A METHOD FOR INTRODUCING NEW DECOMPRESSION PROCEDURES

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In France, in 1984, Comex was awarded a 3 years contract from the F.S.H. (Fonds de Soutien aux Hydrocarbures) to improve the safety performances of the French 1974 official air decompression tables.

Because a large number of parameters are involved in the safety performances of decompression tables, it was clear from the beginning that no :
- mathematical model,
- animal model,
- onshore laboratory manned study,

could be used to test the procedures and that the only way to validate the new tables was to dive with them in actual worksite conditions.

It was also apparent that decompression sickness (DCS) incidence of the air tables presently used for commmercial diving are still relatively low (around 1%-2% overall DCS incidence) and that a large number of man exposures would be required to statistically document any improvement of the new tables over the old ones.

The Comex programme was thus organized into 5 steps (Figure n° 1) :
- evaluation of the existing tables,
- calculation of new tables,
- test of the new tables on selected worksites,
- modifications if required,
- presentation of the proposed procedures to French authorities for integration into the new diving regulations.

This paper presents this original method used to introduce the decompression procedures.

METHOD

Decompression tables

The starting point of the development of the new tables was a study carried out on the safety performances of the French 1974 decompression tables based on a computer processing of worksites dive reports (2). As a complement, Doppler bubble detections were also carried out onshore on a set of selected tables (11, 12).

The conclusions, which apply to the in-water decompression technique only, were that :

- dives of moderate hyperbaric exposure, corresponding approximatively to the permitted bottom times of DOE memo no 7/86, were associated to very safe decompressions (0.1 % DCS incidence).
- deep and/or long dive exposures, corresponding to dives beyond the DOEn border line, were associated to a higher rate of DCS incidence (1 to 2% DCS incidence).
- divers using a safety margin in the selection of the table time had performed significant safer decompression when diving in the critical depth and time range.

These foundings were the basis of the calculation of the new tables which were designed to :

- remain identical to the original French 1974 tables in the range where safe results have been demonstrated,
- become equivalent to longer bottom times of the French 1974 tables elsewhere.

Effectively, the tables displayed deeper and/or longer decompression stops in the critical range. It was therefore possible to claim that the new tables were at any moment more conservative than the former ones, because :

- most decompression theories and models consider that deeper and longer decompression stops yield safer decompression,
- it is current practice among diving supervisors to use longer table times as a safety precaution in case of difficult dive conditions. This procedure is clearly described in the US Navy manual which states that "if the diver was exceptionally cold, or if his work load was relatively strenuous, the next longer decompression schedule than the one he would normally follow should be selected".

With references such as the famous US Navy diving manual, this statment became the corner stone of our approach to decompression tables validation. It provides :

- an ethical basis to the problem of sending new decompression procedures to worksites,
- a simple explanation for applying to government authorities for the permission to use the modified decompression procedures.

Instructions

Practically, the new tables were presented in a small manual edited as special instructions by the company methods department. The instructions were said to be designed for worksites associated with difficult dive conditions, i.e. cold, hard work, current, intensive diving operations, etc...

This procedure was aiming at avoiding questions of divers being exposed to different decompression instructions on different worksites.

Worksites

For obvious reasons, the new decompression procedures were sent only to pilot worksites. The following criteria were used for selection :

- favourable legal environment and good relations with the client permitting the introduction of special instructions without arduous discussions,
- proximity of the worksite or specially well organized operation base allowing a good feed back of information,
- high standard of professionalism among the LST's, diving supervisors and diving superintendents insuring that the new procedures were correctly understood and strictly followed,
- intense diving operations in the depths and times related to the new tables, providing a large volume of dive records.

As far as possible, the operational personnel (diving supervisor, LST's,..) were briefed prior being sent on the barges and interviewed upon their return onshore. Weekly contacts were made by telephone or radio. However, the main source of information was the dive reports.

Dive reports

The dive reports are part of the Comex internal reporting system and include three sorts of document :

- the diving report which contains the basic information on the dive parameters. It is primarily a working document used to keep a good record of all operations. It is also a contractual document between the diving contractor and the client, that serves to control the work performed. It is finally a legal requirement, the report being used as the only reference in case of emergency or accident.
- the chamber log which is filled in whenever a deck chamber is operated. It contains all the information relevant to ambient parameters control, during normal dives, but also all the details of the treatment in case of DCS.
- the accident report which is filled in for DCS cases.

Comex diving report, Chamber monitoring report and Accident report sheets are shown in appendices.

The Comex Data Bank

Whenever a dive is carried out on Comex worksites, a copy of the dive report is sent to the method department in Marseille (the reports have carbon copying sheets which are used for the dispatch, one for the worksite, one for the base and one for method department).

All the dive reports received are fed into a computer. This computer system is called the Comex data bank.

When typing the reports in, the computer runs automatic tests on the consistency of the data. Tests include, for instance, comparison of actual dive depth and time with table depth and time, check of the actual decompression time against correct decompression time, correspondance of dive depth with diving method and breathing gas, etc.. The reports are typed in by operational personnel , who are qualified to check any abnormalities eventually detected.

In addition to the above precautions, the validity of the data is checked at worksite level. The local trends are compared to the general results to identify systematic errors of procedures or simply missing reports that would bias the statistics.

Objectives

Safety was the primary concern of the study.

Safety of the decompression tables was measured in term of number of DCS recorded. Any accident / incident / near misses not directly related to decompression procedures were rejected.

The accident reports were checked by the safety officer, the medical department and the method department. Complementary information was eventually obtained by inquiry, interview, post accident medical examination, etc...

Efficiency was a second objective. A special effort was made to produce a manual with clear and simple instructions. Back up procedures were detailed for decompression emergencies such as exceeding the planned bottom time, impossibility to carry out the 3m stop due to worsening sea conditions, oxygen supply failure during oxygen stops, etc. Efficiency was measured from the comments of the project managers, diving superintendents and supervisors who learned to use the possibilities of the tables and reported on their practical and commercial consequences.

RESULTS

Operations

The validation of the new procedures took place from 1985 to 1986.
The instructions were sent to selected worksites around the world : shallow long tables were tested in the Persian Gulf during welding operations not exceeding 24 msw ; deep tables were implemented in Burundi, for the installation of fresh water lines for Bujumbura city ; surface decompression tables were used in North Sea inspection operations,...

Table below summarises the results obtained in january 1987. An estimated number of 1,000 additional diving reports are still waiting to be treated by the computer.

TABLE N° 1

Dives recorded after two years of offshore evaluation of the new French Air decompression tables

tables	number of men x dives	number of tables used
Air std Standard	124	4
Air/oxy at 6m	814	55
Air/oxy at 12m	573	40
Air Surf D	627	52
TOTAL	2138	

DISCUSSION

The method used to introduce the decompression tables is not new. Even if the process is reluctantly admitted and rarely published, it is the simplest approach to improvement of decompression tables. Most of the diving contractors have used this empirical method to develop their own procedures from the original US Navy manual tables. Even at the worksite level, diving supervisors have for long developed similar recepies for the improvement of decompression safety. However, it is the first time that the method has been used systematically and presented as the only reasonable and practical way of developing new decompression tables.

Potential of the method

The primary limitation of the method is that it only provides improvement over former decompression tables and that there is no room for drastic change or new idea. Using this method, we are bound to "Haldanian" decompression procedures for ever ! However, it must be recognized that the method allows for some innovation and that the work done for the new French tables has at least documented the fact that deeper stops are associated with safer decompression.

The second limitation is that the method tends to produce non optimal decompression schedules. As the basic assumption is to promote longer decompression, it is impossible to consider shortening decompression stops for schedules judged too conservative. In that case, information should be obtained from a complementary source.

In fact, the problem arose with the 1974 French tables for the no-stop decompression limit which was considered too restrictive. To slightly extend the no-stop limit, reference was made to the data published by the DOE on UK North Sea operations (2), which clearly documents that the US Navy no-stop decompressions are very safe.

In any case, these short comings are well counter-balanced by the capacity of the method to produce a large volume of data and to allow statistical analysis of the results.

Time required

As Comex has an international activity, the possibilities to use the new tables were numerous. However, it took two years before sufficient information was gathered. The difficulties did not arise from legal or commercial constraints but rather out of the criteria for selection of the worksites. The list of worksites operating in the "interesting range", providing good feed back of information and control of procedures, appeared relatively short. It must be admitted that even for a large diving company, the process is slow.

Divers acceptance

Divers acceptance was good. The reason being that they are used to such modifications in case of difficult dive conditions and that they merely considered them as "Jesus factors". They even treated our new tables, which we considered as "la crème de la crème", as modified US tables !

Quality of the information

The Comex system of computer processing of diving reports was set up in 1974. Similar systems are known to be run by the US Navy (5), the Canadian forces (6), and the University of Pennsylvania, but until 1983 it was the only example of a data bank covering commercial diving operations The only recent equivalent is the system presently commissioned by the DOE to Dr. SHIELDS for North Sea diving operations.

Besides the volume of the information, the nature of the operations (military,scientific or commercial), what really caracterizes a given data bank is the accuracy of its data. A lot of time and effort must be put in checking the quality of the information but the success depends on two conditions.

The first condition is to have the authority to impose the diving report system. Operational personnel just hate paper work and a lot of incentive is required to get good feed back of information. Governements have legal means of pressure, a diving company pays its personnel, but a university, for instance, seems helpless. At Comex, we used a combination of negative actions (angry notes to worksites, warnings, ...) and positive actions (personal listing of dive records, safety records,..) until the system was recognized as useful for everybody.

The second condition is a simple and efficient diving report form. The first diving reports designed by Comex looked like news papers and were far too complex to be efficient. In fact a lot of information judged irrelevant or time consuming on the worksite was just not filled in. Several modifications of the report were proposed until we came to an acceptable compromise between what we would like to get and what diving supervisors would accept to fill in.

Started in 1974, the Comex data bank has been considered as reliable and fully operational since 1976. Results published (2) have shown to be in good accordance with other published statistics (1, 4, 5) and we believe that the system is a good and reliable tool.

Statistical analysis of the results

A large number of parameters are involved in the final safety performances of a set of decompression tables. The currently accepted independent parameters are listed in table n° 2. Because it is impossible to control all these parameters during a given dive, the outcome of the decompression table has been considered as a probabilistic event. Validation of a new set of decompression procedures thus requires recording many dives, performed by many divers, on many different worksites. This for at least two reasons.

Firstly, considering present commercial diving practice, the list of controlled parameters reduces to :
- dive technique (in-water or surface decompression),
- breathing mix,
- pre-dive surface interval,
- dive depth and time.

This means that the decompression tables must fit all the divers, for all the dive conditions and all the worksites procedures. Good training, adequate equipment and sound procedures may reduce the influence of the other uncontrolled factors but not eliminate them. It is therefore expected that any variations of these uncontrolled factors will remain within the safety margin of the decompression tables.

Statistically, this assumption is equivalent to considering the uncontrolled factors as random events of low incidence. Then, the overall combination of all these secondary variables has a random effect on the final result. Such an assumption requires that the number of dives studied is large enough for the secondary variables to be considered as centered, normal variables of small standard deviation (7). This is not always the case and we can recall a diver who twice got a DCS with the new tables and who certainly introduced some bias in the evaluation of the new procedures.

Secondly, because of the random nature of DCS occurrence, it is necessary, when comparing the performances of different schedules, to implement statistical techniques (7, 8,9, 10).
However, DCS incidence in commercial diving is low. Present state of the art in air decompression procedures ranges from 0.5 % to 2 % DCS occurrence depending on dive exposure (1, 2, 4, 5) and the classic statistic tools appear very unefficient in separating tables performances. Using standard comparison technique for observed percentages, it requires about 100 dives without any accident to show any improvement over a former schedule which was used 25 times with 1 DCS occurrence ! It might be even more drastic if one DCS is recorded during the evaluation of the new table.

The practical implication is that, nowadays, the number of dives required to document any significant improvement of new tables over former ones is large.

Considering the 2,100 dive reports collected and the 1,000 dive reports waiting for processing, we can rely on an approximated of 3,100 dives for this study. It might appear small when compared to the 60,000 dives recorded with the French 1974 tables, but it must be noted that :

- exposures recorded are located in the critical depth and time range,

- a given worksite generally operated at constant depth for almost always the same bottom time and the dives recorded are concentrated on small number of decompression schedules.

However, even though the process of data acquisition has lasted for two years, we must admit that in 90 % of the cases, the information gathered was insufficient to allow conclusive comparison of table by table. As a consequence, when decompressions were insufficiently documented, the results of several schedules were grouped together into categories to allow statistical comparison.

CONCLUSION

Even if the method developed is relatively limited and very slow, it appears to be a reasonable way of introducing new decompression tables because today, lengthy and tedious dive logging is required to document any modifications of procedures.

Even though this study has represented an effort to implement statistical techniques, it is right to say that the exact tables performances will be only known in ten years from now, when tables will have been used as standard procedures and 100,000 dives will have been recorded !

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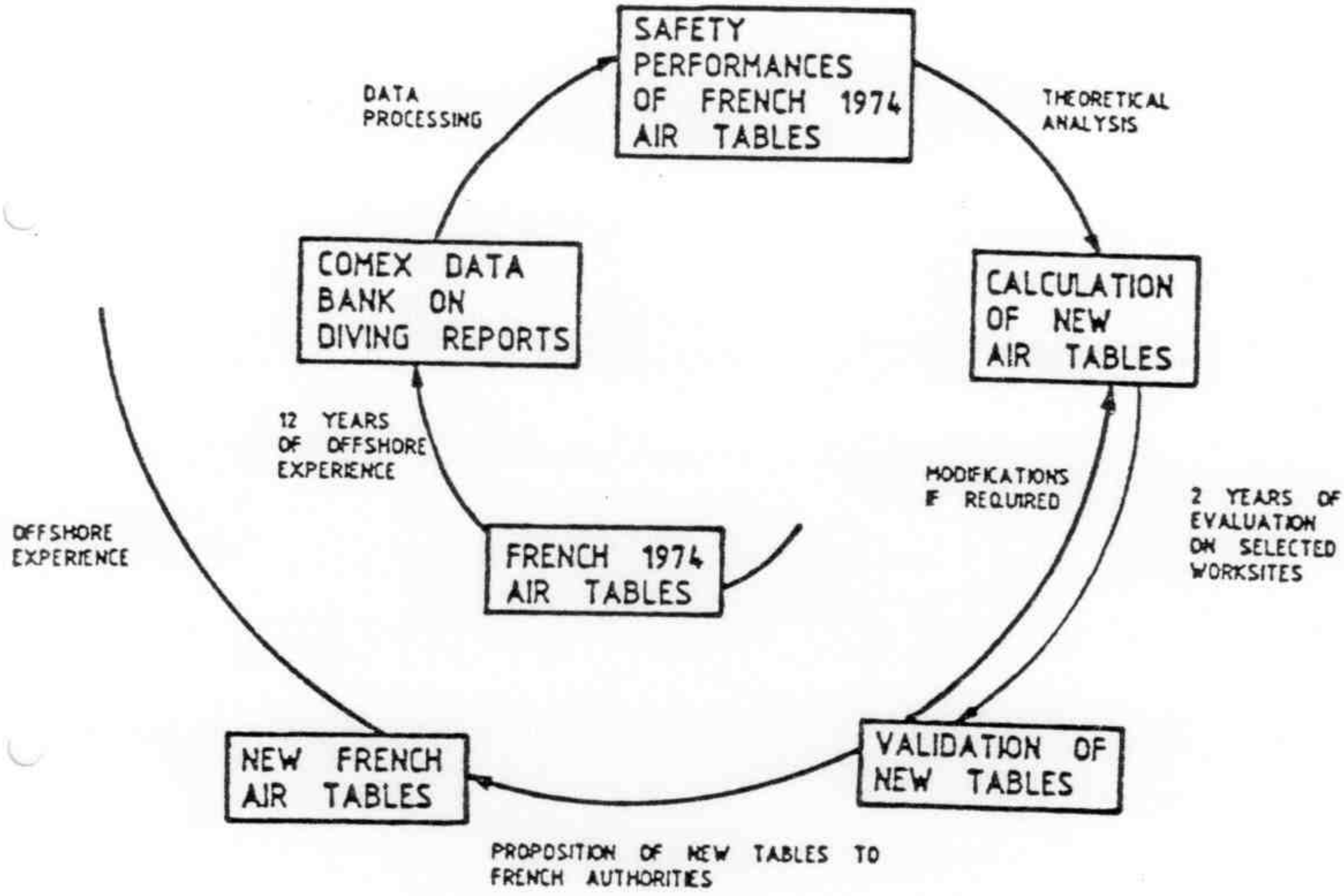
FIGURE N° 1



METHOD USED TO DEVELOP AND VALIDATE NEW AIR DECOMPRESSION PROCEDURES FOR THE FRENCH DIVING LEGISLATIONS.

TABLE Nº 2

LIST OF CURRENTLY RECOGNIZED FACTORS INFLUENCING THE PERFORMANCE OF A DECOMPRESSION

DIVE CONDITIONS	ERRORS OF PROCEDURE	INTER INDIVIDUAL VARIABILITY	INTRA INDIVIDUAL VARIABILITY
- Water or chamber temperature	- Poor control of depth (swell)	- Training, Experience	- Fatigue after travelling
- Wet suit, dry suit, or hot water suit	- Wrong calibration of gauges	- Adaptation to narcosis	- Fatigue after intense diving
- Light or heavy work at bottom	- Error in calculation of bottom time	- Physical fitness	- Hangover, Flue
- Up and down depth variations	- Selection of wrong schedule	- Smoking, Drinking	- Anxiety, Stress
- Swell	- Omitted decompression stop	- Weight, fat content	
- Current	- Shortened decompression	- Age	
- Visibility	- Exceeding the surface interval	- Previous DCS history	
- Narcosis	- Leakage on oro-nasal mask		
- Dry/wet environment	- Wrong quality of oxygen		
	- CO_2 in breathing gas		
	- Work/exercise after decompression		

DIVE REPORT

N° ....

WORKSITE

Date Day ◄└─┘ Month ◄└─┘ 19 ◄└─┘

Surface Support ....

Location ....

Client / project ....

DIVE CONDITIONS

Current (Knt)	☐ <0,5	☐ 0,5 - 1	☐ >1
Swell (m)	☐ none	☐ 1-3	☐ >3
Water visibility	☐ good	☐ poor	☐ none
Water temp. (°C)	☐ 0-10	☐ 10-15	☐ >15

BOTTOM MIX

☐ air ☐ nitrox ☐ heliox

Bottom mix analysis : Mix 1 └─┘.└┘ % O_2

Mix 2 └─┘.└┘ % O_2

PERSONNEL

Superintend.

Supervisor

Diver 1

Diver 2

Bellman

Stand by diver

LST supervisor

DIVERS EQUIPMENT

	Diver 1	Diver 2	Bellman
Suit	....	....	....
Head gear	....	....	....
Bail out	....	....	....
Gas heater	☐	☐	☐
Gas reclaim	☐	☐	

ACCIDENT

☐ No ☐ Yes

Supervisor's signature

SURFACE ORIENTATED DIVING

☐ SCUBA ☐ Surface demand
☐ Wet b...

DIVE

Diver Depth └─┘ m

Diver start descent └─┘

Diver at bottom └─┘

Diver start ascent └─┘

Dive bottom time └─┘ min

DECOMPRESSION

☐ Cx Air No Stop ☐ Cx Air Standard
☐ Cx Air/Oxy 6m ☐ Cx Air/Oxy 12m
☐ Cx Air Surf. Decomp. ☐ Cx Nitrox
☐ Cx Heliox ☐ Other

....

Table depth └─┘ m

Table Bottom time └─┘ min

Table Surface Interval └─┘ h └─┘

STOP	ARRIVAL	DURATION	GAS
36 m			
33 m			
30 m			
27 m			
24 m			
21 m			
18 m			
15 m			
12 m			
9 m			
6 m			
3 m			

Diver at surface └─┘

FOR SURFACE DECOMPRESSION

Diver leaves 9 m stop └─┘

Chamber at 12 m └─┘

Surface Interval └┘ min └─┘ sec

Stop at 12 m └─┘ min

Chamber at surface └─┘

BELL DIVING

☐ Bell bounce ☐ ...ell atm dive
☐ Bell sat ☐ ...ub lock out

DIVE

Diver depth └─┘ m

Bell depth └─┘ m

Storage depth └─┘ m

Hub decomp

Start bell descent

Bell at bottom

Bell pressure up

Door opened

	Diver 1	Diver 2
out		
in		
out		
in		
Total time		

Door closed

Start bell ascent

Start decomp.

Bell on deck

Hub pressure up

FOR BELL BOUNCE DIVE ONLY

Table used ....

Table depth └─┘ m

Table bottom time └─┘ min

End of decompression └─┘

BELL PARAMETERS

Time									
P. Mix 1 bar									
P. Mix 2 bar									
PO_2 mbar									
PCO_2 mbar									
HW Temp. °C									
HW Flow l/min									

WORK PERFORMED

☐ Construction ☐ Inspection
☐ Repair, Maintenance ☐ Welding
☐ Drilling assistance ☐ Other

....

NOTE : All times should be taken from the same watch

TO BE RETURNED TO COMEX SERVICES - OPERATIONS DIVING - 36, Bd ...

- APPENDIX -

INTERNAL ACCIDENT REPORT

PATIENT SURNAME : .... Christian name : .... Date of accident : __ / __ / __
Company : .... Function : ....
Worksite : .... Client/Project : ....
☐ Surface accident ☐ Accident under pressure or related to diving
☐ Wound, fracture, ... ☐ Illness, infection, ... ☐ Decompression sickness

1 CIRCUMSTANCES

Person in charge at the time of the accident : ....
Where did the accident occur ? ....
....
What was the patient doing ? ....
....
....
Was he wearing his safety equipment ? ☐ Yes ☐ No What were his normal working hours ? ....

2 THE ACCIDENT

Time : __ h __ In case of accident related to diving, depth of the diver : ___ m.
What happened ? ....
....
....
1st witness SURNAME : .... Christian name : .... Function : ....
Address : ....
2nd witness SURNAME : .... Christian name : .... Function : ....
Address : ....

3 SYMPTOMS

Nature of accident : ....
In case of a decompression sickness, specify ☐ TYPE I ☐ TYPE II
Symptoms : location of wound / pain (specify right / left), state of consciousness :
__ h __ : ....
__ h __ : ....
__ h __ : ....
__ h __ : ....

4 TREATMENT (In case of decompression sickness, indicate the table selected)

__ h __ : ....
__ h __ : ....
__ h __ : ....
__ h __ : ....
In case of recurrence / worsening of symptoms, new treatment : ....
__ h __ : ....
__ h __ : ....
If a medical doctor was contacted, give his name : .... and the instructions he mentioned :
__ h __ : ....
__ h __ : ....
In case of evacuation / Date : ... / ... / ... Time : __ h __ Destination : ....

5 DIVING ACCIDENT

Previous dive : Date : .. / .. / .. Depth : ___ m Bottom time : ___ min End of dive time : __ h __
Current dive : Working depth : ___ m Bottom time : ___ min Storage depth : ___ m
Method : ☐ SCUBA ☐ Surf. supplied ☐ Wet bell ☐ Bell bounce ☐ Bell saturation ☐ Other
Mix : ☐ Air ☐ Nitrox ☐ Heliox
Decompression table : ....
Table depth : ___ m Table time : ___ min Table interval: __ h __
Circumstances of accident : ☐ During dive ☐ Blow up / Shortened decompression ☐ After dive
☐ Other, specify : ....
....
....

Attached documents : ☐ Supervisor report ☐ Dive report ☐ Chamber monitoring report
☐ Patient check list ☐ Witnesses report ☐ Treatment chamber monitoring report
☐ Others : ....

Diving supervisor : .... Date of report : ... / ... / ... SIGNATURE :

comex

CHAMBER MONITORING REPORT N° ____________

day |__|__| Month |__|__| |__|__|

Surface support |__|__|__|__|__|__|__|__|__|__|__|__|

Location |__|__|__|__|__|__|__|__|__|__|__|__|

SUPERINTENDENT

|__|__|__|__|__|__|__|__|__|__|__|__|

CHAMBER OPERATORS

|__|__|__|__|__|__|__|__|__|__|__|__|

|__|__|__|__|__|__|__|__|__|__|__|__|

|__|__|__|__|__|__|__|__|__|__|__|__|

|__|__|__|__|__|__|__|__|__|__|__|__|

|__|__|__|__|__|__|__|__|__|__|__|__|

PERSONNEL IN CHAMBER 1	PERSONNEL IN CHAMBER 2	PERSONNEL IN CHAMBER 3

TIME	DEPTH metres	OXYGEN						CO_2			HUMIDITY			TEMPERATURE			OBSERVATIONS AND FILTER CHANGES
		C 1		C 2		C 3		C 1 mb	C 2 mb	C 3 mb	C 1 %	C 2 %	C 3 %	C 1 °C	C 2 °C	C 3 °C	
		%	mb	%	mb	%	mb										
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TO BE RETURNED TO MARSEILLES

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