CCO Ltd

Diving management studies
Study No 4

Strengthen the US Navy saturation diving procedures

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Document history

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January 2019	Publication to the general public as diving management study #4.
April 2024	Added the study "A review of accelerated decompression from heliox saturation in commercial diving emergencies" Text modifications and improvements

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Tables of contents

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Purpose

Many diving companies use US Navy saturation procedures. However, these procedures need to be strengthened to comply with the latest requirements for preventing problems resulting from commercial divers' exposure to hyperbaric environments.
Due to resource constraints, many companies modify these tables empirically. As a result, analysis of their diving manuals shows that some modifications they propose are not acceptable from a technical and legal standpoint. Consequently, these manuals may be rejected by clients or expose the enterprises implementing the procedures described in these documents to possible legal action in the event of an accident.

The purpose of this study is to demonstrate that it is possible to strengthen the US Navy's saturation procedures by using publications from recognized competent bodies, making them safer and acceptable to all customers.
However, some may feel that further modifications are required. In this case, it is important to remember that other saturation diving procedures have been published and that it is better to select one of these rather than make modifications that change the decompression model itself, which requires that these modifications be made in accordance with the conclusions of the 37th Workshop of the Undersea and Hyperbaric Medical Society on the Validation of Decompression Tables and the ethical principles for medical research involving human subjects from the "Declaration of Helsinki" issued by the World Medical Association.
Another solution is to consult recognized table designers who are aware of all the constraints involved in modifying and creating decompression procedures.

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1) The US Navy saturation procedures

1.1 - Presentation

Most of the saturation procedures published today by the competent bodies are in metric. Among those approved for public release, the US Navy is the only one designed in feet (US measurement system). It is one of the reasons it is the 1st choice of a lot of companies employing personnel who are more familiar with the Imperial or US measurement systems than metric. Another reason is that a lot of divers in activity in the offshore industry were previously military diver who learned diving using these procedures. Also, public releases of the US Navy manual can be easily found for free on the Internet. As a result, the US Navy manual continues to attract a lot of people which some of them are members of the International Marine Contractor Association (IMCA) committee or managers in charge of diving operations of members of the International Association of Oil & Gas Producers (IOGP)

The US Navy saturation procedures revision seven have been published in December 2016. There is no change in this last revision with the previous review (Rev 6) posted the 15th of April 2008, and I must say that there are no significant changes with these procedures since their 1st public release in the US Navy manual revision 4 in January 1999. These public releases are the evolution of the previous versions studied during the sixties and the seventies that were previously distributed more confidentially. For this reason, we can say that these procedures do not integrate the latest researches regarding decompression accidents and problems resulting from long exposures to hyperoxia.

1.2 - Population and types of operation the procedures are designed for

It is important to notice that the US Navy saturation procedures have been originally designed for military purposes and not for underwater work for the petroleum and construction industries.
The US Navy is part of the US department of defence and not the US labour department. Their documents agreed for public release can be used either by commercial divers or recreational divers, and it is up to the users to ensure whether these tables are suitable or not for the activities they have planned.

The population for whom a table is originally designed must be considered to ensure whether the procedure can be used as it is or whether some reinforcements will be necessary to ensure that the table can be used for underwater works in the petroleum industry. It is also important to consider the conditions in which these tables are applicable and by whom.

US Navy is currently the most powerful war navy worldwide *(480 ships of various sizes)*, and they have huge resources to design diving tables and manage them during the operations they are conducting. They do not need overly strict guide lines as they prefer to adapt their procedures according to the circumstances encountered.
It must be understood that the missions of military divers may vary from direct war action to more peaceful jobs such as:

- Perform a variety of diving salvage operations and special diving duties worldwide
- Take part in construction and demolition projects
- Execute search and rescue missions
- Support military and civilian law enforcement agencies
- Serve as the technical experts for diving evolutions for numerous military Special Operations units
- Provide security, communications and other logistics during Expeditionary Warfare missions
- Carry out routine ship maintenance, including restoration and repair

The population of divers for whom these tables have been studied and tested are young and physically trained:

- The recruitment is limited to people 30 years old maximum.
- Minimum physical performances are mandatory.
- They have daily physical training.
- They are medically followed by a centralised medical service.

Powerful Navies have the means to manage critical situations.

- They have a huge infrastructure.
- They have powerful means of communication.
- They have a lot of diving medical specialists (Diving medical officer), and one of them is normally on board the diving vessel in operation.
- They can contact at any time those who have created (or improved) the tables they use.
- They have the personnel to calculate quickly a new table to sort out a problem if necessary.

1.3 - Adaptation for commercial diving activities

The small private companies working for the oil and gas industry are not likely to have the resources to manage their diving personnel with the same efficiency as navies or competent bodies. Most of their divers are older, don't have the physical training of military divers, and work as temporary employees. Thus, it is clear that a decompression procedure adapted for this population of divers and also the type of jobs they are performing should be used.

It must be remembered at all times that it is the responsibility of employers and their representatives to take care of the health and safety of the people they employ. “Health and Safety at Work etc Act 1974 (1974 c 37)” says page 3 / point 2 /”general duties”: *It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety, and welfare at work of all his/her employees.*

The contractor has several solutions to fulfil the requirements above:

- The conception of specific tables is the 1st solution, but it is the most difficult and expensive, as it is necessary to have competent scientists, a wide data base, adequate means of experimentation, and the support of recognised competent bodies to publish it officially. It must be understood that the vast majority of the clients will not accept the use of procedures not certified by an official competent body.
  The scheme below shows the process normally used to create a diving table.

1st step: Create the table

1) Describe the table:
- What type of dive (sat., Surface gas , air…)
- The population (recreational, militaries, workers..)
- The aim: Improvement or new concept…

2) Existing databases analysis:
- It allows to establish which elements of the existing profiles can be improved to reach the aim.
- This analysis will be used to establish the theoretical model.

3) Choice of the theoretical model:
- Define or modify a mathematic model to provide profiles of dives which correspond to the elements selected and improve the weaknesses seen in the database.

4) Equation formatting:
- Calculation of the charge and discharge, stops, ascent speed, successive dives, etc.

5) Verification:
- Analyse the profiles obtained and compare the results to what is expected.

6) Modification of the model:
- It is difficult to create a mathematic model that fully corresponds to what is expected and some adjustment will be necessary. This phase can be long…

7) When the model seems correct, the team is ready for the “validation phase”.

2nd step: Validation

1) Simulation:
- Using systems simulating the human body.

2) Test on a reference population:
- These tests are often performed in laboratories and under medical control using advanced materials like Doppler, medical imaging, samplings, and others.

3) Statistical analysis:
- Analysis are performed on the results of experiments and the dives carried out

4) Equation formatting:
- The model is adjusted based on observation

5) Final validation:
- Everything is considered safe and ready for use and the aim of the table seems reached

6) The team is ready for the “commissioning”.

3rd step: Commissioning & support

1) Commissioning:
- The document is published and support to the operators is organized.

2) Follow up and database:
- Records of the dives performed, particularly those which led to accidents.

3) Database analysis:
- A statistical monitoring is carried out.

4) Minor changes or tune-ups:
- Minor changes and updates are implemented.

5) If necessary, the team launches the process for the study of a new table:
- The new model does not correspond to what was expected and too many changes are needed.
- New discoveries and publications have made this model obsolete.

- The second solution is to select another recognized decompression model more appropriate to the needs of the company. It is the most simple solution. Unfortunately the procedures available may not fulfill the requirements and the philosophy of the company in full.
- The third solution consists of reinforcing an existing recognized decompression model. It is what is done by the majority of the companies using US Navy saturation procedures, and it is the solution described in this study. However, as indicated in the introduction, these reinforcements must be done appropriately.

2) Elements of the US Navy saturation procedures reinforced and justifications.

2.1 - Elements modified

As described in the previous point, the conception of a diving table is a complex process where nothing is made by chance. Also, these procedures are designed by recognised specialists. For this reason, the structure of the original model, notably the gas values and decompression procedures, must not be modified. If you change these elements you create a new table you will have to justify. Also, only guidelines from recognised competent bodies should be introduced.
The table below shows the original procedure and the elements that have been modified for this study.

Steps	Elements to consider	Values or procedure	Modification
Pressurization to 1st storage depth	**PP O_2**	0.44 to 0.48 ATA (446 to 486 mb)	No modification
	PP CO_2	< 0.005 ATA (< 5 mb)	No modification of CO2 values *Indicated values N2 & argon NORSOK Std*
	Establish 1st partial Press oxygen	Compress the chamber at a moderate rate with a helium-oxygen mixture containing less than 21 percent oxygen. For compression depth use the formula: 33 x (PPO2 - 0.21) / O2% x 100	Added stop minimum 20 min and checks of the diving system to be performed at 33 ft (10 m) . *(Source NORSOK standard U-100)* REMOVED: "Compressing the chamber to 36 fsw with air and then use heliox to obtain the bottom mix" - This method is no more used in the industry and can increase the level of nitrogen in the chamber above the recommended values.
	Rate	Starting surface to 60 ft. (0-18m) = 0.5 to 30 ft./min to 250 ft. (76m) = 05 to 10 ft./min to 750 ft. (229m) = 0.5 to 3 ft./min to 1000 ft. (304m) = 0.5 to 2 ft./Min	No modification
Aborted pressurization procedure	**Ref. depth**	Chamber depth	No modification
	Decompression procedure	<u>Using air for initial PPO_2:</u> Depth less than 40ft for 60 min using air = not counted as bottom time. Then use air or heliox table if Heliox has been introduced. <u>Initial compression using Heliox:</u> Use Heliox table as for wet or closed bell dive	No modification
	PP & % O_2	1.5 to 2.8 PPO_2 using BIBs with breaks 5min every 25min. Chamber PPO_2 between 0.16 and 0.25 ATA PPO_2	No modification
Initial storage depth *(continuation next page)*	**PP O_2**	0.44 to 0.48 ATA (446 to 486 mb) Divers can be 06 ATA during excursions	No modification
	PP CO_2	< 0.005 ATA (< 5 mb)	No modification
	Downward excursion	Allowed immediately upon reaching the storage depth. The maximum deepest excursion depth is to be calculated according to storage depth on the "downward excursion limit table 15-7" 4 hours in the water maximum.	- Added 1 or 2 hr rest prior to excursion - Added "standard excursion". Excursion table USN 13-8 become the "maximum excursions". (See explanation after this table) - 5.30 hrs in water for long dives if 3 divers in bell and 30 min break in the bell (*Sources: NORSOK standard U-100/ French decree 15/05/92)*
	Upward excursion	Allowed immediately upon reaching the storage depth. If the diver has not performed any downward excursion within the last 48 hrs., the maximum shallowest excursion depth is to be calculated according to storage depth on the "upward excursion limit table 15-8	- Added 1 or 2 hr rest prior to excursion - Added "standard excursion" : Excursion table USN 13-8 becomes the "maximum excursions". (See explanation after this table) - Added "ideal bell position", and upward excursions to be avoided - 5.30 hrs in water for long dives with 3 divers in bell with 30 min break in the bell.

Steps	Elements to consider	Values or procedure	Modification
Compressing the chamber to deeper storage depth *(continued from previous page)*	**Upward excursion**	If the diver has performed a downward excursion within the last 48 hrs, the deepest excursion depth reached will be considered as storage depth for the calculation of the upward excursion, using the same table.	No modification of the principle of calculation. (*Sources: NORSOK standard U-100/ French decree 15/05/92)*
	PP O2	0.44 to 0.48 ATA (446 to 486 mb)	No modification
	PP CO2	< 0.005 ATA (< 5 mb)	No modification
	Rate	60 to 250 ft. (76m) = 0.5 to 10 ft./min 250 to 750 ft. (229m) = 0.5 to 3 ft./min 750 to 1000ft. (304m) = 0.5 to 2 ft./Min	No modification
Chamber at deeper storage depth than the initial storage depth	**PP O_2**	0.44 to 0.48 ATA (446 to 486 mb) Divers can be 06 ATA during excursions	No modification
	PP CO_2	< 0.005 ATA (< 5 mb)	No modification
	Downward excursion	Allowed immediately upon reaching the storage depth. Maximum deepest depth to be calculated according to storage depth on "downward excursion limit table 15.7". 4 hours in the water maximum.	- Added 1 or 2 hr rest periods prior to excursion, depending on the distances to reach the new storage - Added "standard excursion" . Excursion table USN 15-7 becomes the "maximum excursions". Explanation after this table. - 5.30 hrs in water for long dives with 3 divers in bell with 30 min break in the bell (*Sources: NORSOK standard U-100 or French decree 15/05/92)* No modification of the principle of calculation.
	Upward excursion	Allowed immediately upon reaching the storage depth If the diver has not performed any downward excursion within the last 48 hrs., the maximum shallowest excursion depth is to be calculated according to storage depth of the chamber using the "upward excursion limit table 15.8" If the diver has performed a downward excursion within the last 48hrs, the deepest excursion depth reached will be considered as storage depth for the calculation of the upward excursion, using the same table.	- Added 1 or 2 hr rest periods prior to excursion, depending on the distance to reach the new storage - Added "standard excursion" . Excursion table USN 15-8 becomes the "maximum excursions". Explanation after this table. - Bell preferably above the job site to avoid ascent excursions - 5.30 hrs in water for long dives with 3 divers in bell with 30 min break in the bell (*Sources: NORSOK standard U-100 or French decree 15/05/92)* No modification of the principle of calculation.
Decompressing the chamber to shallower storage depth	**PP & % O_2**	0.44 to 0.48 ATA (446 to 486 mb) until 50 to 36ft % O_2 must be used as reference the last 50 - 36 feet to surface, and must be between 19% and 23% Can be raised to 0.6 ATA approximately 1 hour before the upward excursion, if using the upward excursion procedure to avoid the PP to be lower than 0.44 ATA at the end of the process. In this case, the max PPO_2 should not exceed 0.48 ATA at the end of the process	- Added: Upward excursion prior to decompression not to be used. (*Sources: NORSOK standard U-100)* No modification of the gas values
Decompressing the chamber to shallower storage depth *(continuation next page)*	**PP CO_2**	< 0.005 ATA (< 5 mb)	No modification
	Procedures and rates	Normal decompression procedure : From 1600 to 200 ft = 6 ft/ hr From 200 to 100 ft = 5 ft / hr From 100 to 50ft = 4ft / hr	Upward excursion prior to decompression is not to be used. *(see continuation next page)*

Steps	Elements to consider	Values or procedure	Modification
Decompressing the chamber to shallower storage depth *(continued from previous page)*	**Procedures and rates**	- There must be a total of 8 hours of rest stop, and no more than 16 hrs travel for 24 hrs decompression. The rest stop should be divided in 2 separated periods. - The chamber can be raised to the upward excursion depth reachable using the table 15.8 “upward excursion limits”. - As for the upward excursion calculation, the deeper excursion depth reached the last 48 hrs will be used as storage depth for the calculation of the upward level. - The travel speed to this level must not be faster than 2 ft/min - If the depth planned is above this level, normal decompression procedure can be used after this point. When the upper excursion limit is reached , there must be a “2 hours hold” (stop) at this point before continuing normal decompression at storage less than 200 ft.	The divers apply a period of stabilization before starting the travel to a shallower level or surface. (Depending on the excursion performed before, it can be 8 hrs or 12 hrs) (*Sources: NORSOK standard U-100/ French decree 15/05/92)* No modification of the ascent rates
Chamber at shallower storage depth than the initial storage depth	**PP O_2**	0.44 to 0.48 ATA (446 to 486 mb) Divers can be 06 ATA during excursions	No modification
	PP CO_2	< 0.005 ATA (< 5 mb)	No modification
	Downward excursion	Allowed immediately upon reaching the storage depth. Maximum depth to be calculated according to storage depth on “downward excursion limit table 15.7”	- Added “standard excursion”. Excursion table USN 13-7 becomes the “maximum excursions”. Explanation after this table. - Recommended 1st excursion to be “standard excursion". (*Sources: NORSOK std / French decree 15/05/92)* No modification of the principle of calculation.
	Upward excursion	“If less than 48 hours is spent at the new storage depth, the maximum upward excursion is based on the deepest depth attained in the preceding 48 hours.”	- Added “standard excursion” . Excursion table USN 13-8 becomes the “maximum excursions”. Explanation after this table. - Recommended 1st excursion to be “standard excursion" (*Sources: NORSOK std / French decree 15/05/92)* No modification of the principle of calculation.
Decompressing the chamber to surface *(continuation next page)*	**PP & % O_2**	0.44 to 0.48 ATA (446 to 486 mb) until 50 - 36ft (when % arrived between 19 and 23%). % O2 must be used as reference the last 50-36 feet to surface, and must be between 19% and 23%. Can be raised to 0.6 ATA approximately 1 hour before the upward excursion, if using the upward excursion procedure to avoid the PP from being lower than 0.44 ATA at the end of the process. In this case the max PPO_2 should not exceed 0.48 ATA at the end of the process	No modification of the gas values
	PP CO_2	< 0.005 ATA (< 5 mb)	
	Ascent rates	<u>Standard decompression procedure</u> From 1600 to 200 ft = 6 ft/ hr From 200 to 100 ft = 5 ft / hr From 100 to 50 ft = 4 ft / hr From 50 ft to 0 ft = 3 ft/hr - There must be a total of 8 hours of rest stop, and no more than 16 hrs travel for 24 hrs decompression. The rest stop should be divided in 2 separated periods. - The last stop must be at 4ft for 80 min. duration. Then the ascent to surface is at 1ft/min.	Upward excursion prior to decompression is not to be used. Added a period of stabilization before starting the travel to a shallower level or surface. (Depending on the excursion performed before, it can be 8 hrs or 12 hrs) (*Sources: NORSOK standard U-100/ French decree 15/05/92)* No modification of the ascent rates *(See next page)*

Steps	Elements to consider	Values or procedure	Modification
Decompressing the chamber to surface *(continued from previous page)*	**Ascent rates** *(continued from previous page)*	<u>Using upward excursion procedure:</u> The chamber can be raised to the upward excursion depth reachable using the table 15.8 "upward excursion limits". As for the upward excursion calculation, the deepest excursion depth reached the last 48 hrs will be used as the storage depth for the calculation of the upward level. The travel speed to this level must not be faster than 2 ft/min If the depth planned is above this level, normal decompression procedure can be used after this point. But when the upper excursion limit is reached , there must be a "2 hours hold" (stop) at this point before continuing normal decompression at storage less than 200 ft.	*See modifications on the previous page*
Emergency decompression	**PP O_2**	Calculated according to the post excursion depth: 273 – 1000 ft = 0.6 ATA 204 – 272 ft = 07 ATA 0 – 203 ft = 0-8 ATA % O2 must be used as reference the last 50-36 feet to surface, and must be between 19% and 23%	No modification
	CO_2	< 0.005 ATA	No modification
	Ascent procedure and speed	<u>Using 1st upward excursion procedure:</u> The chamber is raised to the upward excursion depth reachable using the table 15.8 "upward excursion limits". As for the upward excursion calculation, the deepest excursion depth reached the last 48 hrs will be used as storage depth for the calculation of the upward level. The travel speed to this level must not be faster than 2ft/min There must be a "2 hours hold" (stop) at this point before continuing normal decompression. This stop has to be included in the travel time. Then : Ascent 1 foot by 1 foot, at a speed of 1 ft/min max. Apply the following stops each foot reached : <u>Post excursion depth between 0 and 203 ft =</u> 11 min stop each foot reached from 203 to 200 ft 18 min stop each foot reached from 200 to surface <u>Post excursion depth between 204 and 272 ft =</u> 11 min stop each foot reached from 272 to 200 ft 19 min stop each foot reached from 200 to surface <u>Post excursion depth between 273 and 1000 ft =</u> 12 min stop each foot reached from 1000 to 200ft 21 min stop each foot reached from 200 to surface	No modification of the USN procedure DMAC 31 has been added
Decompression sickness *(continuation next page)*	**PPO2**	Chamber at 0.44 to 0.48 ATA (446 to 486 mb) Casualty on Bibs between 1.5 to 2.8 ATA	No modification
	PPCO2	< 0.005 ATA	No modification
	Treatment procedure deco. sickness type 1	<u>If symptoms occurring more than 60min after the dive:</u> - Recompress 5ft by 5ft at a speed of 5ft/min until distinct improvement of symptoms. - When the treatment depth is reached: Diver on bibs 1.5 to 2.8 ATA O2 with 5min air break every 5 min	No modification

Steps	Elements to consider	Values or procedure	Modification
Decompression sickness *(continued from previous page)*	**Treatment procedure deco. sickness type 1** *(continued from previous page)*	- Hold 2 hours on treatment mix and at treatment depth after resolution of symptoms - NO upward excursion is allowed following the treatment - Decompression can be resumed using only standard decompression procedure <u>If symptoms occurring less than 60 min after the dive:</u> - Recompress 5 ft by 5 ft at a speed of 5 ft/min until distinct improvement of symptoms. When the treatment depth is reached: Diver on bibs 1.5 to 2.8 ATA O2 / 5 min air break every 5 min - Hold at least 2 hours on treatment mix - The casualty shall remain 12 hrs at treatment depth after resolution of symptoms - NO upward excursion allowed following the treatment - Decompression can be resumed using only standard decompression procedure	No modification
	Treatment procedure deco. sickness type 2	- Recompress 5 ft by 5 ft at a speed of 5 ft/min until distinct improvement of symptoms. When the treatment depth is reached: Diver on bibs 1.5 to 2.8 ATA O2 / 5 min air break every 5 min - Hold at least 2 hours on treatment mix - The casualty shall remain 12 hrs at treatment depth after resolution of symptoms - NO upward excursion allowed following the treatment - Decompression can be resumed using only standard decompression procedure	No modification
Post decompression	**Vicinity of chamber**	Direct vicinity: 2 hrs At less than 30 min: 48 hrs	No modification
	No Fly	72 hrs	No modification
	Next dive	Not indicated	Added DMAC 21 "*The duration of saturation exposures and surface intervals following saturations*"
Other elements	**Dive profiles**	Not indicated	Added: U profiles are recommended W profiles possible only when agreed by all parties (*Sources: NORSOK standard U-100/ French decree 15/05/92)*
	Storage limit	According to the excursion tables 850 fsw (249 m)	Limited to 590 fsw (180 m) for standard operations. The operation below this level are considered "special" operations. (*Sources: NORSOK standard U-100/ French decree 15/05/92)*
	Ascent rates during excursions	Limited to 60 ft/min	60 ft/min conserved as maximum rate, but 33 ft/min recommended (*Source: NORSOK standard U-100)*

Note regarding the standby period before flying:
A lot of companies implement DMAC 7 in place of the original value USN in their procedures. This is incorrect as the procedure USN is more restrictive. DMAC 7 has been published by the Diving Medical Advisory Committee (DMAC) to provide a minimum to be applied. However, in the case that the procedure provided by the selected table is more restrictive, this procedure must be applied.
Note that the common rule of safety organization is that where conflicts arise between requirements, the more stringent requirement should take precedence.

2.2 - Justifications of particular modifications

2.2.1 - Excursion limits

As indicated previously, the US Navy tables have been developed to fulfill military requirements, which are not exactly those of the diving industry, Also these procedures have not been changed for more than two decades. It must be noted that the maximum excursion limits proposed are not appropriate for divers doing hard work and have the potential to trigger decompression accidents. Note that in their book “Saturation Diving; Physiology and Pathophysiology” Brubakk, Ross, and Thom say the following in chapter “Decompression tables for saturation diving”: The U.S. Navy’s *“Unlimited Excursion” tables have been tested in excursions from 300 to 250 msw. This study showed that all the divers had large amounts of vascular gas bubbles in the carotid artery, the blood vessel that supplies the brain. None of them, however, showed acute clinical symptoms. The arterial bubbles formed had a long life bubbles were observed 23 h after the excursion ended.”*
Scientists involved in the calculation of decompression tables say that these excursions should be limited. As a result of these recommendations, a lot of companies reduce the excursions limits of their divers to 50% or 70% of the US Navy ones.
However, these limitations of 50% and 70% are empiric and not officially published by a competent body. For this reason, the Health and Safety ministries of some countries have requested the study of suitable excursion limits for the operations carried out in the petroleum industry. The NORSOK standard U-100 excursion limits are the result of these studies in Norway. These limitations are the safest limitations with those of COMEX MT 92 *(French decree of 15th of may 1992)* and NORMAM-15/DPC that are the development of the procedures MT 92. They have been studied for the Brazilian Navy and are currently in force in this country.
As these excursion limits have been studied by two teams not working together are very similar, we can consider that they are not far from the truth.
The tables below and the next page show the comparison of the excursions NORSOK and MT92/COMEX

Comparison downward excursions COMEX MT92 - NORSOK U-100 revision 4							
COMEX and NORSOK life level	**Distance excursion COMEX**	**NORSOK distance excursion**	**Difference**	**COMEX and NORSOK life level**	**Distance excursion COMEX**	**NORSOK distance excursion**	**Difference**
10	5		5	**97**	10	10	0
12	5	3	2	**101**	11	11	0
15	6	4	2	**104**	11	11	0
18	6	5	1	**107**	11	11	0
21	7	5	2	**110**	11	11	0
24	7	5	2	**113**	11	11	0
27	7	7	0	**116**	11	11	0
30	7	7	0	**119**	11	11	0
33	7	7	0	**122**	12	12	0
37	8	8	0	**125**	12	12	0
40	8	8	0	**128**	12	12	0
43	8	8	0	**131**	12	12	0
46	8	8	0	**134**	12	12	0
49	8	8	0	**137**	12	13	-1
52	8	8	0	**140**	13	13	0
55	8	8	0	**143**	13	13	0
58	8	9	-1	**146**	13	13	0
61	9	9	0	**149**	13	13	0
64	9	9	0	**152**	13	13	0
67	9	9	0	**155**	13	13	0
70	9	9	0	**158**	13	13	0
73	9	9	0	**161**	14	13	1
76	9	9	0	**165**	14	13	1
79	9	10	-1	**168**	14	13	1
82	10	10	0	**171**	14	13	1
85	10	10	0	**174**	14	13	1
88	10	10	0	**177**	14	13	1
91	10	10	0	**180**	15	13	2
94	10	10	0				

Comparison upward excursions COMEX MT92 - NORSOK U-100 revision 4							
COMEX and NORSOK life level	**Distance excursion COMEX**	**NORSOK distance excursion**	**Difference**	**COMEX and NORSOK life level**	**Distance excursion COMEX**	**NORSOK distance excursion**	**Difference**
10	1		1	**10**	10	10	0
12	3	0	3	**11**	10	11	-1
15	5	1	4	**11**	10	11	-1
18	5	4	1	**11**	10	11	-1
21	6	4	2	**11**	10	11	-1
24	6	5	1	**11**	11	11	0
27	7	5	2	**11**	11	11	0
30	7	6	1	**11**	11	11	0
33	7	7	0	**12**	11	12	-1
37	7	7	0	**12**	11	12	-1
40	7	8	-1	**12**	11	12	-1
43	7	8	-1	**12**	11	12	-1
46	7	8	-1	**12**	12	12	0
49	8	8	0	**12**	12	13	-1
52	8	8	0	**13**	12	13	-1
55	8	8	0	**13**	12	13	-1
58	8	8	0	**13**	12	13	-1
61	8	9	-1	**13**	12	13	-1
64	8	9	-1	**13**	12	13	-1
67	8	9	-1	**13**	13	13	0
70	9	9	0	**13**	13	13	0
73	9	9	0	**13**	13	13	0
76	9	9	0	**13**	13	13	0
79	9	9	0	**13**	13	13	0
82	9	10	-1	**13**	13	13	0
85	9	10	-1	**13**	14	13	1
88	9	10	-1	**13**	14	13	1
91	10	10	0	**13**	14	13	1
94	10	10	0				

Note that the differences do not exceed 2 metres, except for 12 and 15 m upward excursions, and that most of the distances are nearly identical. A negative difference indicates that MT92/COMEX is more stringent, and a positive result, the inverse.

The difference between the COMEX excursion limits and those from NORSOK standards is that, in addition to the standard excursions, COMEX provides maximum excursions that can be used for light jobs or in the case of an emergency. I Have used the same principle for the creation of the combined table described below:

- To comply with the recommendations indicated above, I have considered that the excursion at work should be reduced in the limits recommended by NORSOK and the French decree of 15th of May 1992, but on the other hand I have considered unnecessary to remove the excursion limits given by the US Navy which may be used in specific circumstances. Thus, instead reducing the boundaries of the original excursion tables 13-7 & 13-8 USN *(pages 683 & 684 of the manual)*, as practiced by some companies, I have organised a similar system like the one in place with the COMEX /MT 92 which propose two types of excursions:
  - The "standard excursions" are the recommended limits for underwater works *(activities with physical efforts)*.
  - The "maximum excursions" can be used in case of emergency or for light jobs not requiring physical activity other than moving in calm waters *(observation jobs)*.

  Thus, in the scope of this manual, the excursion limits recommended by NORSOK U-100 are considered "standard excursion limits", and the "maximum excursion limits" are the US Navy tables 13-7 & 13-8.
- The Standard excursions have been added on the side of the original excursion tables USN. Apart from this modification, and the depths above 50 ft (15 m) that have been removed, because they were not considered suitable by NORSOK and MT92/COMEX, the presentation remains exactly the same as the original.
  Note that the copy of the original USN table has been performed using a specific software to ensure a perfect conformance.

- The original presentation US Navy includes:
  - The storage depth (life level)
  - The shallowest or deepest excursion distance (Maximum excursion distance)
  - The shallowest or deepest depth (Maximum excursion level)

Table 13-7. *Unlimited Duration Downward Excursion Limits.*

Storage Depth (fsw)	Deepest Excursion Distance (ft)	Deepest Excursion Depth (fsw)	Storage Depth (fsw)	Deepest Excursion Distance (ft)	Deepest Excursion Depth (fsw)
0	29	29			
10	33	43	410	106	516
20	37	57	420	107	527
30	40	70	430	108	538
40	43	83	440	109	549
50	46	96	450	111	561

- The combined table has the same presentation with, in addition, the standard excursion distances and the standard excursion depth.

Because the US Navy table is designed in Imperial, the standard excursions, originally in metric, have been converted into feet.

Upward excursions				
Storage Depth (fsw)	Maximum upward Excursion Distance (ft)	Maximum upward Excursion Depth (fsw)	Standard upward excursion distance (fsw)	Standard upward excursion depth (fsw)
50	35	15	10	40
60	37	23	13	47
70	40	30	13	57
80	42	38	16	64
90	44	46	16	74
100	47	53	20	80

$\underbrace{\text{Maximum upward Excursion Distance / Depth}}_{\text{Maximum excursions (tables 13-7 \& 13-8 USN)}}$ $\underbrace{\text{Standard upward excursion distance / depth}}_{\text{Standard excursions (NORSOK excursions)}}$

Maximum excursions
(tables 13-7 & 13-8 USN)

Standard excursions
(NORSOK excursions)

NOTE: The excursion tables are displayed in the chapter 5 “Excursions during the bell runs”. Also, note that NORSOK U 100 limits the storage of the divers to 180 metres.

2.2.2 - Rest times after compression

NORSOK U-100 / point 8.2.3.2 recommends a rest time of 1 hour prior to excursion after a compression in a depth range from 0 to 89 m, and 2 hours in a depth range from 90 msw to 180 msw. This procedure has been introduced as a safety precaution. To recover the 1 m missing in the guidance NORSOK (note that 90-89=1), the rule has been changed to < 90 m (295 fsw) and > 90 < 180 m. Because the US Navy table is in feet, the distances have been converted to feet .

To be consistent, it must be considered that this precaution should also apply for depth storage change, as for example a 1st storage at 20 m and a 2nd storage at 100 m equals 80 m . For relocation of the storage depth, it has been considered that the distance of compression should be considered instead of the depth, thus:

- If the distance from the initial storage depth is less than 295 ft (90 m), there should be a rest period of 1 hour.
- If the distance is more than 295 ft, and the storage depth less than 590 ft (180 m), the rest period should be 2 hours.
- As the maximum storage depth indicated in NORSOK U100 is 180 metres, there are no stabilization times indicated for depths beyond this limit. Note that NORMAM-15/DPC says 6 hours stabilization between 181 and 240 metres and at least 12 hours stabilization between 241 and 300 m. However diving operations at more than 200 metres must be considered specific operations which request huge means of organization. For these reasons, NORSOK U100, The French decree 15/05/92 (tables MT 92), and a lot of petroleum companies limit their normal saturation operations to 180 - 200 m.

Again for consistency, the rules must be adapted for small storage depth changes:
Because increasing the chamber storage depth during a bell run when the divers are conducting a downward excursion is permitted as long the chamber depth doesn’t exceed the downward excursion depth *(French decree 05/92)*, it is logical to consider that if the new storage depth doesn’t exceed the downward excursion limits from the initial storage depth, excursions are permitted immediately upon reaching the new storage depth.
This point is explained more in point 5.7 “Excursion after a change of storage depth”

2.2.3 - Rest times prior to decompression

NORSOK U-100 / point 8.2.3.4 recommends a rest time of 8 hours at living depth prior to decompression after an excursion, and in addition, French decree of 05/92 page 361/point 5.3 recommends 12 hours at living depth prior to decompression after a maximum excursion. These rules are discussed in this study.

Nevertheless for consistency, it has been considered that if the decompression is to readjust the chamber at a depth slightly above the initial storage depth, the stabilisation period can be considered not necessary if the new storage depth is within the upward excursion limits from the deepest depth attained in the previous 48 hrs.

2.2.4 - Saturation profiles

The US Navy manual does not provide guide lines regarding the saturation profiles. As a result, a lot of companies commonly expose their divers to successions of compression and decompression to readjust the chamber at various storage levels according to the needs of their clients.
Profiles where the divers were exposed first to the deepest depth, then returned close to the surface, and then returned to the deepest or an intermediate depth have been reported. Such practices which may result in decompression accidents should be prohibited.
For this reason recommendations from NORSOK U 100 and MT92/Comex are explained and suggested.

2.3 - Summary

The US Navy procedures selected in the scope of this study have not been modified. The compression and decompression procedures remain the same, and the gas values recommended have not been changed.
It must be remembered that US Navy indicates chapter 13 / point 13/14 DDC and dive bell atmosphere control:
Oxygen levels and time limits are essential for safe decompression and the use of the Unlimited Duration Excursion Tables. Increases in the oxygen partial pressure above 0.6 ata for extended periods (greater than 24 hours) risk pulmonary oxygen toxicity and should only be used in emergency situations. A ppO_2 below 0.42 ata may result in inadequate decompression, and a ppO_2 below 0.16 ata will result in hypoxia….
The only modifications are the recommendation of precautions which increase the safety of the initial procedure in the points where there were no particular guidance from the designer.
As already explained point 2.1, changing the values and procedures indicated above results in the creation of a new table that must be justified and approved by a competent body.

To finish, this presentation, the points where the US Navy procedures are the most stringent have been conserved with the recommendation to apply these procedures and not other procedures commonly used. As an example, US Navy diving manual requires that *"Divers shall remain in the immediate vicinity of a chamber for 2 hours and within 30 minutes travel of a chamber for 48 hours after the dive"*. Also, 72 hours surface interval is necessary before authorizing a diver to fly. These recommendations are far more stringent than those from DMAC 7 that are applied by a lot of teams. Not complying with these recommendations US Navy should be considered a breach regarding the respect of the initial decompression procedure.

Note: The US Navy saturation procedures published in the US Navy manual revision 7 are based on heliox and should not be used for air saturation, or saturation with trimix gases.

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

3.1 - Gas quality

A reclaim system similar to those described previously, should ensure a perfect quality of the gas delivered to the divers. Nevertheless, contamination or unexpected changes of the proportion of O2/He due to technical problems may happen.

- Some possible sources of contamination are listed below:
  - Impurities in pipework
  - Oil leakage in compressors
  - Overheating or burning of electrical insulation or other materials
  - Electrical arcing
  - Contaminants associated with the diving operation
  - Nitrogen (or other gas) introduced during maintenance of the system during the operations: For example, when a bell or a chamber is brought to surface for maintenance, its content of nitrogen at the surface will be introduced in the circuit when the bell will be pressurised to depth.

- The system may be broken down into the following sections:
  - Diver Equipment
  - Bell Exhaust Equipment
  - Reprocessing Unit
  - Electric Gas Booster
  - Gas Storage and Supply
  - Control Console

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:
  - Reclaimed gases shall be analysed for O_2 and CO_2 content and other possible contaminants (including, but not limited to N_2, CO, VOC) prior to their re-use. Results shall be < 0,1 HEL.
  - O_2 and CO_2 shall be continuously monitored
  - As it is not possible to electronically/chemically monitor for all possible contaminants, the benefits of human sensation by olfactometry (odour, smell) shall be facilitated, by having at least two trained persons from the surface crew, checking the gas of each living compartment at least once a day, according to guidance in EN 13725, ISO 13301.

- Analysis can be carried out using the tools described in the chapter 4 “gas analysis”. For remembering:
  - The 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). The principles of work of these devices are explained in the chapter 4.
  - N_2 can be monitored using or 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. Notice that OGP requires equipment that can measure hydrocarbon contamination of an equivalent or greater specification to the “Analox Hypergas 2”. This equipment to be capable of alarming and notifying both the Surface Diving Supervisor and the chamber inhabitants of contamination of the breathing atmosphere. This equipment should be activated at all times.

- Every analyser should be calibrated on a regular basis according to national regulations and manufacturers’ instructions. Calibration must be carried out according to the manufacturer’s instructions, but the following general procedures apply:
  - As far as possible, calibrate the instrument in the position in which it will be used. A change of angle or local electromagnetic fields may affect readings.
  - For the instruments using fuel cells, ensure that the cell is still valid and will not give erratic readings.
  - With power off, set the mechanical zero, usually using a screw on the face of the dial. This does not apply to digital instruments.
  - Switch the instrument on and allow it to warm up if necessary.
  - Check in-line filters. Most instruments require a dry gas sample and should have a silica gel filter or similar in-line. Analysis for unusual gases may require additional filters.

- Most analysis equipment actually measures the partial pressure of the gas concerned, although the reading may be given as a partial pressure, percentage, or part per million.

Chemical sampling tubes are calibrated specifically to give a percentage or ppm (parts per million) reading at surface pressure and a correction must be applied if they are used under pressure:

- 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 partial pressures of O_2 indicated in the saturation diving procedures of the US Navy manual are as follows:

Action	Partial pressure O2
Pressurisation to 1st storage depth	0.44 to 048 ATA (446 to 486 mb) 0.60 ATA accepted at the arrival at the storage depth
Aborted pressurization	1.5 to 2.8 bar PPO2 on BIBS Chamber at 0.16 to 0.25 PP O2
Initial storage depth	0.44 to 0.48 ATA (446 to 486 mb) Divers can be 0.6 ATA during excursions
Compressing the chamber to deeper storage depth	0.44 to 0.48 ATA (446 to 486 mb)
Chamber at deeper storage depth than the initial storage depth	0.44 to 0.48 ATA (446 to 486 mb) Divers can be 0.6 ATA during excursions
Decompressing the chamber to shallower storage depth	0.44 to 0.48 ATA (446 to 486 mb) until 50 to 36ft % O_2 must be used as reference the last 50 - 36 feet to surface, and must be between 19% and 23%
Chamber at shallower storage depth than the initial storage depth	0.44 to 0.48 ATA (446 to 486 mb) Divers can be 0.6 ATA during excursions
Decompressing the chamber to surface	0.44 to 0.48 ATA (446 to 486 mb) until 50 - 36ft (when % arrived between 19 and 23%) % O2 must be used as reference the last 50-36 feet to surface, and must be between 19% and 23%
Emergency decompression	Calculated according to the post excursion depth : 273 – 1000 ft = 0.6 ATA 204 – 272 ft = 07 ATA 0 – 203 ft = 0-8 ATA

IMPORTANT: 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 pO_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. 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.

3.2 - 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.

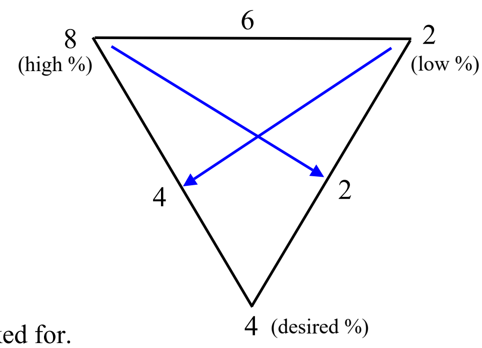
- Example:

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 :

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

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

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

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

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

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

% weak mix = 2

% rich mix = 16

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

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

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

$= \dfrac{457}{14} = 32.6$ 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:

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 m^3

Pressure added = 150/10 = 15 bar gauge

Free gas volume = 40 x 15 = 600 m^3

600 m^3 of gas is required

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

Free gas volume = chamber volume x pressure added

Pressurisation on 12%

Floodable volume = 30 m^3

Pressure added = 21/10 = 2.1 bar gauge

Free gas volume = 30 x 2.1 = 63 m^3

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

Free gas volume = 30 x 6.9 = 207 m

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

- *Example #3* *using imperial system:*
A chamber system has a volume of 1,200 ft^3 . What volume of gas would it take to pressurise it to 500 fsw?

Free gas volume = chamber volume x pressure added

Chamber volume = 1,200 ft^3

Pressure added = 500/33 = 15.15 ata

Free gas volume =1,200 x 15.15 = 18,180 ft^3

18,180 ft^3 of gas is required

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:

$$ppO_2 \text{ added (mb)} = \text{depth added (msw)} \times \text{percentage}$$

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 m³ 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 m³ 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 m³. How much oxygen is used?

- Metabolic use: 2 divers x 2 days x 0.72 m³ = 2.88 m³
- 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 m³
  2.35 *(from calculator)* x 0.6 x 10 = 14.1 m³
- Total oxygen: 2.88 + 14.1 = 16.98 m³

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.

Saturation 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.

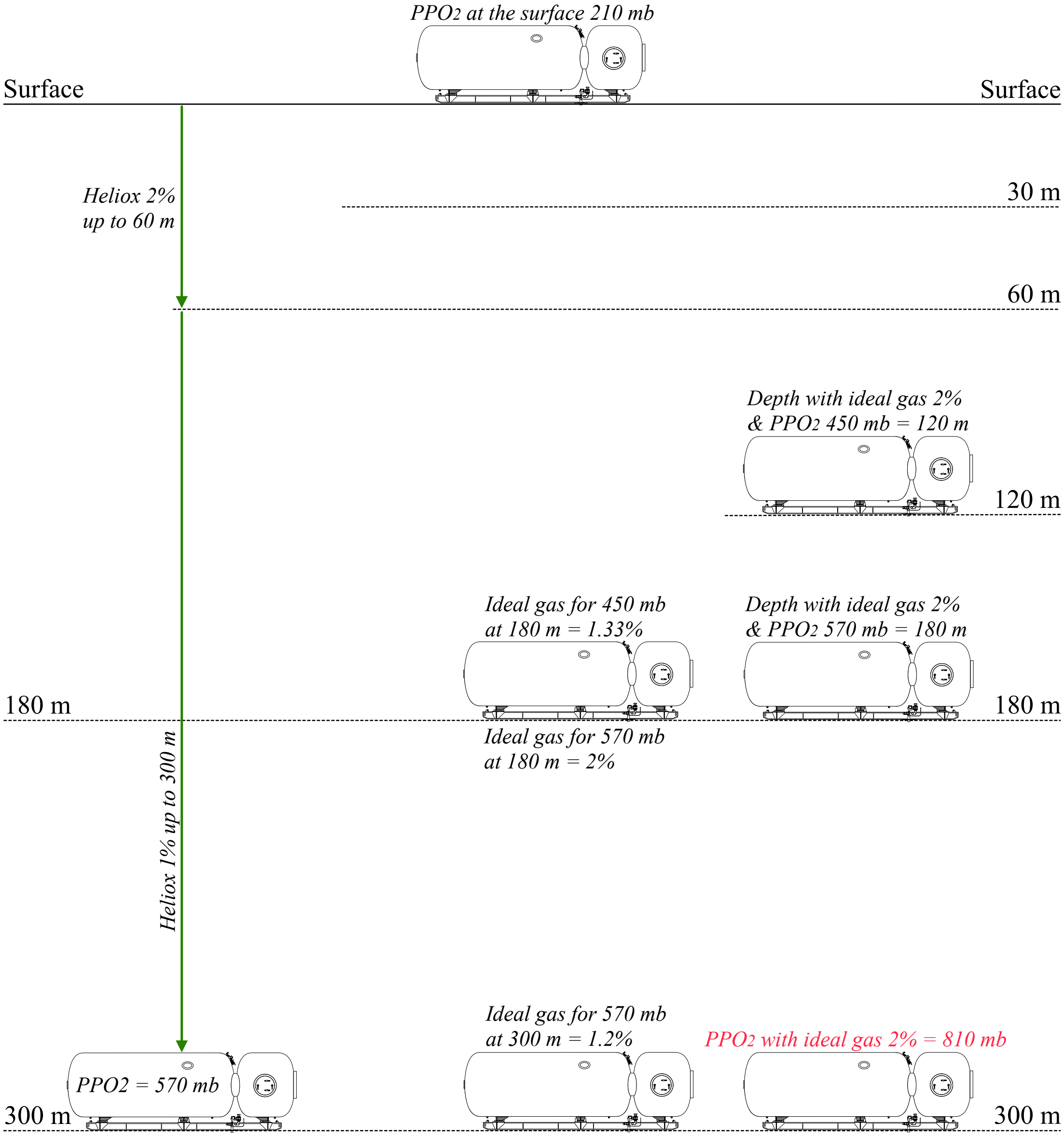
DMAC 5 says: *"DMAC endorses the recommendation that an oxygen and helium mixture should be used in place of pure helium supplied to offshore diving installations. (It is recognised however that contractors may need to use pure helium as a calibration gas.)*
The choice of mixture supplied should be left 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

Note that the depth of 195 m is possible with mixes of 2% 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 as explained in point 3.2.2



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 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 analyse the mixtures and give readings in % with decimals or in Part Per Million (PPM), which is more appropriate when dealing with small decimals values.

4) Pressurisation

The procedure to calculate the chamber atmosphere is explained in the previous chapter

4.1 - Initial seal and beginning of pressurization

The procedure consists to establish an initial seal, then pressurize the chamber to 33 ft (10 m), 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.
Two options 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 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.

4.2 - Descent to 1st storage depth

4.2.1 - US Navy recommends the following values

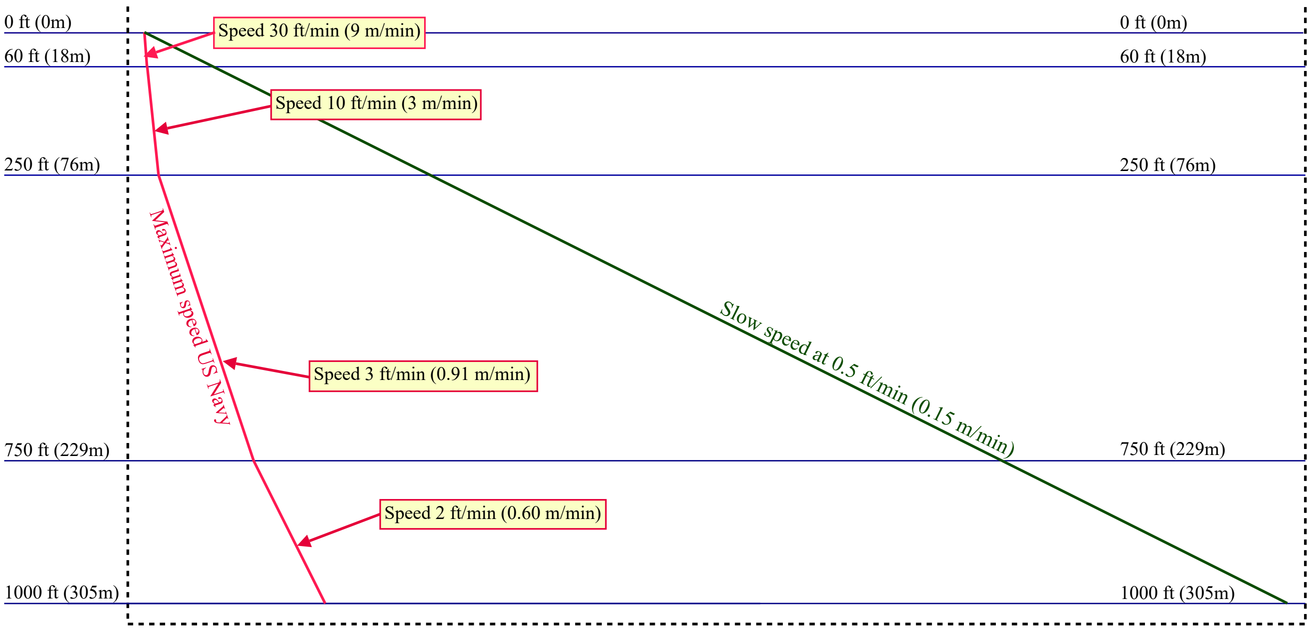
- Gas parameters:

PP O2: 0.44 to 0.48 ata (446 to 486 mb)

PP CO2 : < 0.005 ata (< 5 mb)

- Compression rates:

0 to 60 ft. (0-18m) → 0.5 to 30 ft./min (0.15 to 9 m/min)
60 to 250 ft. (18 to 76m) → 0.5 to 10 ft./min (0.15 to 3 m/min)
250 to 750 ft. (76 to 229m) → 0.5 to 3 ft./min (0.15 to 0.91 m/min)
750 to 1000 ft. (229 to 304m) → 0.5 to 2 ft./min (0.15 to 0.60 m/min)



Curves of maximum and minimum allowable compression rates US Navy

4.2.2 - Recommendation to select the compression rate

Rapid compression to saturation storage depth may provoke symptoms of High-Pressure Nervous Syndrome (HPNS) and may intensify compression joint pains. To avoid these complications, the slowest rate of compression consistent with operational requirements should be used.

If operational necessity dictates, compression to storage depth of 400 fsw or shallower can be made at the maximum rates indicated with little risk of HPNS. Direct compression at maximum rates to deeper storage depths, however, may produce symptoms of HPNS in some divers. These divers may be unable to perform effectively for a period of 24 to 48 hours. Experience has shown that the appearance of such symptoms can be minimized by slowing compression rates or introducing holds during compression. The depth and time duration of holds, if used, may be adjusted to suit operational requirements and diver comfort.

4.2.3 - Incidents during the pressurization

If a problem occurs during the pressurization, the compression must be aborted and the divers recovered to the surface. The procedure proposed in the US Navy manual consists of using the surface orientated tables HeO_2. It is normally used for shallow aborts where the maximum depth and bottom time do not exceed the limits of the table. US Navy says that the following parameters should be applied:

- ***Depth:*** Use the actual chamber depth.
- ***Bottom Time:*** It starts when leaving the surface.
- ***BIBS Gas:*** Maintain BIBS between 1.5 – 2.8 ppO_2
- ***Stops:*** Follow the scheduled stops of the Surface Supplied HeO_2 Tables.
- ***O2 Breaks:*** For every 25 minutes of breathing BIBS gas, take a 5-minute break breathing a gas between 0.16 to 1.25 ata ppO_2 . The 5-minute break counts as a stop time.
- ***Oxygen percentage:*** The lower oxygen percentage shall not be less than 0.16 ata ppO_2.
- **Note:** Upon completing abort decompression, all divers shall be closely monitored and observed for a minimum of 24 hours. For deeper emergency aborts beyond the limits of the surface-supplied HeO_2 Tables, refer to chapter 9 “Emergency decompression”

  IMPORTANT:
  For any aborted pressurisation, the diving superintendent and the Diving medical specialist must be informed.
  The decision to use an emergency decompression procedure must be decided after careful consideration. Specifically, it must be determined if the time saved will benefit the diver’s life despite the increased risks, and whether the emergency abort procedure can be supported logistically.
  Note that the tables used have bottom times that are limited to two hours.

Decompression Stops (fsw)

Stop times (min) include travel time, except first HeO_2 and first O_2 stop

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	Chamber O_2 Periods
			BOTTOM MIX										50% O_2						100% O_2		
100	10	3:20																		0	0
	15	3:20																		0	0
	20	2:00																10	11	17	1
	30	2:00																10	15	24	2
Max O_2=32.3%	40	2:00																10	18	32	2
Min O_2=14.0%	60	2:00																10	25	44	3
	80	2:00																10	28	52	3
	100	2:00																10	31	56	3
	120	2:00																10	32	58	3
110	10	2:20																10	8	11	1
	20	2:20																10	12	20	1
	30	2:20																10	17	28	2
	40	2:20																10	20	36	2
Max O_2=30.0%	60	2:20																10	27	49	3
Min O_2=14.0%	80	2:20																10	31	58	3
	100	2:20																10	33	62	4
	Exceptional Exposure																				
	120	2:20																10	35	64	4
120	10	2:40																10	9	13	1
	20	2:40																10	14	23	2
	30	2:40																10	19	33	2
	40	2:40																10	23	42	3
Max O_2=28.0%	60	2:40																10	30	55	3
Min O_2=14.0%	80	2:40																10	34	63	4
	100	2:40																10	36	66	4
	Exceptional Exposure																				
	120	2:40															10	10	35	65	4
130	10	2:40															10	10	6	8	1
	20	2:40															10	10	12	19	1
	30	2:40															10	10	18	30	2
	40	2:20														7	10	10	22	40	3
Max O_2=26.3%	60	2:20														7	10	10	29	52	3
Min O_2=14.0%	80	2:20														7	10	10	33	60	3
	Exceptional Exposure																				
	100	2:20														7	10	10	35	64	4
	120	2:20														7	11	11	35	66	4

Decompression Stops (fsw)

Stop times (min) include travel time, except first HeO_2 and first O_2 stop

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	Chamber O_2 Periods
			BOTTOM MIX										50% O_2						100% O_2		
140	10	3:00															10	10	6	8	1
	20	3:00															10	10	12	19	1
	30	3:00															10	10	18	30	2
	40	2:40														7	10	10	22	40	2
Max O_2=24.8%	60	2:40														7	10	10	29	52	3
Min O_2=14.0%	80	2:40														7	10	10	33	60	3
	Exceptional Exposure																				
	100	2:40														7	10	10	35	64	4
	120	2:40														7	11	11	35	66	4
150	10	3:20															10	10	7	8	1
	20	3:00														7	10	10	14	22	2
	30	3:00														7	10	10	19	34	2
	40	3:00														7	10	10	24	44	3
Max O_2=23.4%	60	3:00														7	10	10	31	56	3
Min O_2=14.0%	80	3:00														7	10	10	35	64	4
	Exceptional Exposure																				
	100	3:00														7	13	13	36	66	4
	120	3:00														9	16	16	36	66	5
160	10	3:20														7	10	10	8	10	1
	20	3:20														7	10	10	15	24	2
	30	3:20														7	10	10	21	37	2
	40	3:20														7	10	10	26	47	3
Max O_2=22.2%	60	3:00													7	6	10	10	30	56	3
Min O_2=14.0%	**Exceptional Exposure**																				
	80	3:00													7	9	10	10	35	66	4
	100	3:00													7	13	14	14	35	66	5
	120	3:00													7	17	17	17	36	66	5
170	10	3:20													7	0	10	10	8	12	1
	20	3:20													7	0	10	10	16	28	2
	30	3:20													7	1	10	10	23	42	3
	40	3:20													7	4	10	10	28	52	3
Max O_2=21.1%	60	3:20													7	10	10	10	33	62	4
Min O_2=14.0%	**Exceptional Exposure**																				
	80	3:20													9	14	14	14	35	66	4
	100	3:00												7	5	18	18	18	36	66	5
	120	3:00												7	9	21	21	21	36	66	5

Decompression Stops (fsw)

Stop times (min) include travel time, except first HeO_2 and first O_2 stop

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	Chamber O_2 Periods
			BOTTOM MIX										50% O_2						100% O_2		
180	10	3:40													7	0	10	10	9	14	1
	20	3:40													7	0	10	10	17	30	2
	30	3:40													7	4	10	10	25	45	3
	40	3:20												7	0	8	10	10	30	54	3
Max O_2=20.1%	60	3:20												7	5	11	11	11	35	64	4
Min O_2=14.0%	**Exceptional Exposure**																				
	80	3:20												7	9	15	15	15	36	66	4
	100	3:20												7	13	19	19	19	36	66	5
	120	3:20												7	17	23	23	23	36	66	6
190	10	4:00													7	0	10	10	10	15	1
	20	3:40												7	0	2	10	10	19	34	2
	30	3:40												7	0	7	10	10	26	46	3
	40	3:40												7	4	9	10	10	31	56	3
	Exceptional Exposure																				
Max O_2=19.2%	60	3:40												7	9	13	13	13	34	62	4
Min O_2=14.0%	80	3:20											7	3	13	18	18	18	36	66	5
	100	3:20											7	6	16	21	21	21	36	66	6
	120	3:20											7	8	20	23	23	23	36	66	7
200	10	4:00												7	0	0	10	10	11	17	1
	20	4:00												7	0	4	10	10	20	36	2
	30	3:40											7	0	3	7	10	10	27	50	3
	40	3:40											7	0	7	10	10	10	31	58	3
	Exceptional Exposure																				
Max O_2=18.4%	60	3:40											7	4	10	14	14	14	35	66	4
Min O_2=14.0%	80	3:40											7	8	14	18	18	18	36	66	5
	100	3:40											7	12	17	23	23	23	36	66	6
	120	3:40											8	15	21	23	23	23	36	66	7
210	10	4:20												7	0	0	10	10	12	19	1
	20	4:00											7	0	1	6	10	10	22	38	2
	30	4:00											7	0	6	7	10	10	29	53	3
	40	4:00											7	3	9	10	10	10	33	60	3
	Exceptional Exposure																				
Max O_2=17.7%	60	3:40										7	0	9	11	17	17	17	35	66	5
Min O_2=10.0%	80	3:40										7	3	11	15	20	20	20	36	66	6
	100	3:40										7	6	14	19	23	23	23	36	66	7
	120	3:40										7	8	18	23	23	23	23	36	66	7

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	Chamber O_2 Periods
			Decompression Stops (fsw) Stop times (min) include travel time, except first HeO_2 and first O_2 stop																		
			BOTTOM MIX										50% O_2						100% O_2		
220	10	4:40												7	0	2	10	10	13	20	1
	20	4:20											7	0	3	7	10	10	23	41	3
	30	4:20											7	2	6	9	10	10	30	54	3
	40	4:00										7	0	6	9	11	11	11	34	62	4
	Exceptional Exposure																				
Max O_2=17.0%	60	4:00										7	4	9	12	18	18	18	36	66	5
Min O_2=10.0%	80	4:00										7	8	12	17	21	21	21	36	66	6
	100	4:00										7	12	15	20	23	23	23	36	66	7
	120	4:00										8	14	19	23	23	23	23	36	66	8
230	10	4:40											7	0	0	3	10	10	14	22	2
	20	4:20										7	0	3	4	7	10	10	24	44	3
	30	4:20										7	0	5	7	10	10	10	31	57	3
	40	4:00									7	0	3	7	9	13	13	13	34	64	4
	Exceptional Exposure																				
Max O_2=16.3%	60	4:00									7	0	8	10	14	18	18	18	36	66	6
Min O_2=10.0%	80	4:00									7	3	10	14	18	23	23	23	36	66	7
	100	4:00									7	6	12	17	23	23	23	23	36	66	8
	120	4:00									7	7	16	19	23	23	23	23	36	66	8
240	10	4:40										7	0	0	3	4	10	10	14	24	2
	20	4:40										7	0	3	5	7	10	10	25	46	3
	30	4:20									7	0	3	6	7	10	10	10	32	58	3
	40	4:20									7	0	5	8	9	14	14	14	35	64	4
	Exceptional Exposure																				
Max O_2=15.7%	60	4:20									7	4	8	11	14	19	19	19	36	66	6
Min O_2=10.0%	80	4:20									7	7	11	16	18	23	23	23	36	66	7
	100	4:20									7	10	14	19	23	23	23	23	36	66	8
	120	4:00								7	3	12	17	19	23	23	23	23	36	66	8
250	10	5:00										7	0	0	3	4	10	10	15	25	2
	20	4:40									7	0	0	3	7	7	10	10	26	47	3
	30	4:40									7	0	4	6	8	10	10	10	32	60	4
	40	4:40									7	2	5	9	9	14	14	14	35	64	4
	Exceptional Exposure																				
Max O_2=15.2%	60	4:20								7	0	7	9	12	16	21	21	21	36	66	6
Min O_2=10.0%	80	4:20								7	3	9	13	15	21	23	23	23	36	66	7
	100	4:20								7	6	11	14	19	23	23	23	23	36	66	8
	120	4:20								7	8	13	19	20	23	23	23	23	36	66	8

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	Chamber O_2 Periods
			Decompression Stops (fsw) Stop times (min) include travel time, except first HeO_2 and first O_2 stop																		
			BOTTOM MIX										50% O_2						100% O_2		
260	10	5:00									7	0	0	0	4	4	10	10	16	27	2
	20	5:00									7	0	3	4	6	7	10	10	27	50	3
	30	4:40								7	0	2	5	6	9	10	10	10	33	62	4
	40	4:40								7	0	3	8	9	10	15	15	15	35	64	5
	Exceptional Exposure																				
Max O_2=14.6%	60	4:40								7	3	7	10	14	16	21	21	21	36	66	6
Min O_2=10.0%	80	4:40								7	6	10	13	17	23	23	23	23	36	66	7
	100	4:20							7	2	9	13	16	20	23	23	23	23	36	66	8
	120	4:20							7	4	11	14	19	20	23	23	23	23	36	66	8
270	10	5:20									7	0	0	3	3	4	10	10	17	28	2
	20	5:00								7	0	0	3	6	6	8	10	10	29	52	3
	30	5:00								7	0	3	6	6	9	13	13	13	34	62	4
	Exceptional Exposure																				
	40	5:00							7	0	2	5	8	8	12	16	16	16	35	66	5
Max O_2=14.2%	60	4:40							7	0	6	8	10	14	19	23	23	23	36	66	6
Min O_2=10.0%	80	4:40							7	3	8	11	14	17	23	23	23	23	36	66	7
	100	4:40							7	5	11	13	16	20	23	23	23	23	36	66	8
	120	4:40							7	8	12	16	19	20	23	23	23	23	36	66	8
280	10	5:40									7	0	0	3	3	4	10	10	18	31	2
	20	5:20								7	0	0	4	6	7	7	10	10	30	54	3
	30	5:00							7	0	1	5	5	9	9	12	12	12	35	64	4
	Exceptional Exposure																				
	40	5:00							7	0	4	6	8	9	12	17	17	17	35	66	5
Max O_2=13.7%	60	5:00							7	4	6	8	12	15	18	23	23	23	36	66	7
Min O_2=10.0%	80	4:40						7	0	7	9	11	15	17	23	23	23	23	36	66	8
	100	4:40						7	2	9	11	15	17	20	23	23	23	23	36	66	8
	120	4:40						7	4	11	13	16	19	20	23	23	23	23	36	66	8
290	10	5:40								7	0	0	0	4	3	4	10	10	19	33	2
	20	5:20							7	0	0	2	6	6	6	9	10	10	30	56	3
	30	5:20							7	0	2	5	5	9	9	14	14	14	34	63	5
	Exceptional Exposure																				
	40	5:20							7	0	5	7	8	11	13	17	17	17	35	66	5
Max O_2=13.3%	60	5:00						7	0	6	7	9	12	15	20	23	23	23	36	66	7
Min O_2=10.0%	80	5:00						7	2	8	10	12	16	19	23	23	23	23	36	66	8
	100	5:00						7	5	10	12	15	19	20	23	23	23	23	36	66	8
	120	5:00						7	8	11	16	17	19	20	23	23	23	23	36	66	8

Decompression Stops (fsw)

Stop times (min) include travel time, except first HeO_2 and first O_2 stop

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	Chamber O_2 Periods
			BOTTOM MIX										50% O_2						100% O_2		
300	10	6:00								7	0	0	0	4	3	4	10	10	19	33	2
	20	5:40							7	0	0	2	6	6	6	9	10	10	30	56	3
	30	5:40							7	0	2	5	5	9	9	14	14	14	34	63	5
	Exceptional Exposure																				
	40	5:40							7	0	5	7	8	11	13	17	17	17	35	66	6
Max O_2=12.9% Min O_2=10.0%	60	5:20						7	0	6	7	9	12	15	20	23	23	23	36	66	7
	80	5:20						7	2	8	10	12	16	19	23	23	23	23	36	66	8
	100	5:20						7	5	10	12	15	19	20	23	23	23	23	36	66	8
	120	5:20						7	8	11	16	17	19	20	23	23	23	23	36	66	8
310	**Exceptional Exposure**																				
	10	6:00							7	0	0	0	3	3	3	7	10	10	21	36	2
	20	5:40						7	0	0	2	4	5	6	7	10	10	10	31	57	4
	30	5:40						7	0	2	4	5	7	8	11	15	15	15	35	66	5
	40	5:20					7	0	1	4	6	7	8	12	15	19	19	19	36	66	7
Max O_2=12.5% Min O_2=10.0%	60	5:20					7	0	5	6	9	11	13	17	20	23	23	23	36	66	8
	80	5:20					7	3	7	9	11	13	17	20	23	23	23	23	36	66	8
	100	5:20					7	5	9	11	13	17	19	20	23	23	23	23	36	66	8
	120	5:20					7	7	12	13	16	17	19	20	23	23	23	23	36	66	8
320	**Exceptional Exposure**																				
	10	6:20							7	0	0	0	4	3	3	7	10	10	21	38	2
	20	6:00						7	0	0	3	5	5	6	8	10	10	10	32	59	4
	30	5:40					7	0	0	4	4	6	7	9	11	17	17	17	35	66	5
	40	4:40					7	0	4	4	6	7	9	12	16	20	20	20	36	66	6
Max O_2=12.2% Min O_2=10.0%	60	5:20				7	0	2	6	8	9	11	14	17	23	23	23	23	36	66	8
	80	5:20				7	0	6	8	8	13	14	19	20	23	23	23	23	36	66	8
	100	5:20				7	2	7	10	13	16	17	19	20	23	23	23	23	36	66	8
	120	5:20				7	4	9	12	13	16	17	19	20	23	23	23	23	36	66	8
330	**Exceptional Exposure**																				
	10	6:20						7	0	0	0	2	3	3	4	7	10	10	22	40	2
	20	6:00					7	0	0	2	3	4	6	5	10	10	10	10	33	60	4
	30	6:00					7	0	1	4	5	6	8	8	13	17	17	17	35	66	6
Max O_2=11.8% Min O_2=10.0%	40	5:40				7	0	1	4	5	7	7	10	12	17	22	22	22	36	66	7
	60	5:40				7	0	5	6	8	9	11	15	20	23	23	23	23	36	66	8
	80	5:40				7	2	7	8	10	13	15	19	20	23	23	23	23	36	66	8
	100	5:40				7	5	9	9	13	16	17	19	20	23	23	23	23	36	66	8
	120	5:20			7	1	7	10	13	15	16	17	19	20	23	23	23	23	36	66	8

Decompression Stops (fsw)

Stop times (min) include travel time, except first HeO_2 and first O_2 stop

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	Chamber O_2 Periods
			BOTTOM MIX										50% O_2						100% O_2		
340	**Exceptional Exposure**																				
	10	6:40						7	0	0	0	3	3	3	4	7	10	10	23	41	3
	20	6:20					7	0	0	2	4	5	7	8	9	10	10	10	33	60	5
	30	6:00				7	0	0	3	5	5	6	8	9	13	18	18	18	35	66	6
	40	6:00				7	0	2	4	6	7	8	10	13	16	22	22	22	36	66	7
Max O_2=11.5% Min O_2=10.0%	60	5:40			7	0	3	5	6	9	10	13	16	18	21	23	23	23	36	66	8
	80	5:40			7	0	7	7	8	11	13	15	19	20	23	23	23	23	36	66	8
	100	5:40			7	2	8	8	12	13	16	17	19	20	23	23	23	23	36	66	8
	120	5:40			7	4	9	11	13	15	16	17	19	20	23	23	23	23	36	66	8
350	**Exceptional Exposure**																				
	10	6:40					7	0	0	0	2	2	3	3	5	7	10	10	24	43	3
	20	6:20				7	0	0	0	4	4	5	5	7	9	13	13	13	33	63	5
	30	6:20				7	0	1	4	4	5	7	8	11	13	18	18	18	36	66	6
	40	6:00			7	0	1	3	5	6	7	8	11	14	17	23	23	23	36	66	7
Max O_2=11.2% Min O_2=10.0%	60	6:00			7	0	5	5	8	8	11	12	16	19	23	23	23	23	36	66	8
	80	6:00			7	2	7	7	10	11	13	17	19	20	23	23	23	23	36	66	8
	100	5:40		7	0	6	8	9	11	15	16	17	19	20	23	23	23	23	36	66	8
	120	5:40		7	1	7	9	12	14	15	16	17	19	20	23	23	23	23	36	66	8
360	**Exceptional Exposure**																				
	10	7:00					7	0	0	0	2	2	3	3	7	7	10	10	25	44	3
	20	6:40				7	0	0	2	3	4	5	5	8	10	13	13	13	34	63	5
	30	6:20			7	0	0	3	3	5	6	7	8	11	13	19	19	19	36	66	7
	40	6:20			7	0	2	4	5	7	7	9	10	14	20	23	23	23	36	66	8
Max O_2=10.9% Min O_2=10.0%	60	6:20			7	2	5	6	7	9	11	14	16	19	23	23	23	23	36	66	8
	80	6:00		7	0	6	6	8	11	12	14	16	19	20	23	23	23	23	36	66	8
	100	6:00		7	2	7	8	11	13	13	16	17	19	20	23	23	23	23	36	66	8
	120	6:00		7	4	8	10	12	14	15	16	17	19	20	23	23	23	23	36	66	8

Depth (fsw)	Bottom Time (min.)	Time to First Stop (min:sec)	Decompression Stops (fsw) Stop times (min) include travel time, except first HeO_2 and first O_2 stop																		Chamber O_2 Periods
			190	180	170	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	
			BOTTOM MIX										50% O_2						100% O_2		
370	Exceptional Exposure																				
	10	7:00				7	0	0	0	0	3	3	3	3	7	7	10	10	25	46	3
	20	6:40			7	0	0	0	3	4	4	5	5	8	10	13	13	13	34	63	5
	30	6:20		7	0	0	2	3	4	4	7	7	8	11	16	19	19	19	36	66	7
	40	6:20		7	0	0	4	4	5	6	8	10	11	14	20	23	23	23	36	66	8
Max O_2=10.6% Min O_2=10.0%	60	6:20		7	0	4	5	7	8	9	11	13	17	20	23	23	23	23	36	66	8
	80	6:00	7	0	3	6	7	9	10	12	15	17	19	20	23	23	23	23	36	66	8
	100	6:00	7	0	6	7	9	10	14	15	16	17	19	20	23	23	23	23	36	66	8
	120	6:00	7	1	7	9	11	13	14	15	16	17	19	20	23	23	23	23	36	66	8
380	Exceptional Exposure																				
	10	7:20				7	0	0	0	0	3	3	3	3	7	7	10	10	25	46	3
	20	7:00			7	0	0	0	3	4	4	5	5	8	10	13	13	13	34	63	6
	30	6:40		7	0	0	2	3	4	4	7	7	8	11	16	19	19	19	36	66	7
	40	6:40		7	0	0	4	4	5	6	8	10	11	14	20	23	23	23	36	66	8
Max O_2=10.4% Min O_2=10.0%	60	6:20		7	0	4	5	7	8	9	11	13	17	20	23	23	23	23	36	66	8
	80	6:20	7	0	3	6	7	9	10	12	15	17	19	20	23	23	23	23	36	66	8
	100	6:20	7	0	6	7	9	10	14	15	16	17	19	20	23	23	23	23	36	66	8
	120	6:20	7	1	7	9	11	13	14	15	16	17	19	20	23	23	23	23	36	66	8

4.3 - Initial storage depth

Important Note: Some clients limit the maximum excursion depth to 200 m . Also, some official bodies (for example NORSOK & MT92) limit the storage depth to 180 m. Thus, the recommendation is to consider all storage depth below 180 metres (590 fsw) as "non-standard" diving operations.

The living depth (also called storage depth) should be as close to the working depth as possible. The dive planning should be based on minimum change of living depth and excursion exposures.

4.3.1 - US Navy recommends the following values

- Gas parameters:

Oxygen: 0.44 to 0.48 ATA (446 to 486 mb)

NOTE: It is accepted that the final chamber PPO2, can exceed 0.500 bar and reach up to 0.600 bar 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"*

- Temperature:

Depth (fsw)	Temperature range (C°)	Depth (fsw)	Temperature range (C°)
164 and above	22 - 27	656	28 - 31
328	25 - 29	820	29 - 31
429	27 - 30	984	30 - 32

- Humidity:

Ideal should be 50 to 70% . Extremes can be 30 to 80%.

4.3.2 - Rest periods at arrival *(NORSOK Standards point 8.2.3.2)*:

- In the depth range from 0 msw to 89 msw, the diver should have a rest period (non-diving) of minimum 1 hour after the end of the compression period.
- In the depth range between 90 msw to 180 msw, this period should be a minimum of 2 hours.
- For deeper depth, the rest periods should be prolonged.
- Rest periods shall not take place more than 1 msw (3.28 ft) shallower than the planned living depth.
- The ambient pressure and established diurnal rhythm shall be taken into account in the evaluation of when personnel are ready to start work.

4.3.3 - Excursions

- Downward and upward excursions are allowed immediately upon the end of the rest period.

5) Excursions during the bell runs

5.1 - Reminder

Two excursion ranges are proposed in this study:

- The "maximum excursions" are those proposed in the US Navy manual *(Table 13-7 and Table 13-8)*. These excursions can be used for light jobs, observation or/and in case of emergency.
- The "standard excursions" are those proposed in the NORSOK standards U-100, which are similar to those proposed in the tables MT 92/COMEX. The ranges allowed by these excursions are more reduced than those in the "maximum excursions" (USN). The recommendation is to use these excursions for the jobs requiring physical efforts like: Installation, cleaning, burning…

Fundamental rule: ***A saturated diver can perform only two maximum excursions per saturation.***

Apart from a reduced range, the rules and procedures to apply with the standard excursions are the same as the maximum excursion. The standard excursion should be considered a safety procedure.

The combined table has the same presentation as the tables US Navy 13-7 and 13-8 with in addition the standard excursion distances and the standard excursion depth.

Because the US Navy table is designed in Imperial, the standard excursions, originally in metric, have been converted into feet.

Upward excursions				
Storage Depth (fsw)	Maximum upward Excursion Distance (ft)	Maximum upward Excursion Depth (fsw)	Standard upward excursion distance (fsw)	Standard upward excursion depth (fsw)
50	35	15	10	40
60	37	23	13	47
70	40	30	13	57
80	42	38	16	64

Maximum excursions (tables 13-7 & 13-8 USN) — *Standard excursions (NORSOK excursions)*

5.2 - Plan an excursion

To use the excursion tables when planning the dive, select a chamber storage depth in a range that allows diver excursions shallower or deeper than the storage depth.

Storage depth

Maximum excursion depth

Standard excursion depth

Downward excursions				
Storage Depth (fsw)	Maximum downward Excursion Distance (ft)	Maximum downward Excursion Depth (fsw)	Standard downward excursion distance (fsw)	Standard downward excursion depth (fsw)
50	46	96	10	60
60	48	108	13	73
70	51	121	13	83
80	53	133	16	96
90	56	146	16	106
100	58	158	16	116

When using the Upward excursion table, enter the table at the deepest depth attained at any time within the last 48 hours. For example, while the DDC may be at 400 fsw, if one diver had reached a depth of 460 fsw during an in-water excursion, the maximum upward excursion depth for the divers is 360 fsw instead of 307 fsw. *(See below and next page)*

Storage depth in the example above.

Upward excursions				
Storage Depth (fsw)	Maximum upward Excursion Distance (ft)	Maximum upward Excursion Depth (fsw)	Standard upward excursion distance (fsw)	Standard upward excursion depth (fsw)
390	92	298	36	354
400	93	307	39	361
410	94	316	39	371
420	95	325	39	381

Maximum depth reached during the previous 48 hours

Maximum upward excursion limit for the planned dive

Upward excursions				
Storage Depth (fsw)	Maximum upward Excursion Distance (ft)	Maximum upward Excursion Depth (fsw)	Standard upward excursion distance (fsw)	Standard upward excursion depth (fsw)
450	99	351	39	411
460	100	360	43	417
470	101	369	43	427
480	102	378	43	437
490	103	387	43	447

If storage depth falls between the depths listed in the downward table, use the next shallower depth (e.g., if the depth is 295 fsw, enter downward table at 290 fsw), or use the downward excursion distance to calculate the maximum excursion.

Solution #2: Use this distance to calculate the maximum excursion

Enter the table at 290

Storage = 295 fsw

Downward excursions				
Storage Depth (fsw)	Maximum downward Excursion Distance (ft)	Maximum downward Excursion Depth (fsw)	Standard downward excursion distance (fsw)	Standard downward excursion depth (fsw)
50	46	96	10	60
280	89	369	33	313
290	90	380	33	323
300	92	392	33	333
310	93	403	33	343

If storage depth falls between the depths listed in the upward table, use the next deeper depth (e.g., if the storage depth is 295 fsw, enter upward table at 300 fsw, or calculate the maximum excursion using the upward excursion distance.

Solution #2: Use this distance to calculate the maximum excursion

Storage = 295 fsw

Enter the table at 300

Upward excursions				
Storage Depth (fsw)	Maximum upward Excursion Distance (ft)	Maximum upward Excursion Depth (fsw)	Standard upward excursion distance (fsw)	Standard upward excursion depth (fsw)
50	35	15	10	40
280	77	203	33	247
290	79	211	33	257
300	80	220	33	267
310	81	229	33	277

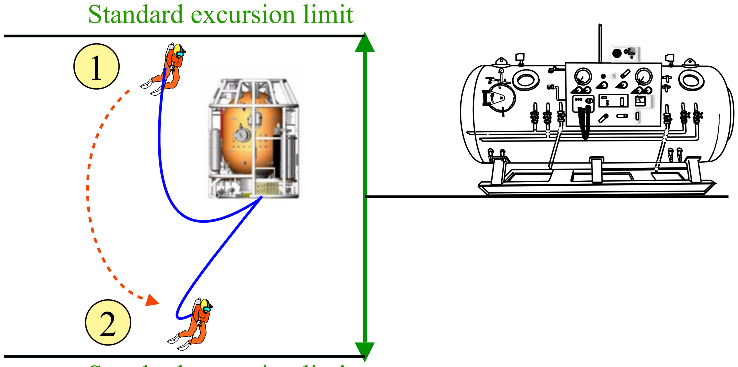
5.3 - Rules for organizing excursions *(Source: French decree of 15th May 1992)*

For a given dive, the choice should be:

- Descending excursions rather than ascending ones,
- Standard excursions rather than maximum ones,
- An ascending excursion followed by a descending excursion, rather than a descending excursion followed by an ascending excursion.

In addition:

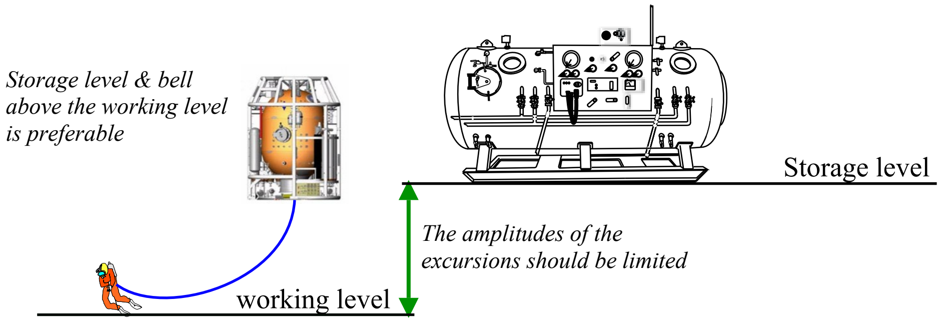
- The maximum excursions should not be used if upward and downward excursions are combined during the same dive. In this case, "standard excursion" can be used.
- A period of 12 hours stabilisation is recommended after a maximum or a combined (upward + downward) excursion.



5.4 - Bell depth during excursions *(Source: French decree of 15th May 1992 & NORSOK U-100)*

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.
- It is preferable to have the storage level (chamber) and the bell above the working level.



5.5 - Ascent speed during the excursions

US Navy says:
The ascent rate should not exceed 60 fsw/min during an excursion. When it is detected that a diver is ascending faster than 60 fsw/min, the diver shall immediately stop and wait until enough time has elapsed to return to the 60 fsw/min schedule. The diver may then resume ascent at a rate not to exceed 60 fsw/min from that depth.

Recommendation:
NORSOK standard U-100 suggests a maximum ascent rate of 10 msw/min (33 fsw/min) during the excursion, and the recommendation is to limit to this ascent speed.

5.6 - Adjust the storage level during a bell run

Increasing the chamber storage depth during a bell run when the divers are conducting a downward excursion is permitted as long as the chamber depth doesn't exceed the downward excursion depth.

Decreasing the storage level is not permitted during a bell run. Notice that NORSOK standard says *"decompression shall not start with a reducing (upward) excursion"* . This point is confirmed in the tables MT92/COMEX.

5.7 - Excursions after a change of storage depth *(US Navy; NORSOK; French decree 15/05/92)*

5.7.1 - Compressing the chamber to new storage depth

- If the new storage depth doesn't exceeds the downward excursion limits from the initial storage depth, excursions are permitted immediately upon reaching the new storage depth.

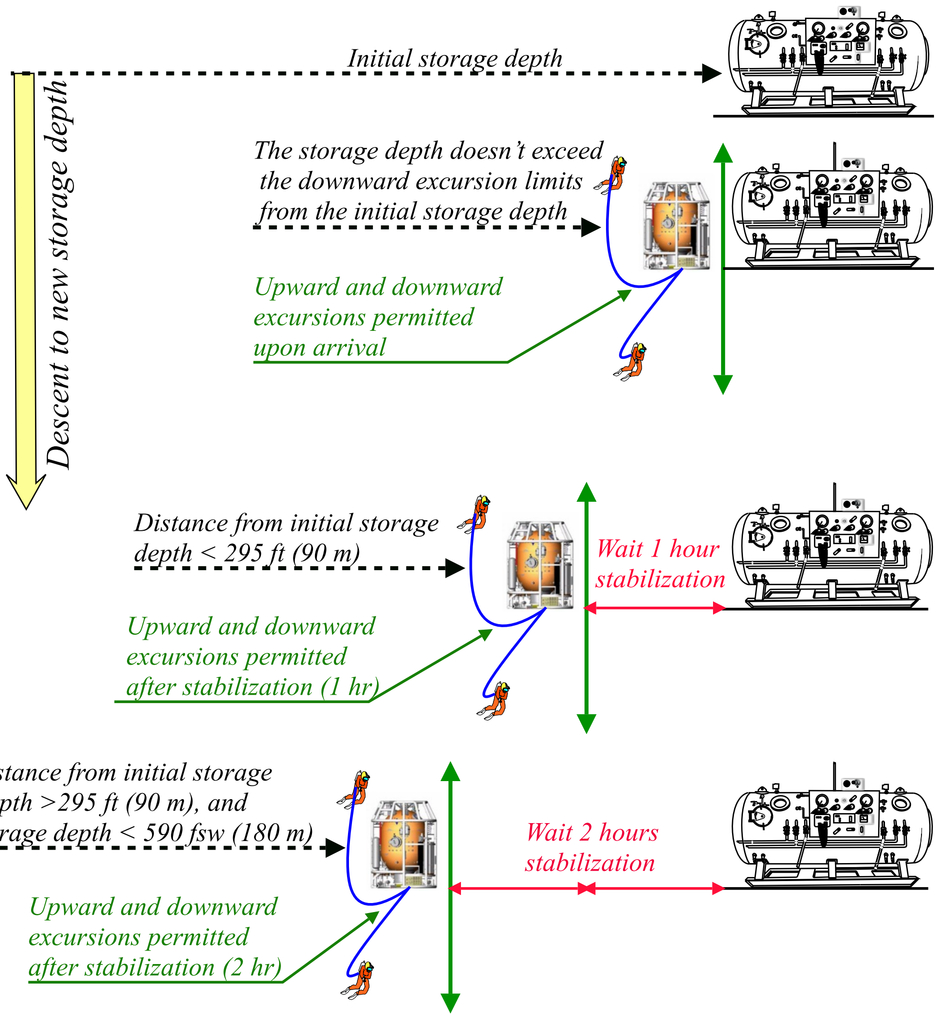
- If the new storage depth exceeds the downward excursion limits from the initial storage depth, the recommendation indicated point 2.3.2 "Rest periods at arrival" *(NORSOK Standards point 8.2.3.2)* should be considered prior to start excursions:
  - If the distance from the initial storage depth is less than 295 ft, there should be a rest period of 1 hour.
  - If the distance is more than 295 ft, and the storage depth less than 590 ft, the rest period should be 2 hours.
  - Longer compression distances should be assessed and discussed as the recommendation is to not consider storage depths below 590 fsw (180 m) as standard operational procedures.

Example 1: From an initial storage depth at 60 fsw, it is decided to relocate the storage depth at 100 fsw.
The downward excursion table indicates that the maximum downward excursion from 60 fsw is 108 fsw. In this case downward or upward excursions are permitted immediately upon reaching the new storage depth.

Storage Depth (fsw)	Maximum downward Excursion Distance (ft)	Maximum downward Excursion Depth (fsw)	Standard downward excursion distance (fsw)	Standard downward excursion depth (fsw)
50	46	96	10	60
60	48	108	13	73
70	51	121	13	83

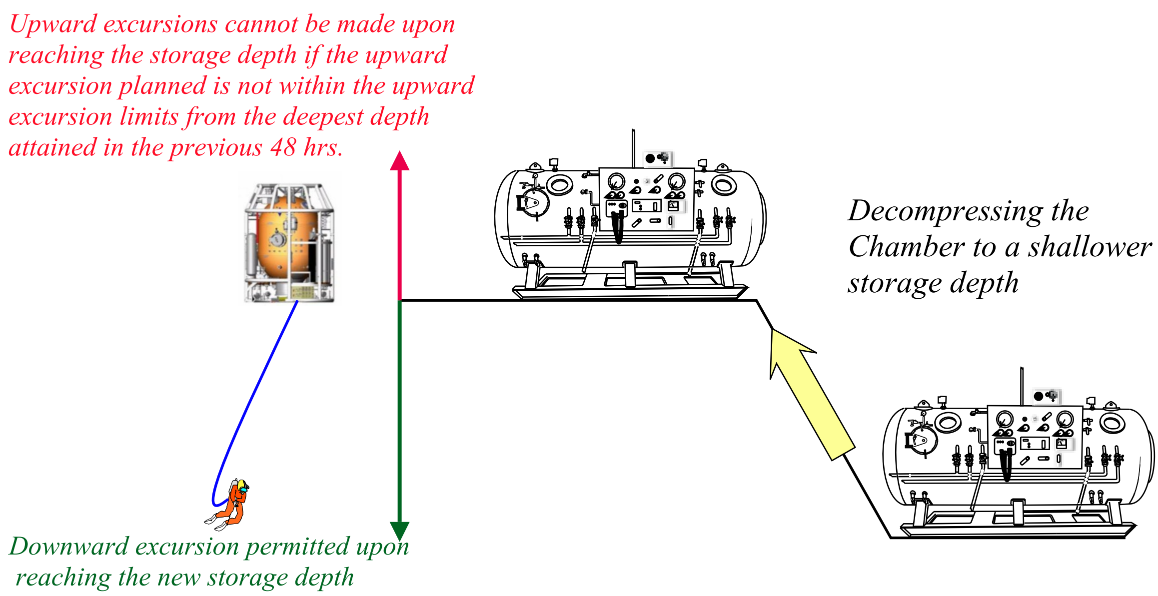
Example 2: From an initial storage depth at 60 fsw, it is decided to relocate the storage depth at 300 fsw.
300 fsw is outside the limits of the downward excursion table from the initial storage depth, and the new storage depth will be 240 fsw (73m) deeper (300-60). Because the distance is less than 295 ft, the rest period prior starting the excursions should be 1 hour.

Example 3: From an initial storage depth at 60 fsw, it is decided to relocate the storage depth at 400 fsw (122m). 400 fsw is outside the limits of the downward excursion table from the initial storage depth, and the new storage depth will be 340 fsw (103.6m) deeper (400-60). Because the distance is more than 295 ft, the rest period prior to starting the excursions should be 2 hours.



5.7.2 - Decompressing the chamber to a new storage depth

- Downward excursions, can begin immediately upon reaching the new chamber storage depth.
- Upward excursions cannot be made upon reaching the new storage depth if the upward excursion planned is not within the upward excursion limits from the deepest depth attained in the previous 48 hrs. US Navy says point 15-21 chapter 15: *"If less than 48 hours is spent at the new storage depth, the maximum upward excursion is based on the deepest depth attained in the preceding 48 hours."*



5.8 - Excursion tables

5.8.1 - Downward excursions

Downward excursions					
Storage Depth (fsw)		Maximum downward Excursion Distance (ft)	Maximum downward Excursion Depth (fsw)	Standard downward excursion distance (fsw)	Standard downward excursion depth (fsw)
50		46	96	10	60
60		48	108	13	73
70		51	121	13	83
80		53	133	16	96
90		56	146	16	106
100		58	158	16	116
110		60	170	23	133
120		62	182	23	143
130		64	194	26	156
140		66	206	26	166
150		68	218	26	176
160		70	230	26	186
170		72	242	26	196
180		73	253	26	206
190		75	265	26	216
200		77	277	30	230
210		78	288	33	243
220		80	300	33	253
230		82	312	33	263
240		83	323	33	273
250		85	335	33	283
260		86	346	33	293
270		88	358	33	303
280		89	369	33	313
290		90	380	33	323
300		92	392	33	333
310		93	403	33	343
320		95	415	33	353
330		96	426	36	366
340		97	437	36	376
350		98	448	36	386
360		100	460	36	396
370		101	471	36	406
380		102	482	36	416
390		103	493	36	426
400		105	505	39	439
410		106	516	39	449
420		107	527	39	459
430		108	538	39	469
440		109	549	39	479

Downward excursions				
Storage Depth (fsw)	**Maximum downward Excursion Distance (ft)**	**Maximum downward Excursion Depth (fsw)**	**Standard downward excursion distance (fsw)**	**Standard downward excursion depth (fsw)**
450	111	561	39	489
460	112	572	43	503
470	113	583	43	513
480	114	594	43	523
490	115	605	43	533
500	116	616	43	543
510	117	627	43	553
520	118	638	43	563
530	119	649	43	573
540	120	660	43	583
550	122	672	43	593
560	123	683	43	603
570	124	694	43	613
580	125	705	43	623
590	126	716	43	633
600	127	727	49	649
610	128	738	49	659
620	129	749	49	669
630	130	760	49	679
640	131	771	49	689
650	132	782	49	699
660	133	793	49	709
670	133	803	49	719
680	134	814	49	729
690	135	825	49	739
700	136	836	49	749
710	137	847	49	759
720	138	858	49	769
730	139	869	49	779
740	140	880	49	789
750	141	891	49	799
760	142	902	49	809
770	143	913	49	819
780	144	924	49	829
790	144	934	49	839
800	145	945	49	849
810	146	956	49	859
820	147	967	49	869
830	148	978	49	879
840	149	989	49	889
850	150	1000	49	899

Notes:

- Storage below 590 fsw (180 m) should not be considered as “standard procedure”
- Some clients (Total) limit the manned underwater operations to 656 fsw (200 m)

5.8.2 - Upward excursions

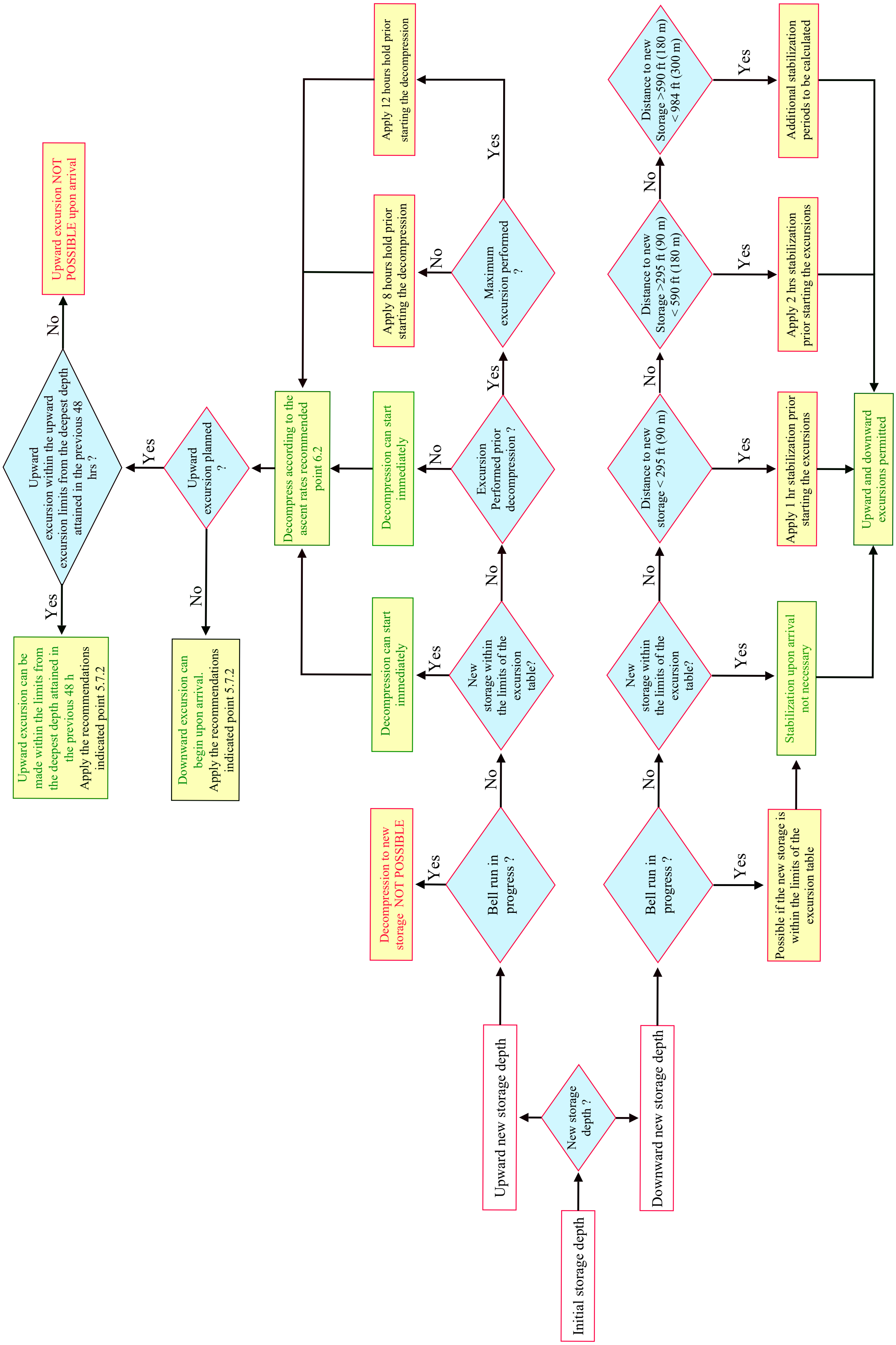
Upward excursions				
Storage Depth (fsw)	Maximum upward Excursion Distance (ft)	Maximum upward Excursion Depth (fsw)	Standard upward excursion distance (fsw)	Standard upward excursion depth (fsw)
50	35	15	10	40
60	37	23	13	47
70	40	30	13	57
80	42	38	16	64
90	44	46	16	74
100	47	53	20	80
110	49	61	23	87
120	51	69	23	97
130	53	77	26	104
140	55	85	26	114
150	56	94	26	124
160	58	102	26	134
170	60	110	26	144
180	62	118	26	154
190	63	127	26	164
200	65	135	30	170
210	67	143	30	180
220	68	152	30	190
230	70	160	30	200
240	71	169	30	210
250	73	177	30	220
260	74	186	30	230
270	76	194	33	237
280	77	203	33	247
290	79	211	33	257
300	80	220	33	267
310	81	229	33	277
320	83	237	33	287
330	84	246	36	294
340	85	255	36	304
350	87	263	36	314
360	88	272	36	324
370	89	281	36	334
380	90	290	36	344
390	92	298	36	354
400	93	307	39	361
410	94	316	39	371
420	95	325	39	381
430	96	334	39	391
440	97	343	39	401

Upward excursions				
Storage Depth (fsw)	**Maximum upward Excursion Distance (ft)**	**Maximum upward Excursion Depth (fsw)**	**Standard upward excursion distance (fsw)**	**Standard upward excursion depth (fsw)**
450	99	351	39	411
460	100	360	43	417
470	101	369	43	427
480	102	378	43	437
490	103	387	43	447
500	104	396	43	457
510	105	405	43	467
520	106	414	43	477
530	107	423	43	487
540	108	432	43	497
550	110	440	43	507
560	111	449	43	517
570	112	458	43	527
580	113	467	43	537
590	114	476	43	547
600	115	485	49	551
610	116	494	49	561
620	117	503	49	571
630	118	512	49	581
640	119	521	49	591
650	119	531	49	601
660	120	540	49	611
670	121	549	49	621
680	122	558	49	631
690	123	567	49	641
700	124	576	49	651
710	125	585	49	661
720	126	594	49	671
730	127	603	49	681
740	128	612	49	691
750	129	621	49	701
760	130	630	49	711
770	131	639	49	721
780	131	649	49	731
790	132	658	49	741
800	133	667	49	751
810	134	676	49	761
820	135	685	49	771
830	136	694	49	781
840	137	703	49	791
850	137	713	49	801

Notes:

- Storage below 590 fsw (180 m) should not be considered as “standard procedure”
- Some clients (Total) limit the manned underwater operations to 656 fsw (200 m)

5.9 - Summary for initial steps of change of storage depth or decompression



5.10 - Recommendations

- 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 *"Bell depth during excursions",* it is preferable to establish a shallower storage depth rather than perform a series of repetitive upward excursions.
- Upon reaching the new storage depth, French decree of 15th May 1992 recommends a stabilisation of 12 hours before a maximum downward excursion. (Standard downward excursions can be performed upon reaching).
- Remember that *AODC 48; DMAC 20; IMCA D 022 point 7.19, NORSOK point 849, French decree of 15.05/92,* recommends 12 hours of unbroken rest following a bell run
- Remember that even when the period of stabilization has elapsed, a period of 12 hours stabilisation is recommended after a maximum or a combined (upward + downward) excursion. *(Already indicated point 5.4).*

6) Decompression

NORSOK standard says: "Decompression shall not start with a pressure reducing (upward) excursion". This point is also confirmed by the French decree of 15th May 1992.

Note: Decompression starting with an upward excursion cannot be considered as "standard decompression procedure", but this procedure can be used in an emergency and is explained in the point... *"Emergency procedures"*.

6.1 - Decompression plan

Decompression should be organised with a proper decompression plan that records at least:

- The name of the company, the surface support, and the location where the decompression is carried out
- The people in charge and the divers to decompress
- The date and the local time the decompression starts
- The depths decreasing foot by foot and the local time at each depth
- The percentage of oxygen and the partial pressure CO_2 at each depth
- The remaining time to surface at each depth
- The ascent rate

6.2 - Stabilisation prior to decompression

US Navy does not indicate any stabilisation period prior to starting a "standard decompression procedure", but again, the US Navy tables are originally designed for military purposes, and the recommendation is to follow the 2 restrictions from other competent bodies indicated below:

- There should be a minimum of 8 hours hold at living depth prior to decompression after an excursion *(NORSOK standard / point 8.2.3.4*). Notice that the NORSOK excursions are the "standard" excursions.
- There should be a 12 hour hold at living depth prior decompression at living depth after a "maximum" excursion *(Source: French decree of 15th May 1992 / page 361/ point 5.3)*

Exception: If the decompression consists to readjust the chamber at a depth slightly above the initial storage depth, the stabilisation period can be considered not necessary if the new storage depth is within the upward excursion limits from the deepest depth attained in the previous 48 hrs. But, the decompression must at the rates indicated in this point.

6.3 - Decompression rates

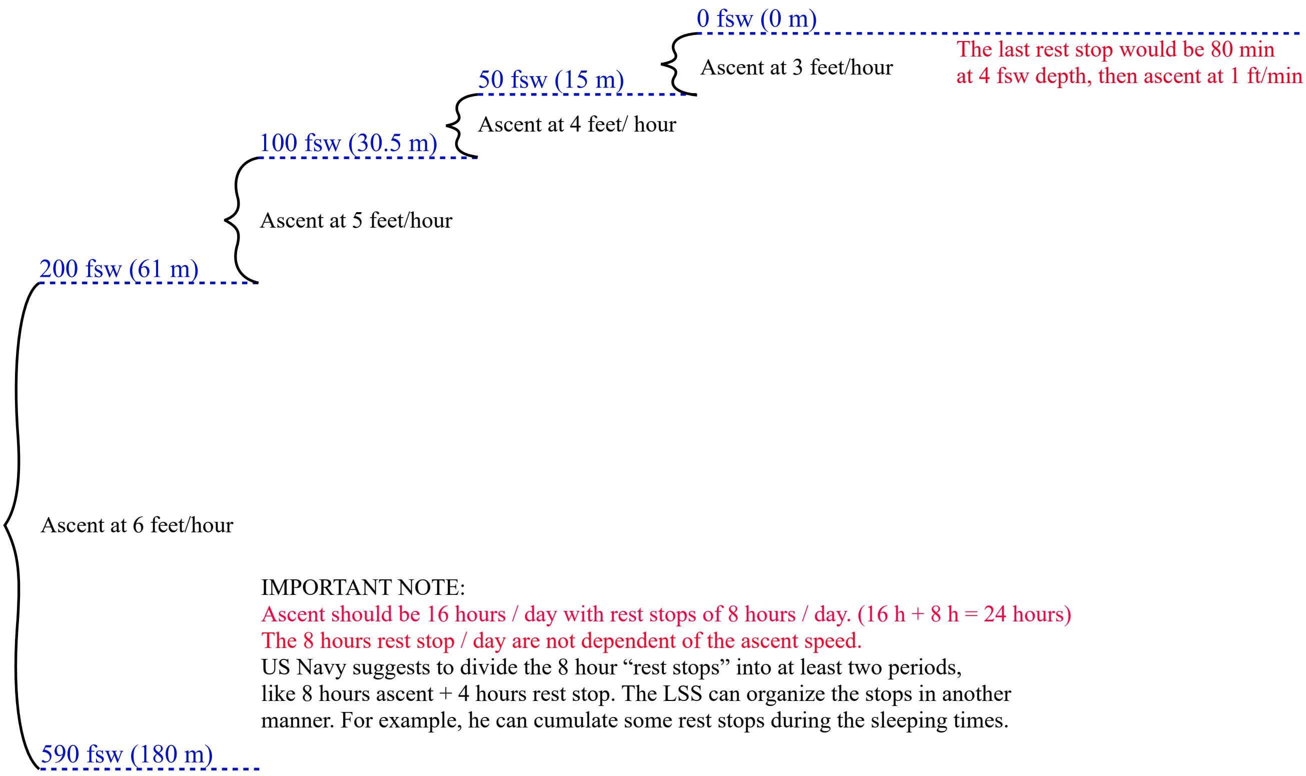
When the stabilisation period is completed, the decompression can be executed by decompressing the chamber in 1 foot increments not to exceed 1 fsw per minute or continuous bleeding.

- Traveling is conducted for 16 hours in each 24-hour period, with traveling "rest stops" for a total of 8 hours out of every 24 hours (16 hrs ascent + 8 hrs stop / 24 hrs). US Navy suggests to divide the 8 hour "rest stops" into at least two periods. These rest stops should be indicated in the decompression plan.
- The last decompression stop before surfacing may be taken at 4 fsw to ensure early surfacing does not occur and that gas flow to atmosphere monitoring instruments remains adequate. This last stop would be 80 minutes, followed by direct ascent to the surface at 1 fsw/min.
- The ascent rates indicated by US Navy are as follows:

Depth in fsw	Rate		Depth in metres	Rate
1,600 – 200 fsw	6 feet per hour		487 – 61 msw	1.8 metre per hour
200 – 100 fsw	5 feet per hour		61 – 30.5 msw	1.5 metre per hour
100 – 50 fsw	4 feet per hour		30.5 – 15 msw	1.2 metre per hour
50 – 0 fsw	3 feet per hour		15 – 0 msw	0.91 metre per hour

Note: *The US Navy tables are originally designed in fsw, and the recommendation is to use these units to manage the decompression.*
The conversions in metric are for information purposes for those who are more familiar with the metric system.

Recommendation: In case of delay incurred in the decompression, no attempt must be made to make up for time lost by accelerating the decompression.



IMPORTANT NOTE:
Ascent should be 16 hours / day with rest stops of 8 hours / day. (16 h + 8 h = 24 hours)
The 8 hours rest stop / day are not dependent of the ascent speed.
US Navy suggests to divide the 8 hour "rest stops" into at least two periods, like 8 hours ascent + 4 hours rest stop. The LSS can organize the stops in another manner. For example, he can cumulate some rest stops during the sleeping times.

6.4 - Atmosphere control during the decompression

The partial pressures should be maintained in the values indicated point 2.3.1, except at shallow depth.

6.4.1 - Gas parameters indicated in point 2.3.1

Oxygen: 0.44 to 0.48 ATA (446 to 486 mb)
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)

6.4.2 - Oxygen partial pressure at shallow chamber depth

As chamber depth decreases, the fractional concentration of oxygen necessary to maintain a given partial pressure increases. If the chamber ppO_2 were maintained at 0.44–0.48 ata all the way to the surface, the chamber oxygen percentage would rise to 44–48 percent.
Accordingly, for the terminal portion of saturation decompression, the allowable oxygen percentage is between 19 and 23 percent. The maximum oxygen percentage for the terminal portion of the decompression shall not exceed 23 percent, based upon fire-risk considerations.

6.4.3 - Temperature and humidity control

Temperatures and humidity should be monitored to be within the following values

Depth (fsw)	Temperature range (C°)
164 and above	22 - 27
328	25 - 29
429	27 - 30

Depth (fsw)	Temperature range (C°)
656	28 - 31
820	29 - 31
984	30 - 32

Humidity: Ideal should be 50 to 70% . Extreme can be 30 to 80%.

6.5 - Activities during the decompression

Diving activities during the decompression cannot be carried out: The decompression must be stopped and the excursions should be performed according to the recommendations explained in the point 5

The divers should have a light activity in the chamber, and be in contact with the LSS/LST.

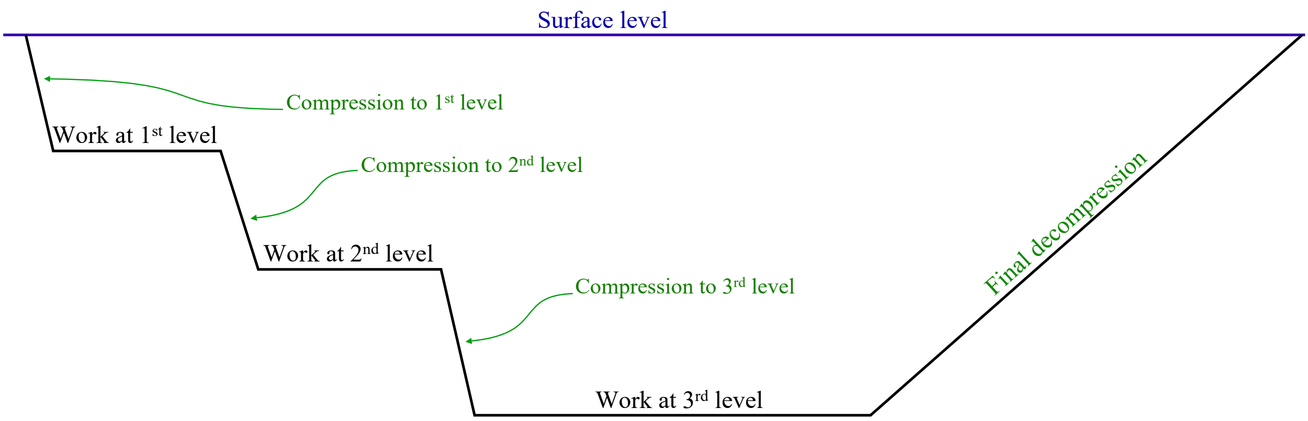
7) Storage depth and saturation profile

There are no rules of saturation profiles indicated in the US NAVY saturation procedures.
Also, the literature regarding this aspect of the operations is limited. However, the following guidelines published by other competent bodies 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 an 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)*

7.1 - Ideal saturation profiles

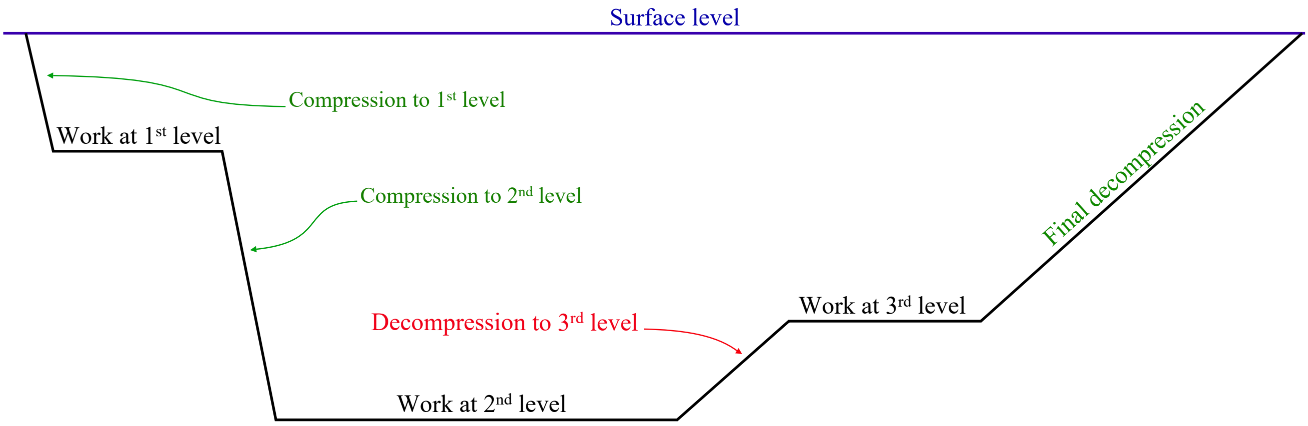
According to the recommendations above, the ideal profile is a U profile, with the change of storage depth by intermediate pressurisation rather than depressurization.



Remember that:

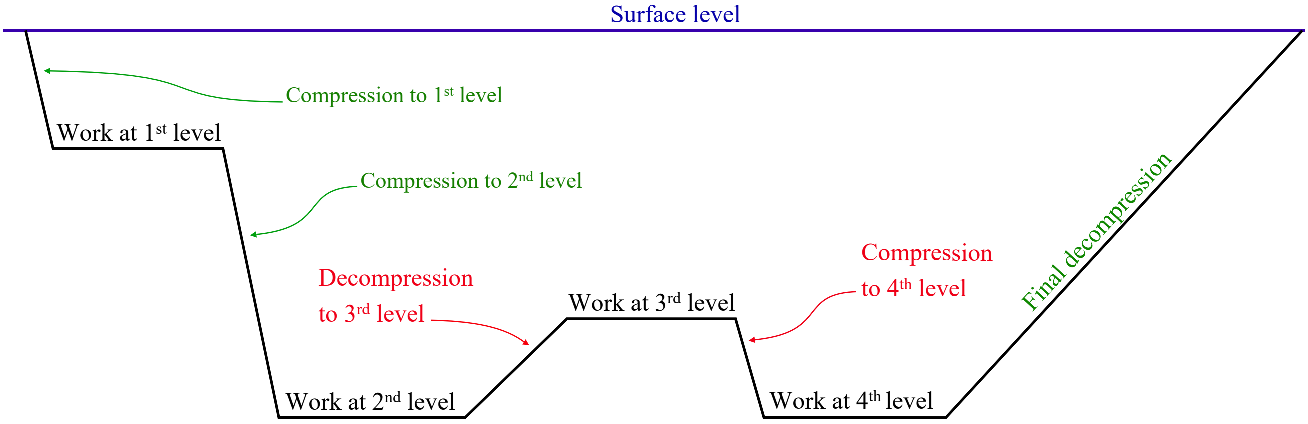
- Downward excursions are preferable.
- It is recommended to limit the change of living depth and excursions exposures.

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.



7.2 - “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 organisms 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 officially 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 exaggerated amplitudes 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.

7.3 - 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.

8) Emergency decompression (US Navy; DMAC)

8.1 - Presentation

In very exceptional cases it could be necessary to execute a mission abort and not be able to adhere to standard saturation decompression procedures. The emergency abort procedures should only be conducted for grave, unforeseen casualties that require deviation from the standard decompression procedures such as:

- An unrepairable failure of key primary and related backup equipment in the dive system that would prevent following standard decompression procedures.
- Unrepairable damage to the diving support vessel or diving support facility and impossibility to launch the HRC.
- A life-threatening medical emergency where the risk of not getting the patient to a more specialized medical care facility outweighs the increased risk of pulmonary oxygen toxicity and the increased risk of decompression sickness imposed upon the patient by not following standard saturation decompression procedures.

Before executing a rapid decompression procedure that does not follow standard decompression procedures a risk evaluation is required. Specifically, it must be determined if the time saved will benefit the diver's life despite the increased risks, and whether the emergency abort procedure can be supported logistically. If possible, the diving medical specialist should be contacted.

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 oral re-hydration 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 are unlikely to increase the risk

A plan for the management of complications arising during and after the decompression should include access to analgesia and antiemetics (a drug that is effective against vomiting and nausea), the availability of continued surface oxygen therapy after completion of decompression and access to recompression elsewhere for treatment of decompression illness.

8.2 - Procedure US Navy

An Emergency Abort Procedure was developed by the US Navy and has received limited testing. It enables the divers to surface earlier than would be allowed normally. However, the time saved may be insignificant to the total decompression time still required, especially if the divers have been under pressure for 12 hours or more.

US Navy warns that executing the Emergency Abort Procedure increases the diver's risk for decompression sickness and complications from pulmonary oxygen toxicity.

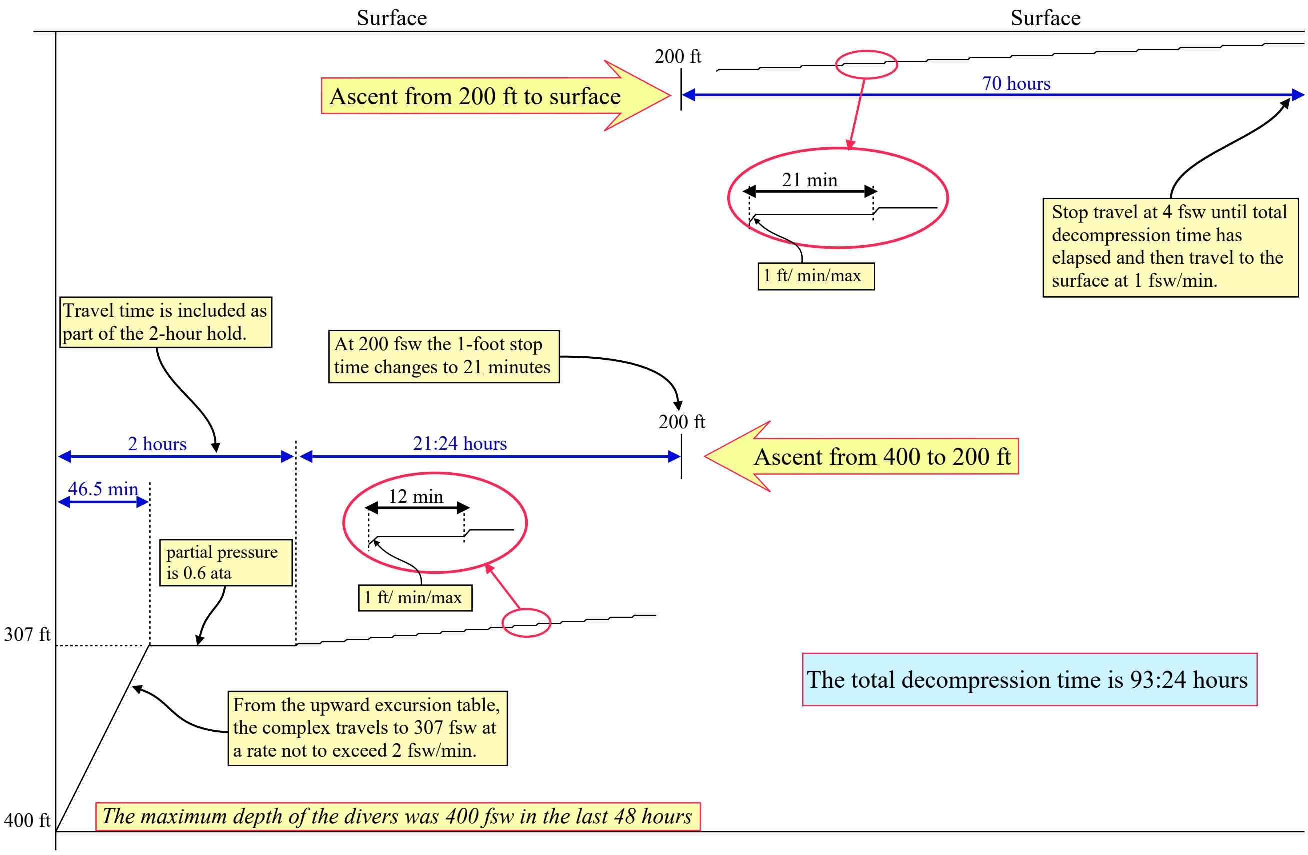
1. Emergency Abort decompression is begun by making the maximum upward excursion allowed by the table US Navy. (refer also to excursions procedures)
2. Rate of travel should not exceed 2 fsw/min.
3. The upward excursion includes a 2-hour hold at the upward excursion limit.
4. Travel time is included as part of the 2-hour hold.
5. Following the upward excursion, the chamber oxygen partial pressure is raised to the value shown in the table below.

Post Excursion Depth (fsw)	ppO_2 (ata)	One-Foot Stop Time (min) 1000–200 fsw	200–0 fsw
0–203	0.8	11	18
204–272	0.7	11	19
273–1000	0.6	12	21

6. Rate of travel between stops is not to exceed 1 fsw/min. Travel time is included in the next stop time.
7. The partial pressure of oxygen is controlled at the value indicated until the chamber oxygen concentration reaches 23 percent.
8. The oxygen concentration is then controlled between 19 and 23 percent for the remainder of the decompression.
9. Stop travel at 4 fsw until total decompression time has elapsed and then travel to the surface at 1 fsw/min.
10. If the emergency ceases to exist during the decompression, hold for a minimum of 2 hours, revert to standard decompression rates, and allow the oxygen partial pressure to fall to normal control values as divers consume the oxygen. Venting to reduce the oxygen level is not necessary.
11. During and following the dive, the divers should be monitored closely for signs of decompression sickness and for signs of pulmonary oxygen toxicity.

Example:

1. The maximum depth of the diver in the last 48 hours was 400 fsw, and the diving superintendent approves using an Emergency Abort Procedure.
2. From the Upward Excursion Table, the complex travels to 307 fsw at a rate not to exceed 2 fsw/min. It takes 46.5 minutes to travel. This time is part of a 2-hour hold requirement as part of the upward excursion for emergency aborts.
3. Because the post-excursion depth is between 273–1,000 fsw, the chamber oxygen partial pressure is raised to 0.6 ata.
4. Once the atmosphere is established and the remainder of the 2-hour hold completed, begin decompression in 1-foot increments with stop times of 12 minutes from 307 to 200 fsw.
5. The travel rate between stops should not exceed 1 fsw/min. Travel time is included in the stop time. It will take 21:24 hours to arrive at 200 fsw.
6. At 200 fsw the 1-foot stop time changes to 21 minutes. It will take 70 hours to reach the surface.
7. The total decompression time is 93:24 hours.
8. By contrast, standard saturation decompression would take approximately 99 hours to complete.
9. During and following dive, the divers should be monitored closely for signs of decompression sickness and for signs of pulmonary oxygen toxicity. The latter includes burning chest pain and coughing. The divers should be kept under close observation for at least 24 hours following the dive.



8.3 - Guidelines from DMAC 31

DMAC 31 has been published in March 2013, and considers that …"many diving manuals contain emergency rapid decompression procedures, in many situations these are too slow to be of value, and decompression over the estimated time available in the emergency may be the only option"…

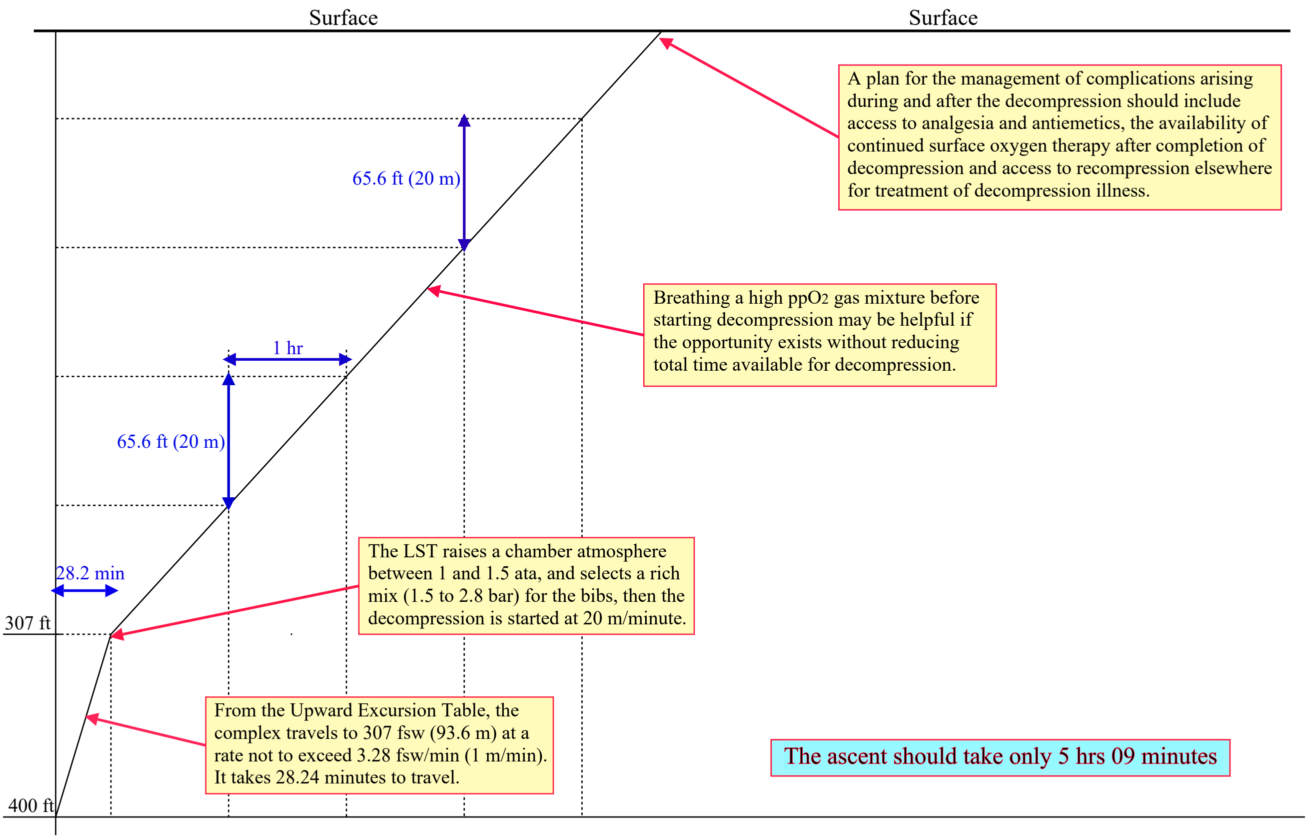
To give an answer to this problem DMAC 31 indicates the following procedure which is very aggressive and should be implemented only if the diving team is dealing with a life or death situation:

1. The decompression should be planned to take place at the slowest rate consistent with a safe evaluation of the emergency timescale.
2. 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.
3. Use of a built-in breathing system (BIBS) would be required for higher ppO_2 mixtures and at shallow depths.
4. 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.
5. Breathing a high ppO_2 gas mixture before starting decompression may be helpful if the opportunity exists without reducing total time available for decompression.

Example:

Using the same values as for the example from US Navy and considering that the master has triggered the abandon vessel procedure and the HRC cannot be launched.

1. The maximum depth of the diver in the last 48 hours was 400 fsw (122 m), and the diving superintendent approves using an Emergency Abort Procedure. The diver is supposed to not have dived during the last 24 hrs.
2. From the Upward Excursion Table, the complex travels to 307 fsw (93.6 m) at a rate not to exceed 3.28 fsw/min (1 m/min). It takes 28.24 minutes to travel.
3. The LST raises a chamber atmosphere between 1 and 1.5 ata, and selects a rich mix (1.5 to 2.8 bar) for the bibs, then the decompression is started at 20 m/minute



Notes:

The decompression using the maximum speed allowed by DMAC 31 (20 m/min) is faster than the decompression given by the tables for surface supplied diving operation at the same depth. For example, the ascent from the same depth after 2 hours bottom time takes 19 hrs 40 min with the COMEX table. It is a good practice to refer to the surface supplied decompression tables to have additional references when selecting the decompression speed. This speed should be as slow as possible and adjusted according to the situation.

8.4 - 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 % O2*	*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.

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		*20*	*3*
240 to 160		*25*	*2.4*
160 to 80	*PO_2 = 0.6 bar (60 kPa)*	*30*	*2*
80 to 20		*35*	*1.7*
20 to 15		*40*	*1.5*
15 to 10		*40*	*1.5*
10 to 5	*FO_2 = 24%*	*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 PO2 until 18 msw when the chamber is flushed with air to change from helium to nitrogen (see next).

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.

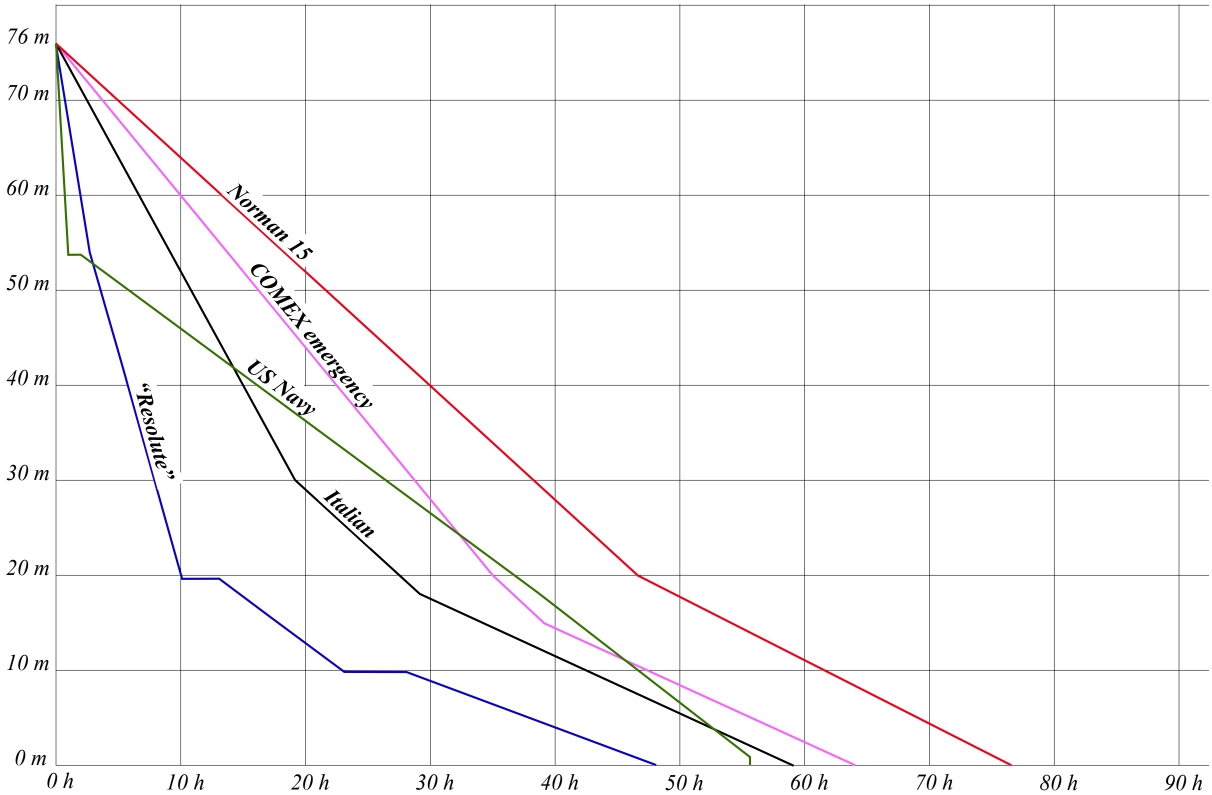
The decision is therefore a balance between the time left to decompress to surface and the accepted risk of DCS and/or oxygen toxicity. This may lead to a graded response where two levels of emergency could be considered:

- 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?

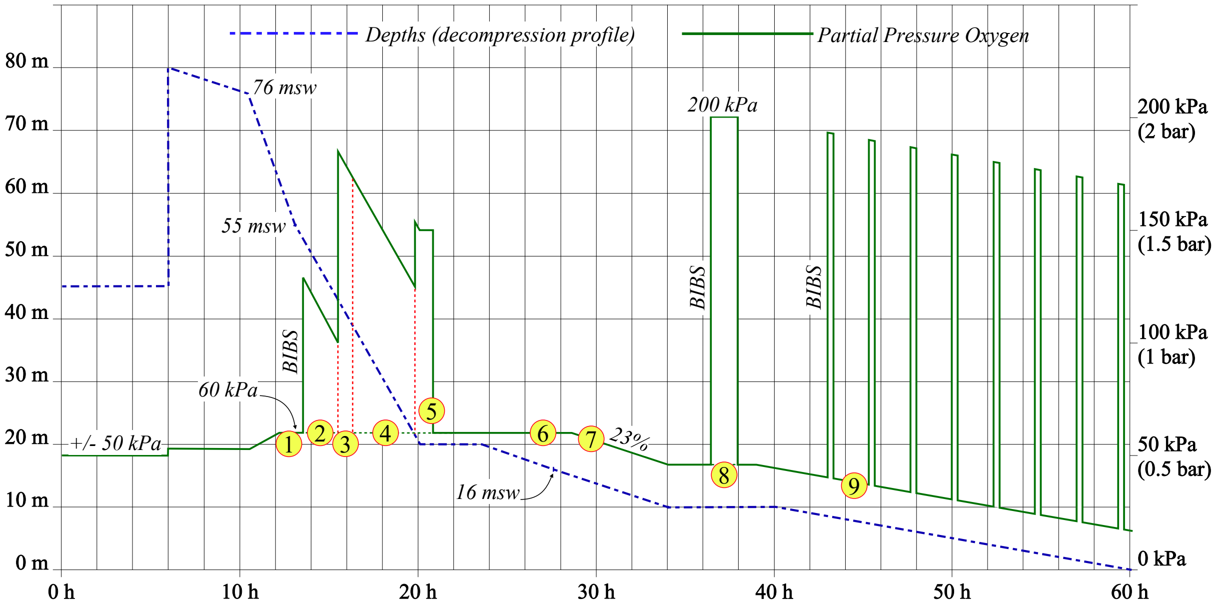
- Initial excursion:
  In several recorded instances, the immediate strategy was to perform a rapid upward ascent or excursion to bring the divers closer to surface. This protocol is described in the US Navy diving manual (paragraph 13–23, revision 7) that allows the start of a final decompression to 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 PO_2 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.

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:
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Other point of contact can be phone through the website Diving and ROV Specialists.com:

- 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

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 standard saturation decompression. The decompression sickness may manifest itself as musculoskeletal pain (Type I) or as 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: The Diving Medical Specialist must be informed As Soon As Possible

9.1 - Type I Decompression Sickness

Type I Decompression Sickness may result from an Upward Excursion or as the result of standard saturation decompression.

- It is usually manifested as the gradual onset of musculoskeletal pain most often involving the knee. Divers report that it begins as knee stiffness that is relieved by motion but which increases to pain over a period of several hours. Care must be taken to distinguish knee pain arising from compression arthralgia or injury incurred during the dive from pain due to decompression sickness. This can usually be done by obtaining a clear history of the onset of symptoms and their progression. Pain or soreness present prior to decompression and unchanged after ascent is unlikely to be decompression sickness.

- Type I Decompression Sickness that occurs during an Upward Excursion or within 60 minutes immediately after an Upward Excursion should be treated in the same manner as Type II Decompression Sickness, as it may herald the onset of more severe symptoms.

- Type I Decompression Sickness occurring more than 60 minutes after an Upward Excursion or during saturation decompression should be treated by recompressing in increments of 5 fsw at 5 fsw/ min until distinct improvement of symptoms is indicated.
    - Recompression of more than 30 fsw is usually unnecessary.
    - Once treatment depth is reached, the stricken diver is given a treatment gas, by BIBS mask, with an oxygen partial pressure between 1.5 and 2.8 ata. Interrupt treatment gas breathing every 25 minutes with 5 minutes of breathing chamber atmosphere.
    - Divers should remain at treatment depth for at least 2 hours on treatment gas following resolution of symptoms.
    - Decompression can then be resumed using standard saturation decompression rates. *(See next page)*
    - Further Upward Excursions are not permitted.

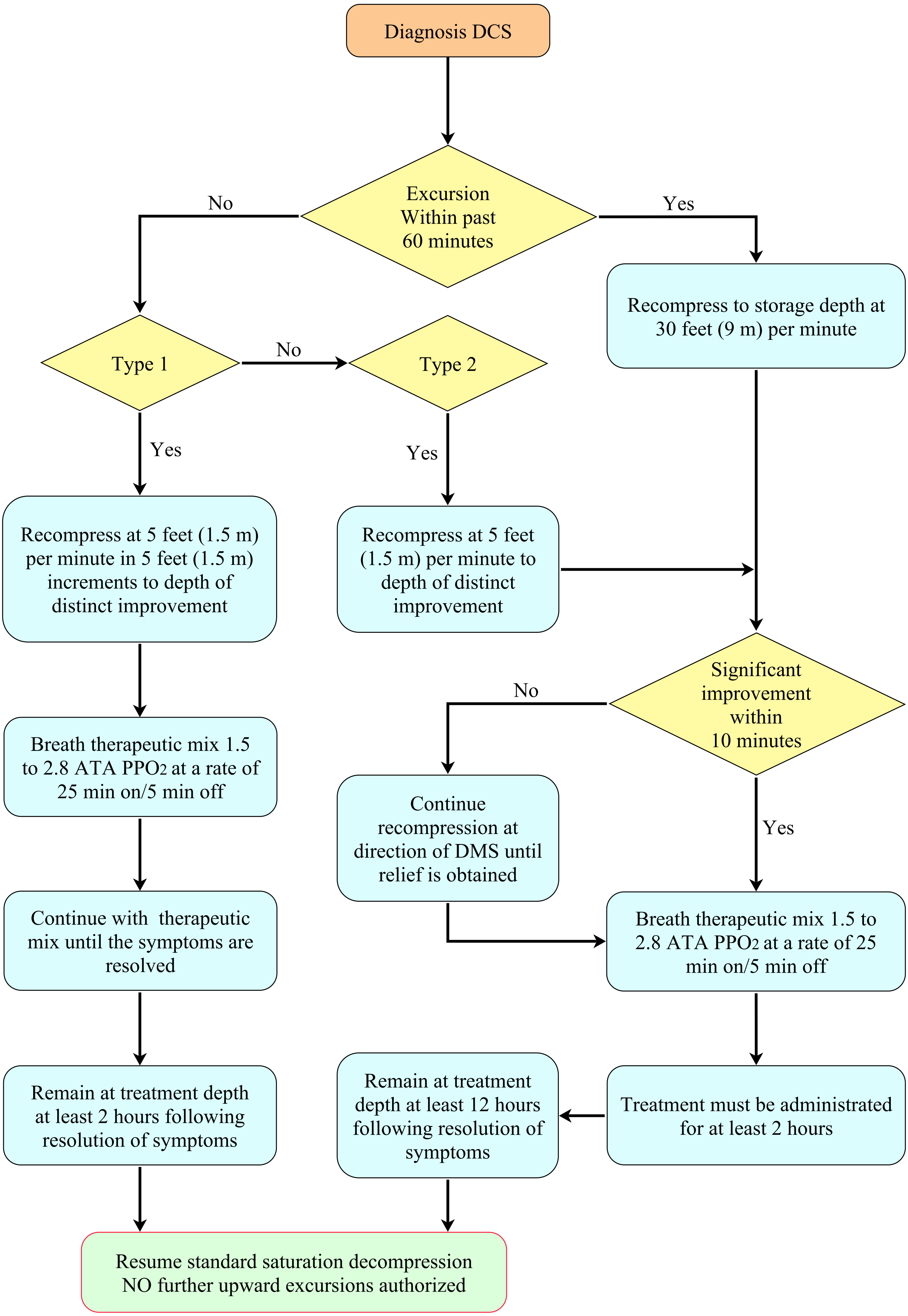
9.2 - Type II Decompression Sickness

Type II Decompression Sickness in saturation diving most often occurs as a result of an Upward Excursion. The onset of symptoms is usually rapid, occurring during the Upward Excursion or within the first hour following an excursion ascent. Inner ear decompression sickness manifests itself as nausea and vomiting, vertigo, loss of equilibrium, ringing in the ears and hearing loss. Central nervous system (CNS) decompression sickness may present itself as weakness, muscular paralysis, or loss of mental alertness and memory.

- Type II Decompression Sickness resulting from an Upward Excursion is a medical emergency and should be treated by immediate recompression at 30 fsw/min to the depth from which the Upward Excursion originated.

- When Type II Decompression Sickness symptoms do not occur in association with an Upward Excursion, compression at 5 fsw/min to the depth where distinct improvement is noted should take place.
    - Upon reaching treatment depth, symptoms usually begin to abate rapidly.
    - If symptoms are not significantly improved within 5 to 10 minutes at the initial treatment depth, deeper recompression at the recommendation of a Saturation Diving Medical Specialist should be started until significant relief is obtained.
    - After reaching the final treatment depth, treatment gas having an oxygen partial pressure of 1.5 to 2.8 ata should be administered to the stricken diver for 25-minute periods interspersed with 5 minutes of breathing chamber atmosphere.
    - Treatment gas should be administered for at least 2 hours and the divers should remain at the final treatment depth for at least 12 hours following resolution of symptoms.
    - Decompression can then be resumed using standard saturation decompression using rates shown in the table next page.
    - Further Upward Excursions are not permitted.

9.3 - Chart “Saturation decompression sickness”



10) After the dive

10.1 - Proximity of a chamber and flight back to home

DMAC 7 has been designed to cover the post dive procedures in the eventuality that the tables used by the contractor has no post dive procedures, or these procedures are insufficient. It must be remembered that when the procedures recommended by the designer of the table are more stringent than DMAC 7, which is the case here, these procedures must be applied. US Navy manual says in point 15-24:

- After surfacing from the dive, the divers are still at risk from decompression sickness:
  - Divers shall remain in the immediate vicinity of a chamber for 2 hours (on the dive station), and within 30 minutes travel of a chamber for 48 hours after the dive.
  - Divers shall not fly for 72 hours after the dive surfaces.
- It should be emphasised to all divers that:
  - Any symptom should be reported before departure from a dive location;
  - Treatment begun soon after the onset of symptoms is often relatively straightforward but 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 - Decompression illness following the decompression

Two sets of medical tables can be applied according to the choice of the diving medical specialist in case of decompression illness after surfacing: The US Navy therapeutic tables that can be found in the US Navy manuals and in the manuals CCO Ltd, and the COMEX table which can be also found in the manuals CCO Ltd.

Note that the chamber must be pressurized with heliox 20/80

10.3 - Flight following a therapy for decompression illness

Following therapy for decompression illness, even when successful, advice should be sought from the diving medical specialist.

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.

The guideline DMAC 21 which specifies the maximum duration of the divers in saturation and the interval between 2 saturations or hyperbaric exposure says:

- Under normal circumstances, saturation duration should not exceed 28 days. In exceptional circumstances it may be appropriate to consider a brief extension, but only with the written agreement of the diving contractor's medical advisor, the divers, and diving supervisor.
- Saturation diving should be planned so that each period spent in saturation by a diver is followed by a surface interval of equal duration.
- A diver may however be recommitted to saturation after a shorter surface interval (in air atmospheric pressure) subject to the following provisos:
  - i) The surface interval should not be less than 50% of the duration of the preceding saturation dive or 10 days whichever is the lesser.
  - ii) Where a diver carries out two saturation dives separated by a shorter surface interval than that defined in 2.1, the surface interval subsequent to the two dives should be not less than the duration of the longer of the two saturations.
- A diver's cumulative saturation exposure should not exceed 182 days in any 12 calendar months.
- 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, e.g. in excess of 200 metres, 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.

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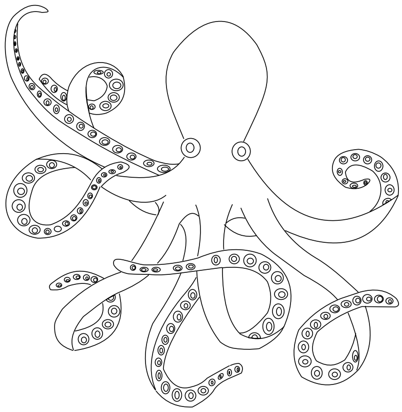

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