HYDRA VIII - DIVING OPERATION AT SEA

Sa Comex

HYDRA VIII

DIVING OPERATION

AT SEA

CONTENTS

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 1

TITLE : **INTRODUCTION**

DATE : October 1988

REVISION : 00

INTRODUCTION

HYDRA VIII diving operation at sea constitutes a major stage in the hydrogen deep diving development programme run at COMEX since 1983.

The various experimental research and diving phases which have introduced HYDRA VIII operation at sea in the offshore industry natural environment are summarised hereafter.

HYDRA III

In June 1983, off Marseille, COMEX uses hydrogen again. Several dives are performed to 72 and 91 meters. The divers breathe a "hydrox" mixture composed of 97.5 % hydrogen and 2.5 % oxygen. No incident is reported to disturb the operations progress and, from a physiological point of view, no restrictive factor is highlighted.

HYDRA IV

The operation was supposed to confirm hydrogen non-toxicity and to highlight its narcotic effect. A long saturation dive in heliox took place in November 1983, in which 6 divers breathed hydrogened mixes at 120, 150, 180, 240 and 300 meters.

Highly positive results were recorded :

* confirmation of hydrogen non-toxicity
* assessment of this gas narcotic effect and quantification of the acceptable concentrations according to depth
* excellent breathing comfort
* important reduction of the muscular fatigue after long efforts

* **PHASE 2**

Development of the techniques and devices meant to control hydrogen handling, namely a hydrogen selective removal system for hydreliox ternary mixes. This equipment was used successfully to eliminate hydrogen during HYDRA VI AND VII "onshore" dives decompressions.

* **PHASE 3**

"Onshore" dive to 520 meters : selection and training of 8 divers for the future operation at sea.

This saturation dive to 520 meters, in a hydreliox mix (H_2-He-O_2) was performed from November 21st to December 18th, 1986, in COMEX Hyperbaric Test Centre chambers in Marseille. It was mainly concentrated on aquatic activities, the divers executing tasks appealing to their intellectual and physical faculties, in a hyperbaric pool.

HYDRA VII

Performed in January 1987, this "onshore" saturation dive to 260 meters in hydrox (H_2-O_2) served to elaborate a control method of the divers' susceptibility to hydrogen. Four extra divers are then available for the future HYDRA VIII operation at sea.

HYDRA VIII OPERATION

FINAL REPORT

SECTION: 2

TITLE : **ORGANIZATION**

INDEX :

1 - Project management
2 - Equipment and device mobilization
3 - Offshore operations
4 - Divers
5 - Medical and scientific teams

DATE : 10 september 1988
REVISION : 00

1 - PROJECT MANAGEMENT

This project is developped by COMEX with the participation of the FRENCH NAVY.

The operation is supervised by three Committees :

- **Management Committee** : acts as a high authority, determining the project outline

- **Operational and Technical Committee**, in charge of the preparation and development of the different project phases

- **Scientific and Medical Committee**, whose part was to determine and control the application of the saturation and therapeutic procedures, gas composition, and the physiological parameters limits to be observed. The Committee was responsible for the divers medical observation throughout the whole operation, and played a crucial part in the relations with the divers.

MANAGEMENT COMMITTEE

- Monsieur **H.G. DELAUZE**, COMEX Group Chairman

- Captain **COUILLAUD**, Commander of the Underwater Intervention Group (GISMER) of the French Navy.

OPERATIONAL AND TECHNICAL COMMITTEE

- **HYDRA VIII Poject Manager :**
  T. CIESIELSKI, COMEX SERVICES Engineer

- **Hydrogen Technology Expert :**
  C. GORTAN, in charge of COMEX Hyperbaric Test Centre

- **HYDRA VIII Operations Manager :**
  J. MAMBRE, COMEX Barge Superintendent

- **FRENCH NAVY Operations Coordinator :**
  Commander PINGUET, GISMER Diving Squad Captain

SCIENTIFIC AND MEDICAL COMMITTEE

- **Hydrogen Programme Manager** **Dr FRUCTUS**	**COMEX Scientific Manager**
- Dr COMET	COMEX Medical Department
- B. BARDETTE	COMEX Physiologist
- Medecin General Inspecteur BROUSSOLLE	Navy Biological Study and Research Centre
- Medecin General DROUET	French Navy Biological Research Centre
- Medecin General MELIET	CEPISMER - Underwater Intervention Practical Studies Centre - Navy
- Medecin Chef LEMAIRE	GISMER

2 - EQUIPMENT AND DEVICE MOBILIZATION

The study and technical follow-up of the project equipment and device preparation were carried out within COMEX SERVICES Technical and Operational Centre in Marseille, coordinated by HYDRA VIII Project Mobilization Team.

ORGANISATION D'EQUIPE DE MOBILISATION HYDRA 8

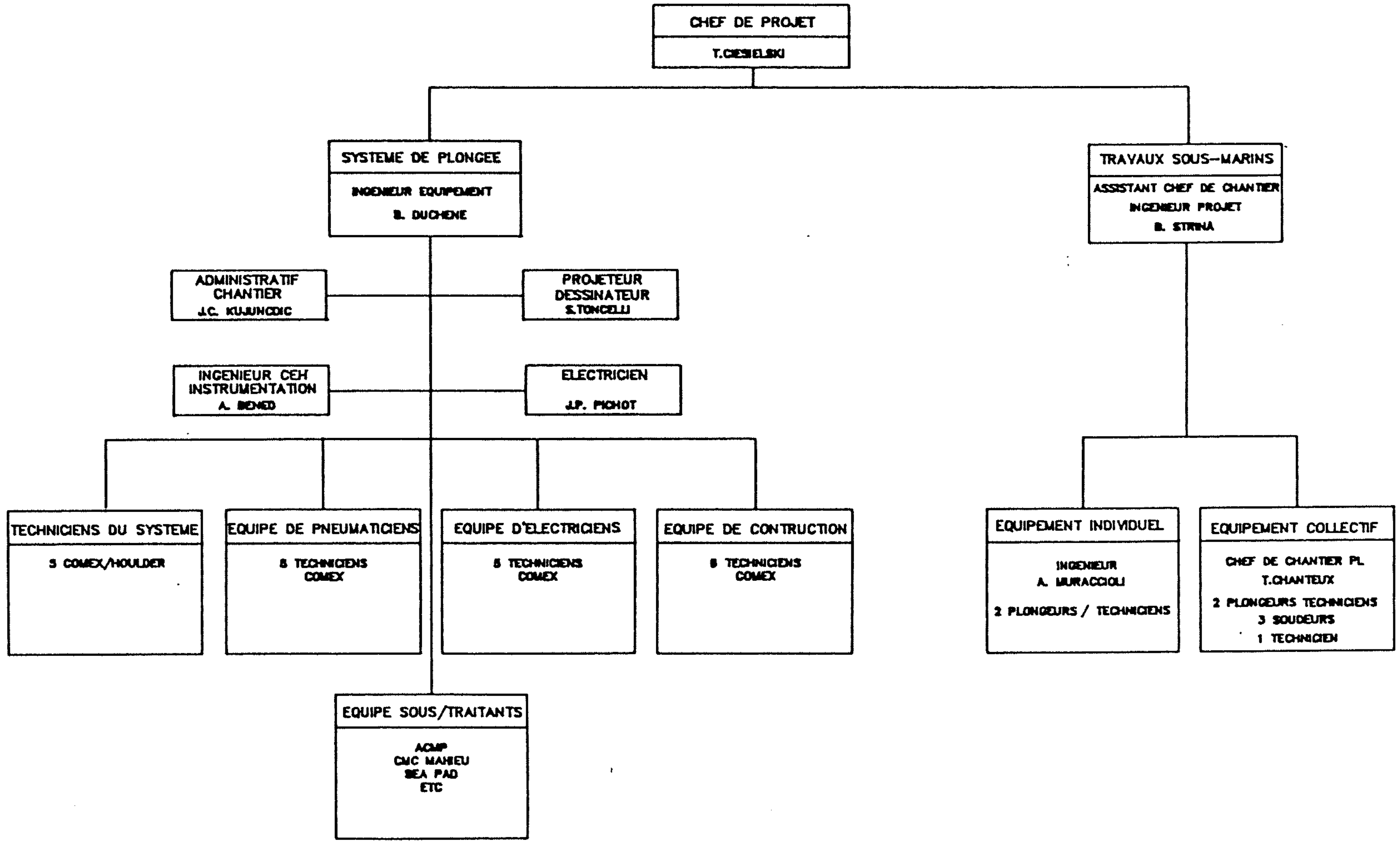


Figure 2-1

3 - HYDRA VIII OFFSHORE OPERATION

The operating chart of the personnel assembled on the support vessel corresponds to the standard organization of a deep diving industrial worksite.

The presence of extra personnel was justified by the operation character and by the important number of installations and prototype equipment requiring specialized technicians and the creation of an extra job. In the future, personnel might be noticeably reduced for this type of operations.

- Management Committee (2 persons)

- Scientific and Medical Committee (6 persons)

- Individual equipment engineer (1), in charge of the hot water suit proper use and of "in situ" tests, of the "BOS" stand-by breathing system, and of part of the prototype monitoring sensors of the diving bell parameters.

- Instrumentation engineer (1), in charge of the functions remote control system, of the gas detection system and of the gas analysts supervision.

- Safety Officers (2), exceptionally detached for this operation in order to control the strict application of the safety procedures. In charge of safety information and visitors supervision (20 to 40 people per day during the operation).

- Analysts (2 watch-keepers), in charge of the working up of the scientific instrumentation used for the analysis of the various gas mixes : chamber gas, inerted area atmosphere, breathing mixes, etc... These high precision analyses were performed as a complement to the routine operations, and carried out by chamber operators.

- Diving system technicians (2 extra watch-keepers), in charge of the maintenance of the catalytic decompression unit and prototype equipment, such as dehydrogenator, oxygen automatic injection, control system and television networks.

- Diving superintendent second assistant (2 watch-keepers). Their presence was essential, due to the distance between the gas distribution set and the dive control room.

- Cameraman-photographer (1 person), in charge of the operation filming on the project behalf.

HYDRA 8 DSV ORELIA

ORGANIGRAMME DE CHANTIER

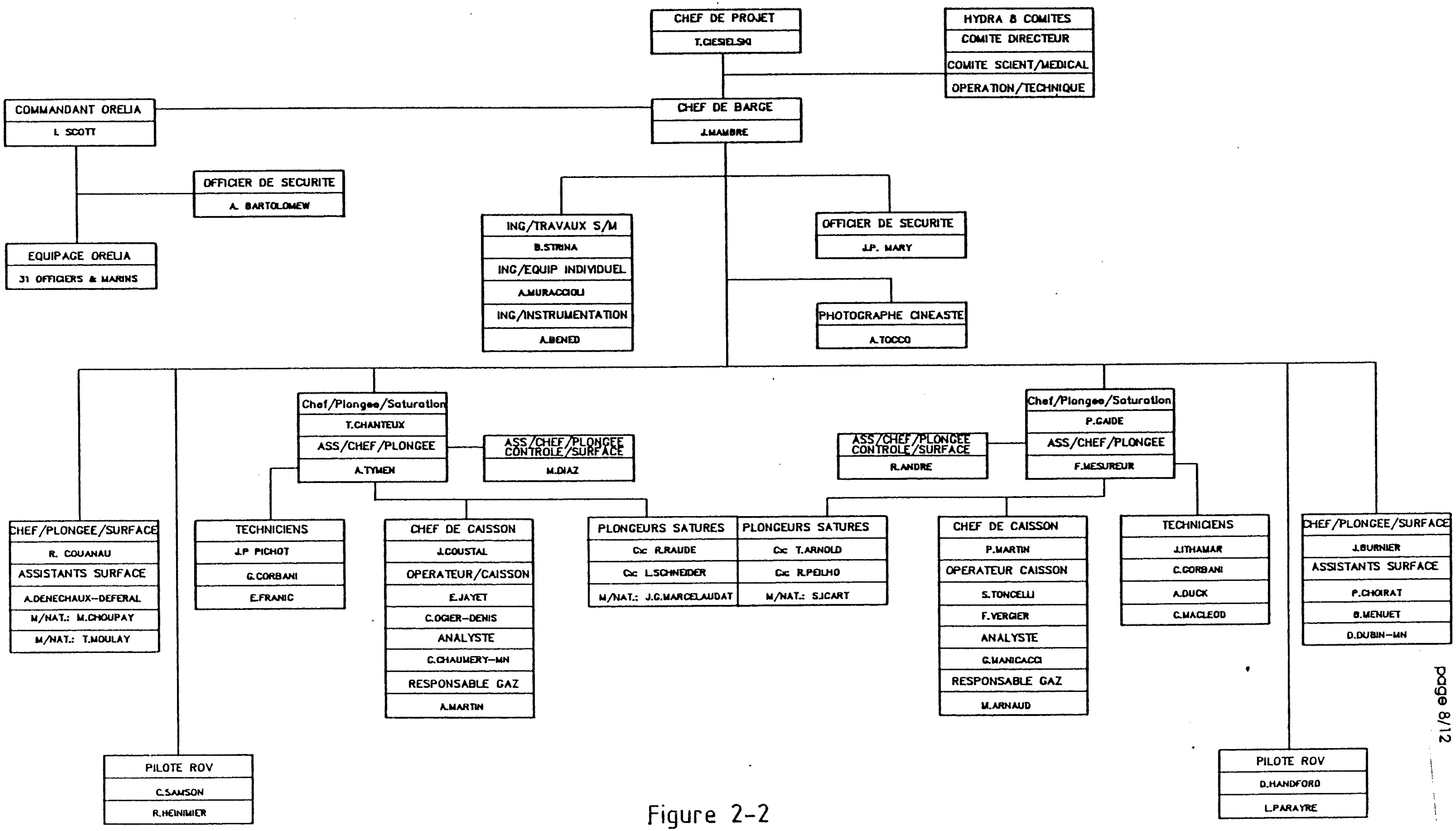


Figure 2-2

22 Février - Equipe des plongeurs HYDRA VIII
22sd February - Diving team
J.G. MARCEL-AUDA
R. PEILHO
L. SCHNEIDER
T. ARNOLD
S. ICART
P. RAUDE

4 - HYDRA VIII DIVERS

Eight professional divers, including two substitutes, were selected for HYDRA VIII, six belonging to COMEX and two to the French Navy (Underwater Intervention Group - GISMER). The main criterion considered for their selection was their aptitude to deep underwater works and their experience of long periods under high pressures.

The six saturated divers constituted two working teams :

Team A

P. RAUDE
L. SCHNEIDER
J.G. MARCEL-AUDA

Team B

T. ARNOLD
R. PEILHO
S. ICART

HYDRA VIII DIVERS PRESENTATION

(In alphabetical order)

* **Thierry ARNOLD - 31 years old - COMEX**

  Joins COMEX in 1981 and has already done 394 saturation days. In 1986, takes part in HYDRA VI operation.
  In 1987, stays 6 days in an argon-oxygen atmosphere at -15 meters, in COMEX Hyperbaric Research Centre. The purpose of this experiment was the physiological effects analysis of the argon used in hyperbaric welding.

* **Serge ICART - 35 - Senior Chief Petty Officer - Navy**

Diver and mine clearance expert, takes part in several missions for the Navy, namely in the Suez Canal mine clearance operation.
With the GISMER since 1979, takes part in numerous deep trials and experimental dives.
Has accounted for 4800 dives.
Participates in HYDRA V in 1985 and HYDRA VI in 1986.
As for J.G. Marcel-Auda, was promoted "Chevalier de l'Ordre National du Mérite", in 1986.

* **Jean-Guy MARCEL-AUDA - 40 - Major - Navy**

Joined the Navy in 1962, at Saint-Mandrier school of mechanics trainees.
In 1968, qualifies as a diver-mine clearance expert and is detached to the Brest Divers Squad.
In 1974, he is a helmet diver.
Eight years later, he is detached to the GISMER, where he follows the deep diving training course.
In July 1975, takes part in the rescue operation of the "Venus des Iles" passengers.
Since 1976, performs numerous saturation dives to the depth of -450 meters.
In 1985, he is one of HYDRA VI operation divers.
Cumulates 5700 dives.
Presently in charge, within GISMER, of the maintenance and operation of the BISM TRITON hyperbaric system.
Since 1986, "Chevalier de l'Ordre National du Mérite".

* **Régis PEILHO - 35 - COMEX**

Starts his diving career with COMEX in 1979 on African worksites, then crosses the globe major oil fields : Brazil, Saoudi Arabia, North Sea.
In 1987, takes part in HYDRA VII.
The same year, takes part in a one-month experiment simulating life in weightlessness. The purpose of this experiment, supervised by the CNES and the NASA, was to study the physiological effects of life in space for a long period.

* **<u>Patrick RAUDE</u> - 37 - COMEX**

Ex-battle swimmer, joins COMEX in 1974, where he specializes into deep diving.
In 1975, participates in the recovery of an underwater well head 326 meters deep, off Labrador.
Two years later, performs his record dive at 501 meters, in JANUS IV operation.
Since 1983, takes part in the HYDRA operations course.

* **<u>Louis SCHNEIDER</u> - 35 - COMEX**

Starts his career in the Navy as a battle-swimmer, then joins COMEX in 1974.
Since then, carried out over 500 saturation days in hard operations, such as the "BOEHLEN" or "TANIO" pumpings.
In 1977, is part of the JANUS IV team and dives to 460 meters, off Cavalaire.
In 1983, he is one of the first to experiment hydrogen narcosis effects, at 240 and 300 meters, during HYDRA IV.
Also participates in HYDRA V in 1985 and in HYDRA VI in 1986.

SUBSTITUTES

* **<u>Patrice CHOIRAT</u> - 31 - COMEX**

Electrical engineer in the Navy, then sport instructor, decides to follow an industrial diving course and joins COMEX in 1984.
Substitute for HYDRA VI, takes part in HYDRA VII.
In 1987, with Régis Peilho, is submitted to a life simulation in weightlessness for a month, in an experiment carried out by the CNES and the NASA.

* **<u>Arnaud DENECHAUD DE FERRAL</u> - 31 - COMEX**

Starts his career as a deep diver for COMEX in 1981, on a worksite in Mexico.
Works then mainly in Africa.
In 1987, participates in HYDRA VII.

5 - MEDICAL AND SCIENTIFIC TEAMS

The operation medical observation and scientific programme were carried out by the Scientific and Medical Committee, supported by the medical and scientific teams external to the project organization :

CNRS -	Tremor evaluation	: Dr ROSTAIN
	Respiratory physiology	: Dr G. IMBERT

Navy Biological Studies and Research Centre team : psychometric tests, EEG, ECG - this team is composed of :

Senior Surgeon GIRY
Senior Surgeon BUGAT
Senior Surgeon GRAPPERON
Senior Surgeon VIDAL
Mrs REYBAUD

Navy Underwater Techniques Studies and Research Centre team - bubble detection - this team is composed of :

G. MAZUREL
N. GUTTIEREZ

OCTARES team (working conditions optimization of biotechnology and safety research) - psychometric tests - team composed of :

J. ABRAINI
E. MARTINEZ
C. LEMAIRE

HYDRA VIII OPERATION

FINAL REPORT

SECTION: 3

TITLE : **OPERATION PROGRAMME**

INDEX :

DATE : 10 september 1988
REVISION : 00

1 - GENERAL SCHEDULE

HYDRA VIII project development covers 21 months, from July 1986 to March 1988. This development period is followed by the results analysis and the operation technical and economical aspects evaluation.

1 9 8 6

July - August 1986

Method examination for the adaptation of a deep diving support vessel to the use of gases containing hydrogen.

September 1986

Selection of the support vessel. First modifications studies on the vessel and on the diving system.

Negotiations and signature of the charter contract for the support vessel "ORELIA".

October - November 1986

Project presentation and methods consultation for the adaptation of DSV ORELIA to the certification organisms by the LLoyd's Register of Shipping and marine authorities - Department of Transport - Marine Directorate.

Updating of ORELIA's diving system and equipment comprehensive drawings.

Evaluation of the diving system hyperbaric space resistance to the working pressure increase to 50 bar, corresponding to the life level at -500 meters.

Studies on the vessel adaptation in process.

November - December 1986

Vessel immobilization for hydraulic testing and general certification of the diving system hyperbaric space for a 50 bar working pressure (Liverpool harbour, then Newcastle).

Selection of an "inerting" solution for the vessel and diving system adaptation.

Engineering survey of the diving system new configuration.

NOTE : In the meantime, HYDRA VI takes place in COMEX Hyperbaric Centre : preparatory phase to the operation at sea, leading to the divers selection and training and to the procedures qualification. The operation at sea preparation takes into account the results of this dive and of the various equipment tests.

1 9 8 7

January - February 1987

Continuation of the ORELIA diving system new configuration study.

Specifications for the ship structural modifications - Space integrity of the inerted area, access locks, extra fire protections and ventilation pipings - Costs verification with the shipbuilding yards (UK , FR).

NOTE : In the same period, HYDRA VII hydrox dive takes place in the Hyperbaric Centre, meant for the divers selection methods validation and hydrogen narcotic power evaluation.

March - May 1987

Specifications elaboration of the system new components construction, purchase and hiring :

- diving bell umbilical
- diving bell parameters monitoring
- hydrogened gas regeneration unit and catalytic decompression
- hydrogen and hydreliox storage system
- nitrogen storage, distribution and control means for the vessel's compartments inerting
- pneumatic and electric components of the new gas distribution and control networks
- deep diving individual equipment integration

* **16 March** The Management Committee approves the operation programme project. The saturation is scheduled to start by mid-February 1988.

NOTE : In March, as most of North Sea diving support vessels, the ORELIA starts her working season.

June - August 1987

Suppliers selection, negotiations of the costs and technical details for the system main components supply.

Start of the gas distribution control system modules construction at COMEX workshop.

Tests of the various components, such as electronic sensors and modules designed for the monitoring system in different gas atmospheres, are carried out at the Hyperbaric Centre in specific use conditions. These tests are supervised by the LLoyd's Register of Shipping representatives.

HYDRA VIII Operational Manual preparation.

September -October 1987

Definition of the project organization structure involving both COMEX and the NAVY. Establishment of a common scientific programme.

An independent mobilization project team for the project is constituted. The engineering works on the particulars proceed. Construction and assembly drawings are elaborated.

Negotiations of the schedule modifications for the support vessel availability. Works programme modifications.

NOTE : In September, the North Sea activity period stops. The ship was to be made available for the project shortly after her last contract. A commercial opportunity followed by the signature of a contract for works in Libya (2 months) brought important modifications to the vessel programme.

In order to meet our obligations, we decided to reduce the time scheduled for the installation works, relying on our teams' experience and on our know-how of hydrogen technology. We thus removed from our programme most of the provisions for technical risks of the prototype system setting up.

The construction and assembly works of the system modules carry on at COMEX workshop.

Vessel immobilization for the first part of works in the chambers compartment. Works concerning structural modifications were carried out by Newcastle shipyard before sailing for Libya. These modifications did not alter the system standard operation.

November - December 1987

Presentation of the Operational Manual to the Governmental authorities : Department of Transport Marine Directorate, and to the qualification organisms : Lloyd's Register of Shipping - Underwater Engineering Section.

The underwater work platform and relevant equipment are determined, the construction of the support structure and of a mock-up submarine pipeline connection worksite is started.

Prefabrication works of the system elements are achieved at COMEX workshop.

15 December : Arrival of the ORELIA in the Port Autonome de MARSEILLE, start of the system integration works.

1 9 8 8

January 1988

The system installation works are in full progress, over 30 technicians share the deck restricted space and the diving system compartments onboard the ship.

As the works proceed, the various equipment is submitted to operation tests and, when necessary, is approved by the Lloyd's Register of Shipping :

- hydrogened gas distribution networks
- diving bell handling device
- chambers compartment inerting system and procedures

18 January : the divers start their technical preparation and physical training. Works on the underwater work platform are simulated in immersion with use of the ORELIA's diving bell.

Preparation of the operating instructions, check lists and operation flow charts to be controlled by the system operators.

Publication of a revised version of the Operational Manual, as per Lloyd's' comments, Department of Transport and Department of Energy.

February 1988

The system mobilization works reach completion in the first ten days, followed by operational tests carried out with the participation of the operational teams (in training).

ROV SEA WORKER is mobilized on deck and submitted to routine tests.

10 February : Hydrogen and associated mixes containers are shipped onboard, the vessel goes under safety regulations close to those applying to vessels carrying natural gas.

Navy GRIFFON submarine performs a series of dives on the operations site

22 February - 22 March : HYDRA VIII diving operation

2 - MOBILIZATION

2.1 POLICY

The mobilization works were based on the following principles :

- reduce the vessel immobilization time for works and match her industrial contracts programme

- workshop prefabrication and testing of the modules easy to integrate in the ORELIA system, and in the future in the other deep diving support vessels

- maximum utilization of the know-how and experience of our worksite technicians and COMEX Hyperbaric Experimental Centre specialists

- adapt the industrial solutions and equipment available on the service and rental market to our requirements

The works performed according to this policy enabled to respect the schedule fixed for the operation and to remain within its budget limits.

2.2 WORKS AND STUDIES DEVELOPMENT

- Examination of the general philosophy for the vessel adaptation and approaches for its qualification by the relevant authorities, jointly carried out by COMEX SERVICES Engineering Department in Marseille, and the ORELIA's Owner/Designer Design Office - HOULDER OFFSHORE ENGINEERING in London.

- Study of the ORELIA's diving system modifications, entirely performed by COMEX SERVICES in Marseille.

- Diving system re-classification tests for a working pressure corresponding to the 500 meters life level, carried out by COMEX SERVICES technicians and supervised by the LLOYD's on the vessel immobilized in U.K.

- Equipment specifications, developped by COMEX SERVICES with the participation of :

  CYBERNETICS S.A. - MARSEILLE : diving bell monitoring
  NAUREX - AIX EN PROVENCE : regeneration
  PRODAIR : nitrogen storage and distribution
  OLDHAM : hydrogen leaks detection
  ENGELHARD : gas catalytic scrubbing

- Construction of the system components

  COMEX SERVICES : modules assembly and integration
  CMC MAHIEU - ISLE SUR SORGUE : regeneration unit
  PRODAIR : nitrogen distribution
  CYBERNETIX : diving bell monitoring system
  DE REGT - HOLLAND : diving bell umbilical
  COMEX PRO : diving equipment and underwater TV equipment

- Modifications of the vessel internal structures, works carried out in UK :

  SEA FAB NEWCASTLE UK - access lock, inerted area insulation, diving bell reinforcement
  HOULDER OFFSHORE LIMITED - modifications of the internal structures fire protection system.

- Preparation of the vessel deck for the system components acceptance. Achieved at the beginning of the ORELIA stay in Marseille harbour by COMEX teams.

- Integration of the system elements onboard the vessel in Marseille harbour - performed by COMEX technicians with the participation of HOULDER OFFSHORE technicians and sailors and the following subcontractors :

  CMC MAHIEU - steel high pressure pipefitting, mechanical- welding
  ACMP - mechanically-welded constructions

2.3 SYSTEM TESTS

The acceptance of a system as complex as HYDRA VIII diving system constituted the crucial part of the mobilization works. All the system functions were submitted to verifications in normal operating and different emergency modes. Tests were carried out by technicians teams under the supervision of the Lloyd's Register of Shipping inspectors, the owner's representatives and the quality control / insurance persons in charge for COMEX SERVICES.

* **Tightness tests**

Every system component containing and conveying hydrogened gas mixes was submitted to very strict tightness controls. Tightness tests of the new components, namely for the gas distribution networks, were performed immediately after the 1.5 working pressure tests. A total of 85 pneumatic lines of high and average pressure were tested.

- **Air tightness initial verification**

All the installation components were air pressurized at working pressure. Detection of leaks at the joints and connection levels was done with soapy water.

- **Heliox tightness verification**

After tightening the joints and repairing the failures reported during the first verification, a final control was performed with heliox containing over 60 % helium. Leaks were detected with soapy water and a helium detector. The final acceptance of the hydrogened mixes pressurized housings depended on the pressure drop rates for a 12 hour period, these rates being corrected according to the temperature changes. The maximum drop rate tolerated for the system acceptance in the compartment under the deck was set at 0.1 % and for the equipment in the open air at 0.25 % (coefficients 5 and 2 were respectively applied with regard to the standard norms).

Janvier 88 - L'ORELIA pendant les travaux de mobilisation au port de MARSEILLE
January 88 - ORELIA during mobilisation works in MARSEILLE harbour

* **Lifting and handling devices tests**

The dives depth required to replace the diving bell lifting cables and guide lines. The winches rigged that way reached their capacity limits and tests on their static and dynamic performances held the specific attention of the operators and control organisms. The whole equipment used for lowering and holding the work platform in suspension were submitted to mechanical resistance tests.

* **Operational tests**

The system operating trials were performed by the future operators. Their participation in this phase constituted the best warranty for the good assimilation of the new operation principles and enabled to check the operational procedures particulars. This mobilization part started in the end of January and, for some functions such as the bell handling, ended at sea the day before the first dive.

3 - DIVERS PREPARATION AND TRAINING

The eight divers selected for HYDRA VIII dive were submitted to a 4- week physical training and technical preparation, starting on January 18th, 1988.

Training was directed by a physical training specialist, under medical control.

Two tests to effort on an ergometric bicycle were performed, before and after the training period, to evaluate the oxygen maximum consumption. All physiological measures taken during the dive were repeated and reference values were determined for each diver (re. Section 8).

Preparation and Training Schedule - 15 working days

Morning	3 hour physical training : foot-racing, swimming and relaxation exercices 1 hour medical visit, technical training
Afternoon	4 hour technical preparation in dry and wet conditions. Dives were performed from the training bell in COMEX pool (see photo on next page), then from the ORELIA diving bell in the harbour. Underwater works programme repetition took place on the work platform hanging under the hull in shallow depth.

For the first time, the divers use individual diving equipment in its new configuration :

HYDRALITE helmet
BOS
SAGA hot water suit
TV cameras and lights integrated on the helmet
Instrumentation - monitoring sensors

This training period led to the definitive elaboration of the equipment integrated on the working bell, namely the assistance devices for the diver lock-out from the bell. Also led to the elaboration of the diving procedures and check lists.

Janvier 88 - Plongeur HYDRA VIII lors de son entraînement en piscine
January 88 - HYDRA VIII divers during training in the pool

4 - HYDRA VIII DIVE

HYDRA VIII dive operation at sea started on February 22nd at 11h00 with the divers compression, and ended on March 22nd, when they came out of the chamber. Compression started in Marseille harbour. The vessel sailed to the operation site on the third saturation day, whereas the divers had already reached 400 meters.

4.1 OPERATION SCHEDULE

(next page)

HYDRA VIII – CALENDRIER DE LA PLONGEE

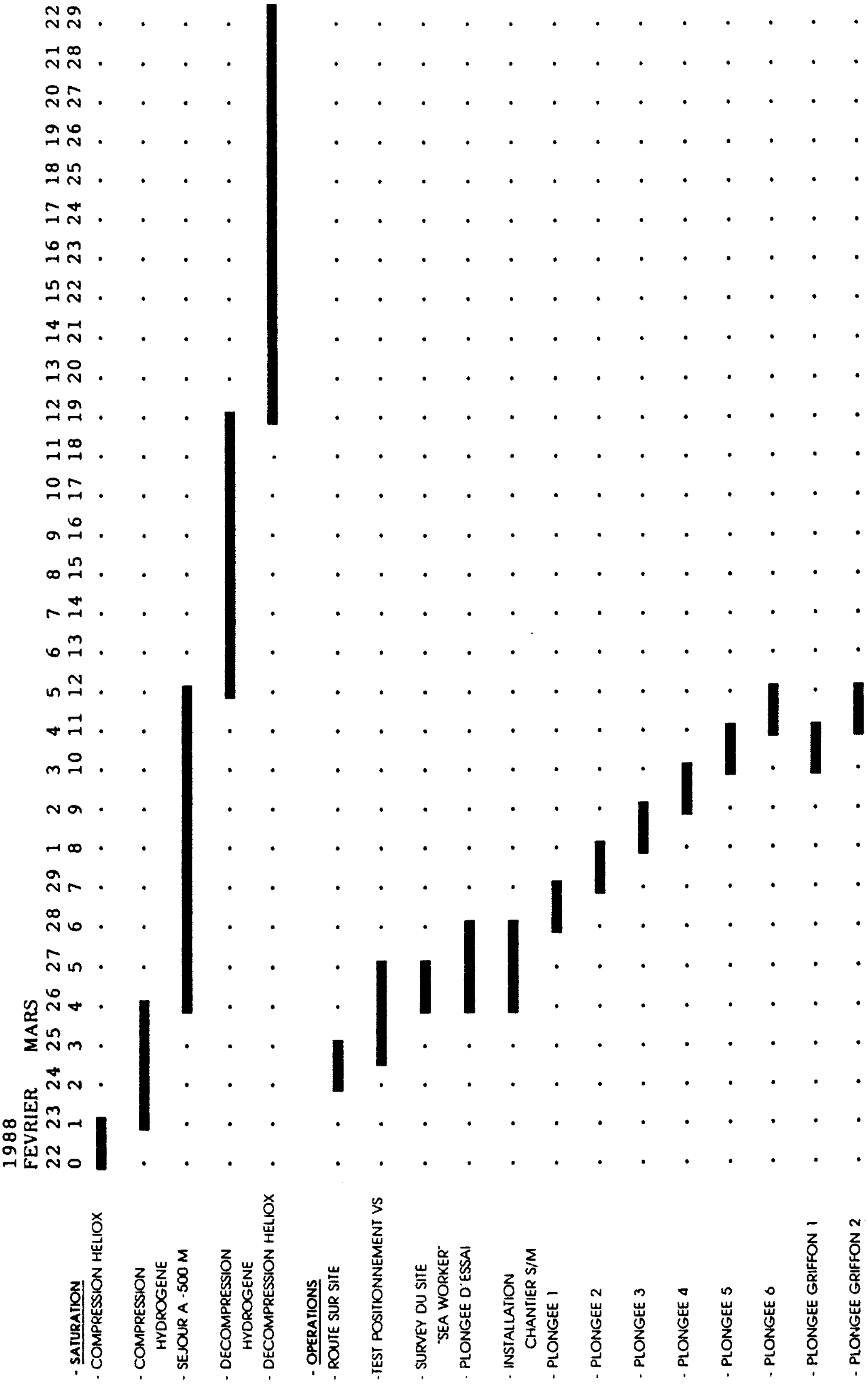


Figure 3-1

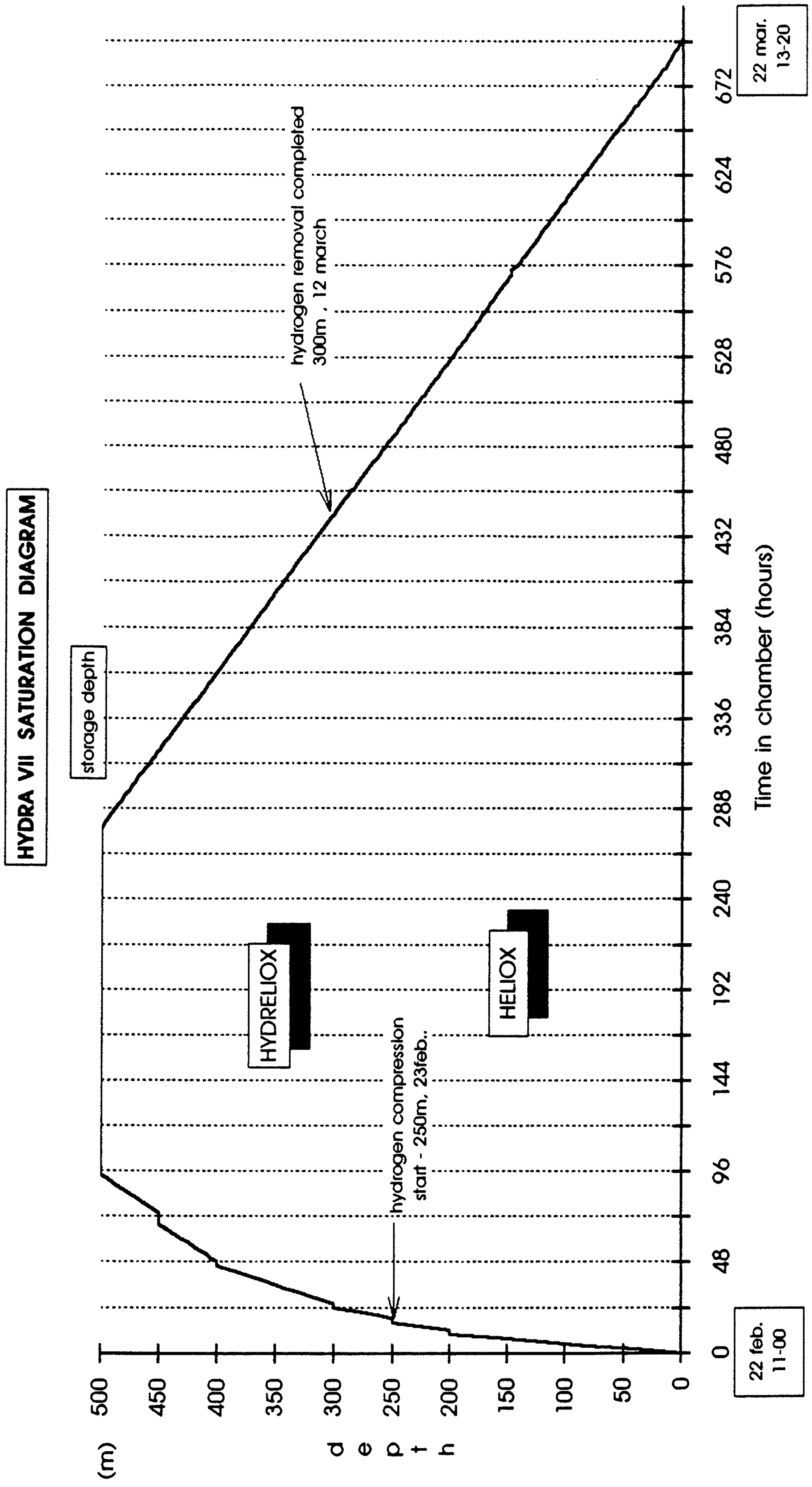

HYDRA VII SATURATION DIAGRAM
storage depth
hydrogen removal completed
300m , 12 march
HYDRELIOX
HELIOX
hydrogen compression
start - 250m, 23feb..
22 feb.
11-00
22 mar.
13-20
depth
(m)
500
450
400
350
300
250
200
150
100
50
0
0
48
96
144
192
240
288
336
384
432
480
528
576
624
672
Time in chamber (hours)

Figure 3.2

4.2 COMPRESSION

Performed in two phases :

- heliox phase
- hydreliox phase

4.2.1 Compression - Heliox phase - 19 hours

The heliox compression allowed to take the divers from surface to the safety depth for hydrogen admission. This safety threshold corresponds to the depth of 250 meters where the oxygen voluminal concentration required for breathing goes below 2.5 %.

Day	Time	Depth	Mix	Action
1	11.00	surface	air	Compression start 20m/hr
	21.00	200	heliox	Star of stop 2 hours
	23.00	200	heliox	Enf od stop
				Compression 10m/hr
2	04.00	250	heliox	Technical stop 2 hours
	06.00	250	heliox	Start of H_2 injection

During this saturation phase, the chambers oxygen partial pressure was kept at 400 mbar. The chamber atmosphere contained nitrogen coming from the chambers residual air (0.78 bar).

The chambers temperature and humidity during this phase were automatically maintained at the following comfort levels :

- **Relative humidity**
  Set point : 50 %, variations : + 9 %, - 2 %

- **Ambient temperature**
  Set point : 30°, variations : + 0.9°, - 1.7°

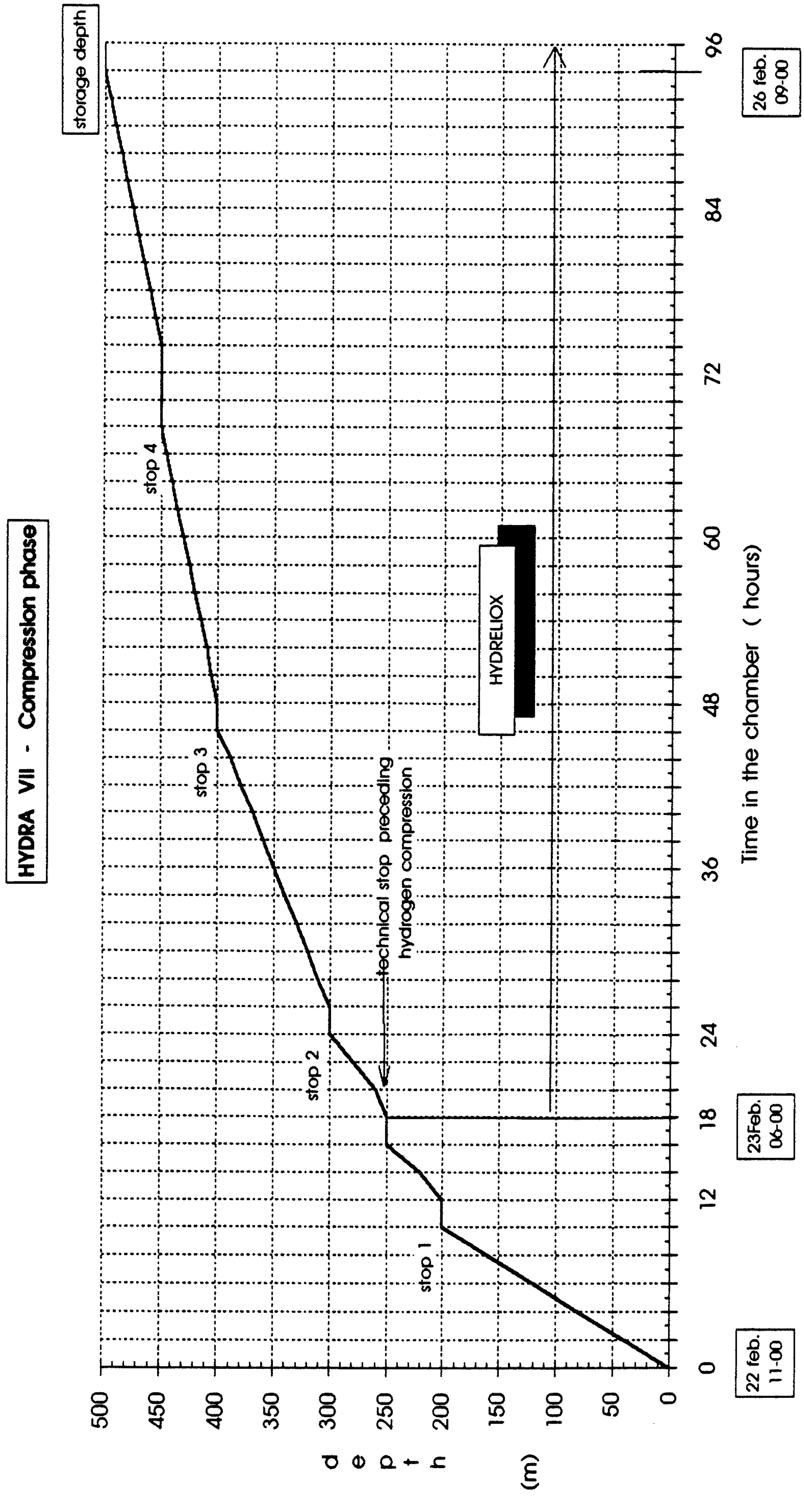

HYDRA VII - Compression phase
storage depth
26 feb.
09-00
23Feb.
06-00
22 feb.
11-00
stop 1
stop 2
stop 3
stop 4
technical stop preceding
hydrogen compression
HYDRELIOX
Time in the chamber (hours)
0
12
18
24
36
48
60
72
84
96
depth
(m)
500
450
400
350
300
250
200
150
100
50
0

Figure 3.3

4.2.2 Compression - Hydreliox phase - 63 hours

The hydrogen admission in the chambers and the compression continuation were conditioned to :

- the oxygen concentration inside the chambers and associated installations - kept below 2.5 %
- the oxygen concentration in the area around the chambers - controlled by the nitrogen inerting system below 2 %

Day	Time	Depth	Mix	Action
2	06.00	250 m	Heliox	Enf of inerting O2 analyses H_2 compression 10m/hr
	11.00	300 m	Hydreliox	Stop n°2 2 hours pH_2 5 bar
	13.00	300 m	Hydreliox	H_2 compression H_2 5m/hr
3	09.00	400 m	Hydreliox	Start of stop n°3 2 hours pH2 15.4 bar
	11.00	400 m	Hydreliox	H_2 compression 2.5 m/hr
4	07.00	450 m	Hydreliox	Start of stop n°4 6 hours pH2 20 bar
	13.00	450 m	Hydreliox	H_2 compression 2.5 m/hr
5	09.00	500 m	Hydreliox	Arrival at life level pH_2 25 bar

During this compression phase, the oxygen partial pressure was maintained at 400 mbar. Temperature and humidity inside the chambers were automatically controlled :

- **Relative humidity**
  Set point : 50 %, variations : + 9 %, -2.92 %
- **Ambient temperature**
  Set point : 31°, variations : + 0.7°, -0.2°

4.3 BOTTOM STAY - 7 DAYS 17 HOURS

Life depth was determined by the ORELIA diving system capacity, restricted by its construction to a 50 bar working pressure, corresponding to the depth of 500 msw. This saturation life depth limited the maximum depth for the runs/work dives. Not supposed to exceed 530 meters with no need for decompression when returning to the chambers. During this operation, the depth limit was extended to 532 meters.

4.3.1 Conditions in the living chambers

Gas mix composition

hydrogen	: 48.7 % ie. pH_2 = 24.8 bar
helium	: 49.3 % ie. pHe = 25.1 bar
nitrogen	: 1.2 %ie. pN_2 = 0.6 bar
oxygen	: 0.8 % ie. pO_2 = 0.4 bar

This composition varied slightly during the stay, due to the handling of the locks and other vessels connected to the system. The locks compression was performed in heliox and produced a hydrogen concentration reduction, periodically controlled by ventilation sequences. Relative variations of the mix gas concentration did not exceed 7 %.

Ambient temperature and hygrometry

Temperature and relative humidity inside the living chambers were maintained at the divers' comfort and safety level.

- **Relative humidity**
  Set point : 50 %, variations : + 10 %, - 3 %
- **Ambient temperature**
  Set point : 32°, variations : + 0.8°, -0.5°

Follow up of the chambers parameters evolution and gas mix composition variations, on next pages.

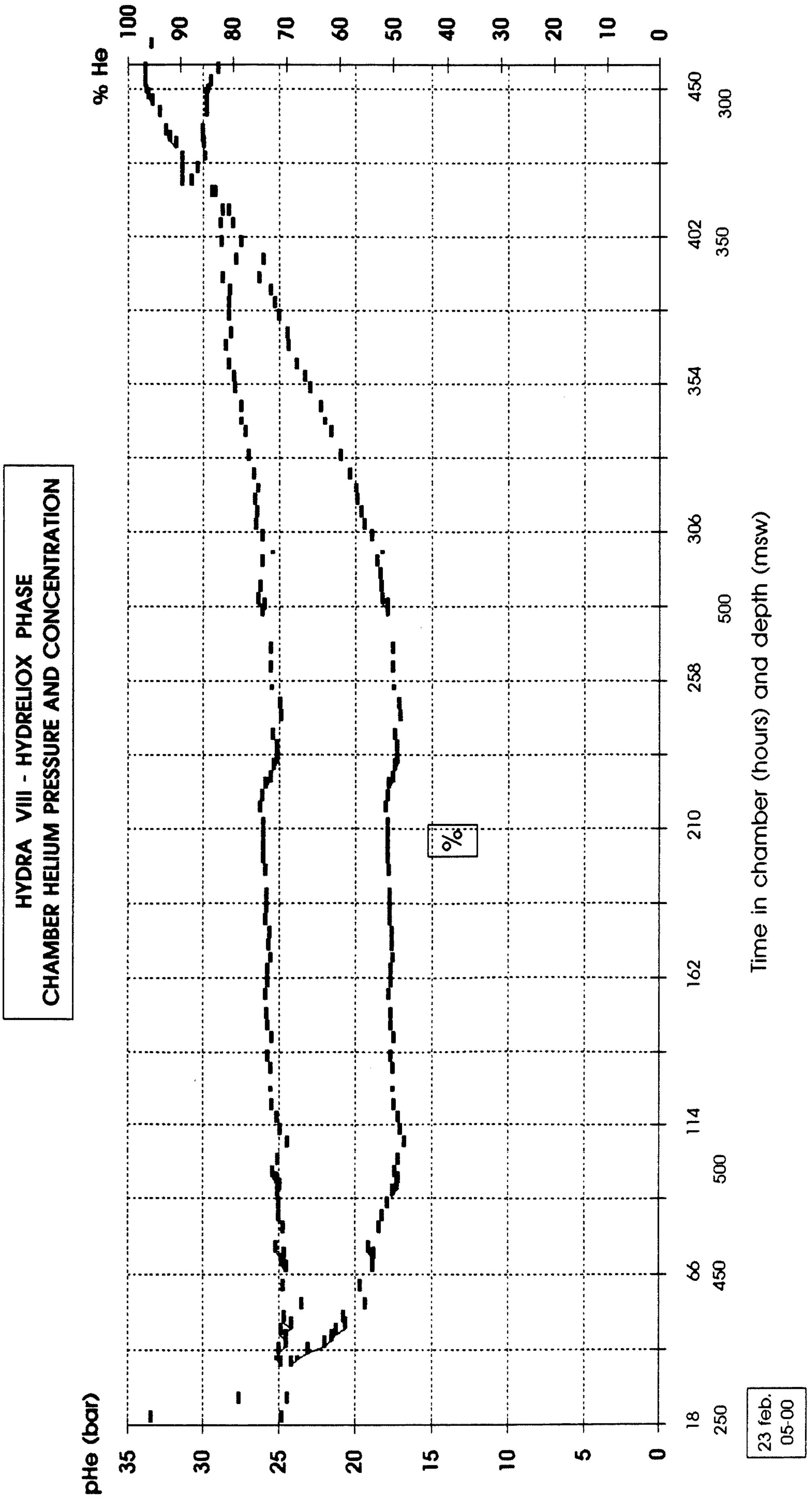

HYDRA VIII - HYDRELIOX PHASE
CHAMBER HELIUM PRESSURE AND CONCENTRATION
% He
100
90
80
70
60
50
40
30
20
10
0
pHe (bar)
35
30
25
20
15
10
5
0
%
18
66
114
162
210
258
306
354
402
450
250
450
500
500
350
300
Time in chamber (hours) and depth (msw)
23 feb.
05-00

Figure 3.4

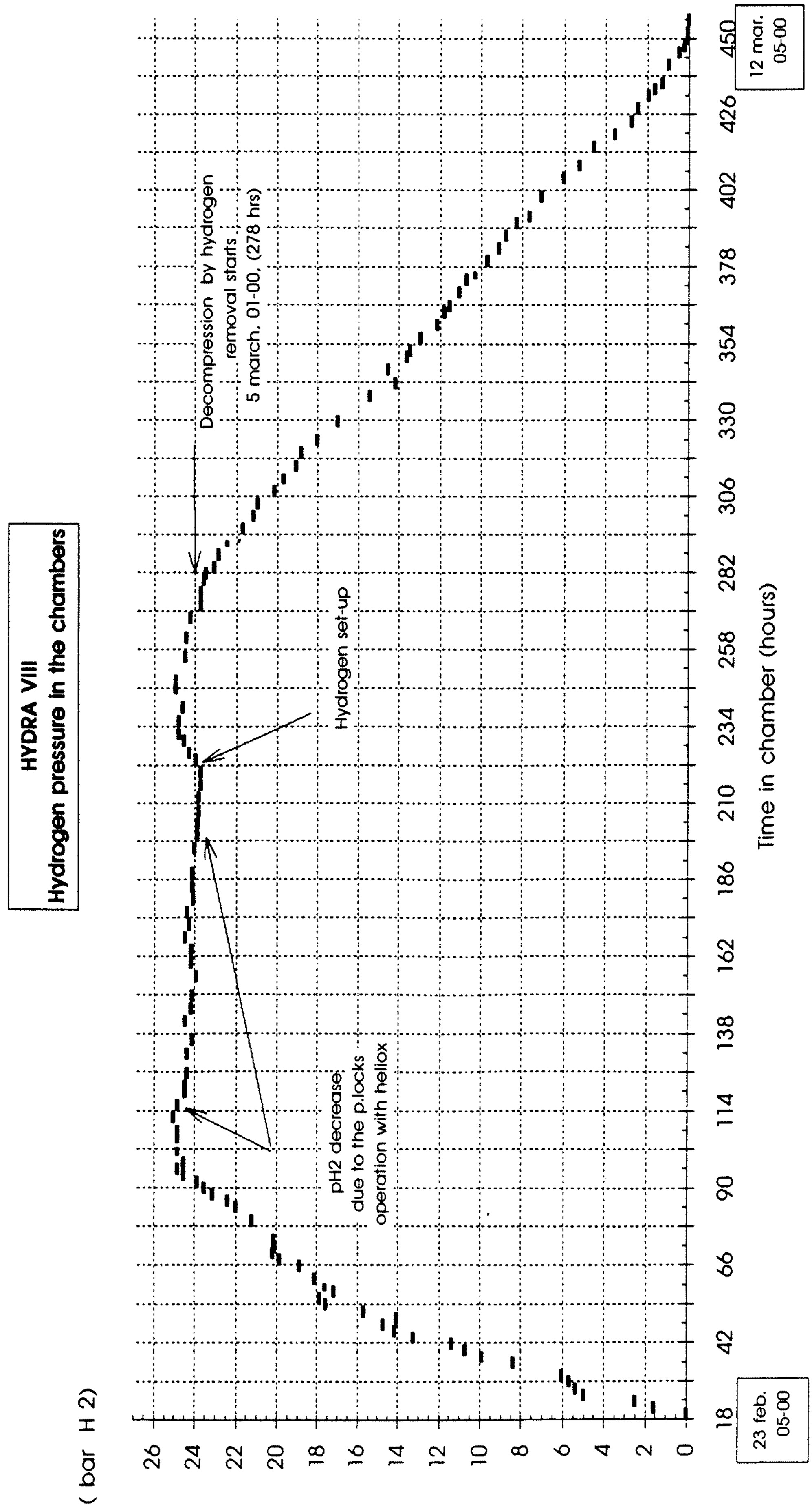
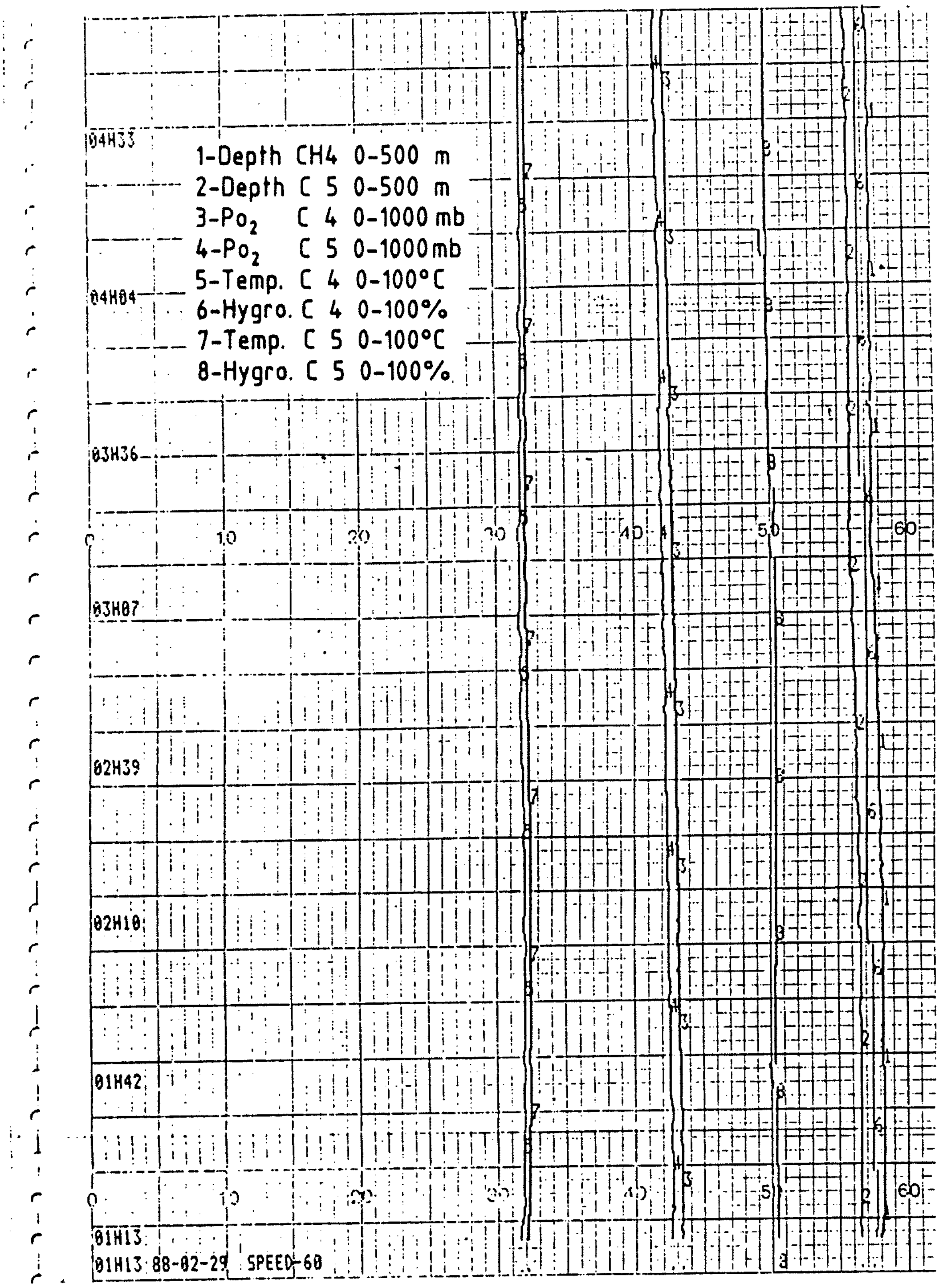

HYDRA VIII
Hydrogen pressure in the chambers
(bar H 2)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
18
42
66
90
114
138
162
186
210
234
258
282
306
330
354
378
402
426
450
23 feb. 05-00
12 mar. 05-00
Time in chamber (hours)
Decompression by hydrogen
removal starts
5 march, 01-00, (278 hrs)
Hydrogen set-up
pH2 decrease
due to the p.locks
operation with heliox

Figure 3.5



ENREGISTREMENT DES PARAMETRES DES CAISSONS

Figure 3-6

4.3.2 Bell dives conditions

The bell stay parameters during the dive differed from the chambers'. The bell immersion depth varied between 510 and 515 meters according to the dives.

Bell atmosphere composition

(at -510 meters)

hydrogen : 48.4 % ie. pH_2 = 25.2 bar
helium : 48.6 % ie. pHe = 25.3 bar
nitrogen : 1.2 %ie. pN_2 = 0.6 bar
oxygen : 1.8 %ie. pO_2 = 0.9 bar

This composition was obtained by the addition of oxygen. The oxygen partial pressure varied along the dive, following the divers' metabolic consumption and the pressurization operations carried out with the bottom mix (1 % O_2). Figure 3.7 on next page summarises the bell oxygen partial pressure evolution during dive 4 (for example only).

Temperature

The diving bell temperature was adjusted with a manual device. The variations due to compressions, decompressions and direct contact with the sea water, were more significant than inside the chambers :

- Set point : 32°, variations : +3°, -2°

Breathing mix

In immersion (average depth 525 meters), the divers breathed hydreliox, composed as follows : (bottom mix)

hydrogen : 47 %ie. pH_2 = 25.1 bar
helium : 52 %ie. pHe= 27.8 bar
oxygen : 1 % ie. pO_2 = 0.6 bar

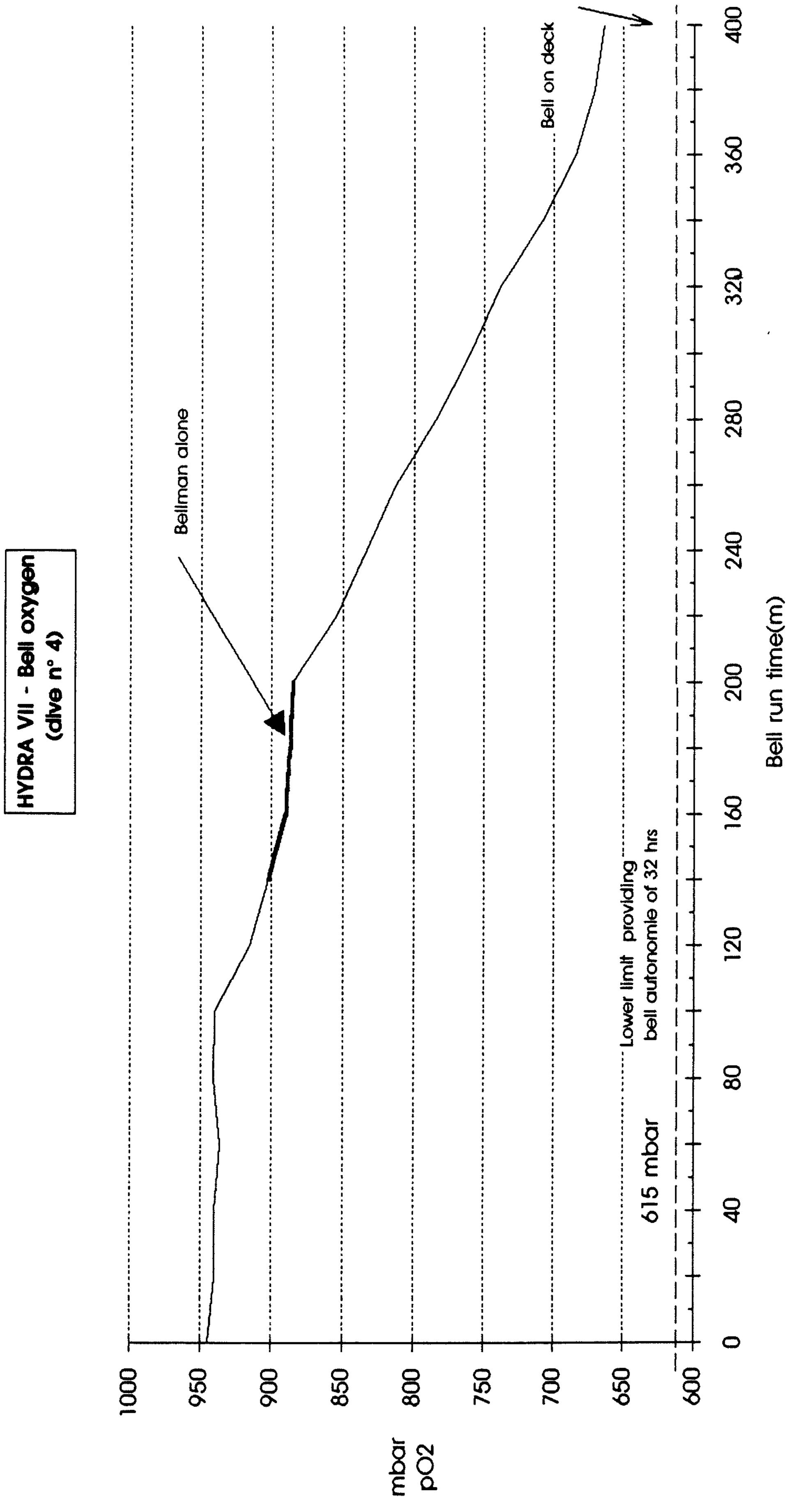

HYDRA VII - Bell oxygen
(dive n° 4)
Bellman alone
Bell on deck
Lower limit providing
bell autonomie of 32 hrs
615 mbar
mbar
pO2
1000
950
900
850
800
750
700
650
600
0
40
80
120
160
200
240
280
320
360
400
Bell run time(m)

Figure 3.7

4.3.3 Activities programme - bottom stay

The stay at 500 meters started with a rest day followed by diving days :

Day	Date	Dive	Team	Activity
1	26/02	-	-	Rest
2	27/02	00	A	Complete bell check list Dive interrupted due to bad weather
			B	Wait
3	28/02	01	A	Work dive : 7h 25 *
			B	Wait
4	29/02	02	B	Work dive : 8h 16
			A	Rest
5	01/03	03	A	Work dive : 6h 03
			B	Rest
6	02/03	04	B	Work dive : 6h 52
			A	Rest
7	03/03	05	A	Work dive : 8h 27
			B	Rest
8	04/03	06	B	Work dive : 8h 31
	05/03		A	Rest

(*) bell run

Except for the first dive, which had been postponed to the next day, all the others were performed as per the schedule, in spite of weather conditions sometimes close to the limits for this kind of activity. The ORELIA's excellent behaviour at sea allowed to proceed with the initial programme. Figure 3.8 on next page summarises this period.

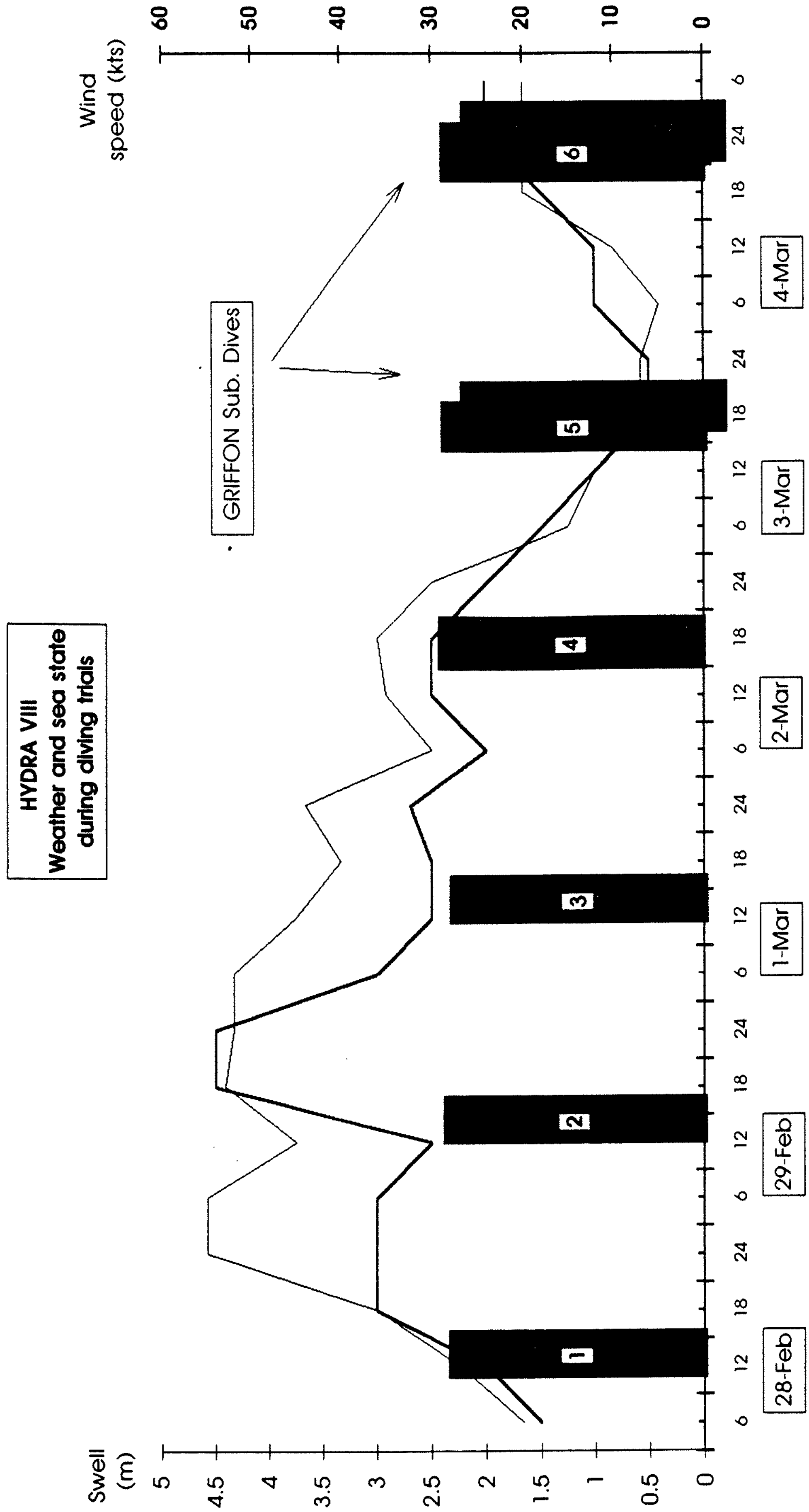

HYDRA VIII
Weather and sea state
during diving trials
GRIFFON Sub. Dives
Wind
speed (kts)
60
50
40
30
20
10
0
Swell
(m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
28-Feb
29-Feb
1-Mar
2-Mar
3-Mar
4-Mar
6
12
18
24

Figure 3.8

4.4 DECOMPRESSION - TOTAL TIME : 17 DAYS 11 HOURS

Decompression was performed in two phases :

- Hydrogen phase
- Heliox phase

4.4.1 Decompression - "Hydrogen" phase - 166 hours

Decompression started on February 5th at 03h00, on team B return to the chamber, after dive 6. Decompression was performed by hydrogen catalytic removal from the chambers atmosphere. Hydrogen was oxided on a catalytic bed and the water produced by the reaction was eliminated by condensation.

Decompression speed
500 - 300 meters : 1.2 meter/hour

Oxygen partial pressure : 500 mbar

Relative humidity
Set point : 50 %, variations : +8 %, -3 %

Ambient temperature
Set point : 32°, variations : +0.6°, -0.6°

4.4.2 Decompression - "heliox" phase - 10 days 13 hours

After hydrogen elimination from the chamber atmosphere, decompression proceeded as per the standard procedure for heliox saturation.

This decompression phase started on March 12th.

The hydrogen elimination from the chambers and distribution circuits allowed to open the inerted area (after ascertainment of the respirable atmosphere by ventilation) and the return to standard safety procedures. On the third day of heliox decompression, the divers were transferred to chambers 2 and 3, in which equipment had not been modified.

Decompression speeds :

300 - 15 meters : 1.2 meter/hour
15 - 0 meters : 1.0 meter/hour

Oxygen partial pressure and concentrations :

300 - 120 meters : 500 mbar O2
120 - 15 meters: 600 mbar O2
15 - surface : 23-24 % O2

Ambient temperature

300 - 200 m Set point : 31°, variations : +0.7°, -0.2°
200 - 130 m Set point : 30°, variations : +0.1°, -0.8°
130 - 0 m Set point : 29°, variations : +1.0°, -1.0°

Decompression ended on March 22nd at 13h00.

5 - SCIENTIFIC AND MEDICAL PROGRAMME

All along the saturation, the six divers were medically observed. COMEX and GISMER doctors, responsible for the divers' safety in the chambers and in immersion, were supported in their decisions by the physiological and psychomotor measures results collected and read in real time by the scientific teams.

The programme hereafter summarises the investigations performed :

- tremor evaluation during the compression phase (D1 and D5) and during the hydrogen decompression (D13 and D19) - **CNRS - CERB.**

- electroencephalogram (EEG) in compression (D1 and D5) and in hydrogen decompression (D13 and D19) - **CERB.**

- electrocardiogram (ECG) at rest and during an effort test in compression (D1 and D5) and at 500 meters, before each dive (D7 and D12). ECG at rest during hydrogen decompression (D13 and D19) - **CERB.**

- psychometric tests in compression (D1 to D5) and during decompression (D14 and D22). Some tests were performed in the water, an operator being onboard the GRIFFON submarine (D11 and D12) - **OCTARES - CERB.**

- breathing rate control and thermic evaluation of the two divers all along their stay in the water (breathing gas, habitat hot water and diver's central temperature) - **COMEX - CNRS.**

- blood count before and after the saturation - **COMEX.**

DATE	TIME	DEPTH	GAS	PROGRAMME
22.02.88	11.00	0	Heliox PO_2 = 0.4 b	Helium compr. start tremor, psychometry, ECG
	16.00	100		tremor - EEG
	23.00	200		end of stop
23.02.88	11.00	300	Hydreliox PO_2=0.4 b PH_2=5 b (16 %)	start of stop tremor, psychometry, ECG
	13.00	300		end of stop tremor - EEG
24.02.88	09.00	400	Hydreliox PO_2=0.4 b PH_2=15 b (36 %)	start of stop tremor, psychometry, ECG
	11.00	400		end of stop tremor - EEG
25.02.88	07.00	450	Hydreliox PO_2=0.4 b PH_2=20 b (43 %)	start of stop tremor, psychometry, ECG
	13.00	450		end of stop tremor - EEG

DATE	TIME	DEPTH	GAS	PROGRAMME
26.02.88	09.00	500	Hydreliox PO_2=0.4 b PH_2=25 b (49%)	arrival at life level tremor, psychometry, ECG
	14.00			tremor - EEG - DOPPLER
27.02.88	06.00	500	Hydreliox	Team A and B waking - ECG
28.02.88	05.00	500	Hydreliox	team A waking - ECG
	10.20	520	H_2 = 47% He = 52% O_2 = 1%	1st dive team A
	17.45	500		
29.02.88	06.00	500	Hydreliox 47/52/1	team B waking - ECG
	09.45	520		2nd dive team B
01.03.88	06.00	500	Hydreliox 47/52/1	team A waking - ECG
	09.00			3rd dive team A
02.03.88	06.00	500	Hydreliox 47/52/1	team B waking - ECG
	09.45			4th dive team B

DATE	TIME	DEPTH	GAS	PROGRAMME
03.03.88	06.00	500	Hydreliox 47/52/1	team A waking - ECG
	09.45			5th dive team A
04.03.88	08.00	500	Hydreliox 47/52/1	team B waking - ECG 6th dive
05.03.88	01.20	500	Hydreliox PO_2 = 0.5 b	decompression start
	02.00	500		DOPPLER - tremor psychometry - EEG - ECG
11.03.88	23.00	300	Heliox PO_2 = 0.5 b PO_2 = 0.6 b fm 120 to 15 m 24% O2 fm 15 m to 0 m	end of hydrogen removal DOPPLER air rinsing at 7 m
22.03.88	13.00	0		surface blood biology

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 4

TITLE : **DIVES PROGRESS**

INDEX :

DATE : 10 September 1988
REVISION : 00

1 - UNDERWATER WORKS EQUIPMENT

1.1 WORK PLATFORM

The specific elements of an offshore oil installation were collected on a platform hanging under the support vessel. The platform was handled by a hydraulic winch equipped with a 36 mm steel cable and a guide pulleys system.

The cable immersed length is another control mean of the working depth.

Specifications of the platform suspension structure :

width	:	6.0 m
length	:	7.2 m
height	:	3.5 m
weight in the air	:	net= 7 500 kg
		gross = 9 000 kg (equipment included)

Two chains lengths fixed under the platform and resting partly on the bottom ensured its horizontal stabilization.

In spite of the suspension point situation at the nearest point of the vessel centre, the ship vertical movements, accentuated by the resonance due to the cable flexibility, produced the platform thumping. These movements amplitude reached 1.5 meters in certain dives, disturbing considerably the divers on the platform.

HYDRA VIII

TRAVAUX SOUS-MARINS
U/W WORK PLATFORM

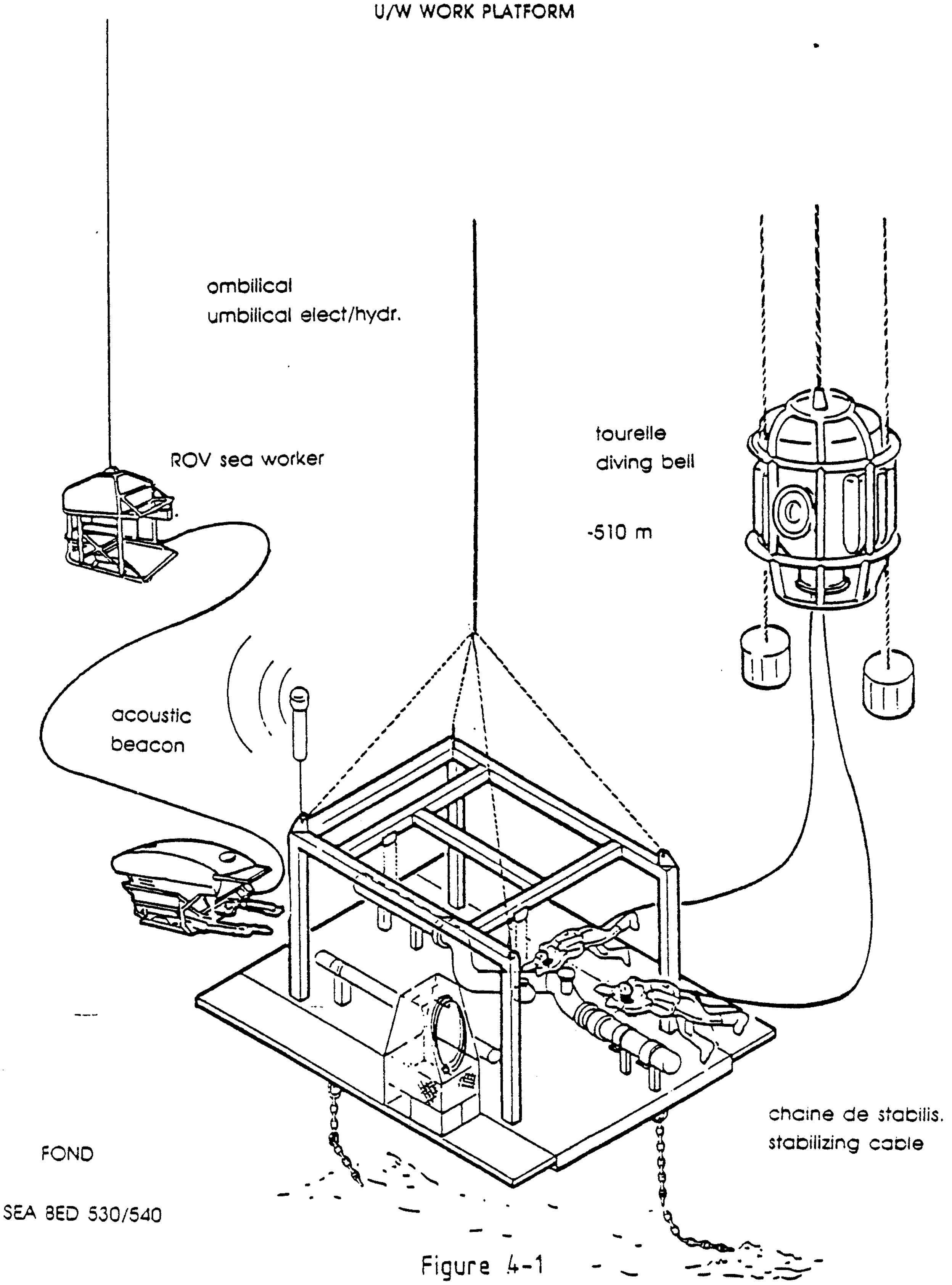


Figure 4-1

1.2 UNDERWATER WORKSITE EQUIPMENT

Using the mock-up of an underwater installation built on the platform, the divers could perform the following operations :

A - Connection of a 12" steel pipe with a flanged spool piece

This operation consisted of :

i. a metrology of the initial position of the spool piece receiving flanges (one fixed and one adjustable)

ii. an adaptation of the adjustable flange as per the measures results compared to the spool piece dimensions

iii. the spool piece lifting and positioning with chain hoists

Spool piece characteristics :

pipe :	12" th. 6.35 mm
overall length :	4 m
flanges :	12 API 150 RTJ
weight in the air :	435 kg

iv. joints and bolts installation

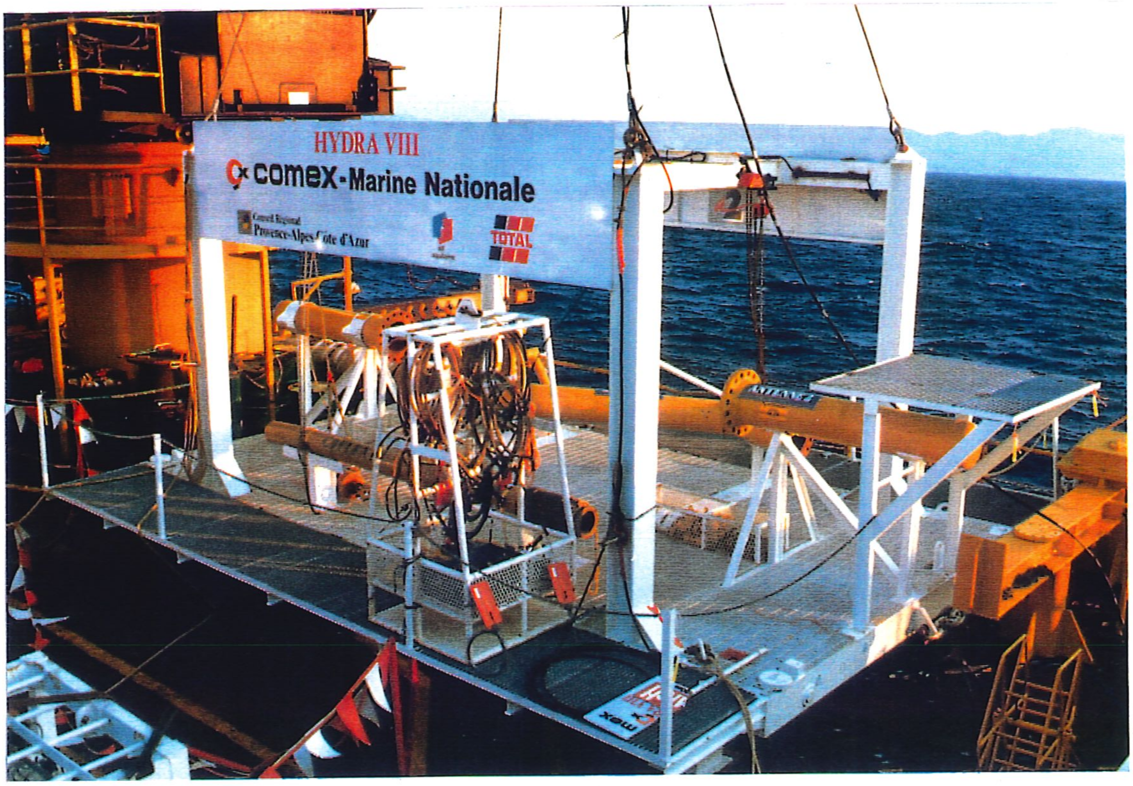
v. flanges tightening with a hydratight system (hydraulic tensioning tool for bolts)

B - Connection of a flexible COFLEXIP pipe on a fixed flange of the spool piece

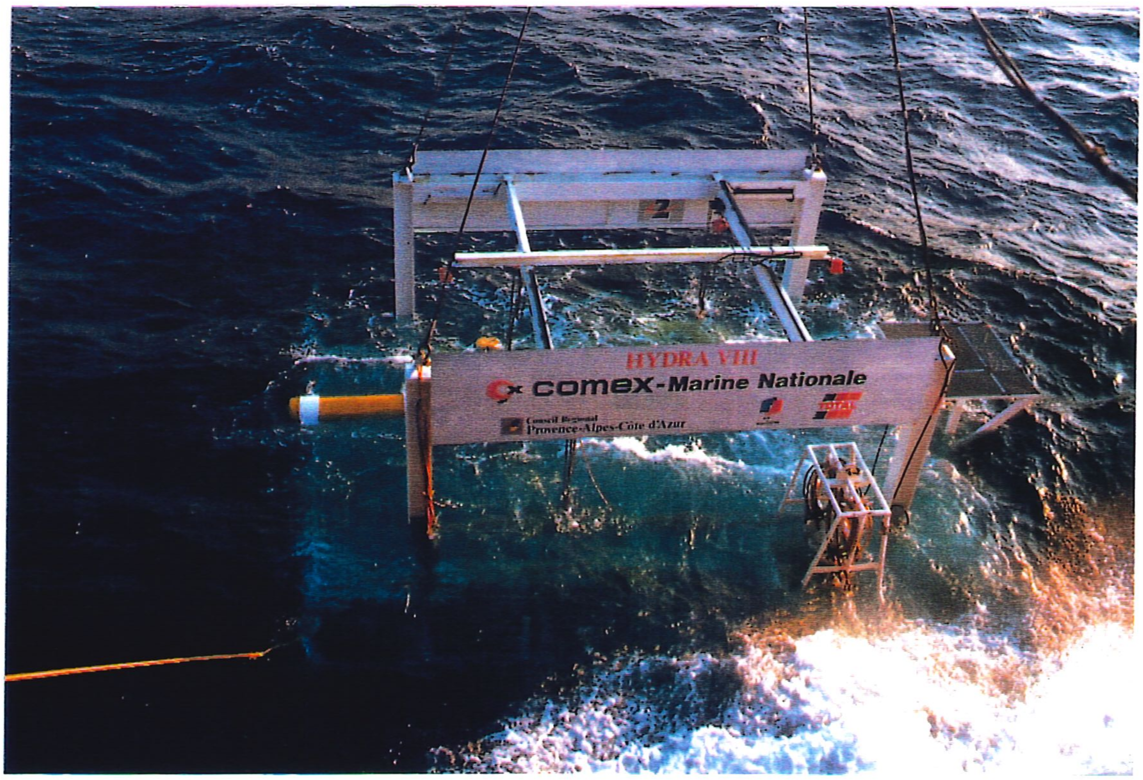
This operation consisted in :

i. lifting and positioning a 6" flexible hose
length : 5.6 m
weight : 410 kg
with a hoist

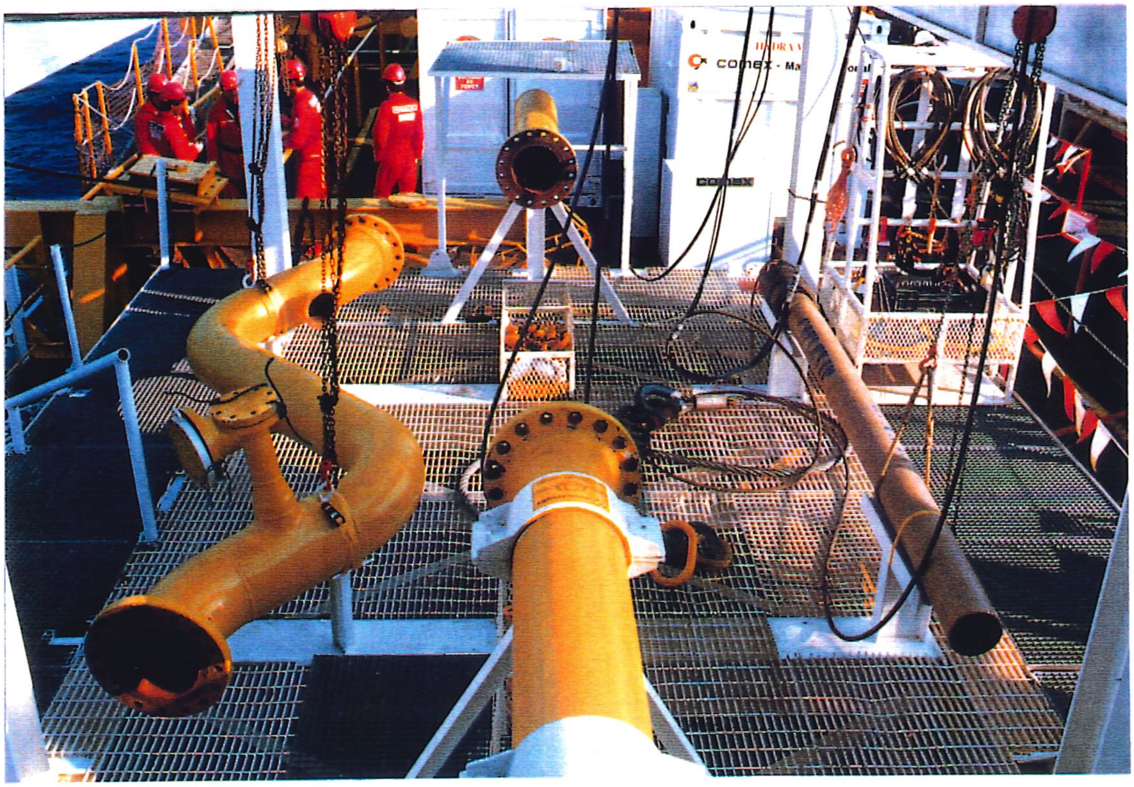
ii. manual tightening of a GRAYLOCK-type flange

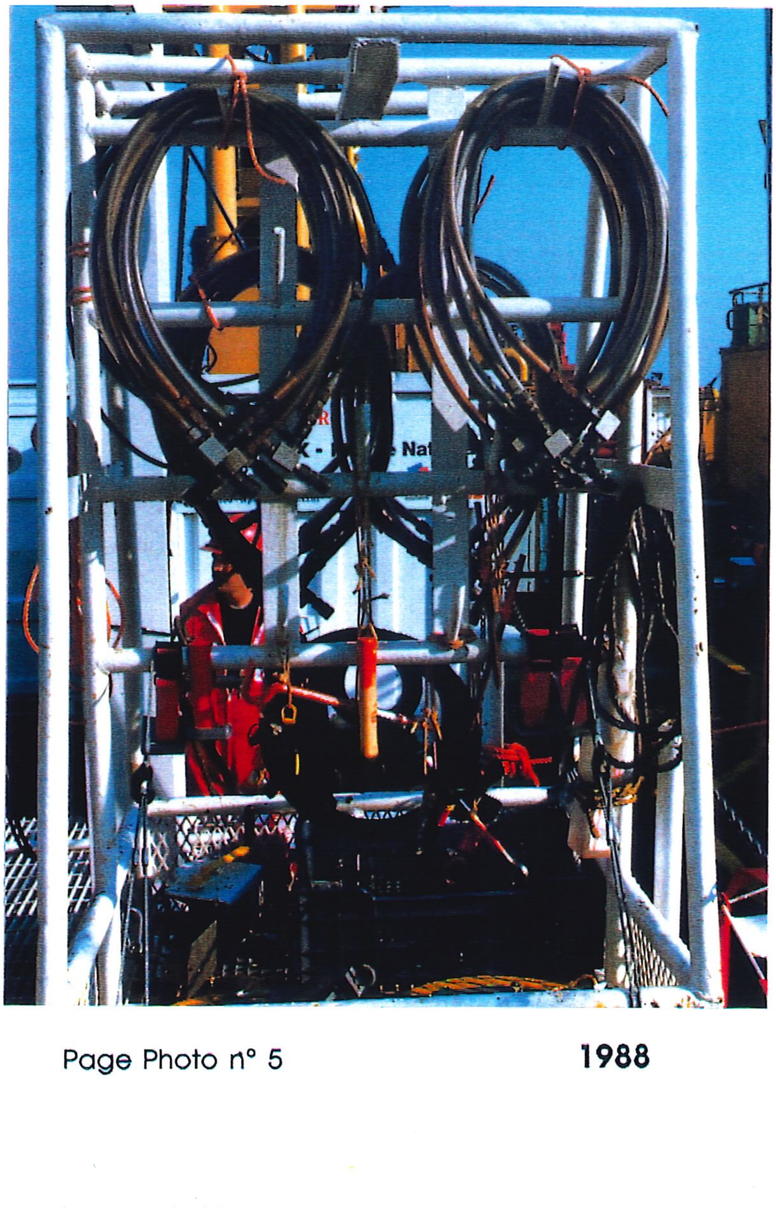


Plateforme de travail - Vue générale
Work platform - General view



Descente de la plateforme
Work platform lowering





Plateforme de travail - manchette
Work platform - Spool piece

Outils de serrage - HYDRATIGHT
Bolts tensioning tool - HYDRATIGHT

This routine operations performance required both precision and a physical effort increased by the platform thumping.

The relative simplicity of the equipment and tools underlined the divers' performance while reducing the chances of technical risks.

1.3 AUXILIARY EQUIPMENT

The underwater worksite was lighted up by six projectors (6 x 500 W).

An acoustic beacon was used to locate the platform and constituted a target for the GRIFFON submarine approach.

A small platform placed in the pipe axis was used as a landing deck for the assistance ROV.

An electro-hydraulic umbilical supplied the worksite with energy from the surface (see figure 4.1).

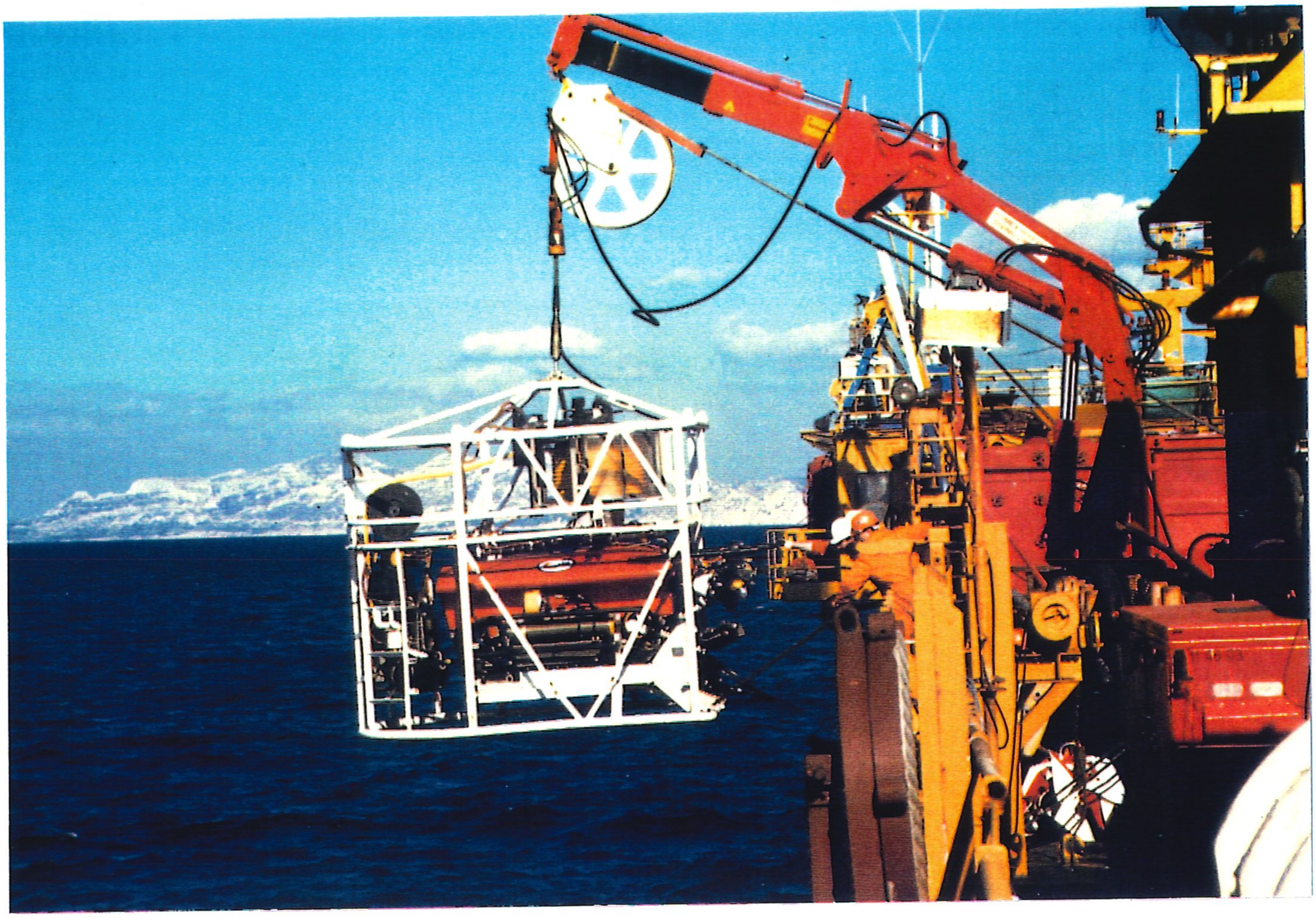
1.4 ROV SEA WORKER

The SEA WORKER was used both for observation and assistance. With its navigation instruments and television cameras, the surface teams could permanently control the relative locations of the divers, of the diving bell, of the work platform, of the GRIFFON submarine, and of various cables such as : guide lines, taut wires, lifting cables, etc..

If required, the ROV projectors could be an extra light source for the worksite.

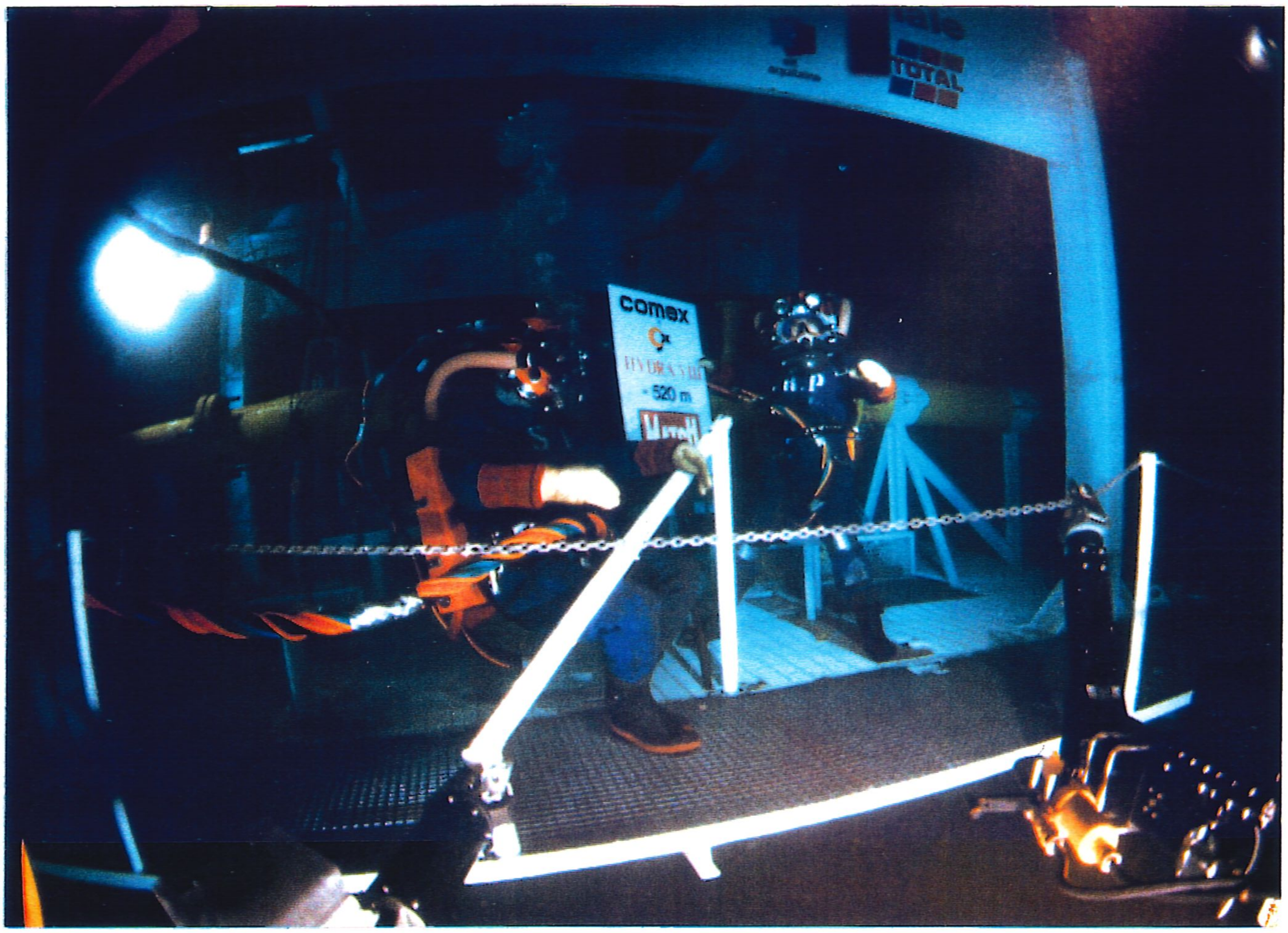
The ROV photographic camera, equipped with a flash, took several photographs of the divers at work.

The SEA WORKER had the first place in the divers' assistance and rescue procedures and in the whole set of immersed equipment. Besides its research and positioning capacities, its manipulator arms allowed it to cut or hook cables and handle all kinds of objects.

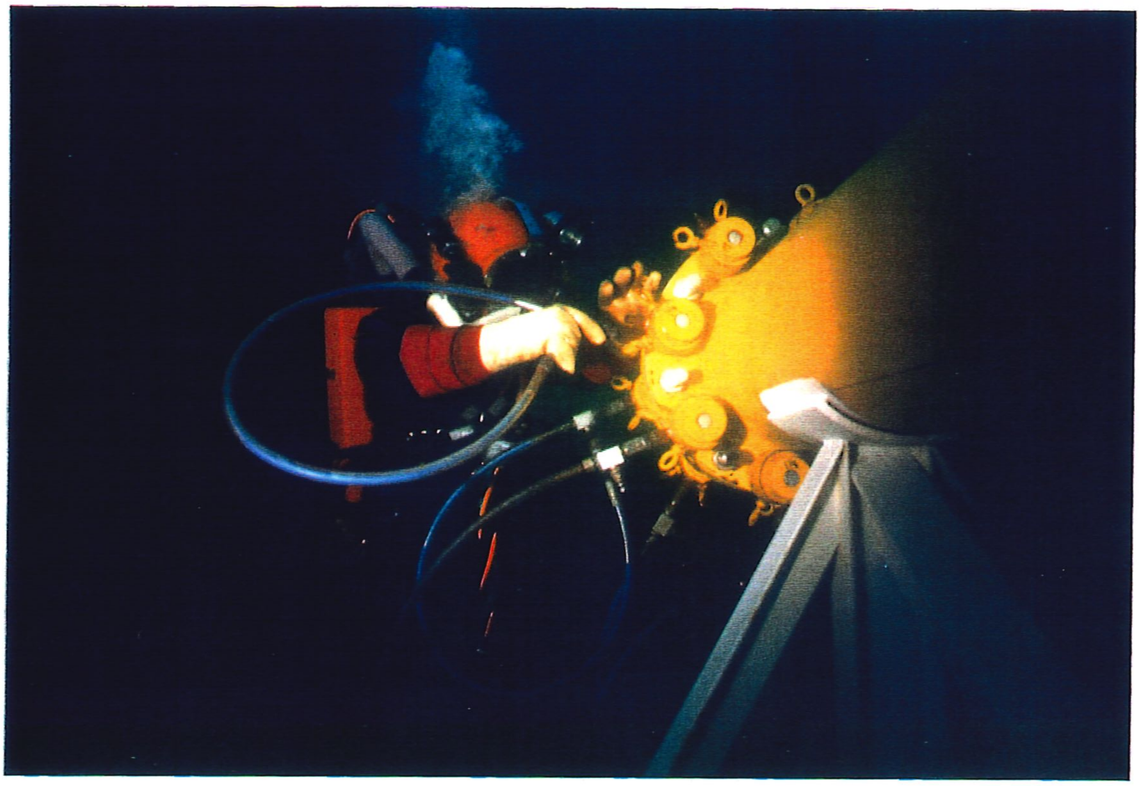


Véhicule téléopéré SEA WORKER
ROV - SEA WORKER

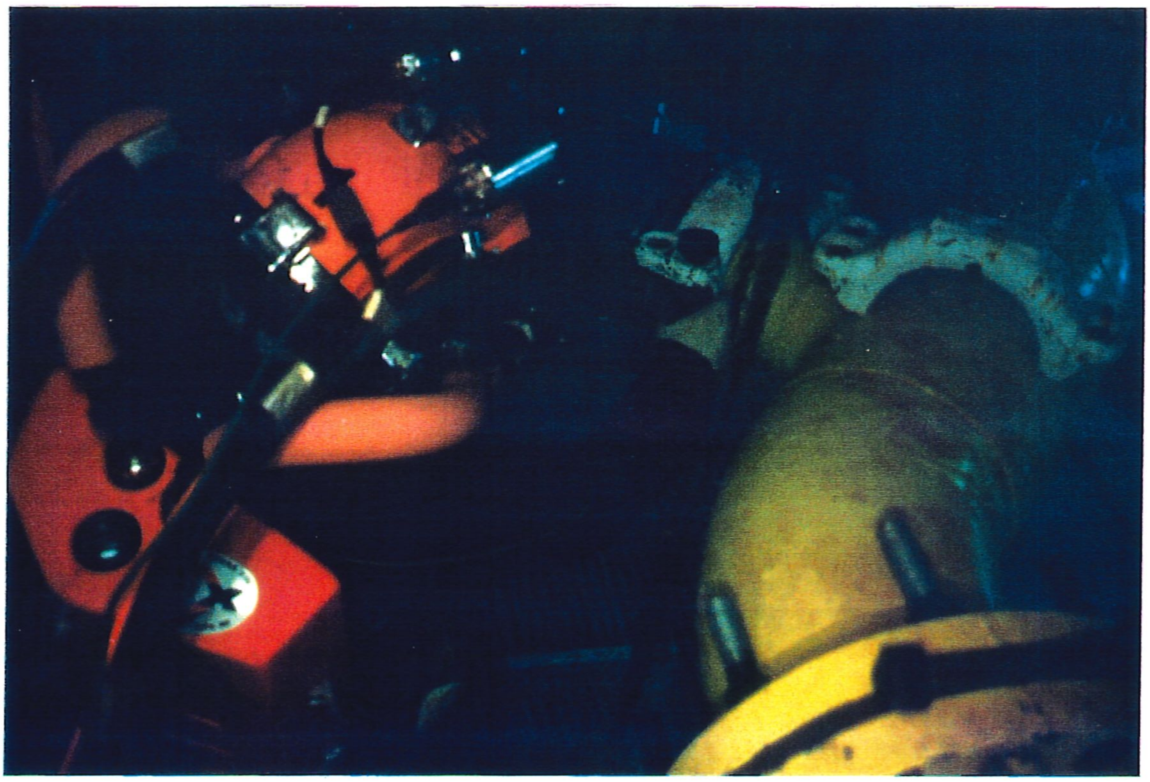
Comments : The ROV itself was exposed to risks. In one of the first operations on the worksite, a breakdown (failure of an electrovalve) provoked the control loss of the ROV movements, which was entangled on the sea bed by a nylon guide-rope caught in a propeller. The divers released it at their first dive.



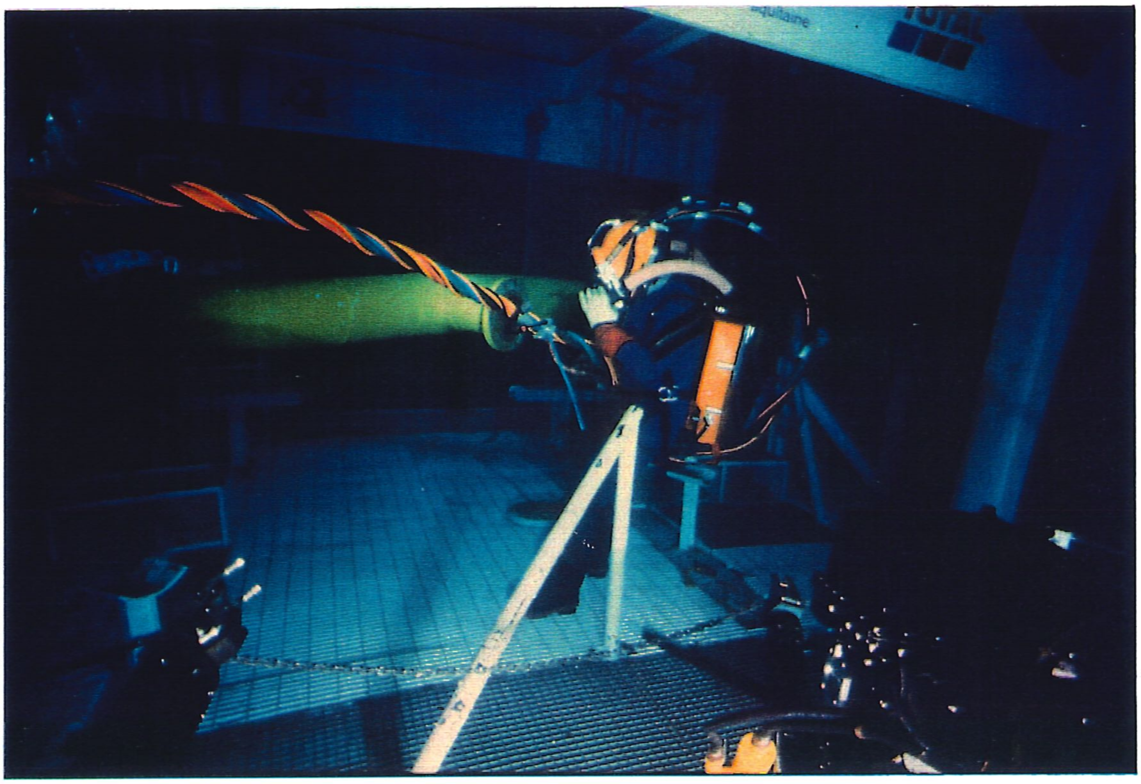
Plongeurs sur la plateforme de travail - Vue du sous-marin GRIFFON - profondeur 531 m
Diver on the work platform - View from GRIFFON submarine - depth 531 m



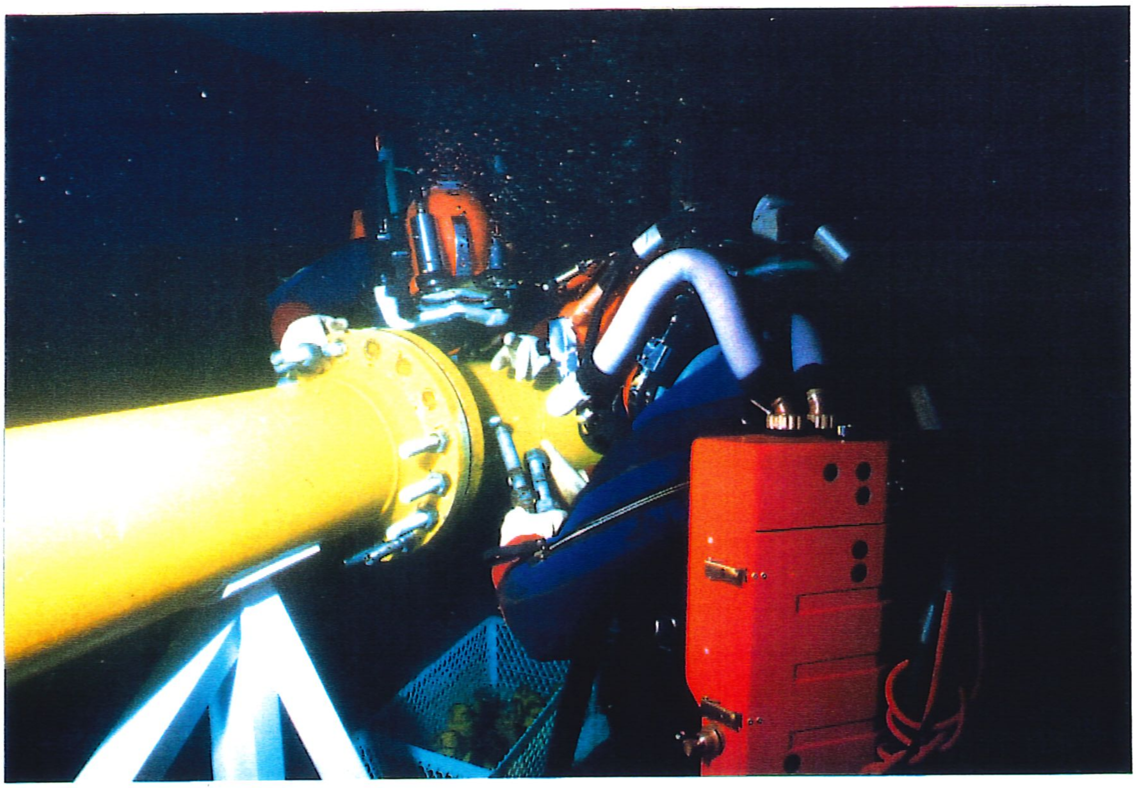
Travail - 520 m - Installation HYDRATIGHT
Work - 520 m - HYDRATIGHT installation



Connexion du pipe COFLEXIP
COFLEXIP connection



Plongeurs au travail - 520 m
Divers at Work - 520 m



Plongeurs au travail - 520 m
Divers at Work - 520 m

2 - UNDERWATER WORKS DEVELOPMENT

Organization of the underwater work

Diver 1	:	Performs the work
Diver 2	:	Helps diver 1 in his tasks
Bellman	:	Operates the diving bell, equips the divers, gives assistance in case of emergency

Dive n° 1 : 28 February 1988

Diver 1	:	P. Raude
Diver 2	:	L. Schneider
Bellman	:	J.G. Marcel-Auda

Description of the tasks performed during the dive.

Installation of the hand rail between guide lines and work platform (15 m long rope).

ROV SEA WORKER rescue. Localization of the vehicle and of the rope connecting it to the platform. Movement (in water) towards the vehicle (15 m), sectioning of the rope caught in a propeller. Return to the work platform.

Metrology. Equipment preparation. False flanges installation. Measure cables tensioning.

Comments : The anxiety of the first dive did not affect the divers' performances. The rescue operation of the ROV SEA WORKER was decided a few hours before the dive.

Dive n° 2 : 29 February 1988

Diver 1 : T. Arnold
Diver 2 : S. Icart
Bellman : R. Peilho

Description of the tasks performed during the dive.

Metrology works continuation trials.
Checking the equipment fastening on the platform.

Comments : the platform thumping makes the works dangerous. On surface, the wind blows at 50 knots. The dive duration is shortened.

Dive n° 3 : 1st March 1988

Diver 1 : L. Schneider
Diver 2 : J.G. Marcel-Auda
Bellman : P. Raude

Description of the tasks performed during the dive.

Metrology works (completion).
Tools disassembly - tidying.

Dive n° 4	:	2 March 1988

Diver 1 : S. Icart
Diver 2 : R. Peilho
Bellman : T. Arnold

Description of the tasks performed during the dive.

. Position adjustment of the mobile reception flange
. Lifting and positioning of the spool piece
. Installation of the joints and threaded rods

Comments : most of the spool piece installation works were performed by only one diver. Diver 1 had returned to the diving bell due to water circuit regulation problems in his suit.

Dive n° 5	:	3 March 1988

Diver 1 : J.G. Marcel-Auda
Diver 2 : P. Raude
Bellman : L. Schneider

Description of the tasks performed during the dive.

* Manual tightening of two flanges bolts

* Psychometric tests, controlled by a psychologist in the GRIFFON submarine

* Installation of Hydratight jacks on the flange bolts. Hydraulic flexible hoses connection.

Comments : the GRIFFON submarine remained on the worksite during the tests and part of the works. The tests consisted of memorizing and figure operations exercises. The questions and problems to be solved were displayed on the computer screen set inside the submarine. The divers watched the screen through the porthole and noted their responses on slates.

Dive n° 6 : 4 March 1988

Diver 1 : R. Peilho
Diver 2 : T. Arnold
Bellman : S. Icart

Description of the tasks performed during the dive.

Hydratight flexibles connection
Flange tightening
Psychometric tests - GRIFFON submarine
Flexible pipe installation
GRAYLOCK flange tightening (COFLEXIP) Tools disassembly and tidying
Acoustic beacon disassembly
Hand rail disconnection
BOS stand-by breathing device trials

Comments : a TV dive broadcasting was carried out during the first part of this dive.

3 - DIVES SUMMARY

The dives schedules and durations are given on summary tables 4.2 and 4.3. The duration analysis of the different bell dive stages is shown on figures 4.4 and 4.5.

HYDRA VIII – SUMMARY OF DIVES

Actions		1 28 - Feb. real time	time	2 29- Feb. real time	time	3 1 - March real time	time	4 2 - March real time	time	5 3 - March real time	time	6 4 - March real time	time
Check list	start	7:15		9:15		7:20		8:04		7:57		16:14	
	end	9:25	2:10	10:55	1:40	8:15	0:55	8:49	0:45	8:27	0:30	16:53	0:39
Dressing	start	9:28		11:16		8:23		8:49		9:00		18:00	
	end	10:18	0:50	11:47	0:31	8:57	0:34	9:41	0:52	9:31	0:31	18:25	0:25
Bell unclamping	start	10:18		11:54		9:01		9:42		9:35		18:27	
	end	10:39	0:21	12:11	0:17	9:18	0:17	10:08	0:26	10:00	0:25	18:55	0:28
Run-down	in water	10:43		12:14		9:30		10:12		10:12		19:00	
	bell open	11:55	1:12	13:35	1:21	10:45	1:15	11:24	1:12	11:17	1:05	20:04	1:04
Equipement	start	12:30		13:38		10:51		11:31		11:18		20:10	
	end	13:40	1:10	14:30	0:52	11:16	0:25	12:03	0:32	12:26	1:08	20:50	0:40
Diver 1	out	13:40		14:17		11:16		12:41		12:25		20:53	
	in	15:45	2:05	15:30	1:13	13:52	2:36	13:39	0:58	14:50	2:25	1:06	4:12
Diver 2	out	14:15		16:00		12:32		12:03		12:47		21:18	
	in	16:10	1:55	16:15	0:15	13:40	1:08	15:39	3:36	15:52	3:05	0:06	2:47
Run-up	bell closed	16:31		16:28		14:02		15:54		16:06		1:20	
	on deck	17:29	0:58	17:40	1:12	15:03	1:01	16:52	0:58	17:02	0:56	2:20	1:00
Bell clamping	start	17:30		17:47		15:07		17:00		17:08		2:24	
	fin	17:43	0:13	17:55	0:08	15:20	0:13	17:15	0:15	17:15	0:07	2:30	0:06
Bell run time		**7:25**		**6:01**		**6:19**		**7:33**		**7:40**		**8:02**	
In-water time			**4:00**		**1:28**		**3:44**		**4:34**		**5:30**		**6:59**

Figure 4.2

HYDRA VIII
In-water time diagram

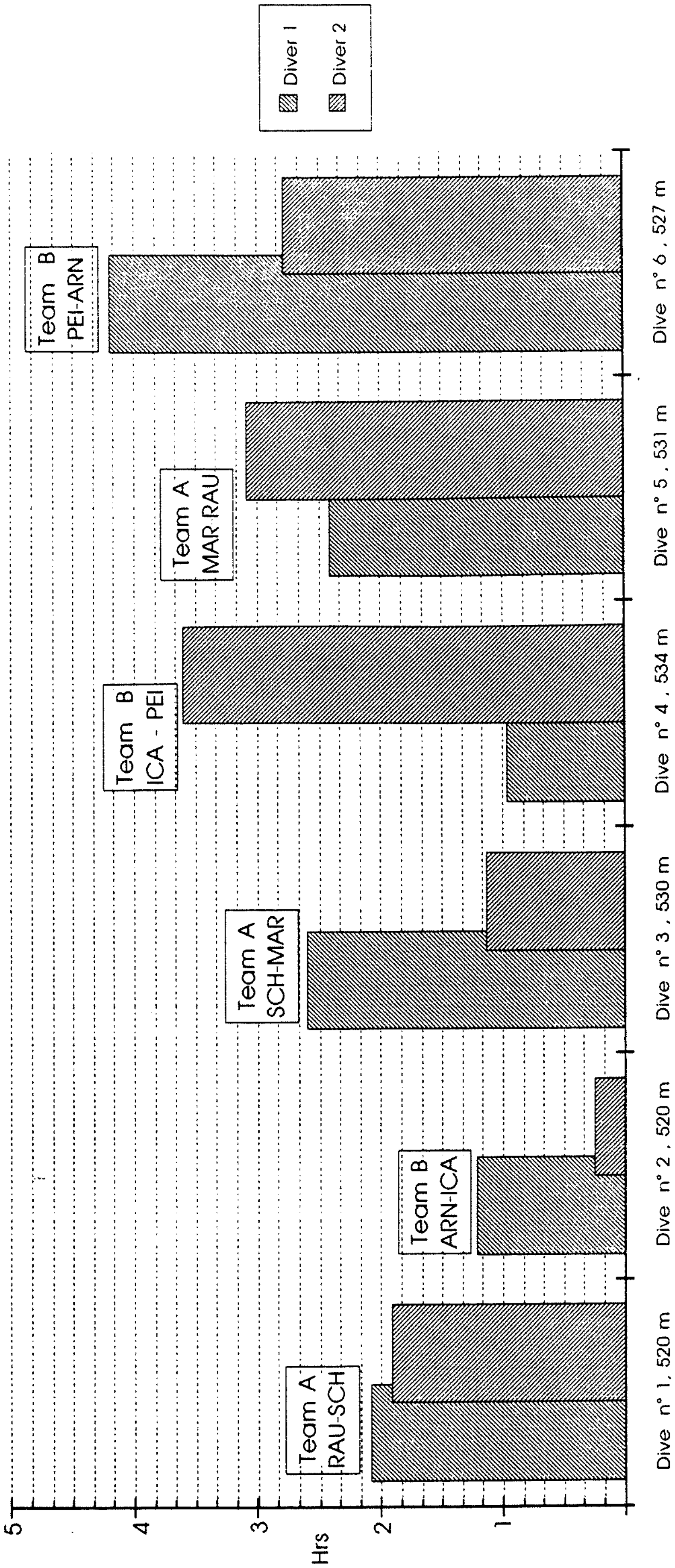


Figure 4.3

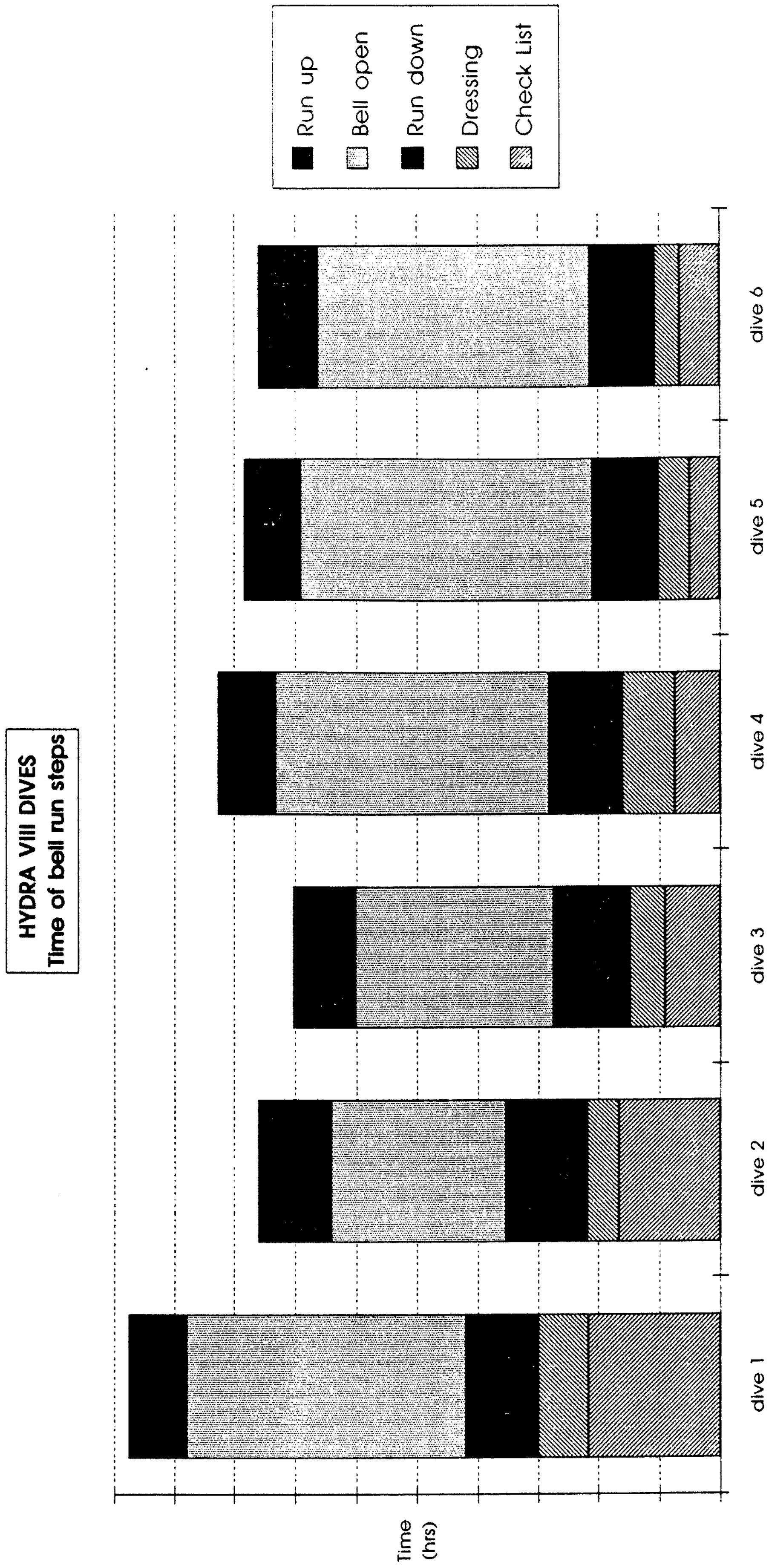
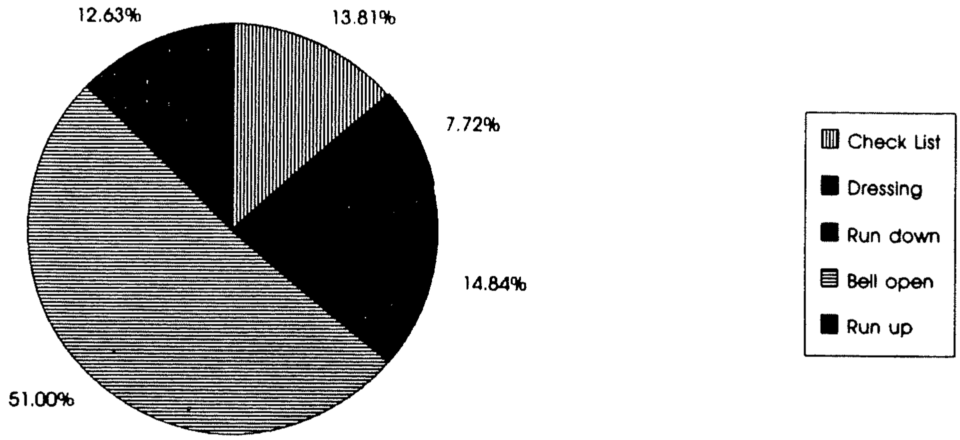

HYDRA VIII DIVES
Time of bell run steps
Run up
Bell open
Run down
Dressing
Check List
dive 1
dive 2
dive 3
dive 4
dive 5
dive 6
Time
(hrs)

Figure 4.4

HYDRA VIII
Bell dive stages
Average time distribution



Comments :

The dives time examination and analytical diagrams bring in the following remarks :

- the effective work time outside the bell can be compared to the average reported on industrial worksites.

- the bottom times "bell open door" are relatively short as compared to the total duration of the complementary operations. This can be explained by :

    * the check list duration (which evoluates in decreasing : training effect and stress reduction)

    * the restricted capacities of the bell handling system

- in some dives, one of the divers works slightly longer than the other. This difference is due to stabilization problems of the divers' heating circuit, inducing a flow decrease and consequently a temperature drop of the hot water in one of the divers' suit.

4 - DIVES PARAMETERS

The evolution diagrams of the breathing rate illustrate the divers' condition during the dives. The curves of inhaled gas and central temperatures are given for information.

Note : the permanent display of these parameters and of their evolution trends on the Dive Control screen allowed to anticipate the divers' cooling before they noticed it themselves (gas or heating water temperature).

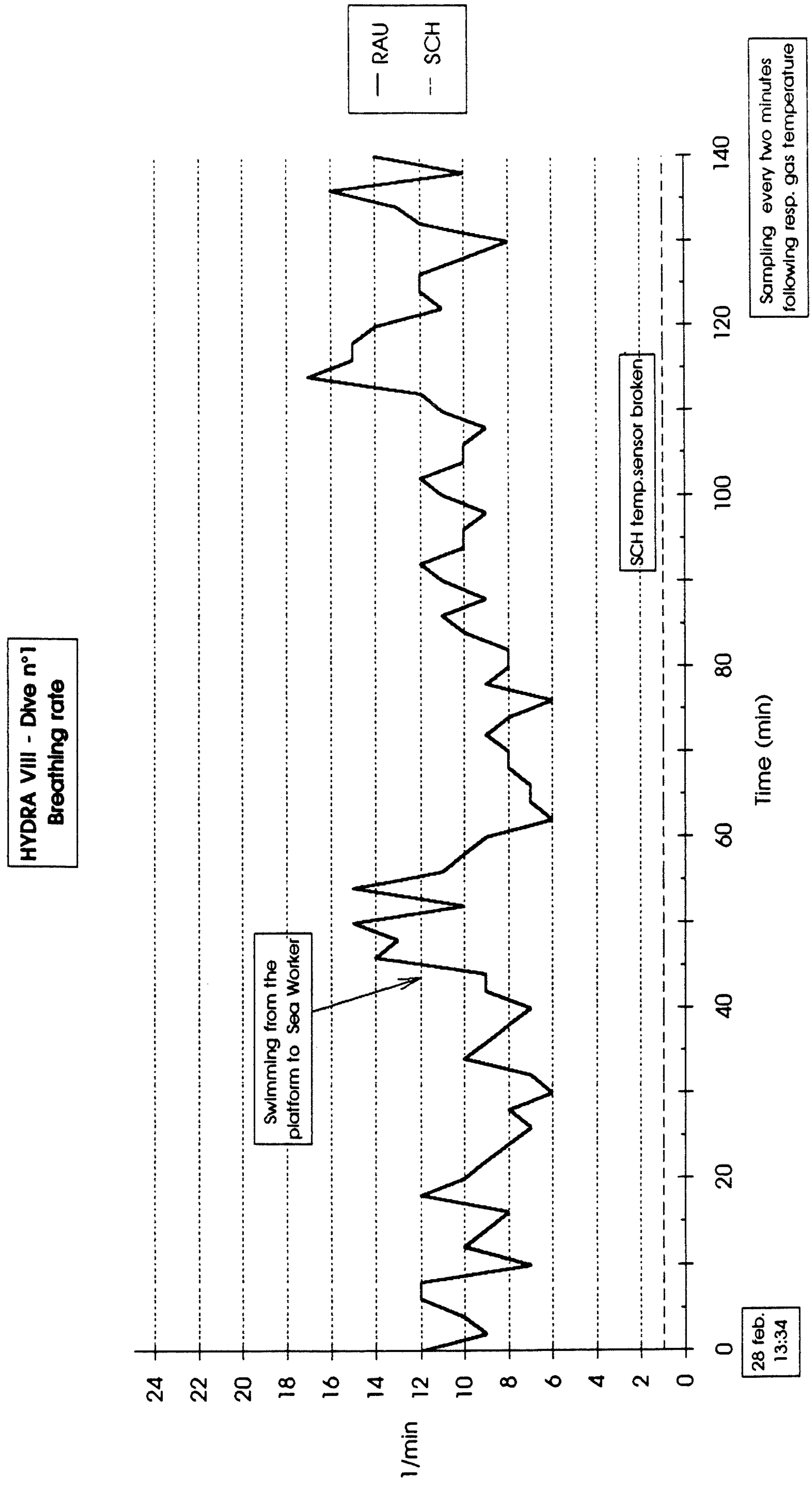

HYDRA VIII - Dive n°1
Breathing rate
— RAU
-- SCH
Swimming from the platform to Sea Worker
SCH temp.sensor broken
Sampling every two minutes following resp. gas temperature
28 feb. 13:34
l/min
24
22
20
18
16
14
12
10
8
6
4
2
0
Time (min)
0
20
40
60
80
100
120
140

Figure 4.6

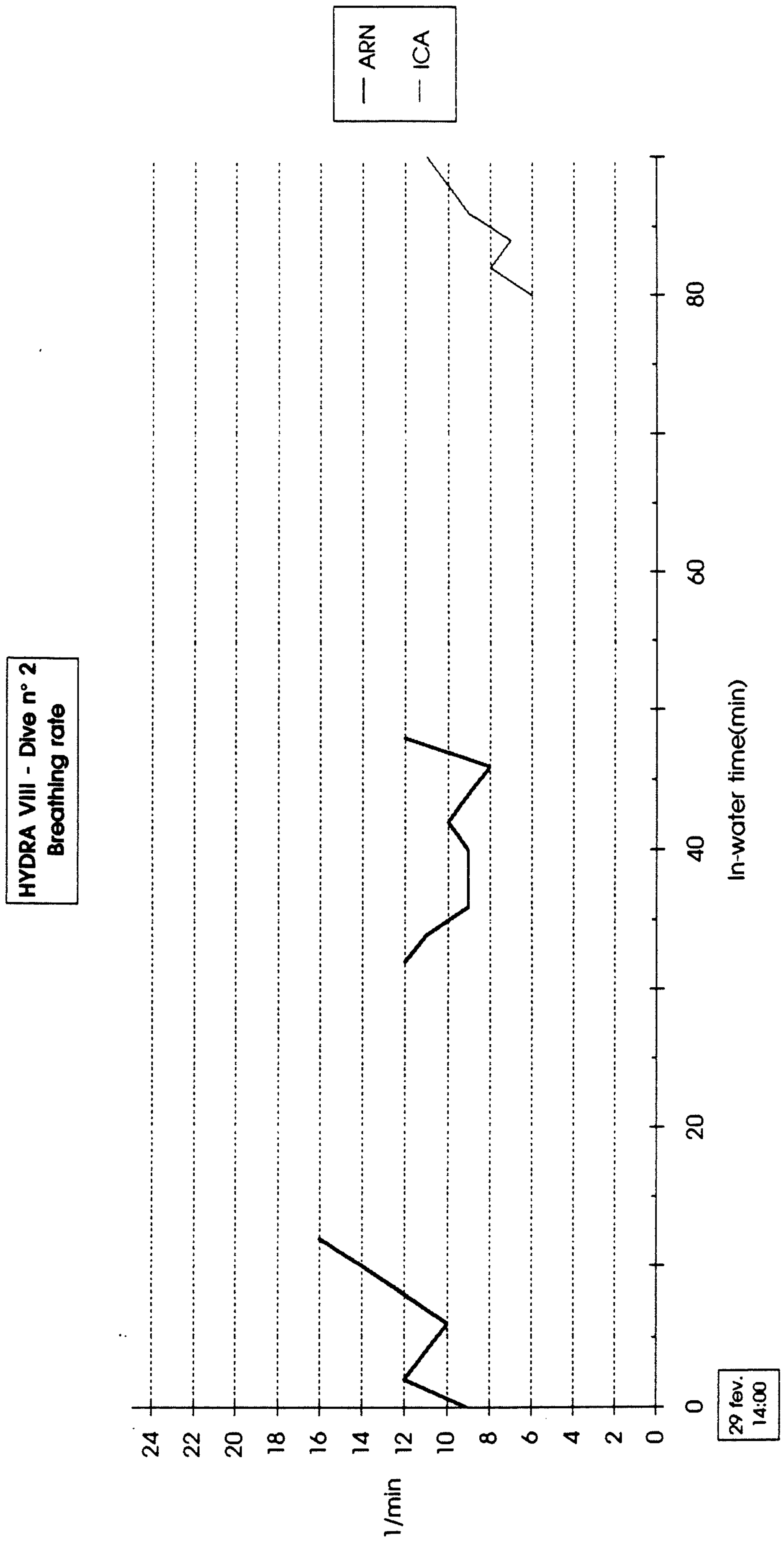

HYDRA VIII - Dive n° 2
Breathing rate
— ARN
— ICA
1/min
24
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
In-water time(min)
29 fev.
14:00

Figure 4.7

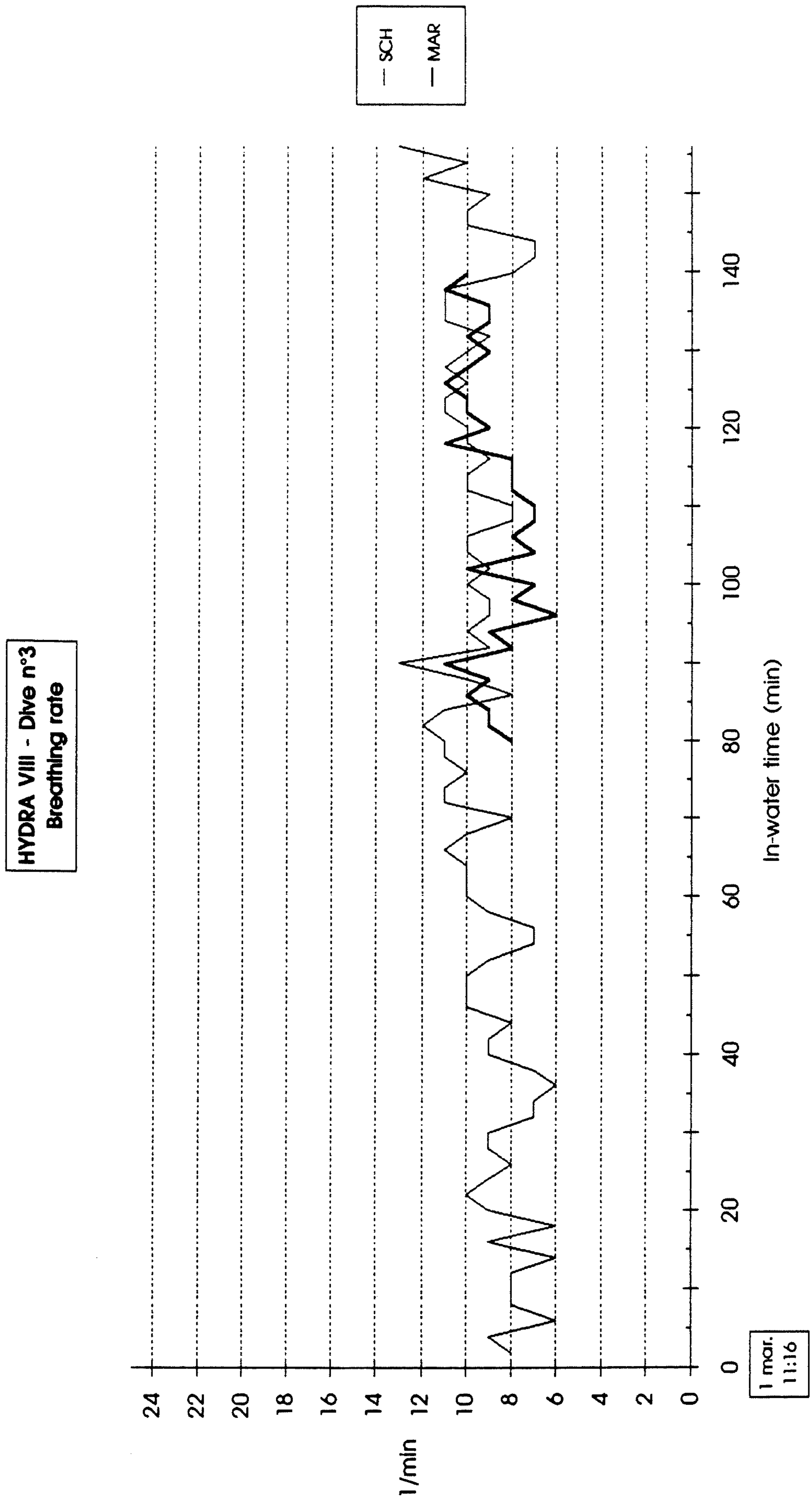

SCH
MAR
HYDRA VIII - Dive n°3
Breathing rate
1/min
0
2
4
6
8
10
12
14
16
18
20
22
24
0
20
40
60
80
100
120
140
In-water time (min)
1 mar.
11:16

Figure 4.8

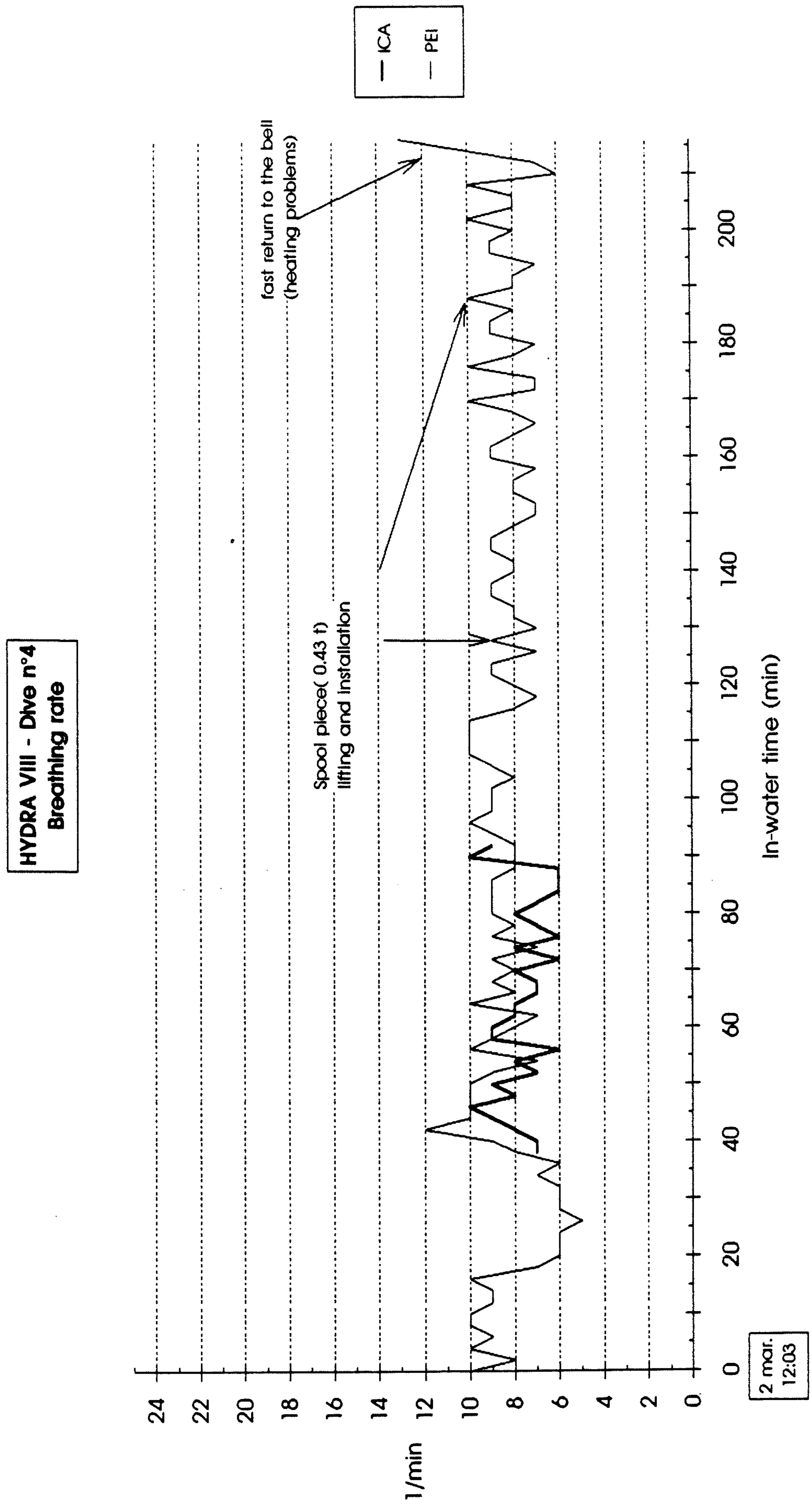

HYDRA VIII - Dive n°4
Breathing rate
ICA
PEI
fast return to the bell
(heating problems)
Spool piece(0.43 t)
lifting and installation
l/min
24
22
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
180
200
In-water time (min)
2 mar.
12:03

Figure 4.9

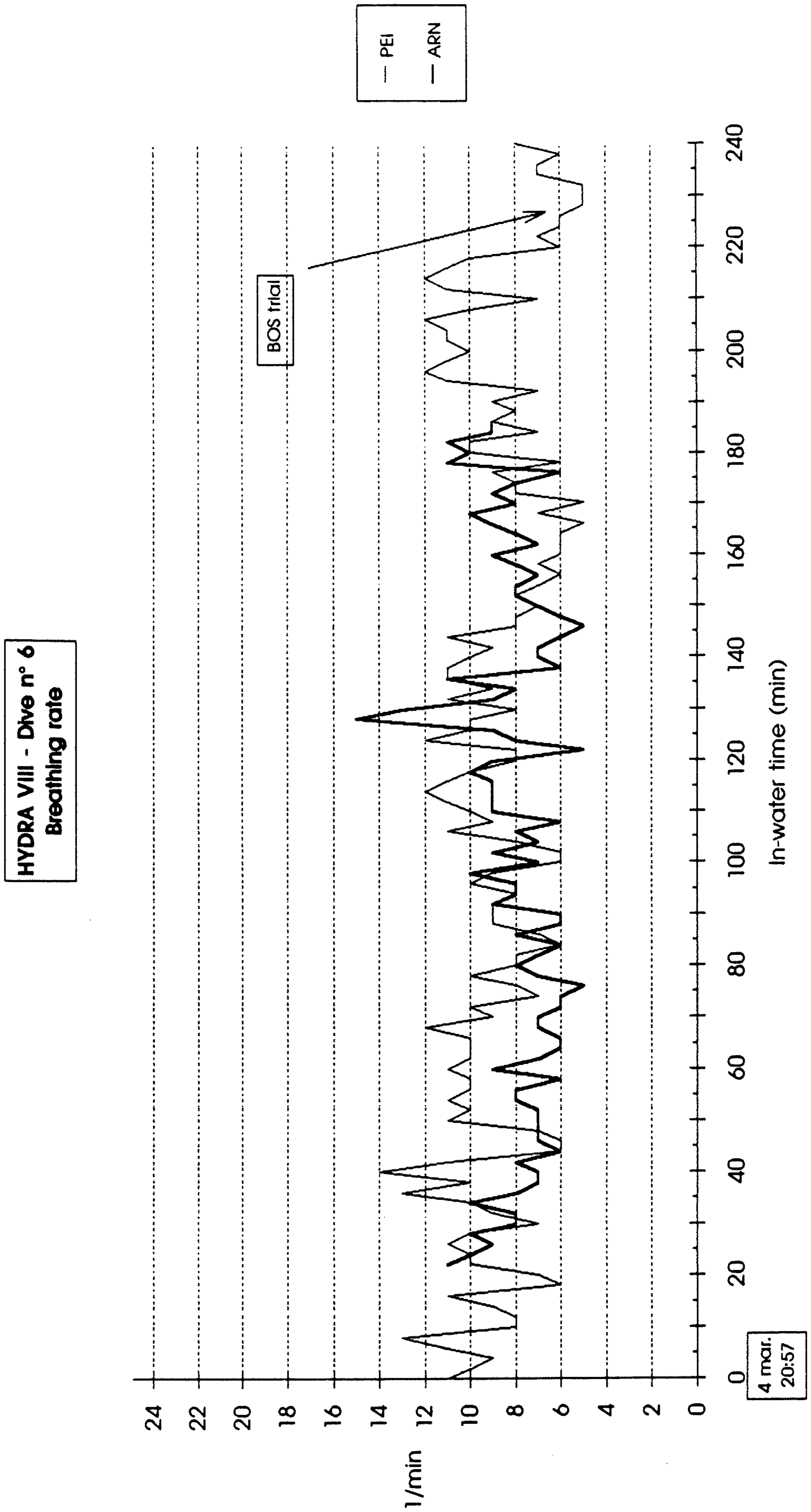

HYDRA VIII - Dive n° 6
Breathing rate
PEI
ARN
BOS trial
4 mar.
20:57
In-water time (min)
0
20
40
60
80
100
120
140
160
180
200
220
240
1/min
0
2
4
6
8
10
12
14
16
18
20
22
24

Figure 4.10

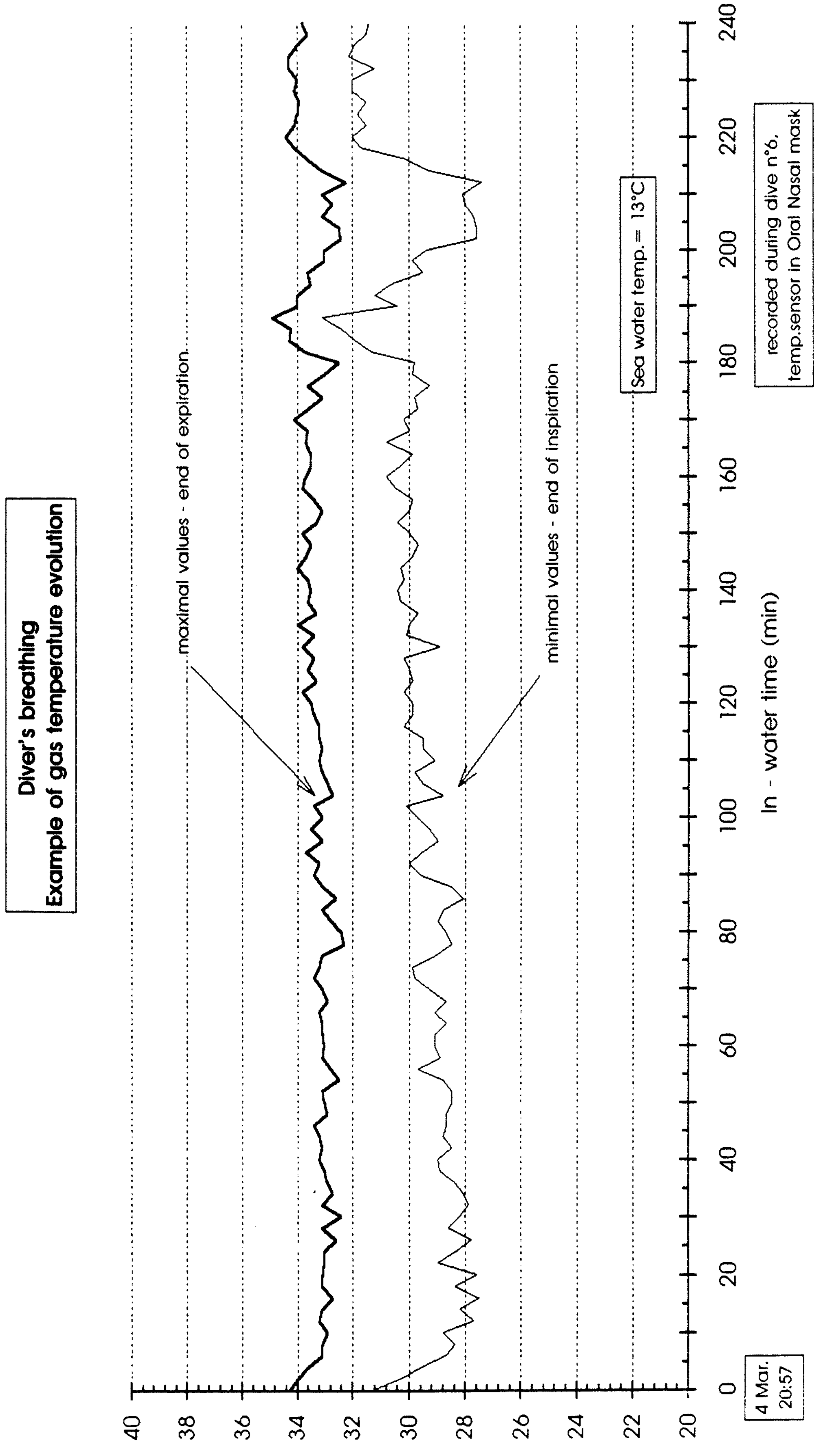

Diver's breathing
Example of gas temperature evolution
maximal values - end of expiration.
minimal values - end of inspiration
Sea water temp. = 13°C
recorded during dive n°6,
temp.sensor in Oral Nasal mask
°C
40
38
36
34
32
30
28
26
24
22
20
4 Mar.
20:57
0
20
40
60
80
100
120
140
160
180
200
220
240
In - water time (min)

Figure 4.11

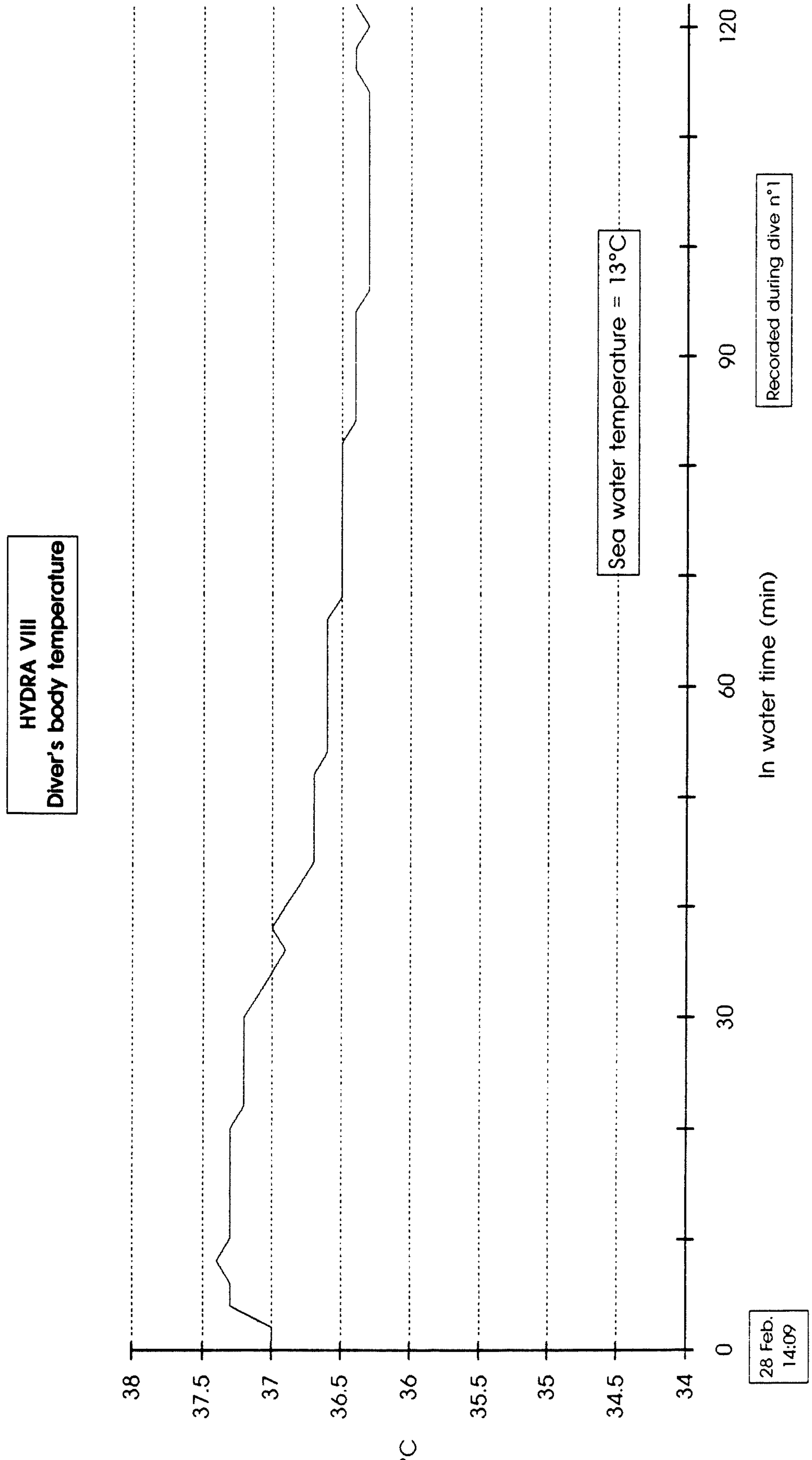

HYDRA VIII
Diver's body temperature
Sea water temperature = 13°C
Recorded during dive n°1
28 Feb.
14:09
°C
38
37.5
37
36.5
36
35.5
35
34.5
34
0
30
60
90
120
In water time (min)

Figure 4.12

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 5

TITLE : **SUPPORT VESSEL - DSV ORELIA**

DATE : 1 September 1988

REVISION : 00

INDEX

1 - GENERAL PHILOSOPHY FOR THE SUPPORT VESSEL ADAPTATION

The use of gas mixes containing a high percentage of hydrogen, which is an inflammable gas, raises numerous safety problems as to the diving installation environment. Due to the low oxygen percentage, hydreliox itself is not explosive, but can generate explosive mixes when in contact with the ambient atmosphere oxygen, in case of leaks. The energy required by the ignition of the air mix containing over 4 % hydrogen is so weak that, in the industrial practice, it is considered as self-explosive. The operation safety of gases containing hydrogen is based on the elimination of the risk of air-hydrogen mixes wild formation.

In industry, two main techniques can be made out in the design of installations conveying hydrogen and associated mixes.

1 **Ventilation** - this method consists in diluting hydrogen leaks in the ambient air, whereas their concentration cannot reach the inflammability limits. This dilution is obtained by natural or artificial ventilation of the environment space. Hydrogen being very light, tends to rise and escape in the atmosphere, which advantages the open air installations. In covered space, forced ventilation systems must create a stirring sufficient to dilute the functional and accidental leaks and evacuate them. Ventilation and extraction devices are usually controlled by the leaks detection systems.

The protection system, based on ventilation and artificial extraction operated by detectors, was used in COMEX Hyperbaric Experimental Centre in HYDRA V and VI operations.

2 **Inerting** - this method is based on the reduction of the compartment atmosphere oxygen concentration, in which hydrogen leaks may occur, below the limit of 5 %. Inerting is performed by total or partial replacement of the air by a neutral gas, nitrogen or CO2. This method is generally used for the protection of compressor rooms onboard ships carrying natural gas such as methane, whose characteristics are close to hydrogen's.

The philosophy chosen for the support vessel adaptation to the use of hydrogen was based on a compromise between these two methods, considering the following principles :

- localization of the hydrogen storage and distribution systems and associated equipment on the vessel main open deck - natural ventilation

- nitrogen inerting of all vessel compartments containing the hydrogened gases installations

2 - SELECTION OF THE SUPPORT VESSEL

COMEX based the support vessel selection on the following criteria :

* vessel diving system capacities
* available surface on deck
* capacities of the dynamic positioning system
* compatibility of the vessel diving system with COMEX diving equipment

Following the specifications examination of all deep diving support vessels available on the market in 1986, we chose the DSV ORELIA. This vessel, belonging to HOULDER OFFSHORE LTD., COMEX british partner, offered some advantages as compared to the other operational diving vessels :

- **Diving system**

The ORELIA system was designed and built by COMEX INDUSTRIES, thus perfectly compatible with COMEX diving techniques. The margins applied in its elements construction calculations allowed to anticipate the working pressure augmentation, initially restricted to 45 bar (pressure limit applied on all diving support vessels in 1986). The system lay out and capacities (5 independent living chambers, 2 transfer chambers, 2 diving bells 25 meters apart), made the adaptation possible in respect of all operations and safety imperatives.

- **Deck surface** : 1800 m2, the largest of all diving support vessels with dynamic positioning

The choice of the vessel carrying the British ensign commanded the application of norms and codes in force in U.K. All HYDRA VIII operations procedures as well as the vessel modifications particulars had to be submitted to the British authorities' approval (Department of Transport with the participation of the Department of Energy).

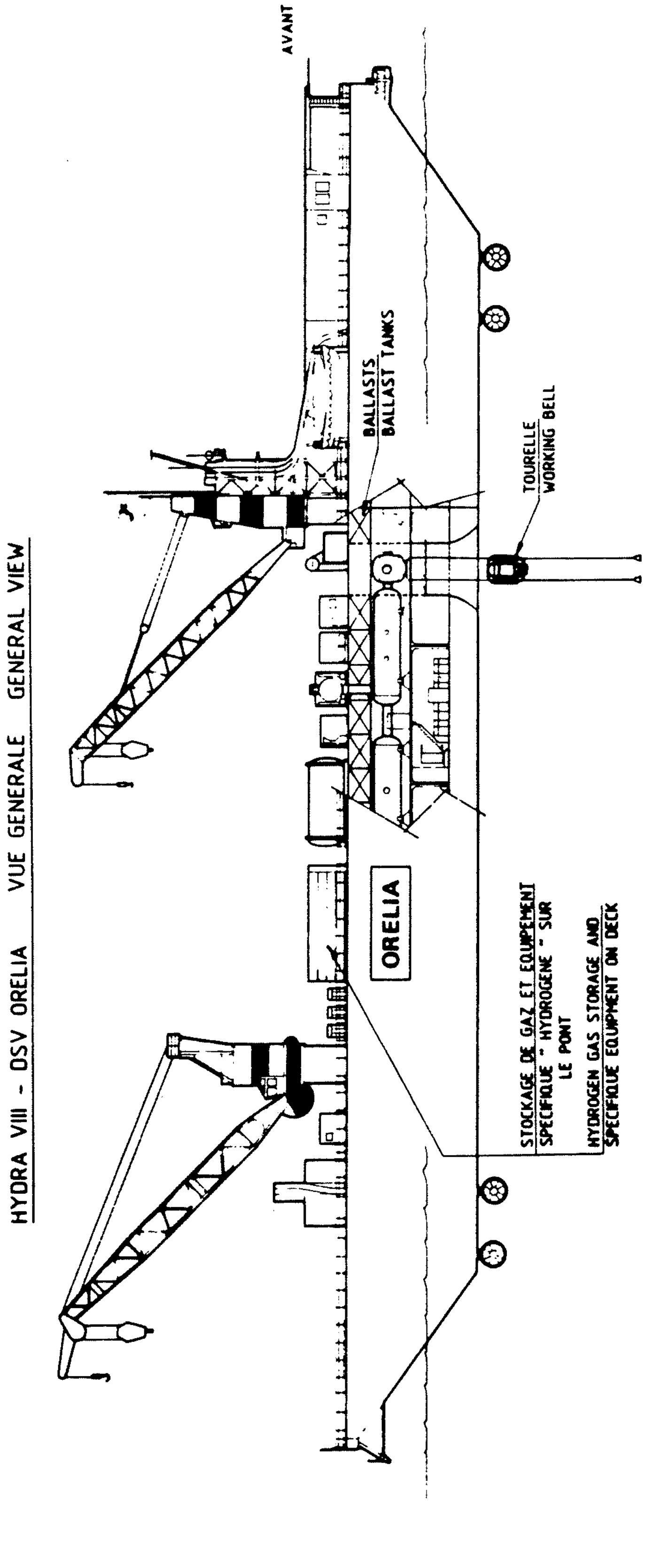

HYDRA VIII - DSV ORELIA VUE GENERALE GENERAL VIEW
AVANT
BALLASTS
BALLAST TANKS
TOURELLE
WORKING BELL
ORELIA
STOCKAGE DE GAZ ET EQUIPEMENT SPECIFIQUE " HYDROGENE " SUR LE PONT
HYDROGEN GAS STORAGE AND SPECIFIQUE EQUIPMENT ON DECK

Figure 5-1

L'ORELIA sur le site des plongées
ORELIA during offshore dives

DSV ORELIA - Passerelle
DSV ORELIA - Bridge O.C.C.

Vue générale du pont de l'ORELIA
Main deck general view

3 - DSV ORELIA TECHNICAL SPECIFICATIONS
(before modifications)

3.1 MAIN CHARACTERISTICS

Overall length	:	119 m	
Overall width	:	19 m	
Depth - main deck	:	11.50 m	
Propellers under the hull	:	2.70 m	
Transit speed	:	7.5 knots	
Transit consumption	:	22 tons/day	
DP consumption	:	8 tons/day	
		Maximum	**Type**
Draught	:	5 m	4 m
Displacement	:	8200 tons	6442 tons
Dead weight	:	3508 tons	1745 tons

3.2 ENGINE

- Six diesel engines (900 kW each) - propulsion
- Four diesel alternators (650 kW each)
- One desalinisation system 40 tons/day
- One desalinisation system 30 tons/day drinking water

3.3 PROPULSION

- Six rotary propellers with variable pitch screws directly connected to the diesel engines - nominal power : 1215 CV each
  Propellers diameter : 2000 mm
  Nominal thrust : 18.2 tons/propeller

3.4 TANKS CAPACITY

Gasoil	:	759 m3
Fresh water	:	353 m3
Ballast	:	737 m3 (double deck)
		1850 m3 (double casing)

3.5 DYNAMIC POSITIONING

Model : Duplex G.E.C. comprising :

- 2 independent computers
- 1 control panel with 3 monitors
- 1 portable console
- 2 auxiliary monitors
- 2 printers
- 1 plotter
- 2 gyrocompasses
- 2 anenometers
- 2 vertical references
- 2 taut wires references
- 1 system of acoustic positioning ultra-short basis Simrad HPR 309T (tracking)
- 1 interface for radio-navigation systems : ARTEMIS, SYLEDIS and PULSE 8

3.6 CLASSIFICATION AND MANUFACTURERS

Flag	:	British
Home port	:	Aberdeen, Scotland
Vessel	:	Lloyd's Register of Shipping + 100 A1 + LMC,UMS,DP(AA)
Diving system	:	Lloyd's Register of Shipping 450 m

Construction rules and authorities :

- Department of Transport (DoT)
- Department of Energy "Guidance on the Design and Construction of Offshore Installation (1977)" (as applicable)
- Department of Energy "Guidelines for the Specification and Operation of Dynamically Positioned Diving Vessels" (1980)
- Lloyd's Register of Shipping

Shipyards and manufacturers :

Hull	:	British Shipbuilders (SWAN HUNTER LTD) Newcastle UK
Equipment	:	HUMBER GRAVING DOCK LTD Immingham
Diving system	:	COMEX INDUSTRIES Marseille

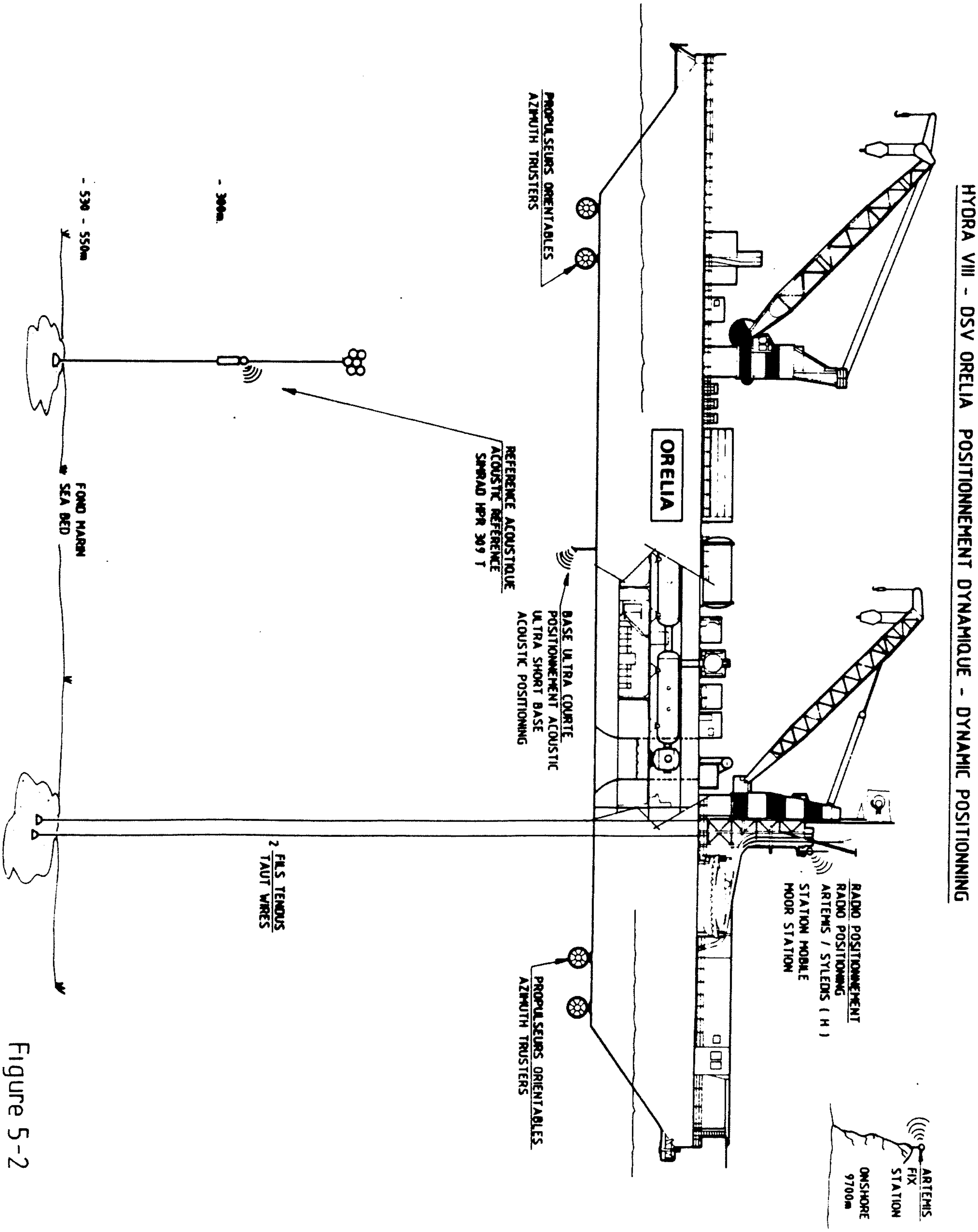

HYDRA VIII - DSV ORELIA POSITIONNEMENT DYNAMIQUE - DYNAMIC POSITIONNING
ORELIA
PROPULSEURS ORIENTABLES
AZIMUTH TRUSTERS
- 300m
- 530 - 550m
REFERENCE ACOUSTIQUE
ACOUSTIC REFERENCE
SIMRAD HPR 309 T
FOND MARIN
SEA BED
BASE ULTRA COURTE
POSITIONNEMENT ACOUSTIC
ULTRA SHORT BASE
ACOUSTIC POSITIONNING
2 FILS TENDUS
TAUT WIRES
RADIO POSITIONNEMENT
RADIO POSITIONNING
ARTEMIS / SYLEDIS (H)
STATION MOBILE
MOOR STATION
PROPULSEURS ORIENTABLES
AZIMUTH TRUSTERS
ARTEMIS
FIX
STATION
ONSHORE
9700m

Figure 5-2

3.7 LIFTING DEVICE

Two electro-hydraulic cranes :

- one with a 100/50 ton capacity, equipped with a precision accelerometer to control the compensation device of the vessel movements
- one with a 100/50 ton capacity

3.8 ACCOMODATION

- 99 people in air-conditioned cabins (2 or 3 berths)

3.9 DIVING SYSTEM

System capacity (prior to modifications) :

The system configuration allows the continuous and simultaneous operation of two diving bells, 25 meters apart. This system is composed of :

Five living chambers 45 bar, 20 berths
Two transfer chambers 45 bar
Two diving bells 45 bar, equipped with compensation system, operating through two moonpools, handling system approved for a depth of 450 meters
Integrated diving gas storage, capacity 18000 m3, pressurized at 200 bar
Regeneration system for the diving and chamber gases
A hyperbaric rescue chamber 20 persons 45 bar

4 - HYDROGEN SECURITY - SPECIFIC AREAS DEFINITION

4.1 DEFINITIONS

With the purpose to determine protection methods against explosion and fire risks, the vessel was divided in areas specified as per international standards.

4.1.1 Hazardous areas

Areas in which the air-hydrogen mix is or may be expected to be present : the electrical equipment, thermic engines and protection system in those areas require the application of specific precautions.

Hydrogen is combustible in the air only, for rates within its flammability inherent limits. From this data, areas can be determined in which a risk of hazardous concentration exists (according to the International Electro-technical Commission).

Hazardous zone 0

- area in which an explosive atmosphere is present either permanently or for long periods
  This type of hazardous zone did not exist on the ship.

Hazardous zone 1

- area in which explosive gases are likely to occur in the ambient air during the installation normal operation.
  A zone of this type was delimited in two places : around the extremities of the exhaust pipes of the hydrogened gases in the atmosphere. No electric or mechanical equipment was present in those areas.

Hazardous zone 2

- area in which explosive gases may only occur in abnormal operation conditions of the installation.
  This type of hazardous zone was limited onboard the ORELIA to the main open deck around installations containing hydrogen, where leaks could occur accidentally.

4.1.2 Non-hazardous areas

Areas in which the explosive mix of hydrogened air is not expected to be present in quantities such as to generate fire risks and require the use of protection systems.

Onboard the ORELIA, the space with no installations containing hydrogened gases and out of the safety area around such installations was considered as non-hazardous.

4.1.3 Non-hazardous areas - subject to special consideration

Areas in which installations contain hydrogen but where the possibility of release of hydrogen explosive mixes is extremely remote and fire risks disregarded.

Onboard the ORELIA, the electrical equipment used in these areas was of the standard type, but submitted to the automatic control system.

4.2 DSV ORELIA - HAZARDOUS AREAS NATURALLY VENTILATED

Two distinct areas on the main open deck, in which the following equipment was disposed :

1. Around the aft moonpool (not used) :

- under pressure storage of hydrogened gas	zone 2
- hydrogened gas mix and transfer stations	zone 2

2. Around the forward moonpool :

- regeneration and dehydrogenation units	zone 2
- umbilical basket and handling system	zone 2
- diving bell n° 2 in frwd moon pool	zone 2
- gas distribution panels	zone 2
- hydrogen gas exhaust in the atmosphere	zone 1

4.3 DSV ORELIA - NON HAZARDOUS AREAS - SUBJECT TO SPECIAL CONSIDERATION

4.3.1 Hyperbaric chambers compartment

The atmosphere of this compartment, set under the deck, was inerted with nitrogen. Due to the low oxygen concentration in this atmosphere, the explosive mix is not likely to occur, even in case of hydreliox accidental leak. In the case of control loss of the compartment inerting, this compartment was considered for a short period **"hazardous zone 2"** (see details in section 6).

4.3.2 Medical lock room

The operation procedures and the room specific arrangement made the possibility of hydrogen release in the non- hazardous area extremely remote. This room installation, isolated from the other compartments of the vessel was used to transfer food and equipment into the hyperbaric chambers without going through the unbreathable atmosphere of the inerted area. In case of failure of one of the protection devices, the room could become for a short period **"hazardous zone 2"**.

4.3.3 Gas analysis laboratory

Since the quantities and pressure of the gases used for the analysis were very low, this laboratory, located in an independent container on the open deck, was classified as **"non hazardous area - subject to special consideration"**. The protection system would automatically cut off the electric power supply in case of leakage detection and/or stop of the extractor.

5 - HYDROGEN LEAKS DETECTION

Two networks of hydrogen detectors were set onboard.

- a network for the leaks detection around the installations on the open deck
- a detection network set in the chambers compartment, part of the control system. Details of this system are presented in section 6.

The operation of the fixed networks could be assisted or, if required, replaced intermittently by portable detectors.

5.1 COMPONENTS CHARACTERISTICS OF THE DETECTION NETWORK ON THE ORELIA DECK

Number of sensors	:	8
Sensors type	:	thermo-catalytic
Model	:	Oldham CEX 800
Multipoint detectors	:	Oldham LDA 745
Operation scale	:	0 - 1 % H2 (20 % LIE)
Resolution	:	5 % measure extent
Alarm level		
lower	:	0.2 % O_2
upper	:	0.5 % O_2

5.2 COMPONENTS LOCALIZATION

3 sensors in the moonpool	zone 2
1 sensor in the gas distribution room	zone 2
2 sensors in the regeneration unit	zone 2
1 sensor in the working compressor unit	zone 2
1 sensor in the gas storage zone	zone 2

The detection board was located on the bridge (OCC)

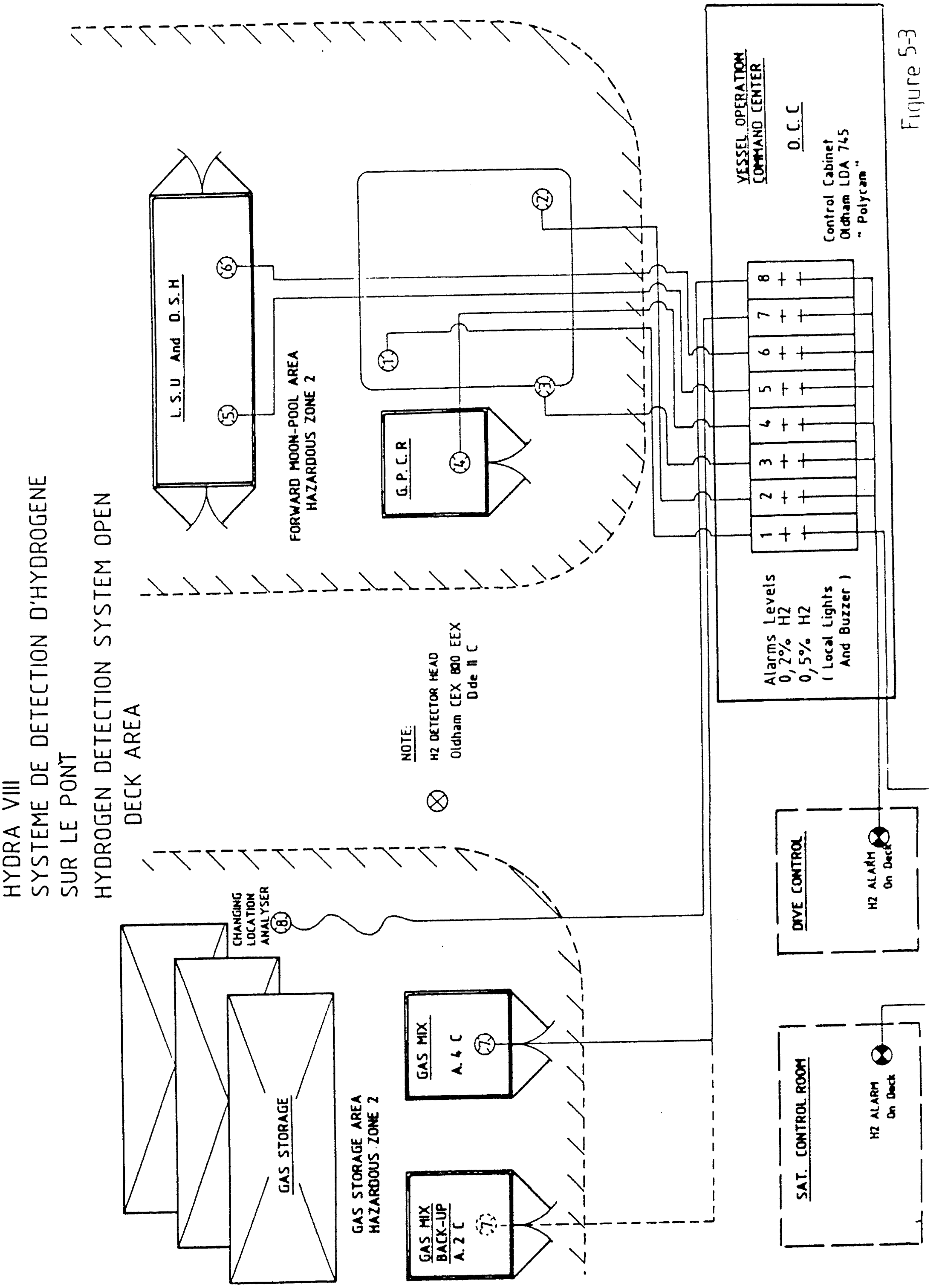

HYDRA VIII
SYSTEME DE DETECTION D'HYDROGENE
SUR LE PONT
HYDROGEN DETECTION SYSTEM OPEN
DECK AREA
L.S.U And O.S.H
FORWARD MOON-POOL AREA
HAZARDOUS ZONE 2
G.P.C.R
NOTE:
H2 DETECTOR HEAD
Oldham CEX 800 EEX
Dde II C
CHANGING
LOCATION
ANALYSER
GAS STORAGE
GAS MIX
A.4 C
GAS MIX
BACK-UP
A.2 C
GAS STORAGE AREA
HAZARDOUS ZONE 2
VESSEL OPERATION
COMMAND CENTER
O.C.C
Control Cabinet
Oldham LDA 745
" Polycam "
Alarms Levels
0,2% H2
0,5% H2
(Local Lights
And Buzzer)
DIVE CONTROL
H2 ALARM
On Deck
SAT. CONTROL ROOM
H2 ALARM
On Deck

Figure 5-3

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 6

TITLE : **INERTING SYSTEM**

INDEX

DATE : 1 September 1988
REVISION : 00

1 - HYPERBARIC CHAMBERS SPACE INERTING

To comply with the methods tested in industry and with the hydrogened gas transportation, the saturation chambers compartment set in the covered space under the deck had to be inerted with nitrogen all along the hydreliox phase. This solution presented several advantages as compared to the alternative, based on ventilation and extraction, previously used during "offshore" dives.

a - the compartment tightness being commanded by the vessel construction imperatives, inerting reduced the adaptation works. On the contrary, the choice of the ventilation system would have made compulsory the construction of large ventilation pipes, disturbing the vessel structure integrity and would have raised the problem of the freeboard.

b - the absence of permanent ventilation (20 exchanges of the space volume per hour) cancelled the problems of heating and noise protection

c - reduction of the number of hydrogen leaks detectors

d - reduction of the quantity of electrical equipment to be replaced

e - increased safety : the formation of the explosive mix being only possible in case of hydrogen leakage accompanied with oxygen inlet in the compartment atmosphere

The chambers insulation and the unbreathable atmosphere of the inerted compartment required the installation of numerous remote control and watching devices. Also the use of breathing apparatus by the technicians who had to intervene inside this area.

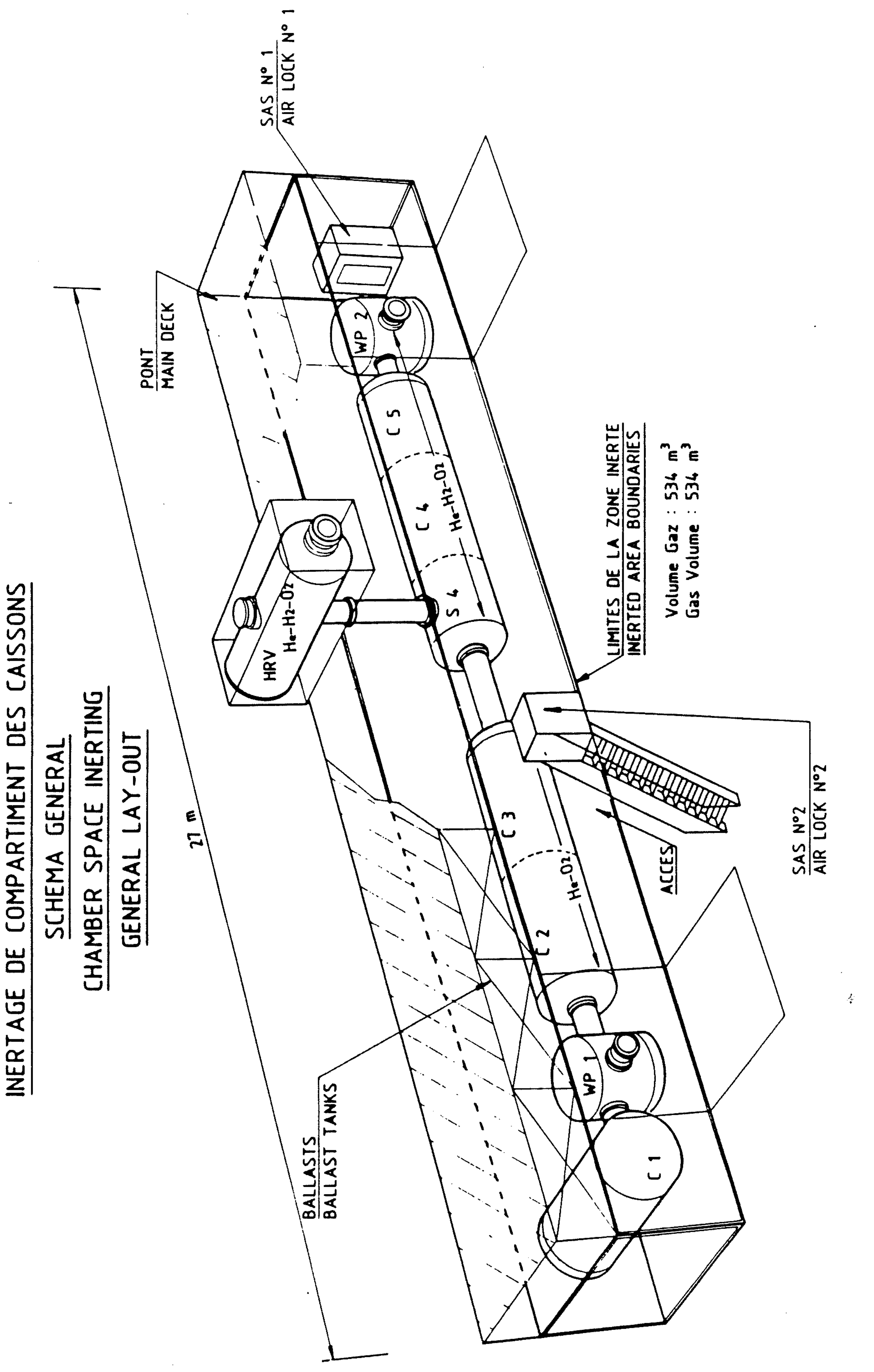

INERTAGE DE COMPARTIMENT DES CAISSONS
SCHEMA GENERAL
CHAMBER SPACE INERTING
GENERAL LAY-OUT
27 m
PONT
MAIN DECK
SAS N° 1
AIR LOCK N° 1
WP 2
C 5
C 4
He-H2-O2
S 4
HRV
He-H2-O2
C 3
He-O2
C 2
WP 1
C 1
BALLASTS
BALLAST TANKS
LIMITES DE LA ZONE INERTE
INERTED AREA BOUNDARIES
Volume Gaz : 534 m3
Gas Volume : 534 m3
ACCES
SAS N°2
AIR LOCK N°2

Figure 6-1

2 - SYSTEM OPERATION

The system was supposed to reduce and maintain the oxygen concentration in the compartment atmosphere on a safety level. The nitrogen ventilation of the compartment made gas-tight, allowed to maintain this concentration. The atmosphere composition was then controlled by the following actions :

- maintenance of the compartment in overpressure with nitrogen preventing the admission of the air oxygen
- elimination of the hydrogen coming from the "functional" leakage with a catalytic scrubber
- massive nitrogen ventilation in case of major leaks (accidental)
- addition of the oxygen necessary to the proper operation of the sensors and catalytic scrubber as soon as the oxygen concentration goes below 1 % with air ventilation sequences.

The system was also designed to give operators and technicians access to the chambers and associated equipment within the system safety. This function was ensured by two access locks.

Operation parameters

- compartment net volume	:	534 m^3
- nitrogen overpressure	:	15 mbar +/- 5 mbar
- oxygen concentration	:	
nominal	:	2 %
upper limit	:	3 %
lower limit	:	1 %
- hydrogen concentration	:	
nominal value	:	0.00-0.02 %
alarm limit 1	:	1 %
alarm limit 2	:	2 %
- ambient temperature	:	15 - 20°C

4 - SYSTEM COMPONENTS

4.1 NITROGEN STORAGE AND DISTRIBUTION

To face the need in nitrogen all along the operation, two liquid nitrogen containers were mobilized onboard.

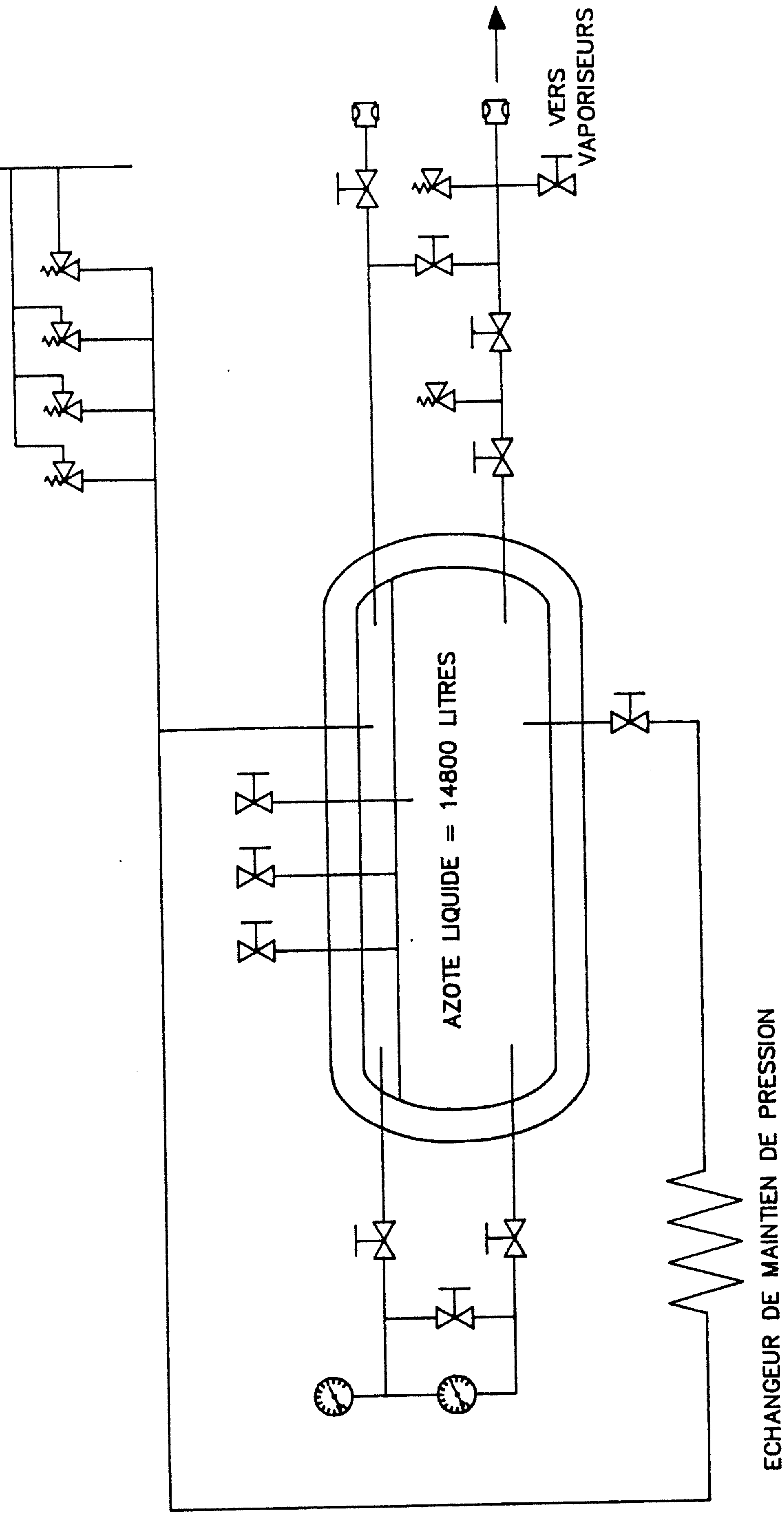
Liquid nitrogen is vaporised into a set of 10 atmospheric vaporisers. This system was designed by PRODAIR in order to ensure its operation with no exterior energy supply.

The vaporisers were controlled through a pneumatic device fulfilling all the logics and timing functions. A pressure reducing manifold adjusted the overpressure in the inerted area.

See next pages for the system diagrams.

HYDRA 8 — NAVIRE SUPPORT " ORELIA "

STOCKAGE DE L'AZOTE LIQUIDE
SCHEMA DE PRINCIPE



NOTE : DEUX UNITES DE STOCKAGE ONT ETE INSTALLES EN PARALLELE

Figure 6-2

HYDRA 8 — NAVIRE SUPPORT " ORELIA "

DISTRIBUTION DE L'AZOTE
SYSTEME DE VAPORISATION ET REGULATION

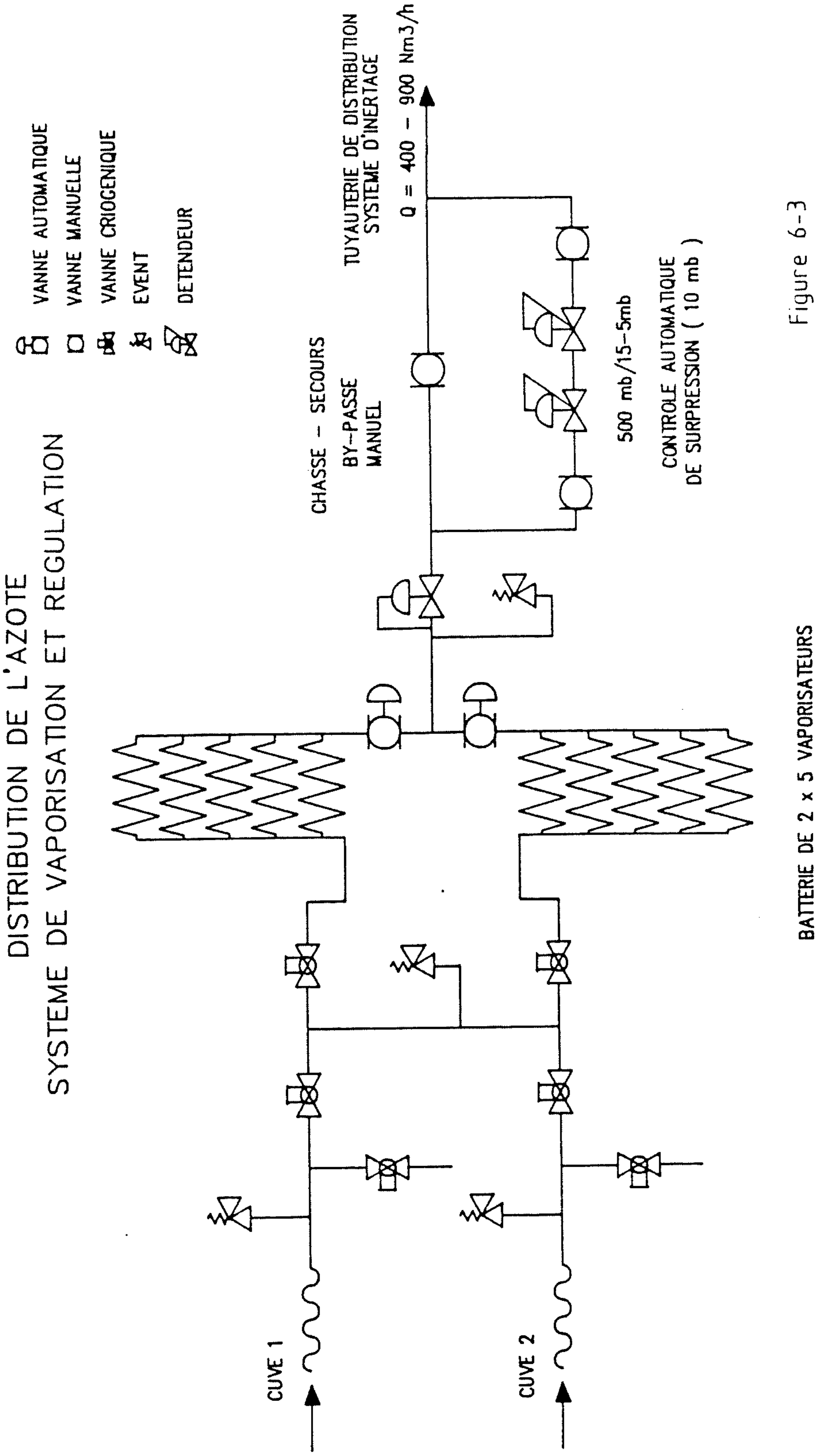


Figure 6-3

4.2 WATER TRAP

The chambers compartment was equipped with a simple water trap safety device ensuring the following functions :

- protection against the risk of excessive overpressure due to chambers gas leakage (possible volume over 2000 Nm^3) or to the operation failures of the nitrogen supply pressure reducers.

- overpressure measure and monitoring by the height of the trap water column.

- extraction and control of the gas exhaust from the inerted area.

4.3 INSTALLATION OF THE GAS ADMISSION AND EXTRACTION

Nitrogen was admitted in the compartment through the distribution network. This network, made of PVC pipes, was adjusted to help the nitrogen stratification during the initial inerting operation. Nitrogen admitted at the ground level at a temperature slightly inferior to the compartment air temperature, was spread in layers. This phenomenon allowed to reduce the nitrogen quantities and the time necessary to eliminate oxygen from the compartment.

During the initial inerting, a pipe network set on the compartment ceiling, extracted the air. A pneumatic air-driven ejector was used as an extractor. This system was also designed for the hydrogen leaks elimination, this operation being facilitated by the gas low density.

INSTALLATION D'INERTAGE

INERTING SYSTEM

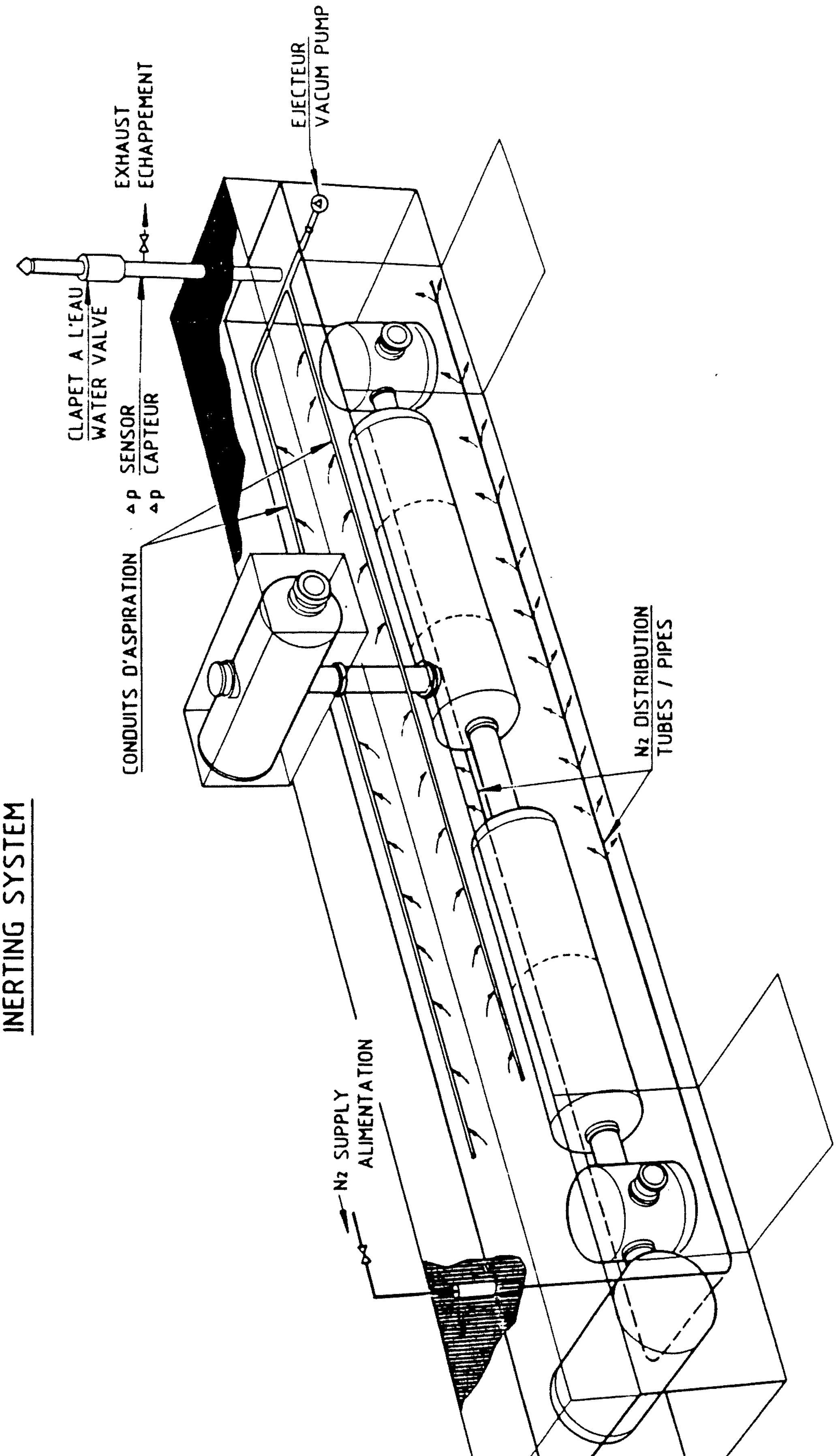
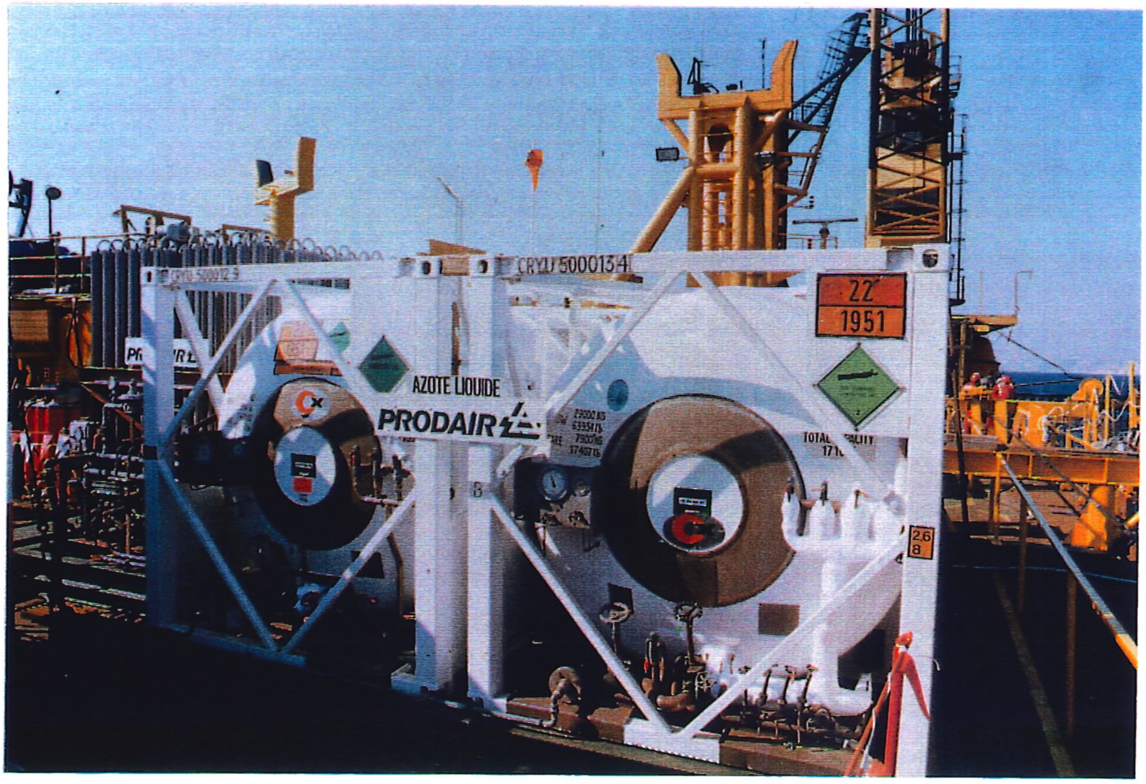


Figure 6-4



Stokage de l'azote liquide
Liquid nitrogen storage

Vaporisateur d'azote liquide
Liquid nitrogen vaporiser

4.4 INERTED SPACE MONITORING

The inerted space was equipped with an automatic monitoring system, with the following functions :

a) Parameters measure and recording

- ambient temperature
- nitrogen overpressure
- nitrogen supply pressure
- hydrogen concentration
- oxygen concentration

All parameters were displayed and recorded on the bridge and monitored by an officer of the watch.

b) Sound and light alarms release when exceeding the safety thresholds

- of hydrogen concentration 1%, 2 %
- of oxygen concentration 3 %, 4 %

The warning devices were set in all the operation vital centres : bridge, diving control and saturation control room.

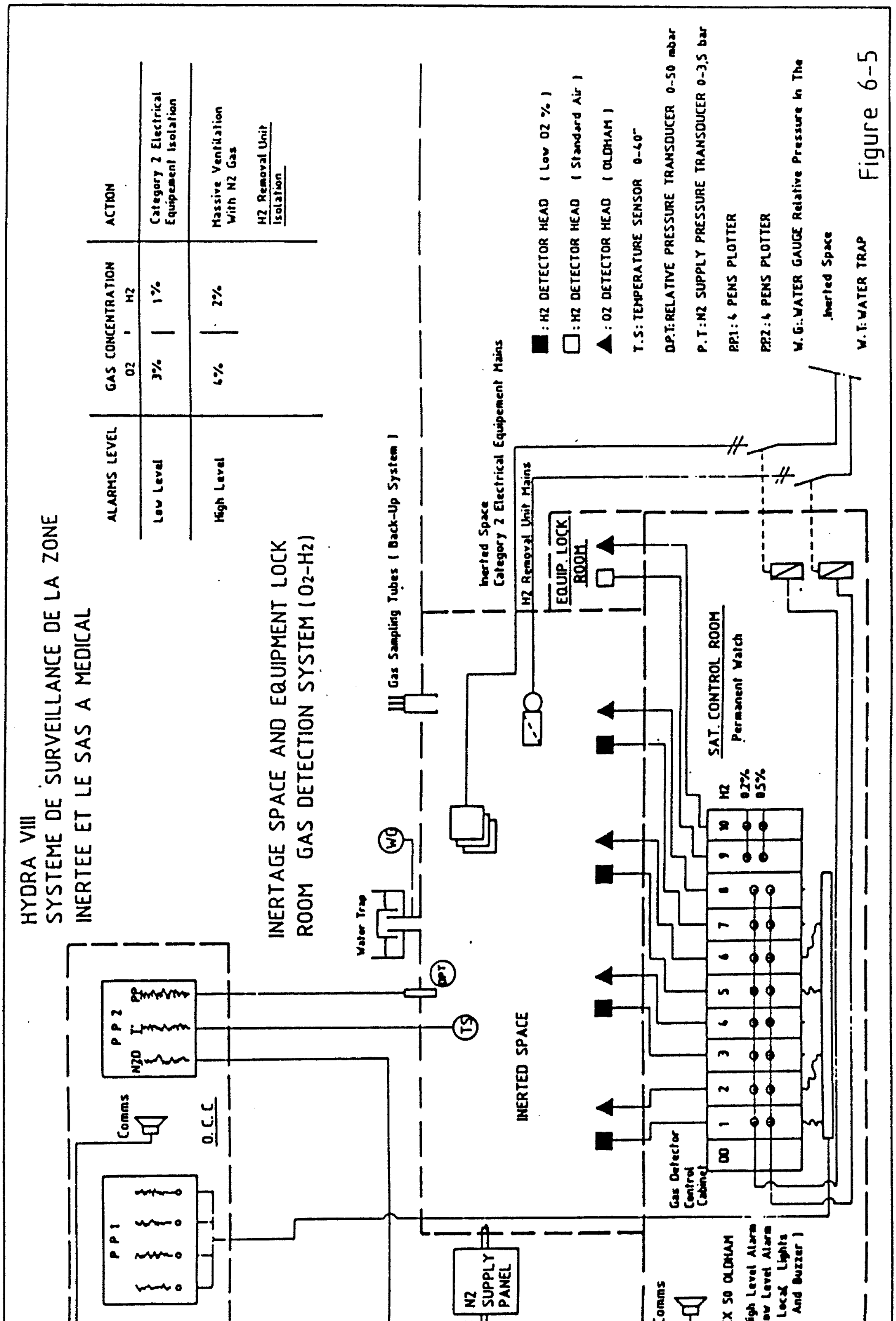

HYDRA VIII
SYSTEME DE SURVEILLANCE DE LA ZONE
INERTEE ET LE SAS A MEDICAL
INERTAGE SPACE AND EQUIPMENT LOCK
ROOM GAS DETECTION SYSTEM (O2-H2)
ALARMS LEVEL
GAS CONCENTRATION
O2 H2
ACTION
Low Level
3%
1%
Category 2 Electrical Equipement Isolation
High Level
4%
2%
Massive Ventilation With N2 Gas
H2 Removal Unit Isolation
Gas Sampling Tubes (Back-Up System)
Inerted Space Category 2 Electrical Equipement Mains
H2 Removal Unit Mains
EQUIP. LOCK ROOM
SAT. CONTROL ROOM
Permanent Watch
INERTED SPACE
Water Trap
WG
DPT
TS
PT
O.C.C
Comms
P P 1
P P 2
N2O
T
PP
N2 SUPPLY PANEL
Gas Detector Control Cabinet
EX 50 OLDHAM
High Level Alarm
Low Level Alarm
(Local Lights And Buzzer)
H2
0.2%
0.5%
: H2 DETECTOR HEAD (Low O2 %)
: H2 DETECTOR HEAD (Standard Air)
: O2 DETECTOR HEAD (OLDHAM)
T.S: TEMPERATURE SENSOR 0-40°
D.P.T: RELATIVE PRESSURE TRANSDUCER 0-50 mbar
P.T: N2 SUPPLY PRESSURE TRANSDUCER 0-3,5 bar
P.P.1: 4 PENS PLOTTER
P.P.2: 4 PENS PLOTTER
W.G.: WATER GAUGE Relative Pressure In The Inerted Space
W.T.: WATER TRAP

Figure 6-5

c) Preventive actions

- cut off category 2 electrical equipment power supply - **lower alarm**
- stop of the catalytic scrubber - **upper alarm**

Note : In the inerted area, the electrical equipment was classified as follows :

- **category 1** : equipment not used during the "hydreliox" phase
- **category 2** : standard equipment in use. In case of hydrogen or oxygen contamination of the inerted area, the devices belonging to this category had to be disactivated and isolated from the electric supply source.
- **category 3** : equipment of which the operation was vital for the divers' safety. This category devices were adapted or replaced so that to meet the work requirements in hazardous zone 2.

4.4.1 Hydrogen detection

Number of sensors	:	five
Principle	:	catalytic thermo-oxidation
Model		
Sensor	:	OLDHAM CEX 810 AD
Detector	:	OLDHAM EX 50
Scale	:	100 % to 2 % H_2 (for 1% O2)
Resolution	:	1 % of scale
Precision	:	5 % of value
Lower limit	:	0.1 %

Alarms

Lower level	:	1 % H_2
Upper level	:	2 % H_2
Calibration gas	:	2% H_2 - 2% O_2 qs N_2

The use of thermo-catalytic sensors in low oxygen atmosphere was submitted to qualification tests, conducted in the Hyperbaric Centre in the presence of the Lloyd's Register of Shipping inspectors (figure 6.6 - example of a test protocol).

4.4.2 Oxygen detection

Number of sensors	:	5
principle	:	electro-chemical cell
model	:	SEDAM
scale	:	0 - 25 %
precision	:	5 % measured value
resolution	:	1 %

COMEX SERVICES

EXPLOSIMETER TEST -10-

DATE : 29/09/87

MANUFACTURER : OLDHAM

Explosimeter model : EX 50 Serial number : 622

Sensor model : CFC 804 Serial number : 583
CEX 810 AD

TEST N° 1 : Response error of the instrument

Composition of gas mixture % O_2	% H_2	% N_2	Response
2	-	q.s.100	00
2	1	"	100
2	0.75	"	73
2	0.50	"	45
2	0.25	"	17

TEST N° 2 : Variation in response

Concentration O_2 in N_2	Response without H_2	with 1% H_2
3	00	113
2	00	114
1	00	100
0.5	00	27

Technical supervisor : comex CENTRE EXPERIMENTAL HYPERBARE DIRECTION TECHNIQUE

Certification society : Test Witnessed
LLOYD'S REGISTER OF SHIPPING 29-09-87 J. WAQUET MARSEILLE

AB/bb - 134/87

Figure 6-6

4.4.3 Inerted area atmosphere composition analysis

Accurate measures of the inerted compartment gas composition were taken with a chromatograph. Gas samples were taken through an analysis tubes network set in the compartment.

Number of points	:	6
Instrumentation	:	IGC 130 chromatograph
Characteristics	:	see section 7
Scale	:	0.05 to 100 % hydrogen
Calibration	:	daily

The method accuracy enabled to follow the hydreliox functional leaks evolution upon manifestation.

4.5 ACCESS LOCK

Two access locks to the the inerted area were built as per the following diagram :

Components :

- Two gas-tight doors (test p. 25 mbar) : **1 and 2**
- Pressure equalization valves prior to doors opening : **3 and 4**
- Gas admission valves : **5 and 6**
- Doors observation portholes : **7**
- Oxygen sensors with direct measure : **8**
- Pneumatic extractor (ejector) : **9**

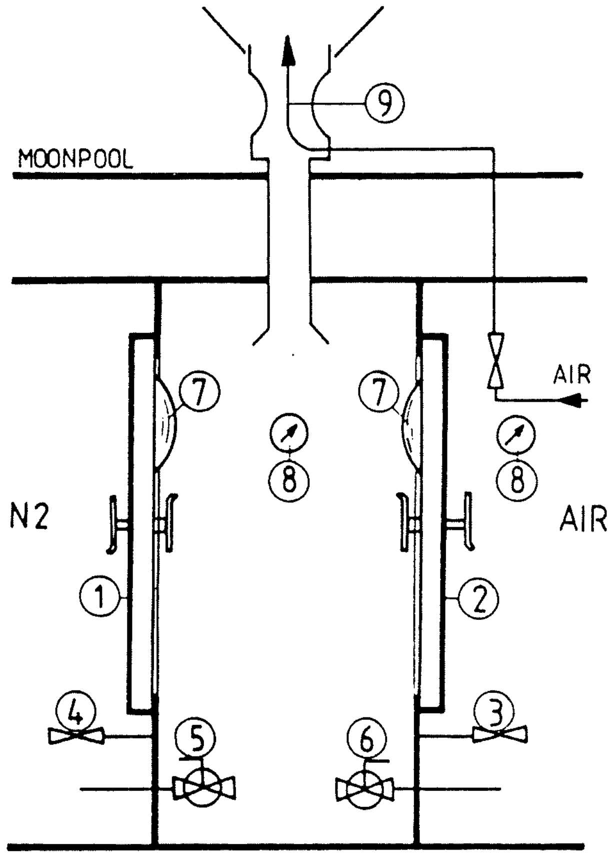


Figure 6-7

Lock operation - Entry in the inerted space

Start : air lock, all valves closed, personnel expected to enter wear breathing equipment

- equalize pressure - valve 3
- open door 2
- enter the lock
- close door 2
- open admission valve 5
    * start pneumatic extractor 9
    * watch O2 concentration drop to below 8 %
    * stop the extractor
- open door 1
- close admission valve 5
- enter the inerted space
- close door 1

Situation : two persons inside the area, lock free.

The inerted space was left as per the same principle, in reverse way and in letting air into the lock. The personnel expected to intervene had to use autonomous equipment operated in semi-closed circuit, giving a one-hour breathing autonomy. In emergency conditions, operations marked (*) could be cancelled, reducing the locking time.

4.6 INERTED SPACE CATALYTIC SCRUBBER

Hydrogen shows a pronounced propension to escape the area containing it and to infiltrate into walls or joints tight to other gases. Even in "perfect" tightness conditions, the existence of hydrogen micro-leaks had to be considered as a normal phenomenon. During the operation, the gas leaks accumulation could reach the safety limits. Hydrogen had to be removed as from its manifestation. In this purpose, a catalytic scrubber was designed and set in the inerted area. This device operating under ambient pressure, removed hydrogen by catalytic combustion (process used in the dehydrogenator). The catalytic reaction required oxygen to be present in the gas to be scrubbed, a reason for maintaining the oxygen concentration in the inerted area over 1 %. The reaction heat inducing the overheating of the gas processed, the scrubber use was limited to hydrogen and oxygen low concentrations. Besides, high concentrations of hydrogen could only result from accidental leaks requiring the use of nitrogen for the compartment massive ventilation.

The scrubber was composed of a radial flow turbine, driven by an electric engine and a catalytic reactor. Gas was sucked over the chambers and, after scrubbing, diffused to the compartment other end.

Characteristics :

Nominal flow of the gas processed	:	120 m^3
Power consumed	:	3.3 kW, 440 v, 60 Hz
Catalyst	:	Deoxo 14 kg
Pressure drop on catalyst	:	180 mbar maximum
Reactor input temperature	:	60°C - preheat
Output maximum temperature	:	230°C - (2% H_2, 2% O_2)
H_2 concentration limit	:	2 %
O_2 concentration limit	:	4 %

Performances recorded during the operation :

Start	:	time	0 hr : 0.18 % H_2
Stop	:	time	5 hr : 0.07 % H_2

In the operation practice, the scrubber was used every day. An oxygen addition operation was performed on the seventh day of inerting (01/03).

Oxygen concentrations :

- after initial inerting	:	2.3 %
- on the seventh day	:	1.7 %
- after the addition	:	1.96 %

5 - TESTS AND PERFORMANCES

The safety of the vessel, of the divers and of the crew depended on the inerting system reliability. All the systems elements and utilization procedures were submitted to tests, carried out in the presence of the Lloyd's Register of Shipping inspectors and under the responsibility of the ship's Captain.

The tests took place between January 27th and February 5th, 1988, during the vessel mobilization in Marseille harbour. They were considered as satisfactory and the method was approved by the relevant authorities (COMEX SERVICES report Eng 012/88).

5.1 CHAMBERS COMPARTMENT TIGHTNESS

The inerted compartment tightness tests were achieved with air pressurization and measurement of the pressure drop speed due to leaks. The pressure drop speed limit was fixed at 1.3 mbar/10 min (0.5" water column).

- test pressure : 16 mbar
- measure precision : 0.2 mbar
- drop speed : 0.5 mbar/10 min
- leaks rate : 41 Nm^3/day - $<$10 % volume

5.2 INITIAL INERTING

Parameters monitored during the test :

- nitrogen flow : 0 - 1000 m^3/h
- input nitrogen temperature : -20 - +40°C
- compartment temperature : -20 - +40°C
- oxygen concentration : 0 - 25 %
- differential pressure : 0 - 50 mbar

The first test results are given in figure 6.8. Inerting was performed in three phases. The nitrogen flow remained low so that to restrict turbulences and facilitate the stratification of the gas introduced.

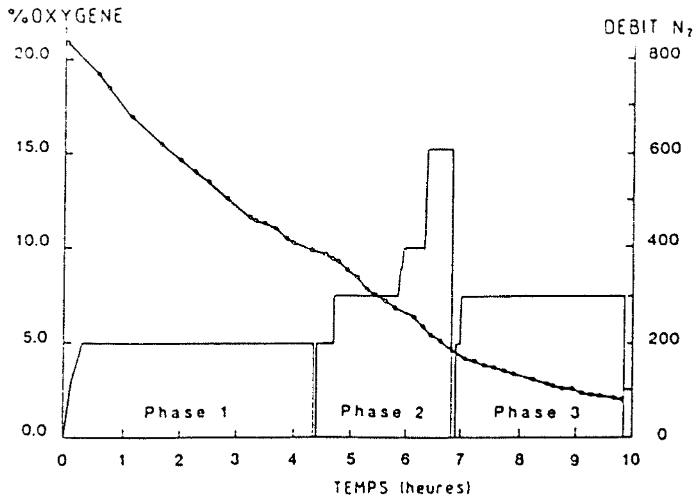


Figure 6-8

During the test, the gas stratification seemed hard to achieve. The difference between the nitrogen and the compartment air temperature was too little. This difference augmentation involved the flow increase of the gas from the vaporizer and generated turbulences in the compartment, thus compromising the stratification. It was decided to consider inerting as an oxygen dilution action.

The following tests allowed to determine the inerting parameters :

N_2 flow **Nm^3/hour**	**Inerting time 21% to 2% O_2** **hours**
100	12 to 13
150	8 to 9
400 (1)	3 to 4
800 (2)	1 to 2

(1) one vaporizer full flow
(2) two vaporizers full flow

The compartment inerting was performed on February 23rd, 1988, after the air tightness test. One vaporizer only was used. The operation lasted 3 hours and 40 minutes.

5.3 ACCESS LOCKS UTILIZATION

The locks utilization procedures and their operation effects on the inerted compartment parameters were submitted to a series of tests and allowed to determine the operation parameters :

Initial overpressure	:	18 mbar
Lock flushing time	:	2 minutes 20% to 2% O_2
	:	4 minutes 2% to 20% O_2
Final overpressure	:	10 to 12 mbar

Eleven interventions in the inerted zone were numbered along the hydreliox phase.

5.4 VENTILATION MAXIMUM FLOWS (EMERGENCY)

Only one vaporizer :

Maximum flow	:	400 m^3/hour
Test duration	:	15 min.
Overpressure	:	25 mbar

Two vaporizers :

Maximum flow	:	900 m^3/hour
Test duration	:	15 min.
Overpressure	:	oscillating around 25 mbar

Note : Water was ejected from the safety trap by the exhaust gas. This did not disturb the ventilation process.

5.5 MASSIVE LEAK CONTROL

Gas leakage from the chambers was simulated by air admission corresponding to the pollutant gas (oxygen) constant flow equal to 17 m^3/h, which represents a hydreliox leakage of 43 m^3/h. The compartment was ventilated with different nitrogen flows. The oxygen concentration was evaluated by four sensors of the monitoring system. The test results, given on figure 6.9, confirm the capacities of major leaks control through rather long periods.

The stabilization concentration limits of the different sensors depended on their localization towards the air intake.

N_2 Flow Nm3/hour	Sensor A	Sensor C	Sensor D *
400	2.7 %	3.5 %	4.2 %
800	0.95 %	2.6 %	3.6 %

* Sensor D was close to the air intake

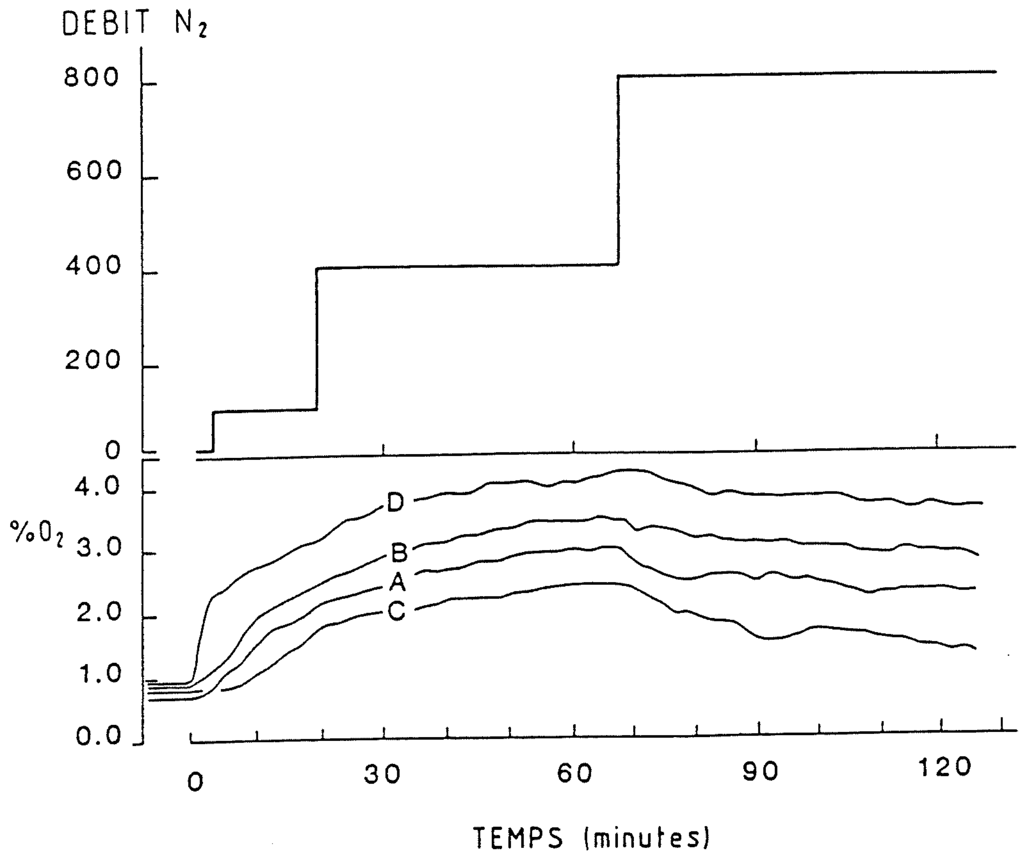


Figure 6-9

5.6 INERTED GAS ELIMINATION

Tests results of the return to normal conditions in the chambers compartment are given on figure 6.10.

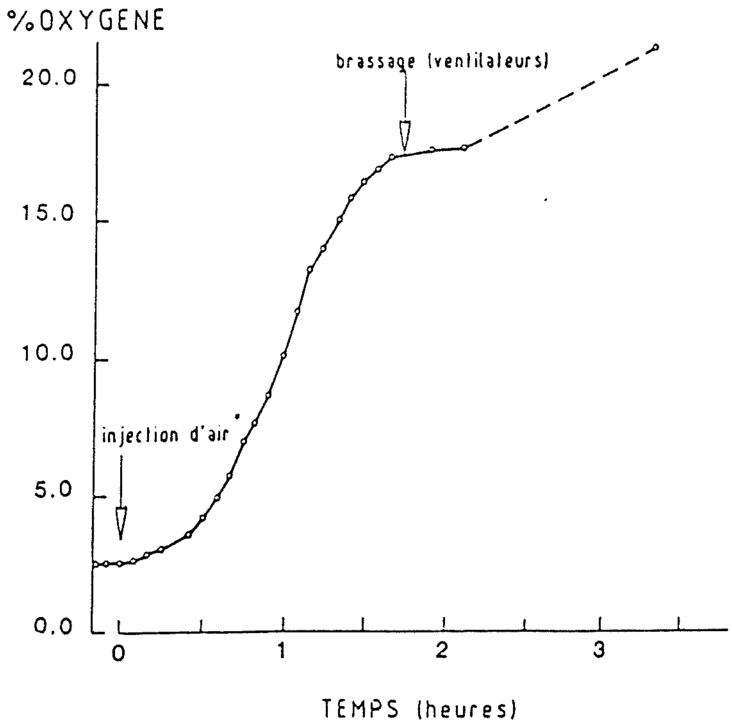


Figure 6-10

5.7 NITROGEN CONSUMPTION RATE

The consumption rate theoretical estimations of the nitrogen necessary to the system operation were corrected according to the tests results. The consumptions recorded during the 22 days of the hydreliox phase corresponded to the anticipated figures.

Operation	Consumption
Initial inerting	1600 Nm^3
Leaks compensation	40 Nm^3/day
Lock operation	5 Nm^3/operation

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 7

TITLE : **SPECIFIC EQUIPMENT AND DEVICES**

INDEX :

DATE : 10 September 1988
REVISION : 00

1 - SATURATION CHAMBERS

1.1 HYDRA VIII LIFE SYSTEM LAY OUT

Part of the chambers of the ORELIA huge saturation system were prepared for the saturation of a team of eight divers maximum. These compartments are as follows :

* **Living chamber 4** : 15 m^3 - four divers
* **Living chamber 5** : 15 m^3 - four divers
* **Transfer chamber 4** : 10 m^3, WC, shower, 2 locks and access to the diving bell
* **Chamber 4 lock** : 9 m^3, WC, shower, access to the HRV and to chamber 3 (locked during the hydreliox phase)
* **Hyperbaric rescue vessel** : 13 m^3 - twenty persons

This system arrangement enabled to saturate two teams at the same life level. If required, the set could be divided into three independent parts pressurized at different levels.

Living chambers 3, 2 and 1, as well as transfer chamber 1, were isolated and inerted with heliox along the hydrogen phase. The connection spool piece between chamber 3 and lock 4 was kept in vacuo.

Most of the chambers equipment remained unchanged. Some of the equipment had to be submitted to tests to work under a 50 bar pressure.

HYDRA VIII SYSTEME DE PLONGEE - DIVING SYSTEM

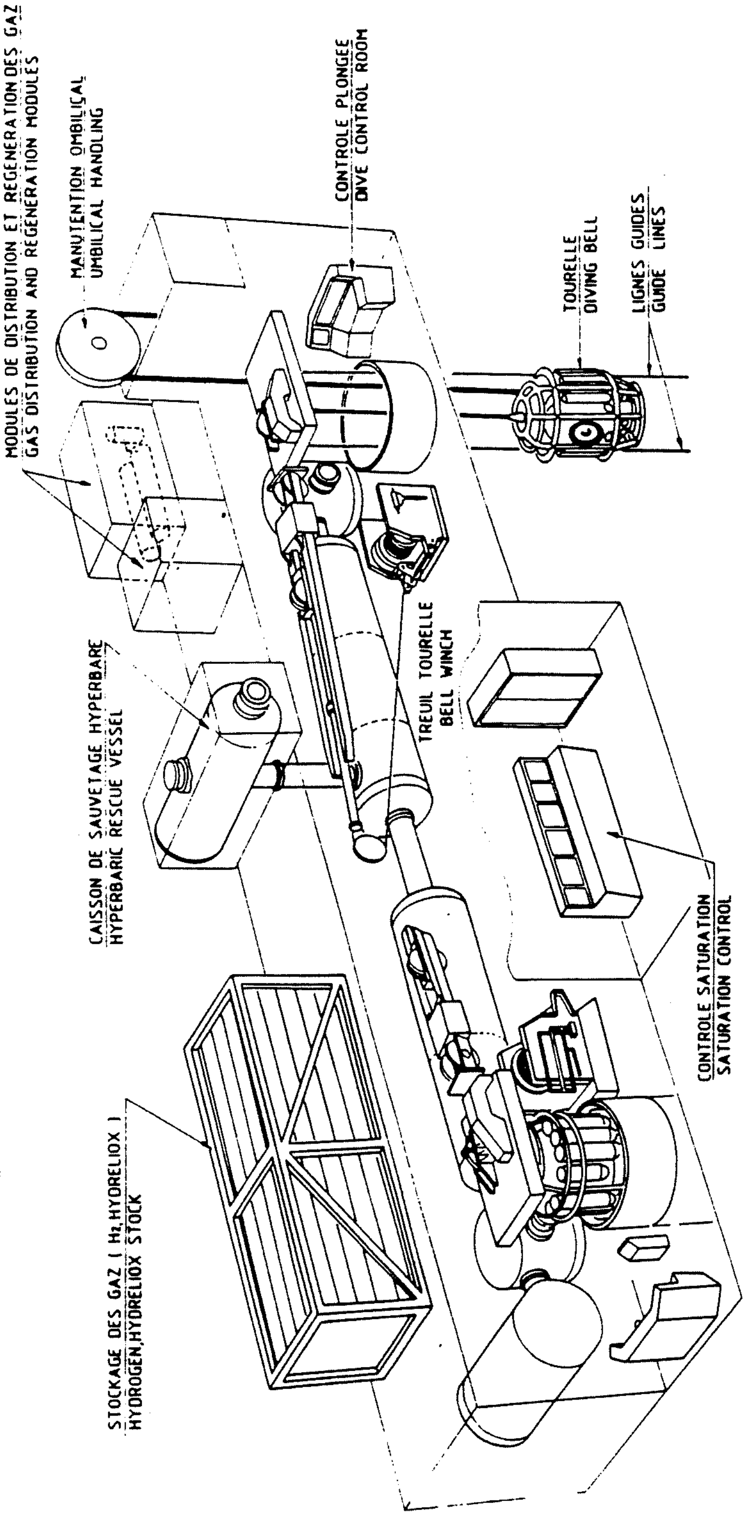


Figure 7-1

HYDRA VIII - CONFIGURATION DU SYSTEME PLONGEE

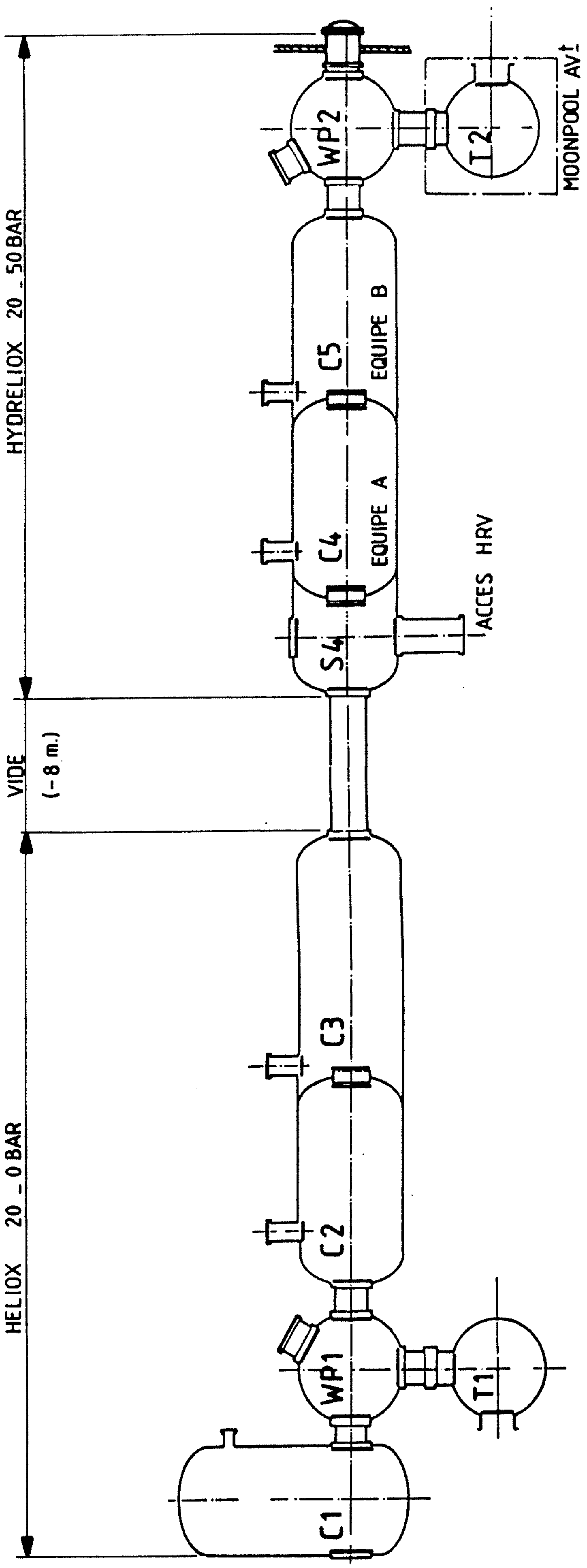
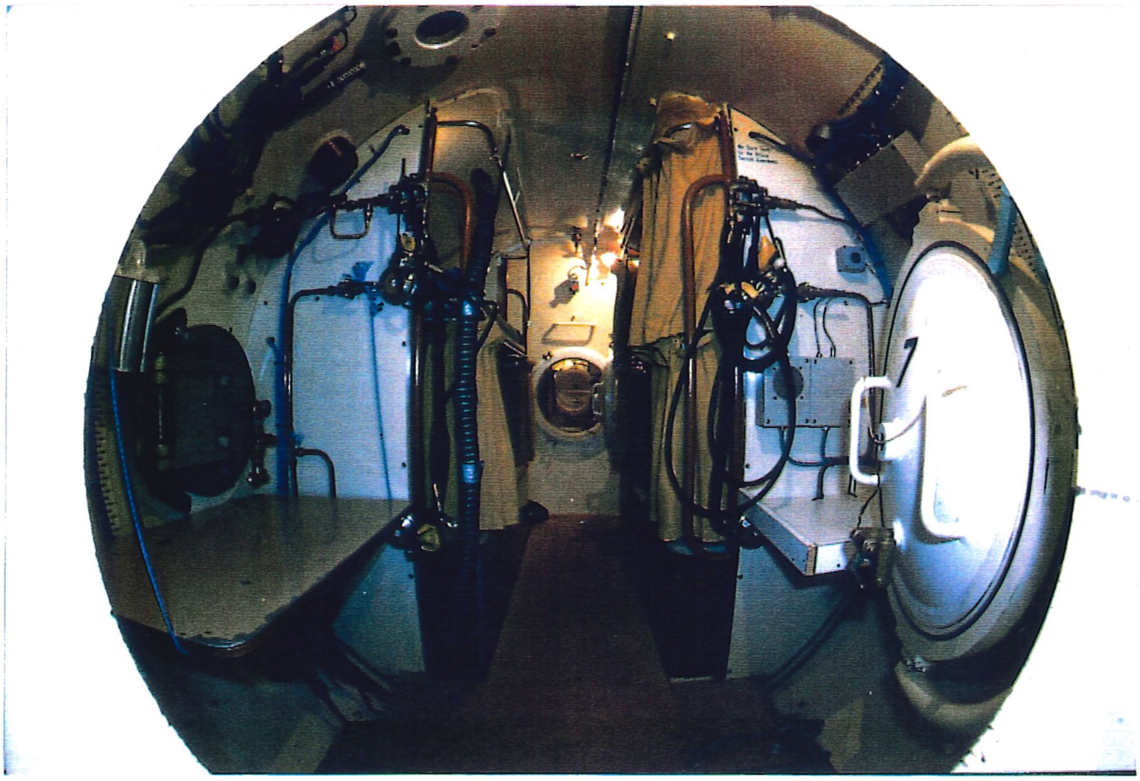
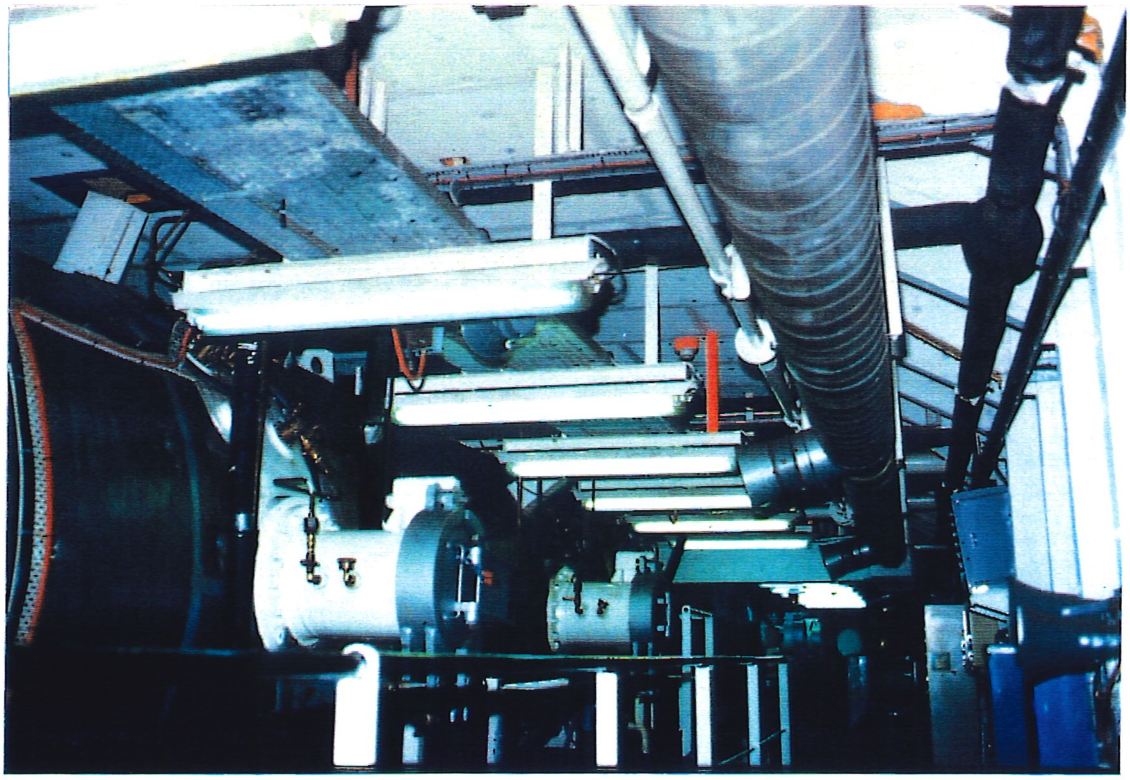


Figure 7-2



Caissons de saturation : intérieur
Diving chambers : interior



Caissons de saturation : extérieur
Diving chambers : extérior

1.2 TRANSFER LOCKS - UTILIZATION

Three locks were used for the transfer of equipment and food :

* a 600 mm lock, clamped on WP 2.

  A special air cabinet is provided to give easy access to this lock. In normal conditions all transfers were performed with this lock.

* two 400 mm locks, clamped on chambers 4 and 5. Their operation required to enter the inerted area. They were restricted to the rescue procedures (failure of the protection system of the main lock and/or different life levels in chambers 5 and 4).

The transfer locks utilization procedure differed from the lock access procedures used in heliox saturations. The lock compression after loading could not be performed directly with the bottom mix. The air oxygen would have composed an explosive mix with hydreliox. Compression was done with heliox 99/1.

The lock opening after decompression and the return to life level required two nitrogen flushings to reduce the hydrogen concentration to the safety level.

Lock operation parameters :

Action	**Lock pressure** (abs. bar)	**Gas concentration** H_2	He	O_2	N_2 (%)
Surface dep.	1.0	0	0	21.0	79.0
Reaching level					
250 meters	26.0	0	95	1.8	3.0
500 meters	51.0	0	97	1.4	1.6
Return	51.0	47	50	1.0	1.8
Decompression	1.0	47	50	1.0	1.8
Flushing					
Nitrogen compression	16.0	2.9	3.1	0.1	93.9
Decompression	1.0	2.9	3.1	0.1	93.9
Nitrogen compression	16.0	0.2	0.2	0.0	99.6
Decompression	1.0	0.2	0.2	0.0	99.6
Opening					

1.3 GAS DISTRIBUTION TO THE CHAMBERS

The existing installation, designed for heliox operations, was completed by the purpose built hydrogen gas system. Gas distribution panels were set on the open deck, in agreement with the system adaptation principles. Pneumatic lines made of copper pipe with welded couplings connected the panels to the chambers.

Function	Number	Working pressure
a. Pressurization	3	172 bar
b. Decompression	3	50 bar
c. Pressure gauge	3	50 bar
d. Breathing masks	3	65 bar
e. Analysis sampling	4	1.5 bar

In order to reduce the risk of chambers gas leak in case of pipe failure, all lines were fitted with protections :

non return valves	: lines a, d
flow restrictors	: lines c, e
remote controlled valves	: b

Heliox pressurization of the chambers only was operated from the existing lines. This function was used in the first compression phase and in case of alarm (gas leak). The hydrogened gas supply network being disactivated, the chamber pressurization with the stand-by mix (heliox) was operated from the existing line.

The operation of the gas distribution standard panels, set on the deck, was completed by devices remotely controlled from the saturation control room.

DISTRIBUTION ET CONTROLE DES GAZ HYDROGENES
CONTROL AND DISTRIBUTION H_2 CONTAINNING GAS

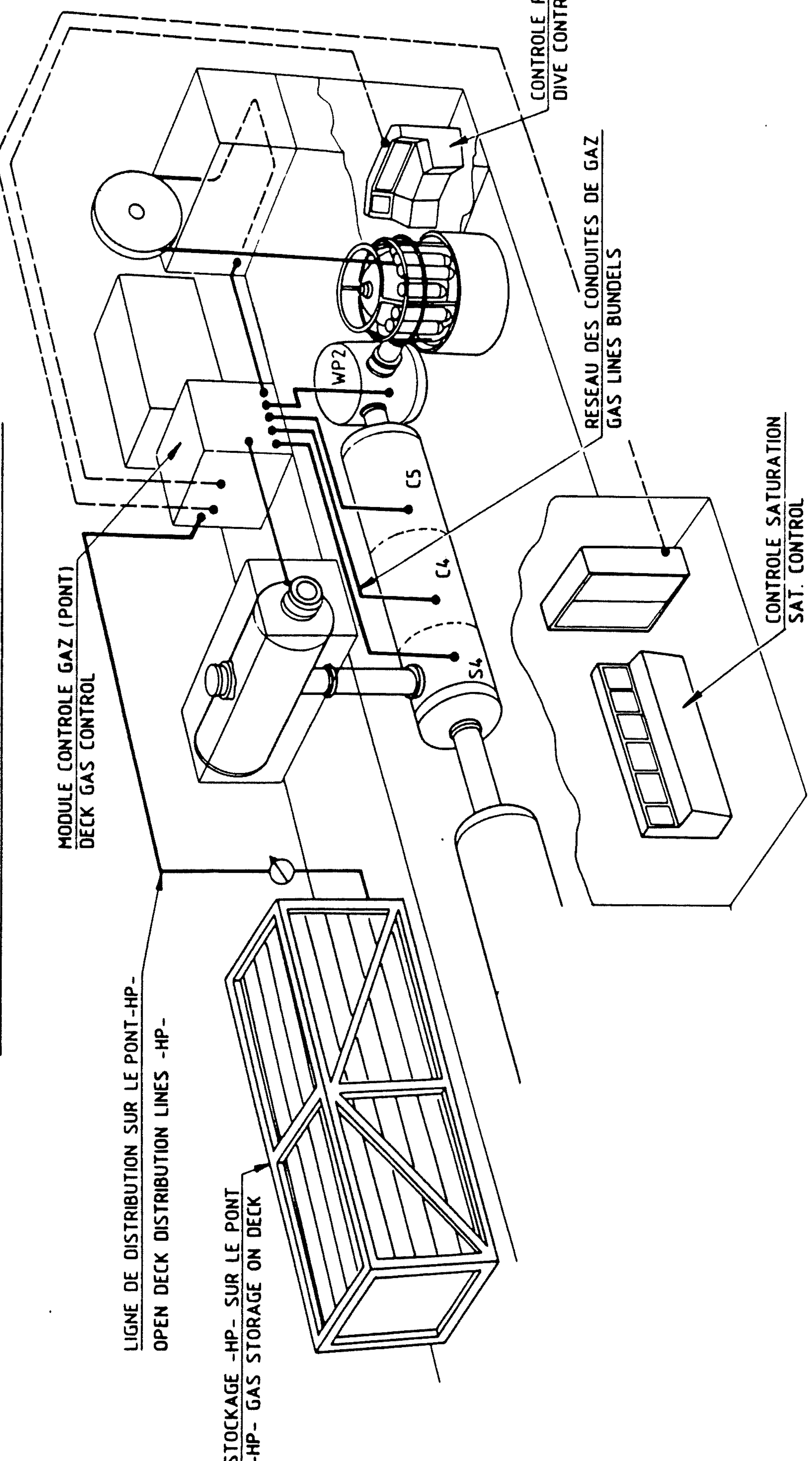


Figure 7-3

1.4 GAS REGENERATION SYSTEM

The gas regeneration system existing was replaced by a specific regeneration unit, with the following functions :

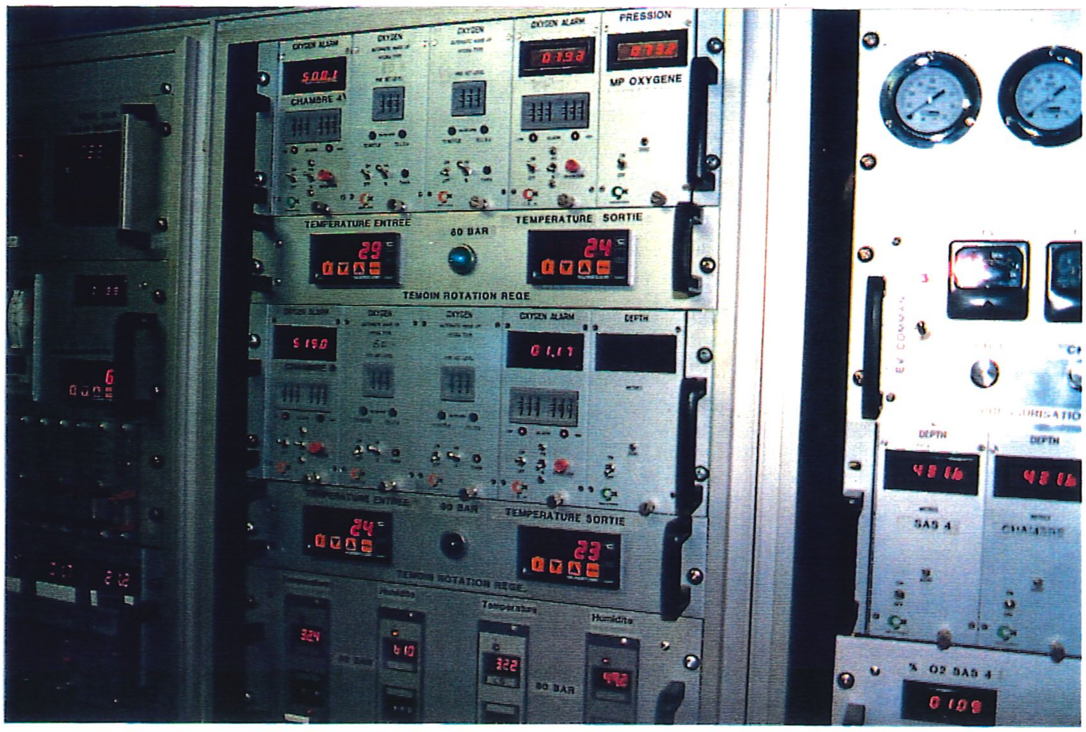
- carbon dioxide elimination
- hydrocarbon substances elimination
- hygrometric regulation
- thermic regulation
- oxygen regulation either in constant partial pressure or in constant ratio.

Two independent regeneration systems, HYDRA type, were installed in the module on the open deck. Each unit alone had the capacity of controlling the atmosphere in all the chambers in use. The second unit was used as a stand-by relay. The chambers could be maintained at different depths by the simultaneous use of the two units.

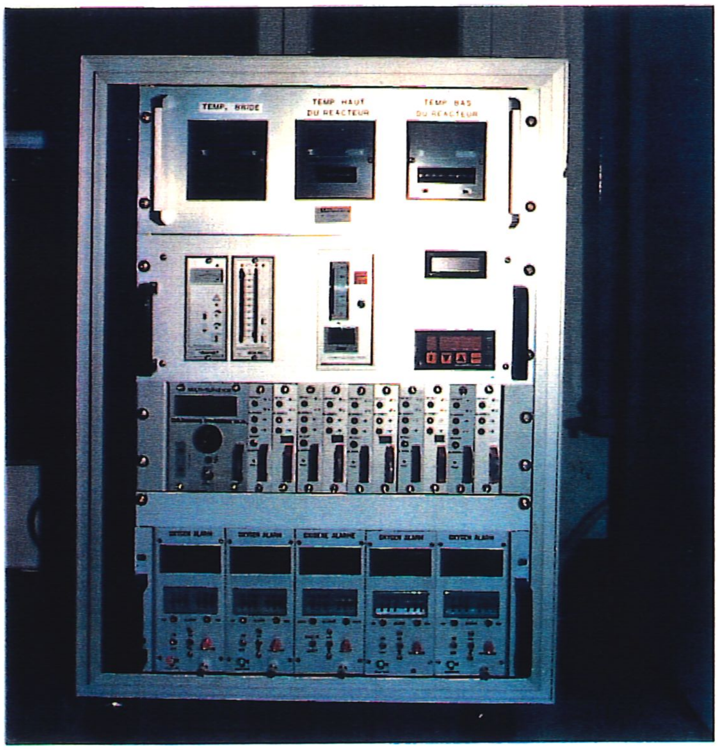
The catalytic oxidation dehydrogenator was part of the regeneration unit. Used to selectively remove hydrogen during the first decompression phase.

Stand-by system : The vital functions of the chambers parameters control could be completed by the stand-by equipment set inside the saturation chambers. This equipment is as follows :

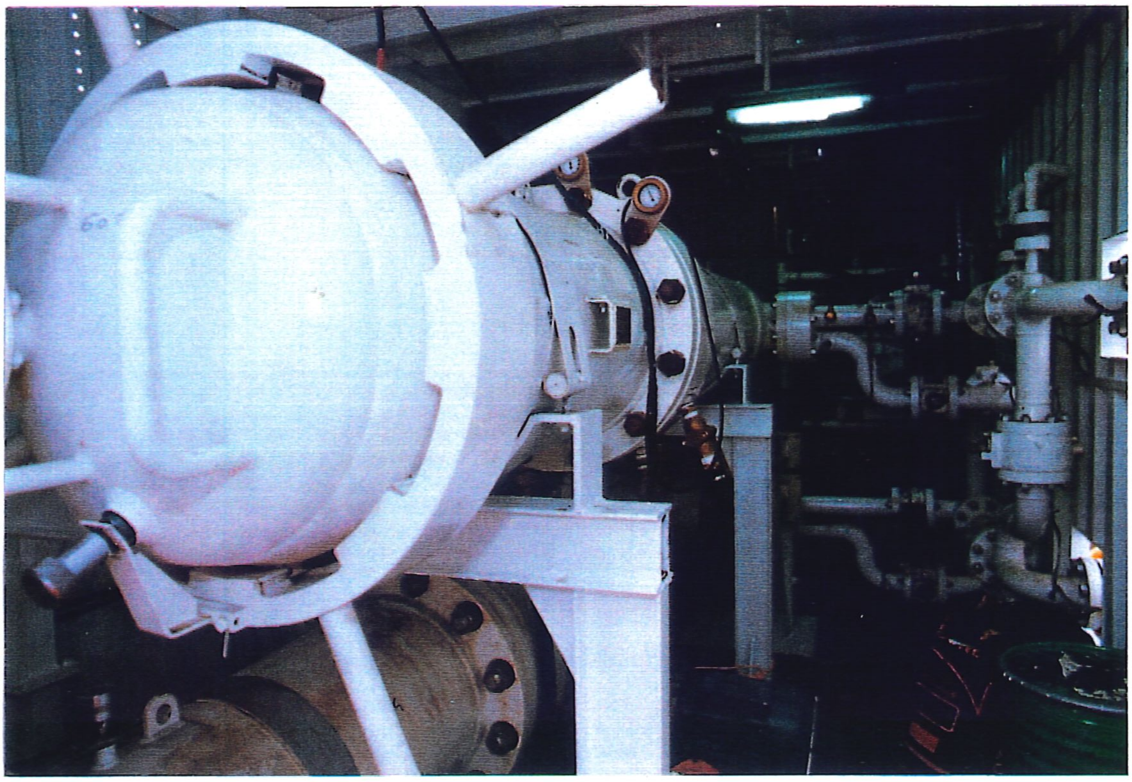
- eating with radiators
- carbon dioxide removal



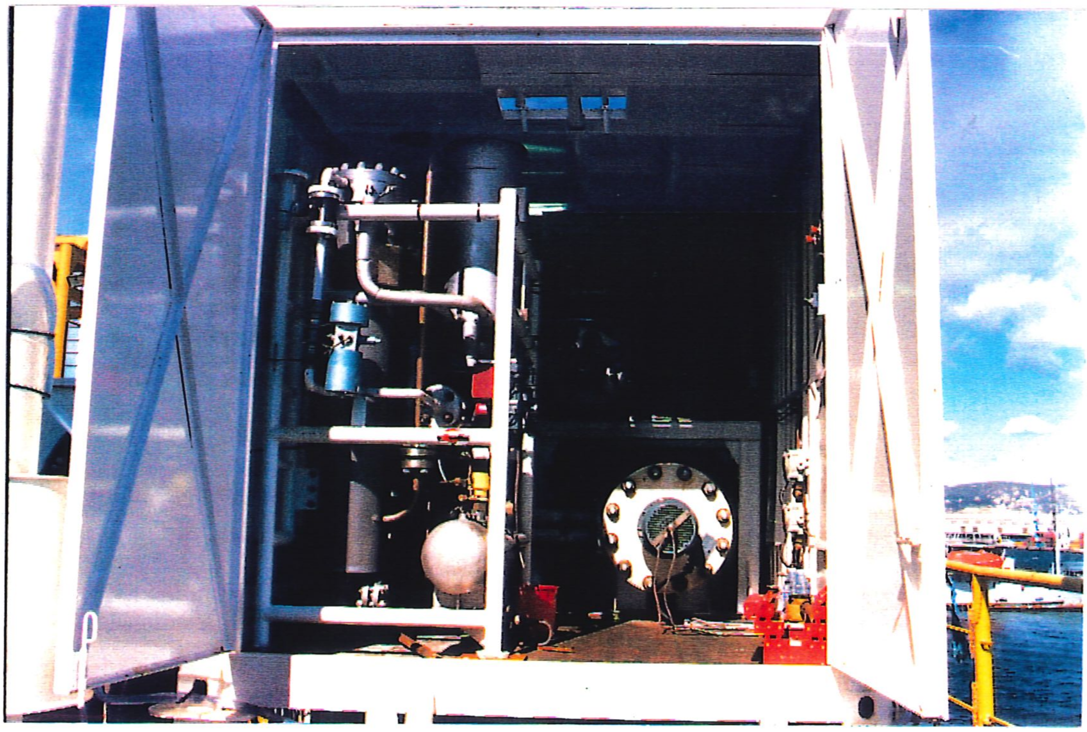
Contrôle des unités de régénération
Regeneration control cabinet



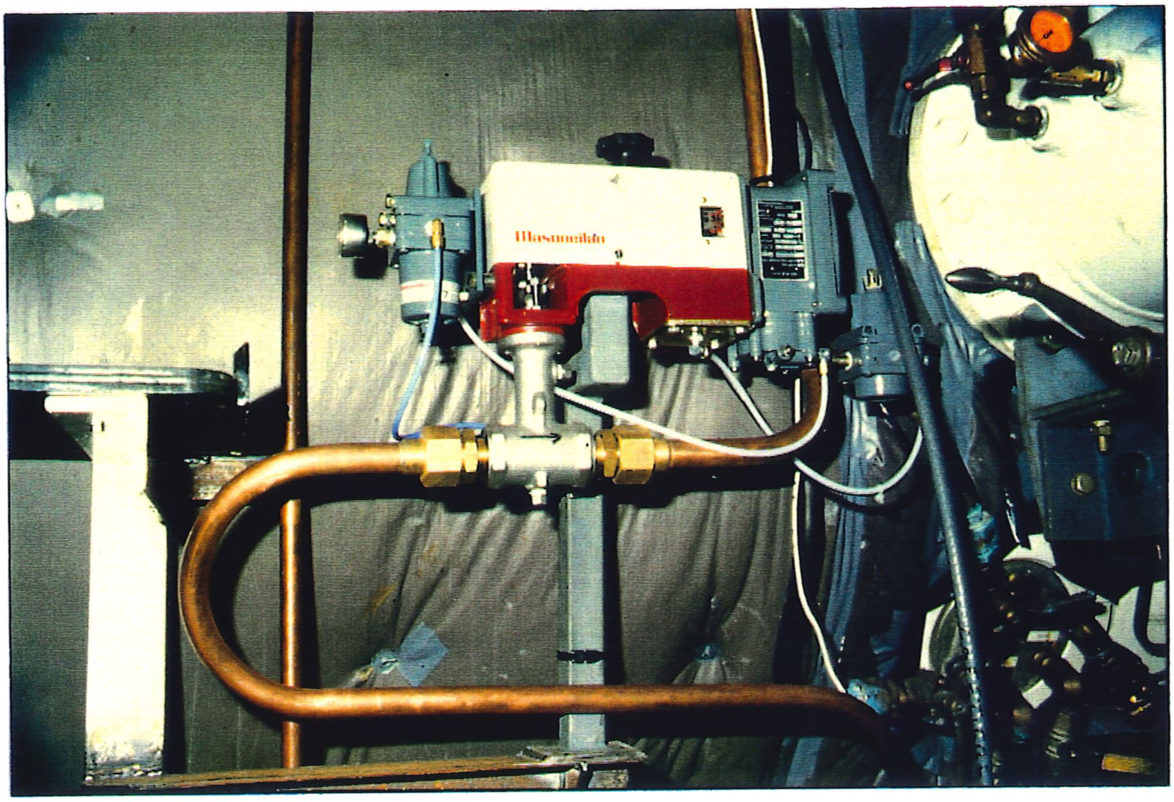
Contrôles des déshydrogénateurs
Catalytic decompression unit controls



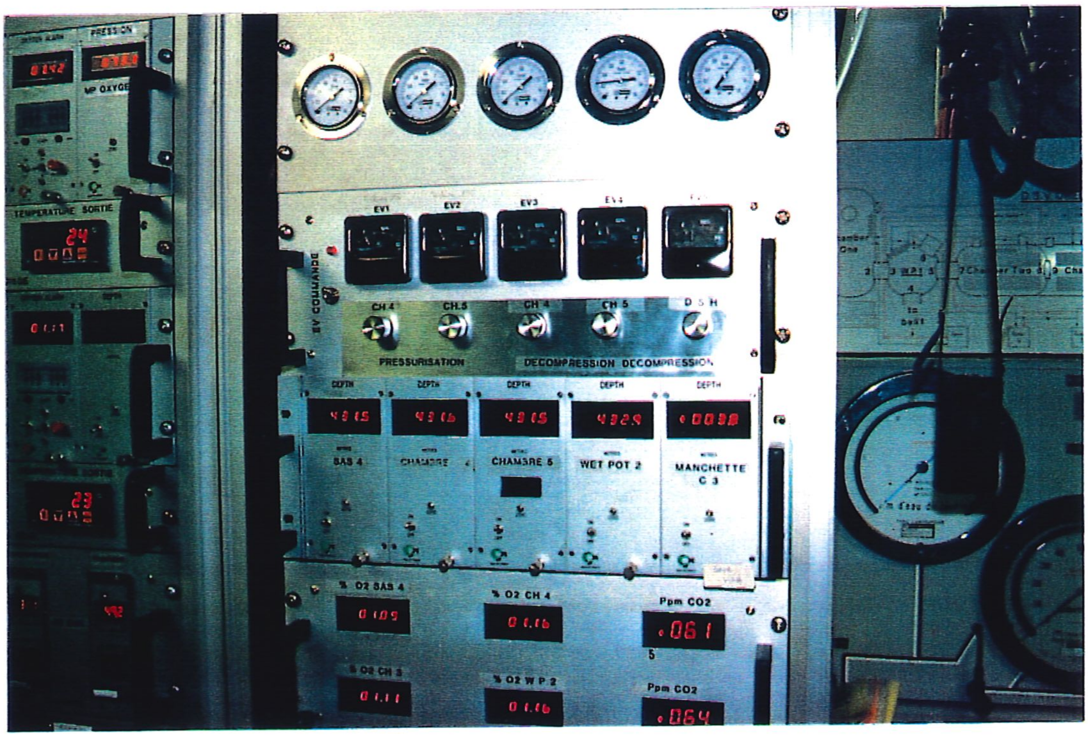
Module régénération - HYDRA
Regeneration units (ECU's)



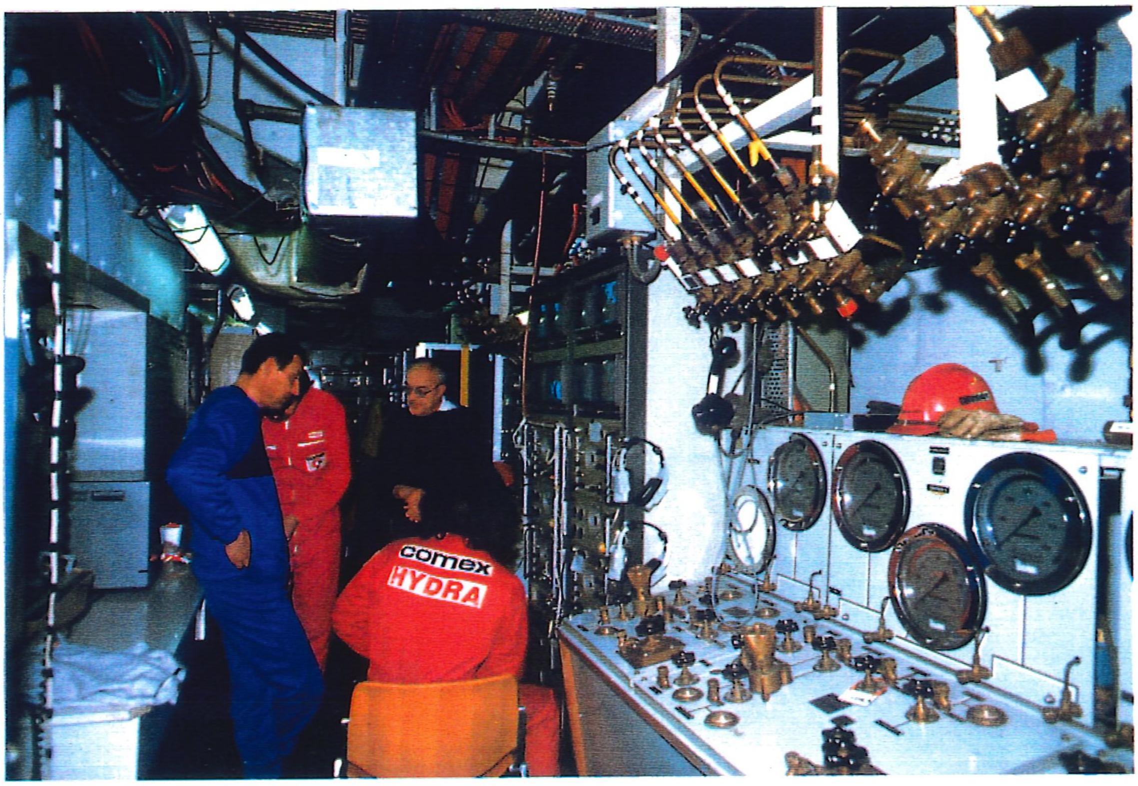
Déshydrogénation
Catalytic decompression unit

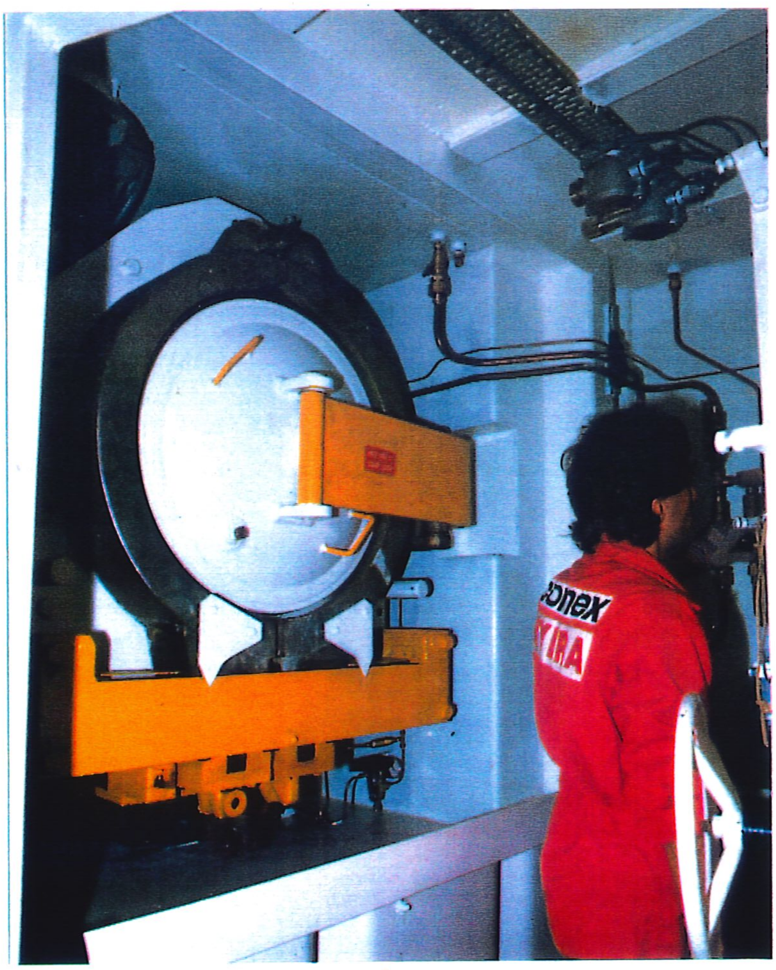


Vanne télécommandée - Zone inertée
Remotely controlled valve - Inerted space



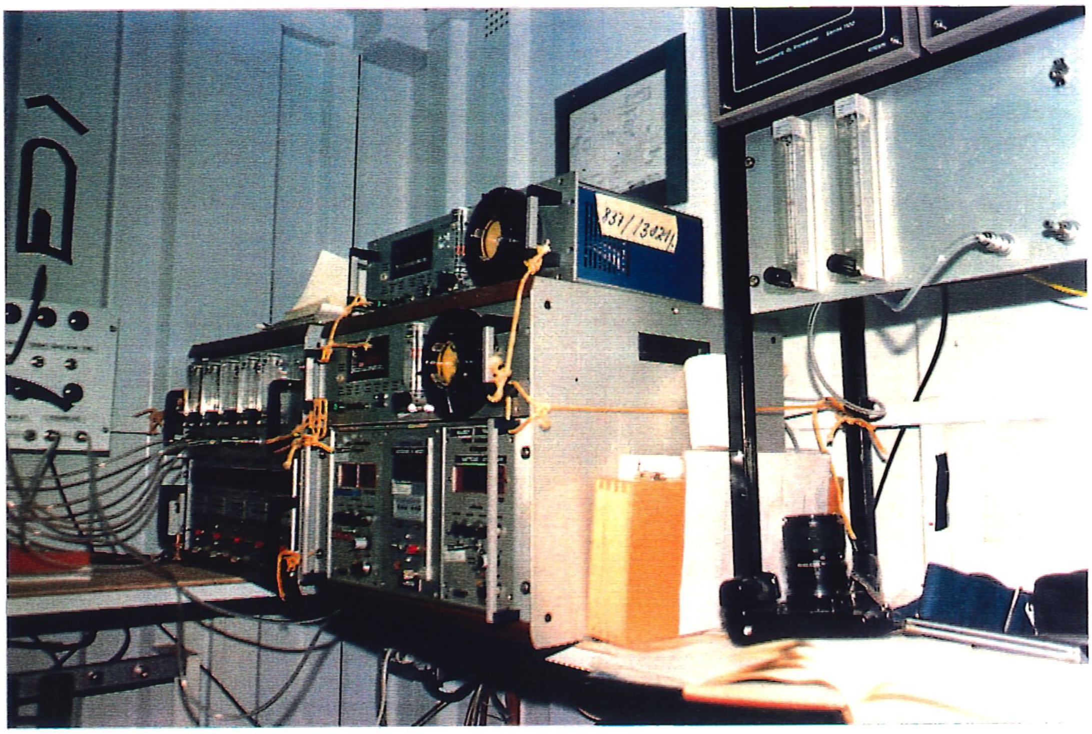
Armoire de télécommande - Contrôle saturation
Remote controls cabinet

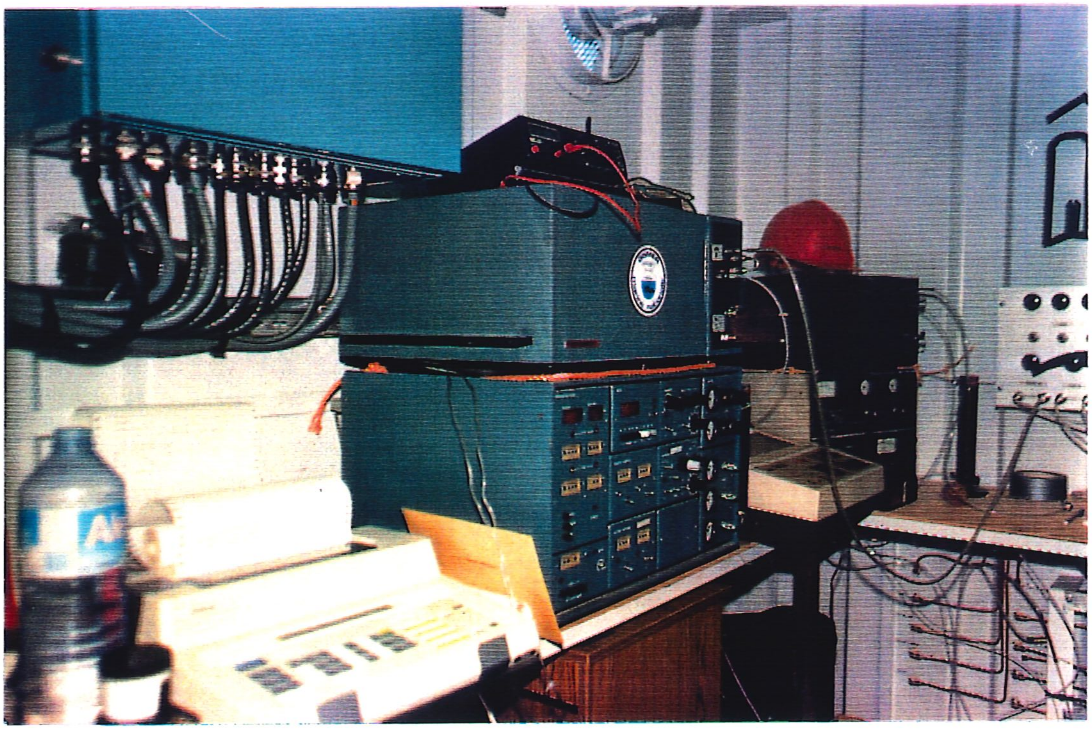




Salle de contrôle saturation
Saturation control room

Sas médical (600 mm)
Pressure lock (600 mm)





Laboratoire d'analyse des gaz - Instrumentation
Gaz analysis laboratory - Instrumentation

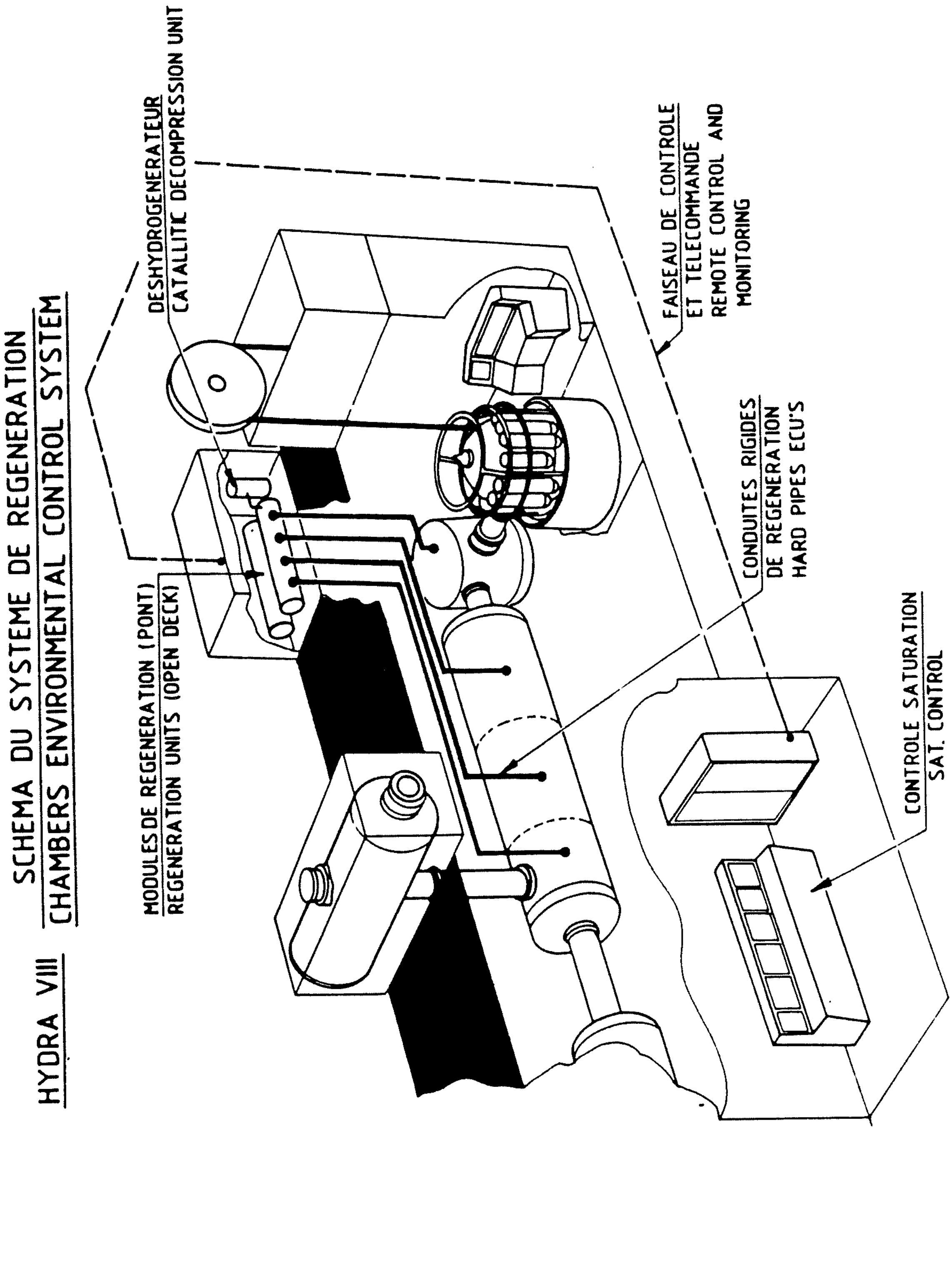

HYDRA VIII
SCHEMA DU SYSTEME DE REGENERATION
CHAMBERS ENVIRONMENTAL CONTROL SYSTEM
MODULES DE REGENERATION (PONT)
REGENERATION UNITS (OPEN DECK)
DESHYDROGENERATEUR
CATALLITIC DECOMPRESSION UNIT
FAISEAU DE CONTROLE
ET TELECOMMANDE
REMOTE CONTROL AND
MONITORING
CONDUITES RIGIDES
DE REGENERATION
HARD PIPES ECU'S
CONTROLE SATURATION
SAT. CONTROL

Figure 7-4

1.6 SATURATION CONTROL

The saturation chambers system operation remained under the control of the technicians acting from the saturation control room located under the system. The operators disposed of the following instrumentation :

1.6.1 Chambers parameters :

- oxygen rate and partial pressure
- helium rate
- hydrogen rate
- nitrogen rate
- carbon dioxide rate
- carbon monoxide rate
- relative humidity rate
- ambient temperature
- pressure - msw depth

Measures of the parameters hereunder were taken with local sensors :

- temperature
- relative humidity
- oxygen partial pressure
- pressure

and with specific analysers for the other parameters :

- infra-red consumption analyser for carbon mono- and dioxide
- chromatographs in gaseous phase for helium, hydrogen and nitrogen
- paramagnetism analyser for oxygen

The analysers were set in the analysis laboratory on the deck.

1.6.2 Process parameters and controls

Regeneration :

- in-out temperature of the gas processed
- gas temperature at the oxygen injection point
- oxygen partial pressure at the injection point
- turbine rotating speed
- engine torque

Dehydrogenation :

- process temperatures (4 points)
- processed gas flow
- condensation level
- gas flow regulation = decompression speed
- feed back opening warning

1.6.3 Remote control of the pneumatic functions

- decompression progressive valves
- compression progressive valves
- masks supply opening valves

1.6.4 Phonic communications

- chambers
- dive control
- analysis laboratory
- bridge
- "medical" lock room
- chambers inerted compartment
- regeneration unit
- gas supply unit

1.6.5 Visual monitoring

- chambers interior
- chambers inerted space

1.7 HYPERBARIC RESCUE VESSEL

The hyperbaric rescue vessel is designed for the saturated divers evacuation in case of abandon of the vessel. During this operation, the HRV was heliox pressurized for a depth of 250 meters. Pressure had to be adjusted by the injection of rich hydreliox to the life chambers depth.

2 - DIVING BELL

A bell of the ORELIA was equipped for the operation. The following modifications were carried out :

- improvement of the monitoring system
- integration of the diving parameters monitoring system
- integration of the individual equipment
- suppression of the manual oxygen addition system
- umbilical replacement

Diving bell general specifications :

- volume	:	6.5 m^3
- diameter	:	2300 mm
- working pressure	:	50 bar inside
- manufacturer	:	COMEX INDUSTRIES

2.1 DIVING BELL HANDLING

The bell handling system was used after fixing cables long enough for diving to 510 meters and specific relevant tests. This systems includes :

- a lifting hydraulic winch
- a swell compensator (passive)
- two pneumatic winches at constant tension - guide lines
- a bell horizontal translation trolley in the moonpool.

2.2 BELL UMBILICAL

The hydrogened gas transfer commanded the use of a specific umbilical and the handling and storage system replacement.

A semi-integrated assembly allowed the dispersion of hydrogen micro-leaks through the umbilical pneumatic components walls. The storage and handling systems for this umbilical were set on the open deck. The use of an umbiliblock system and umbilical storage in a basket, constraint free, avoided the problems connected to the construction of a mixt swivel coupling (gas, water, electricity) and increased the components operational reliability.

* **Umbilical functions** :

Electrical functions

- electric supply for exterior lighting
- interior electric supply
- monitoring electric supply
- telephone communications
- bell monitoring
- observation TV

Pneumatic functions

- bell pressurization
- divers' breathing supply
- hot water - heating supply (divers and bell)
- bell gas analysis sampling

2.3 DIVING PARAMETERS MONITORING SYSTEM

(See drawing 7.4)

Processing, transmission and acquisition of the diving parameters provided by the different sensors were performed by a telemeter based on the use of two microcomputers, linked with a RS422 protocol. The application software on the IBM AT (14) microcomputer ensured the whole set of control, recording and parameters display functions. The updating rate of information on the screen and relevant recording varied according to the parameters types, between 0.5 to 5 Hz. Dive intermediate reports (figure 7.5) and the parameters evolution curves could be printed in real time (15). The bottom electronics was placed in a tight chamber (1 bar) outside the bell (10). The equipment exposed to a hydrogen and helium atmosphere was restricted to the sensors and distribution casing (5).

DIVING BELL MONITORING

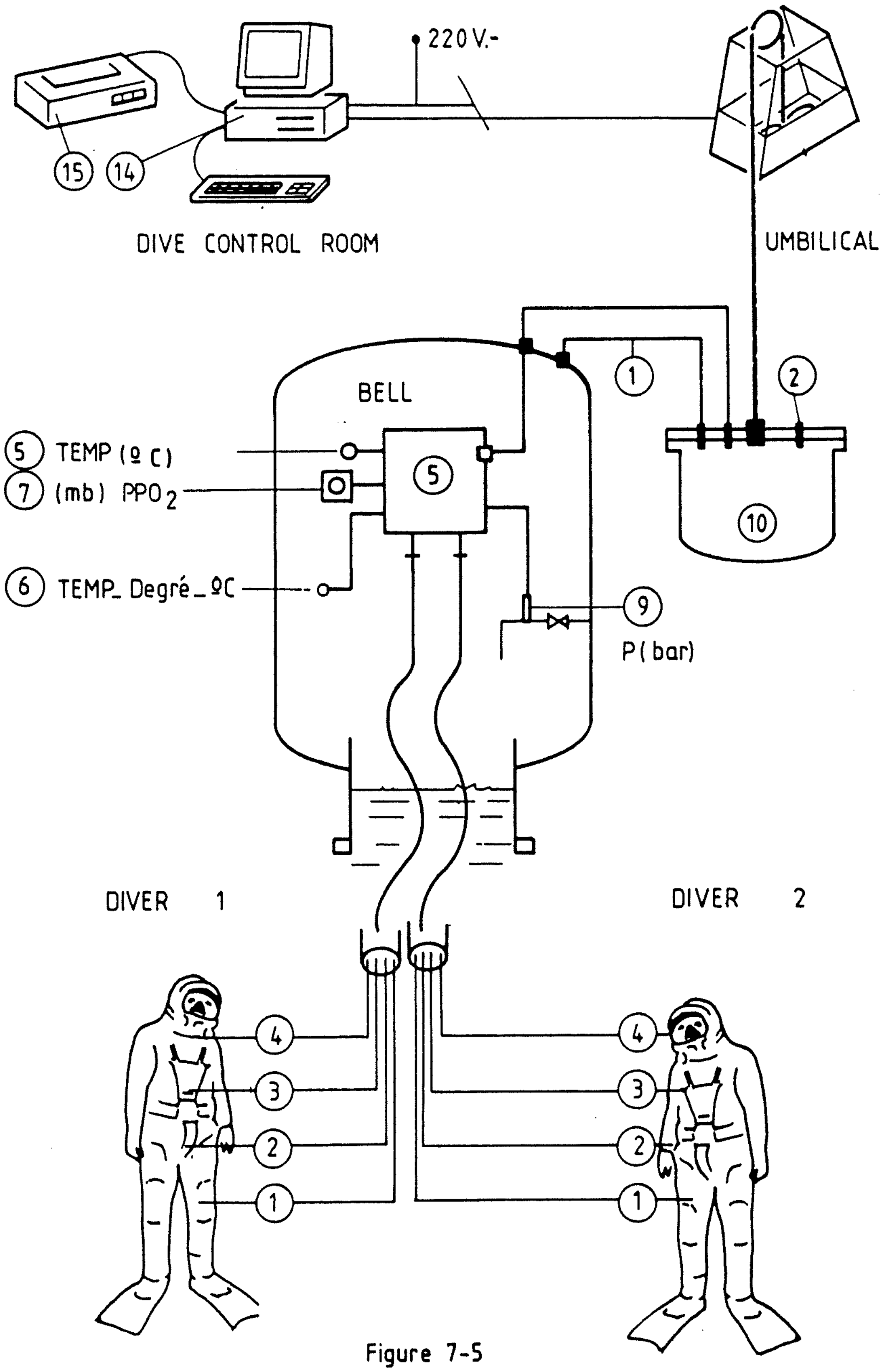
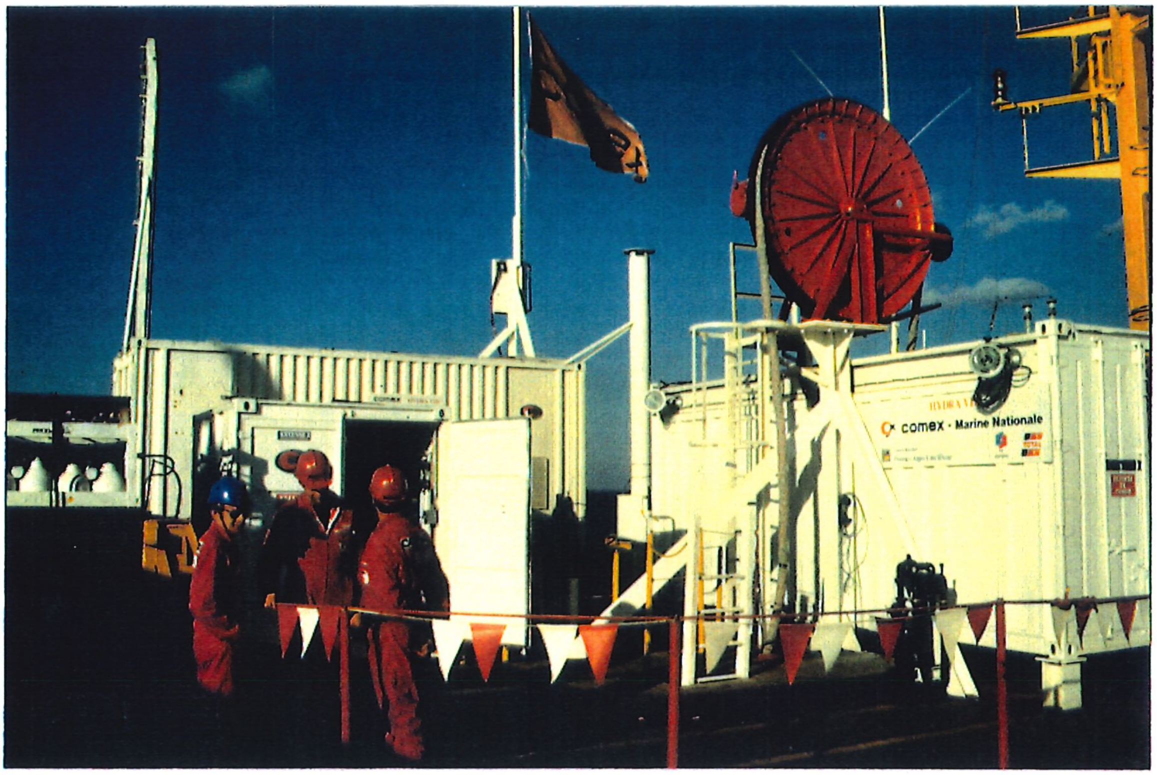


Figure 7-5

Salle de contrôle plongée - Descente de la tourelle
Dive control - Bell run down

Salle de contrôle plongée - Monitoring tourelle
Dive control room - Bell monitoring



Ombilical tourelle - Stokage et manutention sur le pont
Bell's umbilical : storage basket & handling sheave on deck

Moonpool - Descente tourelle
Moonpool - Bell run down

2.3.1 Bell parameters - re. figure 7.4

Designation	Scale	Precision	Mark
Interior depth	0-600m	0.6 m	12
Interior temperature	0-80°C	1°C	8
Hot water temperature	0-80°C	1°C	6
O_2 partial pressure	0-1500 mbar	1 bar	7
Gas supply pressure	0-135 bar	1 bar	9

2.3.2 (Two) divers parameters - re. figure 7.4

Designation	Scale	Precision	Mark
Relative depth	+/- 35 m	0.1 m	1
Hot water temperature	0-80°C	1°C	2
Central temperature	20-40°C	0.1°C	3
Inhaled gas temperature	0-50°C	0.1°C	4

DIVING REPORT

Bell run number : 25
Bell run time : 5:41:44

Time : 15:15: 4 Date : 3 mar 88

Alarms :

DOWN
Bell run start time : 9:33:20
Bell opened : 11:16:34

UP
Bell sealed :
Bell clamped :

DIVERS IN WATER TIME

Diver 1		Diver 2	
time in	time out	time in	time out
12:25: 0	14:50:23	12:47:44	14:52:50
14:52:50	14:53:49	14:53:49	

	Diver 1	Diver 2
Total time out :	2:26:22	2:26:21
Maximal depth :	6 m	7 m
Minimal depth :	-1 m	-7 m

Figure 7.6

2.4 DIVING BELL OXYGEN

For safety reasons, the bell atmosphere re-oxygenation was hard to achieve on the sea bed. The manual adding system had been disactivated. The oxygen level increase in the ambient gas, performed before each dive, ensured the bell autonomy. The lower limit of the oxygen partial pressure, leading to the dive interruption and the bell ascent, was fixed at 615 mbar. This oxygen quantity ensured a 30 hour breathing autonomy for the 3 bell occupants.

The atmosphere re-oxygenation operation was performed with an automatic adding system identical to the one applying for the regeneration units. The example of evolution of the oxygen partial pressure during a dive is illustrated in figure 3.7 in section 2. Reoxygenation operation characteristics were as follows :

- "injection" operation time	:	90 minutes
- O_2 partial pressure at start	:	400 mbar
- injected oxygen volume	:	3.5 Nm^3 average
- O_2 partial pressure upper limit	:	950 mbar

2.5 DIVE CONTROL

Every diving operation was monitored from the "Dive Control" room located in the compartment next to the moonpool. The diving superintendent and assistant disposed of the following :

- diving parameters monitoring (2.3)

- observation television screens
  - bell interior camera
  - bell exterior camera
  - diver helmet camera
  - ROV cameras
  - transfer lock camera

- phonic communications with
  - bell (three independent systems)
  - divers
  - saturation control
  - ROV pilots
  - bridge
  - bell supply gas distribution panel

- bell electric functions controls
- bell winch controls

- pressure and control of the chamber-bell transfer lock

3 - GAS RESERVES AND DISTRIBUTION

3.1 HYDRELIOX 1 % - BOTTOM BREATHING MIX

Composition : Hydrogen 47 %
Helium 52 %
Oxygen 1 %

Use : Divers gas supply for breathing system
Chambers pressure control

Reserve : Hydreliox 1 % was fabricated onboard, with heliox 2 % and pure hydrogen. The quantities needed to the performance of each dive were prepared and stored on the deck in pressurized racks (172 bar).

3.2 HELIOX 1 % BOTTOM MIX

Composition : Helium 99 %
Oxygen 1 %

Use : Chambers pressurization 0 - 250 meters
Locks operations
Associated equipment pressurization
Stand-by pressurization of the whole sat system

Reserve : Helium 1 % was stored in existing built-in tanks, set under the deck. Total volume of heliox shipped : 8500 m^3.

3.3 HYDRELIOX 2 % - RICH IN OXYGEN

Composition : Hydrogen 47 %
Helium 51 %
Oxygen 2 %

Use : Therapeutic mix
Bell stand-by storage
Chambers emergency breathing mix
HRV pressurization (final)

Reserve : This mix rich in oxygen was supplied ready for use by PRODAIR. Constituted a 1600 m3 reserve kept in four racks stored on the deck in the hydrogened gas storage zone.

3.4 PURE HYDROGEN

Composition : Hydrogen 99.9 %

Use : Chambers pressurization
Chambers pressure control at life level
Fabrication of hydreliox 1 % mix onboard

Reserve : Pure hydrogen was kept in adequate tanks set on the deck. Total volume of hydrogen shipped : 5600 Nm^3, storage pressure : 172 bar.

3.5 THERAPEUTIC MIX - HELIOX

Composition : Helium QS
Oxygen from 4% to 50%

Use : Therapeutic treatments

Reserve : Existing built-in tanks onboard allowed to prepare and store therapeutic mixes whose composition changed during the saturation. Heliox 1% and 2% reserves constituted the basis of these mixes.

3.6 PURE OXYGEN

Composition : Oxygen 99 %

Use : Compensation of the divers' metabolic consumption in the chambers and bell
Catalytic oxidation
Treatments

Reserve : Pure oxygen bottles racks were shipped on the deck in agreement with the safety standard procedures. Total volume of oxygen available onboard : 1600 Nm^3.

3.7 COMPRESSED NITROGEN

Composition : Nitrogen 99.9 %

Use : Space and pipes inerting
Space and pipes flushing

Reserve : Composed of 20 bottles shipped in racks on the deck. This reserve of 1800 Nm^3 could be used as a nitrogen extra source for the chambers compartment inerting.

3.8 GAS COMPRESSION AND MIX UNITS

Helium mixes storage, transfer and distribution were ensured by built-in systems. A specific system was mobilized for the operation of gases containing hydrogen. This system included :

- hydrogened gas tanks set on the deck in the delimited and protected zone (Hazardous zone 2)

- gas distribution network comprising high and average pressure lines, valves, pressure reducers and measure instruments.

- safety devices : shut-off valves, remote controls, etc..

- Two gas compression and mixing units set on the deck in the storage zone, including :

  . a CORBLIN A2C 250 membrane compressor
  . a CORBLIN A4C 250 membrane compressor
  . Two mix panels

Stockage et modules de compression des gaz hydrogénés sur le pont
Hydrogen containing gaz storage and compressor station on deck

4 - INDIVIDUAL EQUIPMENT

4.1 BREATHING MAIN APPARATUS

T-82 pressure reducer-overflow integrated to the COMEX PRO HYDRALITE rigid helmet was used. Hydrogened gas regeneration devices being not available within the project, the apparatus was used in open circuit.

4.2 STAND BY BREATHING APPARATUS

The stand-by system based on the principle of semi-closed circuit was integrated to the COMEX PRO helmet. At working depth, the divers had a 10 minute breathing autonomy in case of failure of the main system. The apparatus reserve bottles were filled with hydreliox 2.5 %.

4.3 HOT WATER SUIT

The low circulation hot water suit equipped HYDRA VIII divers. This suit, designed by COMEX PRO, reduces the need of hot water flow and, in case of supply failure, ensures a thermic autonomy sufficient to return to the bell.

4.4 COMMUNICATION

Use of a HELLE standard system of phonic communications, with voice unscrambler.

The unscrambler performances in presence of hydrogen are identical to those obtained in heliox dives.

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 8.1

TITLE : **DIVE GENERAL PROGRESS**
CLINICAL OBSERVATIONS
AUTO-OBSERVATIONS RESULTS

ORIGIN : **COMEX**
SCIENTIFIC MANAGEMENT AND MEDICAL DEPARTMENT

AUTHORS : **B. GARDETTE**
M. COMET

DATE : 1 September 1988
REVISION : 00

INDEX

1 - COMPRESSION

The six divers were compressed from 0 to 500 meters in 3 days and 22 hours, in heliox at the beginning, then in hydreliox from 250 meters. The compression outline has been modified as compared to HYDRA VI (see curve enclosed). For a close access time to 500 meters (HYDRA VI : 86 hours and HYDRA VIII : 94 hours), the stop duration at 450 meters was reduced from 38 hours to 6 hours for the benefit of a compression speed decrease between 200 and 500 meters. All the divers carried this compression perfectly well : lack of articular pains (H.P.A.S.) and no breathing discomfort. Only one case to be reported : for one diver (ARN.), from 450 meters, a congestion of the upper aerial tracts with no breathing difficulty, and mild vertigoes.

On reaching 500 meters, the subjects report a very slight "narcosis".

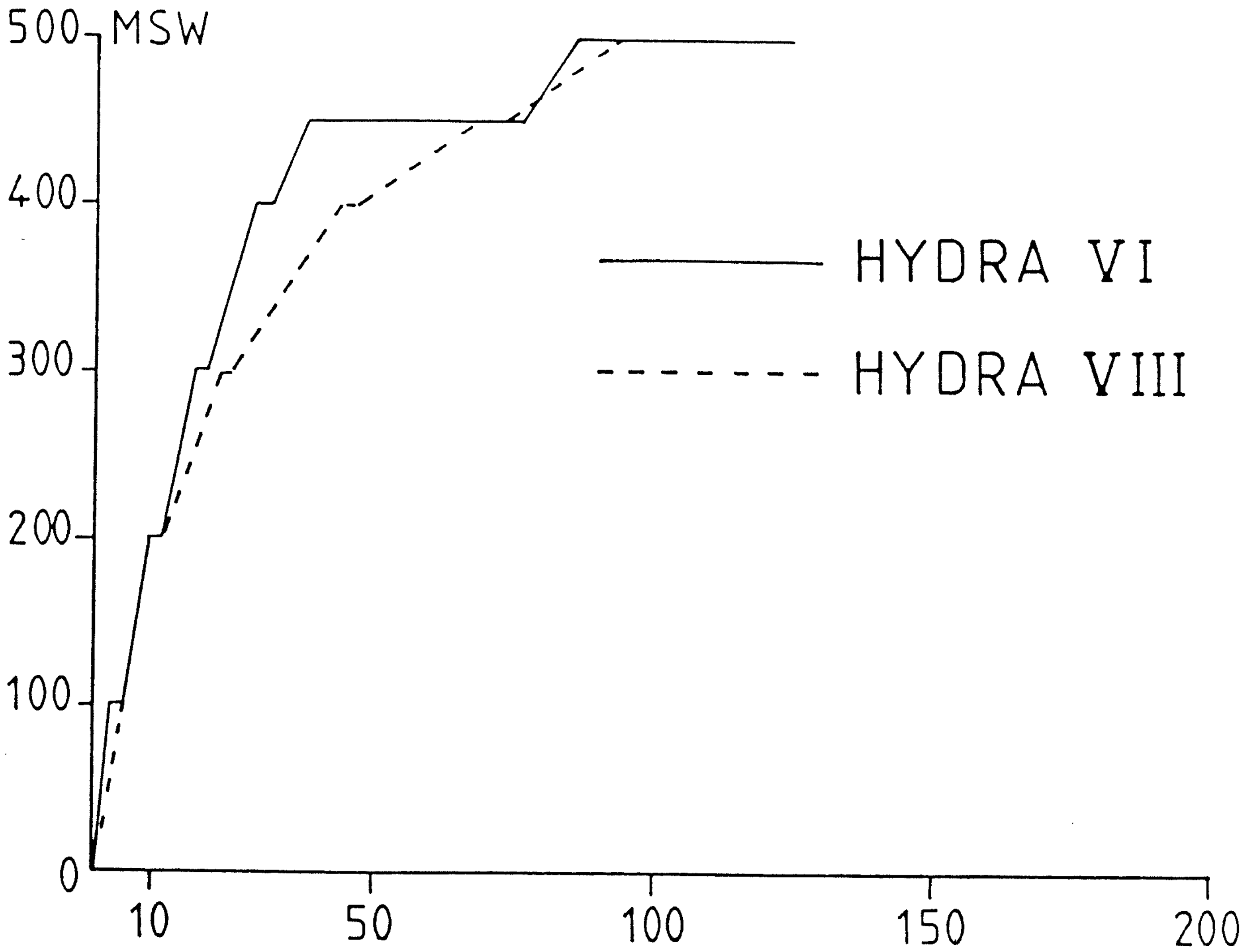
2 - STAY AT 500 METERS

The divers staid 7 days and 17 hours at 500 meters in hydreliox (H_2 = 48.7%, He = 49.3 %, N_2 = 1.2 %, O_2 = 0.8 %) with a 25 bar PH_2. During this period assigned to underwater works, all divers appreciated the wide breathing comfort of the mixture used. However, bad weather conditions, relative chambers discomfort, thermic environment regulation difficulties, added to the specific effects of pressurized gas, can explain the fatigue associated to a vigilance decline and to an emotivity increase for several divers who reported sleep disorders with dreams or nightmares.

3 - DIVES

A total of 6 dives between 520 and 534 meters were performed in hydreliox mix (H2 = 47 %, He = 52 %, O2 = 1 %) for durations exceeding 4 hours. In each dive, the divers worked together on the underwater worksite. They totalized 26 hours of active work on the bottom with a large efficiency, comparable to what is usually observed on a 150 meter worksite in heliox. During the dives, the divers were watched through permanent breathing and thermic monitoring. The parameters controlled remained normal :

- breathing rate	=	10 cycles/mn (average)
- inhaled gas temperature	=	30° C - expired = 34° C
- central temperature	=	37° C


500 MSW
400
300
200
100
0
10
50
100
150
200
HYDRA VI
HYDRA VIII

4 - DECOMPRESSION

Performed with hydrogen progressive elimination : catalytic oxidation (dehydrogenation) between 500 and 300 meters. Thus 23.8 bar H_2 were eliminated in 6 days and 22 hours (ie. 1.4 meter/hour) for a decompression speed of 1.2 meter/hour (50 min/meter). As from 300 meters, a helium decompression was carried out at the same speed. This decompression was performed perfectly well, with no incident. A few momentary articular pains only were felt at 400 meters by SCH., at 280 meters by ICA. and PEI. Some algiae of the external auditory canal also appeared for ICA., MAR. and SCH., soon relieved by therapeutics.

When leaving the chamber, after a 29 days and 2 hour saturation, the 6 divers were in good physical condition. Little slimming was noticed : average weight loss of 1.2 % (see table below).

HYDRA VIII		POIDS	P	%
RAU.	av	78		
	ap	79	+1	+1,3
SCH.	av	71		
	ap	70,5	-0,5	-0,7
MAR.	av	84		
	ap	81	-3	-3,6
ARN.	av	71		
	ap	69	-2	-2,8
PEI.	av	70		
	ap	69	-1	-1,4
ICA.	av	73		
	ap	72	-1	-1,4
		P=	**-1,1**	**-1,2%**

5 - COMMENTS

Generally speaking, this deep saturation in hydreliox mix was very well experienced by the 6 subjects. The objective, that is the operational demonstration at sea of the diver's efficiency, was reached. However, slight disorders occurring during the stay at 500 meters : fatigue, vigilance decline, emotivity, sleep troubles, although not specific to pressurized hydrogen effects (narcosis as described during HYDRA IV), must urge us to be careful beyond 500 meters.

HYDRA VIII does confirm HYDRA VI and VI results, that is the disappearance of H.P.N.S. clinical signs, the possibility of using 25 bar H_2 in a total pressure of 51 bar without any narcotic effect, and finally the need for a thorough selection of the divers most able to get acclimatized to high depths.

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 8.2

TITLE : **DIVERS' PHYSICAL CONDITION EVOLUTION BY INDIRECT MEASUREMENT OF THE OXYGEN CONSUMPTION (VO2 MAX)**

ORIGIN : **COMEX**
SCIENTIFIC MANAGEMENT AND MEDICAL DEPARTMENT

AUTHORS : **B. GARDETTE**
M. COMET

DATE : 11 September 1988
REVISION : 00

Three indirect measures of maximum VO_2 on the divers were taken with the object of estimating their physical condition after a 3 week sport physical training and a 29 day stayin the chamber. These three measures of maximum VO_2 were performed on an ergometric bicycle.

1 - before training
2 - after the 3-week training, this test being used as a reference before diving
3 - 6 days after the end of the dive

The physical training of the 6 divers and of the 2 substitutes, carried out on the basis of one morning each day for 3 weeks, that is 15 mornings, included foot-racing, volley-ball, and swimming.

Results of cardiac rates, of MAX VO_2 and related variations are collected on the following table.

We can observe :

- a VO_2 increase after training, ranging between 0 and 29 %, more especially pronounced as the subject has worse performances at the beginning

- a slight reduction of VO_2 (between + 4 % and -11 %) after the saturation

- a worse recovery after effort (FC 5 min after stopping cycling) for tests performed after the dive.

- 3 divers out of 6 could not achieve the 5 minute muscular exercise at 200 watts during the test carried out 6 days after leaving the chamber. The subjects were limited in the exercise continuation more for muscular reasons than for cardio-respiratory ones.

These results show the interest of a physical training of the divers before a deep and long intervention such as HYDRA VIII during which the divers' physical capacities are diminished, even if this decline remains limited.

DIVERS' PHYSICAL FORM EVOLUTION

		W MAX watt	Time min	FC MAX b/min	FC + min b/min	Weight kg	VO2 MAX l/min	VO2 MAX ml/min/kg	VO2 %
RAU	before training	200	5	160	84	80	4.00	50	-
	after training	200	5	152	84	78	4.20	54	8
	after HYDRA 8	200	5	160	100	79	4.00	51	-5
SCH	before training	200	5	170	112	72	3.60	50	-
	after training	200	5	163	106	71	3.80	53	6
	after HYDRA 8	200	5	164	116	71	3.80	53	0
MAR	before training	-	-	-	-	-	-	-	-
	after training	200	5	160	88	84	4.00	48	-
	after HYDRA 8	200	2.5	154	112	84	4.00	50	4
ARN	before training	200	5	166	90	74	3.70	50	-
	after training	200	5	160	82	71	4.00	56	12
	after HYDRA 8	200	3	170	108	69	3.60	52	-7
PEI	before training	200	5	155	85	70	4.10	58	-
	after training	200	5	156	78	70	4.10	58	0
	after HYDRA 8	200	3	160	104	69	4.00	58	0
ICA	before training	-	-	-	-	-	-	-	-
	after training	200	5	144	76	73	4.60	63	-
	after HYDRA 8	200	5	160	108	72	4.00	56	-11
CHO	before training	200	5	162	100	71	3.80	53	-
	after training	200	5	156	66	71	4.10	58	9
DEN	before training	150	5	180	118	73	2.50	34	-
	after training	150	5	156	80	72	3.20	44	29

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 8.3

TITLE : <u>BLOOD BIOLOGY</u>

ORIGIN : **COMEX**
SCIENTIFIC MANAGEMENT AND MEDICAL DEPARTMENT

AUTHORS : **B. GARDETTE**
M. COMET

DATE : 1 September 1988
REVISION : 00

HYDRA VII - 1988

BIOLOGIE SANGUINE	RAU.		SCH.		MAR.		ARN.		PEI.		ICA.		M		
	12/2	22/3	12/2	22/3	12/2	22/3	12/2	22/3	12/2	22/3	12/2	22/3	12/2	22/3	
Hématies x 10^4	431	472	498	502	499	476	472	475	460	514	466	476	473	485	
Leucocytes x 10^3	6.2	7.8	8.6	8.6	10.0	7.8	7.9	11.0	4.5	8.4	4.7	7.5	7.0	8.5	+21%
Plaquettes x 10^3	177	125	270	197	330	233	304	210	190	215	198	166	245	191	-22%
Polyneutro x 10^3	3.5	3.7	4.8	4.0	5.8	3.7	3.9	5.6	1.7	4.5	2.3	3.3	3.7	4.1	+11%
Lymphocytes x 10^3	2.5	3.7	3.4	4.1	4.2	3.7	3.9	4.7	2.3	3.6	2.2	3.8	3.1	3.9	+25%

HYDRA VIII OPERATION

FINAL REPORT

SECTION : 8.4

TITLE : **HYPERBARIC TREMOR STUDY**

ORIGIN : **CNRS**
HIGH PRESSURE BIOLOGY LABORATORY
FACULTE DE MEDECINE NORD

AUTHORS : **J.C. ROSTAIN**
M.C. GARDETTE-CHAUFFOUR
J. ABRAINI

DATE :
REVISION : 00

INDEX

1 - INTRODUCTION

As from 150-200 meters, deep diving in a helium-oxygen mix brings in nervous troubles grouped in a High Pressure Nervous Syndrome (H.P.N.S.) (BRAUER and al. 1969 - FRUCTUS and al. 1969 - BENNETT 1975 - ROSTAIN 1987). The H.P.N.S. is characterized on one hand by clinical troubles including mainly a fast frequency tremor, dysmetria, fasciculations and myocloniae, somnolence, and on the other hand electrophysiological disturbances marked by electroencephalographic alterations (EEG), disturbances of called forth potentials, reflexes,... Sleep disturbances must be added as well as a decline of performances (LEMAIRE and ROSTAIN 1988). Research carried out on man and animal showed that the H.P.N.S. could be reduced or increased when acting on different variables of the hyperbaric environment. For instance, a fast and continuous compression with speeds slackening as depth increases and interrupted by stops, reduces the intensity of most clinical symptoms of the H.P.N.S. (BENNETT and TOWSE 1971 - ROSTAIN and NAQUET 1974/1978 - BENNETT 1975 - FRUCTUS and al. 1976 - ROSTAIN 1987).

The gas mixture composition also affects the H.P.N.S. characteristics. For instance, introducing 5 % nitrogen in the helium-oxygen mix lessens the intensity of most of H.P.N.S. clinical troubles and enables to compress more quickly (BENNETT and al. 1974 - NAQUET and al. 1975 - ROSTAIN and al. 1980/1987a). This effect would be connected to nitrogen narcotic power and to the narcotic substance - pressure antagonism (MILLER and al., 1973 - BENNETT and al., 1975 - MILLER 1975). From this point of view, hydrogen, with its narcotic power, should also reduce some of the H.P.N.S. symptoms. Moreover, the use of hydrogen should allow to reduce the pressurized breathing mix density. Since 1983, experiments carried out on man proved that the hydrogen-helium-oxygen mix eliminated most of H.P.N.S. clinical symptoms and that it appeared as the best mix to be used in very deep diving (FRUCTUS 1987 - GARDETTE 1987 - ROSTAIN and al. 1987b/1988a). For instance, if the hyperbaric tremor recorded at 450 m. is compared to the same compression curve and to the three mixes used, the slightest intensity is recorded with the hydrogen-helium-oxygen mix with 50 to 56 % hydrogen (ROSTAIN and al. 1988a and b - LEMAIRE and ROSTAIN 1988).

According to these results, it appeared important to search for the presence and the importance of the hyperbaric tremor during HYDRA VIII dives.

2 - METHODS

Hyperbaric tremor was detected through a "minor tremor pick-up" accelerometer model MT3T (NIHON KOHDEN - 1-100 H2) fixed on the prevalent hand second finger. Analysed during the "oath test" (20 seconds), repeated three times consecutively. Signals are visualized on a polygraph (SEFRAM) and are recorded on analogue magnetic tapes (REVOX A77 through a computer FM SEVME multiplex-convertor). Pre-recorded data is analysed on a PLESSEY VIXEN (PDP 11/23+) computer to obtain the signal average amplitude, the tremor power spectrum and frequency. Results are given in difference percentage, compared with reference values.

3 - RESULTS

Surface physiological tremor varies from 10 to 20 % (see figures 1 and 2 on next pages).

During compression, hyperbaric tremor occurs significantly for three subjects : S.I., R.P. and T.A., between 275 and 400 meters. The increase recorded stands from 30 to 60 % (figures 1 and 2).

This tremor abates and disappears at 450 meters for subject S.I. Decreases but remains for subject T.A. Persists for subject R.P. The three other subjects (L.S., J.G.M.A. and P.R.) do not show any tremor significant increase.

During decompression, when measuring again at 460 meters, tremor is recorded for one subject (T.A.) The increase is of about 40 %. While hydrogen rate decreases, tremor appears for the 3 other subjects : L.S. = 40 % - R.P. = 90 % - increases for subject T.A. up to 100 % at 320 meters, whereas there is nearly no hydrogen left in the mix. Hyperbaric tremor regresses afterwards as depth diminishes.

HYDRA VIII - TREMOR

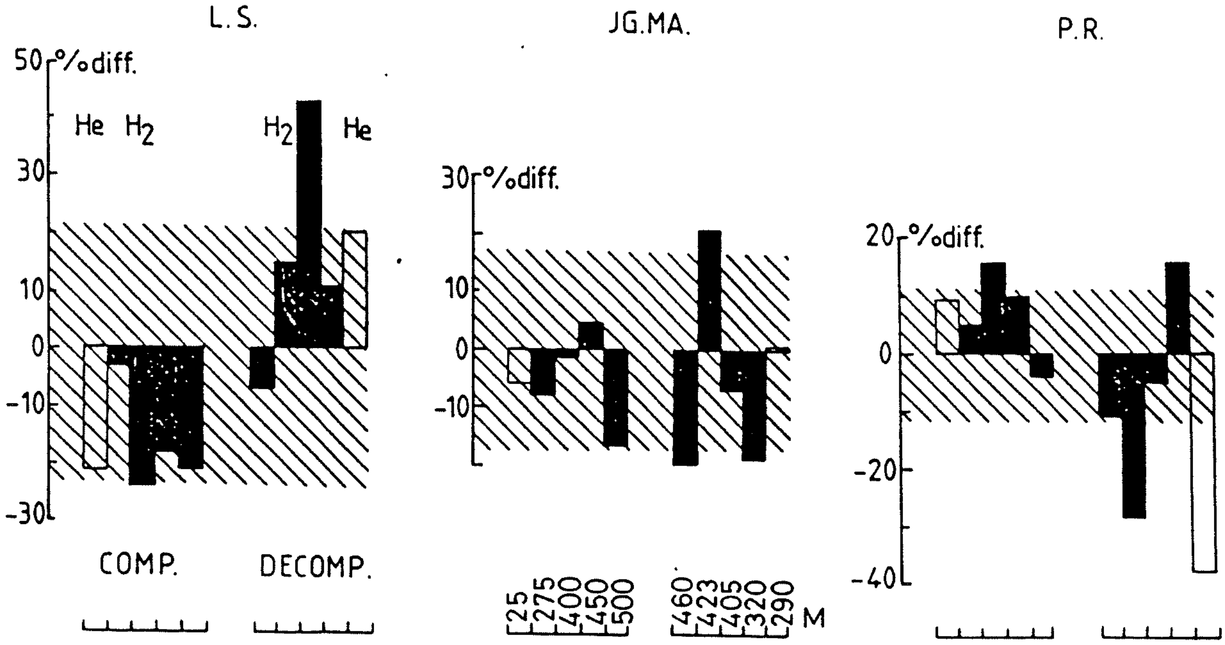


Figure 1 :

Tremor evolution at different depths during compression and decompression (Group A).

The histograms represent the difference evolution in percentage compared with the surface values (% diff.), hachured areas correspond to the surface variability.

Group A three subjects are represented from the left to the right. White histograms give the values obtained in helium-oxygen, black histograms give the values obtained in hydrogen-helium-oxygen.

HYDRA VIII - TREMOR

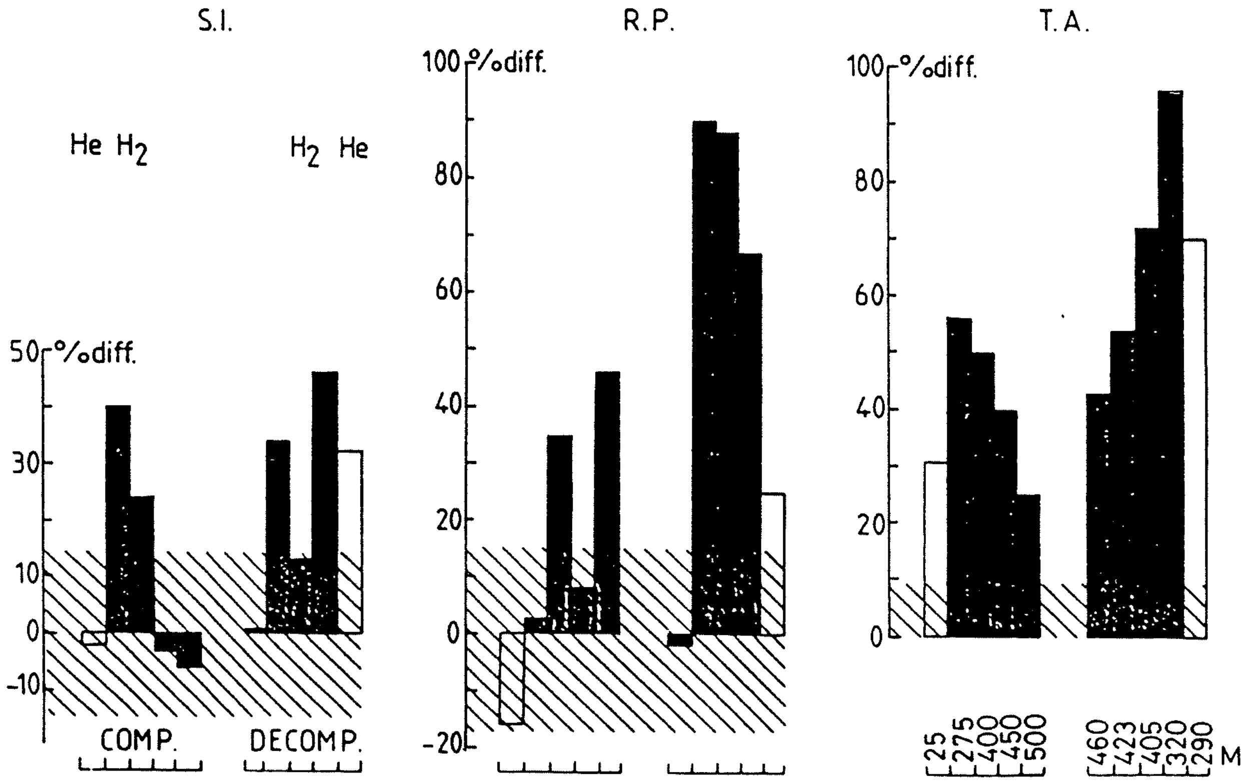


Figure 2 :

Tremor evolution at different depths during compression and decompression (Group B).

The histograms represent the difference evolution in percentage compared with the surface values (% diff.), hachured areas correspond to the surface variability.

Group B three subjects are represented from the left to the right. White histograms give the values obtained in helium-oxygen, black histograms give the values obtained in hydrogen-helium-oxygen.

4 - COMMENTS

The results obtained show that 3 subjects are not affected by tremor until 500 meters and that a 4th subject presents a significant tremor at 275 meters, which regresses and vanishes afterwards. On the contrary, 2 other subjects show a tremor which is not eliminated by hydrogen compression.

According to these results, we can consider that the hydrogen-pressure "antagonistic" effect observed in HYDRA V and VI on H.P.N.S. clinical symptoms (ROSTAIN and al. 1987a and b), does exist and is effective for 4 subjects during HYDRA VIII dive performed with a compression curve and a hydrogen percentage different from HYDRA V and VI.

The tremor emergence and persistence for 2 other subjects can be explained by the fact that hydrogen compression started quite late, at 250 meters instead of 200 meters in the other dives, whereas H.P.N.S., with such compression speeds, is recorded between 150 m and 200 m (ROSTAIN and al. 1983/1987a - LEMAIRE and ROSTAIN 1988). Under such circumstances, and for more susceptible subjects, a late H2 compression might not be able to compensate a H.P.N.S. already well settled. This seems to be confirmed first by the results of subject S.I., whose patent tremor at 275 meters is reduced by a hydrogen compression, then by the decompression results. As a matter of fact, fast hydrogen elimination while depth is still high brings in important tremor for the most susceptible subjects.

Thus, these results prove that it is more advisable to start H2 compression as from 200 meters, that is in a depth area where H.P.N.S. troubles are still faint. Besides, the tremor persistence for some subjects may indicate that for a rate of 49 % H2 at 500 meters compression is too fast at high depth. Consequently, hydrogen must not be removed that fast to prevent the emergence of an important H.P.N.S. in decompression.

As a conclusion, the results obtained during this tremor analysis prove that further research is necessary to improve compression, to determine more efficient hydrogen rates and to establish a procedure for the addition of various gases, in order to reach a better reduction of H.P.N.S. clinical symptoms. These results also show the need for determining the divers' susceptibility to H.P.N.S. and for letting dive only the least susceptible subjects.

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HYDRA VIII OPERATION

FINAL REPORT

SECTION : 8.5

TITLE : **PSYCHOMOTOR AND INTELLECTUAL TESTS SUBJECTS' ANXIETY EVOLUTION**

ORIGIN : **OCTARES MARSEILLE**

AUTHORS : **J. ABRAINI**
E. MARTINEZ
C. LEMAIRE

DATE : April 1988
REVISION : 00

This study fits into the general scope of our research on the divers' psychomotor and intellectual capacities according to the diving methods (compression speed depending on depth, breathing mix).

Though exceptional, this dive does not have an "experiment" character. The purpose is not indeed to study the effects of some dive outline or of any breathing mix, but to ensure the best possible conditions for the divers to achieve their objective, which is to succeed with the scheduled task and to prove their operationality at a depth exceeding 500 meters.

Psychomotor and intellectual tests, as well as the anxiety analysis performed, must enable us to compare the subjects' condition with their test results and to provide broader indications as to the "quality" of the dive conditions (outline and mix) so that to proceed with the understanding of hydrogen action in breathing mixes at high depth.

It is suitable to add that, for the first time, psychomotor and intellectual performances measures were taken during an operation at sea, with all the disturbances involved by the environment constraints peculiar to this situation.

CLASSIFICATION USED IN THE FIGURES :

P1 : RAU
P2 : SCH
P3 : MAR
P4 : ARN
P5 : PEI
P6 : ICA

METHODS

TESTS DESCRIPTION

Manual dexterity : the equipment is the same as for the previous dives.

The subject uses a 50 cm x 12.5 cm plate with 50 holes (dia. 1.1 cm), 1.5 cm apart, set on 4 columns. A receptacle is set at one end of the plate, containing pegs (50 serrated pegs, 4 cm high, 1 cm diameter). On a signal from the operator, the subject takes hold of the pegs, one at a time, from the receptacle (set on his righthand side when working with his left hand and vice-versa) and places them as quickly as possible into the opposite holes.

He works then with his other hand. The operator takes note of the time taken by the subject to set the 50 pegs with each hand, and works out the average number of pegs set per minute.

Visual choice reaction time : here too, the equipment has been used several times in other dives.

The subject is placed in front of a casing comprising a red diode and a green one, and two response buttons, 6 cm apart. When one of the diodes lights up, the subject must push the button set on the side where the light comes from, as quickly as possible. The stimulations sequence includes 31 signals, red or green, following each other in an aleatory manner as for the interval between two stimuli. The subject uses only one finger. The performance is appreciated according to the median value of the 31 responses and inter-quartile values give the dispersion.

Number ordination : In this test, the subject has to write down in ascending order the figures presented in disorder per sets of 7. The performance is measured by the average number of arranged figures per minute on the test total duration (7 min.).

Multiplications : for this test, the subject is requested to perform as many multiplications (2 figures by one) as possible, within 2 minutes. The number of mistakes is also recorded.

RESULTS

MANUAL DEXTERITY

The first set of measures taken at 270 meters, shortly after the 250 m stop, in a mix containing then little hydrogen, shows a comparatively important decline of manual dexterity (-11.5 % as compared to surface). The two divers most affected were the fastest on surface (P2 and P6).

At 400 meters (D3), the performance average reduction is roughly similar, two divers showing a slight progress as compared to 270 meters (P1 and P6).

At 450 meters (D4), the performance continues regressing slightly for all subjects, except for P1 whose regression is more pronounced. On an average, the performance decline, is of 16 %, which is significant for such depth.

This evolution continues at 500 meters (D5) where the manual dexterity decline reaches an average of 19 % (from -11 % to -27 % depending on the subjects).

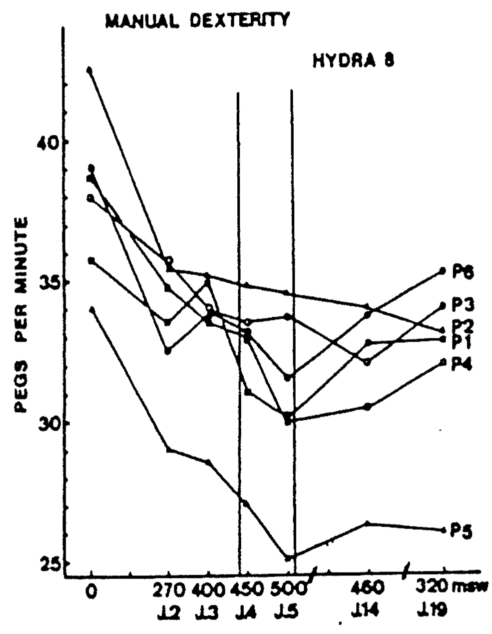
Recovery at 460 meters in decompression is obvious (-15.5 % average), but the general level is equal to the level at same depth in compression. At 320 m, recovery is not achieved; this might be related to the hydrogen important removal.

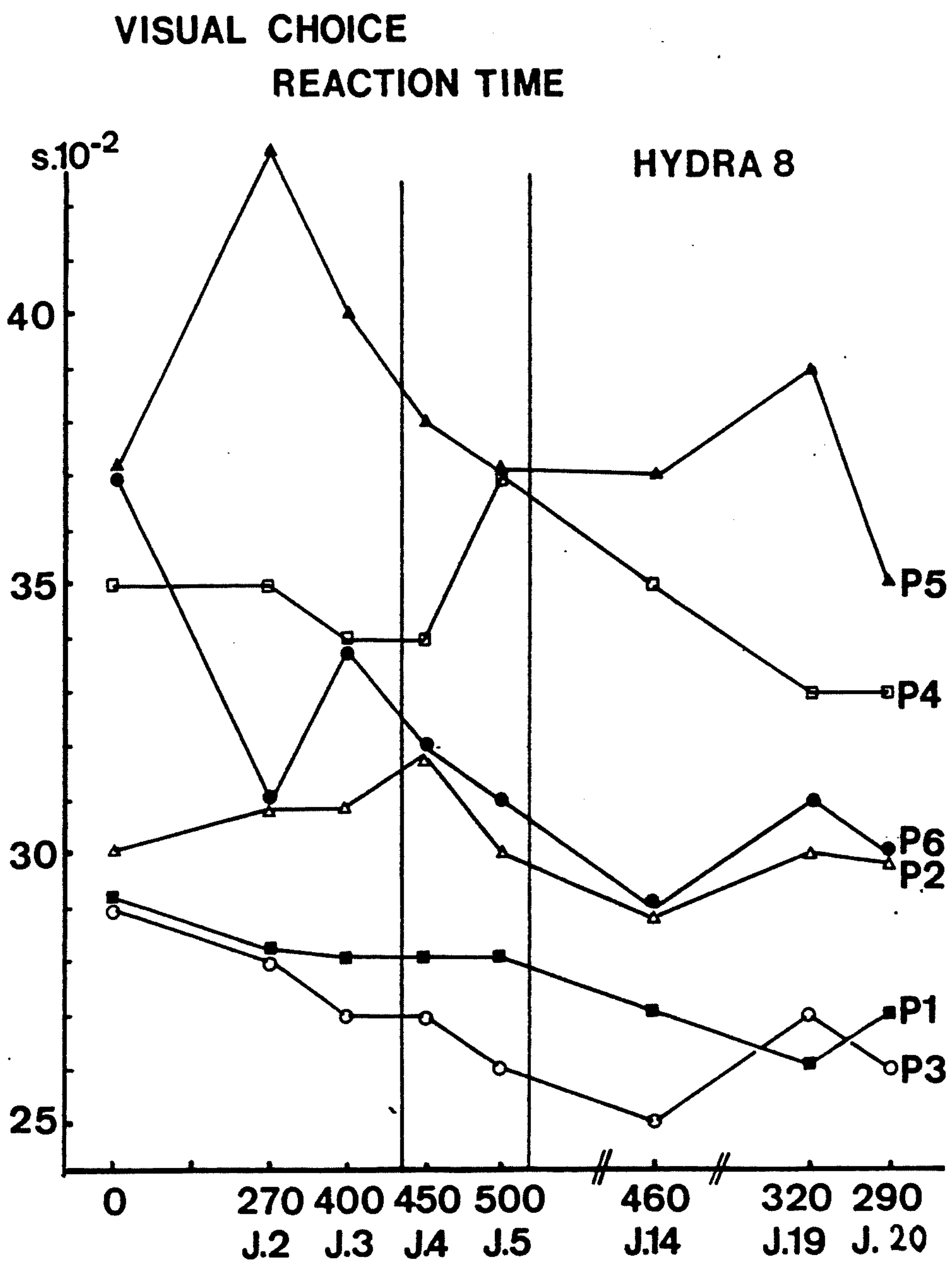
On the whole, such a regression of manual dexterity has seldom been reported, and these values have to be compared with ENTEX XI (heliox compression to 450 m) (-22 % on reaching 450 m).

VISUAL CHOICE REACTION TIME

For this test, no performance decline : at 270 meters, the performance is steady on the average, then increases slightly all along the dive, the profit reaching 7.5 % during decompression, at 460 meters. The only noticeable performance reductions were reported for P2 (-7 % at 450 m) and P4 (-6 % at 500 m). The fact that performance for reaction time be maintained, and even sometimes improved, proves the diver's fair attention/vigilance and their motivation to carry out the tests (a performance important reduction might indicate the contrary).

Such an evolution of the reaction time has sometimes been recorded at shallow depths (to 180 m) during fast compressions, which was explained by some excitability of the divers (more likely a high awakening level). We can wonder here whether a slight degree of narcosis would not be the reason for the subjects' awakening improvement.



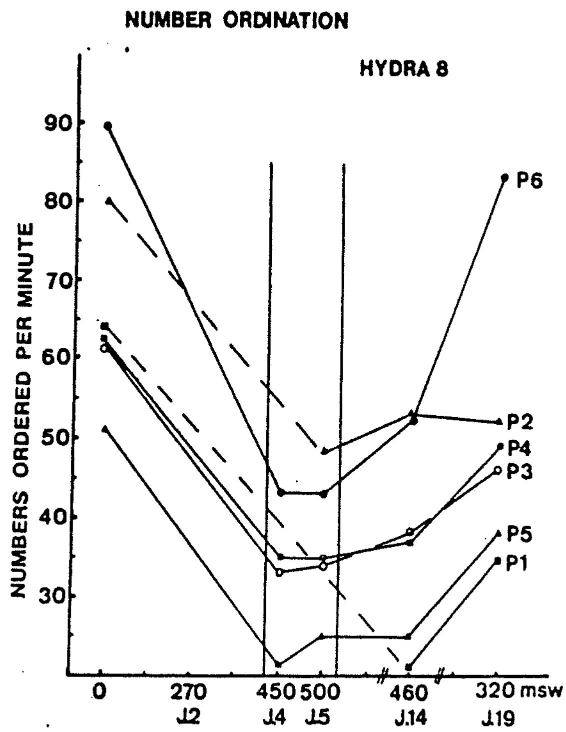

VISUAL CHOICE
REACTION TIME
HYDRA 8
s.10-2
40
35
30
25
0
270 J.2
400 J.3
450 J4
500 J.5
460 J.14
320 J.19
290 J. 20
P5
P4
P6
P2
P1
P3

NUMBER ORDINATION

In order not to exhaust the subjects and to avoid interpretation problems because of the training, this test has not been proposed to the subjects before 450 meters.

At that depth, the average decrease is very important (-50 %) and homogeneous (from -42 to -58 % depending on the subjects). On the following day, at 500 meters, performance is steady, with a slight effect of training for P3 and P5 (+ 2 and + 8 %). The average at 450 and 500 m is calculated on 4 divers only. Actually, at 450 m, neither P1 nor P2 wanted to perform this test. Their performances when starting again at 500 m for P2 (-36 %) and at 460 m for P1 (-68 %) simply show that their results are identical to the other subjects' and that their task withdrawal at 450 m might be only due to the fact that these 2 subjects, realizing their incapacity to achieve a good performance, preferred refraining rather than obtaining bad results. In decompression, at 460 m, the performance improves for all divers (an average of -40 % against -47 % at 500 m), but the level remains low. The performance at 320 m starts showing the effects of training (+ 20 % average as compared to 460 m, with + 34 % for P6 and + 25 % for P5).

During ENTEX XI, which remains one of the dives in which performance was the worst, number ordination had lessened by 37 % upon arrival at 450 m. The -50 % value had only been recorded for SAGITTAIRE IV experimentation, at 610 meters.

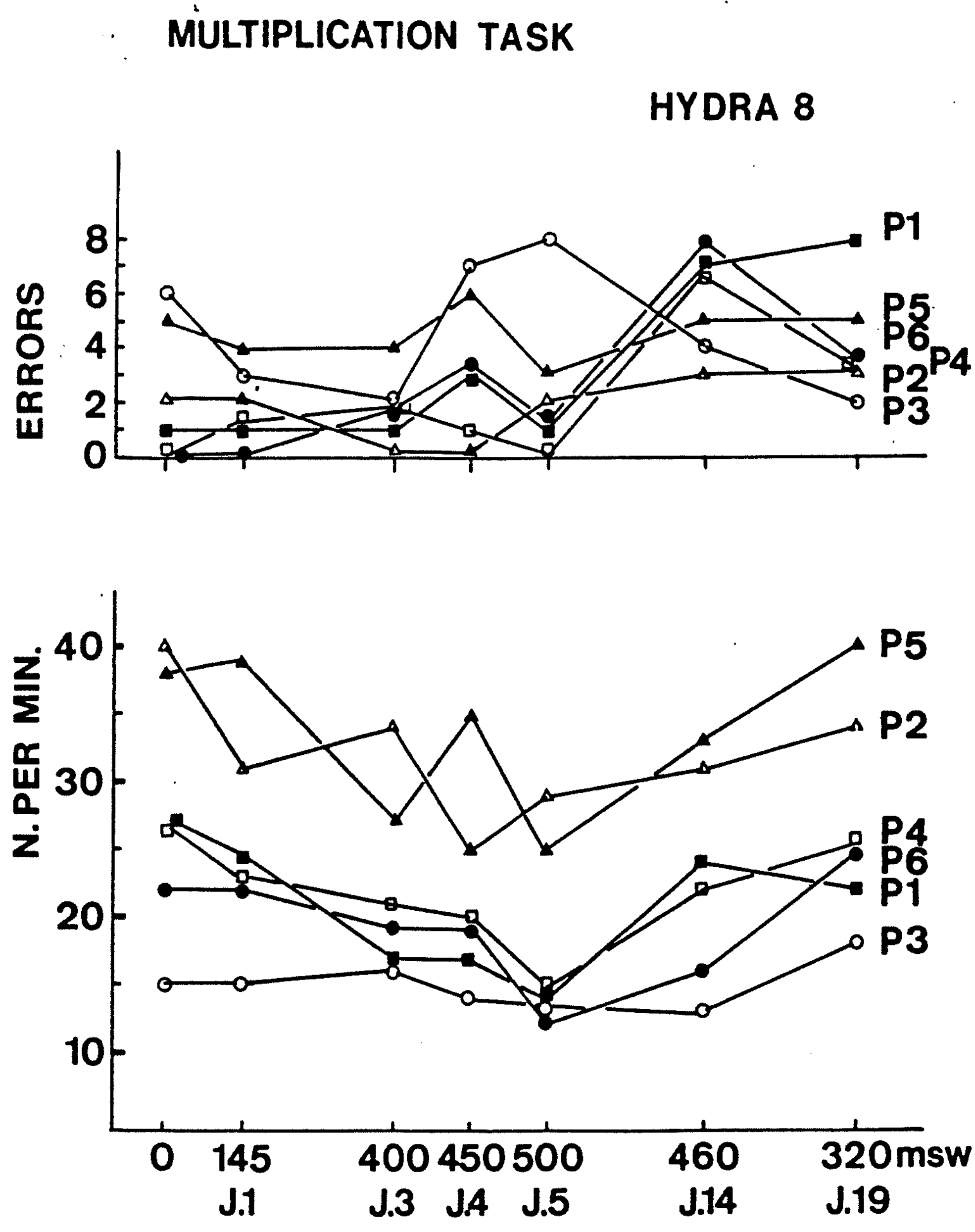


MULTIPLICATIONS

The performance regression is also noticeable in this test. Yet, at the beginning of compression (140 m), the average decrease of the number of operations performed is of 7 %. This value is maintained at 400 m (-8 %) and increases at 450 and 500 m (respectively -15 and -14 %). We remind here that in a "narcosis" situation in JASON I experimentation, a maximum decrease of -9 % was recorded (average between the 6 divers).

As far as mistakes made during this test are concerned, we can observe that the largest mistakes number is recorded at 450 m (which is correlated to a reduction of the number of operations performed). On the contrary, at 500 m, where operations performed are few, the mistakes number is reduced. Actually, the divers chose to work "better" than "more".

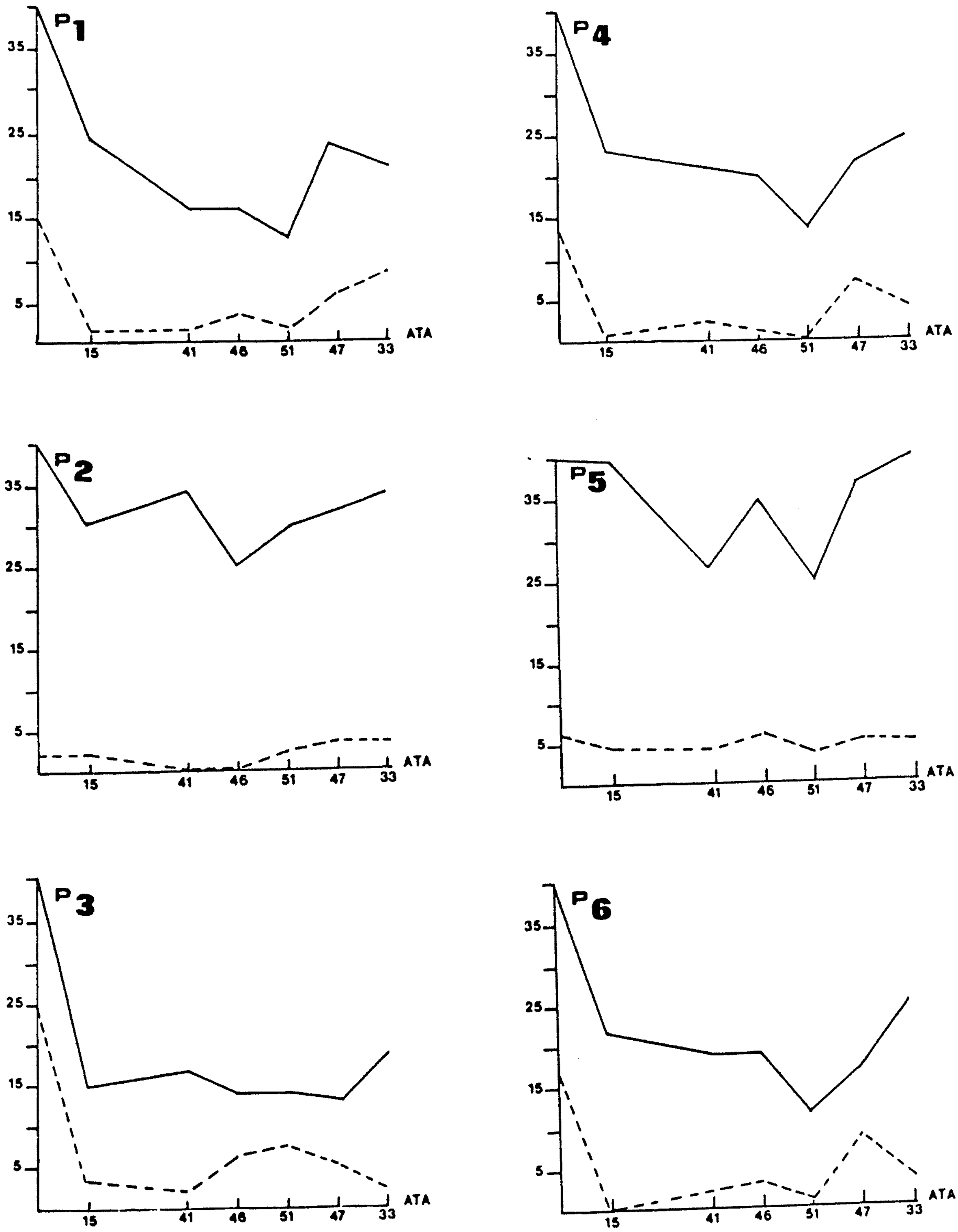
In decompression, at 460 m, the number of operations performed increases again, so does the number of mistakes; whereas at 320 m the global performance increases, there are more operations and less mistakes.


MULTIPLICATION TASK
HYDRA 8
ERRORS
0
2
4
6
8
P1
P5
P6
P4
P2
P3
N. PER MIN.
10
20
30
40
P5
P2
P4
P6
P1
P3
0
145
J.1
400
J.3
450
J.4
500
J.5
460
J.14
320msw
J.19

HYDRA VIII

MULTIPLICATIONS

INDIVIDUAL EVOLUTIONS IN NUMBER OF OPERATIONS : PERFORMED ———— WRONG - - - - - - -

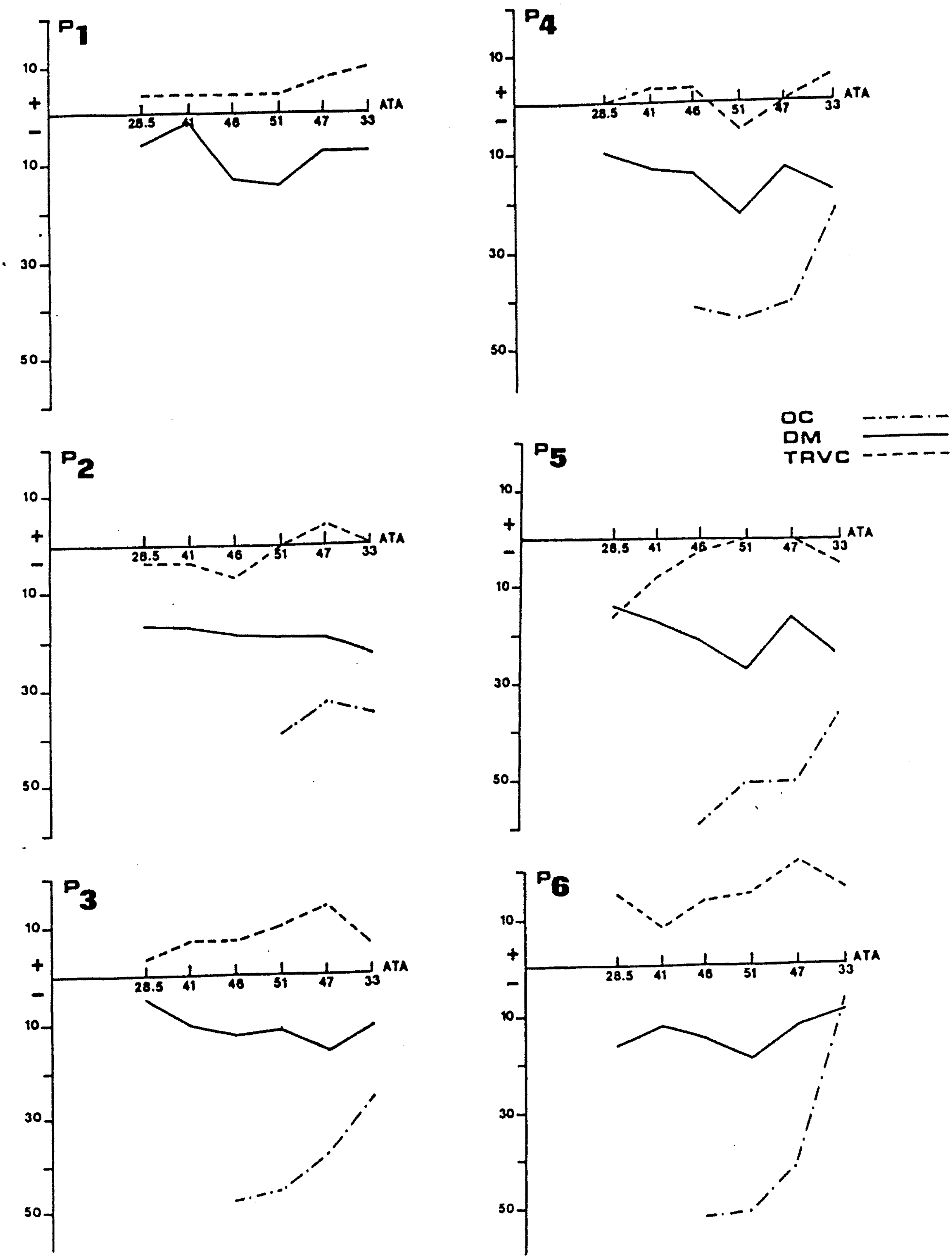


BALL BEARING TEST

The results obtained for this test are very low, but can partly be explained by the execution conditions... It is not easy to catch balls with tweezers when the vessel moves... Consequently, these results have not been processed.

HYDRA VIII

PERFORMANCE INDIVIDUAL EVOLUTIONS IN %



CONCLUSION

The performance variations recorded are important (-16 % for the manual dexterity test, -50 % for number ordination and -14 % for multiplications), whereas the vigilance/attention (visual choice reaction time) is maintained.

Although these modifications range seems larger than during the previous dives in hydrogen mix,, we must consider that this is the first time measures are taken in operational conditions. Therefore we have no references to evaluate the exact capacities of the subjects on the tests usually performed.

CATTELL'S ANXIETY SCALE

Anxiety is a major symptom in psychopathology and its estimation brings in difficult problems, because anxiety somatic outbreaks do not vary in parallel with the intensity felt and the inclination to introspection of such a specific experience is only possible from a virtually high intellectual level.

Moreover, some subjects inhibit their anxious demonstrations, making a correct estimation even more difficult.

Since long, anxiety central position prompted the psychologists into developping an objective method of this painful emotion. Schematically, besides estimation scales, psychophysiological techniques were used (polygraphy, elęctromyography, eyelids flickers recording, electroencephalography), personality objective and projective tests (mirror drawings, RASCHKIS and WELSH index at the Wechsler-Bellevue, Rorschach test), at last personality questionnaires.

Whatever the other methods interest, the questionnaires seem now to be technique giving, in the simplest manner, a correct and quantitative estimation of the anxiety level.

The validity of anxiety questionnaires is either obvious or empiric or factorial. CATTELL could thus develop an anxiety questionnaire composed of 40 items which gives, after examination :

* **a general note for anxiety**, anxiety fa[illegible] measure
* **two separate notes (A and B)**, which respectively correspond to patent anxiety and to concealed anxiety.

Besides, it is impossible to study the contribution of 5 primary personality factors :

FACTOR Q3 :
This factor shows the degree of motivation to the individual behaviour integration based on an accepted and conscious feeling of oneself and on standards socially approved. The absence of such a behaviour integration, with a clear concept of oneself, is, as indicated in second class saturations, one of the major causes of anxiety. Q3 note can also be considered as a level measure on which anxiety is connected to psychopathic structures and to socially approved habits.

FACTOR C :
Factor C represents the capacity of controlling immediately and expressing tensions in an adapted and realistic manner. It is the personality adaptation and defence pole. Faces the exterior world dangers. It is the location of psychic conflicts, partly conscious and partly unconscious.

This factor must be considered dynamically : it regulates and adapts itself, but therefore grows weaker.

FACTOR L :
This factor measures the capacity to face frustrations. Each individual tolerance threshold can vary according to one's environmentn, but also to internal factors.

Anxiety follows opposed directions, either towards oneself (factor O), or by projection towards the others (factor L).

FACTOR O :
From a descriptive point of view, this factor is known as representing the depressive anxious guilt. Can be a constitutional propensity for anxiety. In its extreme condition, seems to be the syndrome of combinated depression, self-accusation and anxiety.

Two levels :

* *the conscious level* : affective condition consecutive to an action or else a diffuse feeling of unworthiness and/or inferiority with no valid reason. Access to this level is certainly very easy when the subject has to face complex situations.

* *the unconscious level* : system of unconscious motivations which can include and explain failure behaviours, suffering, the subject inflicts to himself (melancholy, depression, distress neurosis). In this case, it is an internal conflict generating permanent distress.

FACTOR Q4 :
Constitutes the personality pole. Its contents, pulsions psychic expressions, are unconscious. From an economical point of view, it is the psychic energy reservoir.

It is thus anxiety or fundamental distress, connected to pulsion and to intra-psychic conflicts.

This can indicate the positive relation found, at most levels, between anxiety and the work results, the need for consideration and the apprehension of a given situation.

Its level is shown in the propension for emotivity, tension, irritability and nervosity.

CATTELL's anxiety questionnaire (wearing the discreet title of "auto-analysis sheet", with immediate application, presents the advantage of making possible, with one application, not only an evaluation of the general anxiety (Note A + B), but also an estimation of patent and of concealed anxiety.

* **a standard note (rating) from 0 to 3** applies to a subject able to tolerate tasks comprising frequent moments of crisis and stress.

* **a standard note from 4 to 7** applies to a subject basically normal, as far as anxiety is concerned.

* **a standard note of 7 or 8** indicates a subject susceptible to be a typical anxious neurotic.

* **a note of 9 or 10** shows a strong or very strong anxiety, indicating possible future problems.

Concerning :

P1 : the anxiety load increases with time, as indicated by factors L and O variations, which measure anxiety directly. The concealed anxiety / patent anxiety ratio is reversed on D+19 which tends to demonstrate that the subject will face more and more difficulties in concealing this anxiety from the others, which can therefore begin to show through his behaviour.

Generally speaking, the subject remains essentially normal as far as anxiety is concerned.

P2 : broadly speaking, the values concerning concealed anxiety are higher than those concerning patent anxiety, the difference tending however to lessen, which underlines that the concealed anxiety in the beginning increases regularly to get closer to patent anxiety. The subject prepares a progressive awareness of his anxiety. Values on D+5 (500 m) reach a quotation close to the "distress neurosis" group, the anxiety felt is very significant. The subject uses important adaptation and defence mechanisms, in order to cope with the situation. This involves an augmentation of factors Q3, O and Q4 and an important increase of anxiety and distress phenomena. The rating goes from 1 to 8 between D+1 and D+5.

In decompression (D+19), results do not prove an important recovery of the anxiety load.

P3 : Surface measures show a strong personality structure, and do not vary along the experiment. Little amplitude between concealed and patent anxiety, reversing on D+19 in decompression. But the other factors analysis do not allow to state an anxiety evolution. Distress phenomena are either non-existent or controlled, or totally driven back, which indicates a good integration of the subject.

P4 : Subject essentially normal as to anxiety, with a rating going from 1 to 6 between D+5 and D+19 though. The subject adapts and controls himself; at 500 m (D+5), the process continues its path of anxiety maximum control and on D+19 (320 m), the increase of factors Q3, L, O and Q4 indicates an aggravation of the anxiogenic situation, brought in by a psychic weariness invested with important defence mechanisms. Concealed anxiety goes from 8 to 18 between D+5 and D+19, and patent anxiety from 3 to 16, which takes the rating to 6.

P5 : Subject essentially normal as far as anxiety is concerned. However, through the different quotations, a regression of the concealed anxiety can be ascertained to the benefit of a more pronounced patent anxiety. No results were recorded on D+5 (500 m) for the patent anxiety measure, as the subject only performed part of the test on that day, but we can suppose that the patent anxiety would overcome the concealed anxiety, which characterizes the fact that he has difficulties in hiding it.

P6 : Subject able to tolerate frequent moments of crisis and stress. Surface values show a strong personality structure. We have no results on D5 as to patent anxiety as the subject only performed part of the test. For this subject too, anxiety phenomena are either non-existent, or controlled, or forced back. Good integration of the subject.

When comparing anxiety measures for the subjects who took part in HYDRA V, we can observe the following :

for P1 the anxiety level in absolute values is higher and increases at 450 meters, indicating an anxiety development

for P2 the anxiety level is well controlled, with no aggravation at 450 meters, with even a decrease of anxiety general level

for P3 no significant modification is recorded.

The tables hereafter show the individual evolution of anxiety measure at four particular moments :

* AIR SURFACE
* J+1 (140 m)
* J+5 (500 m)
* J+19 (320 m)

They give information on the *concealed anxiety / patent anxiety position,* on the factors (Q3, C, L, O, Q4) analysis and on anxiety general quotation.

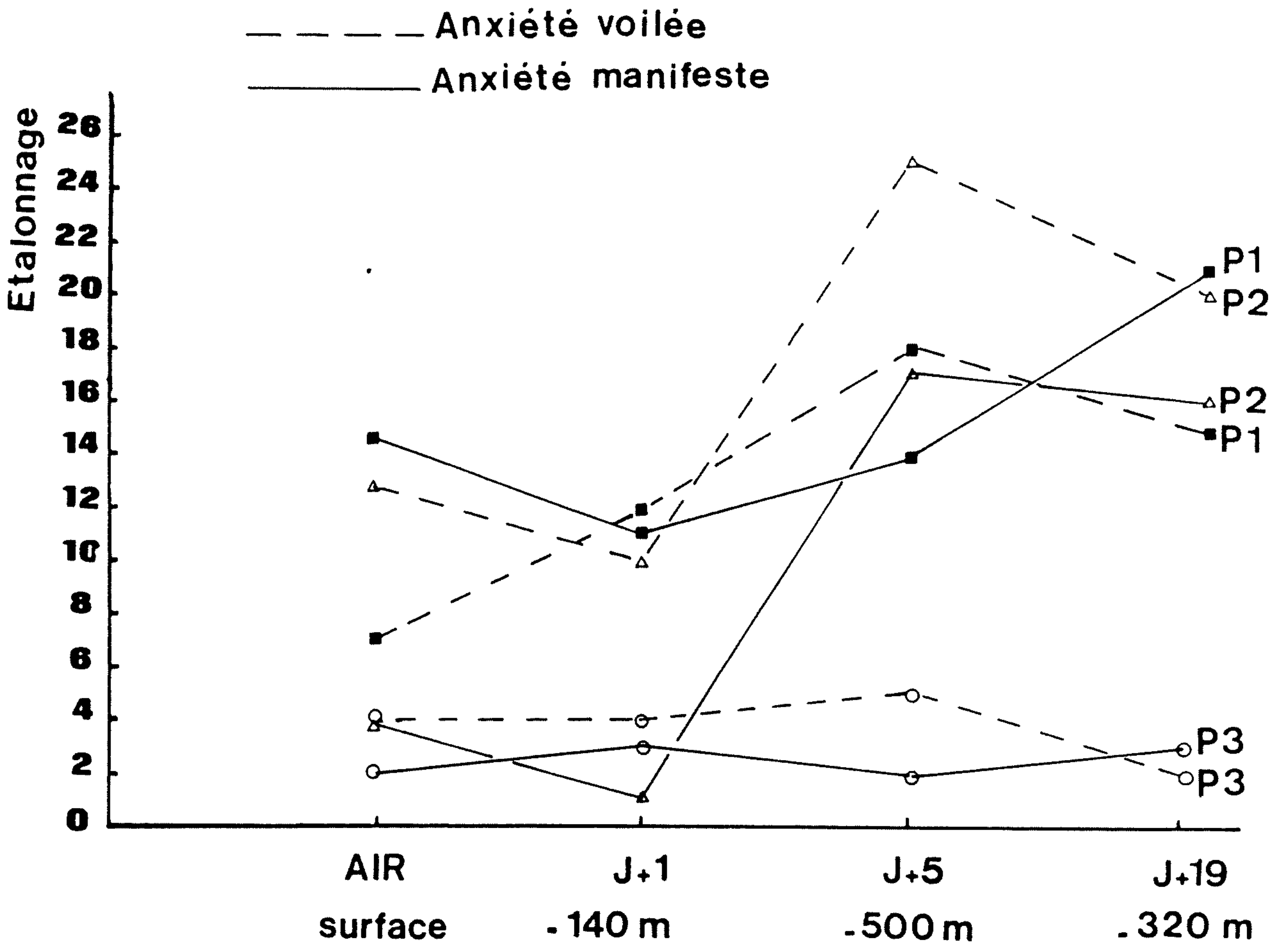
P_1	Anx. voilée	Anx. manif.	Q_3	C –	L	O	Q_4	Etalonnage
AIR Surface	15	7	7	7	4	0	2	4
J.1	12	13	6	5	4	2	4	4
J.5	18	14	7	5	-	3	7	5
J.19	15	21	6	7	7	6	4	6

P2	Anx. voilée	Anx. manif.	Q_3	C_	L	O	Q_4	Etalonnage
AIR Surface	13	4	4	3	4	3	0	2
J.1	10	1	1	3	-	2	0	1
J.5	25	17	6	10	3	8	6	8
J.19	20	16	5	7	6	3	8	6

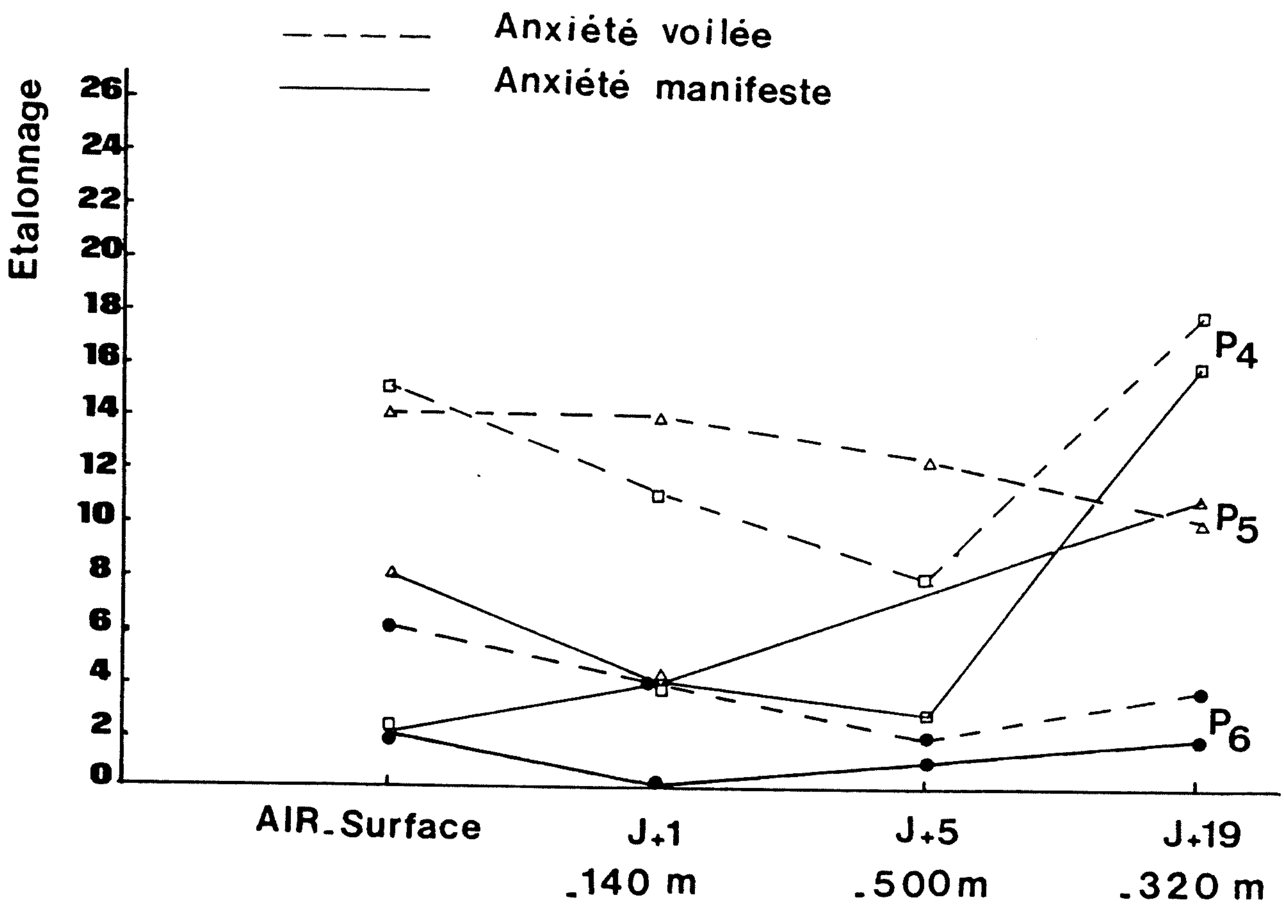
P_3	Anx. voilée	Anx. manif.	Q_3	C_-	L	O	Q_4	Etalonnage
AIR Surface	4	2	1	3	0	0	0	O
J.1	4	3	1	-	0	1	1	O
J.5	5	2	4	-	0	0	0	O
J.19	2	3	1	-	0	0	0	O

P_5	Anx. voilée	Anx. manif.	Q_3	C_-	L	O	Q_4	Etalonnage
AIR Surface	14	8	3	7	4	2	2	3
J.1	14	5	2	6	–	0	5	2
J.5	12	/	2	3	2	2	3	/
J.19	10	11	4	6	4	1	3	3

P_6	Anx. voilée	Anx. manif.	Q_3	C–	L	O	Q_4	Etalonnage
AIR Surface	6	2	2	3	0	0	2	O
J.1	4	0	0	–	0	0	0	O
J.5	2		0	0	0	2	0	
J.19	4	2	0	–	3	0	0	O



Anxiété voilée
Anxiété manifeste
Etalonnage
26
24
22
20
18
16
14
12
10
8
6
4
2
0
P1
P2
P2
P1
P3
P3
AIR
surface
J+1
-140 m
J+5
-500 m
J+19
-320 m


Anxiété voilée
Anxiété manifeste
Etalonnage
26
24
22
20
18
16
14
12
10
8
6
4
2
0
P4
P5
P6
AIR_Surface
J+1
-140 m
J+5
-500m
J+19
-320 m

PHASE 3 : HYDRA VIII OPERATION

FINAL REPORT

SECTION : 8.6

TITLE : **CIRCULATING BUBBLES ULTRASONIC DETECTION**

ORIGIN : **CERTSM - DCAN TOULON**

AUTHORS : **N. GUTTIEREZ**
G. MASUREL

DATE : 1 September 1988
REVISION : 00

INDEX

1 - OBJECTIVE

The aim of this operation was to demonstrate that divers breathing a hydrogened gas mixture were not affected by pressure and could work efficiently at minus 520 meters, proving thus the industrial reality of this new technique.

2 - EQUIPMENT AND METHOD

2.1 THE DIVE

DEPTH	TIME	RATE	STEPS *
0 à 200 m	10 h	20 m/h	2 h à 200 m
200 à 250 m	5 h	10 m/h	2 h à 250 m **
250 à 300 m	5 h	10 m/h	2 h à 300 m
300 à 400 m	20 h	5 m/h	2 h à 400 m
400 à 450 m	20 h	2.5 m/h	6 h à 450 m
450 à 500 m	20 h	2.5 m/h	

DECOMPRESSION SCHEDULE

cumulated time	depth (m)	H2 %	He %	O2 %
0	500	46,7	51,1	1,00
10	488	45,2	52,6	1,00
25	470	42,9	54,9	1,04
34	459	41,3	56,4	1,08
48	442	38,6	59,1	1,10
58	430	34,9	61,8	1,15
72	413	31,7	65,8	1,16
82	401	28,5	69,9	1,24
96	384	25,9	71,5	1,29
106	372	23,1	76,2	1,31
120	355	18,5	78,4	1,41
130	343	14,4	82,2	1,42
144	326	8,0	89,1	1,46
154	314	4,0	92,8	1,66
166	295	1,4	95,3	1,63

DECOMPRESSION SCHEDULE AND PER COMPOSITON

2.1 THE DIVERS

Six deep divers, 4 belonging to COMEX, 2 to the FRENCH NAVY. They all took part in one or more of the previous HYDRA dives and are all accustomed to bubbles detection.

Their biotypological characteristics are collected on table 1.

NAMES	AGE	WEIGHT (kg)	height (m)	pli cutané moyen (mm)
ARN.	31	75	1,75	10
ICA.	35	73	1,76	7
MAR.	43	90	1,90	7
PEI.	35	70	1,65	8
RAU.	38	84	1,82	11
SCH.	37	73	1,76	7
Mean	37	78	1,77	8
Std dev.	4	8	0,08	2

TABLE 1 - DIVERS' BIOTYPOLOGICAL CHARACTERISTICS

2.2 METHODOLOGY

Each circulating bubbles measure sequence comprises : a precordial detection called "at rest" (R) performed on the diver while standing after a few minutes inactivity ; then a detection called "in movement" (M) during and after each of the 3 knee flexions at one minute intervals. Bubbles grades are estimated as per the "KM" code (*).

(*) : **KISMAN K. - MASUREL G. - guillerm R. - Bubble evaluation code for the Doppler ultrasonic decompression data.**
Abstract published in Undersea Biomedical research supplement to vol. 5 (1) 28 (1978)

Sequential measures are taken before pressurization and during the stay on the bottom, to test the probe operation and keep it in the same position in order to avoid disturbing the divers with a position modification.

Contrary to our habit, we could not perform any detection when back from interventions in the water, because of this dive operational character. For the same reason, during decompression, bubbles detections were carried out only twice a day, in the morning around 9 h and in the evening around 17 h.

3 - RESULTS AND DISCUSSION

The individual results recorded during decompression are collected on table 2.

Figures 1 and 2 show the chronological evolution of bubbles release for each diver.

At rest :

Very few bubbles, irregular and discontinuous, for 5 subjects out of 6, not exceeding level 1.

In movement :

The first bubbles appear between 400 and 375 m for 3 subjects (ICA, SCH, RAU) in "hydreliox" mix.

The other subjects (except one - MAR - who will only present bubbles as from 225 m in "heliox" mix) regularly present bubbles respectively from 345 m (PEI) and 320 m (ARN) in "hydreliox" mix.

Figure 3 represents the average value of bubble grades for each detection.

Considering the peaks values in movement, we can ascertain their progressive increase between 400 m and 175 m, then a plateau maintained to 110 m.

An unexplained drop of these values is recorded around 88 m, followed by an increase up to approximately 10 m (which corresponds to the air changeover). Then the level decreases to tend to zero on reaching the surface.

When comparing these results (figures 4 and 5), to HYDRA VI dive, we can observe the following :

- bubbles appear earlier during HYDRA VIII dive in the "hydreliox" phase, which can be explained by the use of a faster initial compression speed.
- a sudden drop of the bubbles rate is recorded around 88 m, for HYDRA VIII dive
- as far as HYDRA VI dive is concerned, bubbles appeared later, at rest as in movement but their flow grew "crescendo".
- when considering the severity ratings (**) (figures 6 and 7) of HYDRA VI and VIII dives, the results analysis of the subjects who took part in both dives states the following :

  at rest * one of them (ARN) shows a null rating for HYDRA VIII and a low rating for HYDRA VI, 2 of them (ICA, RAU) equal ratings for both dives, and the last one (SCH) a high rating for HYDRA VI and a very low one for HYDRA VIII dive.

  in movement * except for one subject (SCH) who presented a very high rating for HYDRA VI dive, the 3 others (RAU, ARN, ICA) show a higher rating for HYDRA VIII dive than for HYDRA VI.

We must notice that the 2 other HYDRA VIII subjects (who did not participate in HYDRA VI), present low ratings at rest as well as in movement.

The 3 other HYDRA VI subjects (who did not participate in HYDRA VIII) show low ratings at rest as well as in movement, except for one who shows a high rating at rest and in movement.

** : **KISMAN K. - MASUREL G. - LAGRUE D. - LE PECHON JC. : Evaluation of decompression quality after a hyperbaric exposition based on the bubbles ultrasonic detection.**
Méd. Aéro. et Spat., Méd. Sud et Hyp., Vol. 17 N°67, pp 293-297

On figure 8, we can state that the severity rating average at rest is higher for HYDRA VI than for HYDRA VIII.

On the whole, if HYDRA VIII dive generated more bubbles than HYDRA VI in movement, the severity rating averages are comparable (only differ by 10 %).

Considering the severity degrees average obtained for all the divers and the results obtained during ENTEX and HYDRA dives (table 3) :

- we can observe that the minimum value at rest corresponds to HYDRA VIII dive

- the severity rating average value for HYDRA VIII in movement can be compared to ENTEX 5 and 9 and to HYDRA VI.

We measured **the cardiac rate** at each bubbles detection. Considering the operational character of this dive, measures were not taken as strictly as during experimental dives and not at the same hours.

Therefore, results concerning the cardiac rate must be read carefully.

On the whole (as for previous dives), we can observe on figure 9 an increase of the average cardiac frequencies all along decompression. Moreover, these frequencies variations go with the bubbles flows evolution (in particular, a drop around 88 m is recorded).

4 - CONCLUSIONS

During HYDRA VI dive, bubbles appeared later in reason of a slower decompression speed (60 min/m up to 300 m).

During the decompression second part, with a speed of 45 min/m, a more important bubbles flow was observed.

In HYDRA VIII dive, a constant decompression speed of 50 min/m produced an earlier emergence of bubbles, with average flows in movement virtually identical to HYDRA VI (variation of the severity ratings average inferior to 10 %).

But, at rest, the quantity of bubbles recorded during HYDRA VI was practically null, which grants it a clear advantage.

Consequently, the choice of a 50 min/m speed, used for HYDRA VIII dive decompression seems satisfactory.

Concerning the reduction of bubbles flows and of the cardiac frequency, around 88 m, it is impossible to know whether this variation is due to a modification in the divers' activity (rest for instance) or if it constitutes a phenomenon connected to decompression.

For these same reasons, we cannot assert from these results, that there is a correlation between the bubbles flow and the cardiac frequency ; both vary in the same way with physical activity.

Temps cumul (h)	Prof (m)	heure de la détec	MAR			RAU			SCH			ARN			PEI			ICA			Moyenne		
			R	M	FC	R	M	FC	R	M	FC	R	M	FC	R	M	FC	R	M	FC	R	M	FC
15	490	17.00	0	0	70	0	0	72	0	0	80	0	0	80	0	0	68	0	0	80	0	0	75
31	463	09.00	0	0	68	0	0	76	0	0	88	0	0	78	0	0	70	0	0	80	0	0	77
39	456	17.00	0	0	64	0	0	88	0	0	80	0	0	76	0	0	64	0	0	80	0	0	75
56	433	10.00	0	0	80	0	0	100	0	0	88	0	0	100	0	0	66	0	0	100	0	0	89
63	423	17.00	0	0	70	0	0	77	0	0	90	0	0	80	0	0	75	0	0	78	0	0	78
79	405	09.00	0	0	78	0	0	95	0	0	80	0	0	88	0	0	80	0	0	94	0	0	86
87	398	17.00	0	0	65	0	0	78	0	*	78	0	0	95	0	0	78	0	1+	82	0	0.26	79
103	377	09.00	0	0	72	0	1+	83	0	1	97	0	0	78	0	0	77	0	1	94	0	0.56	84
111	367	17.00	0	0	72	0	2−	82	0	1	82	0	0	78	0	0	75	0	2	82	0	0.78	79
129	345	11.00	0	0	75	*	1+	78	0	1	75	*	*	80	0	1	70	1	3	92	0.25	1.27	78
135	338	17.00	0	0	76	0	*	80	*	*	75	*	*	*	0	1	74	0	2+	76	0	1.11	76
152	319	10.00	0	0	88	0	1+	97	0	1+	80	0	1	92	0	2	83	1−	2	96	0.11	1.28	89
159	310	17.00	0	0	85	1−	1	88	1−	1+	80	*	2−	*	0	2−	68	0	2	82	0.26	1.28	81
176	290	10.00	0	0	80	*	*	104	0	2−	82	0	2−	78	0	1	85	0	2+	96	0	1.33	88
183	281	17.00	0	0	78	0	1+	95	0	1	80	0	1+	82	0	0	70	0	2	80	0	0.94	81
200	261	10.00	0	0	82	0	1+	95	0	1−	80	0	2−	75	1−	3	75	0	2	96	0.11	1.44	84
207	252	17.00	0	0	88	0	3−	80	0	2	80	0	2	70	0	2−	84	0	2+	83	0	1.78	81
224	232	10.00	0	0	103	0	2	95	1−	3−	96	0	2	83	0	2	83	0	1	98	0.11	1.61	93
231	222	17.00	0	2−	78	0	2	83	0	1+	83	0	2−	80	0	1	74	0	1+	77	0	1.50	79
247	204	09.00	0	1+	99	0	2	88	0	2−	81	0	1−	73	0	2	74	0	1+	90	0	1.50	84
255	193	17.00	0	2−	82	0	2+	84	0	3	74	0	1+	84	0	2+	74	1	2	78	0.17	2.11	79
271	175	09.00	0	1	85	0	1	86	0	2	80	0	1+	88	0	3	90	0	2	90	0	1.72	87
279	165	17.00	0	1+	77	1	2+	82	0	2+	86	0	2	84	0	2	73	0	2+	89	0.17	2.05	82
295	147	09.00	0	0	92	0	1	94	0	2	86	0	2−	82	0	2	82	0	2−	88	0	1.39	87
303	138	17.00	1−	3	83	1	2−	80	0	1−	87	0	2	70	0	2−	76	1−	3	75	0.39	2	79
319	118	09.00	0	*	80	1	2	74	0	2−	85	0	1+	88	1−	1	74	0	2	82	0.28	1.60	80
327	108	17.00	0	2	68	1	2	64	0	2−	80	*	*	84	0	2	80	0	2+	82	0.20	2	76
343	88	09.00	0	0	88	0	0	85	0	0	90	0	0	85	0	1−	96	0	1	94	0	0.28	90
351	79	17.00	0	1+	86	1−	2−	86	0	2−	96	0	1	80	0	2	77	1−	2	93	0.22	1.60	86
367	60	09.00	0	1+	92	0	1	98	0	1+	84	0	1	86	0	2+	82	0	2−	90	0	1.44	89
375	50	17.00	0	2	83	0	2−	90	0	1+	84	0	2	82	0	2+	80	0	2−	89	0	1.83	85
391	31	09.00	0	1+	98	0	2	85	0	2−	90	0	1	88	0	2+	87	0	2	106	0	1.72	92
399	21	17.00	0	1+	86	0	2	83	1−	3+	90	0	1	92	0	2+	77	0	2	89	0.11	1.98	86
415	4.5	09.00	0	2	89	0	0	93	0	3	105	0	0	104	0	2−	84	0	2−	107	0	1.39	97
421	0.0	15.00	0	0	102	0	0	92	0	0	105	0	0	102	0	1+	98	0	1	103	0	0.39	100
Moyenne			0.02	0.63	82	0.16	1.17	86	0.06	1.28	85	0	0.92	84	0.04	1.29	78	0.11	1.55	88			
ice de sévérité			0.01	3.96		0.21	6.19		0.04	8.47		0	3.57		0.03	8.79		0.13	10.4				

TABLE 2

Circulating bubbles detection diving decompression

NAME	SEVERITY DEGREE		RATE
	Rest	Action	of decompression
ENTEX V	0,14 0,23 (n=4)	5,60 6,04 (n=4)	25 min/m from 450 to 160m stop of 4 h every 25m Exponential from 160 to 0m
ENTEX VIII	0,64 1 (n=4)	10,10 6,7 (n=4)	.
ENTEX IX	0,27 0,09 (n=2)	5,6 2,4 (n=2)	54 min/m from 610m to 15m, then 60 min/m from 15m to surface
HYDRA V HELIOX	0,63 0,39 (n=3)	15,2 7,76 (n=3)	45 min/n from 450m to 15m *
HYDRA V HYDRELIOX	0,09 0,15 (n=3)	0,55 0,74 (n=3)	70 min/m from 450m to 350m 65 min/m from 350m to 300m 60 min/m from 300m to 250m 55 min/m from 250m to 15m**
HYDRA VI	0,21 0,30 (n=8)	6,28 8,13 (n=8)	60 min/m to 300m 45 min/m from 300m to surface
HYDRA VIII	0,07 0,08 (n=6)	6,90 2,78 n=6)	50 min/m to 15m 60min/m from 15m to surface

* recompression at 1,3 m

** decreased decompression rate from 15 metres to surface

TABLE 3

SEVERITY DEGREE FOR DIFFERENT DEEP SATURATION DIVES

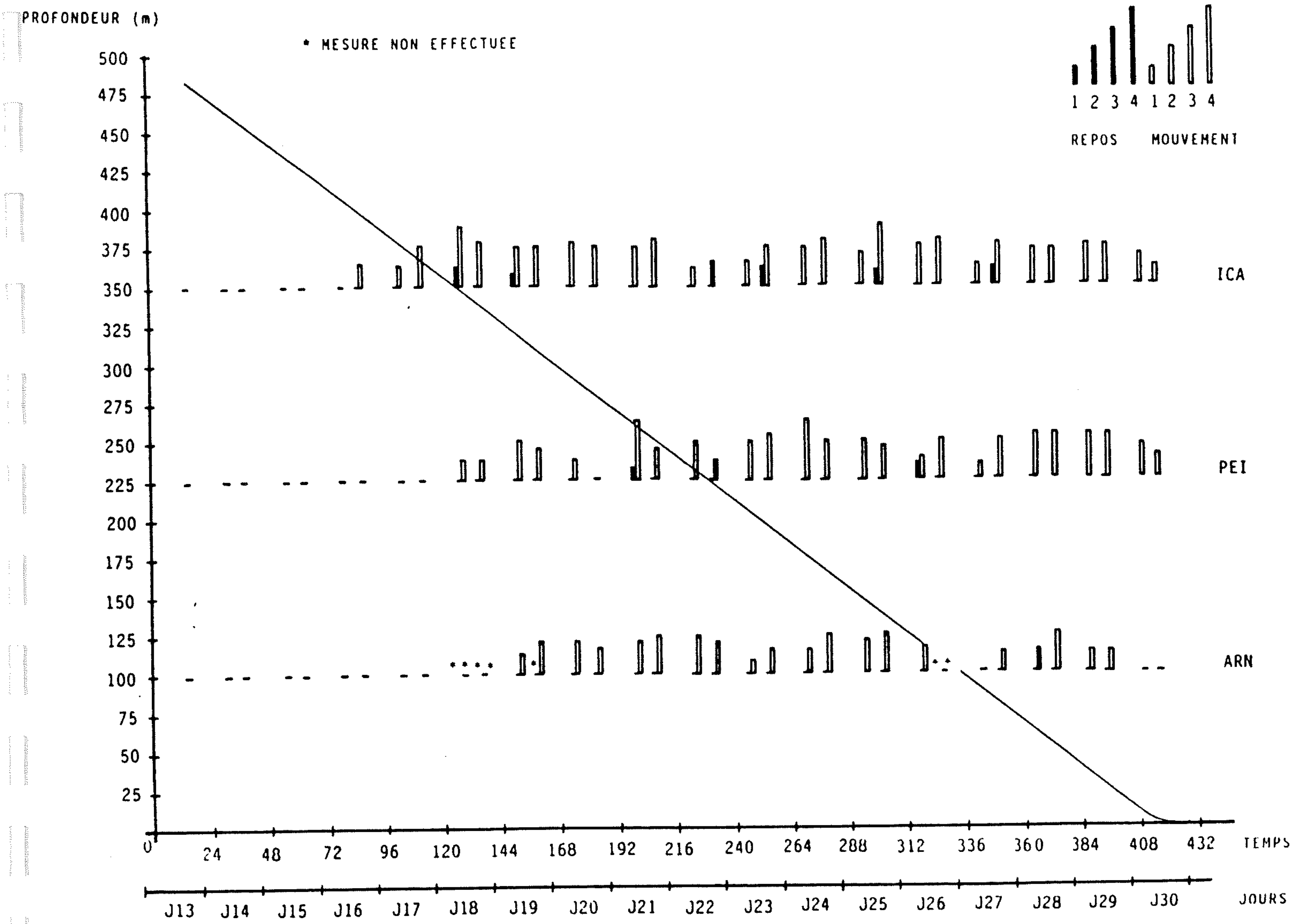


FIGURE 1

HYDRA VIII - Individual results of circulating bubbles detection

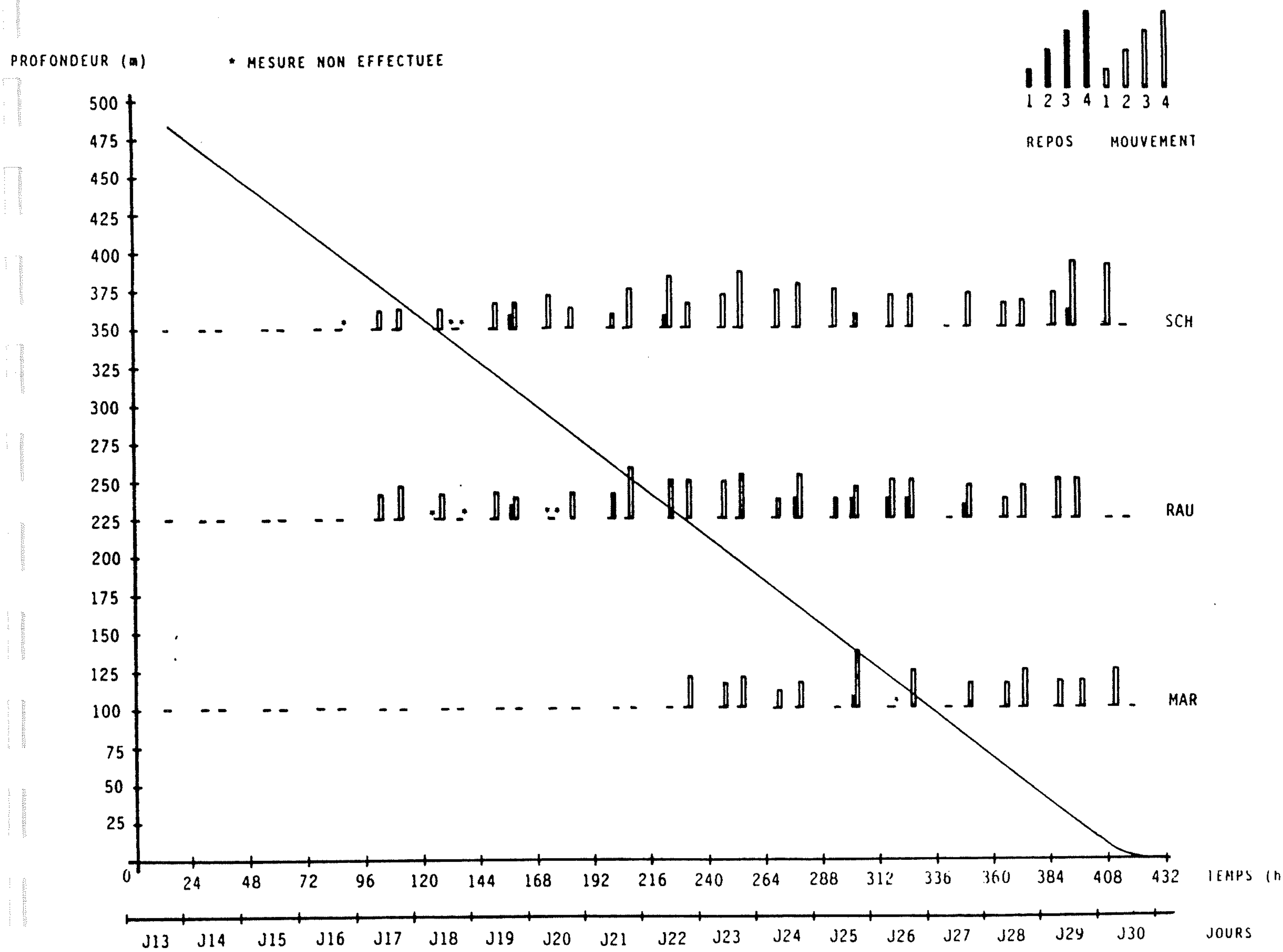


FIGURE 2

HYDRA VIII - Individual results of circulating bubbles detection

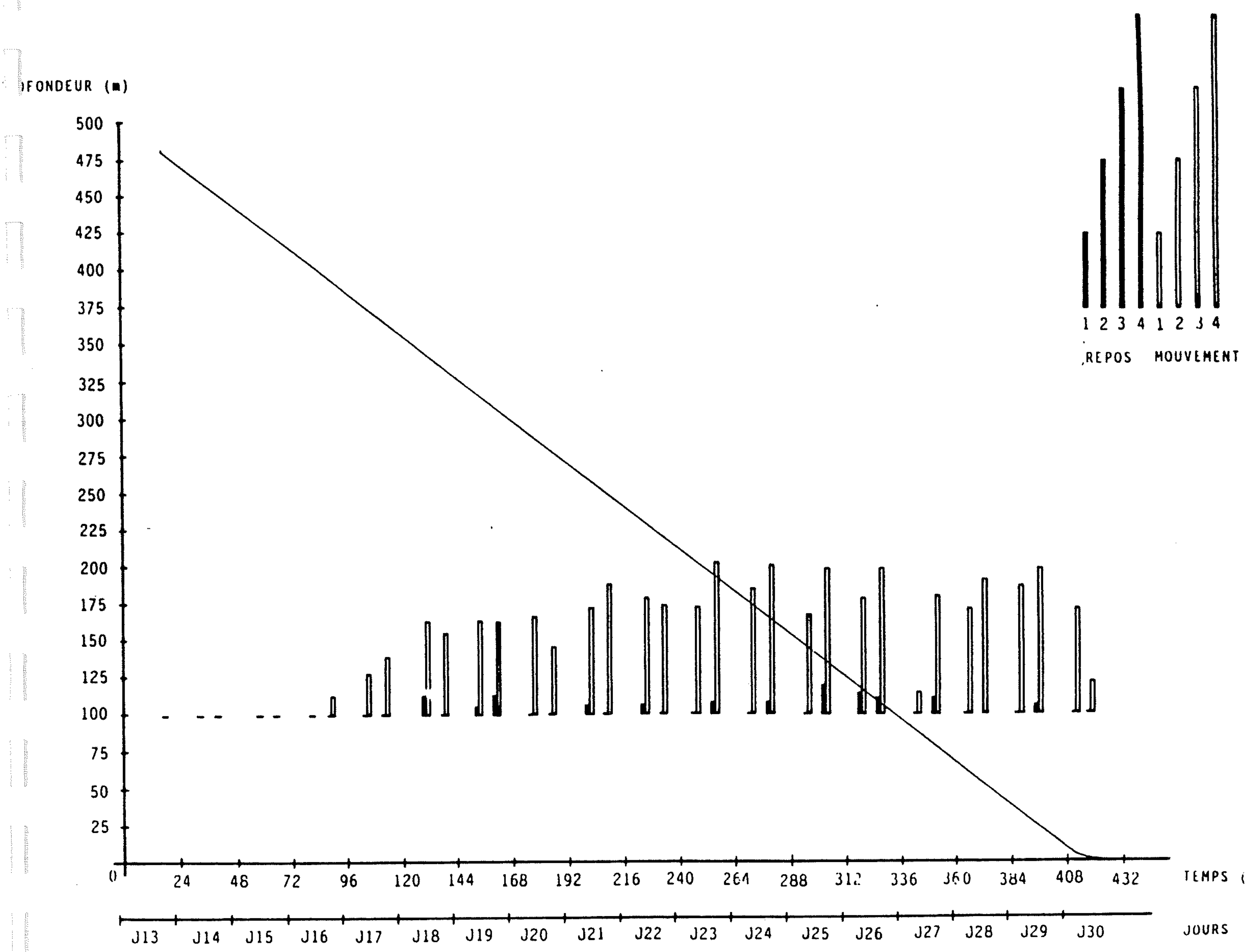


FIGURE 3

Means values for circulating bubbles rate for each detection

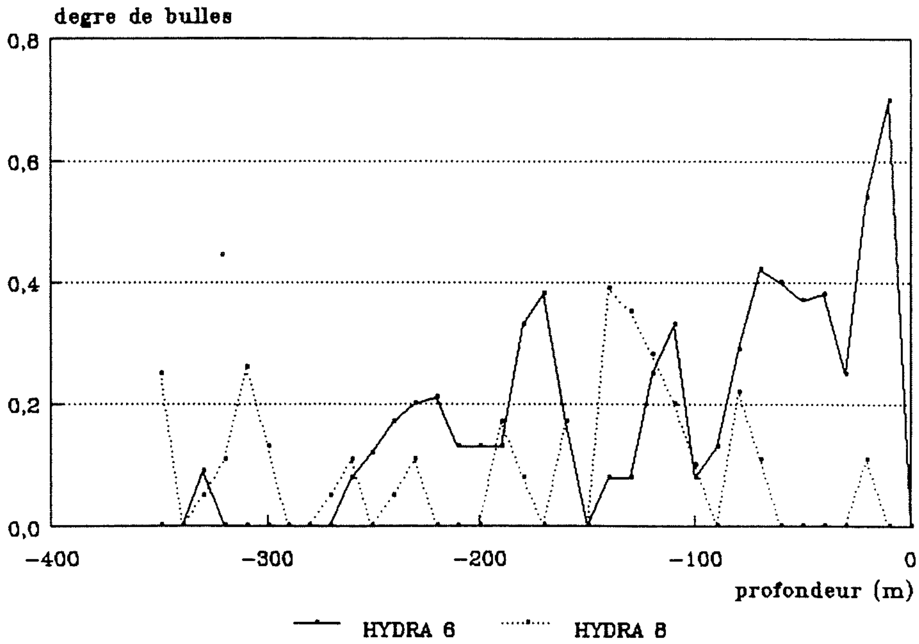


FIGURE 4

Circulating bubbles detection

Means values comparison (rest)

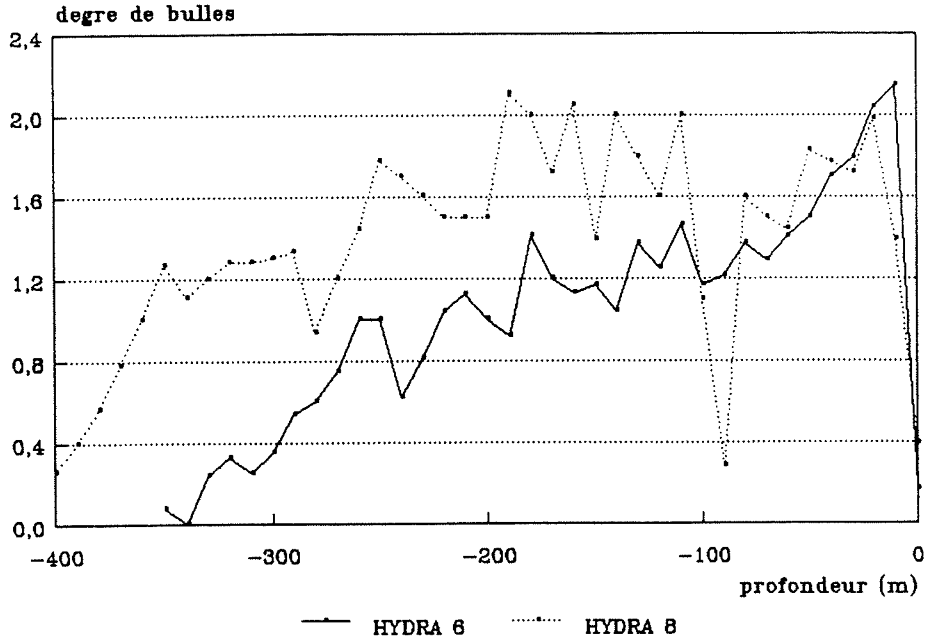


FIGURE 5

Circulating bubbles detection

Means values comparison (action)

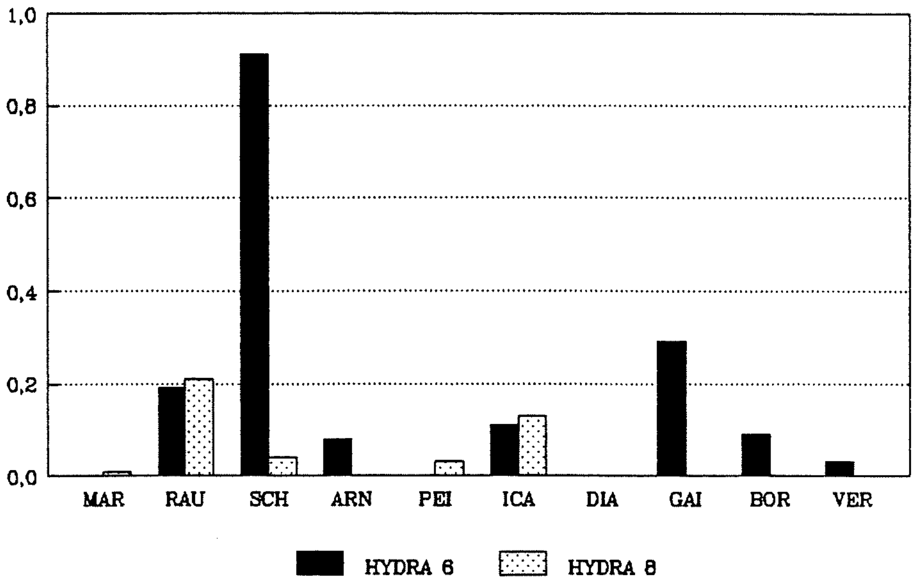


FIGURE 6

Severity degree (rest)

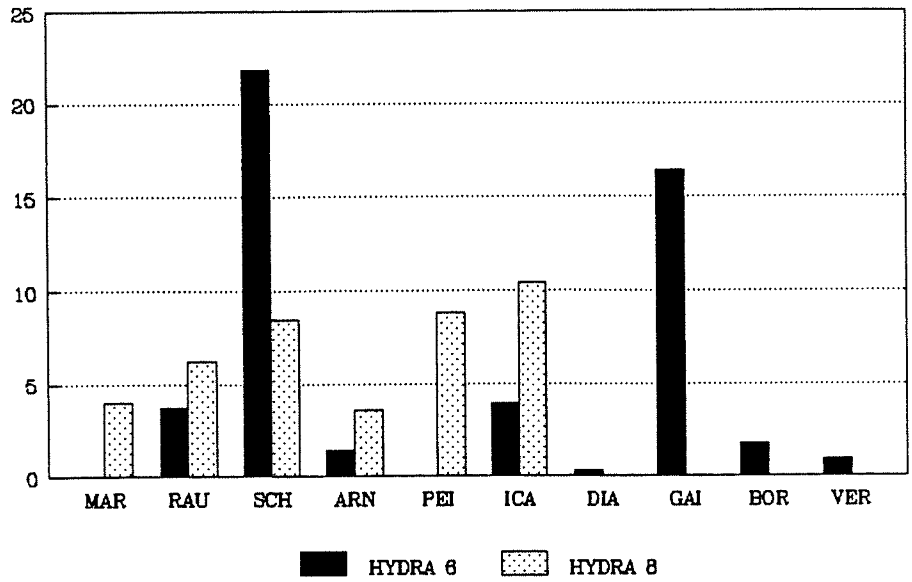


FIGURE 7

Severity degree (action)

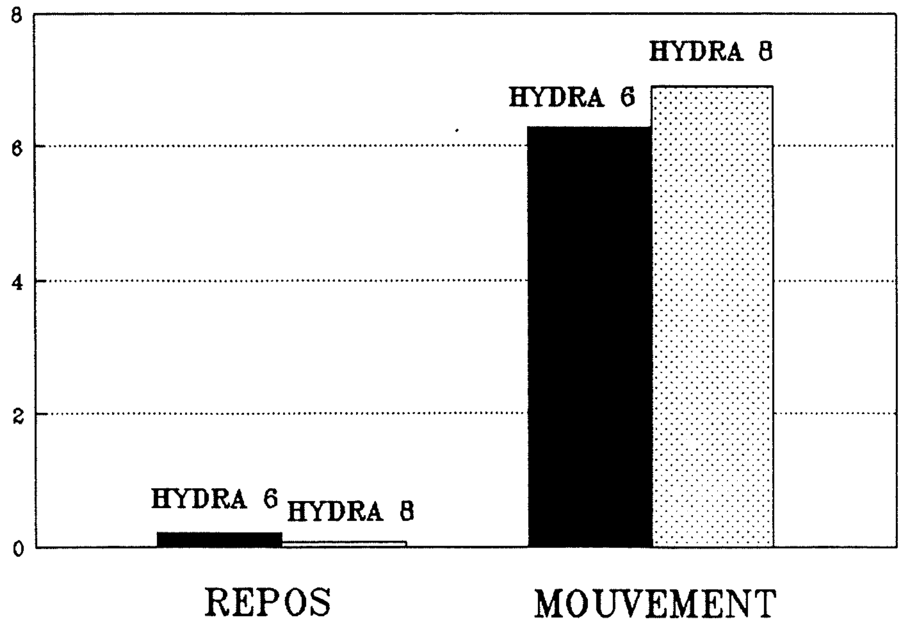


FIGURE 8

Severity degree - Means values

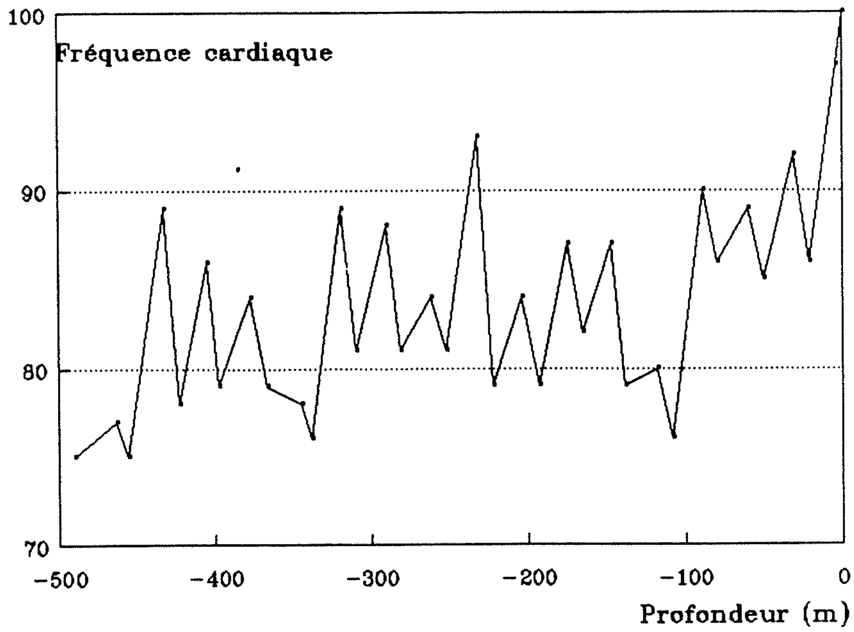


FIGURE 9

Cardiac frequency

Means values in decompression