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Hg Delauze, Maurice Laffont

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by

Maurice LAFFONT
ELF GROUP-PARIS

Henri G. DELAUZE
COMEX - MARSEILLE

Within the framework of its programme "OFFSHORE RESEARCH and DEVELOPMENT", financed by the French Hydrocarbon Assistance Fund, (FONDS DE SOUTIEN DES HYDROCARBURES), ERAP (ELF) was entrusted, in 1963, with the study of man's penetration into the marine environment. The offshore oil exploration and exploitation development requires the frequent intervention of qualified divers, using methods and equipment adapted to the various tasks expected from them.

Our immediate target is the depth corresponding to the limit of the continental shelf, which is approximately 800 ft., but we are already concerned for the time when offshore exploration technique will enable us to tackle the survey and research of the continental slope.

ELF's first attempts were carried out in co-operation with the "GROUPE D'ETUDES ET DE RECHERCHES DE LA MARINE NATIONAL (GERS)", and the "OFFICE FRANCAIS DE RECHERCHES SOUS-MARINES (O.F.R.S.)" in the event of CONSHELF II and III, directed by Commander COUSTEAU.

Saturation Dive

During a 'bounce' dive, the diver is brought back to atmospheric pressure after each dive. His efficiency is indifferent as the time dedicated to work at the bottom is very short in relation with the required decompression time; for example, a one hour dive at 330 ft. (10 atm.) entails a decompression exceeding seven hours. Furthermore, the diver must allow twenty four hours before carrying out another dive if this type of dive is to be repeated daily and successively.

As regards "saturation diving", the divers are permanently maintained under pressure and can carry out two or three dives a day. Decompression is carried out only when the task is finished, and as after 24 hours the tissues of the organism are practically saturated with inert gas, the length of decompression is very much inferior to the total of decompression time which would have been necessary if the divers had been brought back to atmospheric pressure after each intervention. The efficiency is, therefore, greatly improved, the period under pressure being relatively long compared to the decompression time.

The technique of saturation dives was implemented by the U.S. Navy during SEALAB I, II and III in the near future, and by Commander COUSTEAU during the CONSHELF experiments. If, however, the "Houses under the Sea" have led to invaluable knowledge from a fundamental research point of view, they have operational disadvantages due mainly to their fragile and costly submerged structures and their lack of mobility. These drawbacks led us to the idea of maintaining the divers in saturation under pressure, not at the bottom of the sea, but in surface pressurized chambers and transporting them when required to the work site in a pressurized lift or "diving bell".

Several saturation experiments have already been carried out in FRANCE and the U.S.A., in hyperbaric units for simulated dives ashore, and in the open sea, but JANUS has been the first where the divers have been working on a well head at such a great depth and for so long.

JANUS EXPERIMENT

This type of experiment was carried out by the ELF GROUP and COMEX, using the deep diving equipment of the experimental vessel "ASTRAGALE", belong to NARVAL (FORASOL and C.G. DORIS) Society. The decompression chambers were adapted to this purpose after a study carried out by C.G. DORIS and COMEX.

In fact, this experiment included two separate aspects, and its name, JANUS, refers to the shrewd king of Latium whom the Romans represented with a double face.

During the first phase, which may be called the "COMEX Phase", the divers lived for six days under pressure in the surface chambers of the "ASTRAGALE", according to a technique developed by COMEX during fictitious dives carried out in its own research chambers, the divers living at a depth distinctly different from the working depth. These experiments called "LUDION" were carried out in the following conditions:

		CHAMBER PRESSURE (absolute)	BOTTOM PRESSURE (absolute)
LUDION I	1967	5.5 bar (150')	11 bar (330')
LUDION II	1967	9.5 bar (285')	13 bar (400')
LUDION III	1968	10 bar (300')	16 bar (500')

During the COMEX Phase of JANUS, the divers lived at a 10 bar pressure which corresponds to a 300' depth of water. Twice a day they dived to 500' for two hours and were consequently pressurized at 16 bars on each dive. The duration of these dives accrued by the two divers was an average of 34 minutes, during the course of which they performed various preparatory works on the well head. Their work once accomplished, they were hoisted back by means of the diving bell and brought to the initial 10 bar pressure by means of a 120 minute decompression, (20 minutes inside the bell and 100 minutes in the central hatch during undressing and showering).

After the six-day working period, they were decompressed following a table established by COMEX, taking into account the experience acquired during the LUDION experiments.

The second phase of JANUS, which could be called the "Classical" or"GERS Phase", was carried out in a similar fashion to the preceding except for this difference: the divers remained for six days at a pressure which was very close to the working pressure, and the passage from one to the other was carried out by a near instantaneous decompression. Average duration of these dives accrued by the two divers was 52 minutes, during which they performed certain effort and skill tests mainly on an underwater well head installed for this purpose. Once the experiment was over, the divers were brought back to atmospheric pressure by means of a decompression table established by the French Navy "GERS" with the data obtained from CONSHELF III. During the whole course of the experiment, the divers were under continuous medical control.

Both methods present advantages and disadvantages: the aim of Operation JANUS was to make them clear.

Equipment Used

In addition to deep diving equipment studied, manufactured and then adapted to life in saturation by C.G. DORIS and NARVAL, aided by subsidies and loans from ERAP (ELF), the divers of Operation JANUS used the French Navy semi-closed circuit type breathing apparatus, MIXGERS, and the PIEL 6 heating suit, realized within the framework of the ELF marine study program.

The Personnel Involved

Apart from the crew of the ASTRAGALE (approximately 25 men), Operation JANUS involved an important number of personnel from COMEX working around the clock in 12 hour shifts.

- 1 Director of Operations
- 2 Physiologists
- 2 Engineers specialized in gas analysis
- 2 Technicians responsible for decompression programs (Caisson-Masters)
- 1 Chief Diver
- 1 Specialist in charge of gas mixtures
- 2 Saturated Divers
- 2 Stand-By Divers
- 2 Electronicians
- 1 lighting and T.V. technician

It was thus a scientific and operational COMEX team who had the responsibility of carrying out this experiment in a successful manner.

Thanks to the LUDION III rehearsal provided by COMEX in the ELF/COMEX agreement the physiological problems and the decompression programs of the COMEX Phase had been clearly established.

During LUDION III, the working practicalities of deep work had also been defined. Furthermore, thanks to many operational offshore jobs, COMEX has mastered the logistic and human problems of deep diving and has six deep diving units developed in co-operation with C.G. DORIS, in use at the present time in the PERSIAN GULF, the GULF OF GUINEA, the NORTH SEA and the MEDITERRANEAN.

In addition, COMEX's Hyperbaric Experimental Center has achieved nearly 400 fictitious dives from 200' to 700' since 1965 and in 1968 16 man/dives between 1000' and 1200'. It is obvious therefore that the team directing JANUS was perfectly trained for this type of operation, and although it is evident that a great difference exists between operations at sea and those in chambers, we saw that the team sent on board the ASTRAGALE had acquired sufficient routine reflexes to cope with any situation.

Logistics

Operation JANUS was based on the utilisation of the ASTRAGALE, a submarine oil-field multi-servicing ship used to position the ELFOCEAN platform during which operation COMEX divers made 16 bell incursions in 4 days at 330'.

This vessel, with equipment financed by ELF was commissioned by the Society NARVAL (FORASOL - C.G. DORIS). In particular, she is equipped with an ultra-modern deep diving system realized by C.G. DORIS, and serviced by COMEX personnel.

The diving system consists mainly of two large decompression chambers connected by a central lock on which a diving bell may be rapidly fixed, enabling divers to work down to 700'. The bell is immersed by means of a hydraulic "D" frame which swings from a vertical position to the horizontal so as to carry the bell from the deck into the sea.

The bell hangs from an armoured cable wound on to a hydraulic winch. During the ascent and descent the bell is attached by arms to two guide cables kept permanently rigid by constant tension winches. Both these guide cables are moored to the base plate or bottom ballast weighing three tons. The drum of the main winch can hold 1200' of 1" cable. The armoured cable includes three conductors which supply the bell with 10 Kw. of power, and six communication and information conductors.

The cylinder-shaped bell has an internal volume of 160 cu. ft. and is surrounded by 16 bottles of breathing gas or filling gas each having a capacity of 350 cu.ft.

A manifold for the supply and use of breathing gases enables all inside manoeuvres, and the simultaneous supply of gas for two divers or of two divers and a bell supervisor.

The two large surface chambers have a total volume of

480 cu.ft. and are comfortably equipped to accommodate four persons during 15 days. The central lock or wet chamber includes a shower and a W.C. Furthermore, the ASTRAGALE has a compressor and transfer room for high pressure CORBLIN compressors and a manifold for gas mixing which can prepare or retitrate any binary or ternary mixtures and even safely transfer pure oxygen. The chambers and central lock have an elaborate closed circuit air conditioning and regeneration system which controls:

- temperature
- humidity
- CO_2
- Organic Odours
- O_2 %
- N_2 %
- He %

THE EXPERIMENT

Joint Program

The following program was planned: a two hour dive every twelve hours during six consecutive days for each team of two saturated divers.

The work at the bottom was to be carried out by one diver at a time, the second diver remaining in the bell to supervise. After one hour, the diver was to stop his work, enter the bell and his partner was to take over. The work consisted of handling an experimental well head immersed at 500 ft. The divers were to dismantle and reassemble several 140 lb. valves, and then carry out various pressure tests and maintenance jobs. Next to the well head, a work bench was equipped with all necessary tools and underneath, a 70 lb. weight connected to a pulley was provided to enable the diver to carry out pulling exercises in order to study and determine work rates at great depth.

COMEX Program

Life pressure : 10 bar absolute

Work pressure : 16 bar absolute

After each dive, the divers underwent the following decompression:

500' - 340'	:	20 mins. (Inside the bell)
340' - 320'	:	100 mins. (In central lock)
320' - 300'	:	300 mins. (In main caisson)

Owing to the fact that various mixtures were breathed by the divers during the dive and during their life at 300':

- 7% oxygen in the bell
- 7% oxygen during the first 100 minutes of decompression
- 3% oxygen during their life at 300' and during the decompression from 320' to 300',

the living chamber and the bell-lock dressing chamber had to be separated by an opening soft neoprene membrane.

For the preparation of the dive and during the first phase of decompression, the divers used the central lock and the dressing chamber where the percentage contained 7% oxygen. For the rest of the time, they remained in an atmosphere containing 3% oxygen in the living chamber.

After six days of work, the final decompression lasted 65 hours. At 60' the divers breathed air, and from 40' onwards they breathed oxygen intermittently.

GERS Program

All the chambers and the bell contained a 2% oxygen mixture. The system was organised in the same way: one chamber where the divers lived, and one dressing and preparatory chamber. The life pressure was 16 bar absolute. Therefore, no decompression after each dive.

The final decompression lasted 135 hours. At 60', the divers breathed air, and from 40' onwards they breathed oxygen intermittently.

Operation Details

The table entitled "OPERATION JANUS 1968" gives in detail the immersion time of the diving bell and the effective time which each of the two divers spent outside of the diving bell (and consequently in immersion) for each dive, working on the well head.

The principle of the operation consisted, theoretically, of effecting two daily immersions of the diving bell, each lasting two hours. For each of these two-hour immersions, the two saturated divers were to have come out, each in turn, for approximately 45-50 minutes, therefore representing a total immersion time in the region of 90 minutes during a dive of 120 minutes, the remaining 30 minutes corresponding with the time required for the re-surfacing of the diving bell, for the changing over of the divers, and for various logistic operations inside the diving bell for the control of the dive. In fact, the average length of immersion time was not 120 minutes, but 88. The effective diving times were much shorter and the table "OPERATION JANUS" gives the exact duration of these dives and the reasons for which they were not entirely carried out.

It was during the real JANUS Operation that we realized the enormous difference existing between a fictitious operation in a group of experimental chambers (where we have almost managed to meet our objectives) and an operation in the sea.

During JANUS, our principal enemies were the cold, CO_2 build-up, and certain problems associated with the breathing apparatus.

Material and Equipment

We had at our disposal the following working material:

Diving Equipment

The divers were equipped with heated suits, studied and realized by the PIEL Company, in collaboration with GERS and COMEX. This heated suit consists principally of a heated under-garment with a network of veinlets forming an electrical resistance and permitting a power, in the order of 2 to 400 W., to spread over the diver's body. Above this garment is placed a neoprene suit of the "wet" type, but the thickness of this is kept constant under pressure by means of a network of small inter-connected compartments of the "honeycomb" type.

These compartments are kept inflated by a small portable bottle which permits the suit to remain at a pressure slightly above the ambient. On returning to the surface, this suit is automatically equalised so that it does not explode in the course of re-surfacing.

Above this inflatable suit is placed an overall garment which prevents snagging or tearing of the pressurized suit. It has been established that this suit is extremely easy to put on or to take off, but that the hands are still rather poorly protected.

On the other hand, our system of alimentation used during JANUS involves fairly high losses in the line preventing the maintenance of a constant and valid power to the heated under-garment.

Consequently, we were often obliged to adopt an outfit consisting of a PIEL heated under-garment, and a DUNLOP "dry-suit" over-garment.

Besides this, the divers wore woollen clothes between the skin and the heated garment and between the heated garment and the DUNLOP suit. Thanks to these latter arrangements, during the second phase the dives achieved an immersion time in the order of 50 to 70 minutes.

Our divers alternatively utilized a mask and a fibre-glass helmet. This helmet was realized by the PIEL Company, in collaboration with COMEX.

This equipment however had never been submitted to a similar rough operational test, in particular to a rapid pressurization and de-pressurization (in the case of the COMEX Phase), with a humidity at 100%. We had therefore a few mechanical disappointments, but we now know what to do in this field and the co-operation of PIEL has been invaluable.

Two types of breathing apparatus were tested.

The experiment was based above all on the use of a semi closed-circuit breathing apparatus, fed by an umbilical from the diving bell. This apparatus, named MIXGERS, is constructed by the FENZY Society, and has been designed and perfected by the GERS of the French Navy. It allows a saving of helium of approximately 90% compared with the classical open circuit.

It is of a remarkably rugged construction, and we received it from the hands of the French Navy ready to use, and brought to perfection by hundreds of dives. We did, however, experience a few troubles over their employment, but these were due above all to the fact that our divers had never really got accustomed to the intensive usage of this material; in particular, at the beginning of the operation, the loading of soda-lime cartridges left something to be desired.

By the end of the operation, the use of the MIXGERS had become a routine with which everyone was satisfied.

Besides the semi-closed circuit breathing apparatus - MIXGERS, we have made use of a "gas loop" regulator with total gas recovery. This is a breathing apparatus placed on the back of the diver and fed by fresh gases from the supply bottles which surround the diving-bell. It is therefore an open system for inhalation. On the other hand, the polluted gases exhaled by the divers are returned entirely and are discharged into the diving bell. The regulator weight is only 4 lbs. including the harness, and the umbilical is very light.

Of course, the contaminated gases discharged into the diving bell have a tendancy to lower the level of the water in the skirt of the exit; this level however is controlled either manually or by an ultra-sonic level gauge and the diving bell is thus periodically drained by virtue of an umbilical, permitting the total recovery of the gases returned to the surface.

We will come back to the above since this forms part of the whole system of gas recovery from the bottom.

GAS RECOVERY

When we first programmed the experiment a year ago, we estimated the use of 16,000 cu.ft. of helium which would have been entirely lost. Indeed, the equipment of the ASTRAGALE was conceived at a time when the process of saturation was only just beginning to be used, and the major defect of the diving system consists of the fact that it is necessary to evacuate completely the central access lock (the two side main chambers remaining, of course, at the pressure of saturation), each time the diving bell is disconnected for a dive.

Since the beginning of 1968, COMEX engineers have applied themselves to resolving the problem of the recovery of the gases for dives of the LUDION type.

Indeed, for these dives, the surface saturation living level is less than that of the working level, and is about a half or a third of the diving level. For every dive, therefore, it is necessary to complete the filling of the diving bell with Heliox between the living level and the working depth level.

For the re-ascent, it is necessary to bring the diving bell back to the intermediate living level and, to avoid the loss of the gases resulting from this drainage, it is necessary to plan their recovery.

On the other hand, the open-circuit respiratory system with the recovery of the exhaled gases poses equally the problem of the recapture of the contaminated gases brought back into the diving bell.

To save the majority of these expensive gases, COMEX has realized a system called "regeneration and recovery" which consists principally of an umbilical tube linking the diving bell to some very large gasometers which are placed above or below the helicopter platform of drilling ships and rigs. These gasometers are, in fact, reservoirs of from 2000 cu.ft.to 4000 cu.ft., consisting of large neoprene helium proof bags (mattress type).

The control of the discharge of heliox into these bags is carried out by means of a solenoid valve placed on the surface and controlled either manually or by the level gauge of this skirt. Moreover, at the same time taking advantage of the conveyance pressure at the exit of the umbilical, the gases returning to the diving bell are first of all dried by a mechanical filter, then passed over a chemical water absorber and finally into an absorbent canister which filters out the carbonic gas from the contaminated mixture.

The gasometer bags are, of course, at atmospheric pressure although they are capable of supporting an effective pressure of 2 or 3 p.s.i.

Once the dive is finished, the gases stocked in the large storage bags are drawn out by a CORBLIN compressor station and recompressed into high-pressure bottle banks. They are next retitrated into O_2 , H_2, He for re-use.

We have also used this system for the recovery of gases from the central access lock. It can be said that the majority of Heliox mixture which we considered lost in 1967, can now be recovered using this system. (The actual figure achieved was 70%).

CONCLUSIONS

We have learnt many lessons from this operation, enabling us to become fully operational for real undertakings in the future.

Personnel

Up to the present, we have been tempted to underestimate the number of personnel necessary for the realization of operational undertakings in saturation.

At the moment, the very heavy commercial competition which confronts the world-wide diving companies, and the over-bidding which has been made by some of these companies and some of the operating companies, has considerably diminished the deep-sea diving teams employed under traditional contracts on board rigs.

This is carried out in an environment which is too commercial, and to the detriment of the safety and efficiency of the offshore industry deep diving service. It is because of this that the deep-sea diving systems aboard floating drilling rigs are operated by teams not exceeding four or five deep-sea divers on board at the same time.

During a dive, if two of these divers are in the diving bell, there are often only two left on the surface to control the lifting winch, to execute the descent into water and the recovery operation, the mating of the diving bell to the decompression chambers, the checking of communications, the safety precautions etc.....

Here and now, we can affirm that saturation diving does not allow such a reduction of the diving team.

In our opinion, in addition to the saturated divers, it is necessary to have a team including at least the following specialists:

- Head of Operations, responsible for the diving part of the operation only.
- A doctor or a physiologist who is able at the same time to undertake the analyses of gases.
- Two relief divers.
- Two compression chamber supervisors or caisson-masters.
- A gas mixing expert.

With such a team, we are able to utilize the equipment to 100%, and thus work 24 hours out of 24.

COMPARISON OF THE TWO METHODS

Saturation at Working Pressure (or "CLASSICAL")

Advantages

- The divers may be put to work at any time without the worry of anything else but their fatigue. This advantage could be important for short period dives sufficient to carry out the work estimated.
- No necessity to recover the gases in the diving bell on ascent as it is maintained at the same pressure as the surface living chambers.
- Once each dive is terminated, the divers have no need to preoccupy themselves with intermediate decompression and the work of the surface team is also alleviated.

Disadvantages

- Work is only possible within a relatively restricted vertical section around the theoretical depth. This entails therefore extra precautions for the diver, and limits his working possibilities on submerged structures of great height.
- The surface chambers and the diving bell, maintained at bottom pressure, must be extremely resistant for

great depths. The same applies to the regenerating circuit which must function at an increased pressure.

- The final decompression is substantially increased.

Saturation at Intermediary Pressure with Necessary Decompression after each or Repetitive Dives

Advantages

- At very deep working depth (from 5 or 600 ft. up), the inferior living saturation level pressure should give less of a physiological shock. (NOTE: At the end of the "JANUS" Operation, no physiological changes whatsoever were noted on the divers).

- Because of this intermediary surface level, access from external personnel to the saturated divers becomes easier (for example a doctor in case of an emergency).

- Possibility for the divers to work in a less restricted section of water. (From saturated depth equivalent down to working level).

- Surface installations are designed to stand lower pressure, therefore less heavy and less expensive, (important for great depths).

- The final decompression is considerably reduced.

Disadvantages

- The factors arising from the intermediate decompression schedule, increasing with the difference between the working pressure and the living pressure.

- Diving tasks must be programmed for intermediate decompression. This is easy for operations of an average length repeated two or three times per day, but becomes more complex when divers have, in 24 hours, to effect numerous excursions for various periods of time ranging from several minutes to two hours.

- Intermediate decompression may impose the use of a decompression chamber integrated with the main living chamber and eventually, a supplementary breathing mixture. It necessitates more important control and participation from the surface team and a more complicated device for gas regeneration.

- An umbilical should be used if it is necessary to recover the gases lost during each diving bell ascent.

In effect, these two systems seem to be complementary. For average depths (perhaps 300' to 600'), the maintenance at bottom level pressure simplifies the logistic and increases the facility of the interventions. Deeper than this, or for high underwater structure maintenance, it is probable that for both technological and physiological reasons, intermediate decompression is, or will become necessary.

PSYCHOLOGICAL FACTORS

As far as the problem of confinement and their psychological factors is concerned, we have discovered nothing abnormal. One of the two teams remained for eleven days in the chamber complex, and came out in good shape. The atmosphere among the "prisoners" was excellent, and relation with the outer world extremely easy.

DIVERS EFFICIENCY

The efficiency of the divers during their work was more than excellent. Indeed all the tasks foreseen on the well head were carried out in the estimated time and with remarkable precision. The mark given by the specialist from ELF, who was supervising the works on board was 17/20.

LIGHTING AND TELEVISION

We have had to struggle seriously with the problem of lighting and with underwater television. We used six 500 to 2500 W. search lights and three television cameras. These T.V. cameras allowed us to watch the interior of the diving bell, to check the exit and entrance of the divers and to follow them continuously during their work on the well head. In fact, our material was much too sophisticated and too fragile. We found many drawbacks in the UW bulkhead connectors which are available "off the shelf" to the industry, and which are on the whole not very operational and very fragile.

We insist above all on the strength of all this equipment, and on the fact that UW cables and connectors of any value are not yet available on the market for offshore rough servicing.

CAISSONS' ATMOSPHERE REGENERATION AND CLIMATIZATION

We have also had troubles with our air-conditioning equipment and with the surface chambers' environment control system. Thanks to the "COMPAGNIE DES COMPTEURS DE MONTROUGE", we benefitted from a remarkable recirculating helium pump. On the other hand, the de-humidification systems and the temperature controls were not entirely satisfactory. Finally, the soda-lime canisters proved to be too complicated in use, and imposed on our caisson-masters a task which was too exacting.

SURFACE PERSONNEL

The surface personnel behaved perfectly well and although we carried out two twelve-hour shifts, the majority of the personnel was totally occupied for twelve to eighteen hours a day.

The caisson-masters and the gas mixing expert were really overwhelmed with work for a month.

UNDERWATER PERSONNEL

The underwater personnel remained perfectly calm and lent themselves with all willingness to all our behests and tests. They struggled bravely against the cold to the utmost of their abilities.

THE FUTURE

We have learned much and intend to modify various things. We are also certain that we can now currently undertake saturation works between 300' and 700' with an operational logistic which should leave us few unexpected occurrences.

In our opinion, it would have been imprudent of us to launch ourselves into a real operation without having carried out "JANUS" beforehand.