13

Hydra 8: Pre-commercial Hydrogen Diving Project

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Deep divers are exposed to three types of environmental stresses:

- the high-pressure nervous syndrome (HPNS), which is related to the effects of the hydrostatic pressure on the central nervous system. These appear at around 200 m and increase with depth, causing motor disturbances that may impair divers' efficiency.
- stress caused by the density of the breathing mixture, which increases with depth. Breathing dense gas requires increased ventilatory efforts that may reduce divers' work capacity.
- the fatigue of long saturation periods (confinement, thermal stress, bad sleep, lack of appetite, etc.) that is generally related to body-weight losses.

To overcome these environmental stresses, scientists have used the properties of the different constituents of the breathing mixtures.

The first deep dives were conducted using helium as a diluent. Helium has a low molecular weight but no specific anti-HPNS properties. The only way of controlling HPNS was to slow down the compression. In 1972, helium permitted 610 m to be reached during the Comex *Physalie VI* dive.

In 1975, Duke University introduced the concept of the 'pressure-reversal effect' (Simon *et al.*, 1975). A significant reduction in HPNS was obtained by adding to the helium/oxygen mixture a given amount of a narcotic gas, in that case nitrogen. The new mixture was called 'trimix', but we would rather call it 'nitrogen trimix' to be more specific.

The possibilities of nitrogen trimix were further investigated by different research centres. The two milestones of these experiments were the Comex *Janus IV* open-sea dive to 500 m, in 1977, and the Duke University *Atlantis III* simulated dive to 685 m, in 1983.

However, the benefit of using nitrogen to reduce HPNS is counterbalanced by a significant increase in gas density (nitrogen is seven times heavier than helium). During the *Janus IV* dive, the breathing gas, which contained 5% nitrogen, had a density of 10.5 g/litre. It would have been 8.2 g/litre with heliox (22% less). For this reason, a large amount of nitrogen cannot be used without affecting the diver's ventilatory function.

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COMEX *HYDRA* PROGRAMME

The idea underlying the *Hydra* programme was to investigate a new diving gas that would be both light and narcotic. The only possibility left in the Mendeleev table was hydrogen!

Since 1983, four onshore dives using hydrogen have been conducted at Marseille Hyperbaric Centre in collaboration with the US Navy (NMRI), the Swedish Navy (NMD), the French Navy (CERB, CEPISMER, GISMER, CERTSM) and the Centre National de la Recherche Scientifique (CNRS).

The final aim of this programme is to demonstrate the operational feasibility of hydrogen diving with a deep, open-sea dive. The code name of this dive will be *Hydra 8.*

This paper is intended to present the studies and the developments that have permitted Comex to step from the onshore experimental phase to the offshore operational phase of deep hydrogen diving.

ANIMAL STUDIES

Although hydrogen is a very active chemical element, previous experiments with monkeys had shown that hydrogen could be considered as an inert gas from a biological point of view (Brauer *et al.*, 1966; Rostain, 1973).

Comex carried out complementary studies to confirm that hydrogen is a non-toxic molecular gas. In a first series of experiments, 40 mice were exposed for 48 hours at 600 m, breathing hydrogen/oxygen. Comparison with a reference group exposed to helium under the same conditions showed neither behavioural change nor any histological sign of toxicity.

Further experiments were then performed at extreme depths to determine any possible limit to hydrogen use. A group of 120 mice was exposed to depths ranging from 1300 to 2000 m, either with helium or hydrogen. The survival rate at 1800 and 2000 m was much higher with hydrogen than with helium, which tends to prove that hydrogen does not develop any toxic effect up to these depths (Gardette, 1986).

Depth (m)	Helium	Hydrogen
1800	60%	0%
2000	100%	60%

Fig. 1 Fatality rate among mice exposed to extreme depths, breathing either helium or hydrogen mixtures.

MANNED HYDROGEN DIVES

Following the animal studies, hydrogen diving appeared safe and practical in the depth-range that covers human intervention. In June '83, 18 persons,