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Norwegian Deep Diving Trials [and Discussion]

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Phil. Trans. R. Soc. Lond. B 1984 **304**, 143-149
doi: 10.1098/rstb.1984.0015

Phil. Trans. R. Soc. Lond. B **304**, 143–149 (1984) [143]

Printed in Great Britain

Norwegian deep diving trials

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In 1983 NUTEC, together with two diving companies, completed two dives with 12 divers (6 in each dive) to pressures equivalent to 350 m s.w., one dive lasted for 17 d, and the other, 24 d. The purpose of the dives was to demonstrate that the diving companies were prepared for diving to 300 m depth in the North Sea.

No major medical or physiological problems arose during the dives, although all divers had minor symptoms of high pressure nervous syndrome during compressions. During decompression three decompression sickness incidents occurred, which involved pain only, and all were successfully treated. All divers went through comprehensive medical physiological examinations before and after the dives. No significant changes from values measured before diving have been found in the six divers who have so far been examined after diving, except that five of them were considerably more sensitive to CO_2 after the dive than before.

Several problems arose in connection with the divers' breathing equipment, thermal protection and communication, which need to be improved.

Introduction

In 1980 NUTEC started a deep dive series called 'Deep Ex'. The first dive (Deep Ex I) was to a pressure equivalent to 300 m s.w. Six divers participated in this 20 d dive, which contained twelve research projects. Deep Ex II, a 34 d, 500 m dive was ambitious and highly complex, and was completed in the autumn of 1981. Six divers took part, five of them professional divers and one research worker with diving experience. Four of the six had participated in Deep Ex I. Deep Ex II contained fifteen research and development projects, not only physiological and performance experimentation in the dry, but also activities in water with full life support. These included tungsten inert gas and electrode welding with environmental monitoring, both Trimix and Heliox compressions, and parallel saturation decompressions. Before, during, and after the dive, the divers completed a range of neuropsychological tests, which included baseline e.e.g.'s. In addition, O_2 comsumption was measured during maximum work on a bicycle ergometer, respiratory functions such as vital capacity, forced expiratory vital capacity and 15 s maximal voluntary ventilation were recorded. Baseline electronystagmography including bithermal caloric tests were performed. Individual cooling rates were determined with the divers immersed in water at a temperature of 18.5 °C.

Based upon the results of the two Deep Ex dives it was concluded that further research and development would be necessary if practical diving operations are to be performed at depths ranging from 300–500 m s.w.

In 1983 NUTEC, together with two diving companies, completed two dives to pressures equivalent to 350 m s.w., one dive lasted for 17 d, and the other for 24 d. The purpose of these dives was to demonstrate that the diving companies will be capable of diving to a depth of 300 m for a particular commercial task.

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Methods

Before the dives, NUTEC had completed extensive unmanned testing of two different breathing masks with gas reclaim systems, which were to be used. The tests using a breathing simulator were made at different depths, ventilation rates, minute volumes and CO_2 injections.

Sixteen professional divers were selected by the two diving companies before the start of the dive. All divers had extensive medical and physiological evaluations in the period starting approximately four weeks before the dive. The examinations were repeated, when possible, during the dives, one month after the dives, and will be repeated one year after their completion. The evaluation included the following factors.

(*a*) Neuro-psychological system. The neuro-psychological tests were the same as those used during Deep Ex II (Vaernes *et al.* 1982).

(*b*) Neurological system. A comprehensive neurological examination including a 16 channel e.e.g. was completed.

(*c*) Cardiovascular system. Maximum oxygen uptake was measured by using graded exercise in steps of 50 W of 6 min. duration. Anaerobic threshold was evaluated by obtaining 50 μl of capillary blood at the end of each step and 6–8 min after exhaustion. Stress electrocardiogram was recorded during the test for maximum oxygen consumption.

(*d*) Respiratory system. Maximum voluntary ventilation, forced expiratory vital capacity and vital capacity were measured with a spirometer. Control of ventilation was determined by recording the diver's sensitivity to increasing concentrations of CO_2 and decreasing concentrations of O_2. Alveolar gas transfer was calculated from the CO diffusion capacity from a single breath method.

(*e*) Ear-nose-throat. Standard clinical investigations including audiogram were performed. By using caloric stimulation, the sensitivity of the vestibular system was tested by recording the electronystagmogram.

(*f*) Blood. Standard clinical blood chemistry and haematology were performed.

(*g*) Urine. Urine biochemistry was investigated by using a stix method and the urine sediment was investigated microscopically.

Test procedures

Chamber 4 (figure 1) was partly filled with water, with a dry and wet section to simulate a wet dive from a diving bell. The water in the chamber was cooled to temperatures equivalent to those encountered during work in sea water. Each diver worked for approximately 4 h on the test rig, thereby simulating actual periods from a diving bell.

The test rig was designed to include various work tasks: light and heavy physical work, with manual tools; short periods of swimming; quantified heavy arm work and the carrying of sandbags; tests of psychomotoric and cognitive performance (to simulate inspection work).

The test rig consisted of a steel framework 225 cm long, 140 cm wide and 145 cm high. A pipeline, mass 400 kg, 250 cm long, with a diameter of 50 cm, was mounted with flanges in the test rig. The pipe was lifted with two manual tackles. The valves consisted of three parts, which were dismantled and reassembled in a fixed sequence. For both the pipe and the valves, washers were included, which made it possible to pressurize both systems and check for gas leakages after the assembly (Vaernes *et al.* 1983). An arm ergometer was included in the test rig with which the divers lifted a 25 kg weight 30 cm above the floor by pulling a bar up to their chest with both hands. The psychomotor test consisted of two periods each lasting 5 min. The trapeze was mounted above the frame of the test rig and the divers swam against a resistance corresponding to 1.85 km h^{-1}. This resistance was produced by having two weights, 2.5 kg each, which the divers lifted from the floor by pressing the trapeze against a vertical stick while swimming.

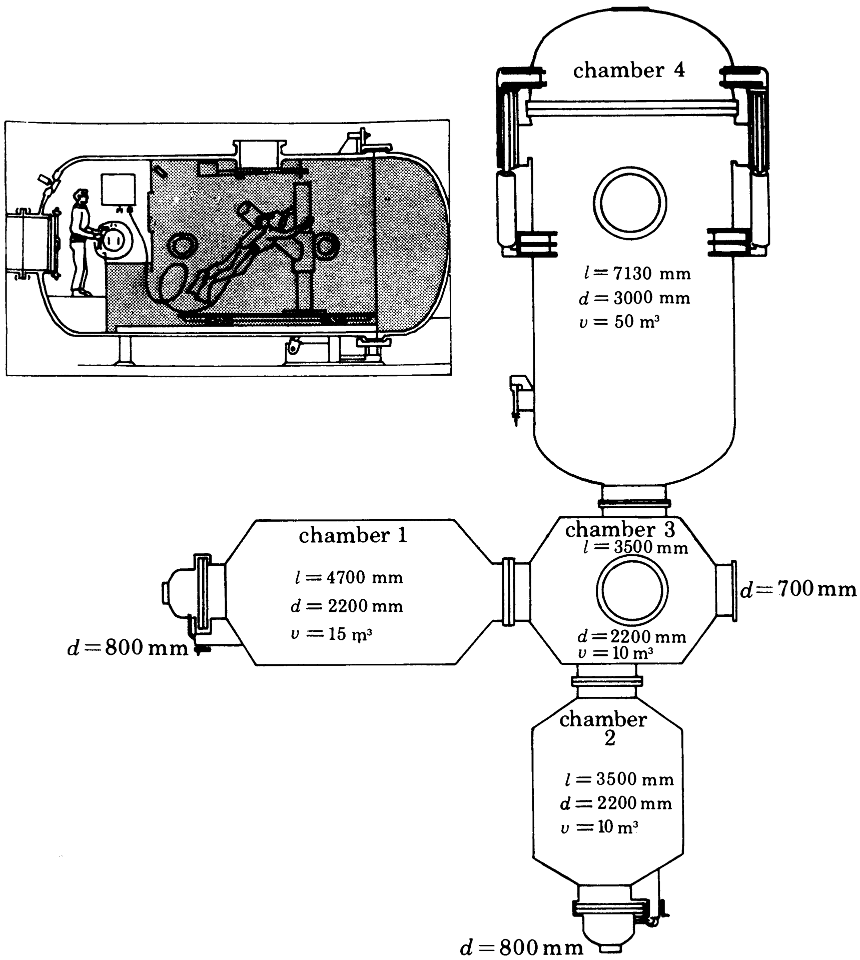

FIGURE 1. The hyperbaric chamber complex at the Norwegian Underwater Technology Centre. Chambers 1 and 2 are living chambers. Chamber 3 has toilet and shower facilities. Chamber 4 can be used either dry or partly filled with water (inset).

THE MEDICAL AND PHYSIOLOGICAL EVALUATION

Compression

No major problems arose during compression to 350 m s.w. to any of the 12 divers participating in the two dives. All divers, however, showed some signs of high pressure nervous syndrome, when tested with the test-battery including e.e.g. changes, but only few reported clinical symptoms. There was a great individual variation in response. In the dive with the fastest compression rate, all six divers reported some dizziness, spinning sensations or nausea, or both, before reaching 216 m s.w., but only two divers reported dizziness on reaching 350 m s.w. During compression there was increased slow wave activity in e.e.g. and postural

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tremor. There was also impairment of hand grip strength, finger dexterity, short- and long-term memory, and in reasoning and perceptual tests. These returned to normal during time at depth or during decompression. Psychomotor performance in water did not, however, indicate any marked impairment.

At maximum depth no major medical or physiological problems occurred during the time spent there for the two dives. The divers had minor problems like sleep disturbances, periods with reduced appetite and mild joint pains. The heart rate monitored in one diver at 350 m s.w. showed clearly that for him, diving at this depth was strenuous. When entering the water and working on the pipeline his heart rate was approximately 160 beats/min, although the workload he was performing can only be described as moderate. Even during testing in water, a light workload, his heart rate was 120 beats/min.

Work periods in water, which lasted 4 h each, were maintained in both dives with no impairment of work performace at the end of the time spent at maximum depth. This may not mean that divers at these depths can work regularly in the water for 4 h, however. Some of the divers reported that they became very thirsty during and after the work in water. It is possible that the breathing of dry, warm gas for long periods might cause some dehydration (Brubakk *et al.* 1983).

Owing to the high density of the helium–oxygen environment at this depth, communication between the divers is almost impossible without using 'unscramblers'. This caused both misunderstandings and frustrations between the divers on the one hand, and divers and 'surface' personnel on the other.

Decompression

During the decompression phase of the first dive, two incidents of decompression sickness with pain only occurred, and in the second diver there was another. All were treated successfully with standard treatment procedures.

After the dive

At present, only half the divers who participated in the two dives have been through their medical and physiological examinations. These are the same as before the dive and in five of six divers CO_2 sensitivity was considerably higher after the dive than before; in the sixth it was lower, and in two of the divers, the values had not returned to levels measured before diving after one month. All other examinations have revealed no changes from values before diving in the six divers.

Results of the technological diving evaluation

Breathing equipment

Before the dives, two closed-circuit gas reclaim breathing systems had been tested unmanned at NUTEC. One system had breathing qualities within the desired range of work at 350 m; the other system had some limitations between 200–250 m. Both systems were used in the two dives together with open-circuit back-up systems. The system with the inferior breathing qualities at 350 m worked well throughout the dive. The other system, however, had several technical failures and was abandoned. The rest of the tests in water had to be completed with the open-circuit breathing system.

Diver heating

The heating equipment for suits and breathing was able to keep the divers in thermal balance during 4 h 'lock-out' periods in cold water. The results revealed, however, that the heating equipment has considerable limitations.

Communication

Communication problems occurred between the divers themselves at high pressures, between the divers in their living chambers and the 'surface' personnel, and thirdly, between the diver in the water and both the standby diver and the surface personnel.

This is important because it related directly to safety. In one of the dives the communication to surface personnel from divers in water was investigated and it was found that 12% of the total speech time was used for clarifying or repeating messages (Andersen *et al.* 1983).

Conclusions

After the two Deep Ex dives it was concluded that further research and development were necessary if practical diving operations were to be performed at depths ranging from 300–500 m. After these two demonstration dives described here, we feel that some progress has been achieved and that some members of the diving industry are now aware of the problems related to deep diving to a greater extent than they were earlier. We feel as well that the areas that require development and research are still: the high pressure nervous syndrome, compression tables, breathing equipment, lung function, work capacity, thermal balance and thermal protection, nutrition, divers communication, decompression tables, hyperbaric welding habitat contamination and environment, blood morphology and possible long term health effects.

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Discussion

R. Peterson (*Fluor House, London, U.K.*). The results from Deep Ex I and II, done at NUTEC in 1980 and 1981, should be of interest in the light of the earlier discussions on h.p.n.s. and nitrogen narcosis. The purpose of both these dives was to compare Heliox and Trimix compression profiles and to perform a gas change from Trimix to Heliox at depth.

On Deep Ex I, a dive to 300 m s.w., identical compression profiles were planned for both gases. This profile had relatively rapid rates of descent with a holding period at 250 m s.w. The three divers compressed on a Trimix, with 10% (by volume) nitrogen, had no symptoms of h.p.n.s., but were euphoric upon arrival at 300 m s.w. These manifestations of narcosis disappeared within the first day at depth.

Two of the three divers compressed on Heliox had severe h.p.n.s. with symptoms such as dizziness and nausea, the onset of which was at about 210 m s.w. The hold at 250 m s.w. was extended by about 5 h and the two men recovered. There was no further difficulty with h.p.n.s. while getting to or while at 300 m s.w. The two men that experienced difficulty were not commercial divers, whereas the third man in the Heliox group, an experienced commercial diver, had no significant h.p.n.s. problems during the compression. On Deep Ex I, the 60 min switch from Trimix to Heliox produced no important effects.

On Deep Ex II, a dive to 500 m s.w., the compression profiles for the Trimix and Heliox groups differed. The Trimix group was to use the ATLANTIS III compression parameters with 10% (by volume) N_2 in the breathing gas. The Heliox group was again to use rapid descent rates with holding periods. The profile was modified from the previous dive, however, so that the first hold was at a shallower depth.

Surprisingly, during the Trimix compression, one of the three divers was markedly affected by h.p.n.s. with onset at 240 m s.w. He appeared to be only semi-conscious for about $\frac{3}{4}$ h at 300 m s.w. and several extended holding periods were inserted into the compression in an effort to improve the situation. A second diver also had some symptoms, which became evident at 300 m s.w. These included an inability to concentrate during performance testing. The severely affected man was one of the divers who had had difficulty with the Heliox compression on the earlier 300 m s.w. The moderately affected man was the one who had had essentially no symptoms of h.p.n.s. on the Heliox compression in the earlier 300 m s.w. dive.

Upon arrival at 500 m s.w., all divers in the Trimix group had about a 20% decrement in performance. These decrements remained stable for the entire period on Trimix, about 4 d, but progressively diminished and then disappeared during the gas switch as the nitrogen was removed over about a 30 h period. Late in the evening, after this gas switch, however, two of the divers had halucinations and all three experienced strong myoclonic jerking. These symptoms had cleared by the next morning. An increase in tremor was noted with the gas switch as well. Though some of the divers symptoms after the gas switch were similar to those found in drug withdrawal, further research to clarify the source of these symptoms has not been conducted.

On the more rapid Heliox compression, one diver became dizzy and a second developed marked tremor and unsteadyness, all symptoms arising at about 360 m s.w. These symptoms were reduced by the planned overnight hold at 376 m s.w., but returned upon further compression to 500 m s.w. the next morning. The third diver had no significant or lasting clinical symptoms. Although the performance scores of all divers in the Heliox group had returned to normal after about 24 h at 500 m s.w., the clinical symptoms in the two divers remained unchanged for 4 d at depth. So, after some hatch sealing difficulties with the chamber system were dealt with, an ascent to 445 m s.w. was tried in an attempt to clear the symptoms. An immediate and marked improvement in both men occurred with the ascent. After an overnight hold at 465 m s.w., they were returned to 500 m s.w. The individual who had been incapacitated by dizziness was, and remained, totally free of symptoms.The other man had a return of tremor.

The e.e.g. changes found on the divers were described by Dr Naquet. Slow wave increase and α-suppression occurred to varying degrees in all divers and no difference was observed between the men compressed on Trimix and those compressed on Heliox.

To close, I would like to make a brief comment on the two very recent 350 m s.w. dives discussed by Dr Tønjum. There are others present who are also familiar with these dives and who view their results and the conclusions to be drawn from them differently from Dr Tønjum. Final reports have not yet been reviewed, or even written in one case, however. So a discussion of these differing views would not be appropriate and could not be fruitful now.

J. T. Florio (*A.M.T.E. Physiological Laboratory, Gosport, U.K.*). Dr Hempleman mentioned that ventilatory response to CO_2 was enhanced during and after saturation dives, and Dr Tønjum observed the response to be enhanced in five out of six subjects after a dive at NUTEC.

Data obtained during 18 man dives at The Admiralty Marine Technology Establishment Physiological Laboratory suggest that the ventilatory response to CO_2 at 'depth' and at the 'surface' immediately after diving are a function of the response on the 'surface' before the dive. The response is enhanced in subjects with a poor pre-exposure reponse. Ventilatory response to CO_2 at a given depth during decompression was generally elevated compared with that at the same depth during compression. The response tended to increase during 'bottom time'. In most subjects the response returns to the value before the dive within a few days of the dive, although elevated responses have been observed several weeks after diving.

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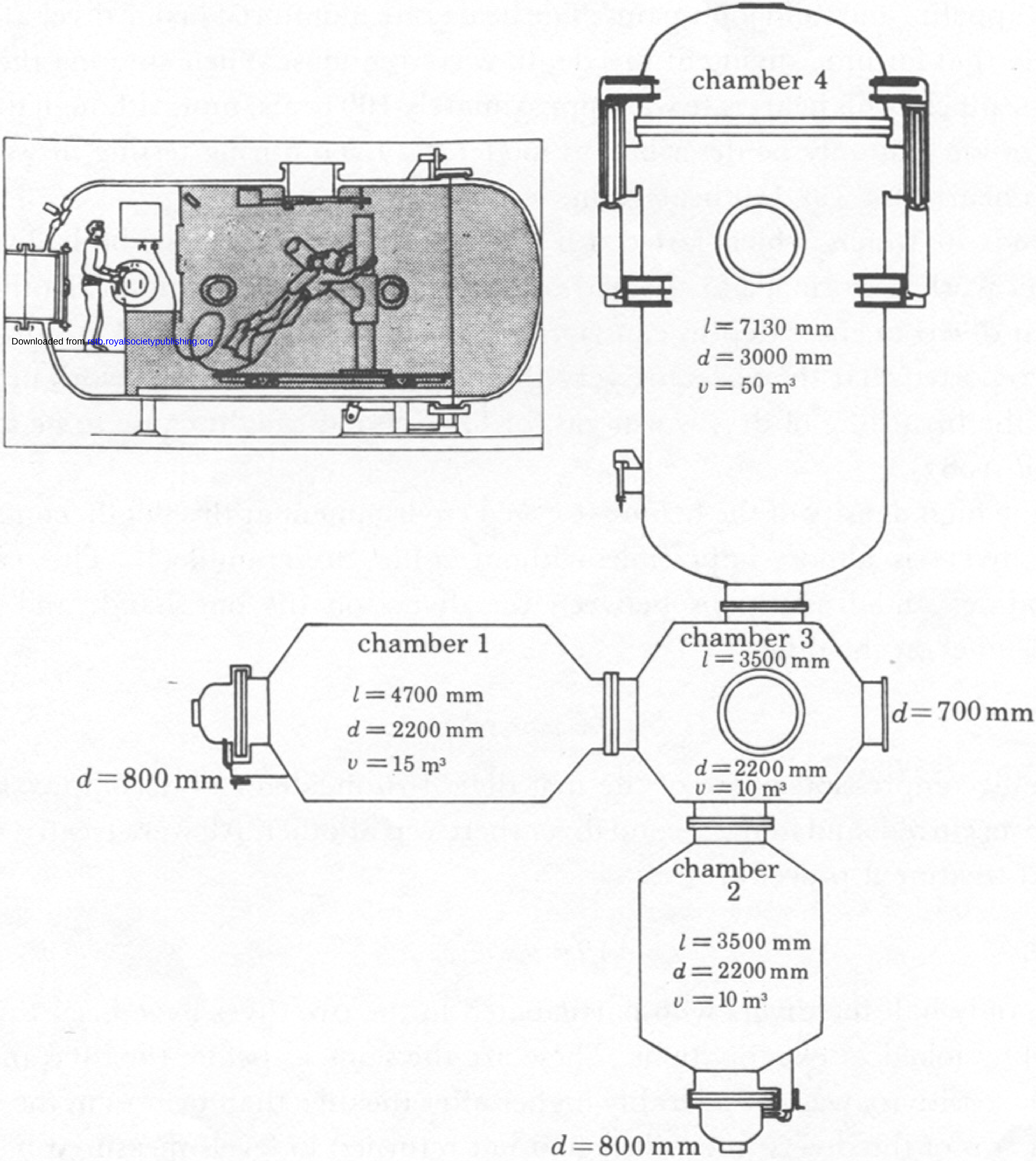

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