesting to indicate that the need for calibration depends on the system of analyzer used and that the manufacturers usually give the recommended frequencies of calibration. Note that the previous edition recommended calibration gases for at least 3 weeks to support a saturation project. Also, I consider that indicating gas percentages to be used is outside the topic. In addition, the authors should explain the reason particular mixes are suggested instead of others.
- Regarding the preparation of deck Decompression Chambers, the texts for "surface decompression gas reserve and therapeutic gases", which were grouped in the same paragraph in the previous editions of the guideline, have been separated in this revision. In the new text about "Therapeutic gases", it is said that gas provision for <u>three surface decompression dives</u> is necessary, which is unclear. Obviously, medical personnel transferred into the chamber may have to be decompressed, and some gas must be stored for this purpose. But in this case, we do not use a surface decompression procedure that consists of performing the in-water stops up to 9 metres and then transfer the diver to the chamber to complete the rest of the decompression. Thus, we can consider that this part of the sentence results from a bad copy-paste of the original text from AODC 14.
- Regarding the equipment provided for "surface support personnel escape from the diving station" in case of an emergency, the authors forget to indicate that new breathing apparatus sets that can be connected to an external supply source and then disconnected exist and avoid the personnel breathing polluted or deadly gas when changing from an umbilical supplied breathing apparatus to a bottle supplied one as suggested in the text.
- Regarding the rebreathers described in "Bailout systems for saturation diving", the authors say that the breathing rate does not need to be considered for rebreathers. It is true that a rebreather recycles the breathed gas. However, the authors should have considered that oxygen and soda-lime (that removes the CO2 from the breathed gas) have to be renewed as oxygen will be consumed by the diver, and the soda-lime saturated with CO2. Also, the systems currently in use require to have their mix adjusted to the depth of intervention, and changing the mix will be the source of gas loss. In addition, mixes may have to be stored if it is planned to change the working depth during the saturation project.
- The text in the previous editions related to air sources has been removed. It would have been interesting to keep and modify this text which says that air from industrial compressors is not suitable for breathing. It would have also been interesting to keep the text explaining the principle of two separated gas sources and that when these gas sources are compressors, they must not be connected to the same power supply.
- Regarding living chamber emergency breathing mixes and therapeutic mixes, even though the authors say that other mixes than those selected in their examples are suitable, insisting on a particular percentage by providing full tables where a more reduced example would have been sufficient to illustrate explanations of the texts, can be considered the intention of imposing these values, which is outside the topic of this guidance that is supposed to be discussing the "minimum quantities of gas required offshore", instead of "optimal composition of gases". It would have also been interesting to explain the principle of "Standard mixes", which are the preferred mixes of the company, and "Alternative mixes" that are available mixes from previous operations or the gas supplier that

can be put online instead of being remixed to provide a standard mix. Also, it would have been suitable to explain that mixes prepared to be online must be organized to cover every depth from the storage depth to the surface without a gap between the two depths. The principle of mixes overlapping that facilitates passing from one depth to another would also have to be explained more.

- In the text describing the gas need for a Life Support Package (LSP), the authors suggest that such equipment can be used for decompression. It is what was in procedures 30 years ago when Hyperbaric Reception Facilities (HRF) were scarce. However, this procedure is not suitable today, except for extremely shallow dives. Thus, such decompression should be considered only if the transfer to the reception facility is not possible.
  The text that says *“it may not be practical or possible for the LSP to contain all of the required gas and consumables for a full decompression or unforeseen events and that in such a circumstance, the equipment and gas supplies need to be managed to ensure that they will arrive at the desired location rapidly”*. It is not suitable for managing emergencies because it is obvious that gases for decompression must be onsite in sufficient quantities before starting the project. It must be considered that places of the world where diving gases can be easily found and quickly transferred to offshore or sheltered places are rare.

- In many texts, instead of providing guidelines, the authors suggest the readers to refer to their company rules. However, the purpose of this guidance is to provide companies advice on how to design their rules. So sending the readers to their existing company rules appears not really suitable!

- The authors have forgotten to consider the needs for Soda-lime, Purafil which are consumables that are essential in saturation and a minimum of which should be indicated. The provision of cartridges for filtration systems such as Divex Gaspure and Helipure essential for gas reclaiming should also be indicated.

- The gases and soda-lime of the Hyperbaric Rescue Units (HRU) are also not clearly discussed and are not in the check lists (see appendix 2)

- As mentioned in point 3.1.7, the references provided by IMCA are based on circular reasoning and are limited to a single document, which is extremely poor. This is probably due to the fact that the organization considers itself to be the only appropriate reference. As a result, nothing is justified in this document, even though many of the promoted practices are mentioned by or come from other organizations that it would have been interesting to cite. This behaviour is a pure case of monoculture and megalomania, unsuitable for organizations promoting guidelines.

- The authors of the document should also consider providing a concise glossary at the beginning of the document, with definitions that cannot be included in the text for ease of reading.

- The problems of storing the various gases and transporting them to and from the site are neglected. However, this is an essential aspect of the proper supply of gases to the diving system.

- Revision 1.1 does not bring any interesting information over revision 1 and is not really justified.

4 - To conclude

Before any discussion, it is essential to admit that the IMCA Guidelines should not be regarded as infallible reference documents to be used similarly to magical formulas, as they are written by individuals who, like all human beings, are prone to errors and work to preserve the interests of the members of the organization. Furthermore, IMCA has become a commercial entity in conjunction with its association status. Therefore, its publications cannot be considered impartial and should only be regarded as suggestions proposed by an organization that defends the interests of some contractors and the personnel it employs to emit these guidelines and manage its members.
In addition, to ensure that its guidelines become unavoidable standards, IMCA commonly says to its members that they must apply its procedures or else be banished from the association, as during the adherents' meeting in Bangkok in 2016. Such authoritarian behaviour appears unsuitable to me, as it suggests that IMCA practices are always the safest, which is, as mentioned above, far from reality. Also, good practices are usually naturally adopted and implemented by those confronted with problems to solve.
To conclude on this crucial point, I should say that, in my opinion, the rule must be: IMCA proposes, and the contractors and their clients dispose. Of course, this is provided that the procedures selected are, at the very least, as safe as those of IMCA and justified by relevant scientific and technical documents! In addition, note that the only organizations that can legally impose regulations and laws are the states.
However, many clients, notably the IOGP (International Association of Oil & Gas Producers) members, require that contractors' manuals fully comply with IMCA and the IOGP guidelines. From my perspective, this is unsuitable for the reasons discussed above, and the analysis of the IOGP recommendations, published in 2021, shows that errors are in their documents. Instead, contractors and clients should analyze IMCA guidelines and those from other organizations and select those they consider suitable for their manuals and the planned diving operations for the project. This is usually done through risk assessment processes. Note that such analysis must be done by people having a sufficient overview of diving operations and not by people educated to follow only IMCA and IOGP guidelines. So, general culture, common sense, and honesty are essential for such tasks.

In analyzing this guideline, I have tried identifying and commenting on any elements that might confuse readers. Some people may have a different perception of this document. For my part, I hope that this analysis makes it clear that a document must be thoroughly evaluated before it is adopted.
The latest versions of IMCA D 050 are much more ambitious than the initial version edited in 2012, which only provided a few general principles. Nevertheless, discussing more detailed topics introduces more questions, risks of omission, and the possibility of straying from the main subject. As a result, some topics have been overlooked, and others, such as the composition of calibration and therapeutic gases, are not relevant to a document that explains the minimum gas quantities required for diving operations rather than ideal gas mixes. In addition, proposed numerical values and guidelines need to be justified as scientists do, which the authors of this IMCA publication have not done! Therefore, we may question whether it would have been more appropriate to develop a few simple and logical rules for each situation rather than discussing topics that do not align with the document's title.
To conclude on the applicability of this document to commercial diving, although I think it is insufficient, not always consistent, and sometimes outside the topic, this document can be used because it describes principles for safe diving. Thus, even though imperfect, the proposed guidelines can serve as a foundation for a company to establish its operational rules. However, it should be considered that these rules will need to be reviewed and strengthened.
Regarding this point, it is essential to highlight that the authors suggest that the mentioned gas quantities are the absolute minimum. For this reason, it is good practice to provide more gas than indicated in this document. As shown in the introduction, many companies consider gases to be consumables that will be used at some point. As a result, they often provide more gases than calculated for safety reasons and to avoid wasting time on calculations that may not be exact due to the numerous changing parameters that need to be taken into account. For example, the rule of 90 m^3 of oxygen is based on this principle. It must be admitted that this approach to the problem has proven efficient.
However, gas reserves may be limited by the available storage space. This point opens up other topics, such as offshore and onshore storage, the means for fast and safe delivery, and the appropriate size of the surface support, which would have been interesting to consider in this document.