REPORT OF EXPERIENCES WITH THE UNDERWATER LABORATORY "HELGOLAND"

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There can be no doubt that scientific, economic and military considerations necessitate increased activities and long-term underwater operations for exploitation of the ocean. One possibility of solving this task is the use of so-called underwater laboratories. These habitats enable one or several persons to stay underwater for periods of weeks or even months. The first underwater laboratories, "Man in Sea" and "Precontinent 1", began to operate in 1962, in the Mediterranean. About fifty different habitats have been tried so far and the depth record for saturation diving with underwater laboratories is 158 metres.

Most of these enterprises, however, were undertaken in clear and warm waters with low currents and favourable weather conditions on the surface. The initial operation of the underwater laboratory "Helgoland" in July 1969, however, was performed under more disagreeable conditions. No depth-records had been set up and, due to the prevailing conditions, personnel as well as material involved were subjected to utmost stress. At the site of the operation of the UWL "Helgoland", water temperatures hardly rise above 14°C during summer and the visibility is often less than two metres. Even storms are liable to occur in this season and the currents are often unpredictable.

All equipment had to be adapted because of these unfavourable environmental conditions. A particular difficulty was the long distance to the shore station and for the very first time, power supply had to be taken over by an unmanned supply buoy.

INTRODUCTION

Investigation into the ecological conditions of the ocean is at present one of the most important scientific tasks. The major concern of marine biological research is the highly complex system of relations between environment and organism. We are therefore trying to advance and increase our knowledge about synthesis, transformation and degradation processes in the ocean.

These great scientific tasks however, can only be solved if new technical methods are developed. Until now, ocean research has been primarily performed from the surface but the method of scuba-diving is now gaining more and more importance in the field of marine biological research and has finally led to the designing, construction and operation of underwater laboratories all over the world.

For a number of years scientist-divers of the Biologische Anstalt Helgoland have dived in the rough waters of the North Sea, where surge and low water temperatures, as well as poor visibility conditions, present difficulties for them. Nevertheless, these diving operations have yielded some very interesting results. Based on the experiences of these divers, German marine biologists were encouraged to start on a very challenging project: the Unterwasserlaboratorium "Helgoland". This underwater laboratory was designed in co-operation with the Institut für Flugmedizin of the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, and was intended for operation near the coast of Helgoland. After the required funds of one million DM had been provided by the Federal Ministry for Scientific Research, and after two years of preliminary planning, the project was finally commissioned to Drägerwerk Lübeck, in November 1968.

In August 1968, the Biologische Anstalt Helgoland had already been provided with a small underwater test station which was constructed by another German company. This was a steel container of cylindrical shape, six metres long, two metres in diameter, standing on four straddled legs. This comparatively simple underwater station was submerged in the Baltic Sea in the autumn of 1968, to a water depth of ten metres. A crew of two divers had been working in the station for a period of eleven days when it was realized that this underwater venture had a severe handicap: the surface power support from a supply vessel. The position of this vessel had to be changed due to weather and wind conditions, thereby interrupting the energy supply and telephone communication to the underwater station for several hours. It became evident that an underwater station operating in the waters of the northern areas would have to be equipped with a maximum of self-contained life support, to render the station independent from surface supply. This experience had already been taken into consideration when the Unterwasserlaboratorium "Helgoland" was under design and construction in Lübeck.

TECHNICAL DESCRIPTION

This underwater laboratory is a cylindrical pressure container of 9 metres in length and 2·5 metres in diameter. The pressurization capacity of the underwater complex is designed for an equivalent water depth of 100 metres, when it is fully closed. The total volume amounts to approximately 43 m³ and the total weight, including the ballast, amounts to approximately 75 tons. The laboratory consists of two separate compartments, one wet room with manhole for escape and one work room. The ends of the laboratory are equipped with two bunks each. The work room, which can be entered through a door, is also intended for use as a decompression chamber so that the aquanauts can be decompressed during their stay. For this purpose the room can stand an additional outer positive pressure of 10 kp/cm². An electric switchboard plant with measuring instruments, switches

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and indicator devices for control of the entire electrical installations and a life-support-system have been installed in the front of this chamber.

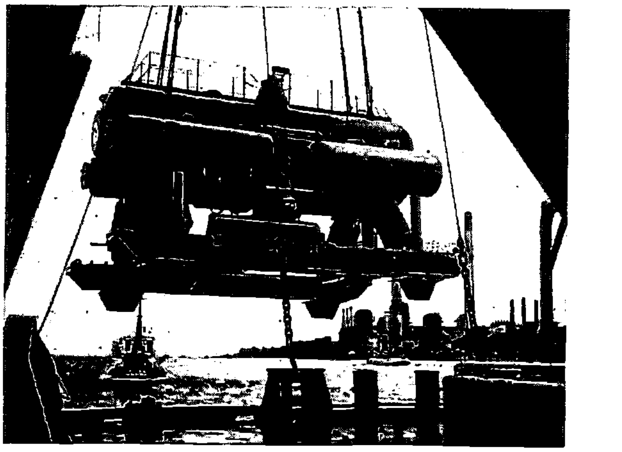

FIG. 1—*Underwater laboratory "Helgoland" being transported to Helgoland by way of a Magnus-Crane*

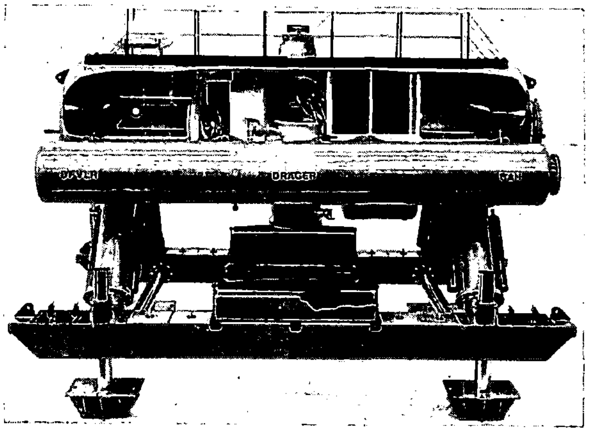

FIG. 2—*Interior spaces of the UWL "Helgoland"*

The atmosphere within the underwater laboratory is continuously regenerated in the closed-circuit system; exhaled carbon dioxide is absorbed by soda-lime, the exhausted oxygen is constantly replenished and impurities are retained by charcoal filters. The oxygen partial pressure amounted to 0·3 to 0·4 ata.

The manhole of the complex on the lower part of the vessel has a length of about 2·5 metres in order that the water level, which is affected by the tides, can be compensated for without any loss of gas. It can be closed to be pressuretight and can be opened hydraulically from inside as well as from outside. Behind the two doors there is a hot water shower, and next to it the WC. The excrements are led through a removing device into an excrement tank. The kitchen is on the opposite side and is equipped with a deep freezer, refrigerator, an infra-red heated stove and a sink. The atmosphere within the laboratory is controlled by numerous metering units. CO_2, O_2, relative atmospheric humidity, pressure and temperature values are constantly measured and recorded. An additional warning device controls the atmospheric CO and CO_2 values, and the water level in the escape tower.

Opposite the manhole is a control panel which is equipped with all the necessary valves and, with regard to ergonomic aspects, the switchboard has been divided into four parts. According to the available gases (air, nitrogen, oxygen and helium) the manometers for supply pressure and working pressure, the control valves, the distributing valves and the pressure reducers were combined to form clearly arranged blocks. This switchboard is equipped with connectors to supply divers by way of a hose. It can also be used as filling station for compressed air cylinders.

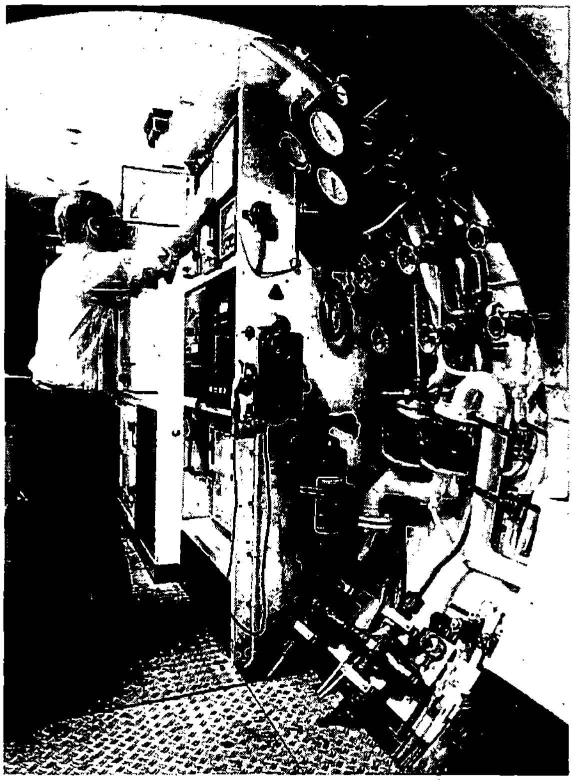

FIG. 3—*Gas switch board and control panel*

The surroundings of the underwater laboratory can be watched through seven small windows. A technical particular of the UWL "Helgoland" is the submerging system. The construction enables submerging and surfacing without assistance from outside. For this procedure the entire interior room has to be pressurized up to the pressure value which is expected at the point of use. Then two of the four straddled legs have to be flooded, until the UWL begins to sink. A negative buoyancy of a few kp is sufficient for this manoeuvre. When the laboratory reaches the seabed, the touching of the ground is softened by an arch-shaped anchor chain fastened to the ballast tank. After checking that the laboratory has reached the expected point, the trimming tanks in the straddled legs are completely flooded and the lateral ballast tanks are filled with water so that a total negative buoyancy of 16 tons is obtained.

Together with the solid ballast within the lower ballast boxes, which contain iron concrete blocks of 1·2 tons each, the centre of gravity has been placed so low that the whole system functions like a cork tumbler. Unevenness of the seabed is balanced by means of telescopic legs, which can be lowered mechanically, so that the laboratory is always kept in a horizontal position. The lower stand surfaces are additionally equipped with long vertical blades to penetrate into the ground and avoid transpositioning of the laboratory. The final effect of all these measures is a safe position for the UWL "Helgoland", even under the most unfavourable conditions.

SELF-CONTAINED SUPPORT BUOY

It is well known that the supply of an UWL with energy and gas is a particularly difficult problem. Nearly all former enterprises have been performed either with a supply line from the land or with a supply vessel or pontoon anchored above the laboratory. In case of the UWL "Helgoland" the first method could not be practised because of a three kilometre distance to the

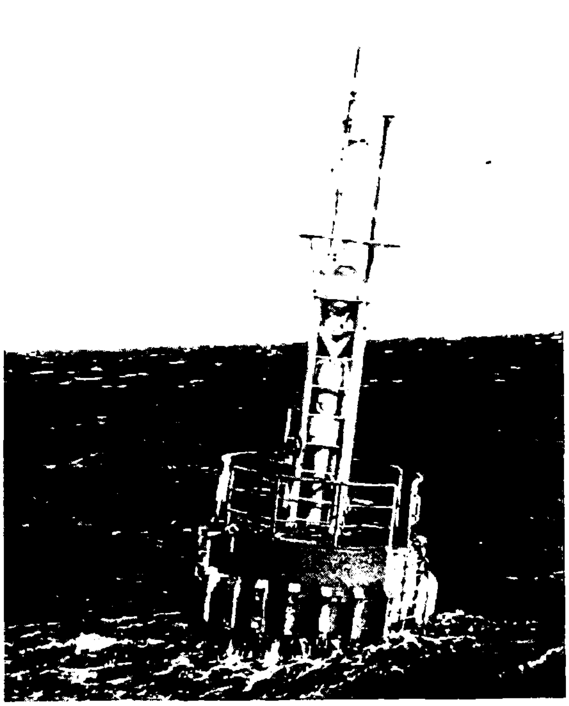

FIG. 4—*Supply buoy*

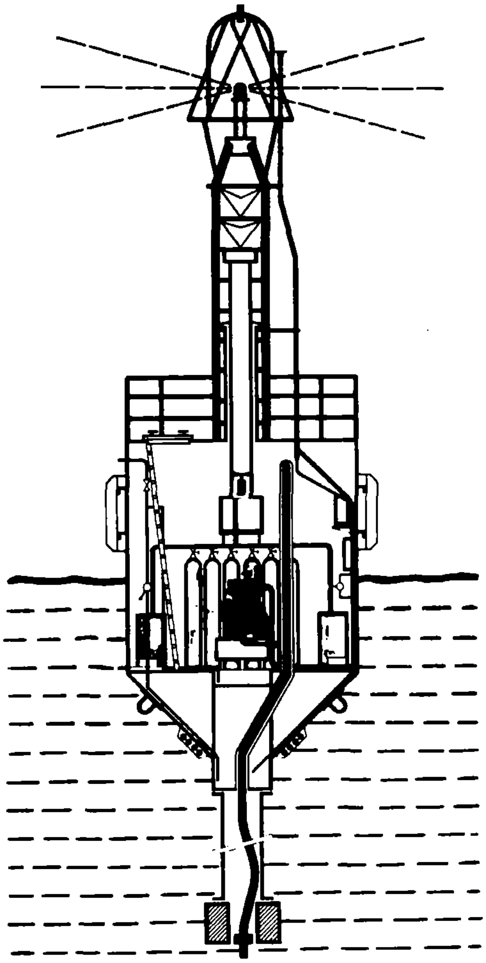

FIG. 5—*Cross-section of the simple buoy for UWL "Helgoland"*

land, making it too expensive. The second method also had to be excluded because of the stormy weather conditions which must be expected in this area, even during summer. It was therefore necessary to find a new solution, which led to the very first employment of a self-contained support buoy, which is moored adjacent to the laboratory by three tetrapod anchors with a weight of 16 tons each. The buoy comprises a Diesel aggregate with a capacity of 25 kVA, two high-pressure compressors, oil tanks and gas cylinders for storage of oxygen, nitrogen and helium.

The buoy carries a radio link and provides for radio and television communication to the central shore station. The actual supply of power, compressed air, nitrogen, oxygen, helium and fresh water to the laboratory is made by umbilical cords. The entire aggregate has been so dimensioned that, without attendance, a supply is guaranteed for at least 14 days. All aggregates and particularly the Diesel aggregate and the compressors work satisfactorily, even if the supply buoy is in an inclined position of 45 degrees. This is achieved by installation of special oil pan lubricating systems.

SAFETY DEVICES

Safety of the divers and particularly of the aquanauts is one of the most important principles for performance of operations. Therefore all preparations for UWL "Helgoland" took into account these safety problems and the lives of the aquanauts are safeguarded by numerous rescue means. A one-man rescue chamber is immediately attached to the decompression chamber of the laboratory. This enables a diver to be rapidly conveyed to the surface in case of emergency without entering the water. The rescue chamber can be recovered by helicopter or boat and will be flanged to a shore-mounted treatment-decompression chamber. Another diving bell is to act as an elevator which will convey the divers to and from the underwater laboratory, especially in case of bad weather and in great operating depths. For weight reasons a very compact design of this lift was needed and it therefore has a maximum capacity of only three persons.

The laboratory is also equipped with a life raft which can be released after the crew have been decompressed. This life raft however should be reserved for those cases of emergency when no help can be expected from the surface. A further and highly

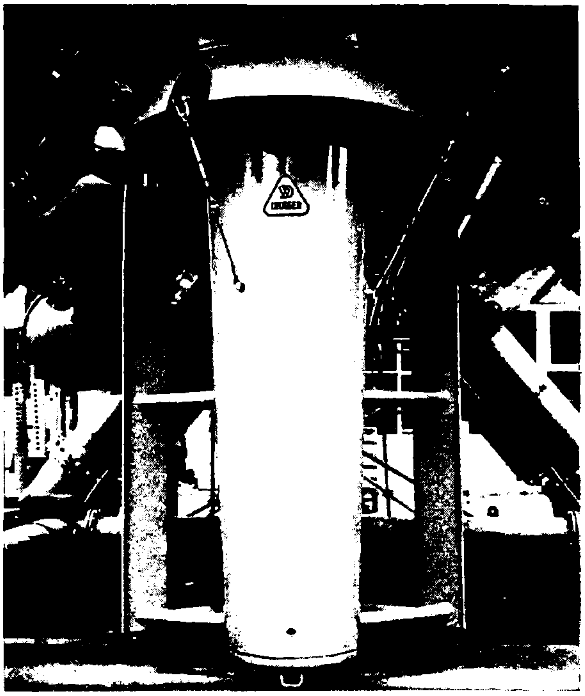

FIG. 6—*One-man rescue chamber at UWL "Helgoland"*

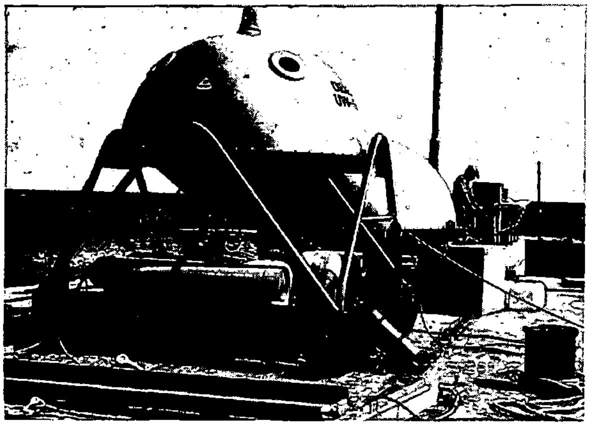

FIG. 7—*Underwater igloo and depot prior to operation in the North Sea*

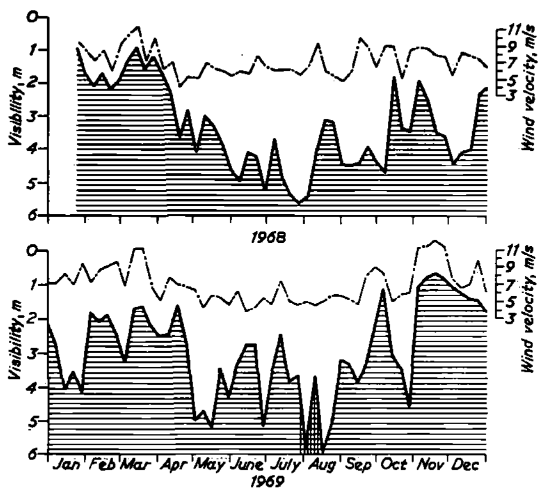

FIG. 8—*Wind velocities and visibility scale*

esteemed safety device for the aquanauts is the underwater igloo which has been projected and designed by Draegerwerk. This "little brother" of the UWL with a diameter of 2 m was equipped with a complete life-support-system, with a reserve apparatus and with a ballast and trimming system. It was intended for short-term stays of two divers and should serve on a distant working place as a shelter and as a safe place of refuge. Prior to initial operation all the equipment and interior fittings were thoroughly scrutinized by Draegerwerk and the other co-operating firms. This is the reason why the entire operation could be performed without complications, thus giving the aquanauts a feeling of security.

FIRST LAUNCHING

On 28 July 1969—only eight months after receipt of a firm order—the Unterwasserlaboratorium "Helgoland" was towed to its actual position by two boats of the Biologische Anstalt Helgoland. The self-contained support buoy had already been moored to its actual position eleven weeks before this event. The laboratory was submerged with a velocity of 7 m/min and had a "dead on target landing" after exactly three minutes. Two engineers (another designing-engineer and the author) and two aquanauts from the Biologische Anstalt Helgoland were on board.

The results of the first 22 days' operation are based on data received by the kindness of Dr. Gotram Uhlig, the chief aquanaut of the Biologische Anstalt Helgoland. The author also calls attention to the fact that he is not a marine biologist, but the chief of the project and construction department for diving techniques of Draegerwerk.

The results obtained during the initial operation of the "Helgoland" laboratory can only be fully appreciated by taking into consideration the local environmental conditions. As has been mentioned before, the North Sea near the Isle of Helgoland is a most dangerous water. One year prior to the initial operation, extensive *in situ* measurements of the tidal current on the seabed near the actual stationing position of the underwater laboratory were performed. The highest current measured was 80 cm/sec, while the average was between 20 and 40 cm/sec. Only a skilled diver is able to overcome such velocities. The comparatively low water temperatures are not at all agreeable. Even during summer the water temperatures near Helgoland never rise above 14°C (57°F), in a depth of 23 metres and the insulation capacity of the commercial type neoprene diving-suits is reduced due to compression in such a depth. (Unfortunately there was no money for heated suits.) Another point which creates considerable difficulties for the scientist under water is the poor visibility.

Fig. 8 shows the average weekly visibility values obtained by means of a Secchi-disc during the years 1968 and 1969. The upper curves indicate the average wind velocities, whereby the relation between wind velocity and visibility can be clearly observed. The most favourable conditions, a view over a distance of three to six metres, are met between the months of May and September. Thus the initial operation of "Helgoland" took place at a time when visibility conditions were most agreeable. It does not seem expedient to carry out investigation tasks during the winter period because, apart from the poor visibility of only a half to three metres average, the low water temperature of almost 0°C limits all diving procedures to a minimum. Apart from that, the wind conditions near the coast of Helgoland limit the periods of manned underwater laboratory operations. Fig. 9 indicates all the wind currents of the last ten years that have exceeded a daily average of 8 m/sec, which corresponds to a wind force of 4 on the Beaufort scale, and which lasted longer than three days without interruption. This shows that there was a minimum of wind during the months from May to September, while during the winter season there were periods of storm which lasted from about three to six weeks, sometimes even more.

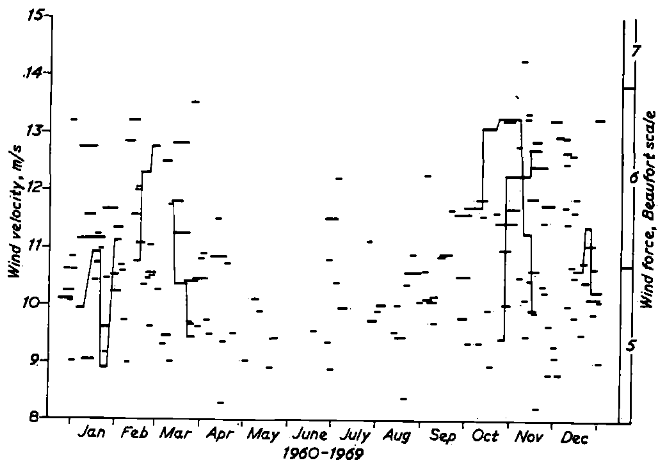

FIG. 9—*Wind velocities*

The Unterwasserlaboratorium "Helgoland" has been equipped so that, in the event of being cut off from surface support, the crew can be sustained for a period of fourteen days. The laboratory carries all emergency supplies such as electric power, gas, food, fresh water, soda-lime, etc. Considerably longer interruption periods, however, are liable to occur during the winter season, and these would involve too many risks for the underwater team.

One day after the initial submergence and after a decompression period of nine hours in the laboratory, the two engineers were replaced by two aquanauts so that the first team was complete. The daily work was primarily devoted to technical tasks as the crew had to be acquainted with the

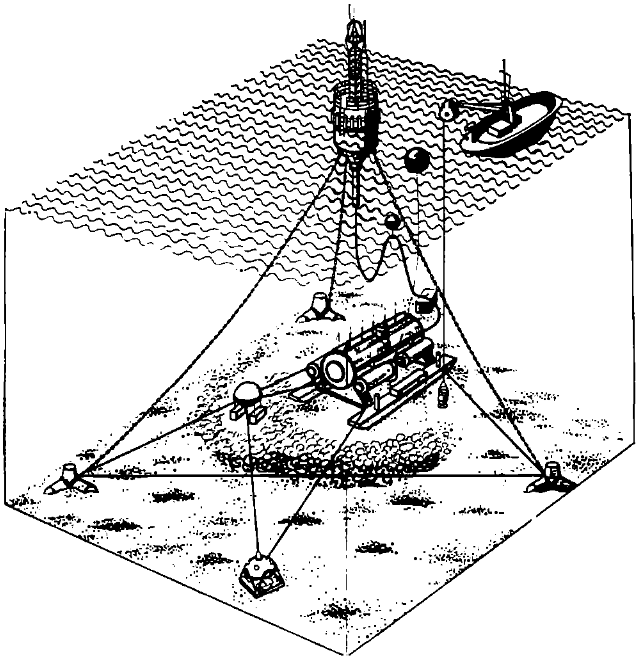

FIG. 10—*View of the panorama at the site of operation*

technology and new conditions. After professional and sport divers had installed all auxiliary equipment, the underwater depot, which has a similar design to the underwater igloo without a life-support-system, is charged with soda-lime and silicagel containers and situated eight metres away from the laboratory. The underwater "igloo" is set up approximately 43 metres away from the laboratory. The triangular area between the tetrapodes, which is marked by guide ropes, was the actual biological investigation area. The excrements, which are first caught in a sewage tank, are let off with the tidal current by way of a plastic tube 100 metres long. Stock replenishment of every-day supplies was by means of a "stew-pot" from a supply vessel. This "stew-pot" was airtight and had to be carried to the laboratory by supply divers. As this operation soon proved to be difficult and did not work very satisfactorily, an automatic submersion procedure is planned for the future.

The diving periods which were daily performed by the aquanauts indicate that the divers became gradually acquainted with environmental conditions and technical systems. After a period of ten days the first team of four divers performed an average diving period of 1½ hours per day, while the second team performed two hours daily and finally the third team of three divers performed three hours daily. Individual diving periods of even four hours daily have been performed by divers, which is doubtless a very remarkable performance considering the unpleasant conditions mentioned above. It is therefore not at all surprising that a consumption of 5000 calories has been recorded by the physicians. Apart from the cold food, the divers prepared deep frozen ready cooked meals of high quality. It was interesting to note that all divers had the feeling of a considerable increase of weight, while in fact a loss of weight of between three to five kilos in ten days was registered after they had returned to the shore.

It cannot be denied that a certain degree of inertia has to be overcome prior to any physical labour in the underwater laboratory. Due to the physiological exertion, the divers had a tremendous demand for sleep. In general they had about nine to ten hours' sleep. According to experience, the working capacity of the aquanaut seems to be dependent on three conditions:

1) on the fitness of the diver;
2) on adaptability to the special environmental conditions;
3) on a certain degree of living comfort.

The combination of a team is of great psychological importance. On the other hand, it should be noticed that interdependence had a very stabilizing effect on the crew.

The fit condition of the aquanauts was proved in very thorough medical examinations which were carried out prior to the dives. The adaptation period of a new diving team takes about one or two days. When an aquanaut is fully saturated in the depth of 23 m he will need a 24-hour decompression period in the underwater laboratory. Therefore it would not be at all economical to assess an operation period in the laboratory of four to six days only. The team should instead be working under water for a period of at least eight to ten days. After all, the labour which is performed under water takes no more time than labour which is performed ashore.

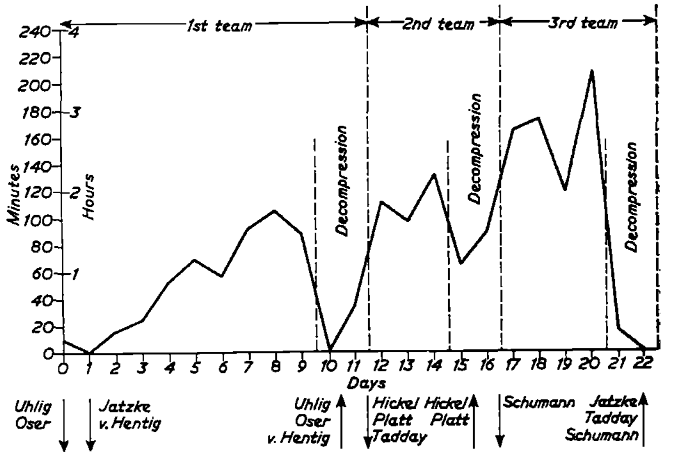

FIG. 11—*Diving periods of the aquanauts*

Uncomfortable living conditions no doubt have a negative effect on the working capacity of the divers. About fifty different underwater habitats have been tested and operated at different water depths by numerous nations during the last eight years, beginning with the French Precontinent enterprises and the American Sealab tests, and up to Tektite II and the Aegir-record operation in Hawaii where, last summer, a depth of 158 m, that is approximately 500 ft, was reached.

Now that we have manned underwater projects it is very important to increase the efficiency of such underwater laboratories with regard to special fields of operation like the living conditions mentioned above. This requirement has in fact been met by the Unterwasserlaboratorium "Helgoland" which provides a considerable amount of comfort in spite of its comparatively small dimensions. The freshwater shower was particularly appreciated, also the hygienic WC with its under-water flush system, as well as the almost noiseless operating air-conditioning plant and last, but not least, the perfect kitchen. The air temperature of the underwater laboratory was set from about 18 to 21°C overnight, and between 20 to 23°C during the day. As the atmosphere did not contain any helium, these temperatures were sufficient. There was a temperature gradient of about 5°C between the floor and the ceiling. In future better air circulation will be required.

The increase of humidity within the laboratory was rather disagreeable. Considerable quantities of water were brought in after the numerous diving tasks and the four silica gel dehumidifiers which were driven by ventilators could not eliminate the humidity. In spite of the fact that the third team of aquanauts consisted of three men only, the situation did not improve very much, since more water was brought in due to the more frequent dives. The humidity value amounted to 83 per cent on the first day of operation and values of about 90 per cent were measured after 13 days. Unfortunately there was no possibility of de-humidifying the laboratory, due to energy insufficiencies. It will therefore be necessary in future operations to separate the wet rooms from the dry rooms or to obtain the water separation by means of condensing systems, provided that the energy supply can be improved.

The regeneration capacity of the life-support-system has been so designed that the CO_2 values range between 0·1 per cent and 0·3 per cent, when the soda-lime containers exchange in a 36-hour cycle. The O_2 values ranged between 15 per cent and 21 per cent, but in general were below 20 per cent.

During initial operations in the Baltic Sea in 1968, all divers had been complaining about irritation of the external auditory meatus, which was occasionally accompanied by pains. In Helgoland the medical doctors have tried to take prophylactic measures, unfortunately with little success, because five of the eight divers had ear complaints. A smear which was made from the clear discharge of the ear showed that it was an infection caused by pyoceanic bacilli.

PROSPECT

The experiences which have been gained with the Unterwasserlaboratorium "Helgoland" until now can be summarized as follows:

even in our rough northern area the operation of underwater habitats is absolutely profitable, both technically and scientifically. Underwater habitats, which are very efficient and important in the field of marine biological research, will have to be further developed to help marine biologists solve the manifold problems which are involved in the exploitation of the oceans.

An official statement with the first evaluation contained the following particulars:

"The initial operation period in the 'Helgoland' underwater laboratory was above all intended to test the various kinds of technical equipment under the special conditions prevailing at the bottom of the sea. Its purpose was to provide information for the detailed planning of a long-term marine biology research programme. To this end initial research work was devoted to simple investigations of marine organisms living in the water and at the bottom, and to systematic examination of the medical and psychological effects on the reactions and performances of the aquanauts."

A full evaluation of the technical and scientific results of these experiments will take months to complete. However, a few fundamental conclusions can already be drawn:

1) There were no psychological problems. All the aquanauts felt very well. Their stay at the bottom of the sea produced a remarkably positive emotional stabilization.
2) There were no fundamental medical problems.
3) The technical equipment worked perfectly.
4) The significance of the UWL for the future of marine biological research at the bottom of the North Sea was viewed with optimism by all aquanauts and by all those in charge of the project. A new dimension has been opened for marine research.

Thus it can be stated with certainty at this early point that the public funds devoted to this project have proved a very useful investment. The question now remains as to the future of this project. The Ministry's report is also very satisfactory from this point of view. It states:

"The 'Helgoland' UWL is expected to remain in its present position for one year—at first unmanned, but under permanent supervision by diving teams working for short periods. During the autumn and winter storms experience can be gained about safety factors and working possibilities under extraordinary conditions."

For the first year of operation the following research projects are planned in the Marine Biology Research Programme.

1) Measurements of biologically vital environment factors, particularly: the use of thermistors to determine temperature gradients in water close to the sea bed and the sea bed itself; measurements of current velocities especially very close to the sea bed; recording of water disturbance caused by tidal currents; measurements of light close to the sea bed using underwater photometers.
2) Collection of plankton for specific purposes and particle counts during the various phases of tidal movements.
3) Collection of sediments (over a period of several successive days) and their analysis.
4) Investigations of micro-biological organisms and of micro-fauna, experiments to determine the qualitative and quantitative parameters for the movement of sediments displaced by and carried in tidal currents and the resultant variations in distribution patterns of micro-organisms; continuous sampling of sediments in sterile conditions to determine changes in micro-flora (cell count factors) under the influence of the environment; studies of the resettlement of sterilized areas.
5) Experiments to determine physiological behaviour, such as setting out lobster grubs, young lobsters and mature lobsters on beds of pebbles, in artificial holes and *in situ* breeding chambers; studies of migration, social, environmental and sexual behaviour as well as daily cycles of activity; parallel studies are also to be made of hermit crabs.
6) It is also planned to investigate the possibility of breeding and feeding ecologically and economically important species of fish crabs and shellfish in large sea-bed "aquariums" and other special underwater units.

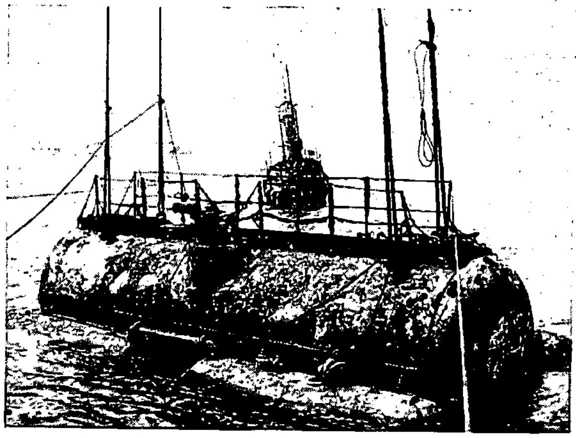

FIG. 12—*UWL "Helgoland" after nine months exposure*

The Underwater Laboratory "Helgoland" was being thoroughly overhauled and partially reconstructed at the time of writing. Preparations are being made for supplementary mounting of a special wet room, so that the problem of humidity would be solved for future operations.

Published by THE INSTITUTE OF MARINE ENGINEERS, The Memorial Building, 76 Mark Lane, London, EC3R 7JN.
Printed by ST. STEPHEN'S BRISTOL PRESS LTD., Bristol, BS12 7JS.