Deep diving limits using heliox as a beathing mixture

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DEEP DIVING LIMITS USING HELIOX AS A BREATHING MIXTURE

COMEX VERY DEEP DIVES
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by

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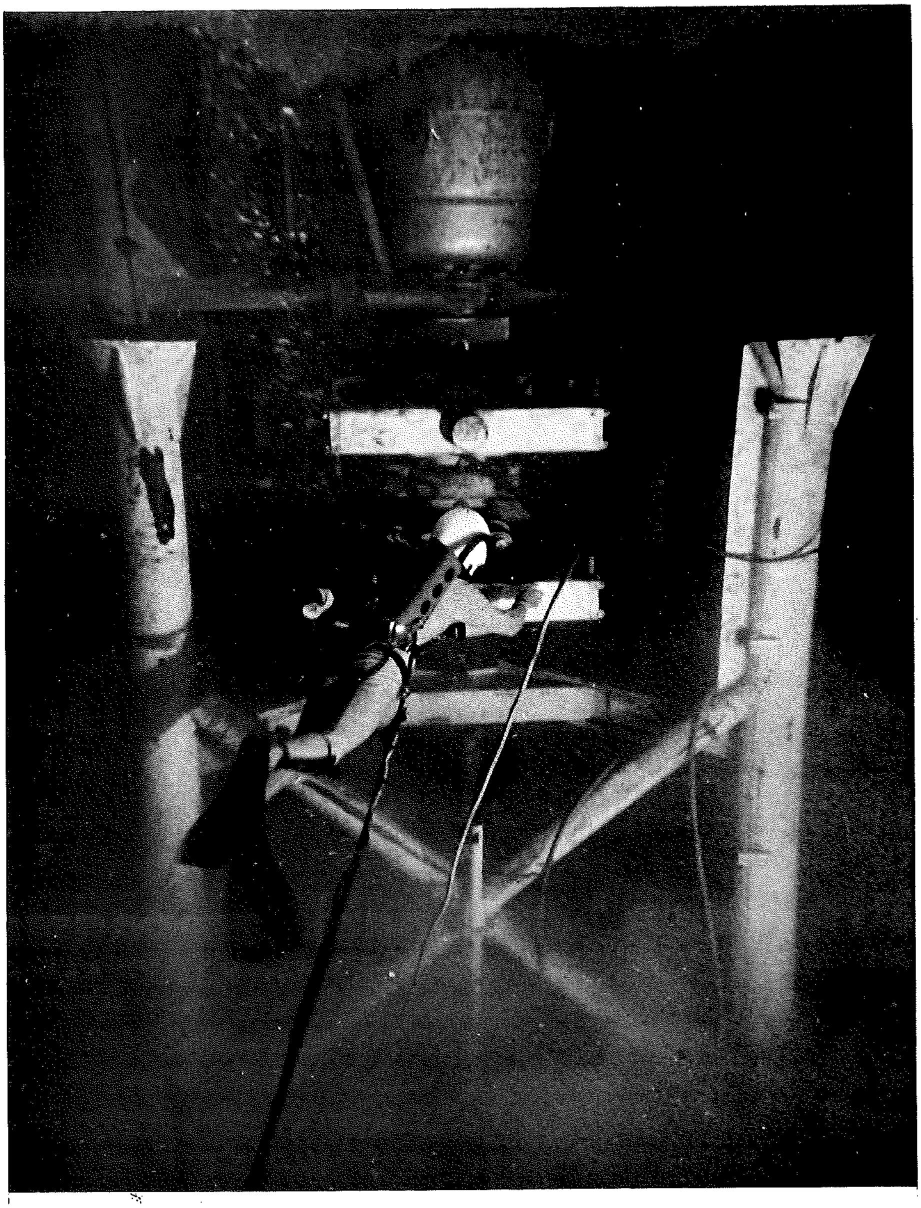


SUBAQUATIQUE - ASSISTANCE OFFSHORE - PLONGÉE PROFONDE ET CLASSIQUE - RECHERCHES HYPERBARES
ENGINEERING - DIVING - ASSISTANCE FOR OFFSHORE INDUSTRY - DEEP OCEAN SYSTEMS - RESEARCH

At the beginning of 1968, the depth of 1000 ft. had been reached during several fictitious dives, and one true dive by KELLER in 1962. We decided, therefore, to undertake a research programme on the possible limits of the utilization of mixtures based on helium between 1000 ft. and 1200 ft.

Deep diving with gas mixtures down to 800 ft. no longer raised serious physiological problems. The various difficulties still arising are of a technical and logistic nature, especially at sea.

The same did not apply to dives made to greater depths and therefore greater pressures, referred to as very deep dives. This is for two reasons:

1 - During the descent and the stay at the bottom, the diver may show nervous disorders whose progression may result in a state of crisis, certainly dangerous in itself, and may be also in its consequences.

2 - During the ascent, the decompression of an organism saturated by a more or less inert gas at such high pressures could give way to accidents if we applied desaturation tables valuable for shallower dives.

Our research, and our progress on the way to very deep depths have benefited from the results of experiments carried out by Dr. R. W. BRAUER of DUKE UNIVERSITY.

With reference to his works, we briefly outline the reactions observed on animals submitted to high pressures:

Mouse	(at 60 atmospheres	: modifications of E.E.G.
	(at 90 atmospheres	: Convulsions

Monkey	(at 25 atmospheres	:	Trembling
	(at 40 atmospheres	:	Modification of E.E.G.
	(at 55 atmospheres	:	Convulsions

The animals were breathing a mixture based on helium in which the level of O_2 was reduced to such a point that would avoid the occurence of phenomena of hyperoxic origin (which would have made the experiment valueless).

However, if a subnarcotic dose of nitrogen were added to the breathing mixture of the mouse, convulsions only appeared at 135 atmospheres.

Our observations on man appear to confirm what R. W. BRAUER was the first to show on animals: that there exists a difference, not only of degree but also of nature between the helium action and that of other gases called "inert", which may be used as oxygen diluents. Although these gases have an anesthetic effect, helium acts first of all as a stimulant.

It is also possible that these stimulation phenomena are due to the pressure itself, and that helium only provokes them due to its slight narcotic power.

Other gases having a greater anesthetic effect, act to a certain extent as antidotes of pressure, and, as stated at the beginning, nitrogen added in subnarcotic doses to the heliox breathed by the mouse, elevated the convulsion threshold from 90 to 135 atmospheres.

The second point concerns the elaboration of the decompression tables.

Our method of calculation should take the form of a working theory extremely prudent and subject to modifications, the consequence of previous experiments where each ascent was accompagnied by signs of the forming of bubbles.

We benefited from an experiment of heliox tables (360 dives/tests from 150 to 800 ft. and around 400 operational dives to depths ranging from 250 to 400 ft.)

These tables were calculated from the WORKMANN method published in his Research Report of the U.S. Navy in June 1965.

The seven fictitious very deep diving experiments took place in our Hyperbaric Centre in the great chamber with diving-tank. During the decompression, from 400 ft., the divers were able to transfer from this chamber to a 'living-room', for the last days of the decompression period. The system allowed fictitious dives down to a depth of 1250 ft.

The first three experiments gave us this information regarding very deep dives:

- a more accurate assessment of reasonable and safe speeds of ascent and descent.

- reassuring information on the behaviour of divers breathing heliox, and environment conditions which are exceptional up to this day.

- new notions on the difficulty of finding valid tests as well as on the probable value of the E.E.G. recordings.

- a few notions on vertigo appearing during descent.

The first series also brought information only obtained by experience. For example, the handling of the hyperbaric enclosure, gases, recordings, the supervision of subjects in the chamber, their food and comfort, CO_2 control etc......

Having done all this preliminary work, we wer a position to undertake the second part of our programme, PHYSALIE I, II and III, prelude to HYDRA.

The second series of experiments was composed of four dives, approaching deeper depths, in preparation for HYDRA.

PHYSALIE I - 1100 ft. - May 21st 1968

Divers: H. G. DELAUZE - President, COMEX,
Dr. R. W. BRAUER

Time of dive, including descent : 123 minutes.

Time spent from 1000 ft. to 1000 ft. (ascent and descent) : 24 minutes

Total time of ascent : 97 hours 33 minutes

Breathing mixture on bottom : O_2:2.6% N_2:4% He:93.4%

Ascent under a PiO_2 of 0.5b from 500 ft.

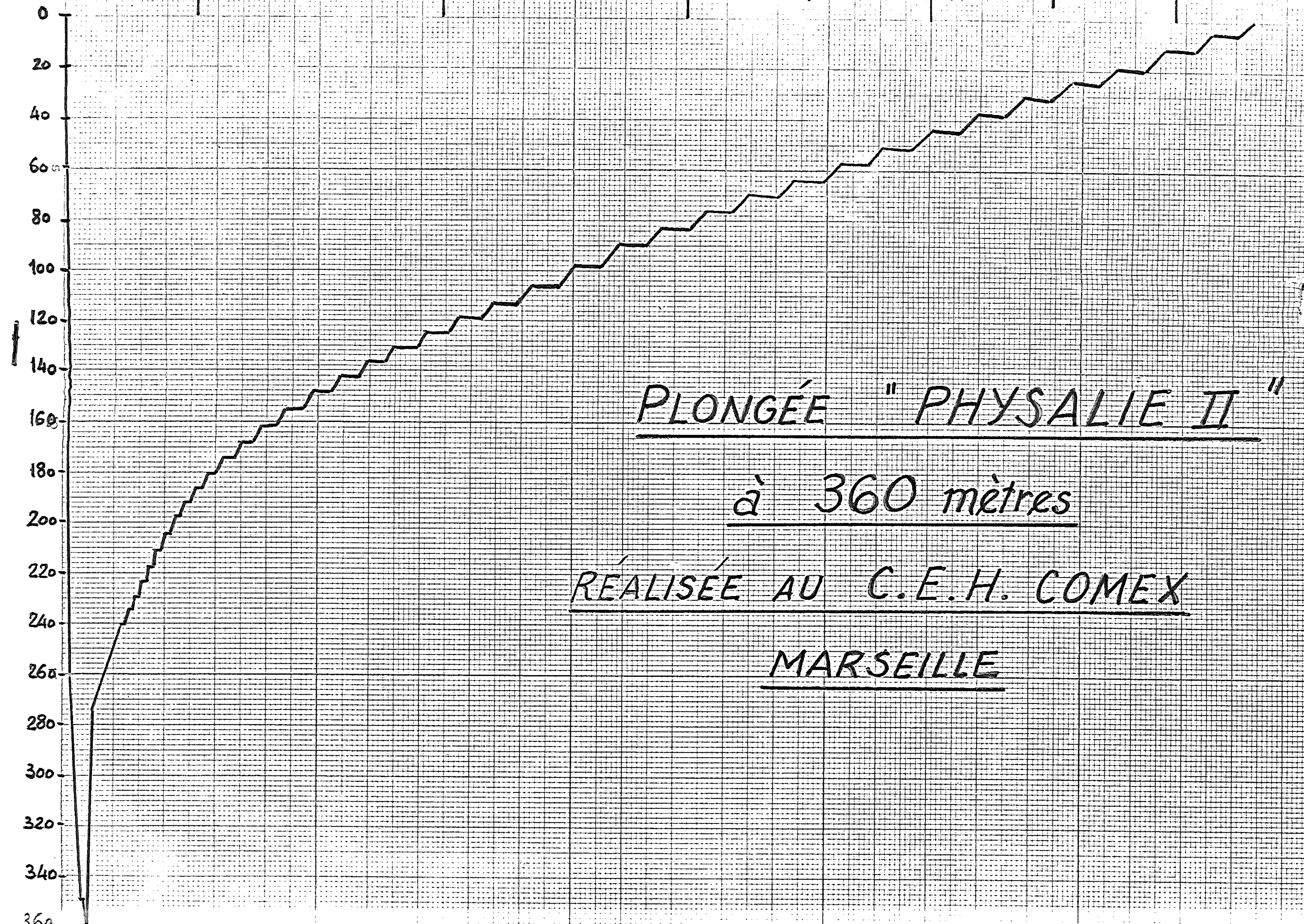
Air from 60 ft. : pure O_2 one third of time from 30 to 0 ft.

Descent speed : 17' to 3,5'/min.

Average speed of Ascent : 2.2"/min.

The main features of this dive were :

- Excellent behaviour of both subjects from the psycho-motor point of view. H.G.D. in particular showed no lengthening of his choice reaction time. When handling the bell manifold, he carried out the operation at 1100 ft. as easily and rapidly as on the surface, adapting himself to all situations.


PLONGÉE " PHYSALIE II "
à 360 mètres
RÉALISÉE AU C.E.H. COMEX
MARSEILLE
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

- HGD showed a certain feverishness (but resumed his self-control and calm when immersed) but no trembling.

The reassuring results of this experiment, added to those of the previous ones, allowed us to try for deeper depths.

RV showed only very slight trembling from 1000 ft. during PLC I, and Dr. BRAUER's "Helium Tremor" during PHYSALIE I was only appreciable beyond 1000 ft. We would, therefore, hope that next time, a team composed of BRAUER and RV could, without too great a risk, dive to 1180 ft., under the condition that they would both be under E.E.G. control and that precautions be taken to prevent the traumatic consequence of eventual convulsions, (protecting helmets, padding of sharp parts in the chamber, completely covered pool etc...)

PHYSALIE II - 1180 ft. - 11th June 1968

Divers: R. W. BRAUER
R. VEYRUNES

Time of dive including descent : 120 minutes

Time spent from 1000 ft. to 1000 ft. (descent and ascent) 77 mins.

Total time of ascent : 114 hours 31 minutes.

Breathing mixture on the bottom : O_2 : 1.8% N_2 : 4% He : 94.2%

Air from 60 ft. : pure O_2, from 30 to 0 feet.

Speed of descent : 20' to 8'/minute

Average speed of ascent : 2"/minute

There were several similarities between this dive and the previous one, however:

- The trembling fits, the fasciculations, the difficulties in movement co-ordination were more apparent in RWB.

- The sleepiness, more apparent with RV occurred around 1120 ft. This phenomenon had never been so visible before reaching 1100 ft.

- This sleepiness showed the characteristics of disappearing during activity, especially during mental tests, and reappeared as soon as the subject's attention slackened.

- The E.E.G. revealed much more than the clinical aspect. Alterations appeared quite soon (750 ft.) The disorders increased with the depth, persisted at the beginning of the ascent and only disappeared at about 800 ft.

- From the psycho-emotional point of view, no anxiety or over excitement, but around 1000 ft. a progressive aboulia. Beyond 1120 ft. the impression that it would be dangerous to carry on, but no effort to ask by sign or in writing to stop.

PHYSALIE III - 1200 ft. - 27th June, 1968

Divers: R. W. BRAUER
R. VEYRUNES

Time of dive including descent : 127 minutes

Time spent from 1000 ft. to 1000 ft. (ascent and descent) 111 minutes.

Total time of ascent : 138 hours 34 minutes.

Breathing mixture on the bottom : O_2 : 1.9 N_2:5% He:93.1%

Air from 90 ft. : pure O_2 one third of time from 40 to 0 ft.

Descent speed : 20 ft. to 1.5 ft/minute

Average speed of ascent : 1.8"/minute.

The main features of this dive were:

- a descent slower than before, with a pause of one hour at 600 ft.

- probable consequence of these precautionary measures: reduced motor troubles in the divers (unimportant trembling, slight dysmetry, slight balance troubles, without dizziness).

- drop of alertness, when resting from 700 ft. both divers putting the blame on the motionless state required for E.E.G. recordings. This is correct as this immobility (closed eyes, open eyes) should act as a detector of sleep tendencies.

- normal performances down to 1000 ft. The test consisting of the complex handling of the bell manifold were executed apparently as correctly as on the surface by JD and FF.

- more or less normal E.E.G. until maximum depth.

In short, a H.P.N.S. reduced to the simplest expression

With this technique, and with the acquired knowledge, we now consider diving to 1000 ft. in a chamber as a matter of routine, and used this as training for the divers who intend to perform OPERATION HYDRA

After having approached the limits of very deep diving with heliox - limits indicated by the HIGH PRESSURE NERVOUS SYNDROM - whose possible evolution was rather alarming, and reassured by BRAUER's extensive experiments on animals, we decided to use hydrogen.

It was necessary that this gas be tried at first as only one dilution (mixture hydrox with 2% O_2 in order to test its own action from 650 ft.)

However, because of its explosive properties, (extremely dangerous in an enclosed space), it was preferable to test it in the open sea, in a special "aerium" coupled together with a diving bell.

This led to "OPERATION HYDRA", sponsored by C.N.E.X.O. (French National Centre for Ocean Exploitation) which took place on board the drilling ship "ASTRAGALE", on the 28th October, 1968, offshore CASSIS (near MARSEILLES).

ASTRAGALE's SDC/DDC allowed a pressurization to 21 Ata and descents down to more than 700 ft. Our divers were trained in it, having used it for four weeks during "OPERATION JANUS", diving dozens of times to 500 ft.

However, for HYDRA this proved to be difficult, due to:

- the necessity for medical observation and E.E.G. recordings and the performance of tests under water at such depths.
- the duration of immersion - requiring a highly efficient protection system against cold.
- the gas supplies needed on the bottom due to the consumption of the 'open-circuits'.

Several months preparation were needed to find a solution to the various problems.

The transmission of the divers' E.E.G. was made through a 1200 ft. cable. The tests were excellent. The lighting and monitoring by television both inside and outside the bell worked perfectly. Thanks to these, and to the plexiglass window on the outer seat, the security of the divers was always ensured. Although difficulties arose causing the interruption of the operation, they were never really in danger.

Equipment against cold has been studied at length. This did not work perfectly, due to the usual technical faults often made with proto-types.

The CO_2 problem was posed when the divers were forced to return inside the bell because of the cold.

However, during the operation, the two divers were able to leave the bell, RV performing complicated works for 30 minutes at a depth ranging from 600 ft. to 820 ft. This, apart from the short KELLER exit at 1000 ft. had never been performed before.

This operation could have continued to greater depths if our goal had been to obtain a world record. As the goal was to test a new gas mixture, we preferred to stop the experiment at 820 ft.

Once more, and we are not the only ones in this case, we have realized the difference between experimental conditions in chambers and actual conditions in open waters.

It is, however, thanks to these fictitious dives that our three divers have realized in open waters, a world premiere, even if hydrogen was not used at these depths, and ascended without any trouble mastering all unforeseen difficulties.

Three days later, the divers left the chamber having passed a relatively fast decompression period without the slightest incident.

GENERAL CONSIDERATIONS AND CONCLUSION

We went deeper than 1000 ft. in 1968. Like our colleagues of ZURICH, WASHINGTON and MURRAY HILL, we wanted to know if it was possible for a man to stay (and later on to live) at these depths.

We haven't sufficient time to fully explain the results of all our experiments, but the following are the most notable:

- When breathing heliox, the effect of pressures on man's central nervous system is much more pronounced when the pressure is higher or when the rate of pressurization is greater.

- This action causes a series of manifestations we have already described as the HIGH PRESSURE NERVOUS SYNDROM (H.P.N.S.) summarized as follows:

a) Motor troubles, especially trembling fits (BENNET's "Helium Tremor") dysmetry (lack of precision and of co-ordination of movements) and balance disturbances.

b) A fall of alertness, tending to a complete lack of interest, slowing down of understanding and actions, sleepiness.

c) Premature modifications of the E.E.G., slight at the beginning, becoming more important with the depth. These tracings, alarming as they correspond neither with normal sleep nor with anesthetic sleep have a tendency to persist at the beginning of the decompression period. Generally, they disappeared after 800 ft.

Up to the pressures already reached, the H.P.N.S. evolution proceeds in three steps, the main features of which are:

: trembling from 21 Ata,

: reducible drowsiness and sleep on E.E.G. at 30 Ata,

: more clinical observations, with alarming anomalies from 34 Ata,

: more accentuated clinical table and alarming E.E.G. anomalies from 34 Ata.

Of course, these nervous disturbances may depend on the subjects and especially be attenuated or delayed by very slow pressurization. For example, this was the case for diver JD, 25 year old engineer, whose handwriting showed signs of trembling as soon as 700 ft. during his first experiment to 900 ft. and proved his state of confusion. But during his second dive to 1000 ft., he wrote normally enough to note a mathematical calculation correctly. The first dive descent was done in 80 minutes, the second being done in 180 minutes, with a one hour pause at 600 ft.

What would happen at deeper depths? We don't yet know, but we may affirm two extremely important things:

1. The H.P.N.S. observed in a heliox atmosphere (slightly hyperoxic) has nothing to do with a narcosis phenomenon with "heavy" gases, nitrogen, argon, xenon.

2. The narcosis due to these gases does not appear much on E.E.G. tracings, whereas the E.E.G. modifications come early, are very important, and consist of a precious alarm signal long before the condition of the subject becomes disturbing.

The problems of ascent from deep depths are, we think, practically solved. This is very fortunate as the decompression risk are great.

The satisfactory results of the PHYSALIES decompression process allows us to think that we have mastered this part (the last but not the least of very deep dives).

These facts allow us to state that the CONSHELF - 1000 ft. - is within our possibilities:

- We know that below this depth, the general physiological and nervous adaptation of selected men is possible.

- We have mastered pressurization and decompression (at least with helium). These two operations imposing a minimum strain on the divers.

At the present time, the only obstacles are of a technical kind: manipulation of instruments, anchorage of ships, or of submarine bases, visibility, guiding, and, above all, the two fields in which HYDRA proved that we were insufficiently prepared:

- the strict control of the respirable atmosphere in the inhabited [illegible], and the protection against cold.

To descend to deeper depths, we should study new breathing mixtures. This is where hydrogen comes in, for its depressing power on the central nervous system opposed to the different power of helium under pressure, and because of its low specific gravity.

The following table shows the importance the specific gravity may have on respirable mixtures under high pressures:

Depths	P (ata)	% O_2	% N_2	% He	% H_2	S.G. (g/nl)	A.E.D.[x] (M)
100	11	2	98			13.8	97
300	31	2	3	95		7.35	46
300	31	2		98		6.30	39
300	31	2		49	49	4.96	28
300	31	2			98	3.63	18
365	37.5	2	3	95		8.8	58
365	37.5	2		98		7.6	49
365	37.5	2			98	4.4	24
500	51	1		99		9.61	64
500	51	1			99	5.28	31
500	51	1		40	59	7.1	45
600	61	1			99	7.2	45

Advanced incursions are of little interest to us. The efficiency of the divers is the only proof of whether the depth is well and truly controlled.

[x] A.E.D. : AIR EQUIVALENT DENSITY

The density of the mixture at these depths will be such that the divers would be perhaps only capable of a slight physical effort.

We have reached and passed 1000 ft. with heliox. The object of our actual programme is to study the possible adaptation of man at depths ranging from 1000 to 2000 ft.. The principal episodes of this programme will be:

1. The study of effects of high pressures and various gas mixtures on cells, animal tissues, elementary beings, and isolated organs.

   This will correspond with a fundamental research which has already been undertaken by several American research workers.

2. The study of effects of high pressures and various gas mixtures on superior mammals, especially the "papio-papio" monkey.

   This experiment will lead to a better knowledge of the H.P.N.S. and of limiting life factors under high pressure (pressure by itself, helium, other gases, hydrogen).

3. Continuation of PHYSALIES dives, benefiting from experiments carried out on monkies, and hydrogen tests in the special design chamber which allows dives down to 4000 ft.

   Perfection of decompression tables for very deep dives using various mixtures (four different gases, hydrogen, helium, nitrogen, oxygen).

   Perfection of techniques and equipment for very deep dives in the open sea.

   Training of dives in a spherical chamber, 15 ft. in diameter, filled with water, into which a diving bell will be submerged, enabling us to create conditions of a true dive down to 1000 ft.

Sea operations will follow these experiments, and will, we hope, be in general industrial use within the very near future.

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