CCO Ltd

Diving management studies
Study No 5

Implement
NORMAM-15/DPC-2011
saturation diving procedures
(Today NORMAM-222/DPC)

07 August 2025

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Thanks to doctor Jean Yves Massimelli *(Centre Hospitalier Universitaire de Nice)*, and Jean Pierre Imbert *(Divetech)* for their support.

01/02/2019	*First publication*
26/10/2020	*Corrected small typo errors*
26/06/2021	*Added the procedure for aborting the pressurization. Added UK HSE occupational exposure limits. Added the decompression times table from various storage depths*
25/12/2022	*Included the study "A review of accelerated decompression from heliox saturation in commercial diving emergencies" published by J P Imbert and doctors Jean-Yves Massimelli, Ajit Kulkarni , Lyubisa Matity , & Philip Bryson.*
02/08/2025	*The procedures promoted in this study were compared with those of the new Normam-222/DPC saturation procedures, which include modifications to some key points. These modifications have been rejected as they are insufficiently documented and inconsistent. Therefore, the title of this study remains "Implement the Normam-15/DPC-2011 saturation diving procedures".*

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1) Deep diving: The Comex experience

The text below has been written and published by Jean Pierre IMBERT in Bergen conference in September 2005

1.1 - Introduction

Diving companies have used reports for monitoring their operations. The reports are first legal documents required by the legislations. There are also contractual documents specified by the client. Finally, they are working documents allowing operational personnel to run specific procedures and keep records of relevant parameters. These reports contain invaluable information on operations, health and safety. In Norway, it is explicitly specified in the U-100 that this information should be stored and accessed easily, as part of a prudent practice. However, the difficulty has always remained how to process this mass of data to benefit from the offshore experience.

In 1974, Comex started a computer system to process its diving reports and access the data efficiently. The system was named the Comex diving data base and run until 1993 in Marseille (1).
The source of the information was the paperwork collected from worksites:

- The diving reports, which are filled in by the diving supervisor whenever a dive is performed.
- The chamber logs, filled in by the life support technicians, which contain the information related to chamber ambient parameters but also details of the treatment in case of a decompression sickness.
- The accident reports, which are used in case of illness or injury or DCS.

The baseline justification of the database was to issue accurate company safety records (2). It was used to build a company image of efficiency and safety awareness. It was also used to negotiate the annual fees with insurance companies by helping to document the risks. The other objective of the database was to develop the company diving procedures. Comex used it to revise its saturation procedures in 1977, 1983 and 1986. Statistical analysis permitted to identify areas of concern and new procedures were sent on selected worksites for controlled evaluation.
After positive testing of these new procedures, they were implemented in the revised manuals (3).
The database proved to be an efficient scientific tool for model validation and was later used for the design of new air decompression tables for the French government (4). No wonder that when deep operations started in Brazil, the database focused on deep diving and served to monitor the procedures performances.

The paper presents information from an internal Comex report on deep diving in Brazil, supported by the Comex database, covering the period ranging from the beginning of the operations, October 1983, to 1990, date of publication of the report.

1.2 - Background to deep diving

It is reasonable to define "deep diving» relatively to conventional diving, that is diving to 100-150 m in the North Sea. There, everything is well defined and organized: regulations, qualifications, medical procedures, diving instructions and equipment. At these depths, there is no doubt that the divers are efficient, their time is unlimited, and their services are affordable. For a commercial diving company like Comex, it represented at the time approximately 30,000 hours of work at bottom per year.
However, in the 80's, diving operations gradually moved to deeper waters in Norway, the Gulf of Mexico and Brazil. The Campos field in Brazil became the scene of routine operations in excess of 200 m. Deeper, everything becomes more difficult: divers must be specially selected and trained, physiology limits their interventions, high performance equipment is required and the concern has raised of possible long term health effects

1.3 - Scientific developments

As usual, research was initiated much in advance of any operational needs and the first deep diving experience came from onshore simulated experimental dives. During the pioneering work of the 60's, it was discovered that deep divers are exposed to 3 types of environmental stresses:

- The High Pressure Nervous Syndrome (HPNS) which is related to the effects of the pressure on the central nervous system. It appears at around 200 m and increases with depth, causing psychomotor disturbances that may impair divers' efficiency.
- The density of the breathing gas, which also increases with depth, and induces ventilation efforts that reduce the diver's work capacity.
- Long confinement in saturation chambers (thermal stresses, bad sleep, lack of appetite) that induces fatigue and body weight losses.

Special diving techniques had to be developed before deep diving operations became possible. In the 70's, research dives were carried out in several countries, originally by navies, but latter by scientific and commercial organizations. These various programs tried to use the properties of the different diluents of the diver's breathing gas to overcome the environmental stresses. Three techniques were successively introduced:

- The early deep dives were conducted with heliox only. Helium has a low molecular weight but no anti-HPNS property and the pressurization must be slow. In 1972, Comex divers reached 610 m during the PHYSALIE VI dive after 7.5 days of pressurization.

- In 1975, the Duke University introduced the concept of "the pressure reversal effect", according to which the HPNS can be counter-balanced by a certain amount of a narcotic gas in the breathing gas mixture. Effectively, a reduction of HPNS symptoms was obtained by adding approximately 5% nitrogen in the pressurization gas. In 1981, divers at Duke University reached 686 m during the ATLANTIS III onshore experimental dive.
- During the 80's, Comex launched the HYDRA program using hydrogen. Because hydrogen is lighter than helium, a large amount of hydrogen can be used without affecting the ventilatory function. The program was conducted step by step to increasing depths to master the technology of hydrogen diving. During HYDRA VIII, in 1988, divers demonstrated its feasibility by performing 10 open sea dives to 520 m offshore Marseille. In 1991, a diver reached the depth of 700 in Marseille hyperbaric center, using a hydrogen mixture. It is still the deepest dive ever performed.

1.4 - Early deep operational dives

Although experimental deep diving has progressed rapidly, there has been a significant gap between the depths reached during onshore or validation dives and the operational capacity. The fact is that up to 1982, deep commercial diving progressed slowly because of the lack of deep contracts.

Comex track records are presented in table 1. Among other diving companies, the most spectacular operations were:

- The Shell Cognac platform installation in the Gulf of Mexico in 1977 by Taylor Diving. Four saturations were conducted at 280 m and 316 m, cumulating 20,000 hours under pressure for 28 divers.
- The Skanevick Fjord test dive to 320 m by Taylor Diving in early 1978.
- The recovery of the gold of the HMS Edinburgh to 240 m by 2W Diving in 1981.

Before the first deep diving contracts were awarded in Norway and in Brazil, deep diving remained limited to isolated operations.

Table 1: Summary of Comex early deep operational dives from 1975 to 1983

Date	***Surface support***	***Location***	***Maximum depth***	***Number of divers***	***Saturation time***	***Bell run time***
1975	Havdrill	Morocco	254 m	6	540 hours	4 hours
1975	Havdrill	Labrador	326 m	6	2016 hours	15 hours
1976	Sedco K	Africa	220 m	12	1584 hours	13 hours
1977	Scarabeo	Libya	273 m	3	576 hours	4 hours
1978	Talisman	Norway	256 m	4	1536 hours	No bell run
1982	Stephaniturm	Tunisia	225 m	4	960 hours	4 hours
1982	Dan Baron	Greece	221 m	2	288 hours	12 hours
			Total	39	7500 hours	88 hours

1.5 - Comex experience in Norway

In 1982, Comex was awarded the 3DP contract in Norway. The aim was to demonstrate for the Statpipe project that hyperbaric repair tasks could safely take place at 300 m. Among other projects, this contract included important R&D programs on divers' equipment. The specifications set for verifications on bench test and evaluation during manned trials permitted to develop a new generation of equipment such as integrated heat shroud gas heater, non return valve hot water suit, gas reclaim system, divers' monitoring systems, etc.

A series of validation dives to 300 m was conducted at Comex facilities in Marseille and at NUTEC in Bergen. The contract was concluded by a demonstration dive to 300 m in the Onarheims Fjord from the semi-sub Uncle John.

Few years later another deep development program was awarded to Comex by Norsk Hydro for the OTS project. Similarly, developments were conducted in an onshore phase followed by an offshore demonstration phase.

Table 2: Summary of Comex experience with Norwegian contracts

Date	***Surface support***	***Location***	***Maximum depth***	***Number of divers***	***Saturation time***	***Bell run time***
1983	Uncle John	Norway	300 m	20	11113 hours	1029 hours
1989	Norskald	Norway	218 m	39	22890 hours	943 hours
			Total	59	24003 hours	1972 hours

These contracts were extremely important because:

- They permitted to fill the gap between experimental and operational diving. They set the first standards for deep operations and permitted the development of an adequate technology.

- They came right before the beginning of the deep operations in Brazil and allowed to transfer the know-how from Norway to Brazil.

Effectively, 3 months after the Uncle John fjord dive, Comex completed the installation of an automatic wellhead to 307 m in the Campos basin.

1.6 - Offshore operation in Brazil

1.6.1 - The Campos field

The Campos offshore basin is the most important Brazilian oil province, producing oil since 1977 and being responsible for 60 % of the national production. The operational headquarters supporting the offshore operations are located in Macae, 200 km north of Rio de Janeiro. Diving operations were first conducted in 100-200 m range of water and progressively proceed to 200-300 m in 1983.
Production was further extended to deeper wells in 1986. A subsea completion was carried out successfully in the Marimba fields at 417 m. The discovery of two giant fields, Albacora and Marlim, made Petrobras, the Brazil state oil company, move to even deeper exploitation in depths from 400 to 1500 m, with diverless systems.
The exploitation in the Campos fields was organized with conventional fixed platforms (Garoupa, Namorado, Cherne, Enchova and Pampo). The deeper production was based on subsea well-heads connected to floating systems with a network of flexible hoses. Two diving companies have operated these contracts, Comex (later SCS and Stolt offshore), which operated in Brazil under the name of various joined ventures, and Marsat, a local company.

1.6.2 - The regulation frame

When deep diving started, in the absence of a comprehensive Brazilian legislation, the rules applied were derived from the companies experience. From this period remains the divers' time limitation to 3 hours in water at 300 m. The implementation of a national legislation took ten years, with a final publication in 1988, closely related to the UK regulations. For instance, the standard saturation period is limited to 28 days, to be followed by a month of non diving stand-by. It must be noted that this legislation covers diving down to 300 m and that any operation within this depth range can be regarded as a routine dive. For instance, some divers can be saturated at 180 m and suddenly sent for a job to 260 m without any official notice. The last revisions came after agreements concluded between the diving companies, the government and the divers' unions (Sintasa). They included the requirement for a stand-by DSV and the limitation of the bell run time to 6 hours for dives deeper than 300 m.

1.6.3 - The Comex operations

Since 1983, Comex has operated an average of 3 to 4 deep diving contracts for Petrobras. Since the beginning and until 1990, the Comex database was used to monitor the operations. During this period, 858 saturations dives deeper than 200m were recorded (5).

Table 3: Summary of Comex deep saturation in Brazil over the period 1983-1990

Depth range	*Number of divers saturated*	*Total saturation time*	*Average saturation time*
200 - 250 m	305	177,356 hours	581 hours
250 - 300 m	142	81,383 hours	573 hours
300 - 316 m	42	23,972 hours	570 hours
Total	489	282,711 hours	578 hours

Deep operations in Campos have mainly consisted in automatic wellheads installations or repairs (guide post change, guide wires installation, hydraulic lines connection, and flexible hose installation). At the time, each wellhead installation required an average of 30 hours of divers intervention at bottom.

Table 4: Summary of Comex deep dives in Brazil over the period 1983-1990

Depth range	*Number of bell runs*	*Total Bell run time*	*Average bell run time*	*Total diver time in water*	*Average divers' time in water*
200 - 250 m	628	6312 hours	10:03 hours	2677 hours	4:15 hours
250 - 300 m	150	1656 hours	11:04 hours	512 hours	3:24 hours
300 - 316 m	80	638 hours	7:54 hours	210 hours	2:36 hours
Total	858	8606 hours	10:02 hours	3399 hours	3:57 hours

Two remarks can be made:

- The amount of work is impressive. It does not bear any comparison with the rest of the deep diving operations around the world.
- The depths reached are important. The average deep operations are around 240 m to 260 m. On two occasions, Comex was called at the Pirauna location and prepared interventions at 386 m and 411 m. However, these dives

were cancelled at the last moment, one because of a sailors' strike and the other because of the faultless diverless completion of the well.

1.6.4 - The saturation systems

In 1983, the local saturation diving systems were upgraded for deep operations. Diving bells were fitted with extra onboard cylinders for gas autonomy and automatic shuttle valve. Bell atmosphere was monitored in pressure by oxygen sensors for faster response. Special relocation system and through-water communications for emergency were installed. Emergency procedures for an eventual lost bell were based on a heavy ROV intervention with manipulating arm or, eventually, on wet transfer to a nearby deep DSV.

Chambers systems modifications included internal life support unit for better control of the chamber environment, larger gas storage, more accurate analysers for gas control. Spare equipment such as life support units and heaters were mobilized as back-up. Systems were progressively equipped with HRV.

Because gas reclaim has always been a concern in Brazil due to the high cost of helium, saturation systems were fitted with collecting circuits and dump bags. Such equipment, along with personnel training and a system of bonuses, permitted to recover most of the gases from locks/filters operations or trunkings and chambers decompressions. Recovered gases were processed through scrubbing units and further re-used as diving gas. A gas chromatograph was installed on site to control the quality of the recovered gases, especially in regard with their nitrogen content. However, the rule was to always use "fresh" heliox for deep chamber pressurization.

1.6.5 - The diver's equipment

Deep waters in Campos fields are characterized by good visibility but strong currents, which may run in different directions at different depths. The water temperature at bottom is around 8°C, which is warmer than the North Sea, but still critical.

ln 1983, the divers' equipment was derived from the one developed during the 3DP contract :

- Non return hot water diving suits with a splitter for the heat shroud,
- 300 bar twin bail out cylinders. These back packs were charged inside the bell to maximum pressure using a Haskel pump and provided a 10 minutes autonomy at 300 m. A quick connector and extra line in the bellman umbilical would permit to extend this autonomy in case of long intervention.
- Surface loop gas reclaim unit mounted on Superlite 17 helmets.

However, as further experience was gained with other deep contracts, worksites were progressively supplied with helmets interfaced with the Comex Pro BOS closed circuit bail out systems. This equipment, which was validated during the Hydra VIII hydrogen dive to 520 m, allowed 20 minutes autonomy in case of gas supply failure.

1.6.6 - The divers involved

At the time, Comex employed around 90 deep saturation divers to run their deep operations. An important effort of selection and training was conducted to use local personnel. Divers were first selected according to their professional qualities and further screened on a medical basis. They were then sent to a special diving school which was located at Rio at the beginning of the deep operations. The courses included intense physical training, familiarization with new equipment, bell emergency drills and bellman lock out exercises. In 1988, 15 % of expat divers were still contracted. In the 1990, all the divers, LST's and supervisors employed were Brazilian.

The policy was to expose divers progressively to increasing depths to obtain familiarization to pressure. A given diver would for instance have to go into saturation at 200-250 m before he could go to 250-300 m. This procedure allowed eliminating divers too sensitive to HPNS. After few years, the pool of deep divers was large enough and their experience sufficient. The diving school was handed over to the state for training for commercial divers.

The divers would do an average of two deep saturations a year, some of them three. Being selected on their experience, they were also “old” divers, from 30 to 45 year old. However, a top physical fitness was required from all the divers selected for deep saturations, something well in accordance with the Brazilian values.

Table 5: List of Comex most active divers and their diving track records (data from 1990)

Divers	***Age***	***Number of deep saturation***	***Number of deep sat days***	***Number of deep bell dives***	***Maximum depth reached***
Af	43	11	245	47	315
CG	40	21	463	64	315
AC	35	15	345	40	250
JTN	26	14	396	36	250
MM	34	16	416	48	290
MG	31	10	260	39	290
JCT	38	17	476	65	290
PLM	31	22	499	45	250

1.6.7 - The medical controls

The deep diver's medical examination was derived from the medical criteria established for deep diving during the 3DP contract in Norway. Onshore, initially, the divers had to undergo a deep diver medical examination just before the dive, at the end of the dive and six months after the dive. Later, when the deep saturations became frequent, examinations were based on a regular six months period.

A system of diver's questionnaires was set on worksites. At the time, it appeared that there was an actual problem of nutrition as divers kept complaining of migraines, stomach pain and lost weight during saturation. It was then discovered that the quality of food on site was poor, primarily based on rice and black beans. Efforts were made to provide divers with more exiting menus and fruit mixers were installed on site. Fresh tropical fruit juices were much appreciated at depth and nicely solved the problem of nutrition.

A system of computer records was organized to follow up divers' medical files more efficiently. The files contain biological and neurological examination results and were used to track any possible negative long term effects. In 1990, there were approximately a hundred of divers' files and 5 years of track records in the computer. To our knowledge, no medical problem specific to deep exposures were identified among the company divers. The present status of this medical data base, run by the company medical advisor, is unknown.

1.6.8 - The procedures used

In 1983, the deep saturations instructions used by Comex were directly derived from the Norwegian 3DP contract procedures. The procedures performances were controlled by direct contacts with the operational personnel who was interviewed at base, or by analysis of the diving reports using the computer database. No problems were expected with these well validated diving procedures.
Surprisingly, many HPNS episodes were reported during pressurization that included tremor, headache, nausea and even "bend during compression" (hyperbaric arthralgia). On decompression, 5 cases of articular pain DCS were recorded in the last meters of decompression over 45 men exposures.

It then became apparent that instructions validated during well controlled conditions by highly selected divers would not yield the same results during day by day operations using a larger group of divers. Revised saturation instructions were edited in 1984 which were more conservative:

- Compression time to 300 m was increased from 14 to 24 hours.
- Stand by period after pressurization was set to 12 hours.
- Decompression rate was set to 45 minutes per meter, using 0.5 bar chamber PO2, and no stop during the night.

Divers were authorized one dive a day with a minimum of 12 hours rest after the bell run. During the bell run, their time in water was limited by instructions to:

- 6 hours up to 240 m.
- 5 hours up to 260 m.
- 4 hours deeper.

As an additional precaution, chamber PO2 was raised to 0.6 bar in the last 120 m (with still the same ascent rate) to ease eventual decompression problems. Since that time, over 250 men saturations were performed with good results. HPNS symptoms were no longer reported and decompression incident rates remained within the diving industry accepted limits (5 cases of pain only DCS reported over 205 men saturations).

The last revision in 1991 of the instructions only covered some details such as a simplification of the procedures for intermediate compressions and decompressions.

1.7 - Discussion and conclusion

Although the study is limited in time, deep diving operations have continued and still go on in Campos. The volume of activity and the number of divers involved in Brazil operations allowed the offshore industry there to consider deep diving to 300 m as a routine activity.

Brazilian operations have much inherited of the developments carried out in Norway in the early 80'. However, it is fair to say that, in 1986, Comex brought back much of its Brazil deep diving experience when it was awarded the OTP contract in Norway.

Brazilian operations have illustrated the long way between the development of a diving technique and its offshore application. They have shown that validation dives are necessary, but that nothing can replace field experience.

The field experience must be assessed quantitatively using databases in order to store and preserve the information. Of course, the various examinations and reports produced at the time provided a cross sectional analysis of the situation. However, when long term effects are the concern, only but databases can support the longitudinal studies.

At the beginning, the key to the success of deep operations in Brazil was obviously the divers' selection. One of the most efficient criteria seems to be their physical fitness. After years of operations, no acute effect related to deep diving has been identified. Of course, this situation might be biased by several local factors but the point remains that after such a long period, if acute effects had to be measured, they would have been brought to the attention of the social partners, state, companies and unions. Today's, authorities, employers and employees have come to share the same experience and same opinion on the accepted level of occupational risk and long term health effects are not a social/political issue in Brazil.

The lesson learnt is that occupational health must be supported by databases. Of course, there are difficulties. The power of the information contained in databases is fascinating and generate needs.
The users may multiply the data stored, required restricted access, etc. Database might become too complex and expensive to run and then disappeared. The point is to precisely define inputs according to the objectives and keep it simple. Several databases have been successfully used in the past; some will be certainly revived in the future, provided the legal, financial and social implications are solved.

1.8 - References

1. *Imbert JP, Montbarbon S. Presentation of the Comex Diving Data Base. European Undersea Bio-medical Society Workshop on Operational Dives and Decompression Data. Amsterdam, The Netherlands, 11-18 August 1990.*
2. *Imbert JP, Montbarbon S. Use of the Comex Diving Data Base. European Undersea Bio-medical Society Workshop on Operational Dives and Decompression Data. Amsterdam, The Netherlands, 11-18 August 1990.*
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4. *Imbert JP, Bontoux M. Safety analysis of French 1974 air decompression tables. Undersea and Hyperbaric Medical Society Workshop on Decompression in Surface-based Diving. Tokyo, Japan, 11-12 September 1986.*
5. *Imbert JP, Irrmann JF and Macchi F. 316 m offshore in Brazil: background of a successful deep dive. Proceedings of the XVIIIth European Undersea Biomedical Society. Basel, Switzerland, 15-19 September 1992.*

2) NORMAM-15/DPC-2011 saturation diving procedures

2.1 - Historic and promoters

NORMAM-15/DPC-2011 saturation diving procedures are the result of the studies described in chapter 1 “Deep diving: The Comex experience”. These procedures, which were specifically studied for the Brazilian offshore industry, can be considered an improvement over those published in the diving tables Comex MT 92, which are still promoted by the French Ministry of Labour, and those used at the beginning of this century by Stolt Offshore.
NORMAM-15/DPC-2011 procedures permit safe hyperbaric exposures up to 350 m and were adopted by the Brazilian Navy Directorate of Ports and Coasts, which published them in Chapter 11 of the official document “Maritime authority norms for subaquatic activities,” released in June 2011. Since then, they have been implemented in many countries and are now considered a reference by scientists.

2.2 - Ranges of saturation proposed

The saturation dives are divided into three depth ranges, considering the effects on the divers:

a) Standard Saturation

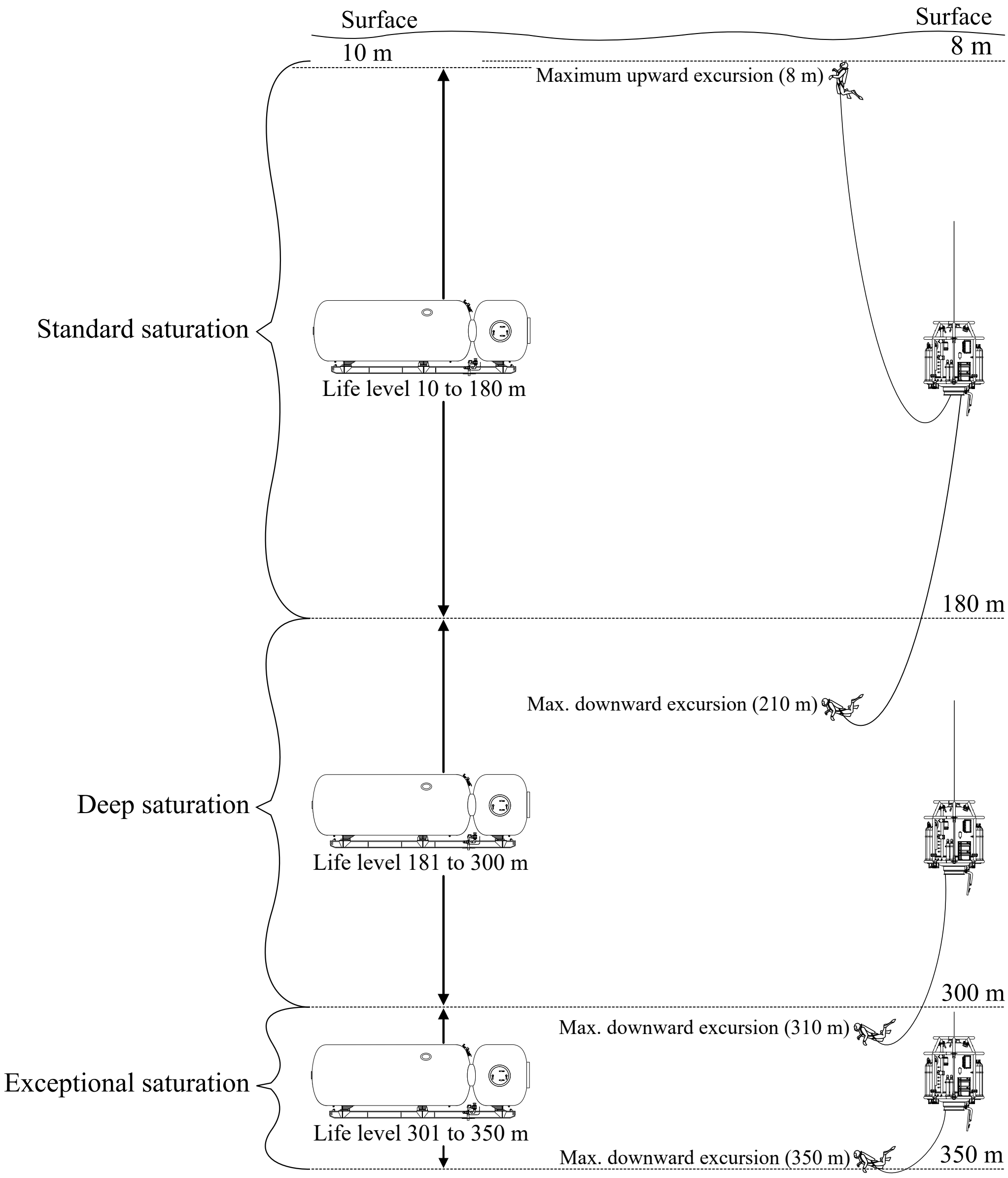
Diving operations in which the life level equal to or less than 180 m, and a maximum downward excursion depth reached by the diver of 210 m

b) Deep Saturation

Diving operations in which the life level is between 181 and 300 m, and a maximum downward excursion depth reached by the diver of 310 m

c) Exceptional Saturation

Diving operations in which the life level is between 301 and less than 350 m, and the maximum downward excursion depth reached by the diver strictly 350 m.



2.3 - Published revisions and reinforcement procedures promoted in this document.

The policy of CCO Ltd is to publish only official documents and never change the original structure of these publications.
For these reasons, there is no change to the original NORMAM-15/DPC procedure published in June 2011 by the Brazilian Navy Directorate of Ports and Coasts. As a result, the main components, such as gas values, compression speeds, ascent speeds, or excursions, rigorously conform to the original procedure. Note that the gas values for the descent and the storage periods that are missing in the official document have been provided by Jean Pierre Imbert, who worked as Comex diving manager at the time.
The reader may consider that some procedures presented in this document are excessively stringent. I can only say that they have been tested, approved, and adopted, and for the reasons explained above, I have no authority to change them.

The publication of the NORMAM-222/DPC procedures, which supersede the Normam-15/DPC procedures, has provided an opportunity to compare the evolution of these guidelines. This evaluation revealed that while most parts of the saturation procedures remain unchanged, the Brazilian authorities made the following modifications, resulting in these procedures no longer being compliant with the original ones published in 2011:

- The initial PPO2 values during the decompression phase, originally between 0.48 and 0.5 bar (see page 18), have been reduced to 0.44 and 0.48 ATA. These absolute atmosphere (ATA) values are those used by the US Navy 2016 for the storage and ascent phases. Considering that a scientist would have used pascals or, alternatively, millibars, given that the table is written in metric units, I have found this modification undocumented. Additionally, recent procedures by Jean Pierre Imbert for IMCA members show that the value of 480-500 mb has been maintained with equivalent storage PPO2 values to those he initially provided for the NORMAM-15/DPC-2011. Furthermore, the study *"Evaluation of North Sea saturation procedures through divers monitoring"* shows that these tables yield very satisfactory results regarding oxygen and decompression stresses. Therefore, the question can be raised about the safety performances that can be expected from new decompression procedures that keep using the former rates of ascent but with lower chamber PO2.
  As a conclusion, it seems to me that no modification of these original gas values was necessary, especially considering that the PPO2 values of the US Navy tables refer to another decompression strategy than the one of the initial NORMAM-15/DPC-2011 and that this modification has been imposed without the support of any published scientific study and without consulting the main author of the original procedure, which the Brazilian authorities implicitly confirmed in a message received 07 August 2025, as they did not provide any documented answers to my questions regarding this critical point.
- The percentage of O_2 during the final phase of decompression is now limited to 21% instead of the initial 25%. While the 25% limit may increase the risk of fire if an imprudent operator exceeds it, it offers a more comfortable operating range for the Life Support Technicians (LST), which is significantly reduced with a limit of only 21%. Considering that the LST on duty will require a certain degree of flexibility, I believe that the 23% value recommended by IMCA, previously retained in the initial edition of this study, is balanced and appropriate. The Brazilian authorities' response to this point is that the final part of the text was incorrectly edited and should have stated that the ideal oxygen percentage must remain within the range of 19% to 23% with 21% as the recommended value. Therefore, a correction is to be made to this already 9-year-old text.
- Note that the PPO2 values for the compression and storage phases that were lost in the initial official 2011 document, despite being provided by the author in the initial COMEX procedure, are still missing in the NORMAM-222/DPC revision.
- The excursion combination #7 *"Exceptional upward excursion followed by a standard upward excursion"* (see section 5.2.3.7, page 36) has disappeared in the document NORMAM-222/DPC. The Brazilian authorities answered that it was due to an editorial oversight at the time of publication, which had not been formally identified until now.

Based on the above, I have concluded that the Brazilian authorities made several undocumented and inconsistent modifications to key points, resulting in some parts of the procedures lacking scientific evidence. Therefore, the procedures Normam-222/DPC are no longer compliant with the original ones published in 2011 and cannot be considered relevant for the operations for which they were created. Consequently, I consider that the only procedures to be implemented remain the NORMAM-15/DPC-2011, faithfully described in this CCO Ltd study, except in Brazilian waters where the authorities may impose their unsuitable modifications. Additionally, while the adoption of the initial saturation procedures by the Brazilian authorities in 2011 could be seen as an example to follow by national bodies, the modifications they implemented since 2016 should be regarded as an example not to follow. Therefore, rather than imposing modifications that have not been scientifically tested, I advocate that the Brazilian authorities implement the COMEX procedures outlined in this Study or the US Navy procedures in full.
For these reasons, the title of this CCO Ltd study remains *"Implement the saturation diving procedures NORMAM-15/DPC-2011"*, with a reference to the new NORMAM-222/DPC in brackets.
Additionally, as noted in previous editions, several improvements to diving procedures have been adopted in the industry since the creation and official publication of this table in 2011, requiring the incorporation of these updates to keep this CCO Ltd study current. Therefore, some complementary procedures from the latest NORSOK standards U-100, the Diving Medical Advisory Committee (DMAC), the International Marine Contractors Association (IMCA), the UK Health and Safety Executive (HSE), and the French Ministry of Labour are recommended in this study, along with conclusions from relevant research.
Note that in this document, the name "NORMAM-15/DPC-2011" is shortened to "NORMAM-15" for convenience.

3) Chamber & bell gas monitoring and make up (NORMAM-15, IMCA D 022, & NORSOK)

3.1 - Gas quality

The reclaim system should ensure a perfect quality of the gas delivered to the divers. Nevertheless, contamination or unexpected changes of the proportion of O_2/He due to technical problems may happen.

- Some possible sources of contamination are:
  - Impurities in pipework, oil leakage from compressors, overheating or burning of materials, dust, micro particles, Electrical arcing. Gasses introduced during maintenance (Nitrogen)
  - Produced/natural gas (hydrocarbons, H_2S, etc.) and contaminants associated with the diving operation
  - Food, drinks, medicines, hygiene, microbiology
  - Unusual events, emergencies, contingencies.

- Contamination may happen in the following sections:
  - Divers' equipment
  - Bell(s) & chambers
  - Exhaust equipment
  - Reprocessing units & gas boosters
  - Gas storage and supplies
  - Control consoles

Thus, to make sure of a perfect filtration and regeneration, the gas must be continuously monitored.

3.1.1 - Analysing

- NORSOK std. says point 5.2.3.3:
  - Breathing gases shall be accompanied by an analysis certificate. Certificates should not be accepted as correct until a competent member of the dive team has analysed it for O_2 and CO content, as a minimum. Results for contaminants shall be < 0,1 HEL at actual pressure.
  - Any new calibration gas should be checked against another calibration gas with similar content, before taken in use, see ISO 6143, ISO 13752, ISO 16664 Annex A , ISO/IEC 17025, and ISO Guide 35.
  - Gas breathed by diver(s) during normal operation, shall as a minimum continuously be analysed online for O_2 and CO_2 content When a diver gas reclaim system is used, a CO_2 analyser with audio and visual hi alarm shall be installed into the diver downstream gas supply.
  - If there is danger of contamination of the bell from natural/produced gas, there shall be online indication with alarm of hydrocarbons, Hg and H_2S. This equipment should be activated at all times. For saturation/living compartments there shall be on-site periodic monitoring of at least CO and N_2.
  - As it is not possible to electronically/chemically monitor for all possible contaminants, the benefits of human sensation by olfactometry (odour, smell) should be facilitated, by having trained persons from the surface crew, checking the gas of each living compartment at least once a day, according to guidance ISO 13301.
  - All living compartments, welding habitat and breathing gas reclaim system shall in addition to O_2, temperature and humidity control, be equipped with gas purification that as a minimum removes CO_2 (e.g. sodalime), CO (e.g. catalyst), VOC (activated charcoal) and odorous compounds (e.g. Sofnofil).

- Analysis can be carried out using the following models of analysers:
  - Oxygen analysis can be carried out using fuel cell analyser, magneto-dynamic cell (also called paramagnetic) analyser, or a thermal conductivity detector (also called universal detector). Note that Magneto-dynamic and thermal conductivity detectors are the most employed in saturation systems.
  - N_2 can be monitored using a thermal conductivity detector.
  - CO_2 and CO analysis can be carried out using an infra-red analyser, thermal conductivity detector or sampling tube.
  - Contaminants can be monitored using thermal conductivity detectors, chemical sampling tubes (Dräger tubes), or by olfactometry (odour, smell) as indicated above in the rules from NORSOK standard.

- Every analyser should be calibrated on a regular basis according to national regulations and manufacturers' instructions. Note that the following recommendations should be taken into account:
  - A change of angle or local electromagnetic fields may affect readings. For this reason, the instrument should be calibrated in the position in which it will be used.
  - Instruments using fuel cells give erratic readings if the cell is too old or has been used for a time above the recommendations of the manufacturer. Note that installed fuel cells that have not been used must be changed every 6 months. It is the reason fuel cells are delivered in air-proof sealed bags.
  - Most analysers require a dry gas sample and have a silica gel filter or similar in-line. The silica gel must be renewed when its colour that is deep blue when it is dry turns to pink. Additional filters may be installed to increase the protection of the analysers.

- Opposite to the analysers of the previous generation that give only one type of display, most recent digital analysers are designed to give a reading in partial pressure, percentage, or part per million, which can be selected in the menu.
- Note that chemical sampling tubes are not originally designed to give a reading in percentage or ppm (parts per million) at depth. For this reason, a correction must be applied when they are used under pressure:
  - For a true percentage or parts per million, divide the scale reading by the absolute pressure in bars.
  - For a true partial pressure, regardless of depth, divide a percentage scale reading by 100 or a parts per million scale reading by 1,000,000.
  - To convert a surface reading from a bell or chamber to a Percentage Surface Equivalent, simply multiply the surface reading by the absolute pressure.

3.1.2 - Acceptable gas values

3.1.2.1 - Oxygen and carbon dioxide

The recommended partial pressures of oxygen are as follows:

Action	Partial pressure O2
Pressurisation to 1st storage depth	0.4 to 0.57 bar (400 to 570 mbar)
Initial storage depth	Chamber: 0.4 up to 0.57 bar at the arrival then stabilized between 0.38 & 0.45 bar (380 to 450 mbar) Bell: 0.5 to 0.8 bar (500 to 800 mbar)
Compressing the chamber to deeper storage depth	0.4 to 0.57 bar (400 to 570 mbar)
Chamber at deeper storage depth than the initial storage depth	Chamber: 0.4 up to 0.57 bar at the arrival then stabilized between 0.38 & 0.45 bar (380 to 450 mbar) Bell: 0.5 to 0.8 bar (500 to 800 mbar)
Decompressing the chamber to shallower storage depth	0.48 to 0.5 bar (480 to 500 mb) up to the depth in which PPO2 is 23%. Then % O2 between 21 to 23%
Chamber at shallower storage depth than the initial storage depth	Chamber: up to 0.5 bar at arrival, then stabilized between 0.38 & 0.5 bar (380 to 500 mbar) Bell: 0.5 to 0.8 bar (500 to 800 mbar)
Decompressing the chamber to surface	0.48 to 0.5 bar (480 to 500 mb) up to the depth in which PPO2 reaches 23% (<). Then % O2 at 21 to 23%
Emergency decompression	DMAC 31: PPO_2 chamber 1.01 - 1.52 bar (1013 -1520 mbar) and 23% O_2 BIBS PPO_2 at 1.5 - 2.8 bar

The partial pressure of carbon dioxide should be less than 5 mbar

3.1.2.2 - Argon, nitrogen, and carbon monoxide

NORSOK standard uses Hyperbaric Exposure Limit (HEL) to set up the limit of exposure to contaminants. HELs take into consideration the special conditions including high pressure, elevated pressure O_2, long exposures and the effects of multiple contaminations.

Hyperbaric exposure limits for argon and nitrogen

	When not in saturation decompression			During decompression after saturation
	Ceiling value	8 h time weighted average	Continuous	Continuous
pN2	3,5 bar (350 KPa)		1,5 bar (150 KPa)	0,8 bar (80 KPa) and < 10 %
pAr	1,5 bar (150 KPa)	1,0 bar (100 KPa)	0,5 bar (50 KPa)	10 mbar (1 KPa)
(2 • pAr) + pN2	3,5 bar (350 KPa)			

Hyperbaric exposure limits for CO

	Duration of exposure	Exposure limits
Breathing gas at work or at rest in bell, chamber, welding habitat etc	Continuous	0.005 mbar (0,5 Pa)
	<12 h	0.02 mbar (2 Pa)
	<15 min	0.05 mbar (5 Pa)
Ambient gas when diver is using breathing apparatus		0.1 mbar (10 Pa)
Breathing gas in emergency situations	No exposure planned, but system to be active for minimum 24 h	0.05 mbar (5 Pa)

3.1.2.3 - Hydrogen sulphide (H_2S)

5 ppm is the UK HSE limit beyond which respiratory protection should be used. For safety reasons, the proportion should be always below 1 ppm.

Notice that rotten egg smell is noticeable at 1 ppm, but with no effect on the body.

3.1.2.4 - Hydrocarbons contaminants listed by US Navy

Alarms of hydrocarbons analysers used in bells and chambers are pre-calibrated by the manufacturers. However, note that the US Navy manual revision 7 gives the maximum concentrations of the following contaminants.

Hydrocarbons	Maximum concentration	Description
Acetone	200 ppm	Acetone is produced directly or indirectly from propylene, also known as propene or methyl ethylene, and is the second simplest member of the alkenes class of hydrocarbons.
Benzene	1 ppm	Benzene is a natural constituent of crude oil, and is one of the most elementary petrochemicals. Benzene is an aromatic hydrocarbon. It is a colourless and highly flammable liquid with a sweet smell. It is an important component of gasoline.
Trimethyl Benzenes	3 ppm	The Trimethyl benzene constitute a group of substances of aromatic hydrocarbons, which structure consists of a benzene ring with three methyl groups (–CH_3) as a subsistent.
Toluene	20 ppm	Toluene is an aromatic hydrocarbon that is widely used as an industrial feedstock and as a solvent. Like other solvents, toluene is sometimes also used as an inhalant drug for its intoxicating properties; however, inhaling toluene has potential to cause severe neurological harm.
Xylenes	50 ppm	A Xylenes is an aromatic hydrocarbon consisting of a benzene ring with two methyl substituents. The mixture is a slightly greasy, colourless liquid commonly encountered as a solvent.

3.1.2.5 - Other contaminants listed by US Navy

Contaminant	Maximum concentration	Description
Ethanol	100 ppm	Ethanol, also called ethyl alcohol, pure alcohol, grain alcohol, or drinking alcohol, is a volatile, flammable, colorless liquid with the structural formula CH3CH2OH, often abbreviated as C2H5OH or C2H6O. A psychoactive drug and one of the oldest recreational drugs known, ethanol produces a state known as alcohol intoxication when consumed as a beverage. Best known as the type of alcohol found in alcoholic beverages, it is also used in thermometers, as a solvent, and as a fuel. In common usage, it is often referred to simply as alcohol or spirits.
Chloroform	1 ppm	$CHCl_3$,is a clear, colorless, heavy, sweet-smelling liquid, used in refrigerants, propellants, and resins, as a solvent, and sometimes as an anaesthetic. Chloroform, once widely used in human and veterinary surgery, has generally been replaced by less toxic, more easily controlled agents.

Contaminant	Maximum concentration	Description
Freon	100 ppm	The name Freon is a trademark registered by E.I. du Pont de Nemours & Company. They are a fluorinated aliphatic organic compounds that are used in commerce and industry. In addition to fluorine and carbon, the Freons often contain hydrogen, chlorine, or bromine. The Freons are colourless, odourless, nonflammable, non corrosive gases or liquids of low toxicity that were introduced as refrigerants in the 1930s; they also proved useful as propellants for aerosols and in numerous technical applications. Their low boiling points, low surface tension, and low viscosity make them especially useful refrigerants. They are extremely stable, inert compounds also used as cleaning agents
Freon 11	100 ppm	Trichlorofluoromethane, also called freon-11, CFC-11, or R-11, is a chlorofluorocarbon *(organic compound that contains only carbon, chlorine, and fluorine*). It is a colorless, nearly odorless liquid that boils at about room temperature. It was the first widely used refrigerant. Because of its high boiling point (compared to most refrigerants), it can be used in systems with a low operating pressure, making the mechanical design of such systems less demanding than that of higher-pressure refrigerants R-12 or R-22.
Freon 12	100 ppm	Dichlorodifluoromethane, also called R-12, is a colorless gas, and usually sold under the brand name Freon-12, is a chlorofluorocarbon halomethane (CFC), used as a refrigerant and aerosol spray propellant.
Freon 114	100 ppm	1,2-Dichlorotetrafluoroethane, or R-114, is a chlorofluorocarbon (CFC) with the molecular formula ClF2CCF2Cl. Its primary use has been as a refrigerant. It is a non-flammable gas with a sweetish, chloroform-like odor with the critical point occurring at 145.6 °C and 3.26 MPa. When pressurized or cooled, it is a colorless liquid. It is listed on the Intergovernmental Panel on Climate Change's list of ozone depleting chemicals, and is classified as a Montreal Protocol Class I, group 1 ozone depleting substance. The US Navy uses R-114 in its centrifugal chillers in preference to R-11 to avoid air and moisture leakage into the system.
Isopropyl Alcohol	1 ppm	Isopropyl alcohol is a common name for a chemical compound with the molecular formula C3H8O or C3H7OH. It is a colorless, flammable chemical compound with a strong odor. Isopropyl alcohol is commonly used as a disinfectant, antifreeze, and solvent, and typically comprises 70 percent of "rubbing alcohol".
Methanol	10 ppm	Methanol, also known as methyl alcohol, wood alcohol, wood naphtha or wood spirits, is a chemical with the formula CH3OH. Methanol acquired the name "wood alcohol" because it was once produced chiefly as a byproduct of the destructive distillation of wood. Modern methanol is produced in a catalytic industrial process directly from carbon monoxide, carbon dioxide, and hydrogen. It is the simplest alcohol, and is a light, volatile, colorless, flammable liquid with a distinctive odor very similar to, but slightly sweeter than, that of ethanol (drinking alcohol). it is used as an antifreeze, solvent, fuel, and as a denaturant for ethanol.
Methyl Chloroform	30 ppm	The organic compound trichloroethane, also known as methyl chloroform, is a chloroalkane. This colourless, sweet-smelling liquid is used as a solvent. It is classified as an ozone-depleting substance. It is a superior solvent for organic compounds that do not dissolve well in hydrocarbons such as hexane.
Methyl Ethyl Ketone	30 ppm	Butanone, also known as methyl ethyl ketone or MEK, is an organic compound with the formula CH3C(O)CH2CH3. This colorless liquid ketone has a sharp, sweet odor reminiscent of butterscotch and acetone. It is produced industrially on a large scale, and also occurs in trace amounts in nature. It is soluble in water and is commonly used as an industrial solvent.
Methyl Isobutyl Ketone	20 ppm	Methyl isobutyl ketone (MIBK) is an organic compound manufactured from acetone. It is used as a solvent for nitrocellulose, lacquers, and certain polymers and resins.
Methylene Chloride	25 ppm	Dichloromethane (DCM) or Methylene chloride is an organic compound with the formula CH2Cl2. This colorless, volatile liquid with a moderately sweet aroma is widely used as a solvent. Although it is not miscible with water, it is miscible with many organic solvents. It is widely used as a paint stripper and a degreaser and also as aerosol spray propellant and blowing agent for polyurethane foams.

3.1.2.6 - UK HSE - Occupational Exposure Limits (OELs) for hyperbaric conditions EH75/2

UK-HSE has published a document that describes a methodology for the use of established Occupational Exposure Limits (OELs) to the hyperbaric setting, taking into account the changes in absolute pressure and exposure duration, such that the resultant Hyperbaric Occupational Exposure Limits (HOELs) represent adequate control for the hyperbaric environment.

Occupational Exposure Limits (OELs) are concentrations of hazardous substances in the air, averaged over a specific period referred to as a time-weighted average (TWA). Two duration of exposures are usually used:

- Short-Term Exposure Limits (STEL) are set to prevent acute effects such as eye irritation, which may occur following exposure for a few minutes. They are usually limited to 15 minutes.
- Long term exposure limits (LTEL) are set to prevent effect that may not be noticeable during the intervention but may appear as a result of long and repeated exposures. They are normally limited to 8 hours.
  Note that the "8-hour reference period" refers to occupational exposures within a 24-hour period. It can be a single uniform exposure for 8 hours (the 8-hour time-weighted average (TWA) exposure) or an addition of several short exposures.
  The calculation proposed is: Time in decimals x concentration in mg.m³ / 8
  Note that time is decimal consists in dividing the minutes by 60 and multiply them by 100. Example: 7:20 hours = 7.33.
- The list of contaminants and their maximum exposure limits to can be found in the UK HSE document EH40 “Workplace exposure limits” that can be downloaded free of charge.
  Note that a lot of substances have several names, and are usually listed under one of them only: That obliges to find the name used through the list of synonyms of the document or through the Internet.

The UK HSE document EH75/2, “Occupational exposure limits for hyperbaric conditions”, which can be downloaded at the address https://www.hse.gov.uk/pubns/books/eh75-2.htm, gives formulas to adjust the surface values of the contaminants listed in the document EH40 to divers in a saturation system.
This publication, which is based on theoretical calculations, concludes that the 8 hours long term exposure limits described above can be adjusted for 24 hours exposures at depth using the formula: *Surface 8-hour TWA in mg.m³ / 5*
The study also states that no time-related adjustment of a 15-minute exposure is necessary for the hyperbaric setting.

The calculations using this procedure can replace the maximum values of hydrocarbons in chambers from the US Navy manual displayed at the beginning of this point.

3.2 - Make up the chamber atmosphere *(IMCA D 22, INPP, various competent bodies)*

The purpose of this point is to remember the fabrication of the chamber atmosphere and highlight the problems arising from uncontrolled partial pressure of oxygen.

To pressurize the chambers, the gases have to be arranged so that the chamber arrives at the storage depth with the correct PPO2. A slightly elevated PPO2 at the arrival at depth that can be up to 0.57 bar can be tolerated.
The Life Support Technician has several different options such as:

- A single gas to storage depth sometimes called an ‘ideal gas’.
- A rich mix to an initial depth then a lean mix to storage.

3.2.1 - Calculation of an “ideal gas”

- Find the amount of PPO2 to be added to the chamber then use Dalton's law formula to calculate the correct gas mix.
The formula is: *(desired PPO2 - Initial PP O2) / depth = % ideal gas*

- Example 1:
A chamber is to be pressurised to 45 metres and after blow-down is to have a PPO_2 of 0.43 bar absolute. What ideal gas can be used ?

- Before blow-down, the chamber contains 210 mb of oxygen, which is PPO_2 of air at the surface.
- The ideal gas will therefore need to have a PPO_2 of 430 mb - 210 mb, which is 220 mb.
- 45 metres of gas are added to the chamber to achieve this:
  - Using the formula PPO_2 = % x depth
  - Transposing the formula: % = PPO_2/depth = 220/45 = 4.9

The chamber can be compressed to 45 metres using 4.9 % and should arrive with a PPO_2 of 430 mb or 0.43 bar.

- Example 2:
A chamber is to be pressurised to 45 metres and after blow-down is to have a PPO_2 of 0.44 bar absolute. What ideal gas can be used ?

- The ideal gas will need to have a PPO_2 of 440 - 210 which is 230 mb.
- 45 metres of gas are added to the chamber to achieve this:
  - Using the formula PPO_2 = % x depth
  - Transposed the % = PPO_2/depth = 230/45 = 5.1

3.2.2 - Calculation of a rich mix to an initial storage depth, then a lean mix to storage

It is not often that an ideal gas is available and in these cases, the chambers are compressed using two gases a rich and a lean mix. These two gases are mixed in the chamber to form the ideal gas.

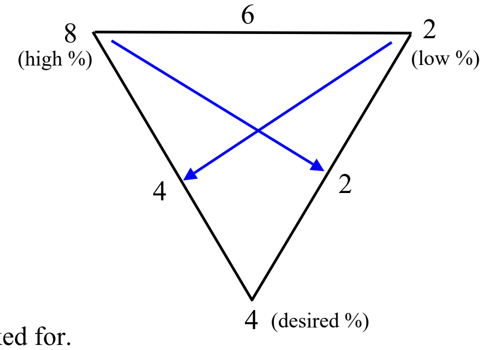
- Example:

A chamber is to be pressurised to 55 metres with 8 % and 2 %. The PPO2 on arrival should be 430 mb. What is the initial blow-down depth using the 8 % ?

- PPO2 of ideal gas = 430 - 210 = 220 mb
- PPO2= % x Depth
- % = PPO2/depth = 220/55 = 4%

55 metres of 4 % is required to be mixed using 8 % and 2 %.

- Using the triangle formula: Pressure of 8% = $\frac{2 \times 55}{6}$ = 18.3 m



Proof:
Surface air = 210 mbs
PPO2 of 8% is 18.3 x 8= 146.4
PPO2 of 2% is 36.7 x 2=73.4
Added together = 429.8 mb which approximately equals 430 millibars asked for.

- To make the calculation shorter the following formula can be used :

$$\textit{Initial Press} = \frac{(\text{PPO2 required (mb)} - \text{PPO2 present (mb)}) - (\text{Low \% x Depth})}{(\text{High \%} - \text{Low \%})}$$

Using the values of the example, the calculation using this formula will be as follows:

$$\text{Initial Press} = \frac{(430 - 210) - (2 \times 55)}{(8-2)} = \frac{220 - 110}{6} = 18.3 \text{ metres, which is the same answer.}$$

NOTE: The formula above is in metric. Using the imperial system, the formula is as follows:

$$\textit{Initial Press (fsw)} = \frac{(3{,}300 \times (\text{PPO2 required in atm} - \text{PPO2 present in atm})) - (\text{Low \% x Depth})}{(\text{High \%} - \text{Low \%})}$$

Example:

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

ppO_2 required = 0.5 ata

ppO_2 present = 0.21 ata

Bottom depth = 250 fsw

6

% weak mix = 2

% rich mix = 16

Depth of rich mix $= \frac{((3300 \times (0.5 - 0.21)) - (250 \times 2)}{16 - 2}$

$= \frac{(3300 \times 0.29) - 500}{14}$

$= \frac{(957 - 500)}{14}$

$= \frac{457}{14} = 32.6$ fsw

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

3.2.3 - Gas volumes for pressurisation

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

- The formula is as follows:

Free gas volume = chamber volume x pressure added

- ***Example #1*** *using metric system:*

A chamber system has a volume of 40 m³. What volume of gas would it take to pressurise it to 150 msw?

Free gas volume = chamber volume x pressure added

Chamber volume = 40 m³

Pressure added = 150/10 = 15 bar gauge

Free gas volume = 40 x 15 = 600 m³

600 m³ of gas is required

- ***Example #2*** *using metric system:*

A chamber system has a volume of 30 m³ . It is to be pressurised to 90 msw, with 21 msw of 12% and 69 msw of 2%. What volume of each gas would be needed?

Free gas volume = chamber volume x pressure added

Pressurisation on 12%

Floodable volume = 30 m³

Pressure added = 21/10 = 2.1 bar gauge

Free gas volume = 30 x 2.1 = 63 m³

Pressurisation on 2% = 69/10 = 6.9 bar gauge

Free gas volume = 30 x 6.9 = 207 m

Pressurisation requires 63 m³ of 12% and 207 m³ of 2%

- ***Example #3*** *using imperial system:*

A chamber system has a volume of 1,200 ft³ . What volume of gas would it take to pressurise it to 500 fsw?

Free gas volume = chamber volume x pressure added

Chamber volume = 1,200 ft³

Pressure added = 500/33 = 15.15 ata

Free gas volume =1,200 x 15.15 = 18,180 ft³

18,180 ft³ of gas is required

3.2.4 - Adding gas to the Chamber

Gas losses must be compensated by new gas. As a result, the partial pressure of oxygen may increase. The formula below Allows to calculate the PPO2 added:

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

To be used with Imperial the formula is:

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

3.2.5 - Metabolic oxygen make up

During a saturation, the divers use up oxygen and give out carbon dioxide. The rate at which oxygen is consumed is impossible to calculate accurately as consumption varies from diver to diver and with exercise. Like the breathing rates an approximation can be used and this is generally taken as 0.5 l/min, 30 l/hour, or 0.72 m³/day/diver. This is irrespective of depth.

- ***Example 1:***

What quantity of oxygen would you expect to use for metabolic make up during a 20 day saturation if there are 4 divers in saturation at 100 m?

Oxygen used per day for 4 divers = 0.72 x 4 = 2.88 m³.

Oxygen used in 20 days = 2.88 x 20 = 57.6 m³.

- ***Example 2:***

A bell of 4 m³ is at a depth of 55 metres and is occupied by one diver. The PPO_2 is 0.5 bar and the $PPCO_2$ is 1 mb. Assuming the scrubber has stopped and no oxygen is added, how long will it take to fall to 0.4 bar and the PPCO2 to rise to 20 mb?

First calculate the amount of each gas needed to change the partial pressures:

Oxygen change 0.5 - 0.4 = 0.1 bar.

The quantity of oxygen needed for this change is :

Free Gas Volume = Floodable Volume x Pressure = 4 x 0.1 = 0.4 m^3 or 400 litres

If the diver is breathing 0.5 l/min then it would take 400 divided by 0.5 which equals *800 min* to change the partial pressure of oxygen from 0.5 bar to 0.4 bar.

Carbon dioxide change 20 mb - 1 mb = 19 mb or 0.019 bar.

The quantity of carbon dioxide needed for this change is :

Free gas volume = Floodable volume x Pressure = 4 x 0.019 = 0.076 m^3 or 76 litres.

If the diver is producing 0.5 1./min then it would take 76 divided by 0.5 which equals 152 min to change the partial pressure of carbon dioxide from 1 mb to 20 mb.

It can be seen from this calculation that it is the increase in carbon dioxide which is the greatest danger in a bell.

3.2.6 - Oxygen and Decompression

Before a saturation decompression begins the PPO_2 in the chamber is normally raised to about 480 mb - 500 mb (0.48 - 05 bar). This is carried out by adding 100 % oxygen. The quantity of oxygen added to the system can be calculated using the following formula:

Free Gas Volume of added oxygen = Floodable Volume of system x Partial Pressure

- Example:

What quantity of oxygen will be added to a 20 cubic metres system to raise the PPO2 from 0.42 bar to 0.5 bar?

- First calculate the increase in PPO_2 from the added oxygen: Increase in PPO2 = 0.5 - 0.42 = 0.08 bar.
- Free Gas Volume of added oxygen = Floodable Volume of system (20) x Pressure (0.08) = 1.6 cubic metres.

As a result of the ascent of the chamber, the oxygen partial pressure set up at the beginning of the decompression will vary. As an example, for a chamber with a partial pressure of 500 mb (0.5 bar) at 100 m, the oxygen percentage in the mix is 4.54%. This partial pressure will drop to 272 mb at 50 m if no oxygen add is made (4.54 x 6/100 = 0.272 bar). The following formula given in IMCA D 022 allows to calculate the oxygen to add during the ascent:

Oxygen used due to the ascent = (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', a mathematical function found on most scientific calculators. 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.

IMCA D 022 says that this formula does not take this into account the high percentage which results of maintaining a partial pressure 500 mb close to the surface. For this reason, no further oxygen additions are made after the percentage reaches a level of 23% (note that 500 mb PPO_2 at 10 m = 25% O2).

The result of the calculation must be added to the oxygen consumed by the divers (metabolic oxygen).

Example:

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

- Metabolic use: 2 divers x 2 days x 0.72 m^3 = 2.88 m^3
- Oxygen used due to the ascent: (Ln of the initial absolute pressure) x ppO_2 (bar) x chamber volume
  (Ln 10.5 bar) x 0.6 bar x 10 m^3
  2.35 *(from calculator)* x 0.6 x 10 = 14.1 m^3
- Total oxygen: 2.88 + 14.1 = 16.98 m^3

3.2.7 - Remember "chronic oxygen poisoning"

"Chronic Oxygen Poisoning" , which is more explained in the document "diving Accidents" of the saturation manual CCO Ltd, is due to long exposure to oxygen at a partial pressure above 500 mbar. Note that some specialists consider that this value should be 450 mbar.

The pulmonary toxicity, intervenes in a manner not yet fully elucidated: The assumptions are that the alveoli are collapsing or the enzymes of cells forming the alveoli do not play their roles, or an oxidative phenomenon occurs, creating inflammations and increasing the thickness of the alveolar membrane which is limiting the oxygen diffusion into the blood and at the same time the elimination of the CO_2. The pulmonary toxicity symptoms are coughs and a significant decrease in vital capacity of affected individuals.

NORMAM-15 procedures partial pressures and maximum times of exposures are calculated to avoid this phenomenon. However, note that a too rich mix may result in such a problem.

3.2.8 - Manage the oxidation resulting from long exposures to elevated oxygen partial pressure.

Recent studies have highlighted that repetitive and long exposures to hyperbaric oxygen may lead to diseases not immediately detectable.
Oxidation reactions are crucial for life, but on the other hand, they can be involved with mechanisms of cells destruction: "Oxidation" is a chemical reaction that transfers electrons from a substance to an oxidizing agent (thus, a loss of electron in the substance). Oxidation reactions can produce free radicals. In turn, these radicals can start chain reactions that can cause damage or death to the cells that compose the body.
To control this phenomenon, the body maintains complex systems of multiple types of antioxidants. Antioxidants are molecules that inhibit the oxidation of molecules. These systems are influenced by diet and genetic factors. It is said that the ability to produce antioxidants decreases with the age, nevertheless the specialists do not currently know the capacity for antioxidant defense.
Many studies have linked the decreased production or the inhibition of antioxidants to diseases such as cancer, insulin resistance, diabetes mellitus, cardiovascular diseases, atherosclerosis and others.
It has been proved that at sufficient pressure and exposure duration, oxygen can inhibit the antioxidant defense, and cause functional impairment. The severity of effects that occur in different tissues are dependent upon interactions between the oxygen dose, and relative susceptibilities of the exposed tissues.

In an article named "Saturation diving; physiology and Pathophysiology", published by "Comprehensive physiology", doctors Alf O. Brubakk, John A.S. Ross, and Stephen R. Thom say that the regulation of these highly reactive molecules and the defense mechanisms must be kept under tight control.

To control these phenomena, NORSOK U100 says point 5.2.3.6.2: *The PO_2 levels shall be kept at a level as close as possible to 21 kPa (210 mbar), balanced against the diver's need for a higher than normal PO_2.*

To take into account what is said above, it is recommended to kept the partial pressure of oxygen within the lower values indicated in the table point 3.1.2.1

3.2.9 - DMAC 5 "Minimum level of O2 in helium supplied offshore" with deep and exceptional saturations.

DMAC 5 says: "*DMAC endorses the recommendation that an oxygen and helium mixture should be used in place of pure helium supplied to offshore diving installations. (It is recognised however that contractors may need to use pure helium as a calibration gas.)*
The choice of mixture supplied should be left to the diving contractor but a minimum of perhaps two percent of oxygen should present no problems operationally from 50 to 150 metres, and from 150 metres a smaller percentage may be appropriate."

To illustrate what DMAC 5 says, the following results, obtained with the formula for the calculation of an ideal gas "*(desired PPO2 - Initial PP O2) / depth = % ideal gas*", should be kept in mind:

- % ideal gas for a PPO2 of 450 mb at 180 m = 1.33%
- % ideal gas for a PPO2 of 570 mm at 180 m = 2%
- Depth with an ideal gas 2% O_2 and a PPO2 of 450 mb = 120 m
- Depth with an ideal gas 2% O_2 and a PPO_2 of 570 mb = 180 m
- Ideal gas from the surface to 300 m with a PPO_2 of 570 mb = 1.2 %
- PPO2 of a mix with an ideal gas 2% O_2 at 300 m = 600 (ideal gas). Thus: 600 mb + 210 mb = 810 mb

Mixes of 2% oxygen cannot be used as "ideal gas" to obtain the PPO2 of 570 mb indicated in the table point 3.1.2.1 at depths below 180 m. Note that the depth of 195 m is possible when pushing the PPO_2 to 600 mb. However, passed these limits the metabolic consumption of the oxygen in excess by the divers can be too slow and chronic oxygen poisoning may occur. It is for this reason that, in addition to the problems posed by the High-Pressure Nervous Syndrome (HPNS), a lot of companies who do not want to use mixes below 2% O2 decide to limit their operations to 180 - 200 m maximum.

Compression to depths between 180 and 350 m is possible using mixes with percentages O_2 between 2% and 1%. Compression to these depths is also possible using two mixes such, as an example, 2% O_2 and 1% O_2:

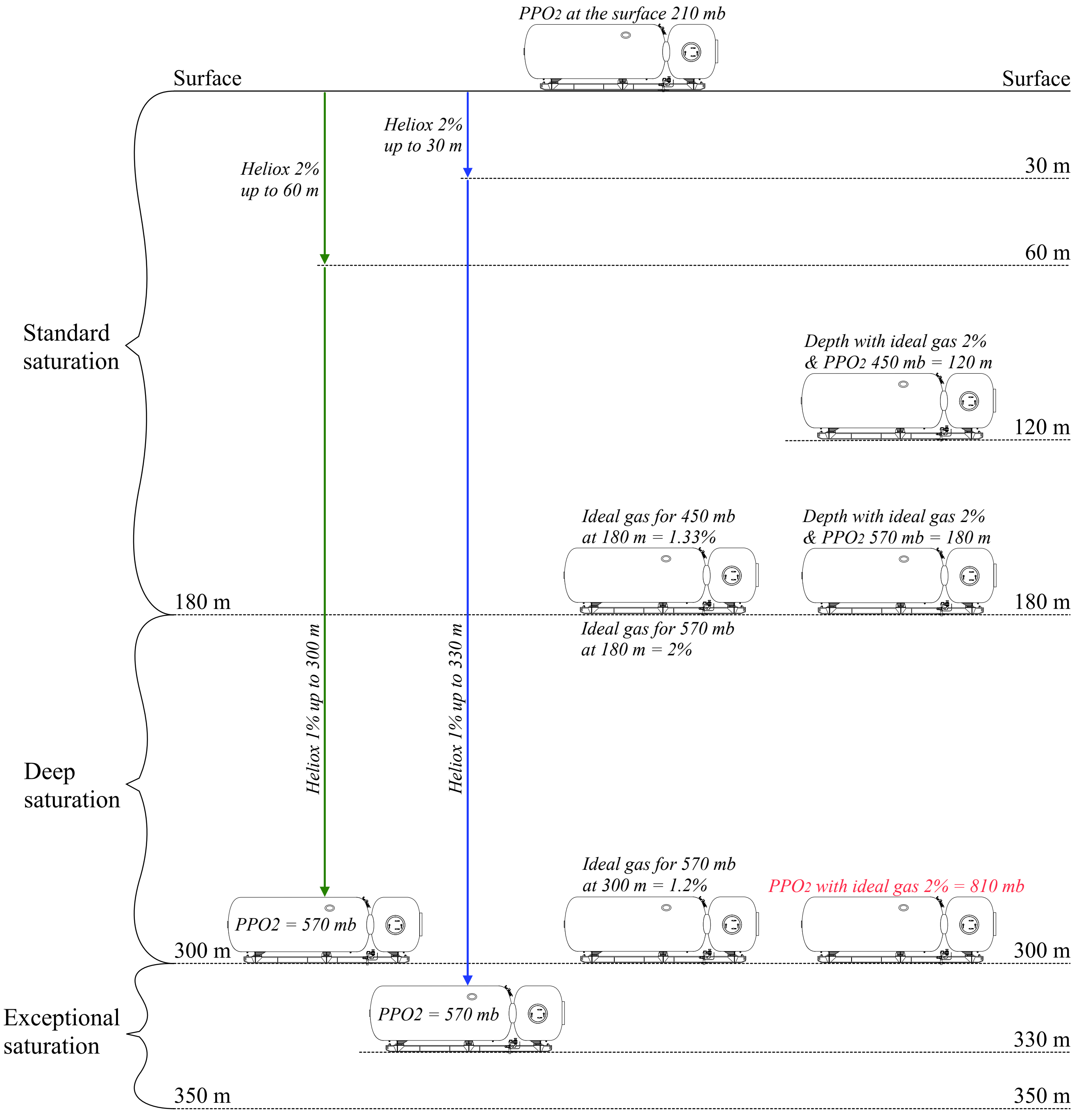
- Depth of 300 m using mixes 2% O2 and 1% O2 and a partial pressure oxygen of 570 mb at the arrival at depth: (570 - 210) - (300 x 1)/ (2-1) = 60 m , which means 2% until 60 m and then 1%.
- Depth of 330 m using mixes of 2% O2 and 1% O2 and a PPO2 of 570 mb at the arrival at depth: (570 - 210) - 330 x 1) / (2-1) = 30 m , which means mix 2% PPO2 until 30 m and then 1%.

Note that, the final depth of a deep saturation can be reached using heliox mixes with an oxygen percentage of 2% or above and a correct PPO2 at the arrival if the dive is organized with one or several intermediate storage levels suitably arranged. This also depends on whether the operations at these shallower levels are of sufficiently long duration to metabolically deplete the oxygen in excess of the lower partial pressure limit prior to moving to the next level. It also depends on the distances between the storage levels.
Also, an alternative procedure promoted by some companies for the compression to a deep saturation is pressurizing the chamber initially with heliox to establish a PPO2 of 0.4 bar and then continuing with pure helium until the final storage depth. However, this procedure obliges to implement specific precautions to protect the divers against pure helium and does not comply with DMAC 5 that recommends a small percentage of oxygen in the mixes used to pressurize the divers.

Note that the implementation of heliox below 2% requires equipment capable of precisely analysing the mixtures and give readings in % with decimals or in Part Per Million (PPM), which is more appropriate when dealing with small decimals values. As a reminder:

- To find the part per million: *PPM = Partial Pressure x 1000,000 / Abs pressure*
- To convert Percentage to Part Per Million (PPM): *PPM = % x 10,000*

Also, only experienced technicians and supervisors should be selected to manage deep, and exceptional saturations as the margin for error at these levels is much reduced compared to those of dives at shallower depths.



4) Pressurisation to the 1st storage depth

Note: *The procedure to calculate the chamber atmosphere was explained in the previous chapter*

4.1 - Reminder

Prior to starting the saturation, the Life Support Supervisor (LSS) must make sure that the following elements that are described in the saturation manual CCO Ltd are in place:

- Sufficient gas reserves, filters, chemical absorbents, CO2 absorbents, and silica gel to complete the planned operation. At least the guidelines of IMCA D 050 “Minimum quantities of gas required offshore” should be implemented, but it is recommended to be always above the quantities indicated in this guidance.
- Sufficient equipment technicians and Life surface technicians to maintain the system and support the divers.
- The entire system has been cleaned and disinfected, and the logistics are in place to supply the divers’ needs.
- The system has been audited and is confirmed good to go. Check-lists and function tests have been completed.
- The hyperbaric rescue unit and reception facility are ready, and evacuation drills have been performed.
- The pre-dive medical check-up of the divers is completed and all the divers are confirmed “fit to dive”.

The compression can start only after instruction from the diving superintendent.

4.2 - Initial seal and beginning of pressurization

The procedure consists to establish an initial seal, then pressurize the chamber to 10 msw, and stop the descent at this depth for a minimum of 20 minutes. During this time, checks must be performed. *(NORSOK standards U-100 point 8232)*

When the checks are completed the chamber can be compressed according to the procedure selected.
The options already explained point 3.2 can be used to pressurise the system:

1. A single gas to storage depth sometimes called an ‘ideal gas’.
2. A rich mix to an initial depth then a lean mix (also called “poor mix”) to storage.

- IMPORTANT:

The divers should be on BIBS at least during the first 10 m.
Also, the LSS and the diving superintendent can decide to keep the divers on BIBS for a longer time if they consider it suitable. *(IMCA D 022)*

Clean fresh gases should be used for compression.

As a reference, note that NORSOK standard says that reclaimed gas should not be used for pressurisation unless the nitrogen content is within the acceptable Hyperbaric Exposure Limits (HEL): 1,5 bar (150 KPa) with a maximum of 3,5 bar (350 KPa). These limits are explained in point 3.1.2.

The Environmental Control Unit and scrubber should run during pressurisation to assist in mixing of the chamber atmosphere. The divers can help in the homogenisation, by shaking towels or similar action.

In the early stages of a pressurisation, divers should not lie on their bunks. They should sit or stand so that the LST can see clearly that they are well and conscious.

4.3 - Gas percentages and compression rates

4.3.1 - Procedures for standard saturations

4.3.1.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mbar) - *570 mbar is acceptable only at the arrival at the storage level*

PP CO2 : < 0.005 bar (< 5 mb)

4.3.1.2 - Compression rates and stabilization prior to starting the diving operations

Saturation area	*Maximum compression speed*	*Stabilization stops in the initial compression*
0 to 100 metres	1 msw/minute	- Two hours at 100 m or proportional time to the depth between the surface and 100 m, calculated by the expression: *Stabilization time (min) = 2 x 60 x depth (m)/100*
101 to 180 metres	1 msw/minute	- 1st stabilization stop for 2 hours at 100 m - 2nd stabilization stop at the arrival at depth, calculated by the expression: *Stabilization time (min) = 2 x 60 x (depth - 100)/100*

4.3.2 - Procedures for deep saturations

4.3.2.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb) - *570 mbar is acceptable only at the arrival at the storage level*

PP CO2 : < 0.005 bar (< 5 mb)

4.3.2.2 - Compression rates and stabilization prior to starting the diving operations

Saturation area	Maximum compression speed	Stabilization stops
181 to 240 metres	- Surface to 100 m: 2 minutes/msw *(0.5 msw/minute)* - From 100 to 200 m: 4 minutes/msw *(0.25 msw/minute)* - From 200 to 240 m: 6 minutes/msw *(0.166 msw/minute)*	- 1st stabilization stop for 2 hours at 100 msw - 2nd stabilization for two hours at 200 msw - 3rd stabilization of at least 6 hours at the saturation depth
241 to 300 metres	- Surface to 100 m: 2 minutes/msw *(0.5 msw/minute)* - From 100 to 200 m: 4 minutes/msw *(0.25 msw/minute)* - From 200 to 300 m: 6 minutes/msw *(0.166 msw/minute)*	- 1st stabilization stop for 2 hours at 100 msw - 2nd stabilization for two hours at 200 msw - 3rd stabilization of least 12 hours at the saturation depth

4.3.3 - Procedures for exceptional saturations

4.3.3.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb) - *570 mbar is acceptable only at the arrival at the storage level*

PP CO2 : < 0.005 bar (< 5 mb)

4.3.3.2 - Compression rates and stabilization prior to starting the diving operations

Saturation area	Maximum compression speed	Stabilization stops
300 to 350 metres	- Surface to 100 m: 2 minutes/msw *(0.5 msw/minute)* - From 100 to 200 m: 4 minutes/msw *(0.25 msw/minute)* - From 200 to 300 m: 6 minutes/msw *(0.166 msw/minute)* - From 300 to 350 m: 8 minutes/metre *(0.125 msw/minute)*	- 1st stabilization stop for 2 hours at 100 msw - 2nd stabilization stop for 2 hours at 200 msw - 3rd stabilization stop for 2 hours at 300 msw - 4th stabilization stop of least 12 hours at the saturation depth

4.3.3.3 - Specific precautions indicated

The divers should have passed medical tests and be selected based on previous deep saturation experience (> 60000 hrs).

The divers' umbilical should be limited to 33 m, counted from the bell, and the bailout system should have an autonomy of at least 15 minutes. Compact Bailout Rebreathing Apparatus (COBRA) or similar systems are mandatory.

4.3.4 - Descents rates and procedures implemented to control the effects of High Pressure Nervous Syndrome (HPNS)

Reduced compression speeds and stabilization stops are organised to control the High Pressure Nervous Syndrome (HPNS). Note that the descent speeds to the final storage depths below 180 metres are seriously slowed down with several intermediates stops and longer stabilization periods at the final depths. These rest periods should take place at the exactly planned depths.

HPNS, which is explained more in the document “Diving accident” of the saturation manual CCO Ltd can be summarized as follows:

- It usually appears at depths somewhat greater than 150 m (500 fsw).
- It involves primarily the central nervous system, and its symptoms are manifested as neuromuscular disturbances (incoordination, fasciculation, tremors) or as disturbances of higher cerebral functions (disorientation, micro-sleep, convulsions in animals).
- These neurological aberrations can be correlated to some degree with changes in electroencephalograms.
- These symptoms normally disappear when the diver returns to pressures above 150 m.
- The development and intensity of the HPNS are augmented by rapid compression to depth.
- Experiences have demonstrated that slow compression rates and stabilization stops reduce the risks of HPNS or

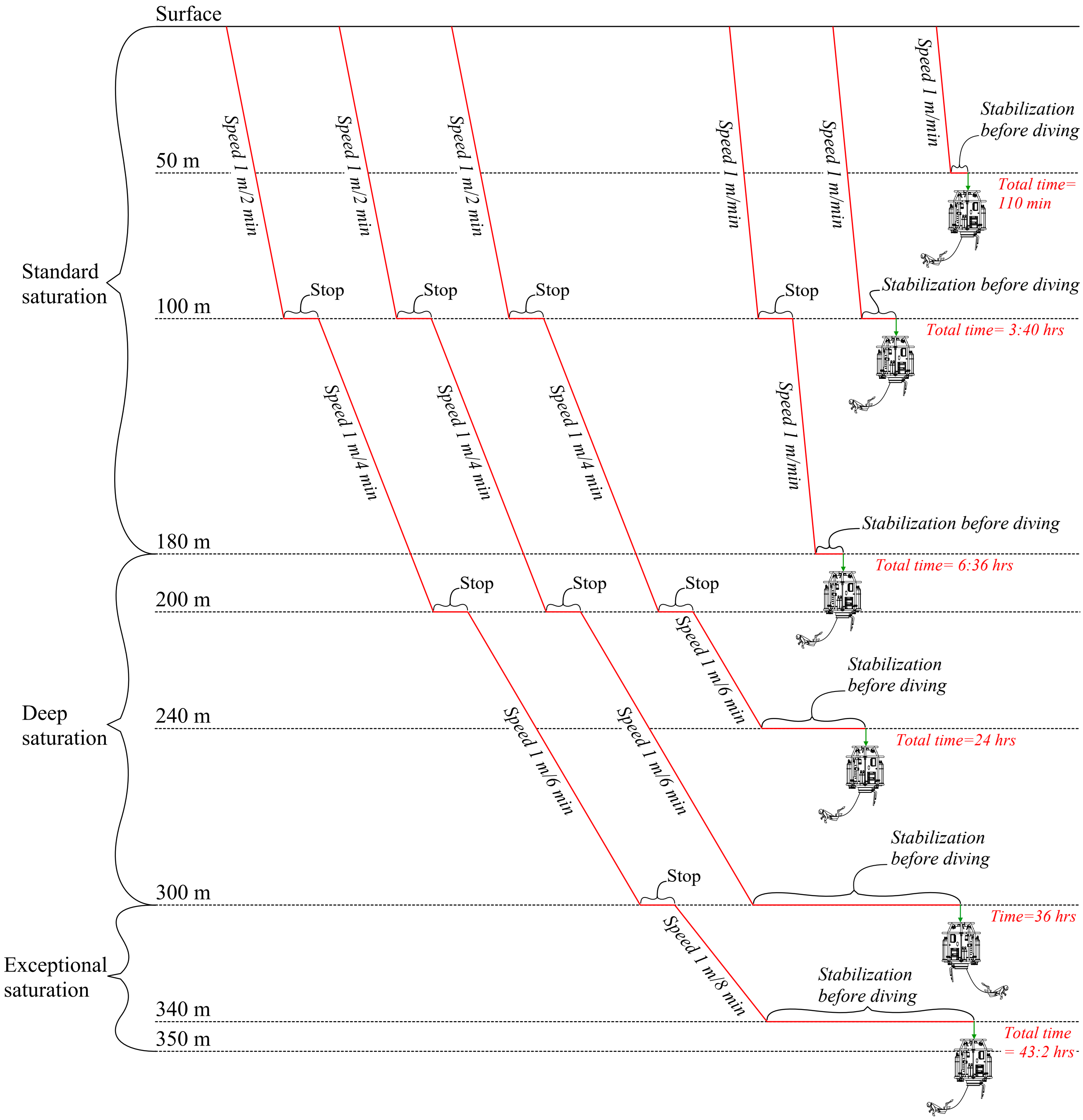
limit its effects. In addition, it has been demonstrated that the use of anticonvulsant may offer some degree of protection against this phenomenon.

- Experiences have also proved that the use of trimix mixtures such as those described in point 1.3 “Scientific developments” give good results.

Note that the descent rates indicated in this chapter can be slowed down and the compression rates can be lengthened without any limitation in the case of severe HPNS.

The drawing below shows the descent curves from the surface to the maximum depths of the areas described in points 4.3.1, 4.3.2, and 4.3.3. Note that the curves do not integrate the leak test at 10 m.

Depth *(metres)*	***surface to 1st stop***	***Stab. at 1st stop***	***1st stop to 2nd stop***	***Stab. at 2nd stop***	***2nd stop to 3rd stop***	***Stab. at 3rd stop***	***3rd stop to final depth***	***Stab. at final depth***	***Total time***
50 m	50 min	–	–	–	–	–	–	60 min	***1:50 hours***
100 m	100 min	–	–	–	–	–	–	120 min	***3:40 hours***
180 m	100 min	120 min	80 min	–	–	–	–	96 min	***6:36 hours***
240 m	200 min	120 min	400 min	120 min	240 min	–	–	360 min	***24 hours***
300 m	200 min	120 min	400 min	120 min	600 min	–	–	720 min	***36 hours***
340 m	200 min	120 min	400 min	120 min	600 min	120 min	320 min	720 min	***43:2 hours***



4.3.5 - Aborting the pressurization

When pressurizing the saturation diving system, a leak test at 10 m is usually organized to ensure the system works satisfactorily and that the pressurization to the storage depth can be safely undertaken. However, the pressurization may have to be stopped for many technical and physiological reasons not seen during this observation period.
Depending on the duration of pressurization and the depth reached, two procedures can be applied to return the divers to the surface.

- The classical saturation decompression procedure allows a safe return to the surface from any depth, whatever is the bottom time. However, this decompression process is slow. For example, 24 hours are necessary to recover divers from 16 m and 55 hours from 50 metres.
- If the depth reached and the time of exposure allows for, the procedure promoted in chapter 2 of IMCA D 022 can be applied. This procedure, based on the procedure of the US Navy diving manual, consists of selecting a surface orientated heliox table that provides an appropriate bottom time and partial pressure of heliox. However, it is limited by the depths and bottom times provided by such tables. The procedure for selecting the decompression procedure is as follows:
    1. Calculate the partial pressure of the helium of the mix used to pressurize the divers. As an example, if the depth reached is 70 m, and the oxygen partial pressure is 0.4 bar, the partial pressure of helium is 8 bar minus 0.4 bar, so 7.6 bar.
    2. Select a table with a depth and a partial pressure of helium superior or equal to those reached during the pressurization. As an example, using the closed bell tables MT92-2019:
        72 m with 16% O 2 = 8.2 bar x percentage helium (100 - 16 = 84) /100 = 6.89 bar is not suitable.
        75 m with 16% O 2 = 8.5 bar x percentage helium (100 - 16 = 84) /100 = 7.14 bar is not suitable.
        78 m with 16% O 2 = 8.8 bar x percentage helium (100 - 16 = 84) /100 = 7.39 bar is not suitable.
        81 m with 16% O 2 = 9.1 bar x percentage helium (100 - 16 = 84) /100 = 7.64 bar is suitable.
        78 m with 12% O 2 = 8.8 bar x percentage helium (100 - 12 = 88) /100 = 7.74 bar is suitable.
    3. Ensure that the bottom time is suitable. As an example, if the planned storage depth was 100 m, the Normam-15's descent rate is 1 m per minute, to which the time of the leak test at 10 m (20 minutes) and the time lost to select the table and implement it must be added.
    4. Ensure that the first decompression stop is above the depth the divers are at. As an example, with the tables 81 m /16% O 2 & 78 m /12% O 2 above, the first stop starts at 57 m and 60 m, so above the divers' depth.

Important points:

In case the compression has to be stopped, the diving medical specialist must be contacted and be kept informed of the procedures implemented and the divers' condition.

The saturation chamber atmosphere is heliox. For this reason, surface orientated heliox tables that use air stops to speed up the decompression must not be used. The reason is that breathing air through a mask in a chamber filled with heliox can induce high tissue gas supersaturation levels and greater susceptibility for bubble formation and decompression illness *(see chapter "Isobaric inert gas counter-diffusion" in Book #4 of the saturation diving handbook published by "Diving and ROV specialists")*.

Note that the tables below that are available on the website http://diving-rov-specialists.com/ are suitable:

- Closed bell tables MT92-2019 are in chamber decompression procedures in heliox atmosphere for dives between 30 and 120 metres and bottom times up to 120 minutes.
- USN navy wet bell heliox tables provide exceptional bottom times of 120 minutes for depths between 18 and 115 metres. These tables use heliox mixes and oxygen. However, the depths of these tables are designed in feet instead of metres.

Shallow depth exposures may result in the table corresponding to the storage depth does not exist and that the first depth available asks for deeper stops than the divers' storage depth. In this case, contact the diving medical specialist to decide on the recovery procedure.

4.4 - Controls during the saturation operations

The following parameters should be measured, displayed, and logged and retained on a continuous basis staring from compression to the end of the saturation:

- Time
- Divers depth
- Partial pressure O_2 and partial pressure CO_2 in the diver's breathing gas
- Hot water temperature and flow, or heating power to the bell
- Bell internal and external pressure
- Bell internal partial pressure O_2 , partial pressure CO_2 and temperature
- Chamber internal pressure, humidity, partial pressure O_2, partial pressure CO_2 and temperature (+ SPHL)
- Habitat internal and external pressure
- Habitat internal partial pressure O_2, partial pressure CO_2, and temperature

- Wet bell/diving basket: gas supply pressure surface/on-board
- Hot water temperatures in the bell and in the diver's suit
- Hot water flow, or heating power, to the diver in the bell

The following shall be measured and logged (not required on-line) on a routine basis:

- Potentially toxic gases in the hyperbaric environment
- Bacterial growth/content in all critical places including fresh water, hot water, BA sets, rebreather
- For saturation/living compartments at least CO and N_2 - Others to be considered
- For saturation/living compartments daily sensory check for odour/smell
- Biological samples when justified

Alarms should be installed for the following gases

- Oxygen in the diver's breathing gas
- CO_2 in the diver's breathing gas
- Hydrocarbons,Hg and H_2S in the bell
- Oxygen in control/gas storage rooms when justified

4.5 - Initial storage depth

4.5.1 - Gas parameters

Oxygen: 0.38 to 0.45 bar (380 to 450 mb)

NOTE: It is accepted that the final chamber PPO2, can exceed 0.450 bar and reach up to 0.570 at the end of an initial pressurisation. No corrective action is required as the excess chamber oxygen will be depleted by diver's consumption.

Carbon dioxide: < 0.005 ATA (< 5 mb)
Argon: 50 kPa (0,5 bar)
Nitrogen: 150 kPa (1,5 bar)
Carbon monoxide: 0,5 Pa (5 µbar)

See chapter 3 "*Chamber & bell gas monitoring and make up*" point 3.1.2 *"Acceptable gas values"*

4.5.2 - Temperatures

Depth (msw)	Temperature range (C°)	Depth (msw)	Temperature range (C°)
0- 50	22 - 27	200 - 250	29 - 31
50 - 100	25 - 29	250 - 300	30 - 32
100 - 150	27 - 30	300 - 350	31 - 33
150 - 200	28 - 31		

4.5.3 - Humidity

High humidity associated with heat provides an ideal environment for infections. Also, it impairs sweat evaporation and restricts the resistance to heat. As a result, dehydration and hyperthermia may occur.

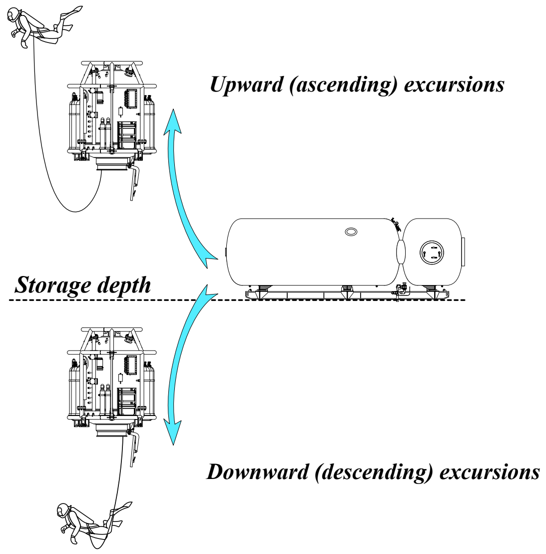
- Ideal percentage should be 50 to 70% for depths shallower than 180 msw and 40 to 60% for deeper depths
- Extremes percentage can be 30 to 80% for short periods.

5) Excursions during the bell runs

5.1 - Types of excursions

5.1.1 - Ascending and descending excursions

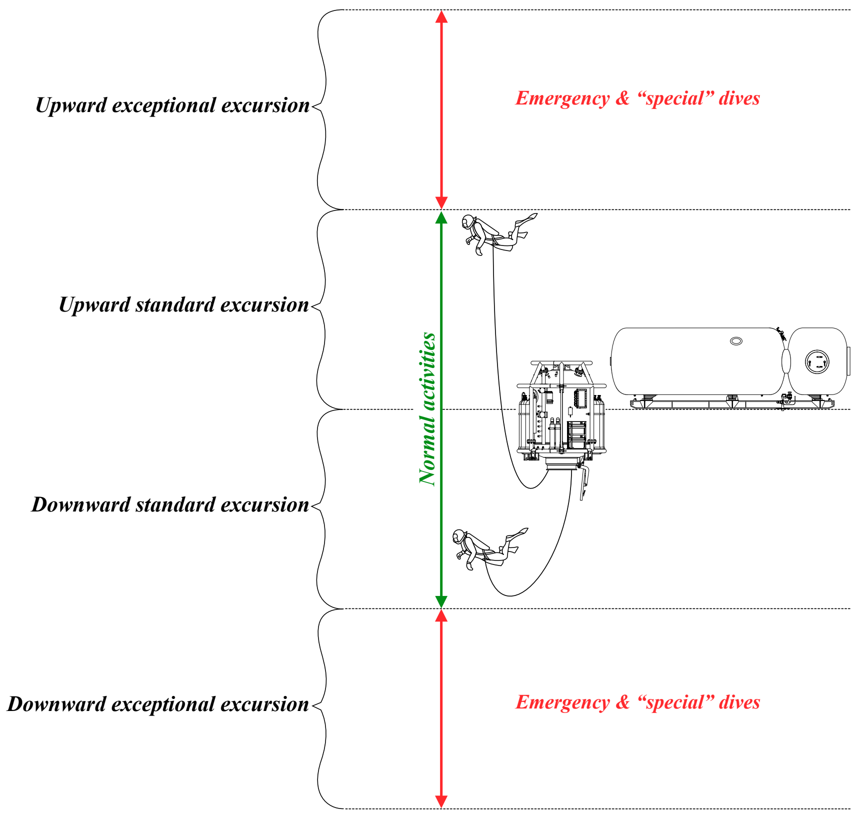
- Ascending excursions, also called upward excursions, are dives performed at depths shallower than the “storage depth”, also called “life level”.
- Descending excursions, also called downward excursions, are dives performed at depths deeper than the storage depth.



5.1.2 - Excursion depths range

Excursions are characterised by the pressure difference existing between the storage depth and the working depth which is called the excursion depth range or the excursion depth amplitude. There are two types of excursion depth ranges:

- Standard excursions allow moderate amplitudes. These excursions are those to be used for normal diving operations undertaken during underwater construction or inspection projects. Depending on the storage depth, they allow from 2 to 15 m amplitude.
- The exception excursions allow greater distances than standard excursions. However, these excursions should not be scheduled as routine and should be employed only in special or emergency situations.



5.2 - Stabilization periods before excursions

5.2.1 - Excursions upon arrival at the storage depth

Excursions upon arrival at the storage depth are not possible.
Prior to undertaking excursions, the stabilization periods explained in chapter 4, and that can be read in the tables in point 4.3 must be completed. After this initial stabilization period, upward and downward excursions are possible regardless of the depth in which the saturation is.

5.2.2 - Excursion after a previous excursion

Normam-15 says that after an excursion the diver should observe a stabilization period before going on another excursion according to the table below:

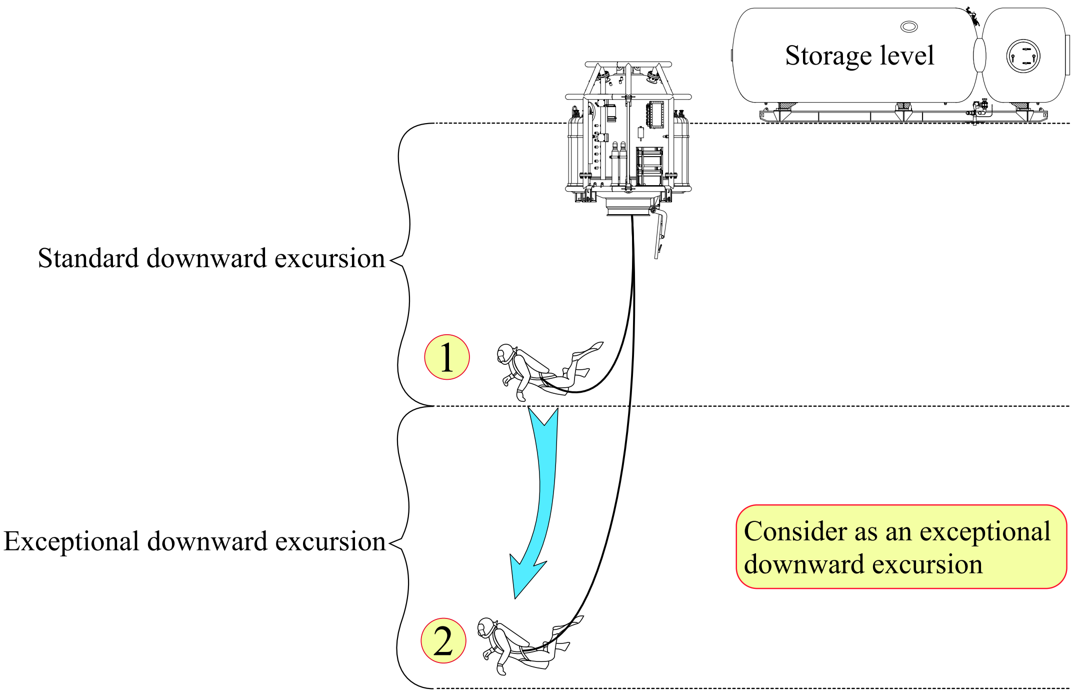
Stabilization period	*After a standard downward excursion*	*After a standard upward excursion*	*After an exceptional downward excursion*	*After an exceptional upward excursion*
Before a standard downward excursion	None	None	None	12 hours
Before a standard upward excursion	None	None	12 hours	12 hours
Before an exceptional downward excursion	None	None	48 hours	48 hours
Before an exceptional upward excursion	12 hours	None	48 hours	48 hours

Fundamental rule:
A saturated diver can perform only two exceptional excursions per saturation.
As a reminder, the maximum duration of a saturation dive is 28 days.

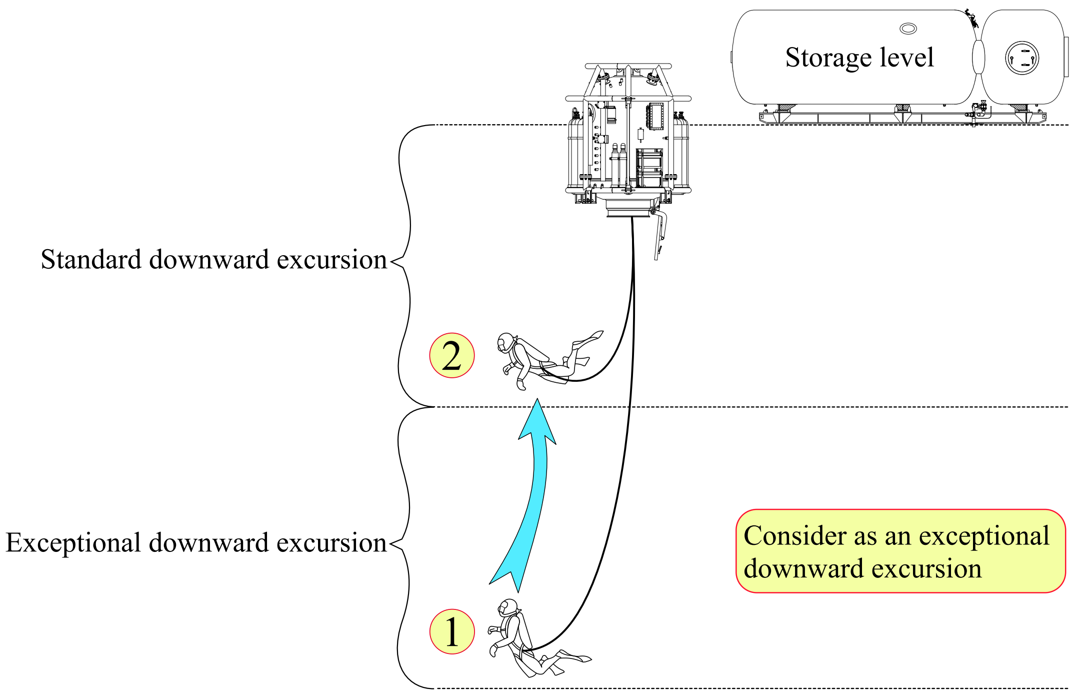
5.2.3 - Combinations allowed for excursions with no break

Combinations of standard and exceptional downward and upward excursions may have to be performed. The possible combinations are recorded below and should be done according to the criteria established on the table point 5.2.2

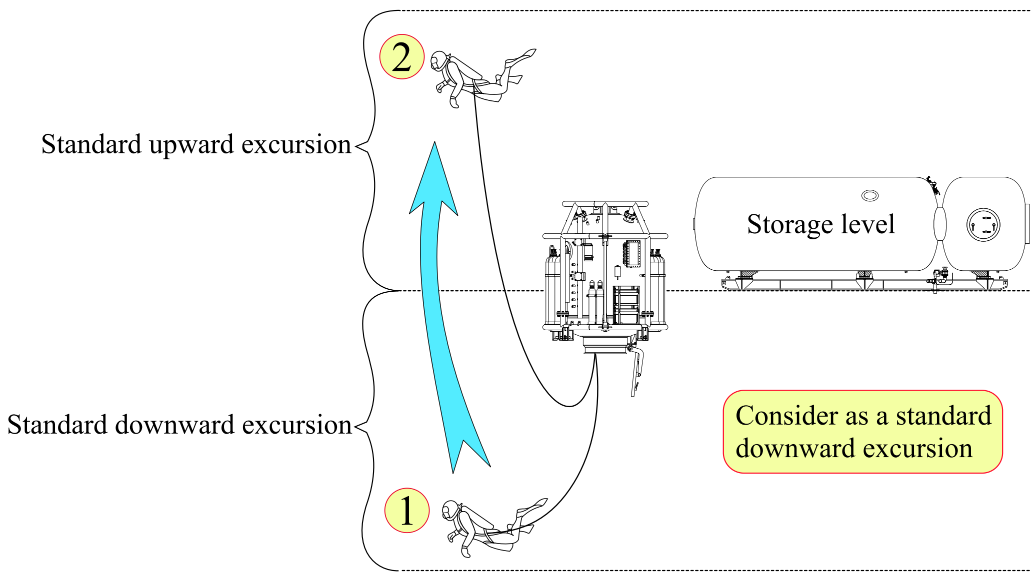
5.2.3.1 - Standard downward excursion followed by exceptional downward excursion



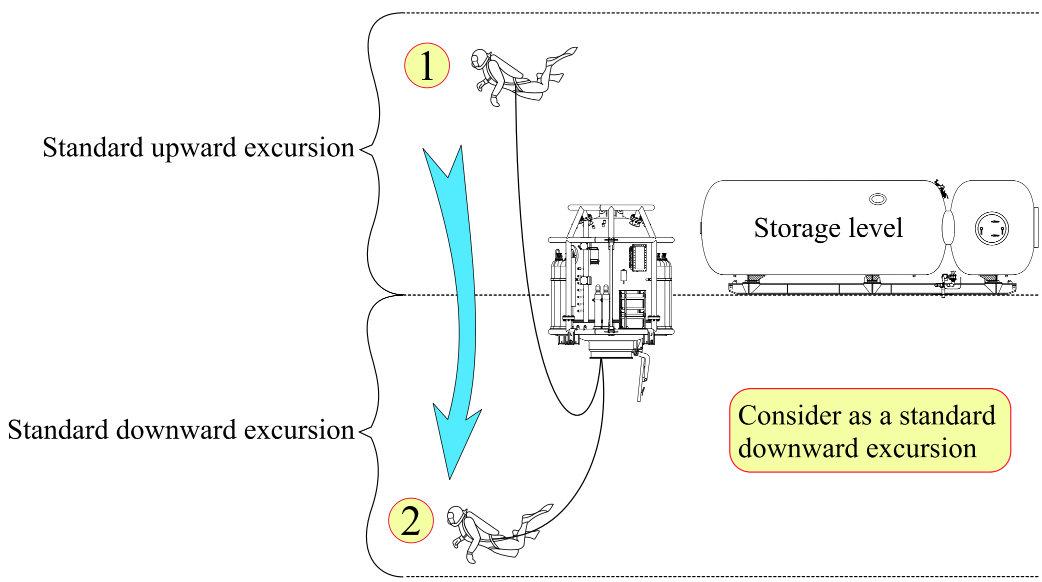
5.2.3.2 - Exceptional downward excursion followed by a standard downward excursion



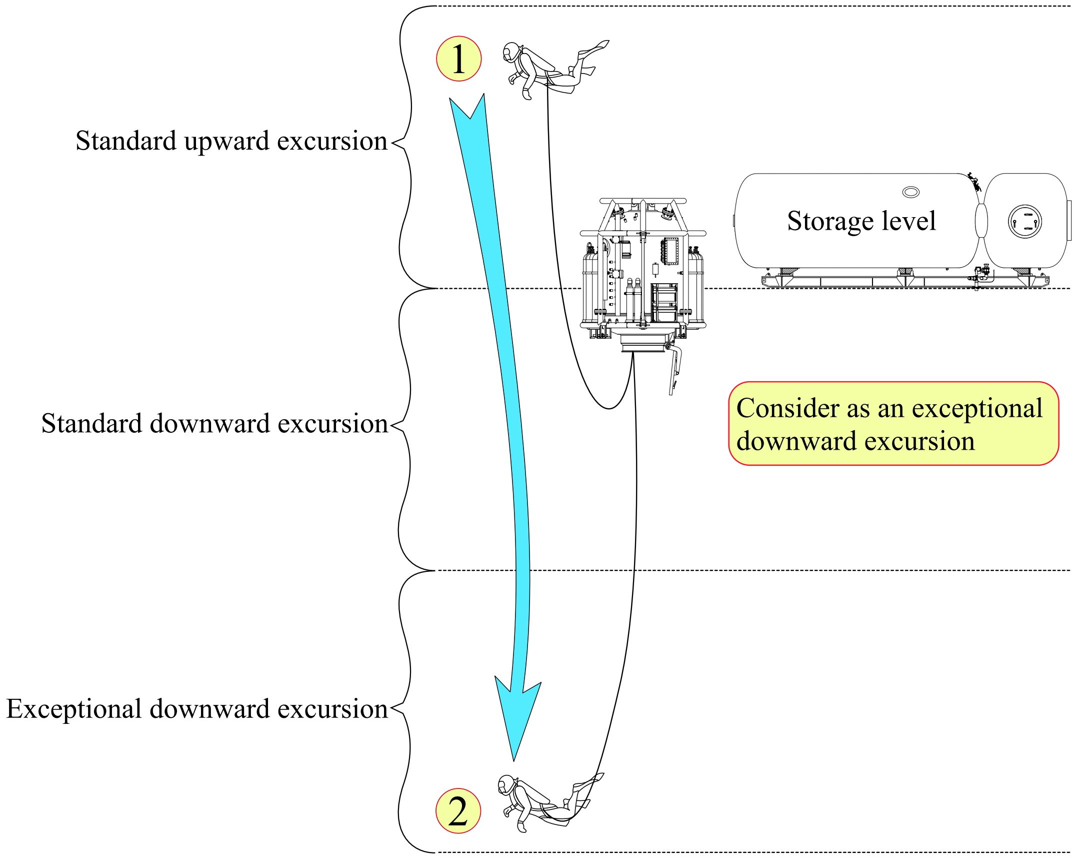
5.2.3.3 - Standard downward excursion followed by standard upward excursion



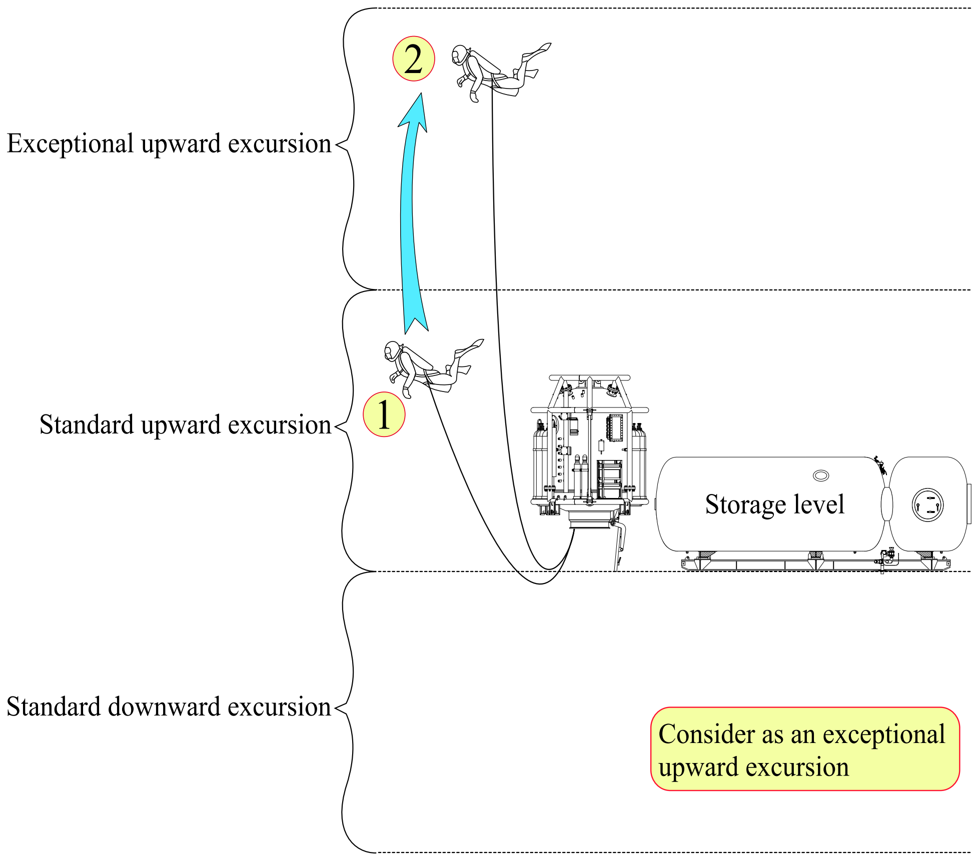
5.2.3.4 - Standard upward excursion followed by standard downward excursion



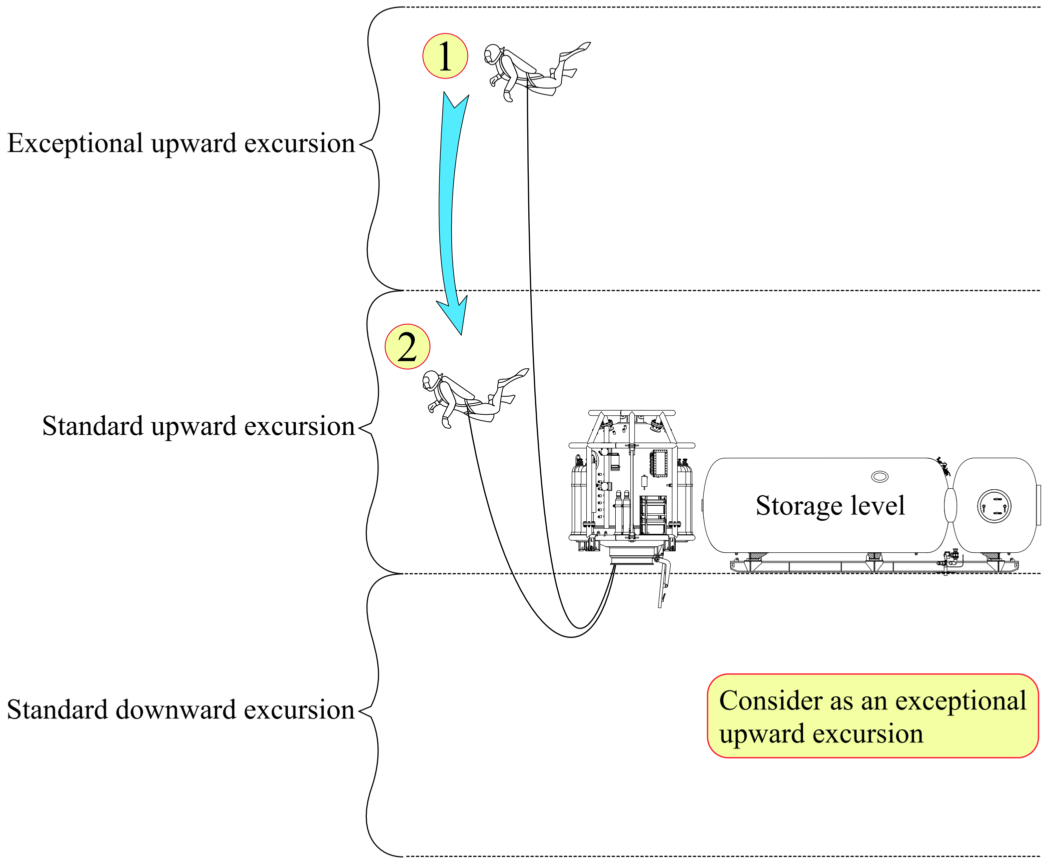
5.2.3.5 - Standard upward excursion followed by exceptional downward excursion



5.2.3.6 - Standard upward excursion followed by exceptional upward excursion



5.2.3.7 - Exceptional upward excursion followed by a standard upward excursion



5.3 - Ascent and descent speed during an excursion

NORMAM-15 says that the descent and ascent rate should not exceed 10 m/min during an excursion.
When it is detected that a diver is ascending or descending faster than this rate, the supervisor must immediately stop him and wait until enough time has elapsed to return to the 10 m/min schedule. The diver may then resume the travel at a rate that does not to exceed 10 m/min from that depth.

Note that NORSOK standard U-100 suggests the same maximum rate.

5.4 - Recommendations for organizing bell runs and excursions *(NORSOK & French decree 15th of May 92)*

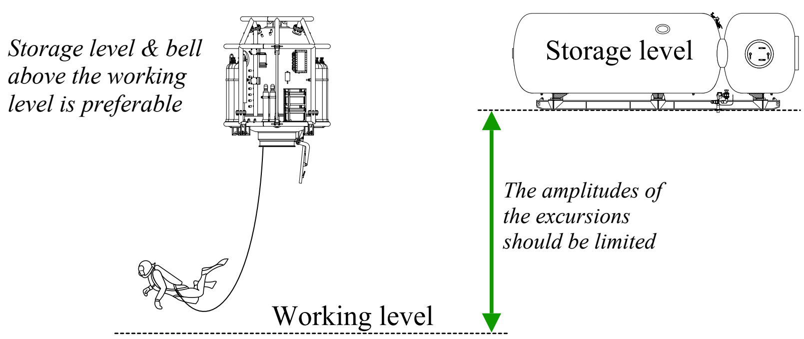
The working times should be organized in a way that the divers have regular rotations, so the working time and recovery times happen at the same hours every day. This point is very important to allow the divers a full recovery of their efforts.

For a given bell run, the preferred choice should be:

- Descending excursions rather than ascending ones. It is preferable to have the storage level (chamber) and the bell above the working level.
- Standard excursions rather than exceptional ones.
- The work planning to be arranged so as to avoid repeated ascents for the divers.
- The living depth that is as close to the working depth as possible.

When adjusting the bell:

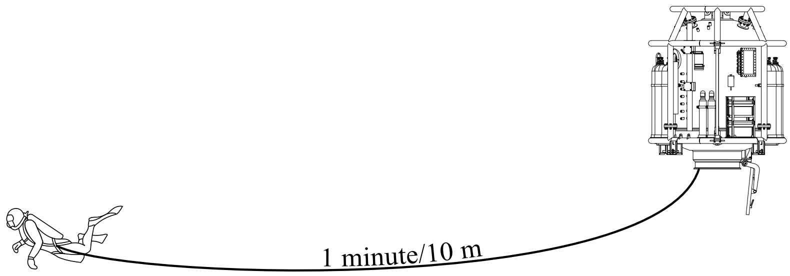
- The depth of the bell must be kept within the limits of "standard excursion" dives.
- A bell depth equal to or deeper than the storage level is preferable.
- The storage level should be as close to the working depth as possible to limit the amplitudes of the excursions.



5.5 - Horizontal distance from the bell during excursions

In addition to the fact that the bell must be as close to the living and working depths as possible, it is recommended to limit the horizontal distance of the diver from the bell and provide him a bailout bottle which contains enough gas that allows him to return to the bell or a place of safety if his main supply fails.

IMCA D 022 says that a calculation should be available showing that the capacity of the cylinder(s) at the depth of diving will allow breathing air for 1 minute for every 10 metres of umbilical deployed from the diving bell.



Note that NORMAM- 15 limits the umbilical length to 33 metres and the bailout duration to at least 15 minutes during exceptional saturation. Also, NORSOK standard U 100, which limits the umbilical length to 45 m, says in point 7.8.3 that the bail-out system should provide the diver with gas for 10 min based on an average consumption of 62,5 1/min.
This consumption value, that should be considered as a minimum, is confirmed by the UK HSE study "The provision of breathing gas to divers in emergency situations" which recommends a rate between 50 & 75 litres.
Most bail-out bottles sufficiently compact to enter in the bell are outside the limits indicated above at depths below 60 m. For this reason, Compact Bailout Rebreathing Apparatus (COBRA), such as those proposed by DIVEX (JFD group - https://www.jfdglobal.com), which significantly increase the reserve of breathing gas available to the diver in the case of an emergency, should be used. Note that COBRA or equivalent are mandatory for deep dives with NORMAM 15.

5.6 - Duration of bell runs

The bell run durations are given "seal to seal" *(from bell locked off the system to bell locked on the system)*.
Note that these durations are the maximum allowed by NORMAM-15 for 24 hours and that there must be at least 12 hours of full rest between 2 bell runs. The bell runs can be shortened according to the real time spent in the water.

The bell runs and times in the water should be organised as follows:

Depth	***0 - 210 m***	***211 - 260 m***	***261 - 300 m***	***301 - 350 m***
Maximum duration bell run	8 hours/24 hours	8 hours/24 hours	8 hours/24 hours	6 hours/24 hours
Maximum time in the water	6 hours/24 hours	5 hours/24 hours	4 hours/24 hours	3 hours/24 hours
Resting time 30 min or diver change *	At mid-dive	At mid-dive	At mid-dive	Not specified *(At mid dive)*

Resting time 30 min or diver change * :
The diver who goes into the water can at his own discretion and with the authorization of his supervisor, be replaced by the emergency diver.
If he is not replaced, he should have a resting period inside the diving bell where he can remove his diving helmet, eat, and re-hydrate. It is recommended that this resting period is to be up to thirty minutes.
Diver change or the rest period should be organized at the halftime of the time to be spent in the water.

Note that NORSOK U-100 says the following:

- The total in water time shall not exceed 5:30 hours and the break in the bell must be logged. During a two-man bell-run, total time in water during a 12 h period shall not exceed 4 h for each diver.
- Each diver shall be given a dry day as bell-man every third day
- The diving supervisor shall have a rest period from the direct communication control after a period of 4 h. The rest period shall be at least 30 min. The total time for this function shall be limited to 8 h in the course of a 12 h period. The workload should determine the length of the rest periods. Inside a 24 h period supervisory personnel should normally have a 12 h period of continuous rest.

5.7 - Excursion tables

The excursion tables displayed on the next pages indicate the maximum excursion depths and distances metre by metre from 10 msw to 350 msw.

To read the table, select the depth in the column on the left side and follow the horizontal line to read the corresponding maximum distances and depths of the downward or upward standard or exceptional excursions.

In the case of a storage depth between two levels:

- For an upward excursion, select the depth immediately deeper. As an example, for a depth between 20 & 21 msw, select 21 m. It is also possible to calculate the excursion using the "upward distance".
- For a downward excursion, select the depth immediately shallower. As an example, for a depth between 20 & 21 msw, select 20 m. It is also possible to calculate the excursion using the "downward distance".

Life depth (metres)	*Standard excursions*				*Exceptional excursions*			
	Downward distances	*Downward depths*	*Upward distances*	*Upward depths*	*Downward distances*	*Downward depths*	*Upward distances*	*Upward depths*
10	3	13	2	8	Forbidden	–	Forbidden	–
11	3	14	2	9	Forbidden	–	Forbidden	–
12	3	15	2	10	Forbidden	–	Forbidden	–
13	3	16	2	11	Forbidden	–	Forbidden	–
14	3	17	2	12	Forbidden	–	Forbidden	–
15	3	18	2	13	Forbidden	–	Forbidden	–
16	3	19	2	14	Forbidden	–	Forbidden	–
17	3	20	2	15	Forbidden	–	Forbidden	–
18	4	22	4	14	Forbidden	–	Forbidden	–
19	4	23	4	15	Forbidden	–	Forbidden	–
20	4	24	4	16	Forbidden	–	Forbidden	–
21	4	25	4	17	Forbidden	–	Forbidden	–
22	4	26	4	18	Forbidden	–	Forbidden	–
23	5	28	5	18	10	33	Forbidden	–
24	5	29	5	19	10	34	Forbidden	–
25	5	30	5	20	10	35	Forbidden	–
26	5	31	5	21	10	36	Forbidden	–
27	5	32	5	22	10	37	Forbidden	–
28	5	33	5	23	10	38	Forbidden	–
29	5	34	5	24	10	39	Forbidden	–
30	6	36	6	24	12	42	Forbidden	–
31	7	38	7	24	14	45	14	17
32	7	39	7	25	14	46	14	18
33	7	40	7	26	14	47	14	19
34	7	41	7	27	14	48	14	20
35	7	42	7	28	14	49	14	21
36	7	43	7	29	14	50	14	22
37	7	44	7	30	14	51	14	23
38	7	45	7	31	14	52	14	24
39	7	46	7	32	14	53	14	25
40	8	48	8	32	16	56	16	24
41	8	49	8	33	16	57	16	25
42	8	50	8	34	16	58	16	26
43	8	51	8	35	16	59	16	27
44	8	52	8	36	16	60	16	28
45	8	53	8	37	16	61	16	29
46	8	54	8	38	16	62	16	30
47	8	55	8	39	16	63	16	31

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
48	8	56	8	40	16	64	16	32
49	8	57	8	41	16	65	16	33
50	8	58	8	42	16	66	16	34
51	8	59	8	43	16	67	16	35
52	8	60	8	44	16	68	16	36
53	8	61	8	45	16	69	16	37
54	8	62	8	46	16	70	16	38
55	8	63	8	47	16	71	16	39
56	8	64	8	48	16	72	16	40
57	8	65	8	49	16	73	16	41
58	8	66	8	50	16	74	16	42
59	8	67	8	51	16	75	16	43
60	9	69	9	51	18	78	18	42
61	9	70	9	52	18	79	18	43
62	9	71	9	53	18	80	18	44
63	9	72	9	54	18	81	18	45
64	9	73	9	55	18	82	18	46
65	9	74	9	56	18	83	18	47
66	9	75	9	57	18	84	18	48
67	9	76	9	58	18	85	18	49
68	9	77	9	59	18	86	18	50
69	9	78	9	60	18	87	18	51
70	9	79	9	61	18	88	18	52
71	9	80	9	62	18	89	18	53
72	9	81	9	63	18	90	18	54
73	9	82	9	64	18	91	18	55
74	9	83	9	65	18	92	18	56
75	9	84	9	66	18	93	18	57
76	9	85	9	67	18	94	18	58
77	9	86	9	68	18	95	18	59
78	9	87	9	69	18	96	18	60
79	9	88	9	70	18	97	18	61
80	10	90	10	70	20	100	20	60
81	10	91	10	71	20	101	20	61
82	10	92	10	72	20	102	20	62
83	10	93	10	73	20	103	20	63
84	10	94	10	74	20	104	20	64
85	10	95	10	75	20	105	20	65
86	10	96	10	76	20	106	20	66
87	10	97	10	77	20	107	20	67
88	10	98	10	78	20	108	20	68
89	10	99	10	79	20	109	20	69
90	10	100	10	80	20	110	20	70

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
91	10	101	10	81	20	111	20	71
92	10	102	10	82	20	112	20	72
93	10	103	10	83	20	113	20	73
94	10	104	10	84	20	114	20	74
95	10	105	10	85	20	115	20	75
96	10	106	10	86	20	116	20	76
97	10	107	10	87	20	117	20	77
98	10	108	10	88	20	118	20	78
99	10	109	10	89	20	119	20	79
100	11	111	11	89	22	122	22	78
101	11	112	11	90	22	123	22	79
102	11	113	11	91	22	124	22	80
103	11	114	11	92	22	125	22	81
104	11	115	11	93	22	126	22	82
105	11	116	11	94	22	127	22	83
106	11	117	11	95	22	128	22	84
107	11	118	11	96	22	129	22	85
108	11	119	11	97	22	130	22	86
109	11	120	11	98	22	131	22	87
110	11	121	11	99	22	132	22	88
111	11	122	11	100	22	133	22	89
112	11	123	11	101	22	134	22	90
113	11	124	11	102	22	135	22	91
114	11	125	11	103	22	136	22	92
115	11	126	11	104	22	137	22	93
116	11	127	11	105	22	138	22	94
117	11	128	11	106	22	139	22	95
118	11	129	11	107	22	140	22	96
119	11	130	11	108	22	141	22	97
120	12	132	12	108	24	144	24	96
121	12	133	12	109	24	145	24	97
122	12	134	12	110	24	146	24	98
123	12	135	12	111	24	147	24	99
124	12	136	12	112	24	148	24	100
125	12	137	12	113	24	149	24	101
126	12	138	12	114	24	150	24	102
127	12	139	12	115	24	151	24	103
128	12	140	12	116	24	152	24	104
129	12	141	12	117	24	153	24	105
130	12	142	12	118	24	154	24	106
131	12	143	12	119	24	155	24	107
132	12	144	12	120	24	156	24	108
133	12	145	12	121	24	157	24	109

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
134	12	146	12	122	24	158	24	110
135	12	147	12	123	24	159	24	111
136	12	148	12	124	24	160	24	112
137	12	149	12	125	24	161	24	113
138	12	150	12	126	24	162	24	114
139	12	151	12	127	24	163	24	115
140	13	153	13	127	26	166	26	114
141	13	154	13	128	26	167	26	115
142	13	155	13	129	26	168	26	116
143	13	156	13	130	26	169	26	117
144	13	157	13	131	26	170	26	118
145	13	158	13	132	26	171	26	119
146	13	159	13	133	26	172	26	120
147	13	160	13	134	26	173	26	121
148	13	161	13	135	26	174	26	122
149	13	162	13	136	26	175	26	123
150	13	163	13	137	26	176	26	124
151	13	164	13	138	26	177	26	125
152	13	165	13	139	26	178	26	126
153	13	166	13	140	26	179	26	127
154	13	167	13	141	26	180	26	128
155	13	168	13	142	26	181	26	129
156	13	169	13	143	26	182	26	130
157	13	170	13	144	26	183	26	131
158	13	171	13	145	26	184	26	132
159	13	172	13	146	26	185	26	133
160	13	173	13	147	26	186	26	134
161	13	174	13	148	26	187	26	135
162	13	175	13	149	26	188	26	136
163	13	176	13	150	26	189	26	137
164	13	177	13	151	26	190	26	138
165	13	178	13	152	26	191	26	139
166	13	179	13	153	26	192	26	140
167	13	180	13	154	26	193	26	141
168	13	181	13	155	26	194	26	142
169	13	182	13	156	26	195	26	143
170	13	183	13	157	26	196	26	144
171	13	184	13	158	26	197	26	145
172	13	185	13	159	26	198	26	146
173	13	186	13	160	26	199	26	147
174	13	187	13	161	26	200	26	148
175	13	188	13	162	26	201	26	149
176	13	189	13	163	26	202	26	150

Life depth (metres)	*Standard excursions*				*Exceptional excursions*			
	Downward distances	*Downward depths*	*Upward distances*	*Upward depths*	*Downward distances*	*Downward depths*	*Upward distances*	*Upward depths*
177	13	190	13	164	26	203	26	151
178	13	191	13	165	26	204	26	152
179	13	192	13	166	26	205	26	153
180	15	195	15	165	30	210	30	150
181	15	196	15	166	30	211	30	151
182	15	197	15	167	30	212	30	152
183	15	198	15	168	30	213	30	153
184	15	199	15	169	30	214	30	154
185	15	200	15	170	30	215	30	155
186	15	201	15	171	30	216	30	156
187	15	202	15	172	30	217	30	157
188	15	203	15	173	30	218	30	158
189	15	204	15	174	30	219	30	159
190	15	205	15	175	30	220	30	160
191	15	206	15	176	30	221	30	161
192	15	207	15	177	30	222	30	162
193	15	208	15	178	30	223	30	163
194	15	209	15	179	30	224	30	164
195	15	210	15	180	30	225	30	165
196	15	211	15	181	30	226	30	166
197	15	212	15	182	30	227	30	167
198	15	213	15	183	30	228	30	168
199	15	214	15	184	30	229	30	169
200	15	215	15	185	30	230	30	170
201	15	216	15	186	30	231	30	171
202	15	217	15	187	30	232	30	172
203	15	218	15	188	30	233	30	173
204	15	219	15	189	30	234	30	174
205	15	220	15	190	30	235	30	175
206	15	221	15	191	30	236	30	176
207	15	222	15	192	30	237	30	177
209	15	224	15	194	30	239	30	179
210	15	225	15	195	30	240	30	180
212	15	227	15	197	30	242	30	182
213	15	228	15	198	30	243	30	183
214	15	229	15	199	30	244	30	184
215	15	230	15	200	30	245	30	185
216	15	231	15	201	30	246	30	186
217	15	232	15	202	30	247	30	187
218	15	233	15	203	30	248	30	188
219	15	234	15	204	30	249	30	189
220	15	235	15	205	30	250	30	190
221	15	236	15	206	30	251	30	191

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
222	15	237	15	207	30	252	30	192
223	15	238	15	208	30	253	30	193
224	15	239	15	209	30	254	30	194
225	15	240	15	210	30	255	30	195
226	15	241	15	211	30	256	30	196
227	15	242	15	212	30	257	30	197
228	15	243	15	213	30	258	30	198
229	15	244	15	214	30	259	30	199
230	15	245	15	215	30	260	30	200
231	15	246	15	216	30	261	30	201
232	15	247	15	217	30	262	30	202
233	15	248	15	218	30	263	30	203
234	15	249	15	219	30	264	30	204
235	15	250	15	220	30	265	30	205
236	15	251	15	221	30	266	30	206
237	15	252	15	222	30	267	30	207
238	15	253	15	223	30	268	30	208
239	15	254	15	224	30	269	30	209
240	15	255	15	225	30	270	30	210
241	15	256	15	226	30	271	30	211
242	15	257	15	227	30	272	30	212
243	15	258	15	228	30	273	30	213
244	15	259	15	229	30	274	30	214
245	15	260	15	230	30	275	30	215
246	15	261	15	231	30	276	30	216
247	15	262	15	232	30	277	30	217
248	15	263	15	233	30	278	30	218
249	15	264	15	234	30	279	30	219
250	15	265	15	235	30	280	30	220
251	15	266	15	236	30	281	30	221
252	15	267	15	237	30	282	30	222
253	15	268	15	238	30	283	30	223
254	15	269	15	239	30	284	30	224
255	15	270	15	240	30	285	30	225
256	15	271	15	241	30	286	30	226
257	15	272	15	242	30	287	30	227
258	15	273	15	243	30	288	30	228
259	15	274	15	244	30	289	30	229
260	15	275	15	245	30	290	30	230
261	15	276	15	246	30	291	30	231
262	15	277	15	247	30	292	30	232
263	15	278	15	248	30	293	30	233
264	15	279	15	249	30	294	30	234

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
265	15	280	15	250	30	295	30	235
266	15	281	15	251	30	296	30	236
267	15	282	15	252	30	297	30	237
268	15	283	15	253	30	298	30	238
269	15	284	15	254	30	299	30	239
270	15	285	15	255	30	300	30	240
271	15	286	15	256	29	300	30	241
272	15	287	15	257	28	300	30	242
273	15	288	15	258	27	300	30	243
274	15	289	15	259	26	300	30	244
275	15	290	15	260	25	300	30	245
276	15	291	15	261	24	300	30	246
277	15	292	15	262	23	300	30	247
278	15	293	15	263	22	300	30	248
279	15	294	15	264	21	300	30	249
280	15	295	15	265	20	300	30	250
281	15	296	15	266	19	300	30	251
282	15	297	15	267	18	300	30	252
283	15	298	15	268	17	300	30	253
284	15	299	15	269	16	300	30	254
285	15	300	15	270	15	300	30	255
286	14	300	14	272	14	300	25	261
287	13	300	13	274	13	300	25	262
288	12	300	12	276	12	300	25	263
289	11	300	11	278	11	300	25	264
290	10	300	10	280	10	300	25	265
291	10	301	10	281	Forbidden	–	25	266
292	10	302	10	282	Forbidden	–	25	267
293	10	303	10	283	Forbidden	–	25	268
294	10	304	10	284	Forbidden	–	25	269
295	10	305	10	285	Forbidden	–	25	270
296	10	306	10	286	Forbidden	–	25	271
297	10	307	10	287	Forbidden	–	25	272
298	10	308	10	288	Forbidden	–	25	273
299	10	309	10	289	Forbidden	–	25	274
300	10	310	10	290	Forbidden	–	25	275
301	10	311	10	291	Forbidden	–	Forbidden	–
302	10	312	10	292	Forbidden	–	Forbidden	–
303	10	313	10	293	Forbidden	–	Forbidden	–
304	10	314	10	294	Forbidden	–	Forbidden	–
305	10	315	10	295	Forbidden	–	Forbidden	–
306	10	316	10	296	Forbidden	–	Forbidden	–
307	10	317	10	297	Forbidden	–	Forbidden	–

Life depth (metres)	Standard excursions				Exceptional excursions			
	Downward distances	Downward depths	Upward distances	Upward depths	Downward distances	Downward depths	Upward distances	Upward depths
308	10	318	10	298	Forbidden	–	Forbidden	–
309	10	319	10	299	Forbidden	–	Forbidden	–
310	10	320	10	300	Forbidden	–	Forbidden	–
311	10	321	10	301	Forbidden	–	Forbidden	–
312	10	322	10	302	Forbidden	–	Forbidden	–
313	10	323	10	303	Forbidden	–	Forbidden	–
314	10	324	10	304	Forbidden	–	Forbidden	–
315	10	325	10	305	Forbidden	–	Forbidden	–
316	10	326	10	306	Forbidden	–	Forbidden	–
317	10	327	10	307	Forbidden	–	Forbidden	–
318	10	328	10	308	Forbidden	–	Forbidden	–
319	10	329	10	309	Forbidden	–	Forbidden	–
320	10	330	10	310	Forbidden	–	Forbidden	–
321	10	331	10	311	Forbidden	–	Forbidden	–
322	10	332	10	312	Forbidden	–	Forbidden	–
323	10	333	10	313	Forbidden	–	Forbidden	–
324	10	334	10	314	Forbidden	–	Forbidden	–
325	10	335	10	315	Forbidden	–	Forbidden	–
326	10	336	10	316	Forbidden	–	Forbidden	–
327	10	337	10	317	Forbidden	–	Forbidden	–
328	10	338	10	318	Forbidden	–	Forbidden	–
329	10	339	10	319	Forbidden	–	Forbidden	–
330	10	340	10	320	Forbidden	–	Forbidden	–
331	10	341	10	321	Forbidden	–	Forbidden	–
332	10	342	10	322	Forbidden	–	Forbidden	–
333	10	343	10	323	Forbidden	–	Forbidden	–
334	10	344	10	324	Forbidden	–	Forbidden	–
335	10	345	10	325	Forbidden	–	Forbidden	–
336	10	346	10	326	Forbidden	–	Forbidden	–
337	10	347	10	327	Forbidden	–	Forbidden	–
338	10	348	10	328	Forbidden	–	Forbidden	–
339	10	349	10	329	Forbidden	–	Forbidden	–
340	10	350	10	330	Forbidden	–	Forbidden	–
341	9	350	10	331	Forbidden	–	Forbidden	–
342	8	350	10	332	Forbidden	–	Forbidden	–
343	7	350	10	333	Forbidden	–	Forbidden	–
344	6	350	10	334	Forbidden	–	Forbidden	–
345	5	350	10	335	Forbidden	–	Forbidden	–
346	4	350	10	336	Forbidden	–	Forbidden	–
347	3	350	10	337	Forbidden	–	Forbidden	–
348	2	350	10	338	Forbidden	–	Forbidden	–
349	1	350	10	339	Forbidden	–	Forbidden	–
350	Forbidden	–	Forbidden	–	Forbidden	–	Forbidden	–

5.8 - Warning regarding the water temperature at 150 msw and below

The temperature of the sea is quite hot in shallow tropical waters. Nevertheless, even at shallow depths, cold currents can be encountered in these places, which will oblige the diver to wear appropriate diving suits.
Regarding saturation diving operations, depending on the location and based on the fact that the temperature drops with the depth, the temperature of the water can be between 15 and 4 Cº, and be close to zero Cº in latitudes that are not far from the poles. As a result, efficient heating systems must be installed as if the divers are not efficiently protected they will quickly suffer from hypothermia, which is a physical condition that occurs when the body's core temperature falls below the normal 37 C° to 35 C° or cooler. Hypothermia affects the body's parts such as the brain, heart, lungs, and other vital organs. The symptoms of hypothermia are as follows:

Internal Body temperature	Symptoms
36°C Mild case	Uncontrollable shivering. Cold extremities. Needs to urinate. (Notice that not all people shiver, and some can become hypothermic without any warning)
34°C Moderate case	Impaired judgement. Fixed ideas. Confusion. Irritability. Amnesia. Slurred speech.
32°C Severe case	Shivering decreasing and replaced by muscular rigidity. Movement becoming erratic and jerky.
28°C Critical case	Irrational behaviour increasing. Stupor. Muscular rigidity increasing. Cardiac rate and respiration slowed. Casualty becoming semiconscious.
27°C	Unconsciousness. Loss of reflexes. Fixed and dilated pupils. Low or undetectable pulse. Ventricular fibrillation may occur.
25°C	Failure of cardiac and respiratory systems. Ventricular fibrillation. Death.

Note that cold water dangerously accelerates the onset and progression of hypothermia since body heat can be lost 25 times faster in cold water than in cold air.
Also, the danger is considerably greater with saturation diving, because of the very high conductivity of helium, which is six times elevated more than air, the respiratory heat loss is enormous. As a result, in the case of a diver without thermal protection, the hypothermia rates should be as follows:

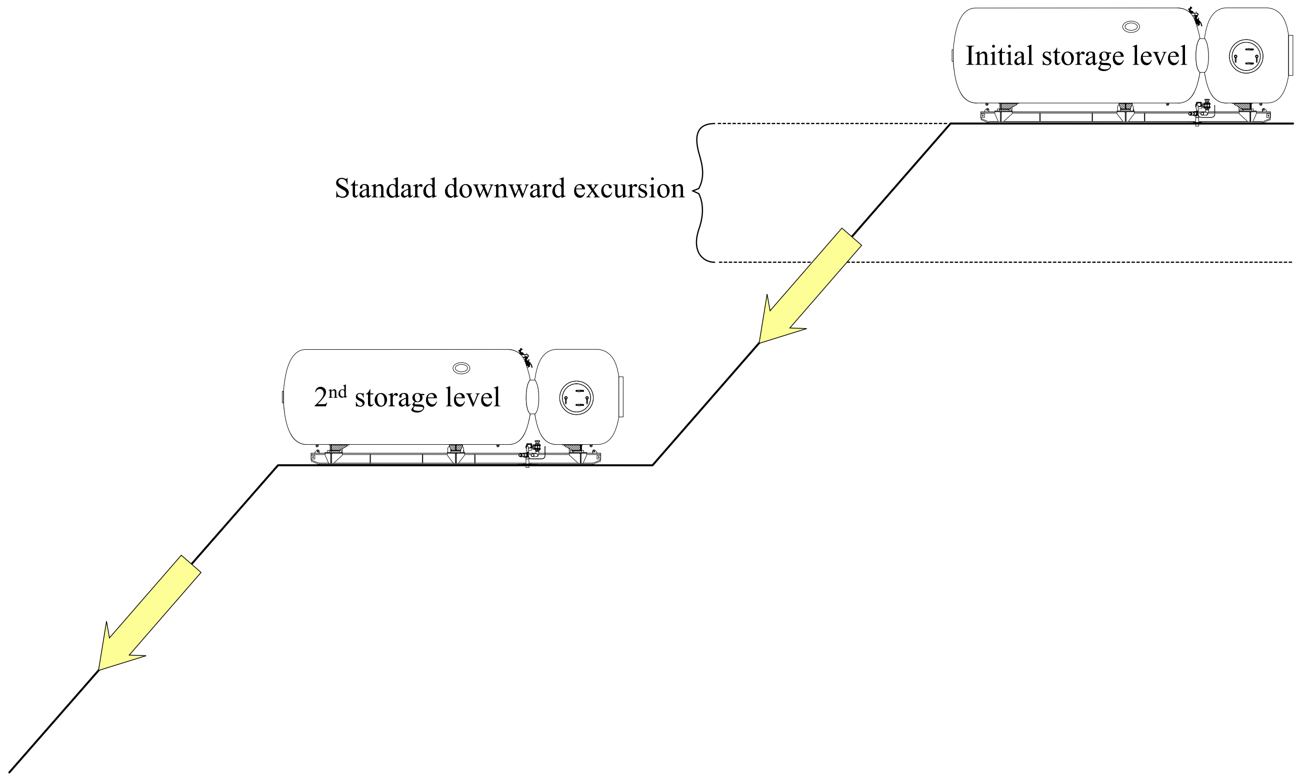
Water temp. (°C)	Loss of dexterity & intense shivering	Expected time before unconsciousness	Expected time of survival
> 27° C	2 to 12 hours	indefinitely	indefinitely
27° C	1 to 2 hrs	3–12 hours	3 hours – indefinitely
21° C	30 to 40 min	2–7 hours	2–40 hours
16° C	10 to 15 min	1–2 hours	1–6 hours
10° C	< 5 min	30–60 minutes	1–3 hours
4° C	< 3 min	15–30 minutes	30–90 minutes
1° C	< 2 min	Under 15 minutes	Under 15–45 minutes

Heating of the divers and the bellman is obtained with hot water machines that create a circulation of hot water from the surface to the bell and then from the bell to the diver's suit where it is distributed to all the areas of the body by the means of small tubes. These machines must be designed to supply sufficient hot water at the depths the operations are undertaken and should be provided with a backup. Also, the diving suits must always be in perfect condition.
According to DMAC 08 "Thermal stress in relation to diving", the comfortable skin temperature in hot-water suits was shown to be about 34°C *(Presentation Dr. Kuehn)*.
Also, IMCA D 022 point 10.4 "heating systems" of "General diving procedures," says that the breathing gas must be heated at depths deeper than 150 msw (495 fsw). As an example, at 200 msw (660 fsw), the gas should be supplied at a temperature of about 24°C (75°F). The gas is normally heated in temperature exchangers that are installed around the 2nd stage regulator of the helmet or in the scrubber of the bell.

6) Intermediate compressions

6.1 - Explanations

The 1st storage depth may be the final life level from which the operations are organized. Nevertheless, it often happens that the chamber has to be readjusted to a depth that allows reaching a workplace that is beyond the range permitted by the downward excursions from the initial storage level.
The relocation of the chamber cannot be undertaken at the speed of 10 metres/minute used by the divers during excursions and a procedure similar to the one used for the 1st pressurization must be implemented.
Two scenarios may happen that are explained in this chapter: Pressurization of the chamber during a rest period and pressurization of the chamber during a bell run.



6.2 - Pressurization of the chamber during a rest period

6.2.1 - Procedures for compressions starting within the standard saturation range

6.2.1.1 - Gas parameters

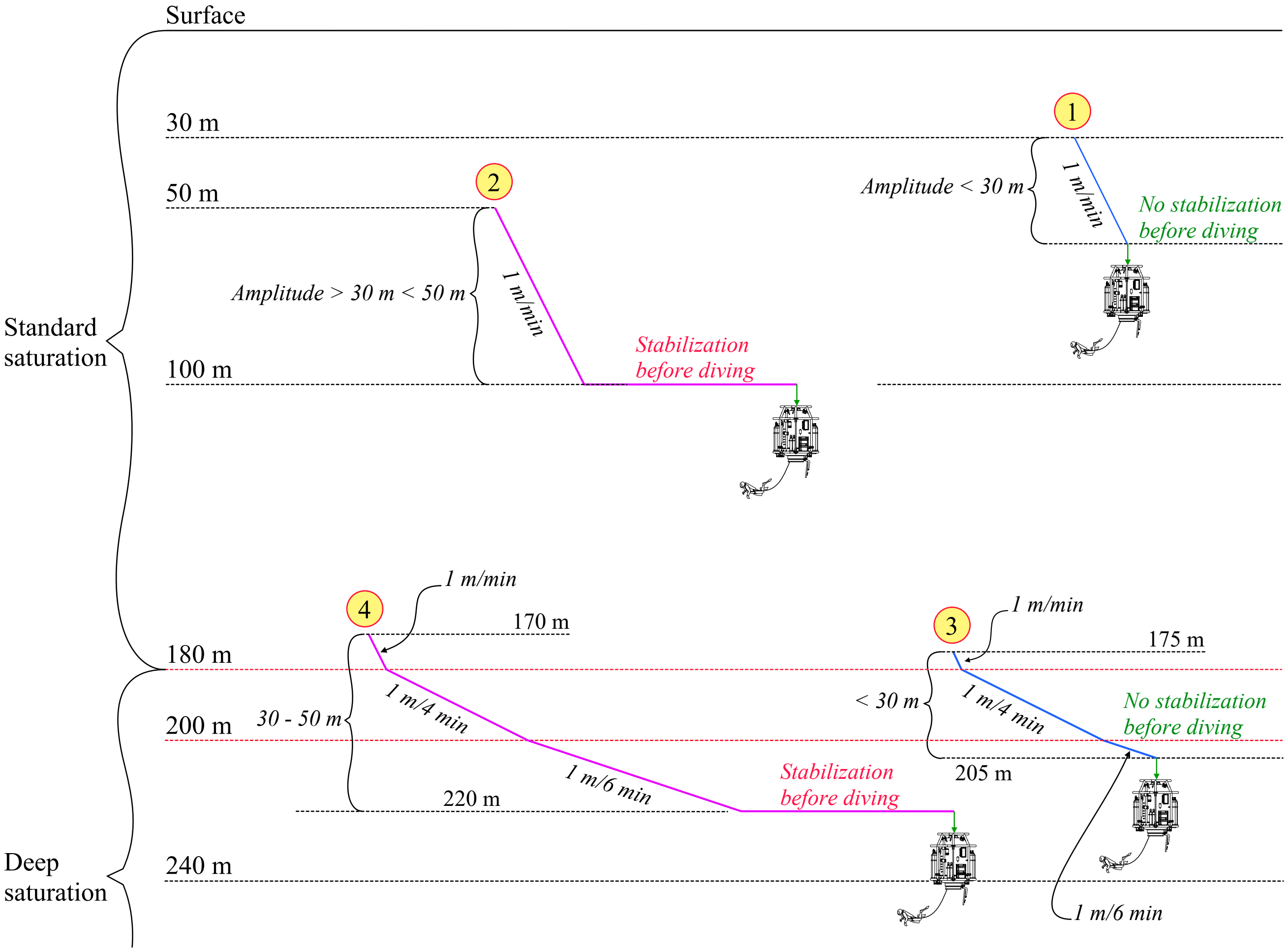
PP O2: 0.4 to 0.57 bar (400 to 570 mb)
PP CO2 : < 0.005 bar (< 5 mb)

6.2.1.2 - Pressurization speeds and stabilization stops

Amplitude of the pressurization	*Maximum compression speeds*	*Stabilization stops*
< 30 metres *Range:* from 10 m to above 210 m	- From 10 to 180 m: 1 minutes/metre - From 181 to 200 m: 4 minutes/metre - From 201 to 210 m: 6 minutes/metre	- No stabilization required, even in the case of transition to a deep saturation *(below 180 m).*
30 to < 50 metres *Range:* from 10 m to above 230 m	- From 10 to 180 m: 1 minutes/metre - From 181 to 200 m: 4 minutes/metre - From 201 to 230 m: 6 minutes/metre	- 2 hours stabilization when reaching the new saturation depth, not stopping at 200m in case of a transition to a deep saturation *(below 180 m)*.
> 50 metres *Range:* from 10 m to above 350 m	Apply the same procedure as for an initial compression: - From 10 to 180 m: 1 minutes/metre - From 181 to 200 m: 4 min/metre - From 201 to 300 m: 6 min/metre - From 301 to 350 m: 8 minutes/metre	Apply the same procedure as for an initial compression: - Depending on the final depth, apply the stabilization criteria of a standard or a deep saturation indicated in points 4.3.1, 4.3.2, and 4.3.3 - Start from the storage depth where the chamber is and apply the procedure from this point to the next depth .

The drawing below shows possible scenarios for compressions inferior to 30 m and from 30 m to less than 50 m described in the tables 6212:

- Curve #1: Compression with an amplitude less than 30 m within the limits of a standard saturation
- Curve #2: Compression with an amplitude between 30 & < 50 m within the limits of a standard saturation
- Curve #3: Compression with an amplitude less than 30 m transiting from standard saturation to deep saturation
- Curve #4: Same scenario as the curve #3 for a compression more than 30 m and less than 50 m



6.2.2 - Procedures for compressions starting within the deep saturation range

6.2.2.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb)

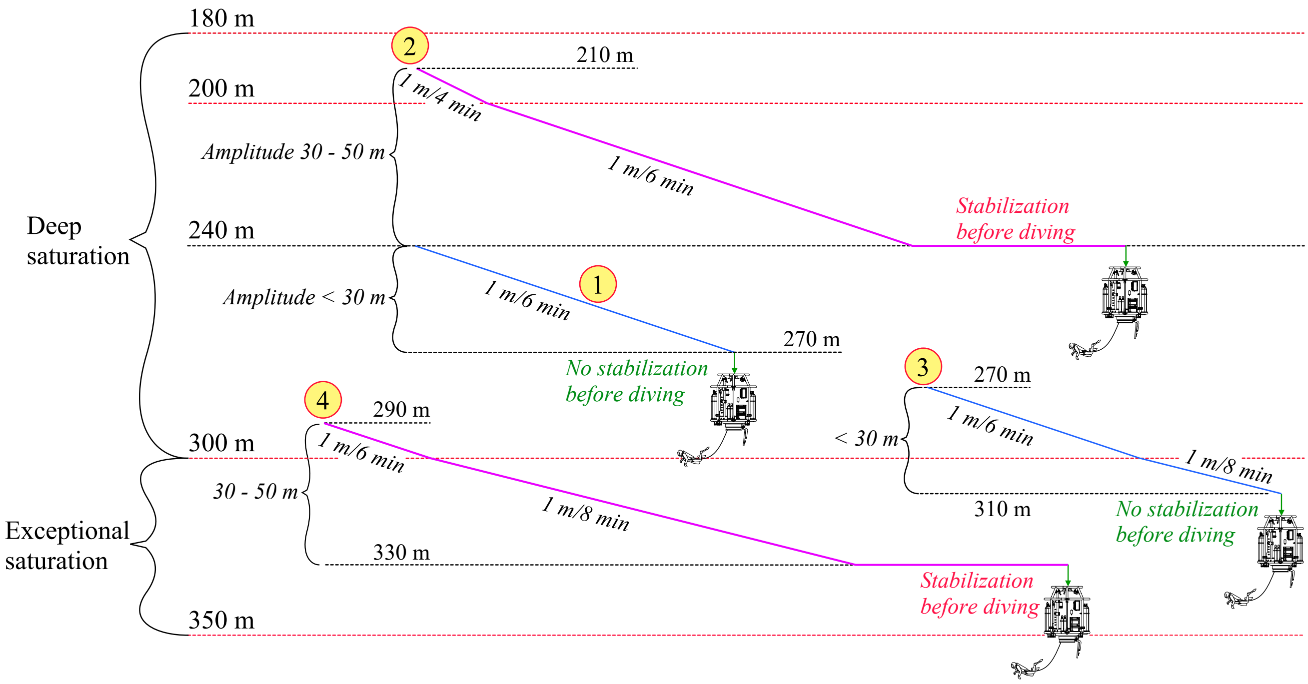
PP CO2 : < 0.005 bar (< 5 mb)

6.2.2.2 - Pressurization speeds and stabilization stops

Amplitude of the pressurization	*Maximum compression speed*	*Stabilization stops*
< 30 metres *Range:* from 181 m to above 330 m	- From 181 to 200 m: 4 minutes/metre - From 200 to 300 m: 6 minutes/metre	- No stabilization required.
31 to 50 metres *Range:* from 181 m to above 350 m	- From 181 to 200 m: 4 minutes/metre - From 200 to 300 m: 6 minutes/metre	- Two hours of stabilization when reaching the new saturation depth.
> 50 metres *Range:* from 181 m to above 350 m	Apply the same procedure as for an initial compression, but starting below 180 m: - From 181 to 200 m: 4 minutes/metre - From 200 to 300 m: 6 minutes/metre - From 300 to 350 m: 8 minutes/metre	Apply the same procedure as for an initial compression, but starting below 180 m: - Depending on the final depth, apply the stabilization criteria of a deep saturation indicated in points 4.3.2 and 4.3.3. - Start from the storage depth where the chamber is and apply the procedure from this point to the next depth .

The drawing below shows possible scenarios for compressions inferior to 30 m and from 30 m to less than 50 m described in the tables 6222:

- Curve #1: Compression with an amplitude less than 30 m within the limits of a deep saturation
- Curve #2: Compression with an amplitude 30 & < 50 m within the limits of a standard saturation
- Curve #3: Compression with an amplitude less than 30 m transiting from deep saturation to exceptional saturation.
- Curve #4: Same scenario as the curve #3 for a compression more than 30 m and less than 50 m



6.2.3 - Procedures for compressions starting within the exceptional saturation range

6.2.3.1 - Gas parameters

PP O2: 0.4 to 0.57 bar (400 to 570 mb)

PP CO2 : < 0.005 bar (< 5 mb)

6.2.3.2 - Pressurization speeds and stabilization stops

Intermediate compressions should not be done in dives with storage depth (life level) between 300 and 350. However, if it is necessary for safety reasons, the speed for pressurization and the procedures for stabilization stops should be those of the initial pressurization that can be found in point 4.3.3 or the table below.

Compression rates and stabilization in the initial compression prior to start the diving operations

Saturation depth	***Maximum compression speed***	***Stabilization stops***
300 to 350 metres	- From 300 to 350 m: 8 minutes/metre (0.125 m/minute)	Stabilization stop of least 12 hours at the saturation depth

6.2.4 - Excursions upon arrival at the storage depth

Prior to undertaking excursions, the stabilization periods for compression distances superior to 30 m that can be read in the tables in points 4.3.1 and 4.3.2 must have been completed. After this initial rest period, upward and downward excursions are possible regardless of the depth in which the saturation is.

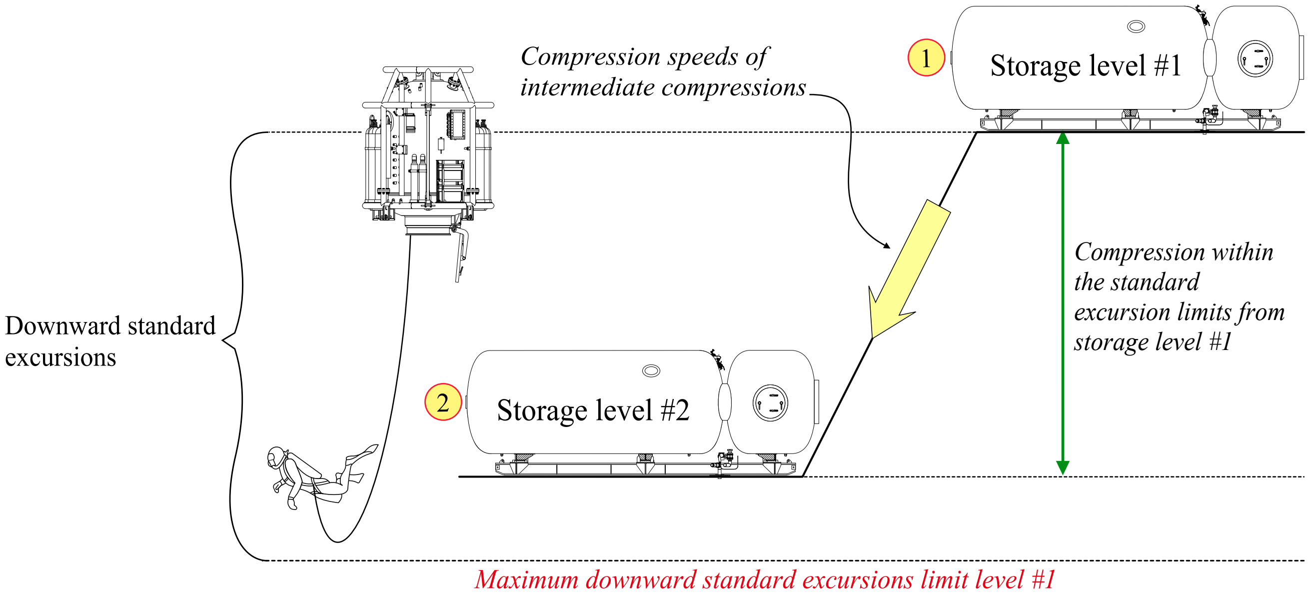
6.3 - Pressurization of the chamber during a bell run

It may happen that small readjustments of the chamber have to be performed during a bell run.

Change the chamber storage level to a deeper depth during a bell run is possible only if the new depth of the chamber is within the standard excursion limits of the divers at work.

Also, the divers at rest in the chamber must not have performed an exceptional upward excursion within the previous 12 hours.

The change of level must be performed at the compression speeds indicated in point 6.2.



Compression speeds of
intermediate compressions
1
Storage level #1
Compression within
the standard
excursion limits from
storage level #1
Downward standard
excursions
2
Storage level #2
Maximum downward standard excursions limit level #1

7) Decompression procedures

7.1 - Decompression of the chamber during normal operations

The standard procedure for decompression is the same for standard, deep and exceptional saturations.

7.1.1 - Gas values

From the beginning of decompression up to the depth in which the oxygen percentage in the chamber reaches 21%, the partial oxygen pressure of 0,48 and 0,5 bar should be kept.
From this depth, the oxygen partial pressure should decrease so that the oxygen percentage in the respiratory mixture used in the chamber is as close as possible to 21% due to the fire risk. However, note that variations up to 23% are acceptable for short periods (23% is the maximum oxygen percentage indicated in IMCA D 022).

7.1.2 - Level from where the ascent starts

NORSOK standard U 100 says in point 8.2.3.3 that a decompression shall not start with a pressure reducing (upward) excursion. This is also confirmed in the French decree of may 1992. For these reasons, we can consider that starting the decompression from the life level is the only acceptable option.

7.1.3 - Stabilization prior to start the ascent

There is no stabilization period before the ascent mentioned with NORMAM-15. However, this procedure is today suggested by several national safety organizations and applied by most reputed companies. For these reasons, a minimum of eight hours of stabilization before starting the ascent is recommended.

Also, note the following:

- NORSOK U 100/point 8.2.3.4 says: *"There shall be a minimum 8 hours hold at living depth prior to decompression after an excursion. This hold period is to be considered as part of the decompression and not the stay at living depth".*
- French decree of 15th May 1992 / page 361/ point 5.3 says: *"There should be a 12 hour hold at living depth prior to decompression at living depth after a "maximum excursion"*

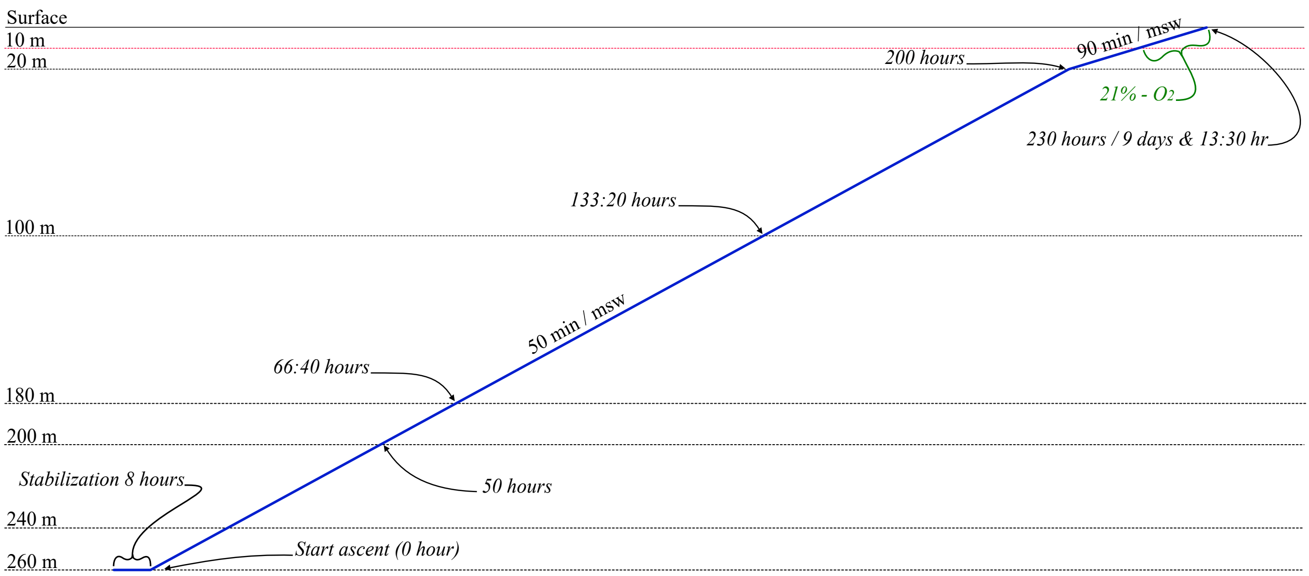
7.1.3 - Ascent speeds and profile

The decompression procedure NORMAM-15 is designed with a continuous ascent *(without stops)*.
Continuous slow ascent profiles give smooth decompressions that are appreciated by a lot of Life Support Technicians (LST), diving supervisors, and divers. The procedure proposes 2 two methods:

- Continuous speed where the gas is bleeding continuously
- Step by step, where the chamber is decompressed metre by metre

The speeds established for the different depth ranges should be met as applicable.

Depth range	*Continuous speed*	*Going up through steps*
350 to 20 msw	50 minutes/msw *(1.2 msw/hour)*	Go up 1 msw every 50 minutes
20 msw to surface	90 minutes/msw *(0.67 msw/hour)*	Go up 1 msw every 90 minutes



7.1.4 - Decompression times from various storage depths

Notes:
- The durations in days are indicated in days + decimals.
- The times below do not include the stabilization period prior to decompression.

Depth in metres	Deco. in hours	Deco. in days
10	15:00	0.625
11	15:30	0.688
12	18;00	0.75
13	19:30	0.813
14	21:00	0.875
15	22:30	0.938
16	24:00	1
17	25.3	1.063
18	27:00	1.125
19	28:30	1.188
20	30:00	1.25
21	30:50	1.285
22	31:40	1.319
23	32:30	1.354
24	33:20	1.389
25	34:10	1.424
26	35:00	1.458
27	35:50	1.43
28	36:40	1.528
29	37.3	1.563
30	38:20	1.597
31	39:10	1.632
32	40:00	1.667
33	40:50	1.701
34	41:40	1.736
35	42:30	1.771
36	43:20	1.806
37	44:10	1.84
38	45:00	1.875
39	45:50	1.91
40	46:40	1.944
41	47:30	1.979
42	48:20	2.014
43	49:10	2.049
44	50:00	2.083
45	50:50	2.118
46	51:40	2.153
47	52:30	2.188
48	53:20	2.222
49	54:10	2.257
50	55:00	2.292
51	55:30	2.326
52	56:40	2.361
53	57:30	2.393
54	58:20	2.431
55	59:10	2.465
56	60:00	2.5
57	60:50	2.535
58	61.4	2.569
59	62:30	2.604
60	63.2	2.639
61	64:10	2.674
62	65:00	2.708
63	65:50	2.743
64	66:40	2.778
65	67:30	2.813
66	68:20	2.847
67	69:10	2.882
68	70:00	2.917
69	70:50	2.951
70	71:40	2.986
71	72:30	3.021
72	73:20	3.056
73	74:10	3.09
74	75:00	3.125
75	75:50	3.16
76	76:40	3.194
77	77:30	3.229
78	78:20	3.264
79	79:30	3.299
80	80:00	3.333
81	80:50	3.368
82	81:40	3.403
83	82:30	3.438
84	83:20	3.472
85	84:10	3.507
86	85:00	3.542
87	85:50	3.576
88	86:40	3.611
89	87:30	3.646
90	88:20	3.618
91	89:10	3.715
92	90:00	3.75
93	90:50	3.785
94	91:40	3.819
95	92:30	3.854
96	93:20	3.889
97	94:10	3.924
98	95:00	3.958
99	95:50	3.993
100	96:40	4.028
101	97:30	4.063
102	98:20	4.097

Depth in metres	Deco. in hours	Deco. in days
103	99:10	4.132
104	100:00	4.167
105	100:50	4.201
106	101:40	4.236
107	102:30	4.271
108	103:20	4.306
109	104:10	4.34
110	105	4.375
111	105:50	4.41
112	106:40	4.444
113	1107:30	4.479
114	108:20	4.514
115	109:10	4.549
116	110:00	4.583
117	110:50	4.618
118	111:40	4.653
119	112:30	4.688
120	113:20	4.722
121	114:10	4.757
122	115:00	4.792
123	115:50	4.826
124	116:40	4.861
125	117:30	4.896
126	118:20	4.931
127	119:10	4.965
128	120:00	5
129	120:50	5.035
130	121:40	5:069
131	122:30	5.104
132	123:20	5.139
133	124:10	5.174
134	125:00	5.208
135	125:50	5.243

Depth in metres	Deco. in hours	Deco. in days
136	126:40	5.278
137	127:30	5.313
138	128:20	5.347
139	129:10	5.382
140	130:00	5.417
141	130.5	5.451
142	131:40	5.486
143	132:30	5.521
144	133.2	5.556
145	134:10	5.59
146	135:00	5.625
147	135:50	5.66
148	136:40	5.694
149	137:30	5.729
150	138:20	5.764
151	139:10	5.799
152	140:00	5.833
153	140:50	5.868
154	141:40	5.903
155	142:30	5.938
156	143:20	5.972
157	144:10	6.007
158	145:00	6.042
159	145:50	6.076
160	146:40	6.111
161	147:30	6.146
162	148:20	6.181
163	149:10	6.215
164	150:00	6.25
165	150:50	6.285
166	151:40	6.319
167	152:30	6.354
168	153:20	6.389

Depth in metres	Deco. in hours	Deco. in days
169	154:10	6.424
170	155:00	6.458
171	155:50	6.493
172	156:40	6.528
173	157:30	6.563
174	158:20	6.597
175	159:10	6.632
176	160:00	6.667
177	160:50	6.701
178	161:40	6.736
179	162:30	6.771
180	163:20	6.806
181	164:10	6.84
182	165:00	6.875
183	165:50	6.91
184	166:40	6.944
185	167:30	6.679
186	168:20	7.014
187	169:10	7.049
188	170:00	7.083
189	170:50	7.118
190	171:40	7.153
191	172:30	7.188
192	173:20	7.222
193	174:10	7.257
194	175:00	7.292
195	175:50	7.326
196	176:40	7.361
197	177:30	7.396
198	178:20	7.431
199	179:10	7.465
200	180:00	7.5
201	180:50	7.535

Depth in metres	***Deco. in hours***	***Deco. in days***
202	181:40	7.569
203	182:30	7.604
204	183:20	7.639
205	184:10	7.674
206	185:00	7.708
207	185:50	7.743
208	186:40	7.778
209	187:30	7.813
210	188:20	7.847
211	189:10	7.88
212	190:00	7.917
213	190:50	7.951
214	191:40	7.986
215	192:30	8.021
216	193:20	8.056
217	194:10	8.09
218	195:00	8.125
219	195:50	8.16
220	196:40	8.194
221	197:30	8.229
222	198:20	8.264
223	199:10	8.299
224	200:00	8.333
225	200:50	8.368
226	201:40	8.403
227	202:30	8.438
228	203:20	8.472
229	204:10	8.507
230	205:00	8.542
231	205:50	8.576
232	206:40	8.611
233	207:30	8.646
234	208:20	8.681

Depth in metres	***Deco. in hours***	***Deco. in days***
235	209:10	8.715
236	210:00	8.75
237	210:50	8.785
238	211:40	8.819
239	212:30	8.854
240	213:20	8.889
241	214:110	8.924
242	215:00	8.958
243	215:50	8.993
244	216:40	9.028
245	217:30	9.063
246	218:20	9.097
247	219:10	9.132
248	220:00	9.167
249	220:50	9.201
250	221:40	9.236
251	222:30	9.271
252	223.2	9.306
253	224:10	9.34
254	225:00	9.375
255	225:50	9.41
256	226:40	9.444
257	227:30	9.479
258	228:20	9.514
259	229:10	9.549
260	230:00	9.583
261	230:50	9.618
262	231:40	9.653
263	232:30	9.688
264	233:20	9.722
265	234:10	9.757
266	235:00	9.792
267	235:50	9.826

Depth in metres	***Deco. in hours***	***Deco. in days***
268	236:40	9.861
269	237:30	9.896
270	238:20	9.931
271	239:10	9.965
272	240:00	10
273	240:50	10.035
274	241:40	10.069
275	242:30	10.104
276	243:20	10.139
277	244:10	10.174
278	245:00	10.208
279	245:50	10.243
280	246:40	10.278
281	247:30	10.313
282	248:20	10.347
283	249:10	10.382
284	250:00	10.417
285	250:50	10.451
286	251:40	10.486
287	252:30	10.521
288	253.2	10.556
289	254:10	10.59
290	255:00	10.625
291	255:50	10.66
292	256:40	10.694
293	257:30	10.729
294	258:20	10.764
295	259:10	10.799
296	260:00	10.833
297	260:50	10.868
298	261:40	10.903
299	262:30	10.938
300	263:20	10.972

Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days	Depth in metres	Deco. in hours	Deco. in days
301	264:10	11.007	316	276:40	11.528	331	289:10	12.049
302	265:00	11.042	317	277:30	11.563	332	290:00	12.083
303	265:50	11.076	318	278:20	11.597	333	290:50	12.118
304	266:40	11.111	319	279:10	11.632	334	291:40	12.153
305	267:30	11.146	320	280:00	11.667	335	292:30	12.188
306	268:20	11.181	321	280:50	11.701	336	293:20	12.222
307	269:10	11.215	322	281:40	77.736	337	294:10	12.257
308	270:00	11.25	323	282:30	11.771	338	295:00	12.292
309	270:50	11.285	324	283:20	11.806	339	295.5	12.326
310	271:40	11.319	325	284:10	11.84	340	296:40	12.361
311	272:30	11.354	326	285:00	11.875	341	297:30	12.396
312	273:20	11.389	327	285:50	11.91	342	298:20	12.431
313	274:10	11.424	328	286:40	11.944	343	299:10	12.465
314	275:00	11.458	329	287:30	11.979	344	300:00	12.5
315	275:50	11.493	330	288:20	12.014	345	300:50	12.535

7.2 - Decompress the chamber during a bell run

It may happen that small upward readjustments of the chamber have to be performed.
However, we must keep in mind that NORSOK standard U 100 says that "a decompression shall not start with a pressure reducing (upward) excursion", and that this point is also confirmed in the French decree of May 1992.
For these reasons, the chamber should never be decompressed during a bell run.

7.3 - Control the divers during the decompression

The controls to be in place during the saturation operations that are listed in point 4.3 must continue until the full completion of the dive. The following points should be kept in mind

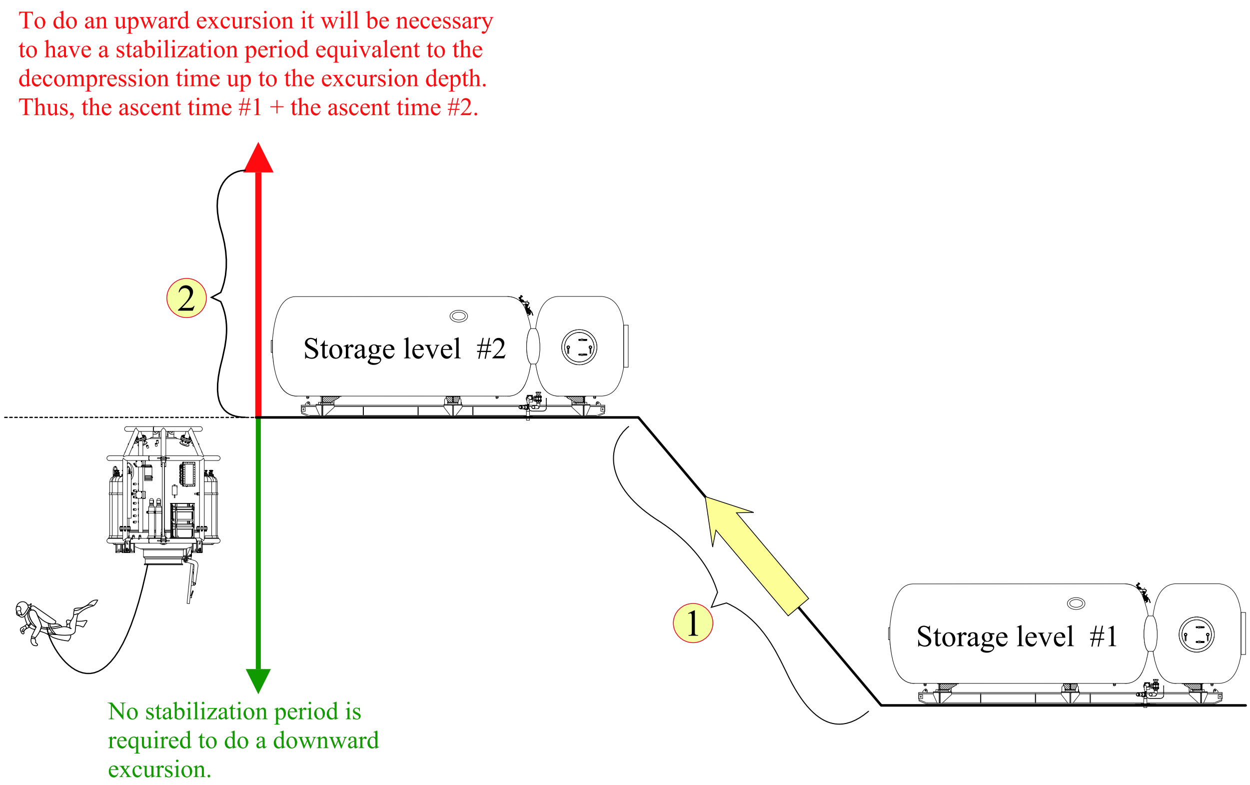
- The divers should be encouraged to perform some light physical activity and report any suspicious event.
- BIBS should be available with the relevant gas at any time.
- Remember that facilities such as toilets cannot be used when the chamber arrives close to the surface.

7.4 - Excursions after an intermediate decompression

NORMAM-15 says:
After an intermediate decompression, no stabilization period is required to do a downward excursion upon arrival at the new depth.
However, to do an upward excursion, it will be necessary to have a stabilization period equivalent to the decompression time up to the excursion depth. In other words, the stabilization period must be equal to time needed to reach the shallower storage level (level #2) at an ascent speed of 50 minutes/metre (or 90 min/metre above 20 m) plus the time that should be necessary to reach the upper level of the planned excursion at the same speed.

Notes:

- After an ascent to a new storage depth, there is an increased risk of a decompression accident which will last several days. Thus, the upward excursions should be avoided or minimised for several days.
- As indicated in point 5.4 "*Recommendations for organizing bell runs and excursions",* it is preferable to establish a shallower storage depth rather than perform a series of repetitive upward excursions.



7.5 - Accelerated decompression

As for all saturation procedures, the recommended decompression process of NORMAM-15 is slow. For this reason, a Hyperbaric Rescue Unit (HRU) which is the means for escaping the system, described in chapter 4.5 of this Book, is usually connected to the system and ready to accommodate and evacuate the divers. The divers and the supporting team must be regularly trained to launch this system and recover it on the accompanying boat, which will transfer it to Hyperbaric Reception Facility where the decompression will be undertaken in the best manner. However, it may happen that in some extreme situations, the use of the hyperbaric rescue chamber is not possible. For this reason, ultimate methods of decompression have been thought to recover the divers to the surface when a critical situation has happened that has resulted that the team in saturation having to be retrieved from the system as soon as possible or being stuck in it without any possibility of escape. Of course, these methods should be used only when the diving team is dealing with a life-or-death situation and should never be used in another condition.
Two documents that describe suitable procedures have been published that should be taken into account to plan for an efficient response to such undesirable events:

- DMAC 31 *"Accelerated emergency decompression (AED) from saturation"*, published by the Diving Medical Advisory Committee (DMAC).
- *"A review of accelerated decompression from heliox saturation in commercial diving emergencies",* published by Jean-Pierre Imbert, and doctors Jean-Yves Massimelli, Ajit Kulkarni, Lyubisa Matity, and Philip Bryson.

7.5.1 - About DMAC 31

DMAC 31 has been published in March 2013, and is based on the conclusion of a workshop held on 13 April 2011 in London (UK), to consider the issues involved in rapid decompression from saturation. This paper, called *"Accelerated emergency decompression from saturation in commercial diving operations"* is available free of charge with DMAC 31 on DMAC's website (https://www.dmac-diving.org/guidance/).
The DMAC says that the knowledge underlying the guidance is limited, that the objective of this guidance is to reduce mortality, and it is recognized that there may be a high risk of injury.
The DMAC also says the following:

- A risk evaluation exercise should be conducted in any circumstance in which the safety of divers in a decompression chamber system is put at risk as a result of fire or mechanical damage to the vessel or chamber system, which may result in loss of the vessel (sinking) or inability to provide continued support to the divers under pressure. Such circumstances have the potential to result in multiple fatalities amongst the divers.
- The chances of an emergency situation resulting in fatalities may range from a possibility to an absolute certainty. Both level of risk and the timescale of progression of an emergency situation are difficult to assess but prediction of the outcome is likely to be more accurate as time progresses.
- Actions to remove the divers to safety need to be considered at the earliest stage possible.
- Emergency decompression will carry a relatively lower risk when storage depth is shallow, divers have made no recent excursions (i.e. within 24 hours) and when there is a longer time window of opportunity in which to conduct the decompression.

- In using an accelerated decompression it will always be safer to reduce the rate of decompression (or stop and recompress) in the event that the emergency resolves, than to speed up the rate of decompression if the emergency scenario progresses more rapidly than anticipated.
- Regarding chamber decompression issues:
  - The decompression should be planned to take place at the slowest rate consistent with a safe evaluation of the emergency timescale.
  - In planning a rapid decompression the selection of either a linear decompression or commencing with an upward excursion (1 msw per minute) should take into account the divers' recent excursion dive (pressure profile) exposure.
  - During the decompression a high PPO_2 in the divers' breathing gas is advantageous.
  - The level of PPO_2 selected will depend on anticipated duration of exposure. At deeper depths, the chamber PPO_2 could be raised to 1.0 - 1.5 ata.
  - Use of a built-in breathing system (BIBS) would be required for higher PPO_2 mixtures and at shallow depths.
  - Decompression rates as fast as 10 - 20 msw per hour using a high PPO_2 may be possible with divers who have not done any excursion in the previous 24 hours.
  - Breathing a high PPO_2 gas mixture before starting decompression may be helpful if the opportunity exists without reducing total time available for decompression.
  - All attempts should be made to obtain assistance from another dive vessel with chamber facilities for the recompression of divers completing decompression at the earliest available opportunity.
  - Maintaining adequate hydration is considered important. This will require an adequate oral fluid intake. Some advocate the administration of higher volumes of fluid by mouth or by intravenous route if practical.
  - The volumes taken or administered will be dependent on the duration of the decompression, but oral intakes as high as 1 litre per hour might be reasonable during a short decompression.
  - For oral hydration water or oral rehydration mixture should be locked into the chamber shortly before use.
  - Thermal control of the chamber should be maintained.
  - If environmental control is compromised, this may increase the risk of the procedure.
  - Where practical, divers should be encouraged to move around but not undertake vigorous exertion during the decompression.
  - There is no human evidence that any drug would offer benefits but analgesia may be valuable. "Glyceryl trinitrate", "non-steroidal anti-inflammatory agents", and "clopidogrel" may all offer some advantage in protection against decompression illness and can be used in the case of an accelerated decompression.
    - "Glyceryl trinitrate" is a nitrate used for chest pain associated with angina. It is also sold under the names of various registered brands.
    - "Non-steroidal anti-inflammatory agents" (NSAID) are a group of medicines that relieve pain and fever and reduce inflammation. They are used to treat mild-to-moderate pain that arises from a wide range of conditions such as headaches, menstruation, migraines, osteoarthritis, or rheumatoid arthritis, sprains and strains, and toothache. Note that the well known "Aspirin" is a NSAID that is also used in small doses to lower the risks of having a heart attack or a stroke caused by a blood clot.
    - "Clopidogrel" prevents platelets in the blood from sticking together to form an unwanted blood clot that could block an artery. Clopidogrel is used to lower the risk of having a stroke, blood clot, or serious heart problem after a heart attack, severe chest pain (angina), or circulation problems.
  - Access to analgesia, antiemetics *(drugs that are used against vomiting and nausea)*, surface oxygen therapy, and a re-compression facility should be in place.

As suggested above, ascent rates of 10 and 20 msw/h are extreme. As a comparison, an ascent from 100 m at 10 msw/hour should take only 10 hours, while the decompression from a heliox dive at this depth using the MT92 heliox 10-12% closed bell decompression table 102 m/120 minutes, displayed in the appendix of this handbook, requires 22:35 hours decompression, and that 10:57 hours is the decompression time using the same set of tables for 45 minutes exposure at this depth.

7.5.2 - About the paper "A review of accelerated decompression from heliox saturation in commercial diving emergencies"

This paper, which has been published through the National Library of Medicine/Diving and Hyperbaric Medicine - Volume 52 (https://www.ncbi.nlm.nih.gov/pmc/journals/3469/) the 4th of December 2022, assesses the benefit of emergency decompression, and provides guidelines, using a collection of data from the authors' direct experience and networks, providing witness or first-hand information. It can be downloaded from our website (click here) and offers detailed step-by-step descriptions of the events summarized below.

- Bell evacuations with emergency decompression:

- "Discovery one", Comex, Nigeria - 1975 *(Source: Michel Plutarque - Comex)*:
  This case discusses 2 divers decompressing in the diving system following a bell bounce dive to 90 msw. Due to the barge abandonment following a drilling incident, they were transferred to the bell, which was fully disconnected from the system, and hanged under a supply boat The bell was recovered on deck one day later,

and the decompression of the divers was completed in the bell at Port Harcourt.

- "Taipan one", Comex, Gabon - 1982 *(Source: Archives Comex)*:
  Discusses the story of a bell dropped to the bottom at 30 m depth after a fire onboard the barge. The bell was recovered 24 hours later and reconnected to a saturation system where the divers were decompressed normally.
- "Garupa PGP-1 Platform", Comex - Marsat, Brazil - 1985 *(Source: J. F. Irrmann - Comex)*:
  The "Garupa PGP-1 Platform" had to be abandoned following a gas leak, and only essential personnel remained on site with four divers at 126 msw in the saturation system. The divers' evacuation was organized by wet transfer from bell to bell with a nearby DSV equipped with a saturation system.

- Bell emergency evacuations with accelerated decompression:

- "Norjarl Semi Sub", Oceaneering, North Sea - 1981 *(Source: Dr Philip James)*:
  The "Norjarl barge" started to list following a collision with a supply boat. Four divers were in the dive system at a storage depth of 87 msw. It was decided to accelerate their decompression using a chamber PO2 of 75 kPa and an ascent rate three times faster than the standard company procedure while the barge was towed to the shore. During the transfer, a storm threatened the safety of the barge, and it was decided to reach 18 msw and finish the decompression with a US Navy Table 6. Fortunately, the weather improved, and the decompression was completed without applying the USN table 6.
- "Sedco Phillips Semi Sub", Oceaneering, Ekofisk Field, North Sea - 1981 *(Source: Dr Philip James)*:
  In November 1981, the semi-sub barge "Sedco Phillips" was operating with Oceaneering in the Ekofisk field with eight divers in saturation at a depth of 70 msw. A storm hit the barge, and the situation became critical. As the Hyperbaric Rescue Unit (HRC) could not be launched, it was decided to decompress the divers using the same principle of accelerated decompression as the Norjarl event described above.
- "Transworld 58 Semi Sub", Argyll Field, North Sea - 1981 *(Source: Dr Philip James)*:
  During the same November 1981 storm, the "Transworld Rig 58" broke all anchor lines and drifted for several hours. Four divers in saturation at 30 msw were decompressed in an emergency, starting with an upward excursion to 18 msw at 6 msw/min. The decompression then proceeded at 1.2 msw/h to the surface with a progressive gas switch from heliox to air.
- "DLB 269", McDermott, Mexico - 1995 *(Source: Michael Krieger)*:
  The Barge "DLB 269" was doing a tie-in at 48 msw depth when a tropical storm that turned into a hurricane hit it. The barge master decided to face the storm with two tugs pulling the barge to maintain position. The divers' decompression was initiated with standard procedures. Then, as the weather worsened, the divers were decompressed via an emergency procedure (Ascent rate of 1.5 m/h). The divers surfaced in the middle of the storm without any symptoms. The following day, the hurricane hit the barge again and sank it, resulting in six fatalities.

Norjarl emergency decompression		
Depth (msw)	***Gas breathed***	***Ascent rate***
63 to 49.5	*Chamber: 0.8 bar PO_2*	*7.8 m/h*
49.5 to 18	*Chamber: 0.8 bar PO_2*	*3.6 m/h*
18 to 0	*Chamber: 23 % O_2*	*1.8 m/h*
Note: *The authors provide the partial pressures in kilo Pascals (kPa). For convenience, I have displayed these values in bar: 1 bar = 100,000 Pascals = 100 kPa*		

DLB 269 emergency decompression			
Depth (msw)	***Gas breathed***	***Ascent rate***	***comments***
30 to 20	*Chamber: HeO_2 - 0.6 bar PO_2*	*1.2 m/h*	*Normal deco. 16 h ascent per day*
20 to 10	*BIBS periods 20/5 BIBS: HeO_2 - 50% O_2*	*1.5 m/h*	*Starting decompression*
10 to 3	*BIBS periods 20/5 BIBS: 100 % O_2*	*1.5 m/h*	
3	*Chamber atmosphere*	*Hold*	*110 min. Stop*
3 to 0	*BIBS continuous BIBS: 100 % O_2*	*Unknown*	*Described as a slow ascent*
Surface	*BIBS periods 10 min 100% O_2/20 min air for 6 hours*	*Hold*	

- "S. Suraksha", Bombay High Field, India - 2005 *(Source: Dr Ajit Kulkarni)*:
  During the transfer of a cook who cut his finger to a platform by basket, the "S. Suraksha" hit a riser resulting in the platform and the vessel catching fire. Six divers who were in saturation at 28 & 42 msw were pressurized to 85 msw, the deepest depth of the field, to be evacuated with the Self Propelled hyperbaric Lifeboat (SPHL). Nevertheless, the SPHL was found in flames, and the power supply of the chamber failed. As a result of the fire progressing, the supporting team was forced to abandon the vessel, and the divers, provided with fluids and food, managed to decompress themselves to 54 msw using the bilge valve. When the fire calmed down during the night, the diving support team of another vessel, the "S. Prabha", which had been fighting the fire, boarded the S. Suraksha and managed the divers' decompression and food. The decompression continued until 23 msw when the supportive team had to abandon the vessel again. The divers were instructed to decompress at 3 msw/h. The supporting team returned on board when possible, organized the divers' recovery to the surface, and transferred them to 30 msw in the saturation system of the "S. Prabha", where a standard decompression was performed according to the US Navy procedures. It is not indicated whether a stabilization period has been performed at 30 msw prior to the final decompression.

Sequence No	Depth (msw)	Gas breathed	Ascent rate	comments
0	0 to 85 msw			Two separate teams of divers compressed to the deepest operating depth in the area
1	85 to 54	Chamber: HeO_2 6% O_2 (uncertain)	4 to 5 m/h	Empirical decompression carried out by the divers
2	54 to 34	Chamber: HeO_2 8% to 12% O_2	2.5 m/h	Decompression during the night, under the control of the LSTs on site. No power, no scrubber, divers on emergency rebreather
3	34	Chamber: HeO_2 12% O_2	Hold	Eight hour hold decided by Dr Kulkarni
4	34 to 23	Chamber: HeO_2 16% O_2	1.2 m/h	Standard decompression performed by LSTs
5	23 to 11	Chamber: 0.6 bar PPO_2	3 m/h	Decompression performed by the divers
6	11	Chamber: HeO_2 20% O_2	Hold	Decision to transfer. Stop for 45 min waiting on the S. Prabha to prepare for divers' reception
7	11 to 2.4	BIBS: 100% oxygen	1 m/min	8.6 min from 11 to 2.4 msw
8	2.4 to 1	BIBS: 100% oxygen	0.16 m/min	10 min from 2.4 to 1 msw
9	1 to surface	BIBS: 100% oxygen	0.08 m/min	12 min from 1 msw to surface
10	Surface			Divers transferred to the S. Prabha
11	0 to 30 m			Recompression to 30 m - One case of knee pain in one diver relieved on arrival at 30 msw. Decompression according to USN procedure.

- Barge Resolute, East Java, Indonesia - 2013 *(Sources: Doctors Bryson and Massimelli)*:
Due to adverse weather conditions, the resolute barge lost anchors while six divers were stored at 45 msw and three others under compression were at 28 msw. These three divers were in the Hyperbaric Rescue Unit (HRC) used as a living chamber. Containers and heavy gas cylinders had been wiped out by the waves and were crushing other deck equipment. The dive control station was flooded. While the rest of the barge's crew were already at the muster station preparing to abandon ship. All the divers were transferred in the HRC that was compressed to 80 msw (76 msw after cooling) and prepared for launching. However, it appeared that the launching of the HRC was impossible. When the barge's condition has been stabilized following the intervention of an anchor handler, the HRC has been reconnected to the system. An emergency decompression has been initiated after 4 - 5 hours of hold. The divers arrived on deck without signs of DCS.

Sequence No	Depth (msw)	Gas breathed	Ascent rate	comments
1	76 to 55	Chamber: HeO_2 0.6 bar oxygen	7.8 m/h (average)	Ascent of 21 msw performed in 2 h 42 min
2	55 to 43	Chamber: 0.6 bar oxygen BIBS heliox: 20% O_2	5 m/h	Decompression 5 BIBS sessions 20/5
3	43 to 20	Chamber: 0.6 bar oxygen BIBS heliox: 35% O_2	5 m/h	Decompression 2 BIBS sessions 20/5 7 BIBS sessions 25/5
4	20	Chamber: 0.6 bar oxygen BIBS heliox: 50% O_2	Hold	3 h 35 min hold 2 BIBS sessions 25/5
5	20 to 16	Chamber: 0.6 bar oxygen	1	Decompression
6	16 to 10	Chamber: HeO_2 23% oxygen	1	Decompression
7	10	Chamber: 23% oxygen BIBS gas: 100% O_2	Hold	5 h hold 3 BIBS sessions 25/5
8	10 to surface	Chamber: 23% oxygen	0.5	Decompression After 4 h on chamber gas 20 min on BIBS 100% O_2 every 2 h to surface. No DCS symptoms reported

The authors also made a review of the following accelerated decompression procedures. The texts below are those of the guideline:

- Early COMEX saturation decompression procedures:
  In the early 1970s, decompressions that were considered as standard procedures appear today as excessively fast ascents.
  Unfortunately, the procedures at the time were a mixture of bounce and saturation diving and cannot be directly translated into modern practice. However, some profiles provide useful references to what can be done in terms of rapid decompression.
  In 1974, Comex published their first set of original heliox saturation procedures that were used until 1979. The ascent could be initiated by a 10 msw upward excursion depending on the last dive interval. Decompression was continuous over 24 hours. Chamber oxygen was controlled to a PO_2 of 60 kPa when deeper than 15 msw, and then adjusted to an inspired fraction (FO_2) of 24% when shallower. It took five days and 16 hours to decompress from 280 msw storage depth to surface (see the table below).
  The overall safety performance based on data from the Comex database indicated a DCS risk of 5 to 10%; all symptoms were related to joint pain occurring in the last 10 msw of ascent.

Depth (msw)	*Chamber gas*	*Ascent rate (min per msw)*	*Ascent rate (Msw per hour)*
280 to 240	*PO_2 = 0.6 bar (60 kPa)*	*20*	*3*
240 to 160		*25*	*2.4*
160 to 80		*30*	*2*
80 to 20		*35*	*1.7*
20 to 15		*40*	*1.5*
15 to 10	*FO_2 = 24%*	*40*	*1.5*
10 to 5		*45*	*1.3*
5 to surface		*50*	*1.2*

- US Navy 2016 emergency abort procedures:
  Revision 7 of the US Navy diving manual, 12 paragraph 13.23.7.2, provides a specific procedure for emergency abort decompression, defined for serious life-threatening emergency, however, no information is provided on its validation. The emergency ascent includes several phases: an initial upward excursion, a hold, and an accelerated decompression (see below this table converted in metric).
  The ascent rates are defined according to the starting depth, which decides the chamber PO2. These ascent rates appear very slow compared to the emergency situations studied and seem of little practical use.
  Note: The authors also say that they could not find any instance when these procedures were used.

Depth (msw)	*Chamber gas*	*Ascent rate or duration*
Decompression from 306.4 to 83.7 msw with 0.6 bar (60 kPa) chamber PO_2		
306.4 to 61.3	*PO_2 = 0.6 bar (60 kPa)*	*1.53 msw·h*
61.3 to 16.1		*0.88 msw·h*
16.1 to 1.2	*FO_2 = 23%*	*0.88 msw·h*
1.2 to surface		*4 min*
Decompression from 83.4 to 62.5 msw with 0.7 bar (70 kPa) chamber PO_2		
83.4 to 61.3	*PO_2 = 0.7 bar (70 kPa)*	*1.67 msw·h -*
61.3 to 20.4		*0.97 msw·h*
20.4 to 1.2	*FO_2 = 23%*	*0.97 msw·h*
1.2 to surface		*1.02 msw·h*
Decompression from ≤ 62.2 msw with 0.8 bar (80 kPa) chamber PO_2		
62.2 to 61.3	*PO_2 = 0.8 bar (80 kPa)*	*1.67 msw·h*
61.3 to 24.8		*1.02 msw·h*
24.8 to 1.2	*FO_2 = 23%*	*1.02 msw·h*
1.2 to surface		*4 min*

- Italian accelerated decompression procedures:
  An accelerated decompression procedure can be found in the Italian UNI 11366 diving regulations. The procedure has continuous decompression varying with depth and constant chamber PO_2 until 18 msw when the chamber is flushed with air to change from helium to nitrogen (see below).
  Note: As for the US Navy procedures, the authors say: *"We could not find any instance when these procedures were used"*.

Depth (msw)	***Chamber gas***	***Ascent rate (msw * h)***
180 to 90		*3*
90 to 30	*PO_2 = 0.65 bar (65 kPa)*	*2.4*
30 to 18		*1.2*
18 to surface	*Air flushing to never exceed an FO_2 of 23.5%*	*0.6*

- COMEX emergency decompression procedure
  In the 1994 revision of its diving manual, COMEX introduced an accelerated decompression procedure that provided three options depending on the starting depth. These procedures were based on a higher level of chamber PO_2, and thus allowed faster ascent rates. Considering pulmonary oxygen toxicity as the limiting factor, the PO_2 selected controlled the maximum decompression time, and therefore the depth of use. Three depth ranges were proposed: 70 msw, 90 msw and 130 msw, with their respective chamber PO_2. For an emergency deeper than 130 msw, the only possibility was to decompress the divers to 130 msw using standard saturation decompression and then consider the possibility of using an accelerated decompression to the surface.
  An option was available where decompression could be further accelerated by putting the divers on a higher FO_2 via the built-in breathing system (BIBS) during the last 10 msw of the ascent to the surface. The ascent rate could be increased to 60 min per msw.
  Note: The authors also say: *"To our knowledge, these procedures have never been used by COMEX"*.

Depth (msw)	***Chamber gas***	***Ascent rate (msw * h)***
Decompression from not deeper than 130 msw		
130 to 16	*PO_2 = 0.6 bar (60 kPa)*	*1.4*
16 to surface	*FO_2 23%*	*0.6*
Decompression from not deeper than 90 msw		
90 to 20	*PO_2 = 0.7 bar (70 kPa)*	*1.6*
20 to 15	*FO_2 23%*	*1.2*
15 to surface	*FO_2 23%*	*0.6*
Decompression from not deeper than 70 msw		
70 to 25	*PO_2 = 0.8 bar (80 kPa)*	*1.7*
20 to 15	*FO_2 23%*	*1.2*
15 to surface	*FO_2 23%*	*0.6*

The authors say the following about the events and procedures presented above:

- The events:
  The weather was clearly a critical factor in four out of the six incidents discussed. It prevented the evacuation via a Hyperbaric Rescue Chamber (HRC) in the Sedco Phillips SS, the Transworld 58, the DLB 269, and the Resolute cases. Accurate planning and preparedness are critical in risk management.
  It is notable today that HRCs are not accepted in the UK or Norwegian sectors of the North Sea and other regions due to their limitations of life support and seaworthiness.
- The options:
  Faced with an event requiring an emergency decompression, a commercial diving company will mobilise its safety response network and involve the diving medical advisor in the decision-making process. The decisions will be made on information received via telecommunication systems, generally with limited real time knowledge of the actual situation and its evolution. The circumstances are often dramatic and changeable, with emotional pressure to manage. History has shown that decisions often must be revised promptly according to the development of the situation.
  Upon deciding whether to use an emergency decompression, the first consideration will be the depth of the divers. An accelerated decompression is only useful if the divers are close enough to the surface and the time

scale allows them to be brought to safety. If these criteria are fulfilled, then methodological options for the rescue would be:

- To decide on a starting depth. The situation may require the recompression of a team in decompression or at a different storage depth to a deeper depth.
- To perform a rapid large excursion to get the divers closer to the surface. However, too great an excursion might cause DCS and impair further decompression.
- Decompress with increased ascent rates. However, too rapid an ascent rate might cause DCS.
- Decompress with an increased PO2 to allow faster ascent rates. However, too high an oxygen exposure might induce oxygen toxicity.
- Possibly store the divers at a depth close to the surface waiting for the best time to evacuate.
- A combination of the above.

The decision is therefore a balance between the time left to decompress to surface and the accepted risk of DCS and/or oxygen toxicity. This may lead to a graded response where two levels of emergency could be considered:

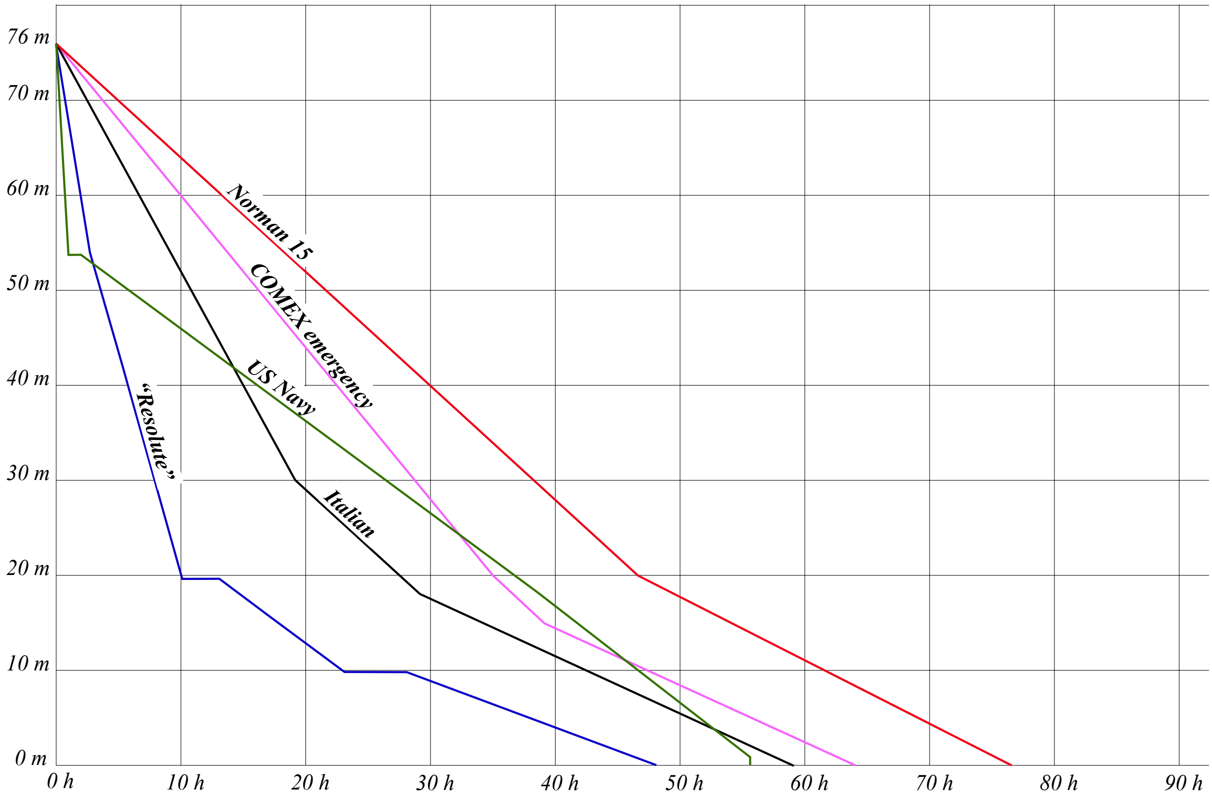
- A 'level one emergency' where time is available and a fast, but still reasonable ascent rate could be employed to minimise the DCS risk.
- A 'level two emergency' where the immediate integrity of the system is at risk and a life-threatening situation involves the whole saturation team. This could justify an aggressive ascent protocol and the acceptance of a higher risk of DCS and oxygen toxicity.

Finally, operational constraints must be evaluated:

- Feasibility:
  - Are communications reliable enough to direct the decompression?
  - Is the diving support vessel a safe place to decompress, and for how long?
  - Are Life Support Technicians (LST) present?
- Acceptability:
  - Can the divers be informed of the options and involved in the decision?
- Control of decompression:
  - Is the chamber atmosphere breathable?
  - Can a breathing mix be supplied on BIBS?
  - Is the chamber temperature within limits?
- Treatment options:
  - In case of DCS, would it be possible to treat a diver during the emergency decompression or would the diver have to wait until he is evacuated to a hyperbaric facility?
  - How long would it take to take the divers to a nearby vessel of opportunity or a shore-based facility equipped with a saturation diving system?

- Initial excursion:
  In several recorded instances, the immediate strategy was to perform a rapid upward ascent or excursion to bring the divers closer to surface. This protocol is described in the US Navy diving manual (paragraph 13–23, revision 7) that allows the start of a final decompression to begin with an upward excursion. The excursion amplitude can be quite significant, for example, a 30 msw ascent from 120 msw to 90 msw.
  Diving companies have become more cautious about upward excursions. This is because the data from the Comex diving database, the Hades database from Seaways, and the US Navy have all shown that too great an excursion may induce vestibular DCS symptoms, which could have a dramatic impact on the rest of the emergency management.
  One way of controlling the risk of DCS is to perform this initial ascent at a slower rate, as during the Resolute case (approximately 7.8 msw·h). Alternatively, the divers may be kept at constant depth for a while after the excursion, as per the US Navy abort decompression procedure, which requires a two hour hold before any further ascent.
- Final excursion:
  Another documented emergency decompression strategy consists of decompressing the divers to a depth close to surface and keeping the divers at this depth until the situation is controlled. The 'holding' depth was 10 msw during the Resolute case, 3 msw during the DLB 269 case, and 11 msw during the S. Suraksha case. This hold has the advantage of stabilising the divers in terms of decompression, providing a higher PO_2 on BIBS (if required for a DCS treatment) and still permitting a rapid escape to surface if needed. The S. Suraksha case showed that divers could ascend from 11 msw to surface in 30 minutes and then be recompressed to 30 msw in a nearby vessel system, with only one case of DCS (pain only) among six saturated divers.
- Faster ascent rates:
  During decompression, the ascent rate and the inhaled PO_2 are closely related. This relationship is linear, according to Vann's model. 16 With the use of data from commercial saturation decompressions, a regression line has been established between the safe rate of ascent and chamber PO_2 in the deeper part (> 60 msw). This is the design principle of the US Navy and Comex emergency procedures that propose three values of chamber PO_2 associated with three different ascent protocols. To control oxygen toxicity, each decompression PO_2 is associated with a time limit, translated into a limitation in starting depth.
  To compare emergency protocols, we first considered the Resolute case and displayed its actual depth/time

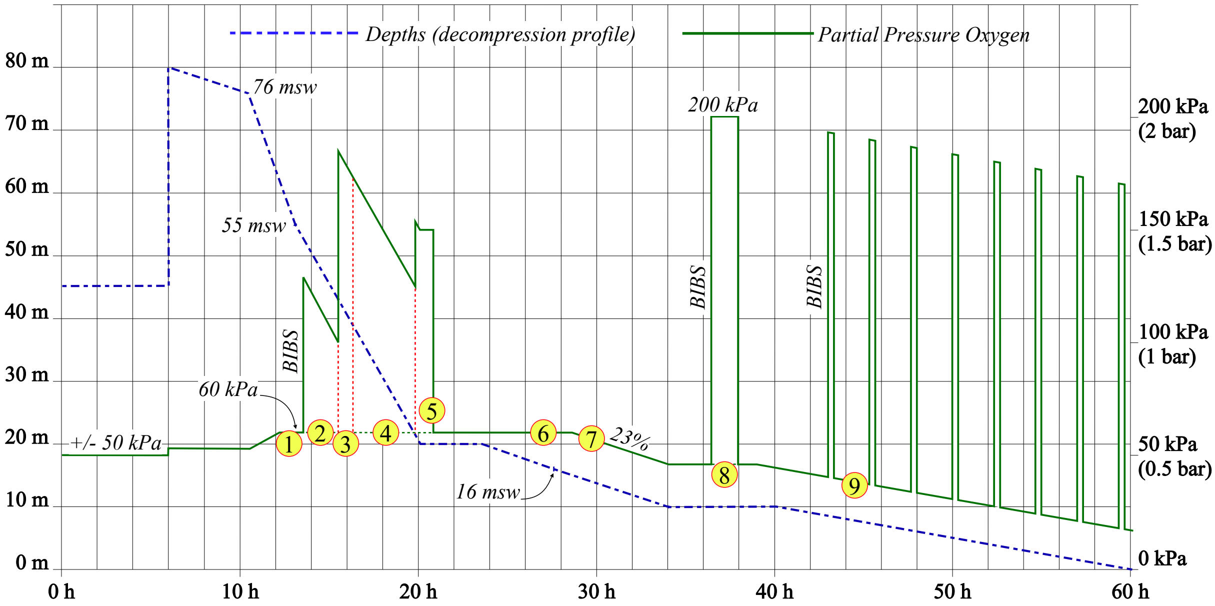
profile. We then added the profiles of the US Navy, Italian and Comex emergency decompressions, for the same starting depth. The Norsok profile was also added to provide a reference associated with a standard and conservative saturation decompression. *Note: For consistency with this manual, the Norsok profile has been replaced by the Norman 15 procedures.*



Two strategies emerge from this figure:
The US Navy and Comex procedures have relatively slow decompression rates (1.5 to 1.8 msw·h and are adapted to the evacuation of a diver with an injury or an illness, where the risk of DCS must be controlled. These situations we class as Level 1 emergencies.
The figure shows that ascent rates can be significantly increased in a life-threatening situation. On board the Resolute, the decompression was initiated with an upward excursion at approximately 7.8 msw·h from 76 msw to 55 msw and then continued at 5 msw·h from 55 msw to 20 msw. This situation represents a Level 2 emergency, and these are imbued with a higher risk of DCS and oxygen toxicity, which are accepted given the circumstances.
Estimation of DCS risk is a key decision factor. For standard saturation decompressions not exceeding 200 msw, a study using data from the Comex database, based on 60 kPa chamber PO_2, showed that DCS cases were associated with pain symptoms alone, which occurred in the last part of the ascent. Therefore, with Level 1 emergency decompression, the risk seems to be limited to mild DCS.
For deeper dives, three cases of vestibular symptoms have been reported during historical deep experimental dives with an initial rapid decompression. These included: a Comex PLC I dive made in 1968, from 335 msw, with an initial ascent rate at 3.5 msw·h; in 1971, a Royal Navy RNPL 457 msw (1500 feet of seawater) dive, varying ascent rates starting at 12 Msw·h; and in 1974, a Comex Physalie VI dive, 610 msw, initial ascent rate at 2.4 msw·h.
With Level 2 emergency decompressions, a tangible risk is vestibular symptoms associated with DCS. Current experience and algorithms do not allow the control of this risk.

- Central Nervous System (CNS) oxygen toxicity:
Increasing the PO_2 allows the ascent rate to be accelerated. However, oxygen toxicity may lead to convulsions, which are dangerous due to their sudden onset and limited warning signs that are either difficult to recognise or absent. The simplest way of managing CNS toxicity is to consider it as a matter of threshold and set limit values to the PO_2.
During immersion, the limit for pure oxygen breathing is set to 175 kPa (1.75 bar). In the dry environment of a deck decompression chamber, the PO_2 is set to 220 kPa (2.2 bar) during normal bounce diving, and can reach up to 280 kPa (2.8 bar) during treatment (US Navy table 6 for instance).
Data from animal studies have documented that oxygen breathing interruptions delay CNS oxygen toxicity.
In practice, BIBS sessions are associated with interruptions, generally five minutes 'off BIBS', then 25 minutes 'on BIBS'. These breaks in oxygen breathing provide divers with the possibility to rest, talk and drink. It is believed that they also allow a recovery from CNS toxicity. Arieli's oxygen toxicity model suggests that a five-minute break after a 25-minute exposure can reduce the CNS toxicity dose by 67%, for this range of PO_2 breathed. If Arieli's model is applied to the Resolute case scenario, a detailed PO_2 profile can be derived, whereby the index computed for CNS toxicity reaches a score of 80 during the BIBS sessions, but is almost zero by the end of the decompression.

Our review has shown that in several instances, the people managing the emergency did not hesitate to provide the divers with high PO_2 in the BIBS breathing mix, but with interruptions to allow a safe, rapid decompression.
Based on the Resolute case, it seems that sessions of 200 kPa PO_2 on BIBS can be managed over a two–three day decompression (*see the scheme below*). It all depends on the interruptions and the expected recovery process, which is difficult to estimate. Interruptions also assume that the chamber atmosphere remains breathable, and this might not always be the case (as in the S. Suraksha event). Finally, we note that during the DLB 269 case, the BIBS sessions were continued out at surface pressure for six hours after the end of the decompression. This may be operationally difficult in some circumstances but certainly helps to protect the divers from developing DCS symptoms, especially if the divers omitted significant decompression.



The scheme above represents the various sequences of oxygen uptake by the divers during the "Resolute barge incident". The depths in msw are indicated on the left side,the PO2 on the right side, and the times in hours on the bottom side. Refer to the reference numbers of the sequences in the table below for the description of the procedures used.

Sequence No	***Depth (msw)***	***Gas breathed***	***Ascent rate***	***comments***
1	*76 to 55*	*Chamber: HeO_2 0.6 bar oxygen*	*7.8 m/h (average)*	*Ascent of 21 msw performed in 2 h 42 min*
2	*55 to 43*	*Chamber: 0.6 bar oxygen BIBS heliox: 20% O_2*	*5 m/h*	*Decompression: 5 BIBS sessions 20/5*
3	*43 to 20*	*Chamber: 0.6 bar oxygen BIBS heliox: 35% O_2*	*5 m/h*	*Decompression: 2 BIBS sessions 20/5*
4	*43 to 20*	*Chamber: 0.6 bar oxygen BIBS heliox: 35% O_2*	*5 m/h*	*Decompression: 7 BIBS sessions 25/5*
5	*20*	*Chamber: 0.6 bar oxygen BIBS heliox: 50% O_2*	*Hold*	*3 h 35 min hold - 2 BIBS sessions 25/5*
6	*20 to 16*	*Chamber: 0.6 bar oxygen*	*1*	*Decompression*
7	*16 to 10*	*Chamber: HeO_2 - 23% oxygen*	*1*	*Decompression*
8	*10*	*Chamber: 23% oxygen BIBS gas: 100% O_2*	*Hold*	*5 h hold: 3 BIBS sessions 25/5*
9	*10 to surface*	*Chamber: 23% oxygen BIBS 100% O_2*	*0.5*	*Decompression: After 4 h on chamber gas 20 min on BIBS 100% O_2 every 2 h to surface*

In relation to CNS oxygen toxicity, benzodiazepines could, in theory, be used as secondary prevention agents *(note: Benzodiazepines are a class of drugs primarily used for treating anxiety)*. However, their prophylactic effect remains unknown. In fact, the respiratory depressant effects of these drugs could potentially lead to CO_2 retention, which would increase the risk of CNS oxygen toxicity. They would also introduce sedation into an unfolding emergency, which could have disastrous consequences. For these reasons, pre-emptive use of such drugs during emergency decompression to mitigate the risk of CNS oxygen toxicity is not justified.

- Pulmonary oxygen toxicity:
  Another recognised type of oxygen toxicity affects the lung (pulmonary oxygen toxicity). The symptoms include coughing, chest pain and dyspnoea. Extreme exposures may lead to pulmonary oedema.

The difficulty is setting the upper PO_2 limit to avoid severe pulmonary toxicity. One study exposed 12 subjects for 48 h at PO_2 = 105 kPa (1.05 bar) during a simulated air saturation dive. Pulmonary oxygen toxicity symptoms occurred, and pulmonary function changes consisted of significant decrements in vital capacity, flow rates and diffusing capacity for carbon monoxide. Subjects showed a complete recovery in both symptoms and pulmonary function in about eight days. In 1979, Comex conducted a deep saturation dive with eight divers to 450 msw. Decompression lasted 10 days and 5 h (corresponding to an average 44.1 msw per day), using 70 kPa chamber PO_2 from 314 msw to surface pressure. No DCS or pulmonary oxygen toxicity of note was reported (Imbert JP, personal communication 2022).
These data suggest that PO_2 may be raised significantly in the event of an emergency, but a mathematical tool is required to evaluate this limit.
Several mathematical models can be used to estimate the pulmonary toxicity dose: the unit pulmonary toxic dose (UPTD) calculation from Clark and Lambertsen; the oxygen tolerance model from Harabin; and the more recent oxygen toxicity index from Arieli. However, these models do not translate well to data drawn from conditions different from their validation. Their weakness is multiple injury pathways and the obvious individual variability that may confound models.
The simplest model is the UPTD, which provides an immediate dose evaluation in an emergency. However, it has well-known limitations. First, it was validated with a PO_2 higher than 152 kPa and its prediction curves were extrapolated to the lower range of PO_2; it tends to overestimate toxicity in saturation diving. Second and more importantly, it does not account for any recovery. The computation of UPTD on emergency dive profiles generally leads to doses higher than 1,000 UPTD that far exceed the daily limit of 625 UPTD set for a 5% decrement in vital capacity.
Arieli's toxicity index offers a new alternative, accounting for recovery. It provides a more relevant dose/limit indication, but its calculation might not be practical during an emergency. We applied both models over the Resolute PO2 profile and obtained a dose of 1,265 UPTD and a cumulative value of 36 with the Arieli's pulmonary index.
This overall 1,265 UPTD dose is not regarded as excessive; in the early Comex experimental dives it was documented that a dose of 1,300 UPTD was acceptable during saturation based on vital capacity measurements. The index computed with Arieli's model for pulmonary toxicity reached a maximum value of 566 during the BIBS sessions but was very low by the end of the decompression. This would indicate that divers' vital capacity decrement reached 7.5% but a recovery took place.
Pulmonary oxygen toxicity remains the limitation of accelerated decompression. A high chamber PO_2 accelerates the decompression but can only be tolerated for a few days. Therefore, efficient accelerated decompressions can only be carried out from depths shallower than 100 msw.

- Divers' hydration:
There is a considerable literature suggesting the importance of hydration during or after immersion. Immersion exposes the diver to heat and cold, exercise, dry gas breathing and modifies cardiac function. In particular, it has been shown that hydration before immersion reduces the level of circulating venous gas emboli post-dive. However, these situations are not pertinent to saturation decompression, where the divers are in a dry environment with controlled humidity and temperature. We could not find studies on divers' hydration during saturation decompression. However, one study showed a diminution of the plasma volume and haemoconcentration *(increased proportion of red blood cells)* between pre-and post-saturation measurements. There is a general assumption that if vascular volume is maintained, it will optimise perfusion and help to eliminate dissolved gases during decompression, thus reducing bubble formation. The DMAC report on emergency decompression from saturation recommends encouraging divers to drink as much as they can. Plain water or oral rehydration mixtures are preferred. DMAC guidance note 31 mentions possible additional treatments, such as analgesics and non-steroidal anti-inflammatory agents but acknowledges that there is no human evidence that such drugs would offer benefits *(see in the previous point "About DMAC 31")*.

- Inert gas switching:
Inert gas sequencing (helium, nitrogen and argon) was developed in the sixties by Dr Bühlmann to accelerate gas exchange during deep bounce decompressions. He reported decompression time of 22 h after a 6 h bottom time at 100 msw and 40 h decompression time after 6 h at 150 msw.
Another study reported 62–64 h decompression time from 220 msw with 66–68 h bottom time using an inert gas switch from 30 msw.
Based on the same principle, chambers were flushed with air at around 10 msw by the end of the heliox decompression
during the Predictive Study experimental dives at the University of Pennsylvania. A gas switch was introduced by slowly venting the chamber with air during the 1981 Transworld incident. An air switch is also prescribed in the Italian accelerated decompression procedures.
The difficulty with an inert gas switch is the control of the dynamics of the gas exchange, which depends on the physical properties of the gas and the depth of switch. When the technique is performed under controlled conditions and the decompression is previously validated, inert gas sequencing allows the design of efficient bounce tables (as for instance, historical Comex Cx 70 or Oceaneering bell bounce tables with transfer to an air-filled deck chamber). In case of an emergency, if the divers have already been subjected to an accelerated decompression, it is difficult to assess the gas kinetics without a complex mathematical model. In fact, the University of Pennsylvania stopped using inert gas switches because of the occurrence of specific DCS symptoms that were difficult to treat. In practice, inert gas switching should not be recommended in an

emergency as it would add complexity to an already difficult situation, for example, at which depth should the change occur, what decompression rate after the change, and how to treat associated DCS?

- Emergency response and responsibility for decisions:
  Diving companies have based their emergency response on a supportive network, that includes all their departments in addition to their medical advisor. In an ideal case, all parties involved cooperate and share the decision. In real cases, the operational personnel are often in the front line before reliable communication can be established with shore-based resources. In most of the cases reviewed, the medical advisor, once contacted, had to take the decision on the emergency decompression. The authors believe that the duty of the medical advisor is too often perceived as exclusively focussed on the responsibility of making therapeutic decisions as an event is unfolding. Ideally, medical advisors should be involved from the earliest stage of project design and elaboration of diving procedures, until project completion. We noted, however, that in several cases, the divers were instructed on the available options and shared the decision on the accelerated decompression (DBL 269) or took the decision themselves (S. Suraksha). The diving industry needs optimised guidance on what can be achieved, depending on the saturation depth and the level of emergency. This guidance must be developed with the involvement of the diving teams themselves.

3.6.1.3 - Additional comments regarding the two procedures presented

It must be noted that three authors of the study *"A review of accelerated decompression from heliox saturation in commercial diving emergencies"*, doctors Massimelli, Matity, and Bryson, are members of the DMAC. Also, Jean Pierre Imbert was one of the participants of the workshop on accelerated decompression organized by the DMAC on 13 April 2011 in London. Thus, the relationship between the two documents presented is more than evident. Note that this document is also available on DMAC's website.

It is essential to consider that many cases discussed in this document finished positively because the catastrophic events that were triggered were finally under control. For example, in the case of the Resolute incident, the weather calming down allowed the marine crew to regain control of the barge. as a result, the Life Support Technicians could slow down the decompression to normal values. Regarding the S. Suraksha incident, the recovery of the divers was possible because the 2nd vessel with a saturation system was on site (and also due to the courage of the diving team of this vessel). These two events highlight that except in areas with a high density of ships equipped with a saturation system that can accommodate the diving team, installing the Hyperbaric Reception Facility on a vessel is more desirable than onshore.

Another essential point for a diving team is ensuring that the emergency decompression can be managed appropriately. For example, the decompression profiles of the "Resolute" and "S. Suraksha" show that the teams adapted the ascent rate and gas values according to the events. Reliable communications with the diving medical specialist and the person competent to provide guidelines are essential. However, communications can be lost, and in such a scenario, the diving support team must be sufficiently skilled to manage an accelerated decompression. We can see that for such scenarios, expertise is more important than an established procedure.

Note:
Doctor Philip Bryson is the corresponding author of the study *"A review of accelerated decompression from heliox saturation in commercial diving emergencies".* He can be contacted through this address:

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Other point of contact can be phone through our website:

- On the home page, click on the tile "logistics" in the navigation bar. Then click the button "Doctors and clinics"
- It is also possible to directly access to the lists through this link: https://diving-rov-specialists.com/doctors.htm

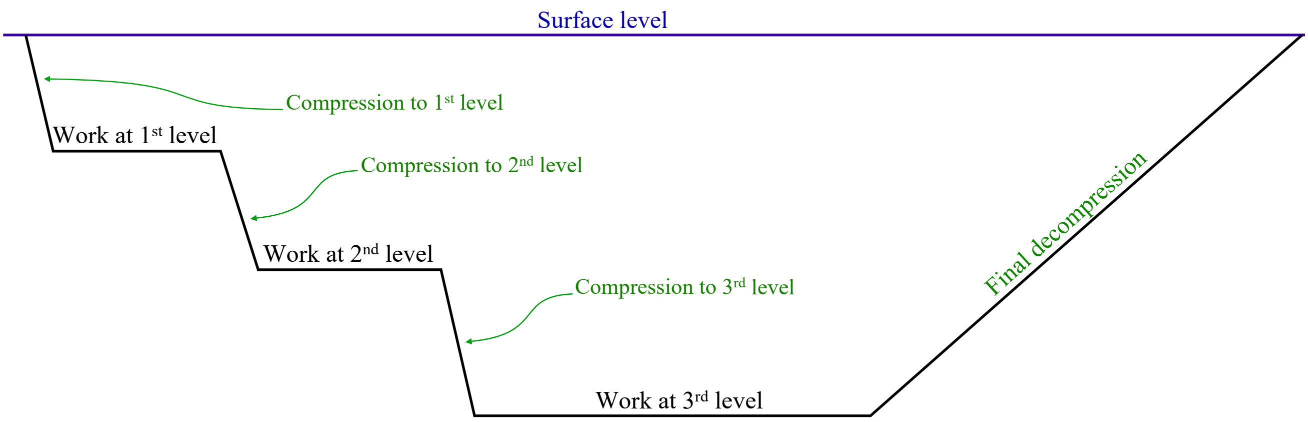
8) Storage depth and saturation profile

There are no rules of saturation profiles indicated in NORMAM-15.
Also, the literature regarding this aspect of the operations is limited. However, the following guidelines published by NORSOK and in the French regulations can be taken as references:

- The dive planning should be based on a minimum change of living depth and excursion exposures. *(NORSOK U-100 point 8.2.3.5)*
- The living depth should be as close to the working depth as possible, based on a total evaluation of all safety aspects. *(NORSOK U-100 point 8.2.3.5)*
- Living depth changes are permitted, but it is not allowed to compress, decompress, and then recompress. *(NORSOK U-100 point 8.2.3.5)*
- When storage depths modifications are necessary, it is preferable to select :
    - A change of storage depth by intermediate pressurisation rather than by decompression, or by planning working levels of increasing depths rather than decreasing depths. *(French decree of 15th May 1992 / page 362/ point 7)*
    - A complete intermediate decompression rather than a shorter one followed by an ascending excursion. *(French decree of 15th May 1992 / page 362/ point 7)*

8.1 - Ideal saturation profiles

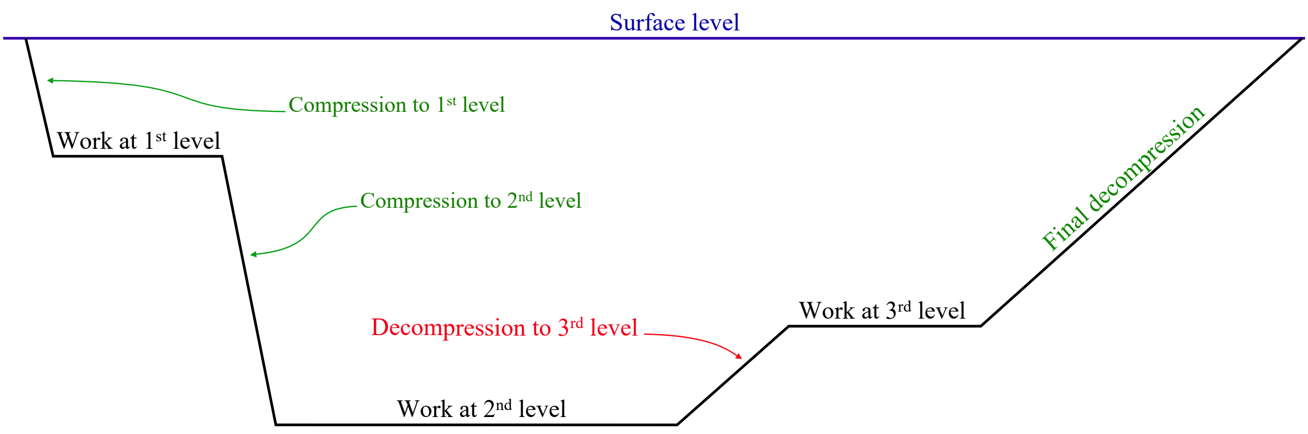
According to the recommendations above, the ideal profile is a U profile, with the change of storage depth by intermediate pressurisation rather than depressurization.



Remember that:

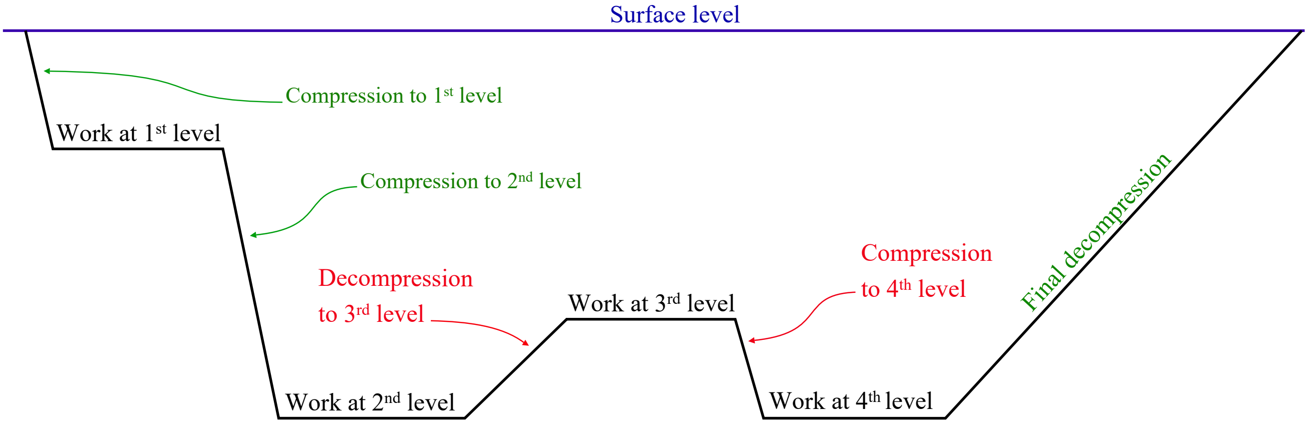
- Downward excursions are preferable.
- It is recommended to limit the change of living depth and excursions exposures.

Despite efforts to organize the dives according to the ideal profile, it may happen that last minute changes or an emergency oblige the team to perform operations at a shallower level.
In this case, work periods after a decompression to a shallower level is considered acceptable. Note that as indicated in the French decree of 15th May 1992 / page 362/ point 7, it is preferable to perform a complete intermediate decompression rather than a shorter one followed by an ascending excursion.



8.2 - "W" profiles

According to the recommendations above, diving teams should be encouraged to perform U profiles. Nevertheless, it may happen that, due to special circumstances, the ideal profile cannot be applied and that a decompression followed by recompression (W profile) is needed.



"W" profiles may result in two possible scenarios:

1) As indicated in the texts from NORSOK standards, only U profiles are permitted in some countries such as Norway. Also, NORSOK standards may have been adopted by some clients and companies. As a result, depending on the country where the project is performed, the policy of the client and the company regarding such profiles, the diving superintendent in charge of the project has to apply for a dispensation and obtain the approval from the organizations and the people listed below for implementing such procedures:
   - The company
   - The client (oil company)
   - The divers involved
   - The diving medical specialist
   - The legal authorities of the country if they forbid such procedures.
2) A lot of clients and countries allow for W profiles. It is also said that W profiles are considered industry standard. Nevertheless, what is called industry standard in the diving word are practices that are applied by some companies but not recognised by an official body. Also, we can see that some organizations reject such practices.
   For these reasons, and because there is currently no study issued by recognized competent bodies that describe the effects of such procedures on the health of the divers, the diving managers of a company commonly performing such profiles should edit rules that should be strictly followed.
   Note that for the reasons explained before, the principle of precautions should prevail and a W with an exaggerated amplitude should be avoided. These rules should be approved by the diving medical specialist of the company. In addition, to cover the company on the legal point of view, the divers should be informed that such practices may have to be applied. For this reason, it should be clearly indicated in their contracts of employment or in another document they sign before starting the operations.

8.3 - Other profiles

As indicated above, W profiles can be applied in special circumstances.
For safety purposes, other profiles should be considered unsafe and never be applied.

9) Decompression sickness during the operations

Decompression sickness may occur during a saturation dive as a result of an upward excursion or as a result of a decompression. The decompression sickness may manifest itself as musculoskeletal pain (Type I) or as the involvement of the central nervous system and organs of special sense (Type II).
Due to the subtleness of decompression sickness pain, all divers should be questioned about symptoms when it is determined that one diver is suffering from decompression sickness.
Note that the classification of the symptoms into type 1 or type 2 categories is done for convenience but that there is no real border between the categories and that a decompression sickness classified type 1 first may quickly become a type 2.
NORMAM-15 does not publish guidelines in the case of decompression sickness during the saturation. However, the procedures developed by COMEX that are well known and commonly used in the industry are applicable.

9.1 - Therapeutic tables COMEX

The therapeutic procedures COMEX are efficient alternatives to US Navy tables. They are designed for air and heliox surface supplied diving, and air and heliox saturation diving. Some tables are initially designed for therapeutic use of heliox, and the set proposed is composed as follows:

- ***Cx 12*** (oxygen) can be used for treatment of "type 1" accident of an air, nitrox or heliox dive.
- ***Cx 18*** (oxy.) can be used for treatment of "type 1" accident after no relief or worsening of symptoms in Table Cx 12.
- ***Cx 30*** (heliox + oxygen) can be used for treatment of "type 2" accident of an air, nitrox or heliox dive.
- ***Cx 30 saturation*** (heliox + oxygen) can be used for treatment of "type 2" accident of an air, nitrox or heliox dive. after no relief or worsening of symptoms in Table Cx 30
- ***Cx B*** (heliox + oxygen) can be used for treatment of "type 1" accident during normal decompression or after a blow-up from deeper than 9 m in an heliox bounce dive or air/heliox saturation
- ***Cx SB*** (heliox + Oxygen) can be used in case of failure of Table "Cx B" during normal decompression or after a blow-up from deeper than 9 m in an heliox dive or air/heliox saturation.
- ***Cx N*** (heliox + oxygen) can be used for treatment of "type 2" accident during normal decompression or after a blow-up from deeper than 9 m in an heliox dive or an air/heliox saturation.

The tables explained in this chapter are only those designed for an accident during saturation operations: Cx B; Cx SB; Cx N.

9.2 - Therapeutic gases

IMCA D 050 says that very worksite must have a provision for therapeutic gases that will allow a higher PO_2 to be given to patients suffering from a decompression accident in a chamber.
IMCA also says that the recommended oxygen partial pressure should be between 1.5 and 2.8 ata *(1 ata = 1.013 bar)*.
The percentages and quantities of mixes that may be used for the depths scheduled should be calculated according to a gas consumption of 20 litres per minute per diver at the surface.

The table below indicates the depths with 2.8 bar and 1.5 bar PPO_2 for various oxygen percentages

Percentage oxygen	Depth in metres with 1.5 bar PPO_2	Depth in metres with 2.8 bar PPO_2		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

9.3 - Table Cx B

This table can be used for treatment of "type 1" accident during normal decompression or after a blow-up from deeper than 9 m in an heliox bounce dive or air/heliox saturation.

Procedure:
- Stop the decompression
- Put patient on BIBS. The patient breathes heliox for 60 minutes without interruption as per table.
- Note the time of relief.

No relief or worsening symptoms:
- No relief after 15 minutes: Apply table Cx SB
- No relief or worsening of symptoms: Apply table Cx N
- Recurrence: Apply a second table CX B

STOP decompression

↓

Put divers on BIBS for 60 minutes without interruption

↓

Depth of treatment	Mix to be used
0 - 18 metres	Oxygen
19 - 40 metres	Heliox 50/50
41 - 110 metres	Heliox 20/80
111 - 210 metres	Heliox 10/90
211 - 360 metres	Heliox 5/95
361 - 450 metres	Heliox 3/97

↓

After successful treatment, resume decompression

Heliox bounce dive

Use the same table (same depth, same bottom time) and add 10 minutes to each stop of the initial decompression protocol

Heliox saturation

Apply standard heliox saturation decompression

9.4 - Table Cx SB

This table can be used in case of failure of Table "Cx B" during normal decompression or after a blow-up from deeper than 9 m in an heliox dive or air/heliox saturation.

Procedure:

- Recompress the patient with the depth increment indicated according to the depth at which the accident occurred.
- Pressurize the chamber with heliox mix
    - Bottom mix for surface supplied diving
    - Pressurization mix for saturation diving
- Note the depth and time of relief.

No relief or worsening of symptoms:

- No relief or worsening of symptoms: Apply table Cx N
- Recurrence: Apply table CX B

Recompress the diver

↓

Put diver on BIBS (25 minutes on + 5 minutes off)

↓

Depth of accident	Depth of treatment	BIBS breathing duration	Mix to be used
0 - 18 metres	Plus 6 metres	120 minutes	Oxygen
13 - 31 metres	Plus 9 metres	120 minutes	Heliox 50/50
32 - 98 metres	Plus 12 metres	120 minutes	Heliox 20/80
99 - 195 metres	Plus 15 metres	120 minutes	Heliox 10/90
196 - 345 metres	Plus 15 metres	120 minutes	Heliox 5/95
346 - 450 metres	Plus 15 metres	120 minutes	Heliox 3/97

↓

After successful treatment, resume decompression

Heliox bounce dive

Apply standard heliox saturation decompression depending on chamber atmosphere.

Heliox saturation

Apply standard heliox saturation decompression

Intervention of paramedics inside the chamber:

A decompression procedure has been prepared in the case of short intervention of a paramedic inside the chamber. This procedure is explained in point 4 "Cx 30 saturation"

9.5 - Table Cx N

This table can be used for treatment of "type 2" accident during normal decompression or after a blow-up from deeper than 9 m in an heliox dive or an air/heliox saturation.

Procedure:

- Recompress the patient 20 metres deeper than the depth at which the accident occurred.
- Pressurize the chamber with heliox mix
  - Bottom mix for surface supplied diving
  - Pressurization mix for saturation diving
- Put the patient on BIBS as per table below (the patient breathes 25 minutes on + 5 minutes off in chamber atmosphere for each 30 minute BIBS period indicated)
- Note the depth and time of relief.

No relief or worsening of symptoms:

- No relief or worsening of symptoms: Keep the patient on bibs on heliox for 25 min/ 5 min session during a period not exceeding 3 hours and wait for instructions from the Diving Medical Specialist (DMS).
- Recurrence: Apply table Cx N

Recompress the diver 20 metres deeper than the depth of accident

↓

Put diver on BIBS (25 minutes on + 5 minutes off)

↓

Depth of treatment after recompression	BIBS breathing duration	Mix to be used
20 - 40 metres	120 minutes	Heliox 50/50
41 - 110 metres	180 minutes	Heliox 20/80
111 - 210 metres	240 minutes	Heliox 10/90
211 - 360 metres	300 minutes	Heliox 5/95
361 - 450 metres	360 minutes	Heliox 3/97
346 - 450 metres	120 minutes	Heliox 3/97

↓

After successful treatment, hold at treatment depth for 6 hours, then resume decompression

↓

Heliox bounce dive

Apply heliox saturation decompression:
- 60 minutes/metre from treatment depth to 15 m. (PPO2 = 600 to 630 Mb)
- 120 minutes/metre from 15 m to surface (O2 percentage < 23%)

Heliox saturation

Apply heliox saturation decompression:
- 60 minutes/metre from 200 to 15 m. (PPO2 = 600 to 630 Mb)
- 120 minutes/metre from 15 m to surface (O2 percentage < 23%)

Intervention of paramedics inside the chamber:

A decompression procedure has been prepared in the case of short intervention of a paramedic inside the chamber. This procedure is explained in point 4 "Cx 30 saturation"

10) After the dive

10.1 - Observation time following completed diving operation

After surfacing, the divers are still at risk from decompression sickness.
For this reason, they must be kept at the direct proximity of the chamber for 2 hours. Then, they should have a minimum rest period of 24 hours at less than 30 minutes from the therapeutic re-compression facility that is organized with immediate access (NORSOK U-100). Note that other competent bodies such as US Navy prolong the observation time after surfacing to 48 hours.
- It should be emphasized to all divers that:

- They should not perform hard physical activities
- Any symptom should be reported as soon as possible, and before departure from the dive location.
- Treatment begun soon after the onset of symptoms is often relatively straightforward but the treatment which has been delayed for a while after the onset of symptoms may be difficult because the condition has become less responsive.

10.2 - Standby time before flying

As no recommendations are proposed by NORMAM-15, those from the Diving Medical Advisory Committee (DMAC 7) should be implemented.

- DMAC 7 says:

The times recommended have never been tested and in commercial diving the interval between diving and flying is commonly longer than that recommended in the guidelines.

In most situations flying involves exposure to reduced barometric pressure (altitude). After diving, exposure to altitude always carries a risk from decompression illness *(DCI)*, in particular if the diver has any symptoms (see later). This together with our evaluation of the existing experimental evidence and experience is the basis of the revised recommendations. Unfortunately there is no evidence relating to repeated exposure to altitude.

For the purposes of these guidelines, it was considered that diving could be divided into two categories:

1. Air and nitrox diving;
2. Mixed gas diving.

Two maximum cabin altitudes were considered, viz:

a) A maximum altitude of 2000' *(600 m)*, provided that the flight plan has been checked – consistent with a helicopter flight from an offshore platform or vessel;

b) A maximum altitude of 8000' *(2400 m)* – all other flights. 2400m is widely used as the maximum cabin altitude in commercial passenger flights.

Caution

The times given below are minimum times: longer time intervals are recommended, in particular if the planned journey involves a number of take-offs. Journeys involving multiple flights are common and are likely to carry an increased risk. Shorter times may be considered but only after the advice of a qualified medical diving physician.

Flying *(or any altitude exposure including road travel)* in the presence of even minor symptoms of decompression illness carries a considerable risk of provoking serious neurological illness.

Table 1: ***Diving without decompression illness problems or any symptoms***	***Minimum times before flying at cabin altitude***	
	2000 feet (600 m)	***All other flights***
1.1 - No stop dives. Total time under pressure less than 60 minutes within the last 12 hours	2 hours	18 hours (24 hours)*
1.2 - All other air and nitrox diving, heliox and mixed gas bounce diving *(less than 4 hours under pressure)*	12 hours	24 hours
1.3 - Heliox saturation *(more than 4 hours under pressure)*	12 hours	24 hours
1.4 - Air, nitrox or trimix saturation *(more than 4 hours under pressure)*	24 hours	48 hours

* 18 hour time applies to short flights (less than 3 hours). For longer flights the time is extended to 24 hours

For those who want to increase the standby time before flying, note that US Navy manual recommends 72 hours after a saturation.

Table 2: Following therapy for DCI, advice must be sought from a diving medical specialist	***Minimum time from completion of therapy (completion of recompression treatment)***	
	2000 feet (600 m)	***All other flights***
2.1 - Immediate and complete resolution of symptoms on first recompression	24 hours	72 hours
2.2 - Cases without immediate response or with residual symptoms must be decided on an individual basis by a diving medical specialist. Generally wait as long as practical	Consult a diving medical specialist	

Residual risks will be reduced by giving 100% oxygen during the flight. Following landing the diver should be assessed by a diving medical specialist.

- DCI in Flight

In most circumstances, the medical decisions concerning an air passenger who develops symptoms of decompression illness during flight will be the responsibility of the air crew and airline. The following guidance may be helpful.

- Where the diver's symptoms consist only of pain in a limb, the diver should be treated with analgesics, oral fluids, and oxygen if available. Advice should be sought from a diving medical specialist. It may be possible for the plane to continue to its destination without diversion or adjustment of altitude, but the risk of development of more serious symptoms, the duration of flight and route need to be considered.
- When the diver has any other symptoms, immediate advice should be sought from a diving medical specialist. The diver should be given 100% oxygen and oral fluids. Reduction in cabin altitude and diversion to an airport where further treatment can be given may be necessary.

10.3 - Medical check up following the decompression

It is a common practice that a medical check up of the divers is organized prior to sending them back home.

This checkup is mandatory in the case of a decompression accident during or following the dive.

10.4 - Duration of saturation exposures and surface intervals following saturations

In addition to the daily working time, the duration of the saturation exposures and the interval between two hyperbaric exposures can influence the organisation of the manning levels.

NORMAM-15 has emitted guidelines which specifies the maximum duration of the divers in saturation and the interval between 2 saturations or hyperbaric exposure that are more stringent than those published in the DMAC 21. These guidelines should be applied in place of those from DMAC 21.

10.4.1 - Standard and Deep Saturation

- Using the Saturation Technique, the maximum one can stay under pressure is 28 days.
- The minimum interval between two saturations will be the same as the saturation time, and it cannot be below 14 days.
- The maximum time one can stay under saturation in a period of 12 consecutive months cannot be over 120 days.
- Until completion of the recommended surface interval (as specified above) after a saturation dive, a diver should not undertake any diving or be exposed to any pressure greater than atmospheric unless cleared to do so by the relevant diving contractor's medical adviser who will take all circumstances into account, including the duration and depth of the previous saturation exposure and the proposed diving.
- Following deep saturation dives, the surface interval should not be less than the duration of the saturation and preference should be given to a surface interval of at least 28 days.

10.4.2 - Exceptional Saturation

- The diver will only be allowed two saturations per year in this depth range, with a minimum interval of 6 months between them and as long as he has not done saturation deeper than 300 m during this interval.
- In case the diver has already done a saturation between 300 and 350 m, he can only perform another up to 300 m during the 4 months after the end of the previous saturation, and he cannot exceed 77 saturated days in the interval of 12 months, counting from the beginning of the saturation between 300 and 350 m.
- The maximum period one can stay under pressure is 21 days.

10.5 - Treatment of a decompression illness following the decompression

Therapeutic tables should be applied according to the choice of the diving medical specialist in case of decompression illness after surfacing. For convenience, the COMEX tables CX 12, CX, 18, CX 30, and CX 30 saturation, have been introduced in this document.

The chamber should be pressurized with heliox 20/80

10.5.1 - Table Cx 12

Can be used for treatment of "type 1" accident

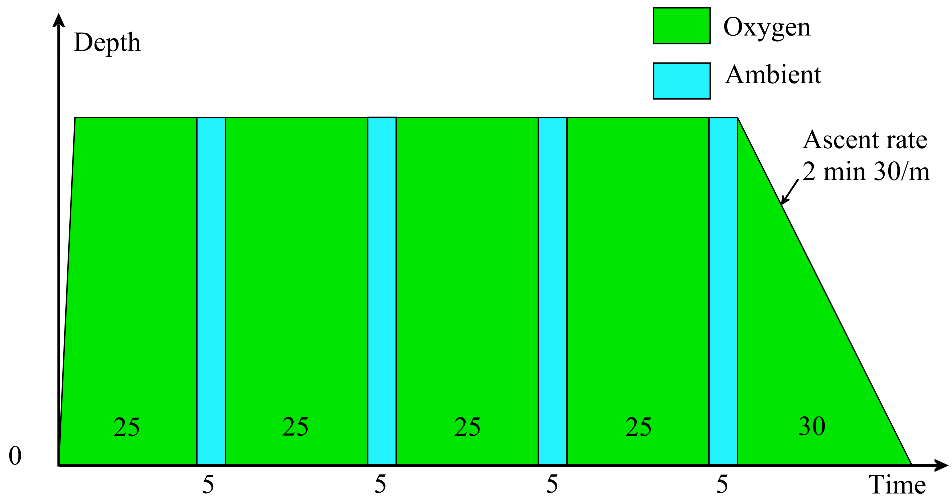
Procedure:

- The chamber should be pressurized to 12 metres on Heliox 20/80.
- Put patient on Oxygen on BIBS ASAP. The patient breathes 25 min. oxygen and 5 min. Air as per table.
- Note the time and depth of relief (if relevant).

No relief or worsening of symptoms:

- No relief within 15 minutes: Apply Cx 18
- Recurrence between 12 m and surface: Apply a second Cx 12
- Worsening of symptoms: Apply table Cx 30

Depth	Duration	Breathing mix		Elapsed time
		Patient	Attendant	
12 metres	120 minutes	Oxygen 4 BIBS sessions 25 min on + 5 min off	Ambient	02:00
12 - 0 metres	30 minutes	Oxygen 30 min on BIBS	Oxygen 30 min on BIBS	02:30



10.5.2 - Table Cx 18

This table can be used for treatment of "type 1" accident after no relief or worsening of symptoms in Table Cx 12

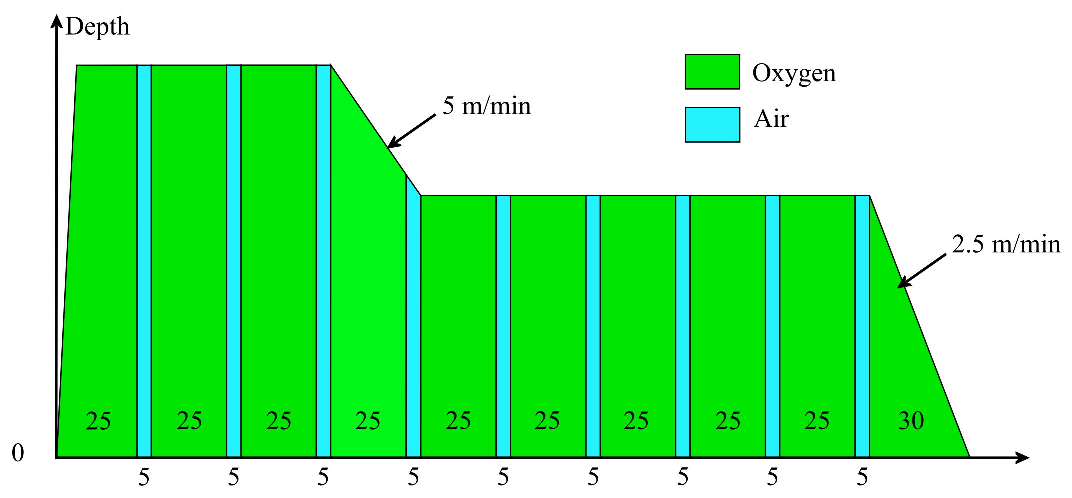
Procedure:

- The chamber should be pressurized to 18 metres on Heliox 20/80.
- Put patient on Oxygen on BIBS ASAP. The patient breathes 25 minutes oxygen and 5 minutes air as per table.
- Note the time and depth of relief (if relevant).

No relief or worsening of symptoms:

- No relief within 15 minutes: Apply Cx 30
- Recurrence between 18 m and 12 m: Apply a second Cx 18
- Recurrence between 12 m and surface: Apply table Cx 12
- Worsening of symptoms: Apply table Cx 30

Depth	Duration	Breathing mix		Elapsed time
		Patient	Attendant	
18 metres	90 minutes	Oxygen 3 BIBS sessions 25 min on + 5 min off	Ambient	01:30
18 to 12 metres	30 minutes	Oxygen 1 BIBS session 25 min on + 5 min off	Ambient	02:00
12 metres	150 minutes	Oxygen 3 BIBS sessions 25 min on + 5 min off	90 min ambient. Then, oxygen 2 BIBS sessions 25 min on + 5 min off	04:30
12 m to surface	30 min	Oxygen 30 min on BIBS	Oxygen 30 min on BIBS	05:00



10.5.3 - Table Cx 30

This table can be used for treatment of "type 2" accident.

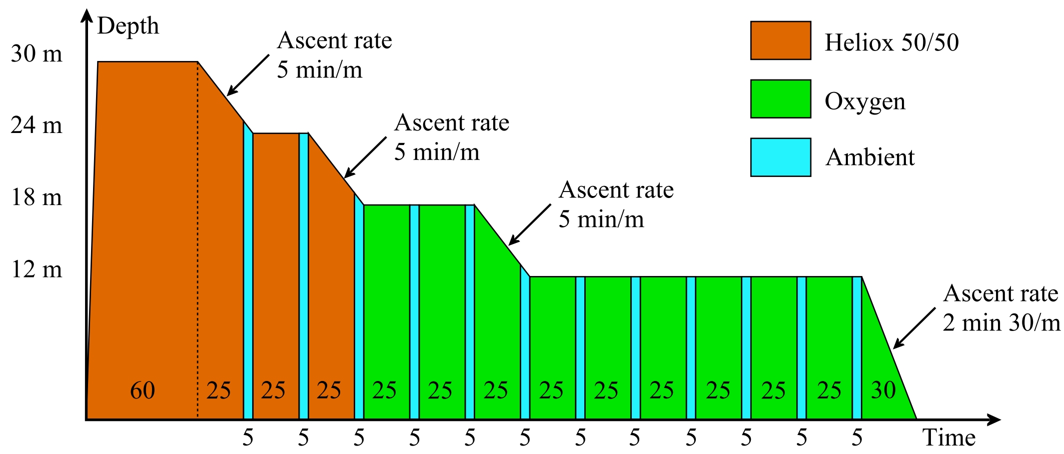
Procedure:

- The chamber should be pressurized to 30 metres on Heliox 20/80.
- Put patient on BIBS ASAP. The patient breathes heliox and oxygen as per table.
- Note the time and depth of relief (if relevant).

No relief or worsening of symptoms:

- No relief or worsening of symptoms: Keep the patient on bibs on heliox for 25 min/ 5 min session during a period not exceeding 3 hours and wait for instructions from the Diving Medical Specialist (DMS). "Cx 30 saturation" should be applied for more than 60 minutes at treatment depth..
- Recurrence: Recompress to 30 m and apply the procedure above

Depth	Duration	Breathing mix		Elapsed time
		Patient	Attendant	
30 metres	60 minutes	Heliox 50/50 60 minutes on BIBS	Ambient	01:00
30 to 24 metres	30 minutes	Heliox 50/50 1 BIBS session 25 min on + 5 min off	Ambient	01:30
24 metres	30 minutes	Heliox 50/50 1 BIBS session 25 min on + 5 min off	Ambient	02:00
24 to 18 metres	30 minutes	Heliox 50/50 1 BIBS session 25 min on + 5 min off	Ambient	02:30
18 metres	60 minutes	Heliox 50/50 2 BIBS sessions 25 min on + 5 min off	Ambient	03:30
18 to 12 metres	30 minutes	Oxygen 1 BIBS session 25 min on + 5 min off	Ambient	04:00
12 metres	180 minutes	Oxygen 6 BIBS sessions 25 min on + 5 min off	Oxygen 6 BIBS sessions 25 min on + 5 min off	07:00
12 m to surface	Min	Oxygen 30 min on BIBS	Oxygen 30 min on BIBS	07:30



10.5.4 - Table Cx 30 saturation

This table can be used for treatment of "type 2" accident after no relief or worsening of symptoms using Table Cx 30.

In the case where a Type II accident does not respond to a standard Cx 30, the diving medical specialist may decide to switch to heliox saturation at 30 metres.

Procedure:

- Saturation treatments are long and the chamber selected should be sufficiently wide to welcome comfortably the patient and at least one diver medic. More possibilities such: additional bunks, toilet, and shower are welcome. The evacuation of rubbish, vomit, fluids and faeces should be organized prior to starting the diving operations.

- The chamber should be pressurized with 20/80 heliox:

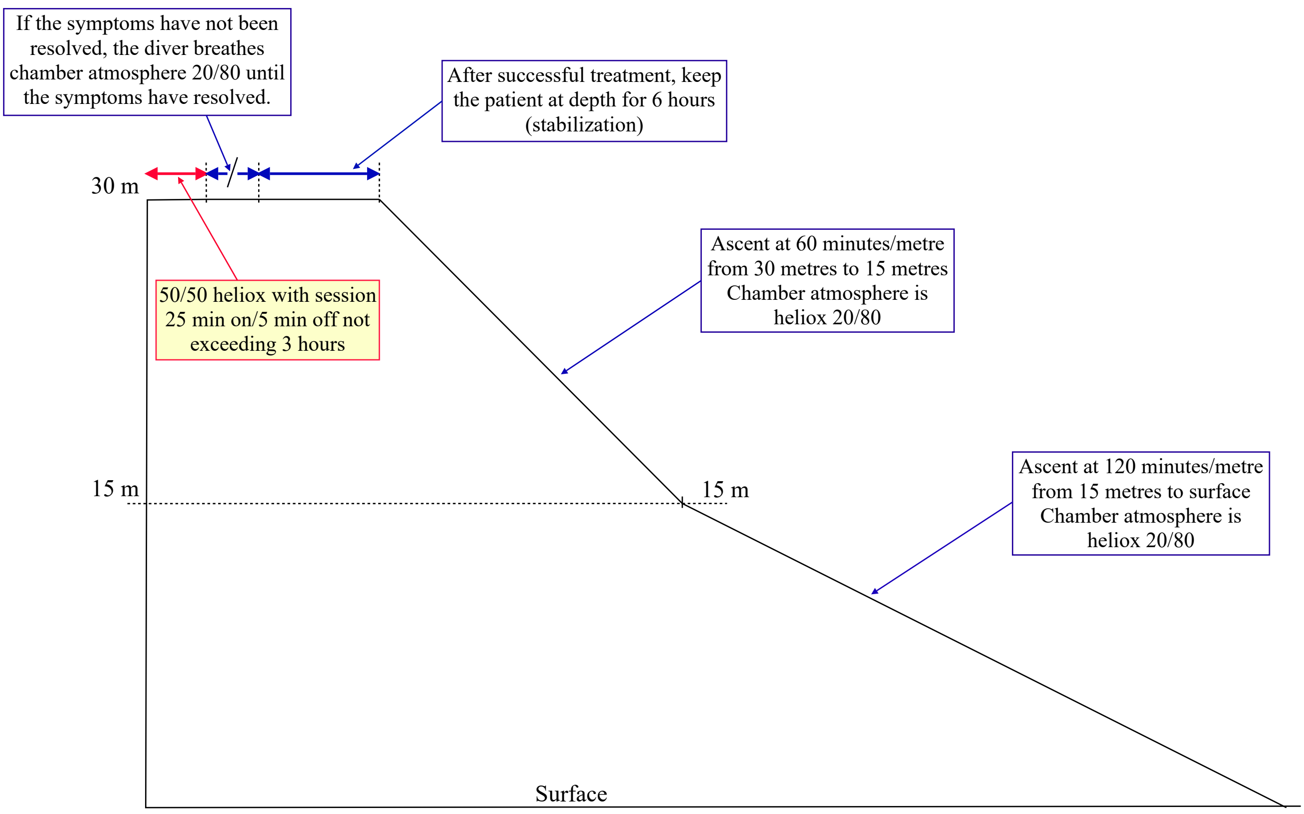
  - If the chamber was pressurised on 20/80 heliox, no action is required.
  - If the chamber was initially pressurised on air, change the chamber atmosphere with heliox 20/80.

Treatment at 30 metres:

- Oxygen percentage in the chamber should not be less 20%, and not above 23%.
- The patient should be on BIBS on 50/50 heliox for 25 minutes/5 minutes sessions for a period not exceeding 3 hours.
- At the end of this period, the patient breathes the chamber atmosphere
- The patient should be kept at depth until the symptoms have resolved, and instruction from the Diving Medical Specialist
- Note the time and depth of relief (if relevant).
- After successful treatment, the patient should be held at treatment depth for 6 hours. The decompression can start after green light from the Diving Medical Specialist.

Ascent to surface :

- From 30 to 15 metres, the ascent speed is 60 minutes/metre.
- From 15 metres to surface, the ascent speed is 120 minutes/metre.
- The oxygen percentage must be kept between 20% to 23%.



10.5.5 - Intervention of paramedics inside the chamber

A decompression procedure has been prepared in the case of short intervention of a paramedic inside the chamber. This procedure is as follows:

- Intervention of personnel (400 to 600 millibar PO2 in the chamber).
- Decompress personnel in chamber lock
- Personnel is put on BIBS from the beginning to the end of his decompression. He first breathes Heliox 20/80 and then Oxygen from 12m. to surface.
- If Oxygen stops are not mentioned at 3, 6 or 9 m., the personnel will slowly ascent from his last stop to surface with Oxygen on BIBS in 2 minutes

Chamber depth	Bottom time	Time to first stop	Heliox 20/80	Oxygen	Total decompression (h: min)
			30m - 27m - 24m - 21m - 18m - 15m	12m - 9m - 6m - 3m	
12 metres	90 min	1 min			0:01
20 metres	30 min	1 min		10 - - -	0:13
	60 min	1 min		20 - - -	0:23
	90 min	1 min		30 - - -	0:33
30 metres	30 min	2 min		15 - - -	0:19
	60 min	2 min		30 - 10 - -	0:44
	90 min	1 min	- - - - - 5	30 - 40 - -	1:18
40 metres	30 min	2 min	- - - 3 - 3 - 3	30 - 5 - -	0:48
	60 min	2 min	- - - 5 - 10 - 15	30 - 40 - 30 -	2:14
	90 min	2 min	- - - 5 - 15 - 15	30 - 40 - 50 -	2:39
50 metres	30 min	2 min	- 3 - 3 - 3 - 5 - 10	30 - 40 - -	1:38
	60 min	2 min	3 - 5 - 5 - 10 - 15 - 10	30 - 40 - 50 - 40	3:37
	90 min	2 min	5 - 5 - 15 - 15 - 20 - 30	30 - 40 - 50 - 80	4:54

Obviously, where the intervention is too deep or too long, the paramedic will have to stay in the chamber and be decompressed in saturation with the divers.

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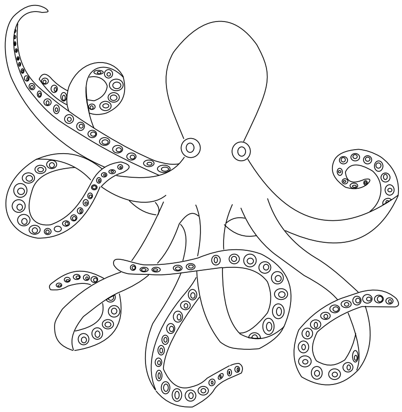

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