PAPER TITLE: DEEP DIVING: THE COMEX EXPERIENCE

AUTHOR: JP IMBERT, DIVETECH, FRANCE

PUBLICATION: Long term Health Effect of Diving Conference. Bergen, Sept. 15-17, 2005.

INTRODUCTION

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

In 1974, Comex started a computer system to process its diving reports and access efficiently the data. The system was named the Comex diving data base and run until 1993 in Marseille (1).

The source of the information was the paperwork collected from worksites:

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

The baseline justification of the database was to issue accurate company safety records (2). It was used to build a company image of efficiency and safety awareness. It was also used to negotiate the annual fees with insurance companies by helping to document the risks.

The other objective of the database was to develop the company diving procedures. Comex used it to revise its saturation procedures in 1977, 1983 and 1986. Statistical analysis permitted to identify areas of concern and new procedures were sent on selected worksites for controlled evaluation. After positive testing of these new procedures, they were implemented in the revised manuals (3). The database proved to be an efficient scientific tool for model validation and was later used for the design of new air decompression tables for the French government (4). No wonder that when deep operations started in Brazil, the database focused on deep diving and served to monitor the procedures performances.

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

BACKGROUND TO DEEP DIVING

It is a reasonable to define "deep diving» relatively to conventional diving, that is diving to 100-150 m in the North Sea. There, everything is well defined and organized: regulations, qualifications, medical procedures, diving instructions and equipment. At these depths, there is no doubt that the divers are efficient, their time is unlimited, and their services are affordable. For a commercial diving company like Comex, it represented at the time approximately 30,000 hours of work at bottom per year.

However, in the 80’s, diving operations gradually moved to deeper waters in Norway, the Gulf of Mexico and Brazil. The Campos field in Brazil became the scene of routine operations in excess of 200 m. Deeper, everything becomes more difficult: divers must be specially selected and trained, physiology limits their interventions, high performance equipment is required and the concern has raised of possible long term health effects.

SCIENTIFIC DEVELOPMENTS

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

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

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

- The early deep dives were conducted with heliox only. Helium has a low molecular weight but no anti-HPNS property and the pressurization must be slow. In 1972, Comex divers reached 610 m during the PHYSALIE VI dive after 7.5 days of pressurization.
- In 1975, the Duke University introduced the concept of "the pressure reversaI effect", according to which the HPNS can be counter-balanced by a certain amount of a narcotic gas in the breathing gas mixture. Effectively, a reduction of HPNS symptoms was obtained by adding approximately 5% nitrogen in the pressurization gas. In 1981, divers at Duke University reached 686 m during the ATLANTIS III onshore experimental dive.
- During the 80’s, Comex launched the HYDRA program using hydrogen. Because hydrogen is lighter than helium, a large amount of hydrogen can be used without affecting the ventilatory function. The program was conducted steps by steps to increasing depths to master the technology of hydrogen diving. During HYDRA VIII, in 1988, divers demonstrated its feasibility by performing 10 open sea dives to 520 m offshore Marseille. In 1991, a diver reached the depth of 700 in Marseille hyperbaric center, using a hydrogen mixture. It is still the deepest dive ever performed.

EARLY DEEP OPERATIONAL DIVES

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

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

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

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

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

Date	Surface support	Location	Maximum depth	Number of divers	Saturation time	Bell run time
1975	Havdrill	Morocco	254m	6	540 h	4 h
1975	Havdrill	Labrador	326 m	6	2016 h	15 h
1976	Sedco K	Africa	220 m	12	1584 h	13 h
1977	Scarabeo	Libya	273 m	3	576 h	4 h
1978	Talisman	Norway	256 m	4	1536 h	0 h
1982	Stephaniturm	Tunisia	225 m	4	960 h	4 h
1982	Dan Baron	Greece	221 m	2	288 h	12 h
Total				39	7500 h	88 h

COMEX EXPERIENCE IN NORWAY

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

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

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

Table 2: Summary of Comex experience with Norwegian contracts.

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

These contracts were extremely important because:

- they permitted to fill the gap between experimental and operational diving. They set the first standards for deep operations and permitted the development of an adequate technology.
- they came right before the beginning of the deep operations in Brazil and allowed to transfer the know-how from Norway to Brazil.

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

OFFSHORE OPERATIONS IN BRAZIL

The Campos field

The Campos offshore basin is the most important Brazilian oil province, producing oil since 1977 and being responsible for 60 % of the national production. The operational headquarters supporting

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

The regulations frame

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

The Comex operations

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

Table n° 3: Summary of Comex deep saturations in Brazil over the period 1983-1990.

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

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

Table n° 4: Summary of Comex deep dives in Brazil for the period 1983-1990.

Depth range	Number of bell runs	Total bell run time	Average bell run time	Total divers time in water	Average divers' time in water
200-250 m	628	6312 h	10h03	2677 h	4h15
250-300 m	150	1656 h	11h04	512 h	3h24
300-316 m	80	638 h	7h54	210 h	2h36
Total	858	8606 h	10h02	3399 h	3h57

Two remarks can be made:

- The amount of work is impressive. It does not bear any comparison with the rest of the deep diving operations around the world.
- The depths reached are important. The average deep operations are around 240m to 260m. On two occasions, Comex was called at the Pirauna location and prepared interventions at 386 m and 411m. However, these dives were cancelled at the last moment, one because of a sailors' strike and the other because of the faultless diverless completion of the well.

The saturation system

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

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

.

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

The diver's equipment

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

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

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

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

The divers involved

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

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

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

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

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

The medical controls

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

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

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

The procedures used

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

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

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

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

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

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

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

DISCUSSION AND CONCLUSION

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

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

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

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

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

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

REFERENCES

1. Imbert JP, Montbarbon S. Presentation of the Comex Diving Data Base. European Undersea Bio-medical Society Workshop on Operational Dives and Decompression Data. Amsterdam, The Netherlands, 11-18 August 1990.
2. Imbert JP, Montbarbon S. Use of the Comex Diving Data Base. European Undersea Bio-medical Society Workshop on Operational Dives and Decompression Data. Amsterdam, The Netherlands, 11-18 August 1990.
3. Imbert JP, Bontoux M. Diving data bank: a unique tool for diving procedures development. 20th Annual Offshore Technology Conference, Houston, Texas, 2-5 May 1988.
4. Imbert JP, Bontoux M. Safety analysis of French 1974 air decompression tables. Undersea and Hyperbaric Medical Society Workshop on Decompression in Surface-based Diving. Tokyo, Japan, 11-12 September 1986.
5. Imbert JP, Irrmann JF and Macchi F. 316 m offshore in Brazil: background of a successful deep dive. Proceedings of the XVIIIth European Undersea Biomedical Society. Basel, Switzerland, 15-19 September 1992.