6 Under-water Habitats

Manned under-water stations have already played an important role in the study of the continental plateau. In the future it will not always be possible to carry out operations from the surface either by diving, which will become severely limited as the depth increased beyond 300 m, or by manned intervention in the form of submersibles. It is probable that production systems and manned stations on the sea bed will be required in order to produce hydrocarbons from deeper depths or in adverse surface conditions such as ice. In this case operators will have to remain on the seabed unattended for long periods with the need to be resupplied and the crew changed. Many projects are being formulated to meet these needs in the future and, whilst the many habitats that have been installed over the last two decades have been non-commercial, designed primarily for research, they are invaluable for the experience that has been gained. This chapter discusses the development of habitats and the essential considerations that need to be taken into account, of which energy to meet the power requirements is among the most important. If this is solved many of the limitations disappear. Risk areas are reduced to acceptable proportions and the concept becomes cost-effective. Properly conceived and designed, the habitat can give the operator a number of options when fulfilling a work task which are not necessarily available to the surface-orientated operation. The possible work tasks where using a habitat may provide a solution are listed below. In certain circumstances it may be the only solution.

1. Salvage of ships, aircraft, missiles, submarines in hostile areas and in deep water.
2. Salvage of precious or dangerous cargo in hostile weather areas and in deep water.
3. Extended repairs on dams and reservoirs.
4. Submarine supply.
5. Subsea production.
6. Subsea drilling.
7. Oceanographic, biological and geological observations and investigations.
8. Site preparation prior to installation/construction, i.e. concrete structures.
9. Research and development into marine biology and associated subjects.

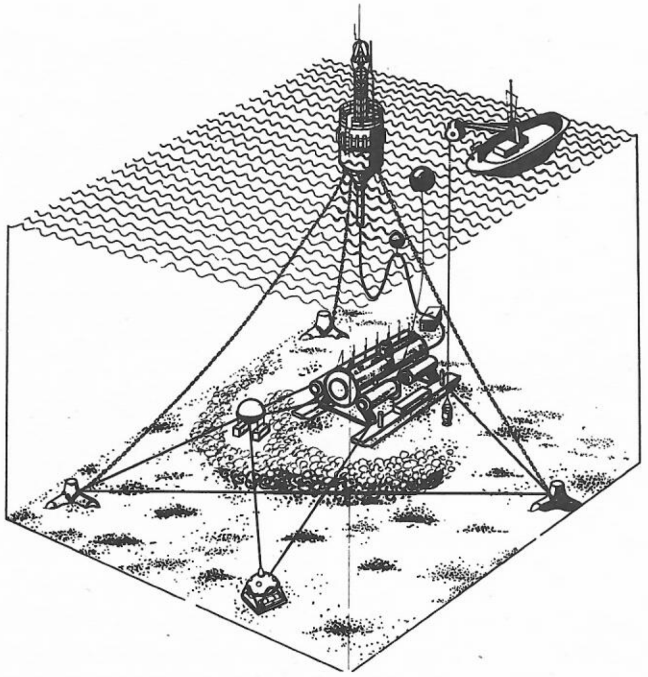

Fig. 6.1. Under-water installation of the under-water laboratory *Helgoland.*

10. Research and development of divers' equipment and work tools.
11. Welding.

The scope of the habitat will vary considerably depending on the requirement. Whereas a short intervention in shallow water may demand little more than an inflatable open-ended bag or tent, another deeper and sophisticated requirement may need to accommodate large numbers of technicians and scientists. Many problems are identical and basic whatever the depth and requirement. In this chapter the aim is to identify the different features of habitats and show in practice how some have been overcome and how other problems will be met in the future.

Conventional Designs

The size and shape of a habitat are determined on much the same basis as those of a surface hyperbaric complex. The size is governed by the number of personnel using the facility and the shape is dictated by external parameters. In this latter case the diving system as well as the habitat may be designed for permanent emplacement or be capable of being moved from one position to another. Unlike diving systems, however, there are a number of conceptual variations in habitat systems with satellites. Figs 6.2–6.5 show the use of these satellites, not unlike igloos, which can fulfil the functions of observation and

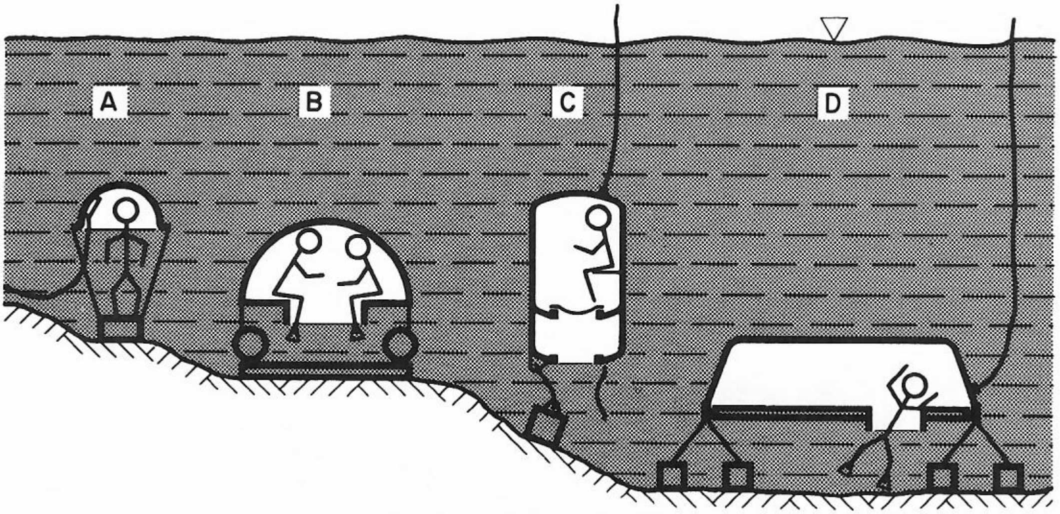

Fig. 6.2. Designs for under-water shelters for short use.

communication posts centred around and dependent on a master station. There are a number of options based on the free movement of divers and not in these cases deploying one-atmosphere systems. In much the same way as modern surface diving complexes have standardized on the use of modular chamber construction which allows for any number of chambers to be mated in a suitable configuration, so also does this practice lend itself to the construction of a habitat complex to support different tasks with different configurations, for example in salvage and marine research. The main requirement stipulates that the habitat should embody its own life-support system, unlike a diving bell. This life-support system must be common to all configurations.

Satellites are dependent upon a central habitat and can only be considered for short duration. Therefore the materials and fittings do not all necessarily have to meet the same requirements of the habitat. The satellites can be used for a number of purposes and Fig. 6.2 summarizes the different current designs.

Type A is a simple 'telephone box' used for communication, with clear reception, to the central habitat base. It is in the form of a simple hemispherical design made of acrylic glass, for good visibility, and with a diameter rarely exceeding 600 mm. The correct breathing gas is maintained by flushing the air space through with new gas in preference to using a removal system for CO_2 and other various gases. If the bottom currents are not strong, the cell can be kept in position by the attachment of a bottom weight. In strong currents the ballast weights need to be increased.

For longer duration, possibly for the use of two divers, the single cell, or igloo, is not suitable and a large hemispherical igloo (*Type B*) can be used. An optimum size would be 2000 mm bare diameter giving minimal drag when exposed to bottom currents. The space inside would be sufficient for two divers to sit or lie down for short periods and a gas supply is provided. The inverted T-shape support at the base carries both the breathing gases for normal and emergency use and the ballast tanks for recovery. A small life-support system inside provides a CO_2 scrubber, oxygen at required partial pressure, lighting and communication. The unit can be either self-contained or, if close to the central habitat, supplied with life-support and power from there. The overall capacity of the main habitat can determine the number of igloos that can be maintained. Because of limited instrumentation and life-support fittings needed, this allows more efficient utilization of space. Stores needed for the main habitat, such as CO_2 absorbent, can be stored in these units.

Type C. Small vertical cylinders can be used for short periods but are very restrictive, with diameters of less than 1 m, and therefore are more effectively used in the transport role. In this role they can transport divers to and from the main habitat in the same way as a diving bell and also provide an eventual safety function for use in an emergency evacuation. The UWL *Helgoland*, whilst operating in north-west Europe, had two rescue chambers permanently operational, adjacent to the habitat.

Whilst spherical, hemispherical or cylindrical designs in acrylic or steel are usual, other box type structures can be installed using flexible rubber materials spread over metal frames and secured (*Type D*). To alleviate the tension load on the surface netting can be spread over the inflated structure and directly secured to the ballast weights. Larger units can be fabricated to accommodate two to four people. The inflated fabric has very poor insulation properties and is suitable only for warm waters or brief stays. By the nature of their construction they are modestly equipped.

The main habitats have greater space for additional fittings as distinct from cells or igloos which are only used for short durations. Even if supplied with power and life-support from the surface, the additional secondary life-support systems will impose space limitations. Illustrated in Fig. 6.3 are the different geometric forms suitable for straightforward habitats capable of equalization.

For the deepest depths the sphere (*Type A*) is the most favoured form because its construction can more easily allow differential internal and external pressures. With the change in depth, whilst ascending and descending, the pressure is equalized internally and externally. A sphere will utilize space economically if split into different floor levels. With an overall diameter of 6–8 m several floors can be installed with a crew of up to ten.

The horizontal cylinder (*Type B*) is by far the most usual design for a habitat with up to three separate compartments. One compartment can be designed for differential pressures and used for diver lock out operations not possible with the sphere. Normal dimensions range from 1.20 to 4 m in diameter for the hull form and from 4 to 17 m in length, with a minimum crew of two and a normal maximum of ten. One of the great difficulties of the pressure equivalent design is the controlled lowering onto the site with all the dangers inherent in this type of operation.

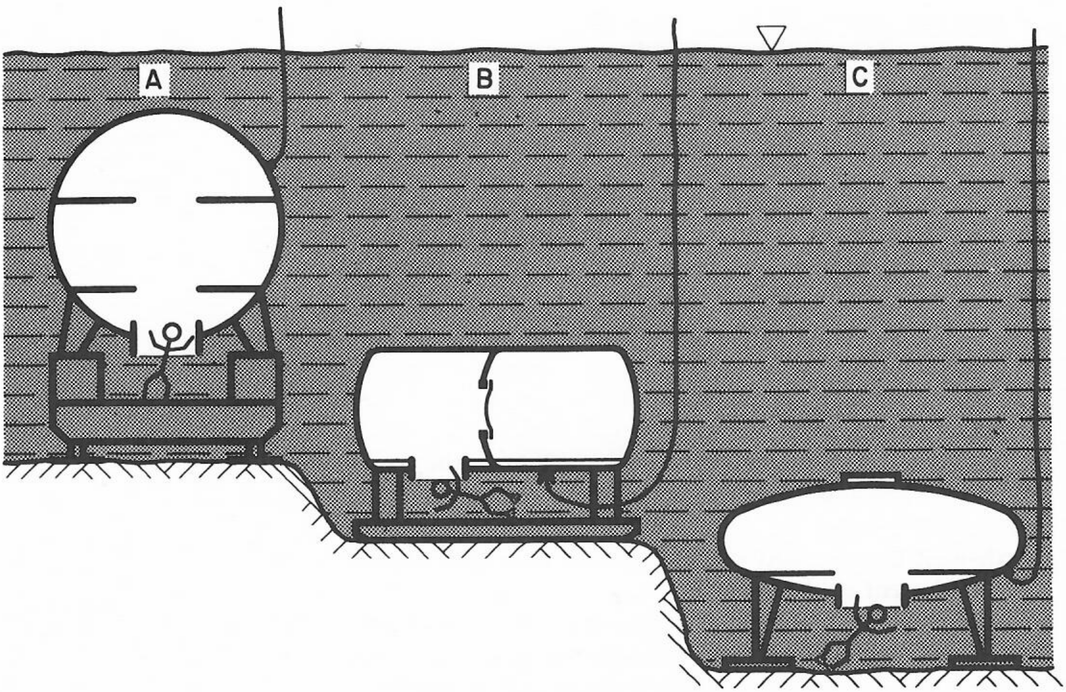

Fig. 6.3. Simple designs for under-water laboratories suitable for longer stays.

The advantages of the ellipsoid (*Type C*) for an under-water habitat are not due merely to the aesthetic value of this shape but also to the fact that it has minimal drag characteristics and greater overall strength. However, the constructional problems would be reflected in the very high cost, although the shape is economical in terms of meeting the maximum space requirements for a given volume. An ellipsoid with a minimal internal diameter of 4–5 m would be practical, given that the higher costs of the habitat were acceptable.

Advanced Designs for Habitats with Integrated Pressure Hulls

For practical reasons the use of integrated modular hull forms is more favoured. Surface compression and decompression chambers have been designed in modular form to facilitate transport and assembly, and with the option to extend or decrease the overall capacity to suit the requirement, and the same disciplines will apply to the design of habitats. Also, by separating the units, certain safety requirements are met should some sections sustain damage or become unserviceable, allowing evacuation into safe areas. In Fig. 6.4 three basic configurations are described.

Type A consists of a parallel arrangement with two vertical cylinders connected by a horizontal shaft in the upper portion. This

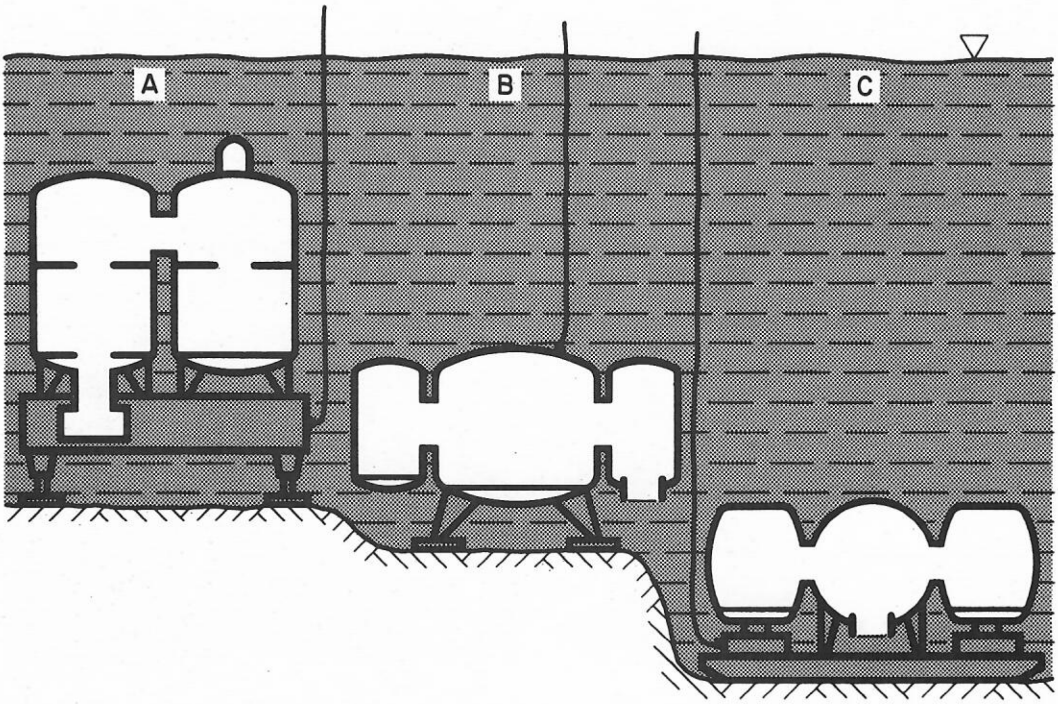

Fig. 6.4. Designs for under-water habitats with integrated pressure hulls.

was the basis of the American *Tektite* design, allowing the space to be divided into two levels, whether they were for work or living. In this configuration the machinery can be isolated in one chamber and the controls and living space in the other. The design allows for longer missions than other designs but is severely restricted in use due to the large hull area exposed to the currents whilst on the seabed, and basic instability in shallow waters and during launch and recovery through the interface of air and water, imposed by the limitations of the sea state on the surface.

A centralized design with peripheral compartments installed around the central chamber is shown in *Type B*. This was first put into practice in Captain Cousteau's French-designed *Starfish* house. The central hull may be cylindrical or spherical and several compartments for different functions can be connected to this nucleus, housing the central control, life-support and monitoring functions. Certain advantages lie in the possibility of increasing or decreasing the number of peripheral compartments, perhaps even whilst under water.

Type C is a modular concept establishing the American *Bottom Fix* theoretical design and allowing different sized spheres to be combined together. The present Underwater Test Range at Hawaii using the same concept is very modest as shown in Fig. 6.4C with two cylinders connected to a centre sphere, on the same axis and the whole resting on a pontoon. The pontoon allows the complex to be towed

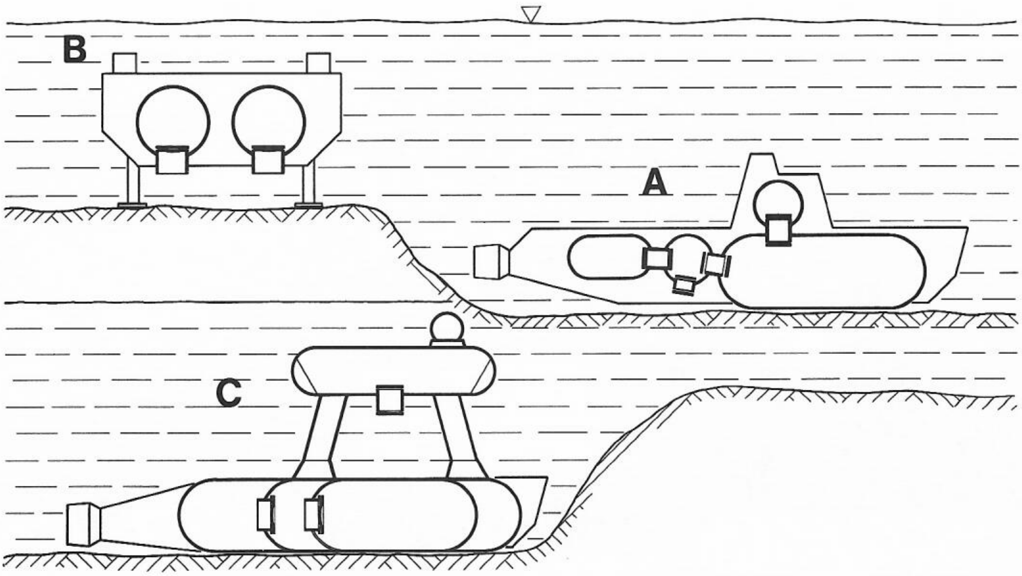

Fig. 6.5. Examples of under-water mobile stations.

to and from the site in sea states which preclude similar transport for other systems with reduced stability. The advantage of designing the overall system for safe towage is considerable, as the only alternative is launch and recovery which demands heavy lift cranes and barges. Another design which incorporated towage facilities was the habitat design by Perry Oceanographics known as *La Chalupa* where two horizontal chambers forming the habitat were designed into a pontoon.

Mobile Under-water Habitats

Except for habitats designed as part of deep sea production systems where they can be considered permanent and provide oil and gas separation, water injection and other requirements, the modern concept of the habitats demands that it should be capable of being moved from location to location and able to undertake research and investigation. The latest concept, *Ocean Lab*, planned by the National Oceanographic Atmosphere Administration, has incorporated an integrated pressure chamber complex which comes close to being a submarine. However, with its ability to operate aquanauts and remain in one position for relatively long periods of time, it should continue to be classified as an under-water station or mobile habitat.

The main constructional forms for these mobile habitats are shown in Fig. 6.5.

The concept of the submarine hull enclosing a habitat (*Type A*) was advanced by Captain Cousteau in the design of the *Argyronete*. The hull was in fact built before the high cost of completing the vessel and

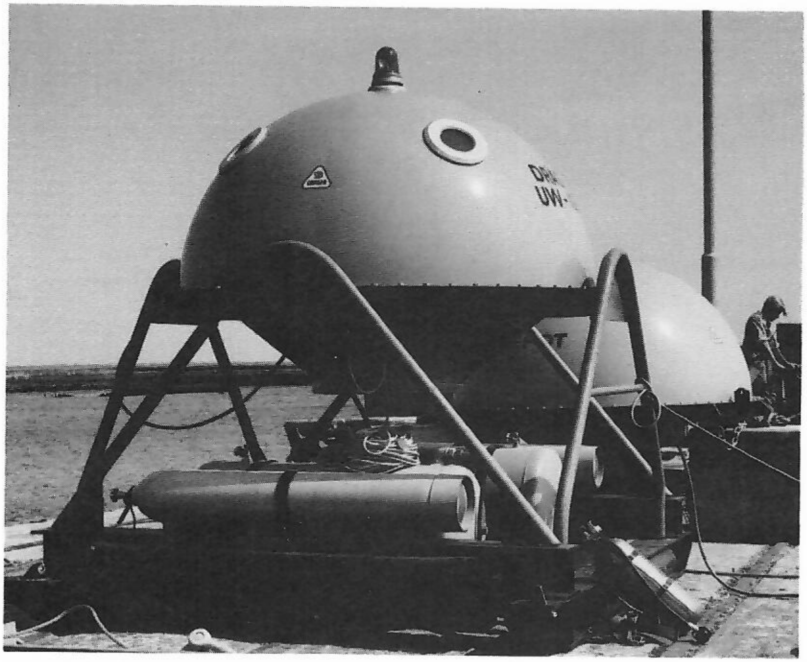

Fig. 6.6. Under-water *Igloo* before operations in the North Sea.

the limited commercial return at that time put an end to further work. However, the principle is valid and as the commercial opportunities are realized for this configuration, the design will be updated and the autonomous submarine habitat will finally be built.

A less conventional but in many ways more practical approach to the problem is in the submersible catamaran design (*Type B*). The catamaran can meet the basic requirements of a habitat, which is to provide a work base on the seabed from which to operate divers and carry out investigation in a one-atmosphere environment, and also undertake other missions. By transporting and supporting welding habitats and small submersibles to the work place, other tasks could be carried out. The sea-keeping qualities of the catamaran design in a semi-submerged condition will give additional flexibility whilst stationary or underway on the surface. An additional feature is the use of the catamaran as a deep diving vessel where a diving bell can operate from a transfer under pressure system inside the hull and below the waterline. Operating diving bells and submersibles from a position below sea level overcomes the inherent dangers and limitations when operating caused by wave motion and possibly surge near or on the surface.

Construction of Habitats

The various designs already discussed, some theoretical and unproven, now lead to actual constructions based on those basic designs.

For short missions the under-water shelters or igloos need to be relatively small. A good example of this is shown in Fig. 6.6, either

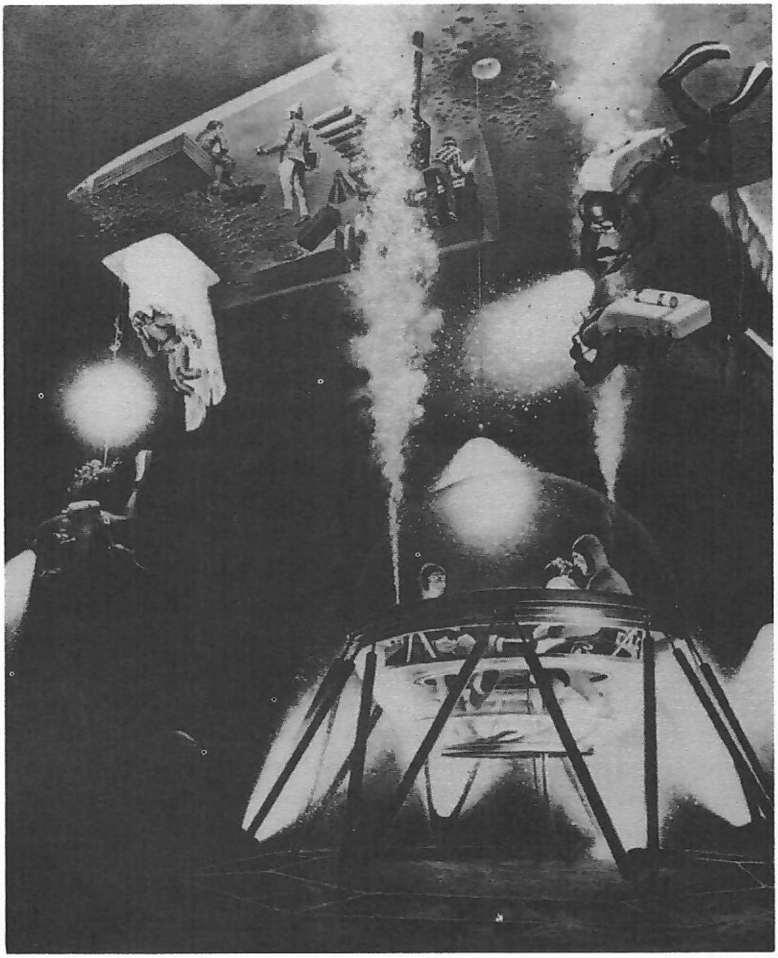

Fig. 6.7. *Sub-Igloo* (Canada) was successfully employed in Antarctic exploration programmes in 1972 and 1974.

used autonomously or connected to a central habitat supplying certain life-support functions and direct line communications. The hull is a hemispherical shell, made from corrosion-proof, well insulated glass-reinforced polyester resin, and closed towards the bottom with a flat dished shell with a central shaft for lock-out made of the same material. The lock-out shaft has no door and is open to the water. The gas or air inside is at ambient pressure to prevent the water from flooding the interior.

Large viewports are installed for good observation. A flashlight on the top will indicate the position of the igloo in poor visibility.

To some extent the internal fittings of the igloo will reflect the proposed use of the shelter. The use of the unit in an emergency, whilst in transit or occasional shelter, will demand more modest fittings than if it is used as a forward-operating base from which to undertake a task. Generally the interior will have an electrically driven CO_2 scrubber, an oxygen supply unit adjustable for the number of occupants breathing the air or gas mixture and an air supply or gas mixture for keeping the water level constant, and for ventilation by flushing should this be necessary. The gas supply is stowed in two 50-litre cylinders which are mounted on the base frame. Communication and appropriate lighting are provided inside the igloo which can be connected to the central habitat. At least two closed-circuit or scuba breathing sets are provided with each igloo in this case.

Even with these small units, very careful ballasting is needed. With a radius of 0.9 m and an overall volume of 1.5 m^3, the displacement of the water has to be compensated with weights. The base frame was built with additional steel bars for ballast and two large buoyancy tanks were used to control the descent, without a crane. This allowed the igloo to be towed out to a coastal site by a small boat and placed on the seabed in shallow water using divers. On land it is easily transportable by road.

Acrylic glass can be used for this type of igloo in addition to the smaller 'telephone box' shown in Fig. 6.2A. In the larger installation by Dr MacInnis, known as *Sub-Igloo* and pictured in Fig. 6.7, the use of acrylic for the hemisphere, although considerably more expensive than glass-reinforced plastic, allowed scientific observations to be made with exceptional all-round observation in Arctic waters. In this case the diameter of the acrylic dome is 2.5 m. The use of under-water tents, where only short and temporary operations are contemplated, requires durable waterproof materials.

For large habitats designed for the deployment of satellite igloos or other variations of small habitats, the construction clearly becomes very complex. Common to most habitats that have been built there is the horizontal cylinder. Fig. 6.8 shows a plan and section drawing of *Sealab III* built for the U.S. Navy and Fig. 6.9 shows *Sealab* suspended on a crane, shortly before its tragic first operation off California. The cylindrical main body has a length of 19.4 m and an internal diameter of 3.65 m. There is no internal pressure-proof subsection and the working and living areas are separated by flexible bulkheads. Additional compartments are connected at each end and below the main chamber. One compartment is the diving chamber with the main diver lock-out and the other is built with large viewports for under-water observation. An additional lock-out is fitted in this observation compartment as an emergency lock out. The ballasting arrangement incorporates an unusual design in that the main horizontal chamber is not secured rigidly to the ballast frame but suspended on cables, in much the same way as a balloon. The ballast frame carries all the gas supplies, which are considerable. The habitat has to be launched and recovered by a crane using a pontoon on which the habitat is towed to the site and therefore is very dependent on weather and surface conditions. The first operation, off the west coast of California at a depth of 183 m, resulted in a fatal accident and further operations were promptly ended due to some basic technical problems.

Spherical under-water stations are rare in spite of the advantages already discussed. The best known was Cousteau's habitat deployed in the Mediterranean in 1965 at a depth of 100 m. Also deploying a

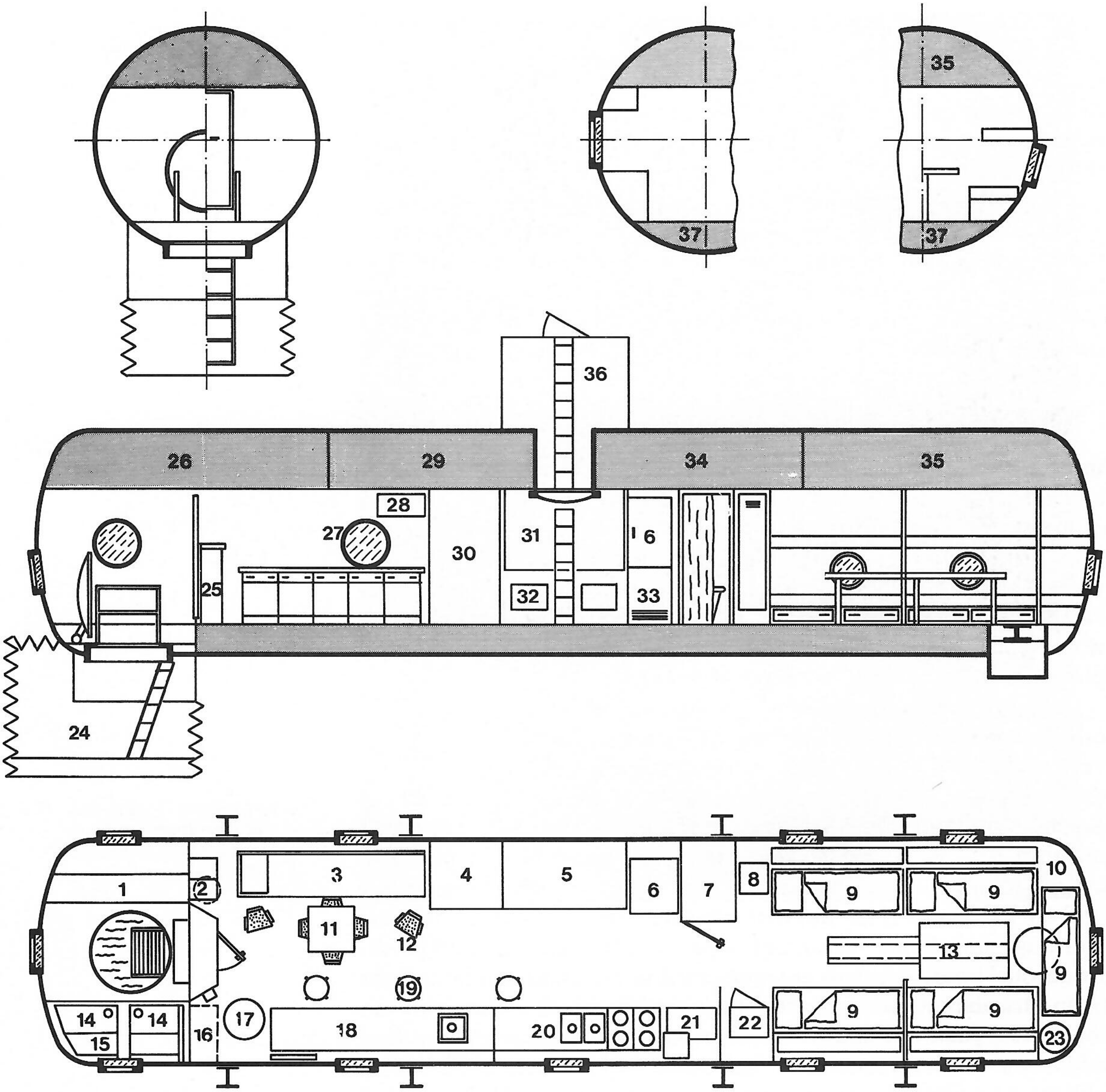

Fig. 6.8. Scheme of *Sealab III* (side and top view)

1 swim gear stowage
2 TV
3 work bench
4 fan room
5 electric power and light
6 refrigerator
7 WC
8 locker
9 berths
10 stowage
11 table
12 chair
13 table
14 bath
15 shower
16 canister stowage
17 water heater
18 work bench
19 stool
20 galley
21 laboratory
22 locker
23 CO_2 canister
24 anti-shark cage
25 cable locker
26 water ballast
27 window
28 O_2 monitor
29 water ballast
30 ventilation machinery
31 power panel
32 stowage
33 fridge-freezer
34 water ballast
35 water ballast
36 upper access
37 concrete ballast

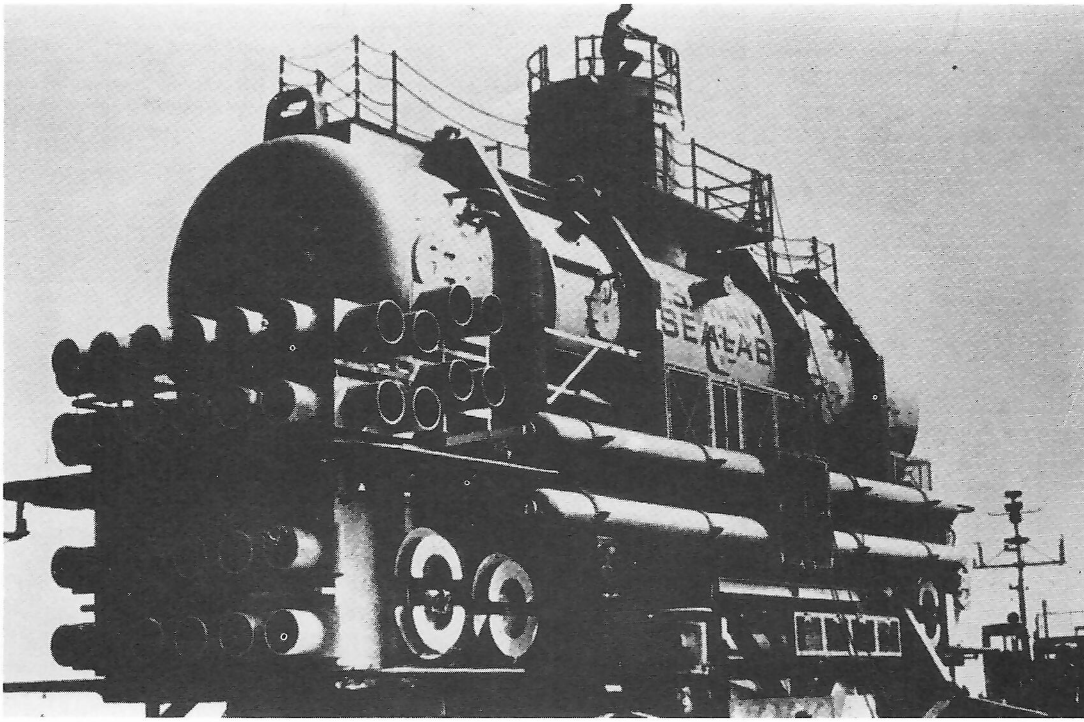

Fig. 6.9. *Sealab III* suspended on a crane shortly before its unlucky first operation.

satellite, a considerable depth and area was covered. Some Eastern European countries have built spherical habitats and in the Baltic Sea the *Sadko 1* was built, enlarging the vertical axis by incorporating a second sphere.

Under-water habitats with integrated separate chambers are less common than the 'monocells' described. Best known are the *Precontinent II*, *Tektite One*, *Sadko II*, *Aegir*, *La Chalupa* and the under-water laboratory *Helgoland*. Especially of interest is the *Aegir* at the Makai Underwater Test Range in Hawaii. Shown in Fig. 6.10 is a picture of the *Aegir* with two cylindrical chambers and an intermediate sphere on the same axis, with two rescue chambers, each for four people. Finally the two ballast chambers and gas storage cylinders are mounted with the main chamber on a catamaran pontoon. The sea-keeping qualities of the pontoon are good, up to sea state four whilst under tow, and generally the design is considered most successful, holding the record for the deepest depth of 158 m, achieving a duration of 14 days in 1970. The ability of the habitat to control its descent and ascent without the need for a crane rates it as an advanced design. The habitat can support four to six people, with separate chambers for saturation diving, and decompression can be completed whilst allowing the whole unit to come to the surface. The life-support system on board allows for 20 days operation without surface support. An unusual feature of the system allows for some recovery of the cost of the habitat by making it available to other

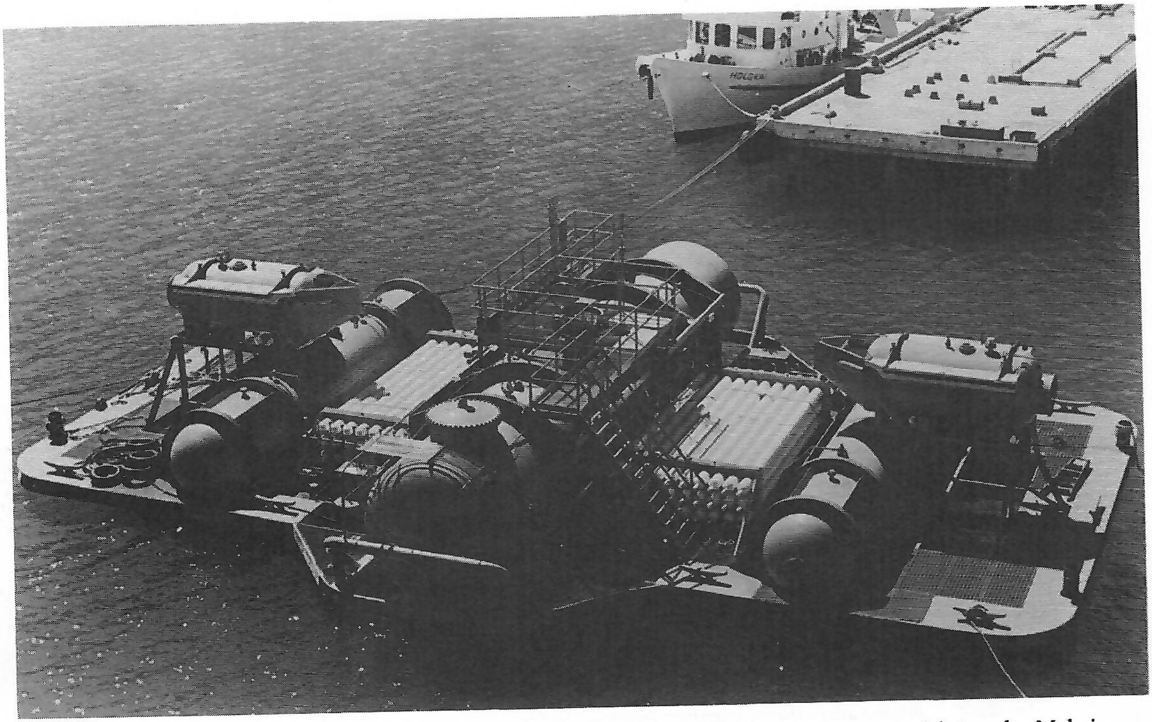

Fig. 6.10. The under-water laboratory *Aegir* and the *Holokai* at the Makai Range Pier (Makai Undersea Test Range, Oahu, Hawaii).

interested scientific bodies to carry out their own programmes. A similar arrangement was later offered for the lease of the under-water laboratory *Helgoland* for scientific research.

The integrated pressure hull concept incorporated in the *La Chalupa* in 1972 went further in perfecting the pontoon arrangement by designing the pressure hulls into the contours of the vessel.

Most habitats have been designed for operation in sites on the seabed without any ability to move except in the vertical mode for lowering, emplacement and recovery, using controlled buoyancy systems but without any propulsion units. Usually the movement of the habitat has been by crane onto a barge and subsequently from the barge into the water. The under-water laboratory *Helgoland* was transported suspended under a crane 90 miles from Hamburg to the launch area for its first operation (Fig. 6.11). As an alternative method the Dutch company Skadoc proposed that the habitat should be slung underneath a working submersible and moved from the base to the operating site where they would be lowered together, releasing the habitat on the bottom. The delicate handling of the habitat in this final stage of manoeuvring on the seabed is covered later in this chapter.

Stationary habitats without the ability to change position and lacking any form of self-propulsion tend to be used for scientific research where they are required to operate in the same place for long periods. In the future it is likely that production of oil and gas will

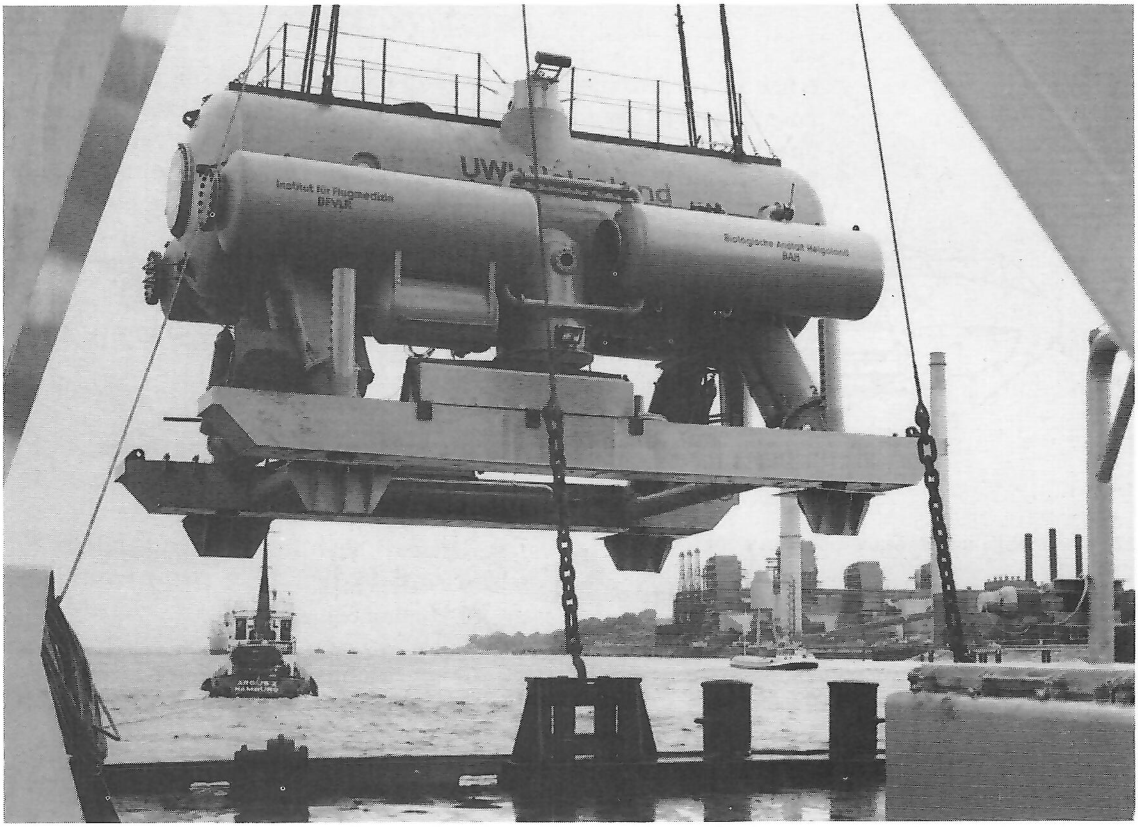

Fig. 6.11. The under-water laboratory *Helgoland* during transport from Hamburg to Helgoland.

take place on the seabed, probably in depths of water between 200 and 1000 m. By the nature of this requirement and the scope of the services that are needed it seems likely that the habitat will be separate from but connected to the main complex. The larger complex will need to undertake some or all of the tasks of oil and gas separation, water and gas re-injection into the well and the servicing of the well and be a permanent structure for the life expectancy of the field. In the small under-water laboratories the depths are very shallow and they usually have power supplied from the surface or from shore if the distances are not too great. Therefore it is unlikely that these habitats will be autonomous, particularly with regard to energy needs. The large habitats currently being considered as part of deep sea hydrocarbon production systems will need to have their own energy sources, refuelled over long periods. Mobile habitats strive to be to some extent autonomous and early concepts in this flexible role envisaged the use of conventional submarines refitted to withstand internal as well as external pressures and to provide lock-out facilities for divers. Nevertheless the constraints of limited energy sources, which usually required recharging, restricted the time spent on the bottom whilst also remaining mobile. However, the development of

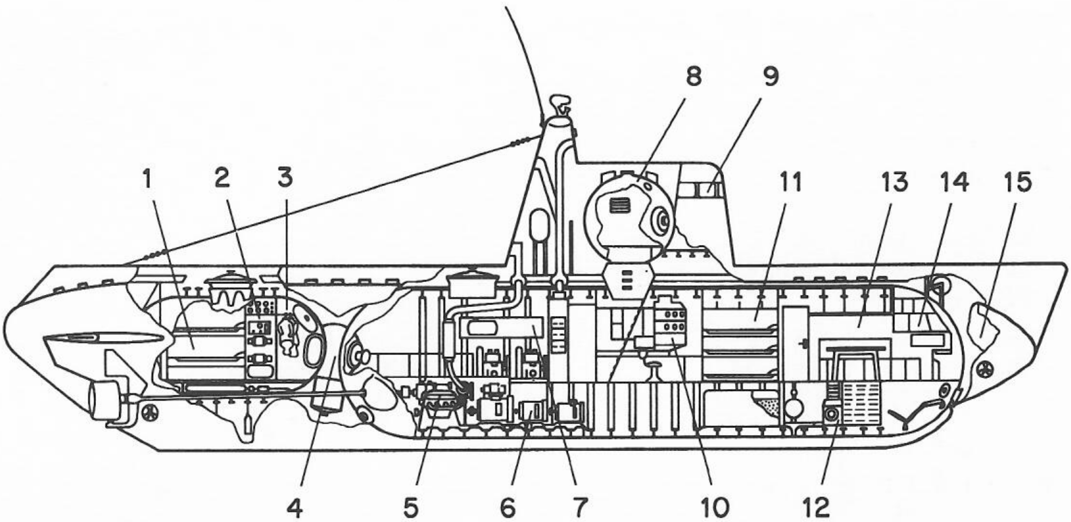

Fig. 6.12. The mobile under-water laboratory *Argyonete*.

1 sleeping space
2 electrical switchboard
3 diver compartment
4 two transfer chambers (transfer and lock-out)
5 diesel engine and main propulsion
6 generators
7 engine room
8 large pressure (rescue) sphere
9 surface bridge
10 control centre
11 sleeping areas in submarine
12 air circulation and purification
13 living room
14 oceanologists' room
15 trimming tanks

fuel cells and closed-circuit diesel engines and the design of commercial as distinct from military submarines has recently opened up many possibilities for the 1980s. The role of the autonomous submarine is discussed in Chapter 8.

The concept of a habitat contoured within a submarine hull is shown in Fig. 6.12. The *Argyronete*, as already discussed, was never completed beyond the hull but many of the ideas associated with the design were later incorporated in the American NOAA Habitat project, the *Oceanlab*.

Some designs have tried to incorporate an umbilical cable for the supply of energy from the surface to self-propel the habitat. Such a design was the *Seabed Vehicle* built by Cammell Laird with considerable government funding. Designed with large surface area wheels operating separately for movement across rocky or soft sea bottoms, the project was scrapped at a late stage. Basic design parameters that could not be met during the initial trials could have been foreseen at the early design state. Had the vehicle ever progressed into operation one of the greatest drawbacks of the surface-supplied concept would have been the sheer weight and drag of the umbilical. Mobile habitats must as a general rule aim to be autonomous. The diver lock-out technique is the same in stationary units as in mobile units.

Logistics Support Systems

In whatever circumstances man finds himself operating under water the need for life-support is fundamental. Habitats have a greater permanency than other under-water systems, such as diving bells and submersibles, in that they are not designed to be launched and recovered at short notice. Submersible and diving operations are surface-orientated with decompression, living, maintenance and repair all carried out onboard a vessel. Habitats therefore require a much higher standard of safety, particularly with regard to life-support and secondary back-up systems than submersibles and diving bells.

Support of habitat operations means supplying the following:

1. Energy (usually electrical).
2. Gases (oxygen, nitrogen, helium and air).
3. Water (drinking and for domestic use).
4. Food (prepared and deep frozen).
5. Stores (spare parts and consumables).
6. Mail.

Other support factors not directly associated with the logistics of supply are as follows:

7. Waste disposal.
8. Communications.
9. Medical.
10. Rescue.

Undoubtedly the energy requirement is paramount since without sufficient energy the endurance of the habitat is either reduced or terminated. Experience with stationary habitats indicates that power of at least 25 kW is required for an under-water team of four and this precludes the use of just battery sources.

Water in sufficient quantity is another major need. If not supplied from the surface support vessel, fresh water can be made from sea water but considerable electrical energy is needed to make the conversion.

In Fig. 6.13 the various options for stationary habitats are illustrated. If the habitat is close inshore a cable may be laid from shore to habitat as shown in Fig. 6.13A. The power cable from a shore generator needs protection, particularly on the beach and above and below the surface. For semi-permanent sites consideration should be given to trenching cables into the seabed and covering them with concrete or with fastenings. Other services that can be supplied along the same route are gas, water and communication and data lines, making up a composite umbilical. This option can be very expensive because of the danger to the umbilical from trawlboards, anchors and other intrusions and may not be acceptable particularly if the distance off-shore is considerable. Food and stores are carried out by supply boat from the surface as and when needed. Another disadvantage is

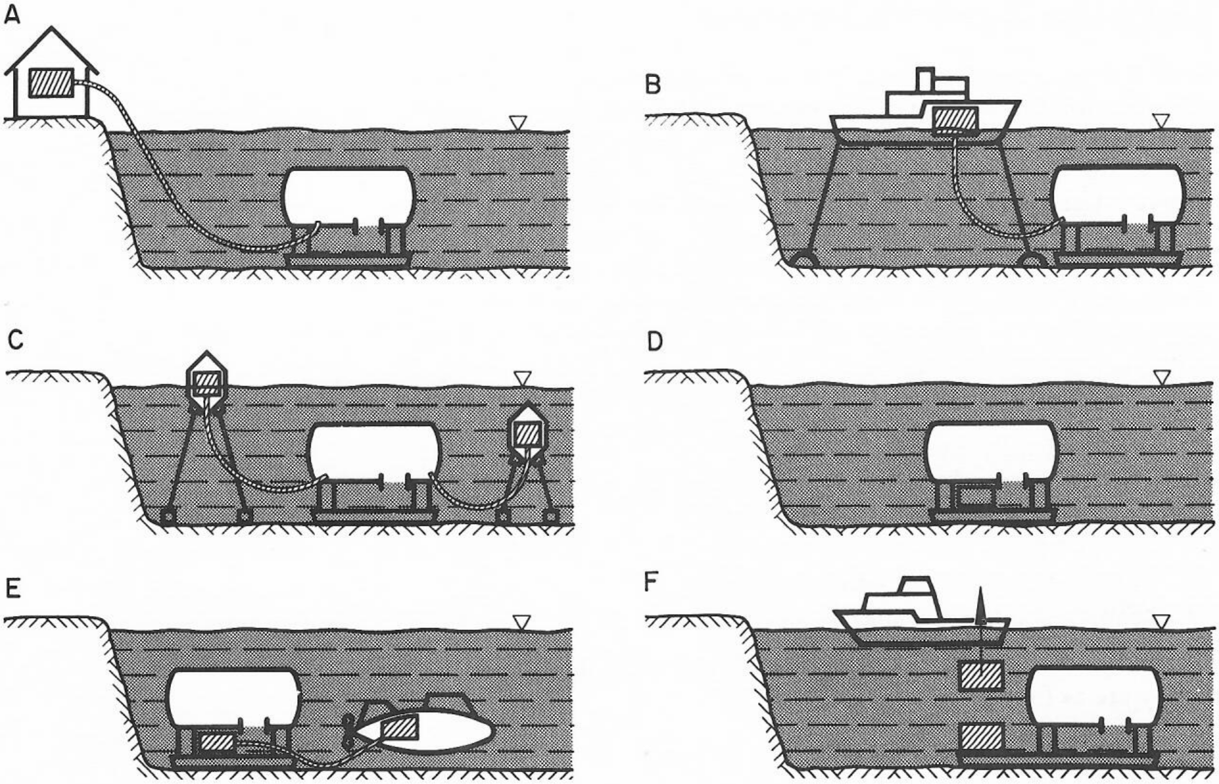

Fig. 6.13. Support systems for stationary under-water habitats.

- **A** Energy supplied from shore. Suitable only where the distance between shore and habitat is short
- **B** Energy and water supply from a moored ship or pontoon
- **C** Energy and gas supply from surface or under-water buoy
- **D** Autonomous habitat with nuclear energy supply or source, i.e. batteries or fuel cells
- **E** Periodic support from surface ships or submarines
- **F** Periodic supply of a complete life-support package

that, should the habitat subsequently need to be moved to a different site, an alternative shore supply would be required. The remaining options in Fig. 6.13 therefore need to be considered.

All the services can be supplied from a moored or dynamically positioned vessel but with two fundamental disadvantages: the limitations of weather and the disproportionate number of personnel manning the vessel to the number of personnel in the habitat, a ratio of as much as 20 to 4. Generally this method of surface support is for short periods of days or a few weeks. For longer periods the method in Fig. 6.13C has proved very successful; the power source is contained in a buoy either on the surface or below sea level to avoid contact with surface vessels. This solution presupposes that in all such operations it is essential to designate an exclusive zone and prohibit

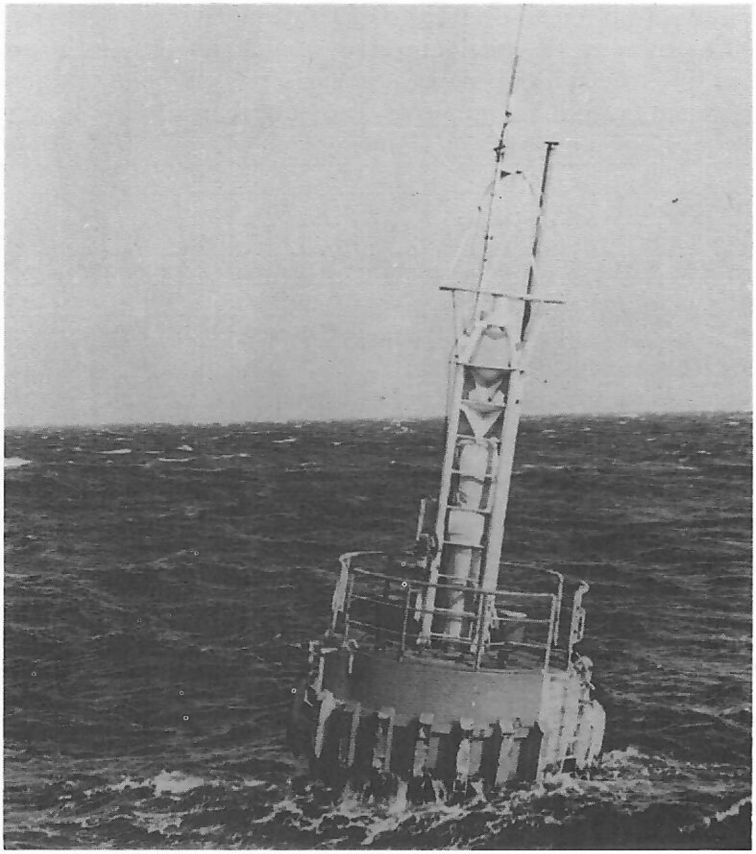

Fig. 6.14. Support buoy for the under-water laboratory *Helgoland* in the North Sea (DFVLR system).

all shipping and submarines from entering the area. The buoy can be left unmanned and operate for up to about 20 days before resupply and maintenance. The submergence of the buoys beneath the sea level does present air intake problems. These were investigated in an experiment for an under-water village in a lake in northern Italy. Diesel generators in large cylinders were fitted with snorkels to the surface. The most outstanding example of the buoy technique was that of the surface buoy used several times to supply the UWL *Helgoland* in the North Sea, the Baltic Sea and finally off the east coast of America, near Boston. The buoy is pictured in Fig. 6.14 in calm conditions in the North Sea. This buoy, one of the largest floating sea marks in the North Sea, was moored to three concrete blocks, each weighing 6 tonnes, and secured with anchor chains. Fig. 6.15 shows the mooring plan with the additional scope of umbilical to allow for any slight lateral or horizontal movement and designed with additional buoyancy. The umbilical is led through a goose-neck fitting to avoid any damage and to allow for free movement. Carefully adjusted, the buoy maintains position in prevailing sea states and tidal movements in both the horizontal and the vertical position. The overall weight of the buoy is about 16 tonnes with an external diameter of 3 m and an overall height of 13 m. Fig. 6.16 shows the inside of the unit with very much the same fittings as one

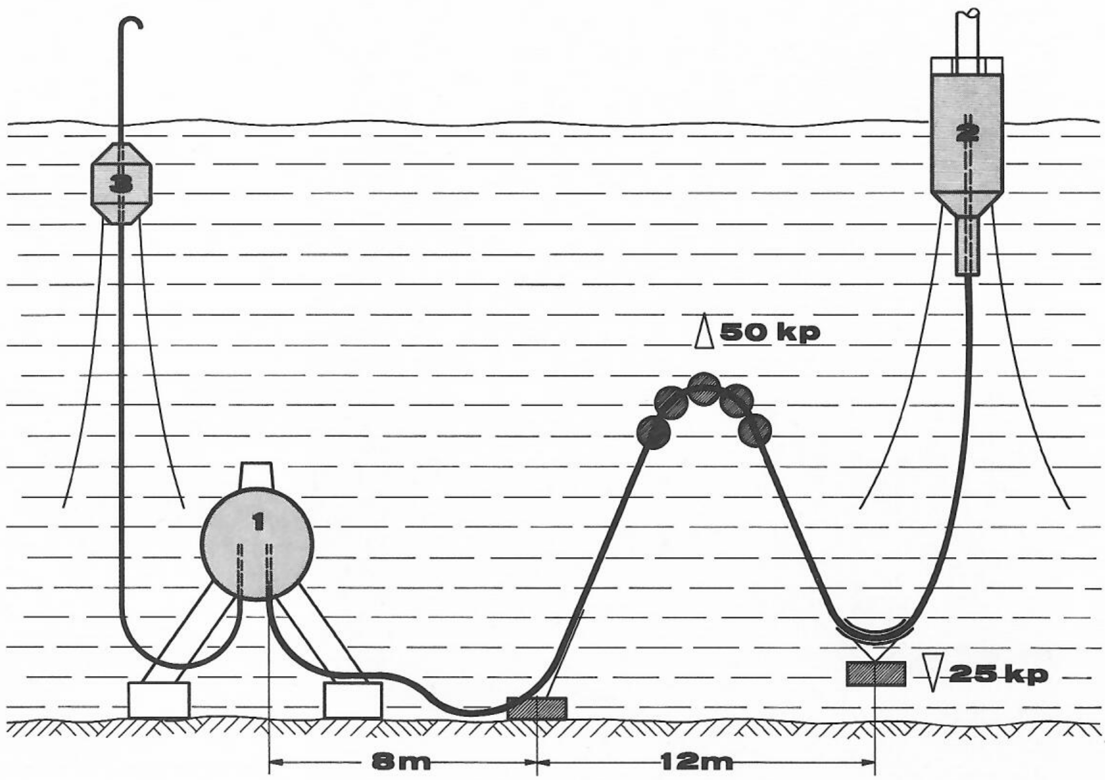

Fig. 6.15. Support buoy with goose-neck faired lead-in for umbilical from the habitat.

1 Under-water habitat
2 Supply buoy
3 Decompression buoy

would expect in a ship's engine room. The centre of the internal space is taken up by the diesel generator with an output of 25 kW. By redesigning the generator with a larger oil sump maintenance was reduced to periods in excess of 1000 hours. The fuel tanks contained 3200 litres and fitted into the bottom of the buoy, giving an endurance of at least 20 days.

The power was not only supplied direct to the habitat but also used to drive two high-pressure air-compressors sited inside the buoy. The compressor with intakes of 120 litres/minute compressed air into two banks on the habitat itself. These air reservoirs each had a capacity of 3000 litres. The habitat drew on the air reservoirs for maintaining the air pressure inside and for recharging scuba bottles as required for excursions into the water. The compressors were fitted with automatic start and stop switches to keep the air reservoirs within preset pressure levels, cutting in and out as required to keep the pressure not more than 200 bar and not less than 120 bar, allowing for sufficient air in an emergency. The compressors were carefully designed to operate without maintenance within the 20-day period and to achieve this had automatic water drainage valves. The alternate use of the two units spread the work-load over the operating period.

An axial blower was fitted to the top of the buoy for the necessary intake of air into the engine space supplying the required 3200 m^3/hour. The additional engine fittings were the oil pumps, fuel and bilge pumps. The compressors and generator had to meet the strict requirements imposed by the movement of the buoy in bad weather with inclinations of up to 45° and accelerations of $2g$.

Also installed inside the buoy were the other life-support requirements of oxygen, nitrogen and helium, as required, contained in 14 gas storage cylinders, each with a capacity of 50 litres. With a crew of four in the habitat the oxygen supply is sufficient for at least 14 days without having to use the emergency supply in the habitat. For depths down to about 30 m the helium and nitrogen supplies are not needed but as the site becomes deeper the use of these gases, either in a tri-mix of helium, nitrogen and oxygen or for deeper depths in oxy-helium mixtures, becomes necessary.

In addition to its purely logistical function, the buoy is fitted as a relay station providing a communication link to the habitat and if necessary also a television link. Using radio for the external link to the outside world from the buoy, the communication link is through direct line to the habitat. This line communication and all the other sources of gas, power and water are passed through 16 hoses joined together to form the composite umbilical protected by a non-abrasive plastic sheath. For the UWL *Helgoland* the length of the umbilical was 60 m. Marine growth was eliminated by the use of anti-fouling paint, an important consideration in all buoyancy design calculations. The buoy was also used for landing supplies, mail and other essentials including the transfer of crew.

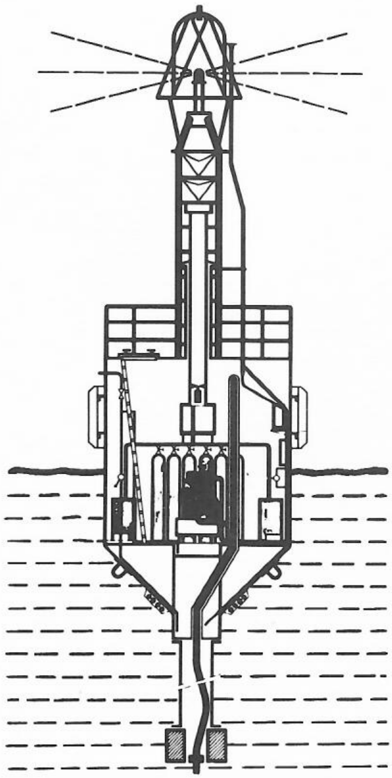

Fig. 6.16. Cross-section of the support buoy for the under-water laboratory *Helgoland*.

The buoy technique has been used with other habitats notably the *Aegir* off Hawaii and the much frequented *Hydro Lab* in the Bahama Islands where the buoy housing the diesel generator was designed as a monohull. A later system using the autonomous energy buoy was the Perry-built *Prinul*. Much of the background study of various competing systems has been taken from the work of Dr P. A. Borovikov.

Energy Supply

The three systems already discussed are all in some way dependent on surface support, whether ashore or to a ship or buoy, and there is an inherent vulnerability in total reliance on outside sources. The more difficult solutions involve maintaining some measure of autonomous survival without recourse to the surface. The fundamental problem lies in creating an energy source at the site. If this can be satisfied other needs for life-support, such as gas supplies and the elimination of noxious or toxic gases, are relatively uncomplicated. The following are the possible sources of energy which need to be considered.

Batteries

Lead–acid, nickel–cadmium and silver–zinc batteries will all, to a greater or lesser degree, provide power to a habitat. Careful

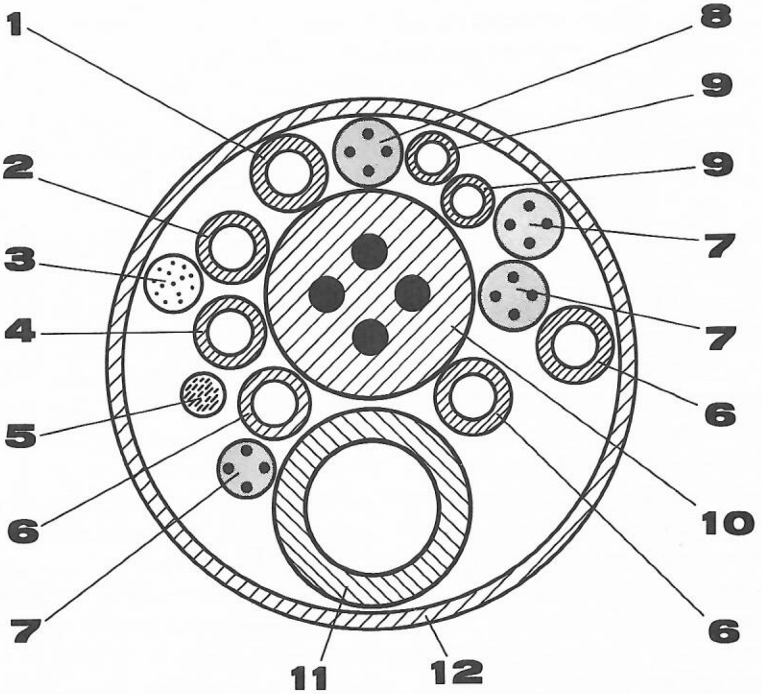

Fig. 6.17. Cross-section of the umbilical of the under-water laboratory *Helgoland.*

1	nitrogen	7	electrical control system
2	oxygen	8	electrical control system
3	communications	9	compressed air
4	helium	10	power cable
5	television	11	fresh water
6	exhaust air	12	protective plastic sheeting

insulation is needed in a seawater environment where it is necessary to surround them with oil or nitrogen. Clearly the main disadvantages are the high weight-to-output ratio and the requirement for recharging. For long missions or where there is an increased demand for power, such as may be needed for heating, the battery source may not be able to provide this power. Depending on the tasks being undertaken from the habitat a power supply of between 1 and 10 kW per person is needed, with more under special circumstances.

Fuel cells

Fuel cells are being seriously considered as the ultimate solution to the question of energy in habitats and submersibles. In these units the energy is not stored as in a battery but initiated as a product of a chemical reaction, usually with a high measure of efficiency. The fuel sources considered are mainly hydrogen and methanol but other hydrocarbons may be possible in the future. Water produced in the process could possibly be used for domestic purposes. The whole fuel cell concept is very expensive and still in the trials development stage.

A 30 kW fuel cell has been tested down to depths of 1700 m in the Lockheed *Deep Quest* submersible.

Internal combustion engine

By recycling the gases within a closed-circuit system made possible by resupplying the engine with oxygen a system was developed for use in military submarines during World War II. Theoretically very high powers can be generated but currently it is limited to a few hundred kilowatts. As power increases the oxidant storage and exhaust disposal requirements become greater in addition to the fuel tanks needed in the habitat.

Nuclear energy

The use of nuclear reactors may provide the best solution as the refuelling period can be extensive, allowing for extended missions. Theoretical design work is being carried out on the feasibility of using mobile nuclear reactors, profiting from the experience of nuclear plants fitted into military submarines. It is beyond our scope to examine the possibility of using nuclear power except to say that it does offer very real possibilities for use in large habitats connected to permanent subsea hydrocarbon production systems, particularly in areas of ice where surface-supplied power is not possible and where a great deal of energy, to supply water injection, gas separation and compression and other systems in addition to those of the habitat, is necessary.

Other sources

Other sources of energy are radio-isotopic, heat reservoirs, converters for thermal energy, thermionic converters and magnetic hydro-dynamic converters. Perhaps in the future ocean thermal energy conversion will be possible.

The power requirements of the habitat depend on its purpose and tasks that are to be undertaken and, as variations are considerable, it is not possible accurately to assess and compare the respective costs and the sizes and weights of the optional power sources. The need for a power supply as technically secure as possible is greater than in a surface vessel or production platform where a power failure in most cases will be an inconvenience until restoration of power or the arrival of outside assistance. A power source for total submergence demands the highest possible integrity. A failure of power supply may require a shutdown of the complete system and in most circumstances the emergency battery system cannot provide the same power output to continue normal services. To avoid having to evacuate the habitat, a secondary power supply is necessary. Batteries are power storers rather than power sources and although essential for emergency use should only be considered, in the long term, in conjunction with true power sources.

In Fig. 6.13D the power source is part of the habitat, whether battery, fuel cell or nuclear reactor. With regard to future

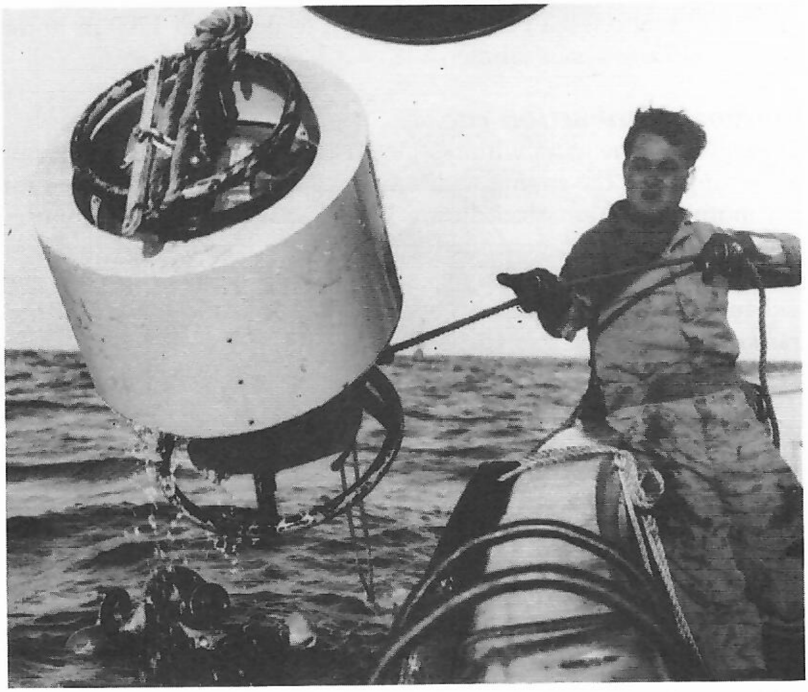

Fig. 6.18. Recovering a supply container.

development clearly the use of a nuclear reactor is expensive. In Fig. 6.13E the power source is being recharged by a submersible but this facility is now likely to be carried out from a surface vessel or a submarine because of the small power resources of submersibles in general. For smaller habitats with short mission cycles the arrangement illustrated in Fig. 6.13F has been used successfully with the exchange of used for new life-support packages containing a CO_2 absorbent cannister with blower, an oxygen supply, drinking water, hot-water generator, food and lights and batteries. In this particular project the units were exchanged every 24 hours.

Replenishment

In addition to energy, gases, water, food, stores and mail have to be delivered on site. In the event that water cannot be produced in the habitat, a sufficiently large water tank needs to be provided, the capacity being dependent on the frequency of supply. Where a vessel is on station supplying through an umbilical, there is no need for a large tank in the habitat but with a buoy connected to the umbilical a larger tank is needed to hold water long enough to cover a maximum period of bad surface weather when a supply vessel cannot approach and service the buoy. Should the habitat be supplied by submarine there are normally no limitations imposed by weather, assuming that the submarine is autonomous and can move from base to the site in any weather state.

For the transfer of stores, mail and food, both fresh-prepared and frozen, pressure-compensated water-tight containers need to be

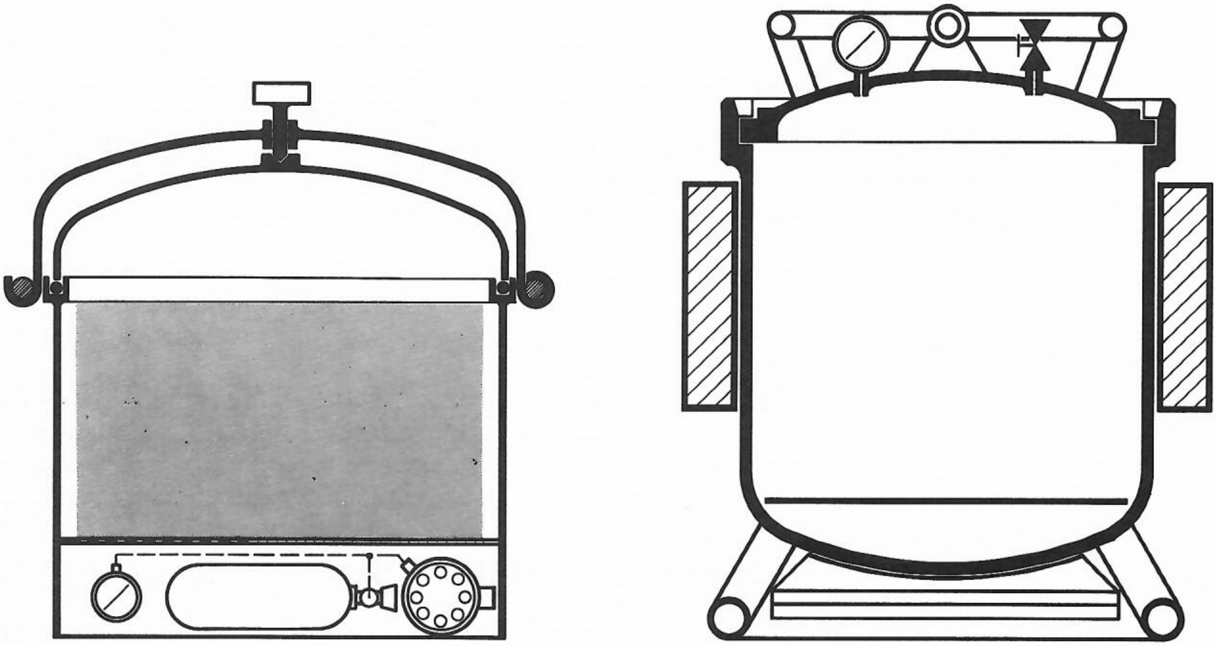

Fig. 6.19. Design of a pressure-compensated and pressure-resistant supply container.

provided. Sometimes known as stock pots, the containers have in the past had a capacity of between 50 and 100 litres. The sealed unit must, of course, be designed for external and internal pressure and equal pressures and because the transfer at sea needs to be carried out quickly and efficiently, the sealing design must be foolproof but capable of a quick operation. The use of bolts and butterfly nuts to maintain a seal, in preference to a bayonet flange and seal, is not advised. The procedure is for the container, filled with the required stores, to be pressurized on the surface to the same pressure as the habitat on the bottom. The control system for this includes a charging inlet, a pressure gauge, a relief valve and a blow-off safety valve. Buoyancy is controlled on the descent by weights or enclosed ballast tanks. However, at greater depths the units tend to become too heavy for efficient handling on the surface, in which case an alternative method can be designed using automatic pressure-compensating control systems. In conjunction with light-weight containers, open-ended at the bottom similar to a diving bell, the pressure control automatically vents air into the chamber commensurate with the increase of pressure during the descent. The gas supply is either from the surface or from cylinders attached to the unit and the design is naturally simplified by avoiding expensive sealing locks.

The containers are lowered to the habitat either manually or by surface winch and a convenient pick-up arrangement on the habitat can pull the slightly buoyant container from the surface into the habitat. A straightforward way is for the divers from the habitat to enter the water, collect a negatively buoyant container and return to the habitat. However, wherever possible divers should not be employed to do this work if alternative methods can be used. The pick-up method was used in *Sealab III* operations and subsequently applied several times for operations from UWL *Helgoland*. For the transfer of bulky stores, bigger containers have to be used or alternatively a diving bell. If the equipment is not sensitive to contact with water plastic bags to wrap up the stores are quite acceptable for the transfer from container or diving bell to the habitat. If this method is not possible because the stores and equipment are sensitive to contact with water, the use of the pressure- and water-tight rescue chamber can overcome the problem.

For the transfer of equipment from depth to the surface in open-ended containers, waterproof plastic bags are ideal as they will automatically blow off as the depth of water, and consequently the pressure, decreases, with little chance of water penetrating the inside.

Support of a Habitat in an Emergency

The supply of services and the operation and replenishment of an under-water habitat is not exceptionally difficult if properly planned and designed in the first place. This chapter has covered some of these aspects but the planning and design stage needs to carry out a risk analysis and evaluation of the risks to the personnel in the event of unknown design failure for any factors outside the control of the designers and operators. Habitat operations involving personnel working on the seabed demand higher standards of safety than other subsea operations involving personnel either in one-atmosphere normal pressure conditions or under pressure in hyperbaric conditions. Other subsea operations involving personnel, such as diving and submersible operations, are eventually surface-orientated, in that the aim is to inject the diver and craft to a work site and return to the surface after a given time. In habitat and autonomous submarine operations the design and capability allow for continuous uninterrupted operations and these are dependent on the logistics of re-supply. As long as supplies of the various items can be continued within the framework of a reasonable mission cycle, and within the bounds of accepted technology, advances will be made but the ability of habitats to survive under emergency conditions where no re-supply is immediately forthcoming is a primary design factor. This, as previously stated, involves electrical energy, food and drinking water, oxygen and other gases for pressure maintenance and the absorbent materials for life-support.

Emergency Electrical Supply

The needs of lighting and heating, important analysing equipment, communications and the operation of the primary life-support system are all demands on the emergency power supply. The importance of an autonomous power supply has been discussed and

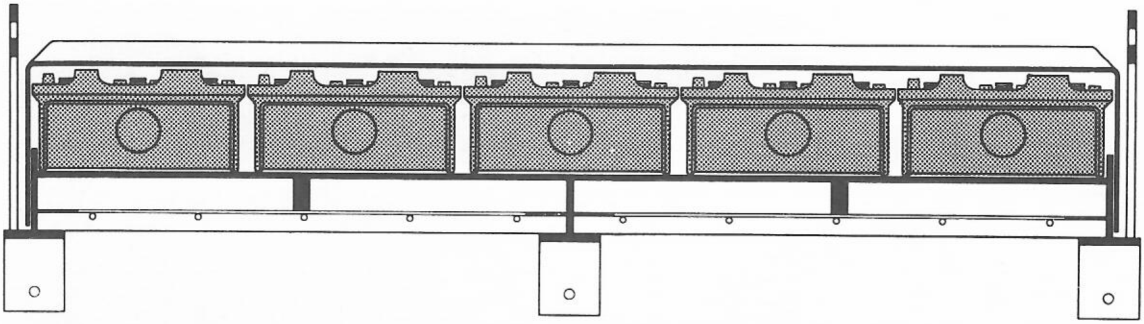

Fig. 6.20. Cross-section of an under-water battery pack.

the same considerations apply to emergency supplies. As standby units they should ideally be autonomous but smaller habitats will need to rely on power stored in emergency batteries similar to those provided in submersibles. Standby units in the future may well use recycled diesels or fuel cells, separate from the main power source. These standby power units are essential for any proposed subsea production system which involves personnel working in a habitat as part of the total complex and without surface or shore power supply. The continuous running of main services and machinery without any significant reduction, except for maintenance and repair, demands the installation of standby units which will also provide emergency power. In the event of the standby power sources failing, emergency batteries can only be expected to provide emergency life-support and communications; all other services will probably be shut down prior to an emergency evacuation.

An emergency battery pod for the under-water laboratory *Helgoland* is shown in Fig. 6.20. The batteries will function in the habitat at the ambient pressure with the bottom part placed in water. Relatively inexpensive car batteries are used and as long as the terminals are protected with acid-proof grease against the effects of humidity, they are a dependable power source. To maintain air space around the terminals the batteries are covered with a water-proof insulated housing, such as glass-reinforced plastic, placed over the whole assembly. To keep the water inside the battery cells at a constant level during pressurization whilst descending to the site, air or nitrogen can be blown inside the housing controlled automatically by a supply pressure valve. The build-up of explosive gases is prevented by periodically purging the free space above the batteries with nitrogen. The explosive gas mixtures which are formed in the process are dispersed by the periodic purging of the space above the terminals with pure nitrogen. Battery pods can be designed as a permanent part of the habitat. They require inspection and maintenance and the design must allow for easy access to carry out these routines so as to avoid the premature removal of the batteries and replacement. Battery cells will, in any event, discharge slowly without being used and a charging system is needed to maintain their capacity. Apart from free flooding cells, an alternative battery design

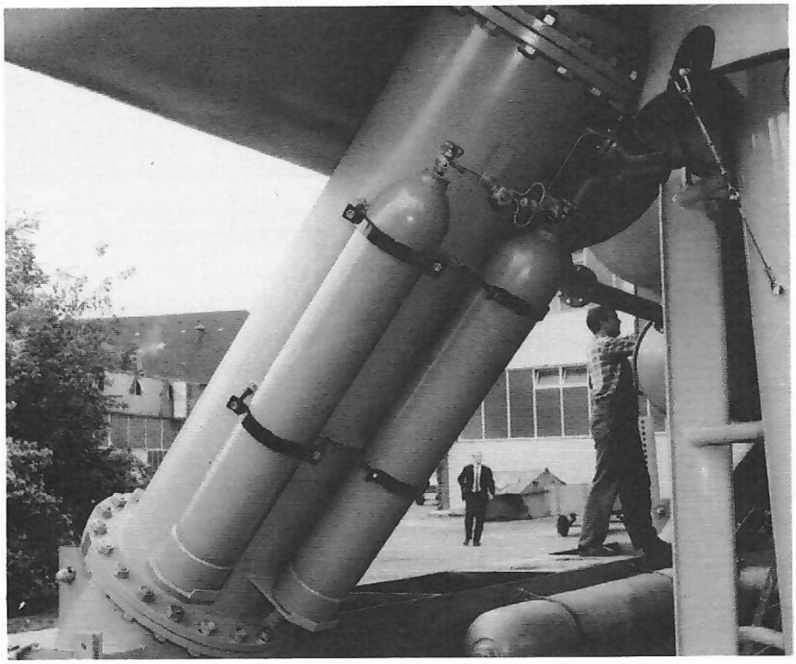

Fig. 6.21. Cylinder stowage on the support leg of the underwater laboratory *Helgoland*. On the ballast is a 300 litre reserve tank for compressed air.

is the oil-filled battery unit, with the advantage that the danger of seawater coming into contact with the terminals is excluded. Another alternative is the encapsulation of the batteries in pressure-proof vessels as used in submersibles and described in Chapter 7.

Emergency Water Supply

The technical problems of producing fresh water from sea water preclude the use of desalination plants in habitats, at any rate for the foreseeable future. Water for drinking and for general domestic use has to be carried in or around the habitat in quantities which will suffice should the regular supply from the surface or from shore be interrupted or terminated. Rather than using pressure-proof vessels outside the habitat, which are expensive, flexible containers or bags secured to the outside of the habitat do fulfil the requirement to some extent, but there is a danger that the water bags may develop leaks, caused by the damaging effects of strong currents and the interaction against the structure, or, worse, they may be swept away. A logical solution is to place the water bags inside the rigid buoyancy tanks of the habitat and to compensate for the weight and volume of fresh water consumed by filling the area between the tank and the container with sea water. The buoyancy characteristics of the habitat will not vary sufficiently to alter the stability. On the *Helgoland* 6000 litres of fresh water were stored in this way with a sight glass to indicate the water level inside the tank. A further fresh water supply was carried for special missions and this was fitted between the support legs and resting on the seabed where the weight was taken. This additional water supply considerably increased the mission cycle.

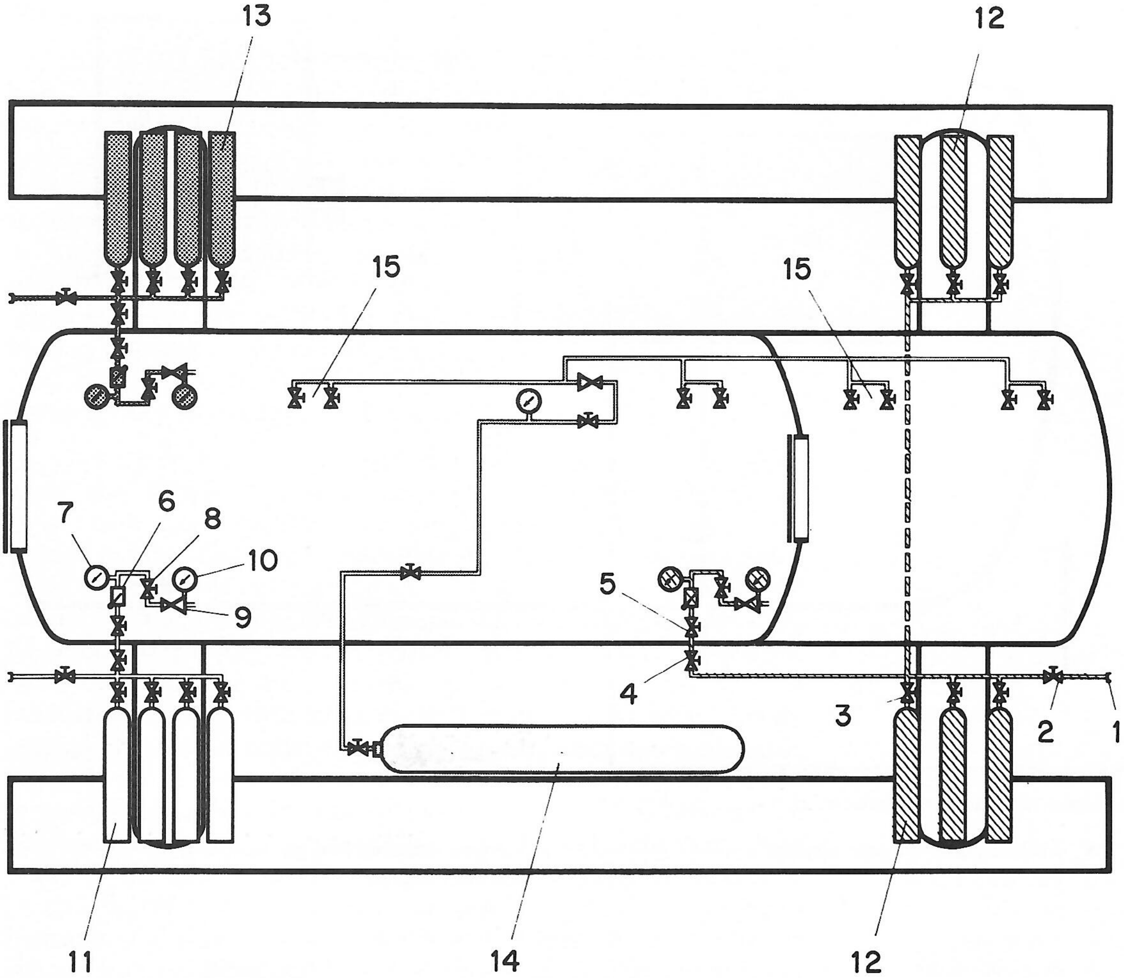

Fig. 6.22. Emergency gas supply system for the under-water laboratory *Helgoland*.

1 charging connection
2 charging shut-off valve
3 cylinder valve
4 shut-off valve, external
5 shut-off valve, internal
6 one-way valve
7 supply pressure gauge
8 outlet valve
9 pressure regulator
10 operating pressure gauge
11 nitrogen storage (30 m^3)
12 oxygen storage (60 m^3)
13 helium storage (30 m^3)
14 air storage (120 m^3)
15 breathing connections

Emergency Gas Supplies

The additional supplies of gas needed in the event of an emergency, should the re-supply be terminated or the main supply be contaminated, are clearly dependent on depth and physiological requirements. In the most complicated situation all the breathing gases will be stored separately, these being oxygen, nitrogen, helium, air and possibly some prepared gas mixtures as well. Separate storage

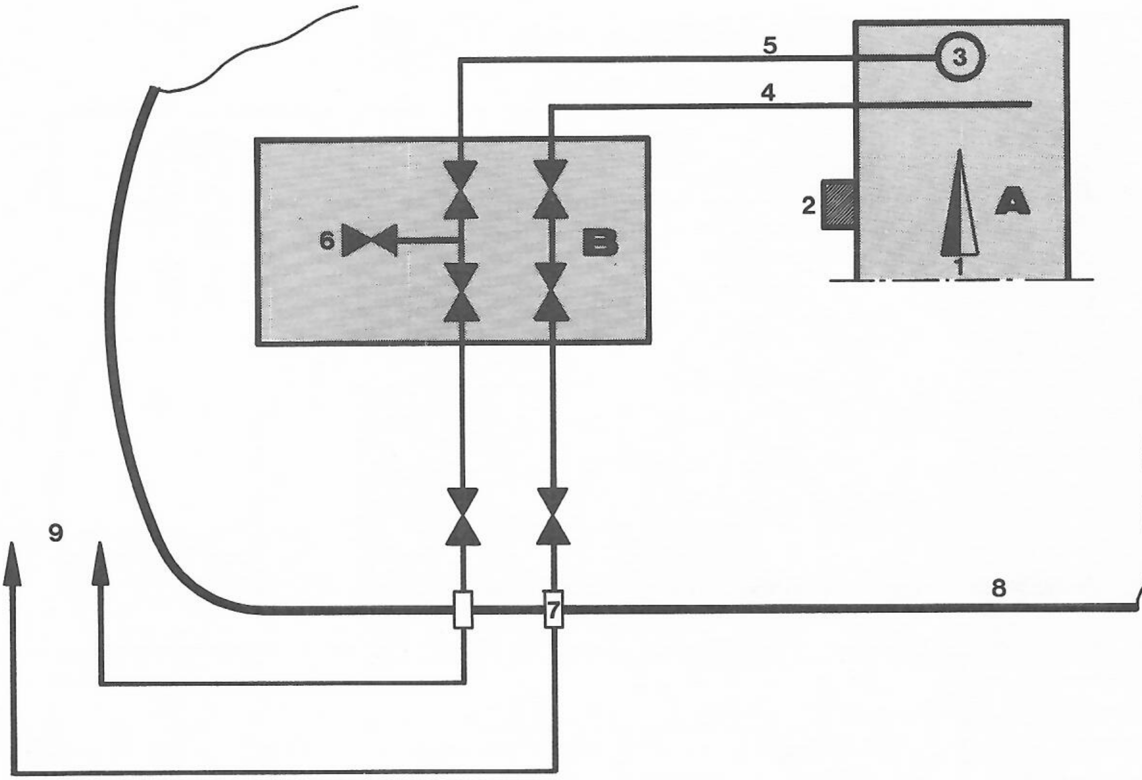

Fig. 6.23. *Sealab III* emergency helium, air and oxygen system.

- A scrubber/filter exhaust plenum
- B gas control panel
- 1 gas flow
- 2 Po_2 sensor
- 3 distribution duct
- 4 helium and air, charging and make-up
- 5 oxygen make-up and gas sampling
- 6 gas sampling hose
- 7 stuffing tube
- 8 bottom of hull
- 9 to umbilical connections topside

space to accommodate these has to be designed around the habitat's main chamber and be interchangeable to meet the requirements of depth and task. The gas supply arrangement for the *Helgoland* is shown in Fig. 6.21. It is preferable to position the cylinder connections inside the air or gas pocket within the dome of the habitat so that these cylinders can be exchanged without sea water entering the system. Fig. 6.22 shows the emergency gas system of the *Helgoland* for the initial trials. Subsequent alterations are made at later stages to conform to national certification as these are liable to change in different countries. The gas supply arrangement for the U.S. Navy *Sealab III* was such that the emergency supply was linked to the surface whilst the normal consumption was met from onboard supplies. There are clearly different views as to how to provide satisfactory emergency cover.

Emergency Food

The diet of habitat dwellers is dependent on the type of food that can be stored for long periods under pressure or in moist conditions. If the supply of food is interrupted to the extent that emergency rations need to be breached, food must fulfil the minimum dietary and energy requirements. As power supplies in an emergency will be very restricted, cooking will be limited to heating pre-cooked food either deep-frozen or canned if the latter is possible under ambient pressure conditions. Power may not be sufficient to maintain deep-freezers. Vacuum-dried food needs less storage and by adding water and heating nutritious food can be served.

Emergency Re-supply of Stores

An emergency plan to provide additional stores, should re-supply from the surface become impossible, is needed because the consumable items such as food supplies and CO_2 absorbent are needed in large quantities, depending on the number of occupants. They are bulky in volume and space is severely limited inside the habitat. If the life-support system is on closed circuit the CO_2 filtration system will greatly increase the demand for CO_2 absorbent. With the possibility of emergency periods without re-supply or evacuation in excess of 20 days, the bulk requirements can be met by locating the stores in under-water store depots placed near the habitat. Fig. 6.24 shows the use of a storage depot in conjunction with other systems that may be part of a total habitat operation. The storage can be a construction of reinforced polyester resin and has the shape of an under-water igloo. No life-support or other equipment is needed except shelves to make use of the available space. The water-tight hemispherical shell with a diameter of 2 m floats like an umbrella secured by two chains attached to two concrete weights, about 1.5 m above the seabed to allow good access for the divers when recovering the stores.

Safety and Rescue

An evaluation of the risks to personnel, based on the design of the habitat, needs to be undertaken. It cannot be overstressed that the standards of safety and the integrity of rescue facilities need to be far greater than other undersea systems which are based on intervention only from the surface. In the final analysis a straightforward recovery system is needed for the evacuation of all personnel. This has not always been the case and consequently there have been fatal accidents although in most cases these have been caused by human error. Financial considerations should not influence the design for safety and rescue and if the project cannot be adequately funded then its concept should not be implemented.

In Fig. 6.24 a number of important aspects are shown diagrammatically. They are not all essential to the overall plan but

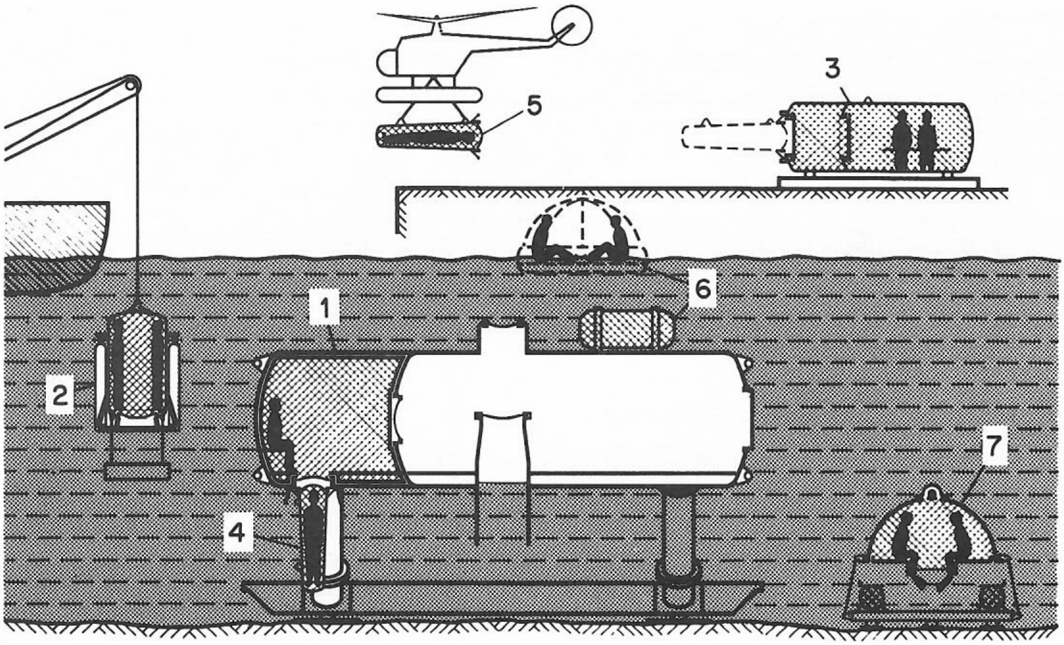

Fig. 6.24. Safety installations for manned under-water stations.

1 decompression compartment inside the under-water laboratory
2 personnel transfer chamber
3 stationary recompression chamber
4 one-man rescue chamber
5 transportable one-man chamber
6 rescue float
7 under-water igloo

should be considered on their merits to fulfil a rescue plan for all known eventualities. If the 'aquanauts', as they might be described, need to be decompressed on completion of their mission cycle, the ability to decompress inside the habitat whilst it is being recovered to the surface is clearly a major safety factor. This means that the habitat must have an internal decompression chamber. Conversely, manned under-water stations which need to be in pressure equilibrium are not suitable except in very shallow water or if transportable one-man chambers are designed which are capable of transporting divers under pressure from the habitat to the surface to transfer under pressure into a surface compression chamber. Unlike transportable chambers used on the surface, for instance to transport an injured diver from an off-shore installation to a medical chamber ashore, the chamber may need to withstand an external pressure as great as the internal pressure. The use of free ascent is practical for occupants not under pressure, based on the experience of naval submarine crews. It requires training beforehand and is not an established practice outside certain navies. The Russian attitude is not to consider free ascent for commercial or scientific operations.

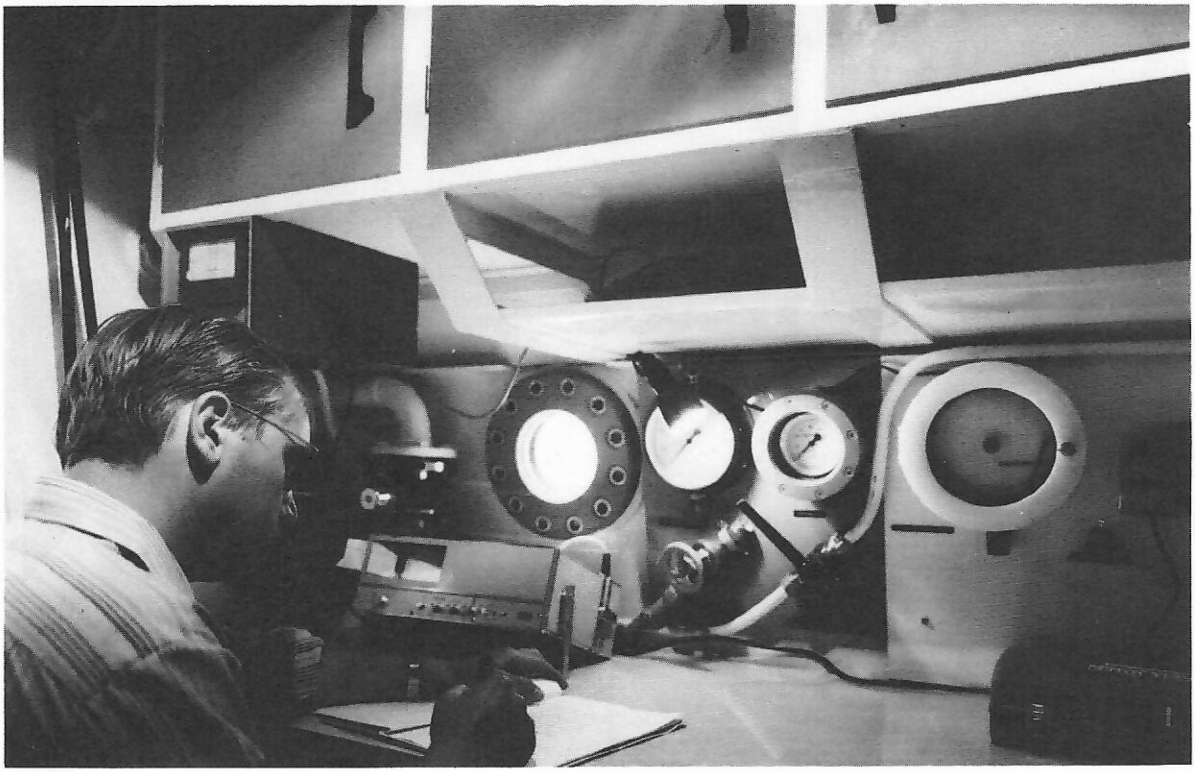

Fig. 6.25. Diving superviser's control panel in the under-water laboratory *Helgoland*.

In Fig. 6.25 a diving supervisor's control panel is shown inside the habitat. The layout and fittings are standard and do not differ significantly from a control panel on the surface. In certain situations where all the occupants may be under pressure the control panels are by necessity inside the diving chamber and controlled directly by those under pressure. Therefore any decompression requiring a reduction in pressure, change of gas mixtures and the continuing need to control and monitor the atmosphere, will be done by the divers or others similarly under pressure. During the recovery phase of the operation the responsibility and control of these factors will remain with the occupants until connected to a surface control system. To reduce the decompression period and so avoid exposing the divers continuously to the maximum depth at the seabed, the chamber for living may be maintained at marginally less pressure. This technique, known as excursion diving, is used extensively in deep diving operations from the surface. Excursion diving effectively limits the amount of inert gas that is absorbed by the tissues of the body by returning the body to a lesser pressure for living and sleeping, exposing the body to the greater pressure only for the work periods.

It is probable that a personnel transfer system will be used and essential if there are no decompression facilities contained within the

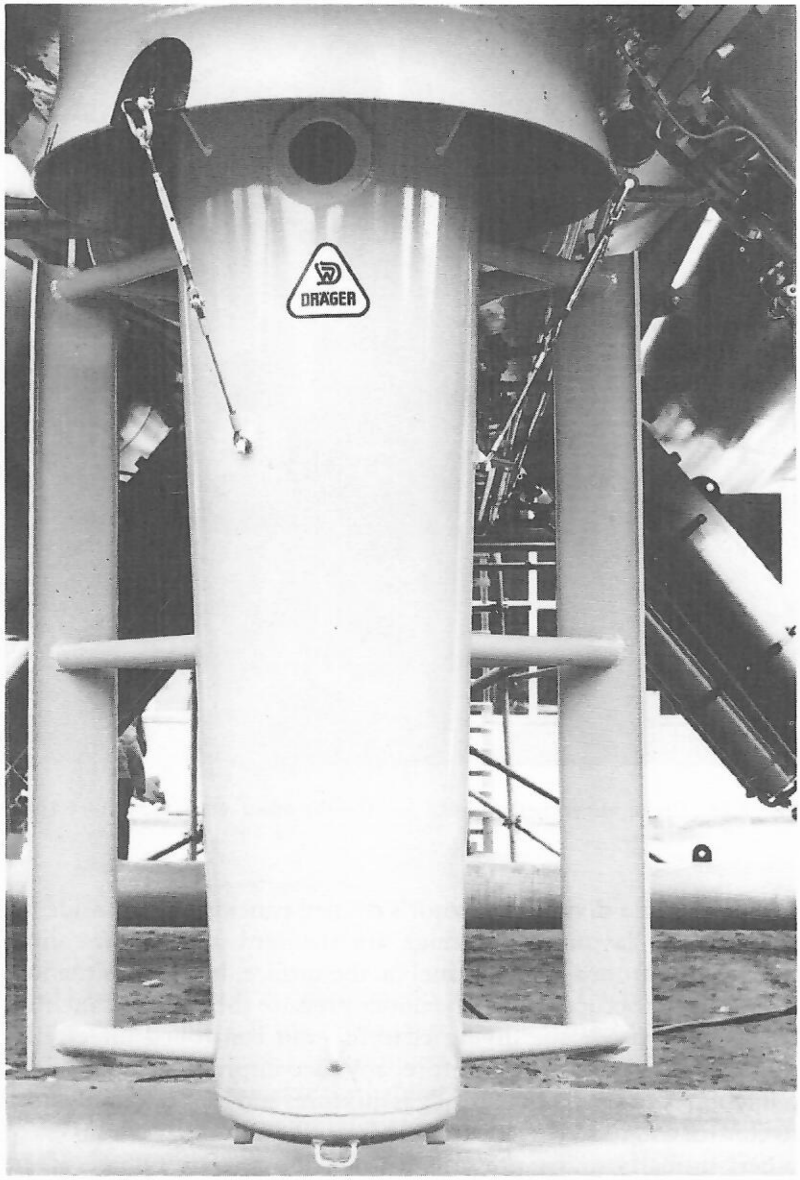

Fig. 6.26. One-man rescue chamber of the under-water laboratory *Helgoland*

habitat. Even where there are such internal pressure chambers a transfer system is usual. The recovery phase of the habitat will be conditioned largely by other factors such as tidal conditions and weather on the surface and these can cause delays. Also if the decompression period is long, and bearing in mind that any long exposures to pressure will effectively have saturated the divers' body tissues, the de-saturation period of decompression will run to some days. Conveniently, and for safety, the personnel can be transferred to the surface compression chamber to complete the decompression. This transfer is made by a diving bell or submersible with the ability to mate with a surface unit on board a vessel and transfer personnel

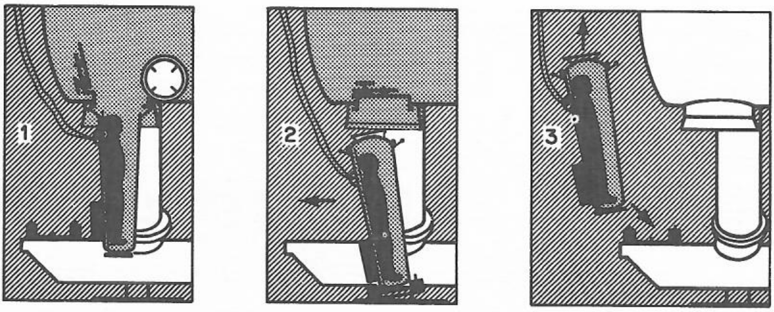

Fig. 6.27. Releasing procedures for the one-man rescue chamber of the underwater laboratory *Helgoland*.

1 diver being placed in the one-man rescue chamber
2 ballasting and shift of the chamber to the side
3 dropping the ballast and surfacing the chamber

under pressure. This is already standard operating practice and presents no great technical difficulties. This method of transfer was used during the *Sealab, Helgoland* and *Tektite* operations.

For the stand-by emergency use SCC or diving bells are frequently stationed permanently near the habitat for emergency evacuation. Recovery may be by hoisting from the surface or, alternatively, it is technically possible for the occupant to control the winch from the bell. The surface compression chamber is required to be of sufficient size to cater for therapeutic decompressions and with a compatible medical transfer chamber for evacuation ashore.

A one-man rescue chamber of the type shown in Fig. 6.26 allows for a dry transfer of an injured person from the habitat to the surface. On the surface the chamber is recovered by a support vessel, rescue launch or helicopter depending on the conditions and circumstances. The skids attached to the chamber facilitate the pick-up operation on the surface. The sequence of disconnecting the chamber from the habitat is illustrated in Fig. 6.27 in three stages. The initial pressure needs to be adjusted to equalize the pressure inside the transfer capsule and the main chamber allowing the pressure-tight doors to be opened. The injured person is placed in a supporting stretcher which slides down retaining rails inside the capsule. A CO_2 scrubber is the main life-support fitting, filled with new absorbent. The three retaining bolts are released, securing the capsule to the main chamber trunking of the habitat, and the attending divers in the water compensate to achieve a negative buoyancy. A guide wire pulls the capsule clear and releases the ballast frame. The capsule will become positively buoyant and rise to the surface. The capsule can be used for the transfer of larger dry stores by the same method. Although this method of evacuation is based on a bottom transfer, recent submarine rescue techniques are being perfected by submersibles and recovery

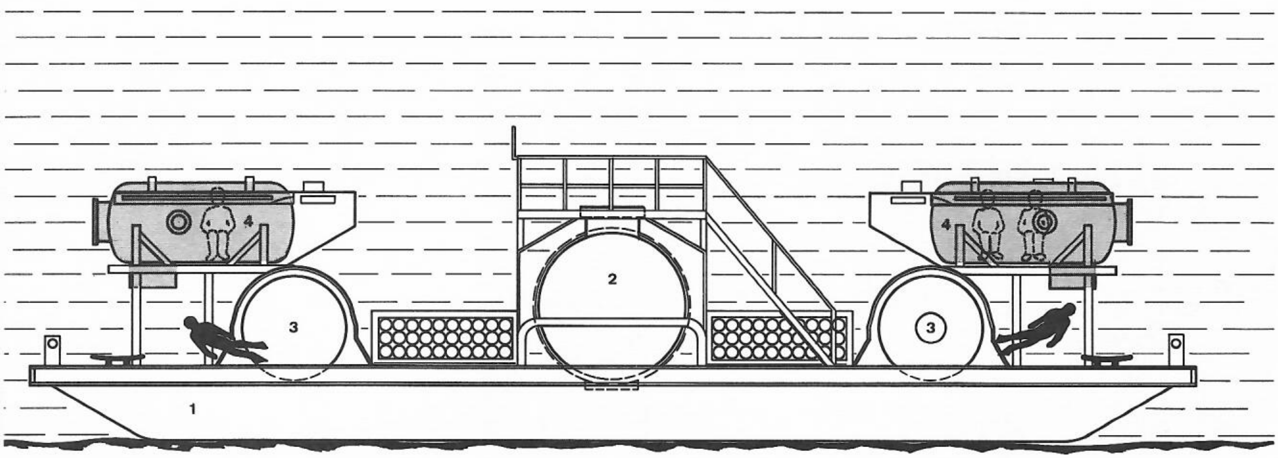

Fig. 6.28. Arrangement of rescue chambers on the under-water station *Aegir* of the Makai Undersea Test Range, Hawaii.

1 pontoon
2 habitat pressure hull
3 ballast tanks
4 rescue chambers

vessels using a mating collar on the top of the submarine casing. This same technique can be successfully applied to a habitat, with the advantage that the habitat is a stable and flat platform.

Another interesting variation on evacuation techniques is designed into the *Aegir*, the habitat at the Makai Undersea Range in Hawaii. The general arrangment is shown in Fig. 6.28. Two small emergency life boats are fitted separately on each side of the main chamber as part of the buoyancy chambers. Each life station can accommodate two people normally but four people for short periods. Each carries its own life-support system and is positively buoyant, the buoyancy being restrained by a special winch system. On surfacing they are either towed to a sheltered area or recovered immediately by a surface vessel, depending on the weather conditions. For long decompression the chamber can be mated to larger chambers as required. This concept of a lifeboat is a forerunner of the hyperbaric lifeboat designed and favoured by the Norwegians and French for the evacuation of divers under pressure from surface vessel or structure and designed to surface and then operate as a boat. This is described in Chapter 3.

There are many under-water operations other than habitats where surface decompression is not suitable for lengthy and complicated therapeutic treatments possibly involving surgery. The use of one-man transfer chambers and larger chambers for several people, constructed with titanium alloy for minimum weight and maximum pressure, and with helicopter attachments, is covered in Chapter 5.

In an extreme situation where the emergency standby chambers are not available and an immediate recovery is needed, an ultimate safety plan could allow the aquanauts to remain inside the habitat, if decompression is still possible, and allow the habitat to achieve positive buoyancy with the release of ballast weights and gain additional buoyancy. Theoretically it would be possible for the ascent to allow the habitat to remain below the surface, secured to floats on the surface allowing for the subsequent location and recovery by surface vessels and divers. If the habitat has to be evacuated because it is flooded or the main services have been destroyed, the only alternative if transfer chambers are not available may be temporary refuge in the satellites or igloos described earlier in this chapter.

The use of fire-resistant materials and the careful selection of materials is clearly of great importance for the same reasons as apply to any manned pressure chamber. These considerations cover the need for alarm systems and methods of fire control such as sprinkler systems. Using separate emergency breathing systems a dangerous explosive atmosphere or an actual fire or explosion can be controlled by purging the whole atmosphere with an inert gas such as nitrogen or helium.

Lowering Procedures, Ballast and Trim Systems

There are certain technical difficulties which need to be taken into account when designing a system for placing on the seabed. In the past in some cases insufficient attention has been given to this aspect and where difficulties have been experienced they have not been caused solely by weather problems. Equal-pressure systems, as distinct from closed systems, are the most difficult to control during their descent from the surface. Basically there are five methods of placement for habitats that do not have their own propulsion and these are illustrated in Fig. 6.29.

In *Type A* the habitat is placed by a crane and is at its most vulnerable if there is movement of the crane or the barge and is clearly very vulnerable to weather and the sea state. This procedure was used for *Sealab III* (see Fig. 6.9). As the off-shore construction industry has acquired lifting barges capable of a 1000 tonne hoist to lift production modules with pin-point accuracy and control, so comparative technology has lessened the risks of using the straight lift technique.

In *Type B* a more sophisticated approach allows the habitat to be towed to the site and secured to the bottom area with a ballast weight. Ballast tanks are flooded to a trim condition where the remaining buoyancy is less than the negative lift of the bottom weight and the habitat is winched to the bottom. There are a number of variations on this method.

A descent controlled entirely by buoyancy and trim is illustrated in *Type C*. It is particularly suitable for a closed habitat since the crew can control the descent with precision. However, with open-ended habitats the variable volumes which need to be taken into account may lead very quickly to an unstable condition. Experience has confirmed this in practice.

In *Type D* the placing of the habitat presupposes that the position is known and allows for a weight to be placed on the seabed

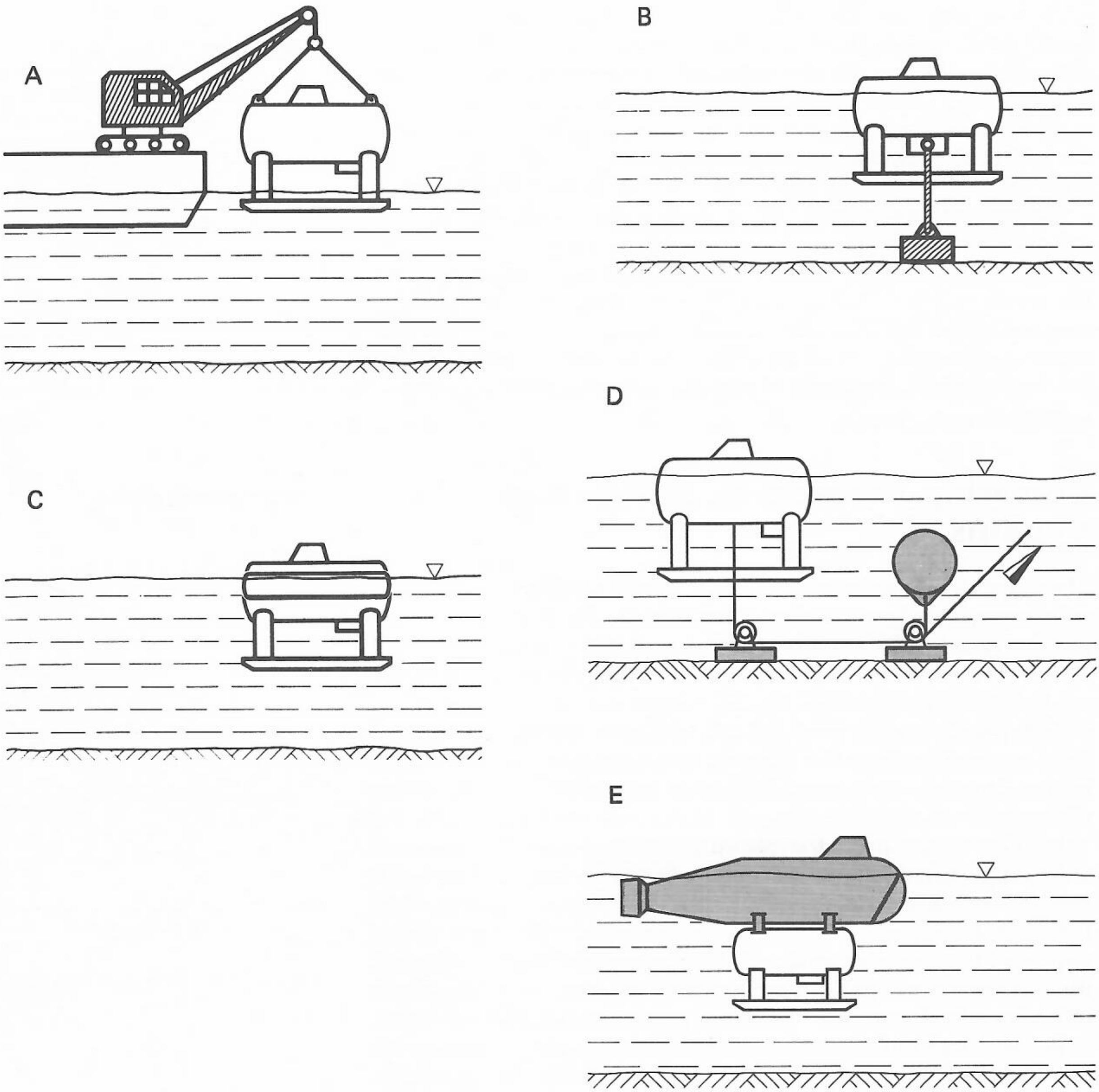

Fig. 6.29. Lowering procedures.

A The habitat is totally ballasted on the surface and then lowered by crane. Requires support by ship or pontoon and good surface conditions

B From the floating habitat a floatable ballast tank or weight is first lowered. The habitat is then hauled down

C Free descent of the habitat by controlled flooding of buoyancy and trimming tanks

D Use of cable rollers which are mounted on bottom weights and by lifting ballon or surface winch

E Submarine brings the habitat to the operating area and places it on the seabed

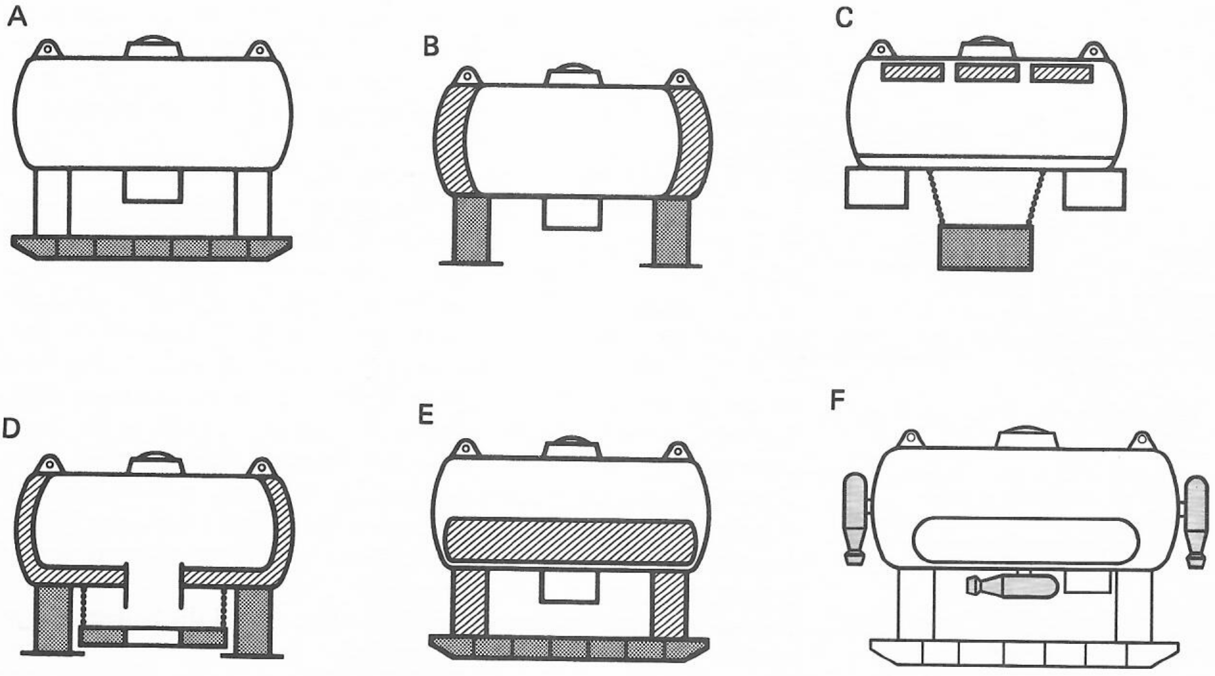

Fig. 6.30. Trimming and ballast systems.

- **A** Ballast in the support legs is adjusted in such a way that sufficient negative buoyancy is obtained to ensure stability. The ballast can be in the form of iron-filled concrete blocks. Descent and ascent are possible only with use of appropriate lifting gear
- **B** Solid ballast is mounted in the four support legs in the form of metal or concrete. For lowering, the tanks on both front ends can be flooded. These tanks are blown with air for ascent
- **C** The complete habitat is suspended on the bottom weight like a balloon. The bottom of the habitat is filled with concrete. For final descent the tanks in the ceiling are flooded
- **D** Permanent solid ballast hangs below the habitat in the form of a concrete plate. The support legs may be filled as well. Ballast tanks are located at both ends around the hull
- **E** The legs are filled with solid ballast in the form of iron-filled concrete blocks. The support legs are constructed as trimming tanks which can be flooded for lowering. Stability on the seabed is obtained by flooding the side ballast tanks
- **F** Basically the same construction as in E. Additional propulsion units mounted on the habitat provide a certain mobility in the vertical as well as horizontal planes

accommodating a roller through which the down-haul line is passed and secured to a buoyancy device with a defined buoyancy. The movement upwards of the buoyancy device can be assisted with a surface hoist. As in Type B, the habitat is trimmed to a slight positive buoyancy and is suitable for use as a closed chamber.

In *Type E* a submersible to lock on to the habitat using its own propulsion and buoyancy can transport the personnel to the bottom. This method is only suitable for very small habitats, such as welding habitats.

Submersibles conceived in a catamaran design will be more suitable for this, with the catamaran astride the habitat.

Whereas trimming tanks are mainly used for the controlled descent, integral ballast systems are fundamental for the ultimate stability of the whole to achieve a large negative buoyancy for a given volume. The different trim and ballast systems are summarized in Fig. 6.30.

The simplest procedure shown in Fig. 6.30A demands a solid ballast tray fitted with ballast. The support legs may support ballast as well. Sufficient negative buoyancy will maintain stability and the choice of ballast is limited to lead, scrap iron or concrete blocks and is usually dependent on local conditions. Lead is expensive, although weight-for-volume it is preferable, and is not used because of the cost. Scrap iron is generally available at low cost but the corrosion of iron in the water may not be compatible with biomarine ecology. Concrete mixed with scrap iron and set into blocks is the most practical method. Scrap rivets, for example, have proved most successful. Special weights for size can be made and designed to handle well. By adjusting the number of concrete blocks the habitat can quickly achieve a floating position. To achieve a low centre of gravity the position of the ballast will need to be as low as possible. For habitats that are required to float or be towed the ballast carried needs to take into account the safe surface trim of the whole. Where ballast tanks are incorporated to control the descent as in Fig. 6.30B the partial flooding of the tanks at both ends will achieve a negative lift which can be controlled for a slow descent and is suitable for a closed system. For open systems a retaining lifting wire from a crane is usually needed for additional security. In Fig. 6.30C the use of a concrete weight will reduce the amount of ballast needed on the habitat. By flooding trimming tanks located in the upper part of the pressure hull the descent is made. This system was used in *Sealab II* and *Sealab III*. The trimming arrangement in Fig. 6.30D incorporates a concrete weight hanging below the habitat in addition to the support weights being filled with ballast. The trim tanks assisting the descent and recovery of the habitat surround the pressure hull.

In Fig. 6.30F a basic design similar to Fig. 6.30E illustrates the use of a thruster providing limited propulsion vertically and horizontally. If the crew has good visibility the habitat can be manoeuvred in the hovering position over short distances. Greater propulsion is possible in the future, moving towards the submarine concept.

The whole procedure of trimming and ballasting is shown in Fig. 6.31 for the under-water laboratory *Helgoland*. A buoyant situation is shown in A without ballast. In B solid ballast in the form of concrete blocks and scrap iron is fitted and a lower floating profile is reached. A good floating position without rolling and a stable position during descent requires the solid ballast to be placed very low. For precise trimming on the surface containers on the ends can be filled with small amounts of scrap. For a soft landing a chain was suspended below the ballast tray to relieve the moment of impact by reducing the negative buoyancy gradually. A greater relieving effect was found by using the surface buoy shown in C and pulling it under water at the moment of impact. The legs were then flooded. The different

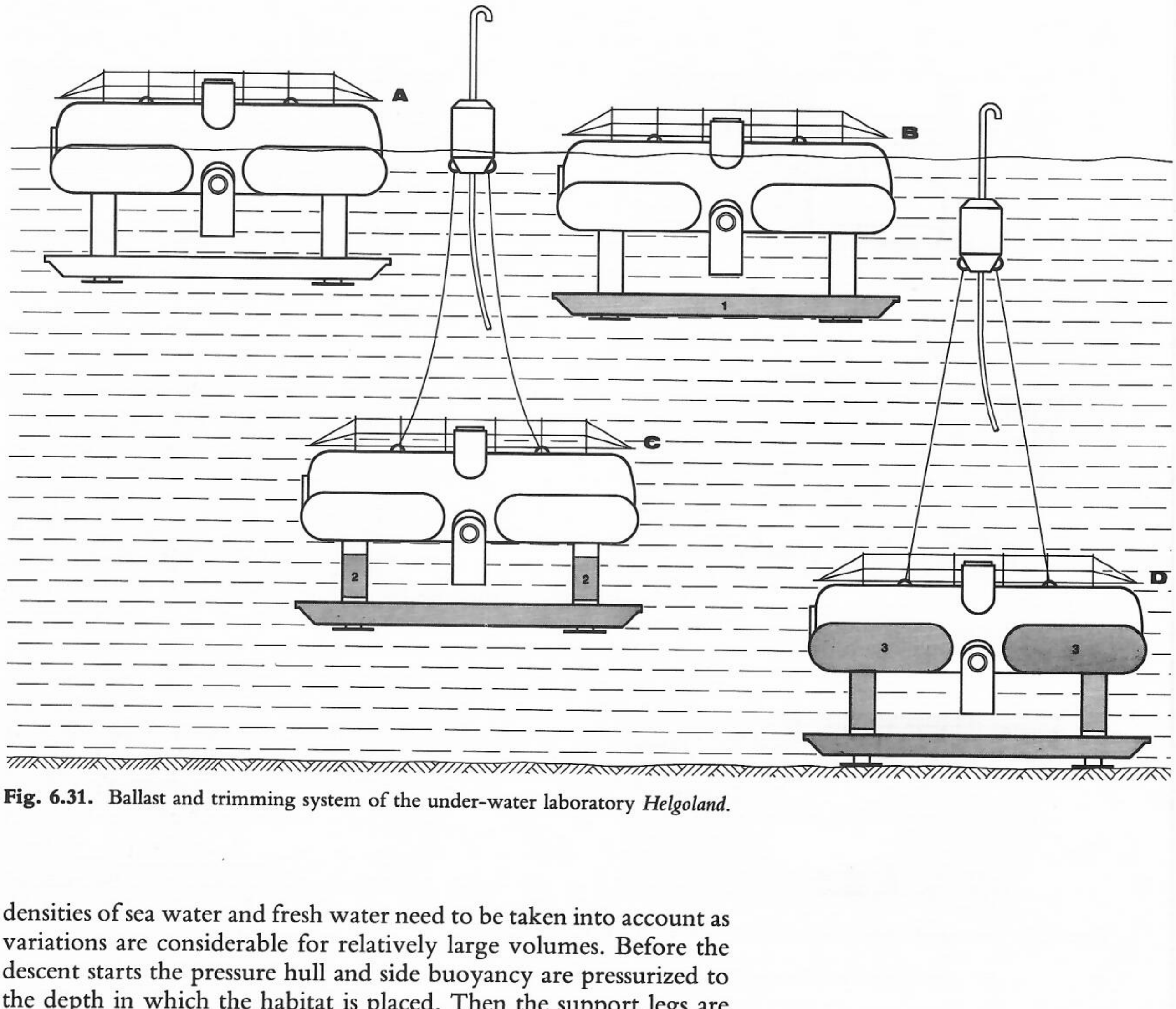

Fig. 6.31. Ballast and trimming system of the under-water laboratory *Helgoland.*

densities of sea water and fresh water need to be taken into account as variations are considerable for relatively large volumes. Before the descent starts the pressure hull and side buoyancy are pressurized to the depth in which the habitat is placed. Then the support legs are flooded crosswise until a minor negative buoyancy of a few kilograms is achieved and the habitat begins to sink. At this moment no more water is put into the trim tanks so as not to increase the descent rate. The descent is controlled by the crew inside the habitat and the control system with valves and gauges is underneath the flooring for economy of space as they will not be used again except for recovery.

When the habitat reaches the sea floor the effect of the chains and the surface buoy is felt. If the negative buoyancy is minimal and the scope of the chains and the surface buoyline adjusted, the habitat hovers over the seabed. When in position the trim tanks are quickly flooded achieving negative buoyancy. To obtain the maximum required negative buoyancy for stability the ballast tanks are flooded and the telescopic legs are extended. For the first operation the negative buoyancy of the *Helgoland* was 16 tonnes and was sufficient

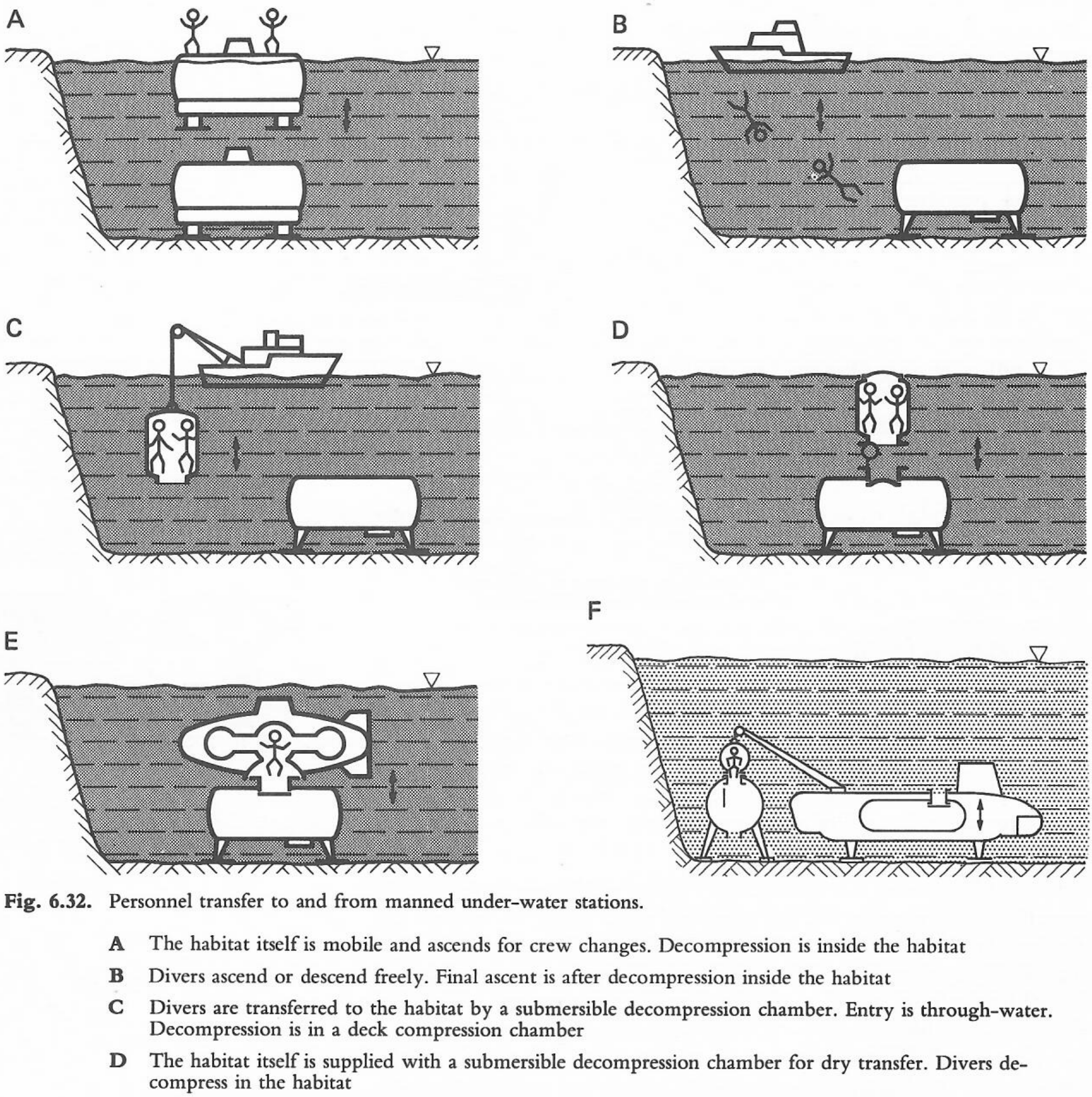

Fig. 6.32. Personnel transfer to and from manned under-water stations.

- **A** The habitat itself is mobile and ascends for crew changes. Decompression is inside the habitat
- **B** Divers ascend or descend freely. Final ascent is after decompression inside the habitat
- **C** Divers are transferred to the habitat by a submersible decompression chamber. Entry is through-water. Decompression is in a deck compression chamber
- **D** The habitat itself is supplied with a submersible decompression chamber for dry transfer. Divers decompress in the habitat
- **E** Divers are brought to and from the habitat by a submersible which mated to the habitat
- **F** Divers are transferred to and from the habitat by bell from an autonomous submarine

to keep a firm position during heavy storms passing over head. The correct distribution of the ballast weights, the calculation of the buoyancy contained within the hollow volumes beneath the pressure chamber and skirt and the scope of the telescopic legs gave the maximum stability so that even in strong currents no damage or movement was experienced. Even if the habitat tilts it will always right itself on the tumbler principle. After the experience of carrying out hoisting and lowering, lowering to 20 m was done in less than five minutes.

Personnel Transfer to Manned Under-water Stations

Transfer of personnel in an emergency situation has been discussed. Fig. 6.32 summarizes the methods which are available for transfer. Clearly the important factors—frequency of crew change, depth, average weather conditions, sea state, distance from shore base and not least the financial resources of the enterprise—determine the method. An acceptable safety factor is common to all.

In Fig. 6.32A the crew descend and ascend in the habitat after the mission has been completed or the endurance of the crew is exhausted. For multiple missions in the same position this will need a special anchoring and positioning system. Although generally a safe approach, there are disadvantages in that any permanent connections and installations on the seabed require disconnection and subsequent reconnection. In a closed habitat the decompression is carried out normally, but with an open habitat a controlled ascent has to be made to different levels to complete the decompression. As far as is known the Russian *Chernomore* missions were performed using this technique. In B the habitat is reached from the surface by free-swimming divers and crew changes are carried out in this way. This is in very shallow water, in all probability where no decompression is needed. If decompression is needed it has to be carried out in the habitat, with divers returning to the surface along a buoyline. This guideline is important in strong currents. The surface boat should have a compression chamber and be prepared for all emergencies. This free ascent method is not used, for example, in Russia, where it is considered to be too hazardous. The method in C is currently the most practical because it uses the conventional diving bell to transfer the personnel from surface to habitat and back. The diving bell may be a compression chamber on the surface where divers can either be decompressed or held in saturation pending a crew change by transferring under pressure. This method was used in the *Sealab III* operations and Fig. 6.33 shows the American surface support vessel *Elk River* in this role. The disadvantage of the method is that it is dependent on weather and to close this gap larger surface vessels are needed to operate successfully in marginal conditions. The divers are obliged to transfer to the habitat by swimming, unless an overhead lock-on is available, a method illustrated in D. There are a number of technical difficulties in this solution but these are being overcome with experience in submarine rescue techniques. The use of submersibles for submarine rescue has proved that the concept illustrated in E is quite feasible and overcomes some of the problems of keeping a surface support vessel over the position in bad weather conditions to effect a transfer. The same weather restrictions will

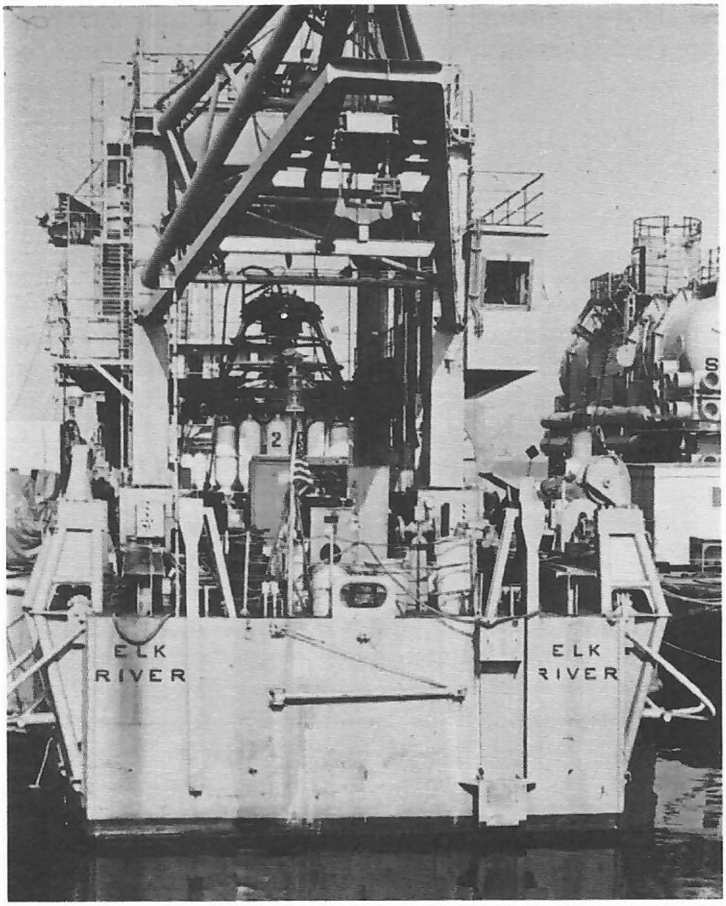

Fig. 6.33. Diver transfer installation on the American support ship *Elk River* (U.S. Navy).

affect the hoist and recovery of the submersible but possibly not so severely. The use of wet submersibles can be considered more as a transport from one station to another where there are no great variations in depth.

A sophisticated and somewhat unlikely concept which has been considered in France was to place a transfer shaft from the surface to the seabed with intermediate locks to enable divers to exit. The supporting leg of a structure connected to a seabed habitat would fulfil the same function.

Materials and Equipment

The numerous alternatives already discussed regarding the shape, size, operating depths, mission requirements and methods of transfer will lead to many options in the type and selection of materials and equipment.

The materials which are used in the hull will naturally depend on the configuration and the depth. To date in most cases boiler steel has been used. For equal-pressure systems a rubber-coated fabric can be used, supported and retained by a net or grill to reduce the stresses,

Fig. 6.34. Under-water station being insulated with glass foam.

particularly at the seams. Usually balloon-shaped, the habitat has an entrance trunk underneath the air–water interface. Glass-reinforced polyester resin is a good material to work in and is more durable than rubber-coated fabric. It needs no surface protective coating and has relatively good insulation properties. Boiler steel, on the other hand, needs most careful protection. After preparing a clean surface several layers of paint are needed, which must not be incompatible with marine life, especially where the purpose of the research is in this field. For recognition a good colour is yellow, orange and sometimes white.

Insulation is particularly important as energy is at such a premium in any event and heat losses through the walls of the chamber must be reduced. Cork applied internally is resistant to sea water but apart from having an uneven surface the adhesives used to secure the material may be toxic and frequently have an unpleasant smell. External insulation would appear to be better and a number of materials may be considered. They must all be seawater-resistant, pressure-proof for the depth, easy to form and apply, not toxic, a good volume-to-weight ratio and economic. The use of plastic-based materials has proved the most successful. For instance, polyurethane foam (Fig. 6.34) has been sprayed on to the external surface to a thickness of about 50 mm with excellent results, particularly if the steel is well prepared before the application, and this also will prevent

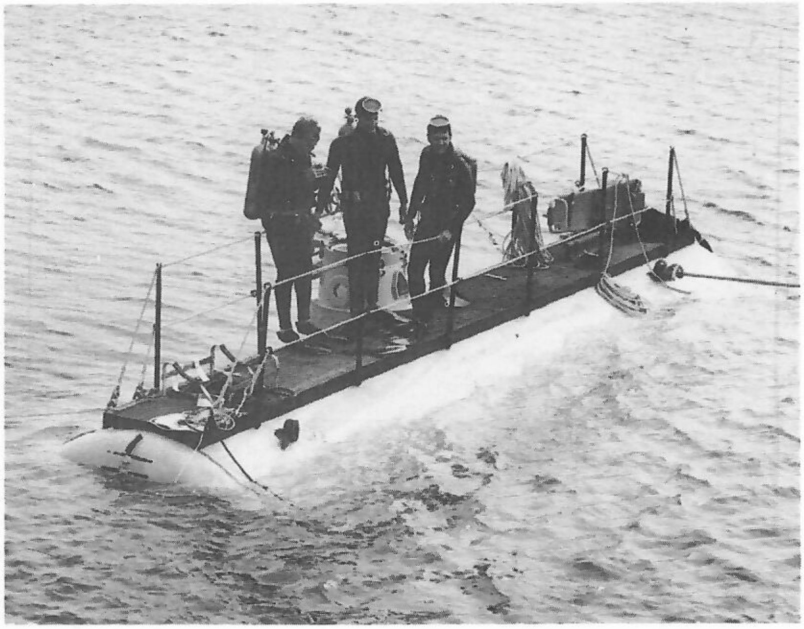

Fig. 6.35. Under-water habitat *Helgoland* just prior to its first descent in the North Sea. The author is on the right.

corrosion for many years. The application process is dirty but with a further application of glass-reinforced plastic the result is strong and effective. More expensive applications are Ecofloat and, separately, rubber strips. Unvulcanized rubber has been used as insulation on some smaller habitats. After applying the rubber, carefully treating the seams, the whole chamber is placed inside a vulcanizing boiler. This process can produce reasonable coatings of between 15 and 20 mm. The use of glass-reinforced polyester resin as the only coating will provide limited insulation although it gives a rugged finish.

The design and construction of lock-out trunking, doors and windows will vary, particularly with regard to whether the habitat is open or pressure-proof. The upper entrance trunking and door shown in Fig. 6.36 are used for preparation prior to immersion. If the missions are likely to be short between launch and recovery a single double-acting bayonet-locking door should be considered, allowing quick and easy through access. The door should be capable of being opened from both sides and the height of the trunking should be sufficient to stop spray and the surface movement of seawater from entering the habitat. Ideally view ports set into this column will give all round coverage in good visibility before the descent from the surface and whilst on the seabed. This column shown in Fig. 6.36 may be modified for a mating with a diving bell or submersible requiring a support and guide frame.

It is essential that the observation viewports give the crew the best possible coverage dependent on the visibility conditions. A very large window incorporated into the *Hydrolab* habitat in the Bahamas gives a panoramic view. Special observation compartments have been built into the habitat with either large windows or even observation domes

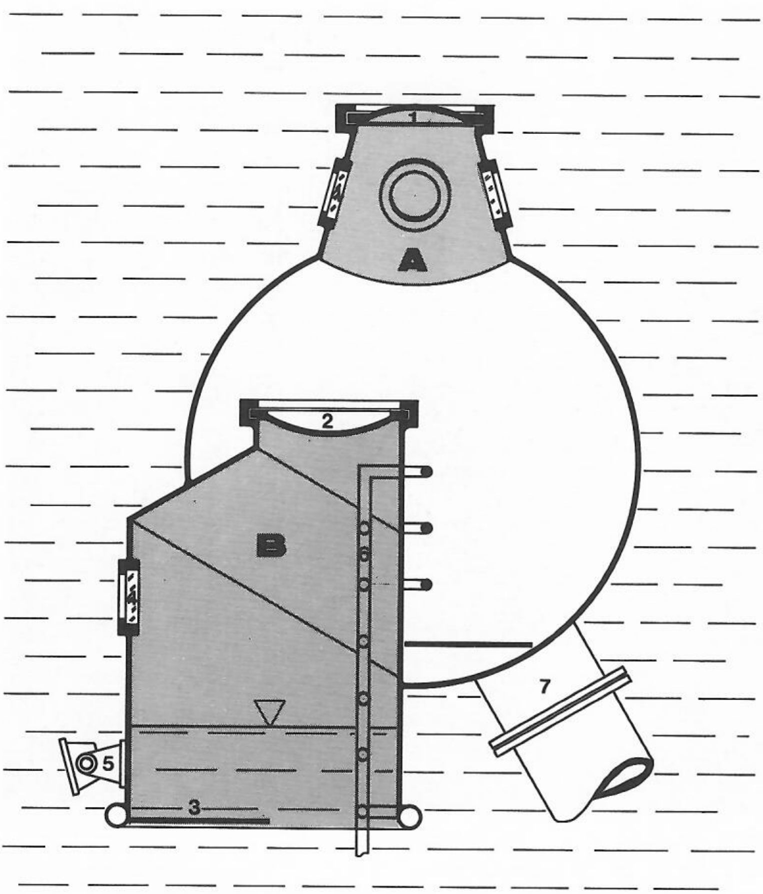

Fig. 6.36. The diver lock-out and trunking for a habitat allowing tidal movement.

A Upper escape trunking
B Lower escape compartment
1 one-way pressure door
2 diver lock-out compartment
3 floor boards
4 windows
5 external light
6 ladder
7 support leg

such as in the *Tektite* habitat. In the *Helgoland* an observation dome was fitted to the wet laboratory compartment which extended sufficiently to enable it to rotate through 360°. The same criteria of design and selection of materials that apply for windows in hyperbaric chambers and diving bells also apply to habitats. Acrylic glass is used almost exclusively to meet all these requirements.

The bottom lock-out will normally face directly downwards although there is no technical problem in having the lock-out position on the side using the principle incorporated into the Buffalo hyperbaric simulator described in Chapter 1. There may be more than one lock-out position but in any design consideration will need to be given to tidal differences in order to avoid losing any gas inside the compartment by calculating the correct length of the trunking,

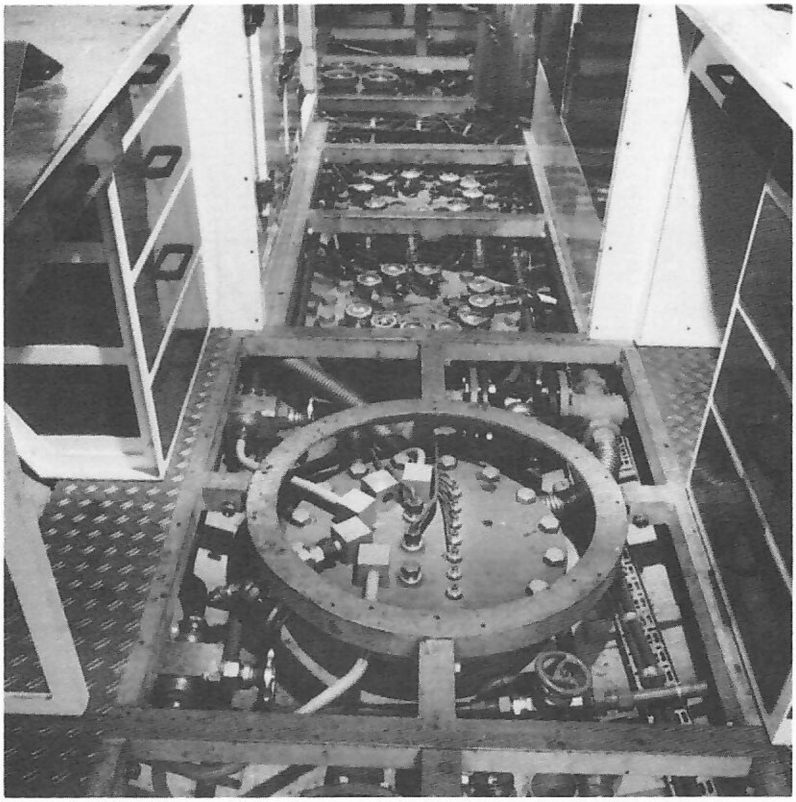

Fig. 6.37. Inner hatch of the connection domes and below-deck installation of instruments and pipework.

taking into account the cross-section of the trunking and the maximum tidal lift. As in the upper access the door should be a single double-acting door opened and closed with a hydraulic drive. The trunk shaft should preferably be large enough for two divers and their equipment with the facility to remove their equipment and possibly have a shower to clean off dirt and debris brought in from the worksite. The space offers a dry shelter for resting between working. Fig. 6.36 shows a lock-out trunking system designed to operate in a tidal movement of about 3 m. The trunking is set off centre to gain the maximum economy of space and not so high as to make it difficult for the divers to re-enter the compartment with their equipment. In some lock-out arrangements the trunking becomes a compartment capable, as in *Sealab III*, of supporting a team of several divers and designed to be used for temporary storage of equipment. Protective cages are sometimes necessary in the water around the trunking to keep out unwelcome and dangerous fish. These cages were fitted to the *Tektite* and *La Chalupa* habitats.

Connections for the main services, such as gas, power, water, sanitation and communications are better situated in the lower portion of the pressure hull as there is the least danger of leakage. In Figs 6.37 and 6.38 the penetration can be seen with the various services combined into a single connection point. The domes around the

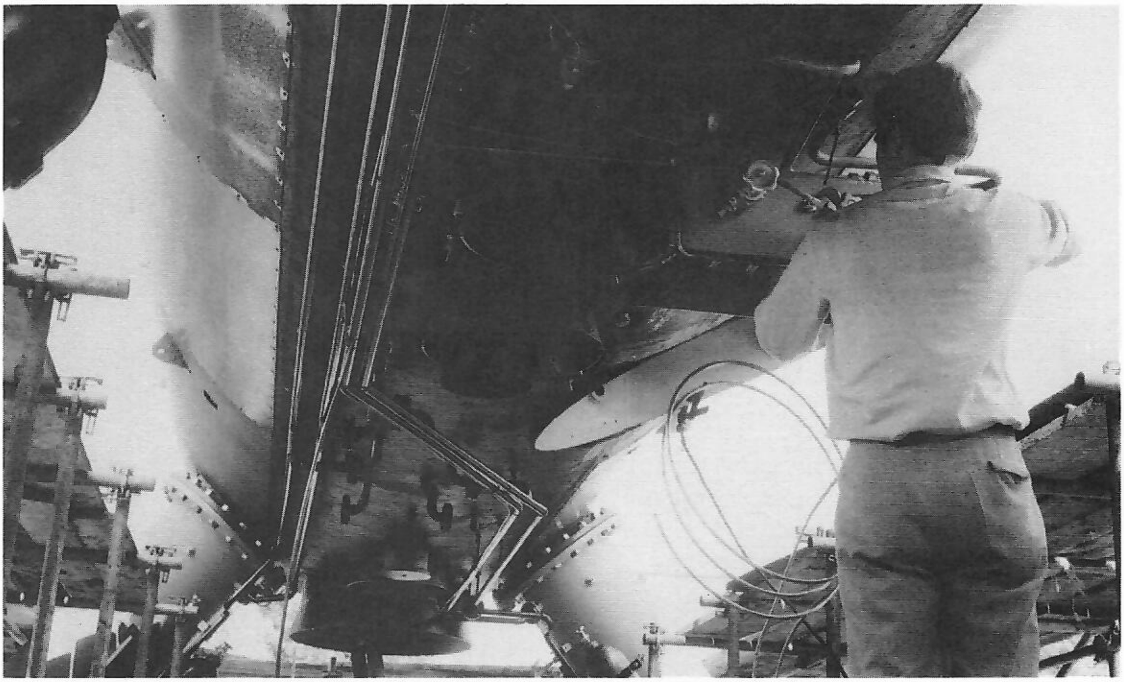

Fig. 6.38. External connection domes of the under-water laboratory *Helgoland.*

connection are filled with nitrogen after the habitat is placed on the bottom so as to remove any likelihood of sea-water contact. At a later stage the dome was replaced by a right angle shaft, filled with gas and large enough for the divers to operate.

Life-support Systems

In Chapter 10 the whole subject of life-support is discussed in some detail. The same requirements for life-support have to be met in the design of habitats to control the partial pressures of oxygen and the amount of inert gases and also the monitoring of carbon monoxide, hydrocarbons, hydrogen sulphide and other toxic substances. There is also the constant need to control the temperature and humidity. There are, however, some particular points that are relevant to habitats depending on their size and shape.

Air as a breathing gas is only used if the habitat is positioned in shallow water. If it is assumed that the oxygen partial pressure should not exceed 0.3–0.4 bar for long periods, normal air as we breathe it would limit the depths to about 10 m if the air is passed through an open circuit. Using a closed circuit, where the CO_2 is absorbed and removed, the O_2 partial pressure is controlled and the oxygen content can be lowered to the desired level. For approximate calculations the average oxygen consumption per person is about 0.5–0.6 litres/min. The supply of the correct amount of oxygen into the system may be controlled automatically or manually.

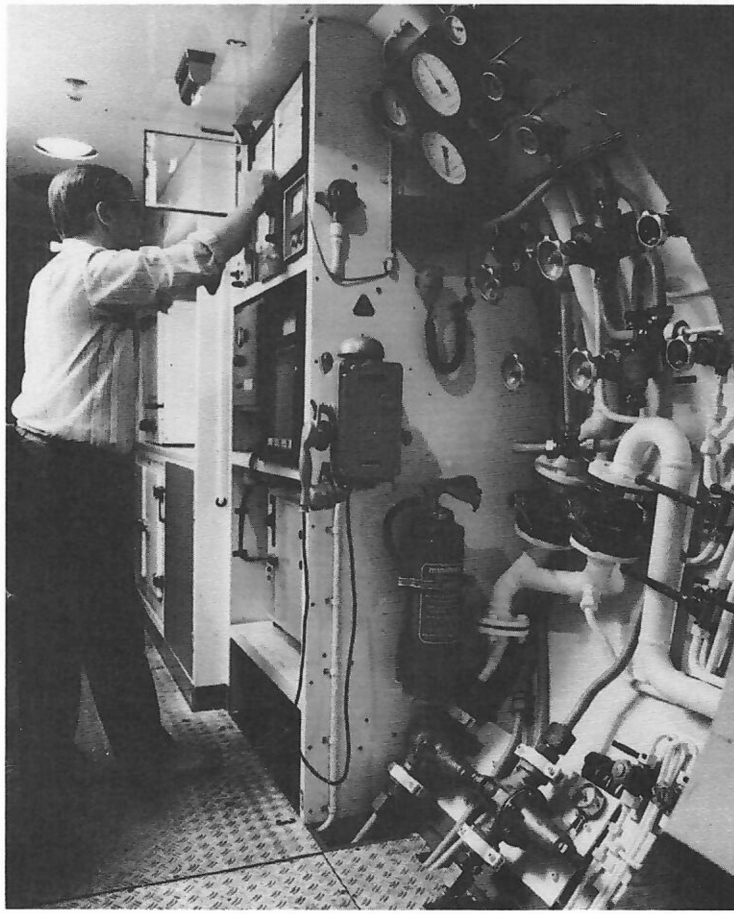

Fig. 6.39. Control and monitoring panels in the under-water laboratory *Helgoland*.

Air is also needed to charge scuba diving bottles as well as for filling buoyancy tanks and for trimming. Air will be needed for pneumatic tools and for pressurizing the lock-out trunk and other services. These services may not require air to the purity required for breathing standards. Part of the central gas control panel of the *Helgoland* is shown in Fig. 6.39 and illustrates the large number of regulators, valves and gauges that are needed to support the system. The actual means of compressing air and the storage of the air has been covered previously in the chapter including the need for emergency cylinders on the habitat itself.

With regard to oxygen, it is usual for a closed-circuit system to be installed, reducing the amount of air needed to service the chambers and maintain the correct oxygen content. For oxy-helium mixtures the partial pressure of oxygen has to be very carefully controlled with accuracy between 2.7 and 3.6% for depths of about 100 m. Because there are less constraints on space inside the compartments than in lock-out submersibles and diving bells, this allows for accurate monitoring; analysis and control systems are either automatic or manual, or both. To ensure a blanket distribution of oxygen the

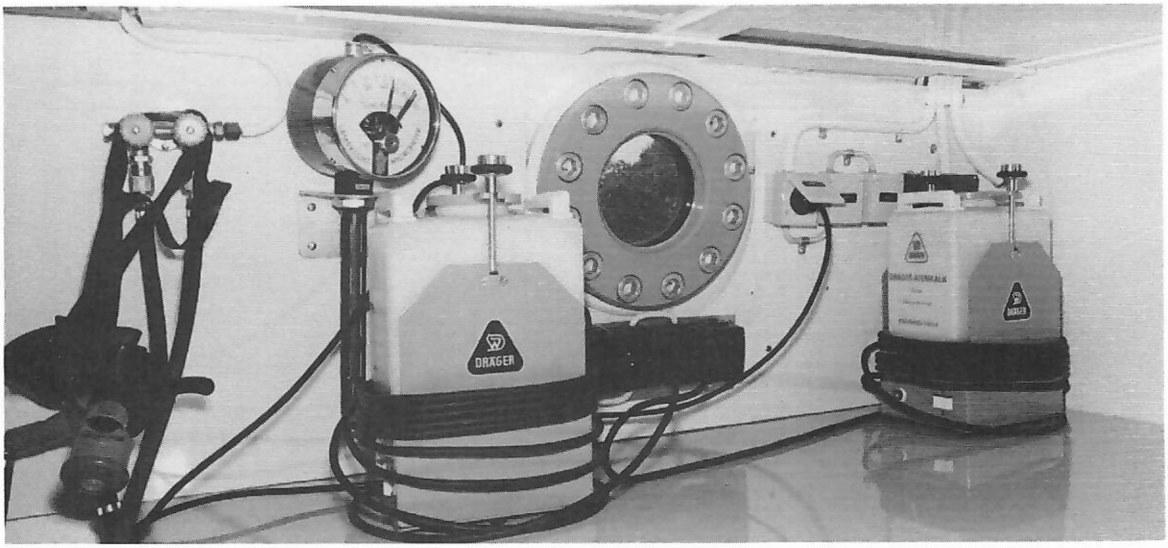

Fig. 6.40. Simple carbon dioxide absorption systems for an under-water habitat. These units can also operate from emergency batteries.

supply is best fed into the blower of the CO_2 absorption unit. An alternative standby position is needed to keep a sufficient quantity of oxygen in reserve for 14 days emergency supply, based on a four-man team using 3000 litres of oxygen per day.

The carbon dioxide content in air at atmospheric pressure should not exceed 1.5%, equal to a partial pressure of 0.015 bar; lower values are preferable. If air supply is on the open-circuit principle, sufficient ventilation flows are necessary for the removal of CO_2 and these flows are discussed and laid down in the tables in Chapter 2. The amount of CO_2 produced is clearly related to the oxygen consumption of the crew of a habitat. For a rough calculation it may be taken that 0.9 litre of CO_2 is produced per litre of oxygen consumed. Therefore with an average consumption of 0.5 litres/min, about 650 litres of carbon dioxide need to be removed from the atmosphere per day for each person. The method of ventilating or flushing through has been mentioned but it is only suitable for shallow depths and where supplies of air are plentiful. The other methods—freezing the CO_2 or washing out the CO_2 in the seawater—can be considered but the most usual method is for the CO_2 to be absorbed by passing through soda lime or lithium hydroxide. Fig. 6.40 shows a simple electric blower connected to an absorbent container. Careful design of these systems is needed in regard to the motors for safety reasons in view of the risk of electric fires and explosions. Pressure-proof casings and purging with inert gases need to be considered. A closed ventilation system is usually designed for large systems. Such a system which absorbs the CO_2 in a two-compartment habitat occupied by two to four people, is shown in Fig. 6.41. Two blowers with a total input of 200 W provide the

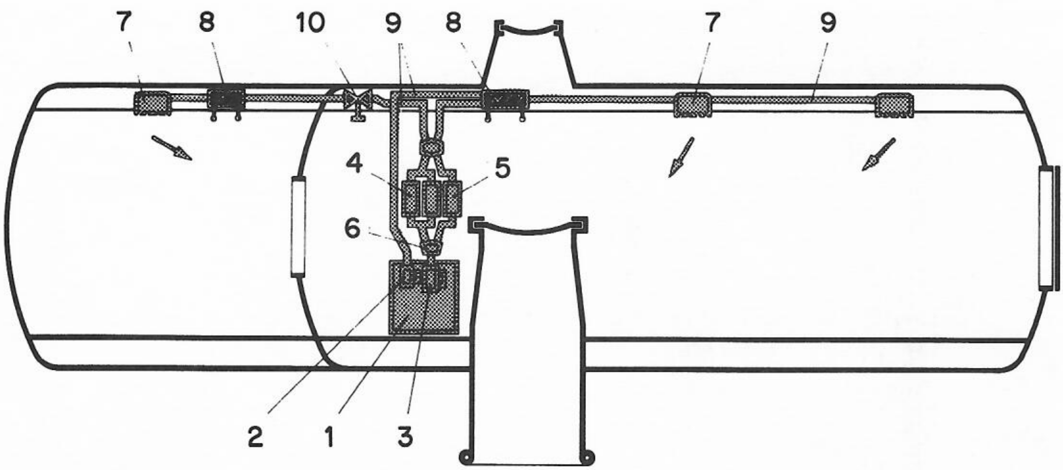

Fig. 6.41. Central carbon dioxide removal system in a two-compartment under-water habitat.

1 inlet filter
2 blower I
3 blower II
4 CO_2 absorption filter
5 fine dust/odour filter
6 air distribution box
7 air outlets in ceiling
8 heating elements
9 distribution line
10 shut-off valve

necessary circulation. To reduce the noise level the blowers are installed inside a grill casing which is filled with sound insulating material and filters. These filters act to trap dust particles. Six 4-litre containers are sited in a frame designed for easy replacement and connected in parallel. Assuming that 1 litre of absorbent absorbs 100 litres of CO_2 under normal conditions of humidity, temperature and a set constant flow, a total capacity of at least 2400 litres of CO_2 is achieved. For example, if there are four people in the habitat, theoretically, after 20 hours of operation, the container will need to be refilled or replaced. A special filter can be mounted in the circuit which will temporarily remove carbon monoxide, fine dusts, odours and oil vapours but it is important that the flow characteristics are the same. The cleaned air is passed through distribution piping to adjustable exhaust louvres set over the deckhead which can be regulated. An air heating system with an input of 2.5 kW is sufficient to heat the clean air and may be regulated for a comfortable temperature.

In an oxy-helium atmosphere where the helium content is high a comfortable temperature is between 30 and 36°C. Electrical heating is the only known method of providing heat. Excessive waste of power can be avoided by using insulating material. Local heating can be provided by individual blowers and infra-red heaters are especially welcomed by divers in the lock-out and changing compartments.

In warm waters where habitats are in temperate or tropical regions, good insulation only may be sufficient and in certain circumstances, due to the heat generated from electrical equipment, it may be necessary to cool the atmosphere. Air conditioning systems which

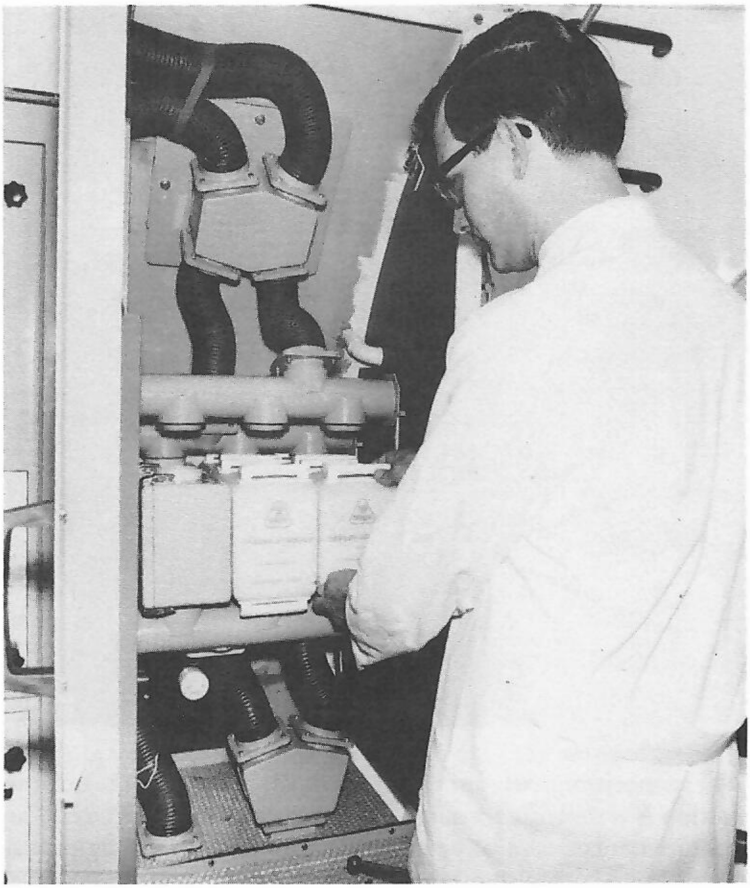

Fig. 6.42. Air circulation system of the under-water laboratory *Helgoland*. The two central blowers are located inside the bottom grill box which is covered with dust filter plates on the inside.

also dehumidify the system work well but special attention needs to be paid to the correct insulation of the units.

Humidity control is always a major problem, particularly in habitats. If possible the lock-out compartments which are exposed to the water should be separate, though this is not always possible in smaller designs. A relative humidity of 55–60% is comfortable for the crew but if soda lime is used for CO_2 absorption, a better efficiency is achieved with an increase of relative humidity to 70%. If there is no central dehumidification unit, separate units can be sited in areas of high humidity. Depending on the limitations imposed by the power requirements humidity can be controlled by cooling aggregates. An alternative method requiring less power is the use of chemicals, for example silica gel. A basic method is to install cooling coils with sea water passing through them, or even exposing a chamber wall, not insulated, which allows the water vapour to condense if there is sufficient difference in temperature each side.

The monitoring of the life-support inside the habitat is clearly vital. Measurement and recording require very high precision instruments which need to be capable of operating to their maximum efficiency in high pressures at depth. The life-support may be monitored from the surface or from the habitat itself. A monitoring unit is shown in Fig.

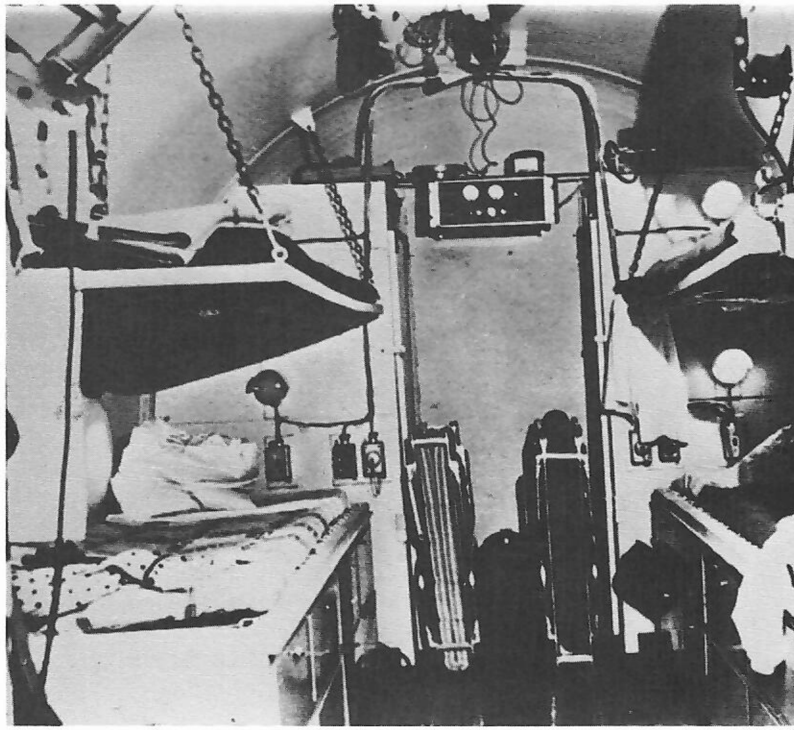

Fig. 6.43. Sleeping accommodation of the under-water station *Aegir*. Oxygen and carbon dioxide sensors are at the end of the chamber.

6.39 where measurements and recordings are made in situ, but the information is transmitted visually by television to the surface. The basic requirements are an oxygen analyser for measuring the partial pressure of O_2. Alarm systems can be fitted for an increase or decrease of O_2 partial pressure set within adjusted limits. A further refinement is to actuate a solenoid which controls the input of oxygen. A carbon dioxide analyser can also be fitted with an alarm when reaching an upper level. A CO_2 partial pressure of 0.015 bar is normally considered to be the maximum permissible level. The actuation of the CO_2 absorbent blower may be controlled by the alarm or at a lower setting. A CO meter to sense and measure carbon monoxide is important as its source cannot always be ascertained. A high warning is usually set when CO reaches 50 ppm. A temperature gauge can be incorporated to measure and to control the temperature automatically by controlling the heaters. An hygrometer will measure the relative humidity of the atmosphere; pressure gauges give the precise measurement of internal pressure and possibly will also determine the differential pressure in the collar of a lock-out. If the gas can be analysed on the surface, very accurate measurements can be taken using gas chromatographs which can be used in normal atmosphere conditions. In the chamber an instant measurement of contaminants and gases can be obtained using chemical test tubes. They are also useful in an emergency as they do not use power.

If the chamber atmosphere becomes toxic in an emergency where there has been a fire, or the oxygen supply has been cut off and the normal filter and absorbent systems are unable to contain the

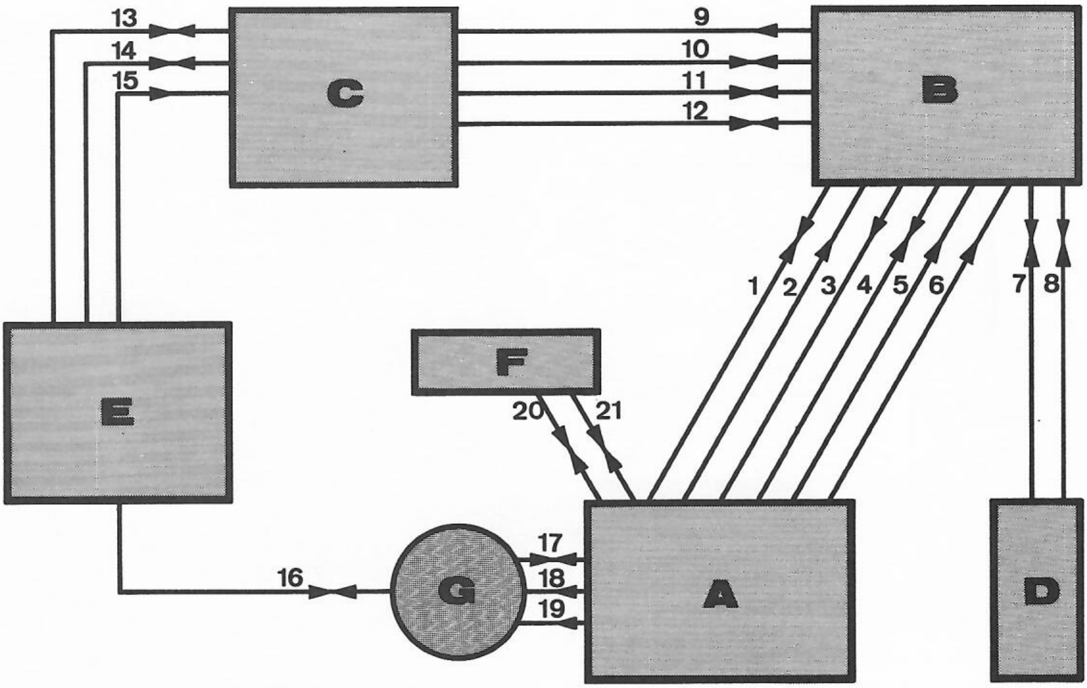

Fig. 6.44. Communication system of *Sealab II.*

A	habitat	8	wire audio
B	support	9	closed-circuit TV
C	shore control	10	telephone (3 lines)
D	PTC	11	battle phone
E	benthic control	12	radio
F	swimmers	13	telephone
G	benthic laboratory	14	audio
1	electrowriter	15	TV
2	closed-circuit TV	16	coax multiplexed link
3	entertainment TV	17	audio
4	audio	18	TV
5	oxygen partial pressure	19	data
6	wedge spirometer	20	sonic audio
7	sonic audio	21	wire audio

contamination, an emergency breathing system will provide the necessary life-support. A careful design will provide for a breathing system to be available at every station. A BIBS which has independent supplies of breathing mixture will also have sufficient oral-nasal masks or mouth pieces at the various positions. If decompression is being undertaken closed-circuit breathing units will be required if pure oxygen or breathing gas rich in oxygen content is being breathed to reduce the fire risk. A closed-circuit system will need its own CO_2 absorption unit and breathing systems used in mine rescue work may be adapted for this use.

Communications are vital for the transmission of data and no operation can succeed without good clear speech. The communicat-

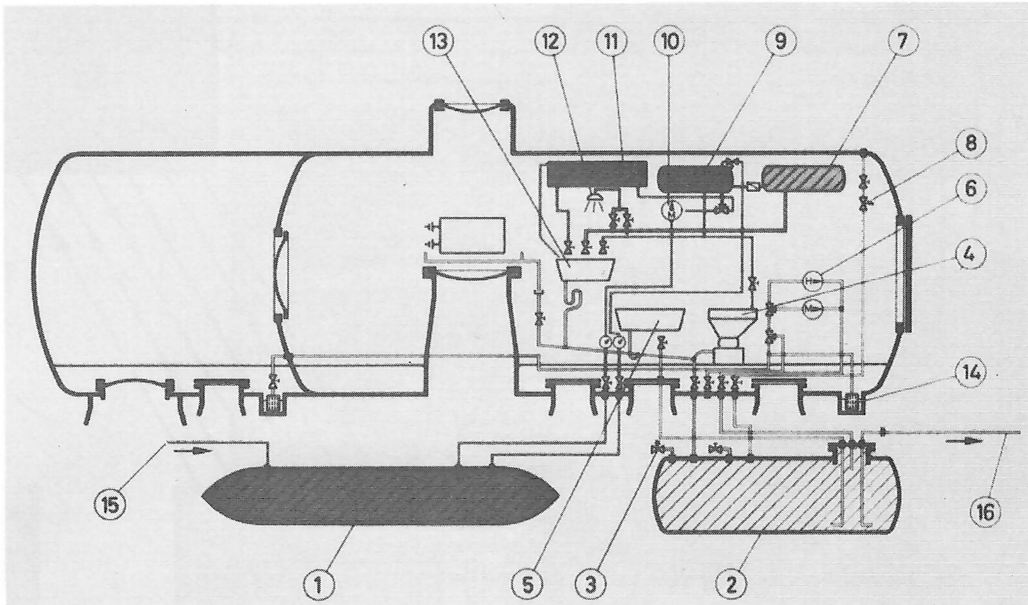

Fig. 6.45. Sanitary installations in the under-water laboratory *Helgoland.*

1	fresh water tank	9	pressure tank
2	sewage water tank	10	fresh water pump
3	overpressure valve	11	ready-use water tank
4	WC	12	shower
5	basin	13	bidet
6	sewage water pump	14	bilge drainage
7	hot-water boiler	15	fresh water connection
8	air exhaust valve	16	sewage water drainage hose

ion layout is shown in Fig. 6.44 for the *Sealab* project. Hard line wire systems are preferable for communication with the surface. A push-button talk-back system is preferred using loudspeakers. A radio telephone buoy on the surface is an essential back-up system should the support craft have to be released. If it incorporates a receiver the buoy can provide the essential link between the habitat and the surface support or shore base. Telewriters are a most useful development as they are not influenced by pressure and can transmit drawings as well as written messages. They can be used with line or wireless communication. Television links to the surface and within the system are normal. Apart from monitoring the behaviour of the crew they can pass visual information.

Proper sanitary and domestic arrangements are essential and require detailed planning. The arrangement in the *Helgoland* is illustrated in Fig. 6.45. The supply is carried in flexible bags placed in containers where they are immersed in sea water. The fresh water bags will tend to float and withdrawal pipes are set low in the containers to pump out the maximum amount of water. It is not

Fig. 6.46. WC compartment with water lavatory, water pumps and control valves on the under-water laboratory *Helgoland.*

always possible to design a natural differential flow and pumps are needed in most cases. Washing facilities should include a shower and bidet. Because showers increase the humidity they are better confined to the wet compartments. If this is not possible additional dehumidification units may need to be installed.

Adequate and safe WC facilities require sufficient water for flushing and also a waste disposal unit to shred the waste and avoid a blockage (Fig. 6.46). The sewage is discharged either into a tank or direct into the sea. There are certain advantages in integrating the bilge and sewage tanks.

The appetites of habitat dwellers are not diminished by being under pressure, perhaps the contrary, even though the quality and taste of certain foods diminish under pressure. Fig. 6.47 shows the kitchen in the *Helgoland*. Careful design of the fittings within the

Fig. 6.47. The kitchen of the underwater laboratory *Helgoland,* with deep freezer, refrigerator, stove, sink, cupboard and water tank for daily consumption.

available space will need to take into account the food that is suitable for cooking. Baking and roasting are unacceptable because of contamination. Prepared frozen food is ideal and therefore deep-freezers and refrigerators are essential. Heating arrangements for solid and liquid foods are shown in the *Helgoland* which catered for four people. Small habitats will have few facilities, confined perhaps to a heating facility or food provided from the surface in containers.

Electrical systems may be complicated and the needs of a well equipped habitat can be summed up as follows:

1. Internal lighting, external lights, search lights, indicator lights and emergency lighting.
2. Measuring instruments and recording devices.
3. Air circulation blowers, fresh water pumps and sewage water pumps.

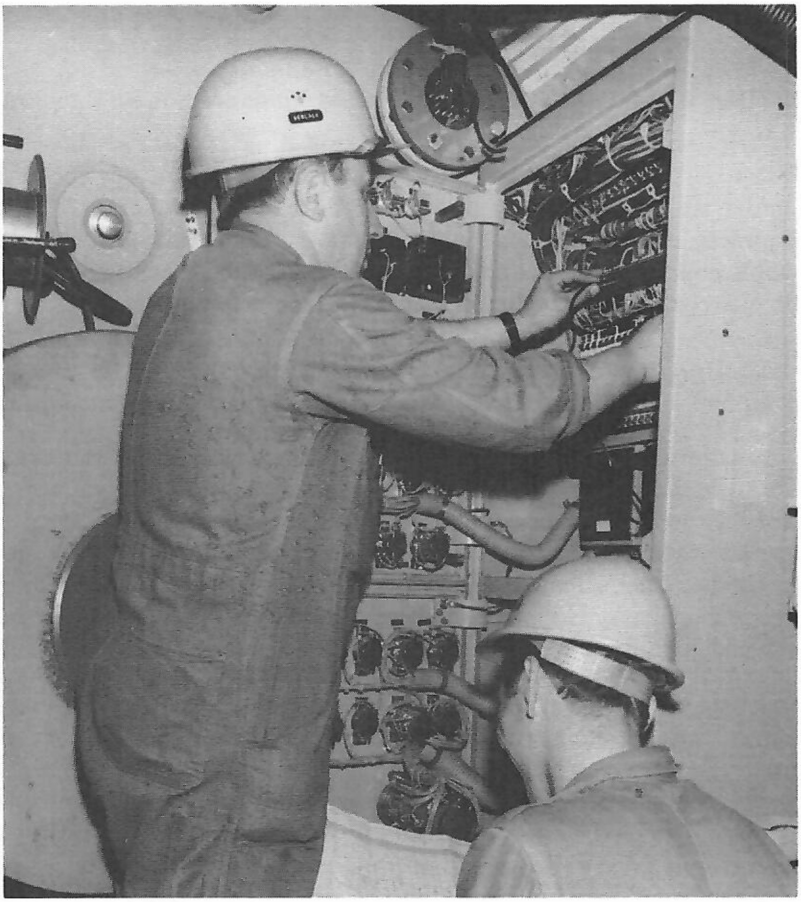

Fig. 6.48. Electrical switchboard on the under-water laboratory *Helgoland*.

4. Communication systems, such as radio and television, telewriter and loudspeaker systems.
5. Refrigerators, freezers, stoves, hot water generator, cooling aggregates.
6. Compressors, hydraulic pumps, bilge pumps.
7. Winches.
8. Push/pull diving pumps.
9. Electric blankets.
10. Instrumentation.

A central switchboard (Fig. 6.48) shows a distribution box connecting up the various services. A typical power requirement based on the experience in the *Helgoland* was 20 kW whereas the power requirement for *Sealab II* was 75 kW.

With regard to furniture and general fittings, careful design to make use of available space must take into account comfort, lighting and decor, particularly for longer missions. The small comforts of life may become more important than the more obvious ones and a practical consideration is to have a practice run on the surface before installation so that, as far as is possible, nothing is forgotten.

Brief Descriptions

Man in Sea I (USA)

In September 1962, just about the same time as the *Precontinent I* (*Conshelf*), the American scientist E. A. Link carried out the first under-water laboratory project. This experiment proved that humans could live and work under water, even in cramped conditions, for long periods of time. Although there were difficulties it was confidently predicted that these would be overcome.

Precontinent I (France)

Jacques-Yves Cousteau's *Precontinent I* project was started only a few days after Link's successful under-water laboratory experiment had been carried out. The first location was only 10 m under water, but for the first time two divers, Albert Falco and Claude Westy, were a whole week under water. The station was equipped with two one-man chambers, so that under-water decompression could be carried out if necessary. However, decompression was dispensed with and instead the divers were given a breathing mixture of 80% O_2 and 20% N_2 over a period of two hours, whereby the nitrogen was successfully eliminated.

Precontinent II (France)

In June 1963 the first steps of the previous year were followed by Cousteau's great success. His *Starfish-House* and *Rocket* as well as the 'under-water shed' for the diving saucer *Denise* created together what could be called the first small under-water community. Cousteau did not choose the Mediterranean as a location this time but instead installed the habitats in the Red Sea. In these ideal conditions they were able to live a full month under water for the first time.

Man in Sea II (USA)

Now it was the Americans' turn. Edwin Link operated his *Man in Sea II* project near the Bahama Islands at a water depth of 132 m. Two divers lived and worked at this depth for 49 hours, which was a major step forward. The under-water laboratory was a flexible, cylindrical balloon covered with a net.

Sealab I (USA)

The *Sealab I* project was carried out by the US Navy in July 1964 under the direction of George Bond who was responsible for much work in saturation diving. The under-water house with a long profile was constructed out of naval pontoons. It was designed to be pressure-compensated so a crane was necessary to help lower it. This caused many difficulties and Dr Bond described the seemingly endless problems they faced in his report.

Sealab II (USA)

The former astronaut Scott Carpenter took part in the *Sealab II* project. This under-water laboratory, weighing about 200 tonnes and 17.4 m long, was lowered to the seabed off the Californian coast at a depth of 60 m in August 1965. Carpenter spent 29 days in the habitat. Again, as in the previous *Sealab I* project, there were technical difficulties.

Kitjesch (USSR)

The Russians entered the experimental under-water field for the first time in summer 1965 with their under-water laboratory *Kitjesch*. The pressure hull was made out of a locomotive boiler and divided into three chambers. The two end rooms were used to live in, and the middle chamber served as command centre and bathroom facilities. Twelve windows were used for observation and two hatches for entrance and emergency exit.

Precontinent III (France)

In this project Cousteau designed and built a two-storey under-water laboratory. In October 1965 six divers dived to 60 m to live in a sphere of 7.5 m diameter in the Mediterranean for three whole weeks. 70 tonnes ballast was necessary to launch the under-water habitat.

Permon II (Czechoslovakia)

The *Permon II* project was plagued by misfortune from the beginning. Two trials of the habitat were aborted one after the other due to bad weather. The first launch took place near the Yugoslavian coast near Split where waves pounded the ballast tanks under the habitat until the cables finally broke and the ballast tanks sank. Eventually the habitat was recovered. The second time was worse; heavy waves again pounded the ballast tanks and broke the cables. The cable securing *Permon II* to the shore parted as well. Because the habitat itself began to drift into a congested sea area, the sea cock valves had to be opened and the *Permon II* sank. This marked the last trial at sea. The next trial took place in a local lake.

Ikhtiandr 66 (USSR)

In 1968 the Russians installed their *Ikhtiandr 66* for the second time during the summer. No details are available.

Sadko I (USSR)

In 1966 the Russian habitat *Sadko I* was launched. This one-room spherical chamber with an external diameter of 3 m was very basic, with space for two divers. Both electricity and air supply came from the surface (either from a support ship or from land) and the laboratory was lowered by a winch and block system. The first trials involved the accurate measurement of water currents and temper-

Table 6.1. Technical data on under-water habitats

Project name	First trial	Country	Dimensions	Crew (number, time)	Depth	Respiration gas	Supply	Pressure ratio	Remarks
MAN IN SEA I (E. A. Link)	1962 (Sept.) Mediterranean, France	USA	Length 3.2 m Diameter 0.9 m	1 person 1–4 days	61 m	3% O_2; 97% He	From ship energy + gas	Positive pressure inside–outside possible	Double chamber Weight 1.9 tonnes
PRECONTINENT I (Conshelf I, Diogenes)	1962 (Sept.) Mediterranean, France	France	Length 5.2 m Diameter 2.45 m	2 persons 1 week	10 m	Air		Balanced pressure	
PRECONTINENT II (Conshelf II, Star House, Deep House)	1963 (June) Red Sea	France	Diameter uncertain, about 11 m	5 persons 29–31 days 2 persons 1 week	11 m 27 m	Air (5% O_2; 20% N_2; 75% He)	From ship energy + gas		Ballast 90 tonnes
MAN IN SEA II (Spid)	1964 (June/July) Bahamas	USA	Length 4.2 m Diameter 1.2 m	2 persons 49 hours	132 m	4% O_2; 5% N_2; 91% He		Balanced pressure	Rubber tent
SEALAB I	1964 (July) Bermudas	USA	Length 12.2 m Diameter 2.7 m Height 4.5 m	4 persons 11 days	59 m	4% O_2 17% N_2; 79% He	From ship energy + gas	Balanced pressure	Double chamber
SEALAB II	1965 (Aug.) Pacific, Calif.	USA	Length 17.4 m Diameter 3.65 m Height 4.5 m	28 persons (3 teams 10 days each) Carpenter 29 days	60 m	4% O_2; 25% N_2; 71% He	Ship energy, own gas	Balanced pressure	Total weight 200 tonnes. Decompression time about 33 hours
KITJESCH	1965 (summer) Crimean coast	USSR	Length 5.6 m Diameter 2.55 m	4 persons	15 m		From land		Volume 30 m^3. Three chambers
GLAUCUS	1965 (Sept.) Plymouth	UK	Length 3.7 m Diameter 2.1 m	2 persons 7 days	10 m	Air (closed-circuit)	Electrical energy from surface	Balanced pressure	Ballast 13 tonnes
PRECONTINENT III (Conshelf III)	1965 (Oct.) Mediterranean, France	France	Length 14 m sphere Diameter 7.5 m Height 8 m	6 persons 3 weeks	100 m	1.9–2.3% O_2; 1% N_2; rest He	From surface gas Autonomous		Total weight 130 tonnes. Ballast weight 70 tonnes
PERMON II	1966 (July) Yugoslavian coast at Split	Czechoslovakia	Length 2 m Width 2 m	2 persons	30 m. planned		Autonomous	Balanced pressure	Water displacement 5 m^3 Abandoned
IKHTIANDR 66	1966 (Aug.) Black Sea, Crimean coast	USSR	Width 1.8 m Height 2 m	2 persons 3 days	11 m	Air	From land		Single-chamber laboratory Weight 1.1 tonnes Volume 6.8 m^3
HYDRO-LAB	1966 Bahamas	USA	Length 4.9 m Diameter 2.4 m	4 persons, 14 days/crew	20 m	Air	Surface-supply buoy	Balanced pressure	Many crews since 1966
SADKO I	1966 Black Sea Caucasus coast	USSR	Sphere 3 m diameter	2 persons, 6 hours (1 month at 25 m Oct. 1966)	40 m		From land, From ship	Balanced pressure	Volume 14 m^3, Ballast weight 13.5 tonnes

CARIBE I	1966 (end of year)	Cuba	Length about 3 m Diameter about 1.5 m	2 persons, 3 days	15 m		From ship, gas partly autonomous	Balanced pressure	
PERMON III	1967 (March) Bruntal	Czechoslovakia	Length 2 m Width 2 m	2 persons, 4 days	10 m		Energy from land. Gas autonomous		Ballast weight 5 tonnes. Weight of station 1.5 tonnes
MEDUSA I	1967 (July) Lake Klodno	Poland	Length 2.2 m Width 1.8 m Height 2.1 m	2 persons, 3 days	24 m	37% O_2; 63% N_2	From land	Balanced pressure	Weight of station 2.95 tonnes
HEBROS I	1967 (July) Bay of Varna	Bulgaria	Length 5.5 m Diameter 2 m	2 persons	10 m				No details
OCTOPUS	1967 (July) Black Sea, Crimean coast	USSR		3 persons, (Several weeks?)	10 m	Air	From land	Balanced pressure	Collapsible Hemispherical
IKHTIANDR 67	1967 (Aug.)	USSR	Length 8.6 m Height 7 m	2–5 persons	12 m				Three chambers Weight 27 tonnes
SADKO 2	1967 (summer) Black Sea, Caucasus coast	USSR	Ball diameter 3 m	2 persons, 10 days	25 m (50–60 m)		Energy from land-ship. Gas autonomous	Exterior positive pressure, 4 bar	Buoyancy of laboratory 12 tonnes. Ballast weight 27 tonnes
KOCKELBOCKEL	1967 Sloterplas	Netherlands	Height 4.6 m Diameter 1.9 m	2–4 persons. Short period	15 m	Air	Gas and energy autonomous	Balanced pressure	Ballast weight 9.5 tonnes
UWL-ADELAIDE	1967–1968	Australia		Several persons			From pontoon		No further details
ROMANIA LS I	1968? Bicaz Lake	Roumania		2 persons			From ship		
KARNOLA	1968?	Czechoslovakia		5 persons	8–15 m				Data incomplete
CHERNOMOR	1968 (June) Crimean coast	USSR	Length 8 m Diameter 3 m Height 6.1 m	4 persons. Several crews 1 month in total	5–14 m (poss. 30 m)		From surface (ship)	Balanced pressure	Water displacement 62 tonnes. Autonomous for three days
MEDUSA II	1968 (July) Baltic	Poland	Length 3.6 m Width 2.2 m Height 1.8 m Total height 2.5 m	3 persons, 14 days	30 m	Air	From ship		Autonomous up to 50 hours
ROBINSUB I	1968 (July) Ustica Island	Italy	Length 2.5 m Width 1.5 m Height 2 m	1 person	10 m	Air	From land	Balanced pressure	Wire cage, rubber tent, volume 5 m^3
HEBROS II	1968 Cape Maslennos	Bulgaria	Length 6.7 m Diameter 2.5 m	2 persons	30 m (10 days?)		From surface		Effective volume 30 m^3
SPRUT	1968 Crimean coast	USSR	Height 1.5 m Diameter 3.0 m	2–3 persons 14 days	10 m				Flexible net-enclosed ball

Table 6.1. *Continued*

Project name	First trial	Country	Dimensions	Crew (number, time)	Depth	Respiration gas	Supply	Pressure ratio	Remarks
BAH I	1968 (Sept.) Baltic	Federal Republic of Germany	Length 6 m Diameter 2 m	2 persons 11 days	10 m	Air	From ship	Balanced pressure	
IKHTIANDR 68	1968 (Sept.) Crimean coast	USSR		Several crews Total 8 days	12 m		From land		'Glass chamber' Water displacement 15 m^3
MALTER I	1968 (Nov./Dec.) Malter Dam	German Democratic Republic	Length 4.20 m Diameter 1.80 m Height 3.50 m	2 persons 2 days	8 m	Air	From land and autonomous	Balanced pressure	Effective volume 10 m^3 Weight 14 tonnes
TEKTITE I	1969 (Feb.) Virgin Islands	USA	Cylinder height 5.5 m Cylinder diameter 3.8 m	4 persons 59 days	12.7 m	8% O_2; 92% N_2	From ship	Balanced pressure	Ballast 175000 lb Negative buoyancy 20000 lb
SEALAB III	1969 (Feb.) St Clemente, Calif.	USA	Length 17.4 m Diameter 3.65 m Height 4.5 m	5 × 12 persons	183 m	2% O_2; 6% N_2; 92% He	From land and ship	Balanced pressure	Project suspended indefinitely
ROBIN II	1969 (March) Genoa, Mediterranean	Italy		1 person 7 days	7 m			Balanced pressure	Transparent plastic hull
AEGIR	1969 Hawaii	USA	Length 2 × 4.6 m Diameter 2.75m Ball diameter 3 m Total length 15.2 m	4–6 persons 14 days	147 m	Variable gas mixtures	From land, buoy or ship	Internal pressure 18.3 bar	Ground pressure 40 tonnes. Ascent and descent totally controlled from inside
UWL-HELGOLAND	1969 (July) North Sea, Baltic Sea, USA, East Coast	Federal Republic of Germany	Length 9.0 m Diameter 2.5 m Height 6 m	4 persons 10 days each up to 30 days	23–31 m	Air	From buoy	Internal pressure 10 bar External pressure 10 bar	About 64 tonnes (First unit)
SUBLIMOS	1969 (June) Lake Huron		Diameter 2.4 m Height 2.7 m Total height 6.4 m	2–4 persons	10 m	Air	From land via umbilical	Balanced pressure	Weight 8 tonnes Ballast approx. 5 tonnes
BAH II	1969 (June/July) Lake Constance	Federal Republic of Germany	Length 6 m Diameter 2 m	2 persons. Several days	10 m	Air	From surface	Balanced pressure	
SD-M 1 (SD-M 2)	1969 (August) Malta	UK	Length 2.9 m Width 1.85 m Height 1.85 m	2 persons 1–7 days ,	9 m (6 m)	Air	Autonomous	Balanced pressure	Rubber tent with steel frame
CHERNOMOR-2	1969 (Oct.) Black Sea	USSR	Length 8 m Diameter 3 m Height 6 m	4 persons Several weeks	25 m, 35 m	O_2–N_2 mixture	Autonomous		With rescue chamber. Water displacement approx. 75 tonnes

ATLANTIDE	1969 (Sept.) Lago di Cavazzo	Italy	Length 7 m Diameter 2 m (Two rooms)	12 persons 25 days (three houses)	12 m	Air	Under-water machinery house		Under-water village with three houses and one machinery house
SADKO 3	1969 (Oct.) Black Sea	USSR	Diameter 3 m Height 7 m	6 persons 6 days	25 m	15% O_2; 85% N_2	Autonomous	Balanced pressure	Ballast 39 tonnes
TEKTITE II	1970 (April) Lamashur Bay	USA	Height 5.5 m Diameter 3.8 m	5 persons 11–30 days	12.7 m	N_2–O_2 mixture	From land		11 crews, 5 persons each
SHELF 1	1970 (autumn) Black Sea	Bulgaria	Length 6 m Diameter 2.5 m	3 persons 7 days	21.5 m	Air	Surface support ship	Balanced pressure	
EDELHAB	1970 Alton Bay, New Hampshire	USA	Length 3.7 m Diameter 2.4 m	4 persons 36 h	7.6 m	Air	From land		
MINITAT	1970	USA	Height 3.5 m Diameter 2.4 m	3/2 persons 7 days 14 days	26 m 56 m	N_2–O_2 mixture	Surface		Not used owing to technical difficulties
ASTERIA	1971 Lake Garda	Italy							
SEATOPIA	1971	Japan	Length 11.9 m Diameter 2.3 m Height 6.5 m	4 persons 30 days?	design diving depth 100 m	O_2–N_2–Hc mixture	Surface support vessel	Internal pressure-resistant	
HUNUC	1971	South Africa							Abandoned during launching
LAKE LAB	1971 Lake Michigan	USA	Width 3 m Height 2.1 m	2 persons 2 days	10 m	Air from land			
SUBIGLOO	1972, 1974 Arctic waters	Canada	Sphere diameter 2.5 m	2 persons 1 day	13 m	Air	From surface	Balanced pressure	Designed as acrylic work station
LA CHALUPA	1972 Puerto Rico	USA	Length 5.8 m Width 2.4 m Height 2.4 m	5 persons 2 weeks	33 m	N_2–O_2 mixture	Surface vessel or supply buoy	Internal pressure resistant	Autonomous for 48 hours
LORA	1974 Newfoundland	Canada		3 persons 24 h	8 m	Air	Surface		
GALATHÉE	1977	France	Length 7 m Width 6.6 m Height 4.75 m	5 persons 2 days	approx. 18 m	Air	Surface vessel	Pressure compensated	Weight 7 tonnes
NERITICA	1977 Red Sea	Federal Republic of Germany	Length 2 m Width 2 m Height 3.4 m	3 persons	10 m	Air	From shore	Pressure compensated	Volume 14 m^3 Ballast 18 tonnes

ature. The habitat went down to between 10 and 40 m depth and divers made excursions into 45 m depth. The system was only meant for short-term habitation as the available documentation refers only to under-water exposures not exceeding six hours.

Caribe I (Cuba)

About the end of 1966 Cuba's first under-water laboratory was installed at a depth of 15 m off the north coast near Havana. From all reports this habitat was primitive and small, a fore-runner of the larger more sophisticated project *Caribe II*.

Permon III and IV (Czechoslovakia)

In March 1967 Czech divers installed the laboratory in 10 m depth in a quarry lake. Conditions on the surface created more difficulties than those below: the intense cold and high winds almost halted the under-water work. A further experiment, *Permon IV*, was also successfully completed. Two divers lived at 25 m depth for 102 hours and carried out a wide range of psychological tests and practical tasks.

Medusa I (Poland)

Whereas between 1962 and 1965 only about two or three under-water laboratories were set up a year, after 1967 there was an increase in the use of these stations. The Poles entered the field with their *Medusa I* sited in Lake Klodno in July 1967. Two divers worked for three days at 24 m depth with the experiment serving as forerunner for the *Medusa II* and *Medusa III* stations which were to follow later.

Hebros I (Bulgaria)

In July 1967, the Bulgarians installed their *Hebros I* under-water laboratory. Other than that the laboratory body was 5.5 m long, with a diameter of 2 m, and operated at a depth of 10 m, not much else is known.

Octopus (USSR)

In July 1967 the Russians installed flexible, hemispherical under-water laboratory called *Octopus* in the Black Sea off the Crimean coast. It was reported that a three-man team spent several weeks at a depth of 10 m under water.

Ikhtiandr 67 (USSR)

It is not clear whether this project was a new under-water laboratory or simply a modification of the previous year's attempt. The under-water team was increased from two to five persons. Trials were held in the Black Sea off the Crimean coast with the object being to gain more detailed information concerning human gas exchange and to carry out psychological studies while living under water for long periods of time.

Sadko II (USSR)

After gaining experience with *Sadko I*, scientists at the Leningrad Hydrometeorological Institute, cooperating with the Institute of Acoustics at the Russian Scientific Academy, designed and developed the *Sadko II* station. This construction was a double-sphere arrangement with one sphere on top of the other. The first trials were reported to have taken place in the summer of 1967 in the Black Sea. The aim was to study long-term human habitation under water as well as certain physiological studies.

Kockelbockel (Holland)

A simple design and construction limited for use by amateur sport divers.

UWL Adelaide (Australia)

Not many technical details are known about this habitat except that it had a number of compartments including separate living accommodation, pressure chambers and laboratories. Installed in September 1967 it was supplied from a surface raft.

Roumania LS I (Rumania)

The Rumanians designed the *Rumania LS I* and installed it in the Black Sea. With a diameter of 1.8–2 m and about 5 m long, it accommodated two people.

Karnola (Czechoslovakia)

Karnola was the third under-water laboratory produced by the Czechs. Not much is known about this project. Apparently it served to house five people in 8–15 m water depth, and was probably installed in 1968.

Chernomor (USSR)

Gelendshik, a blue bay in the Black Sea, was the location for the first installation of *Chernomor*, a relatively large Russian under-water station. The laboratory was installed in June 1968 and accommodated up to 30 divers for a month at a time at 14 m depth with teams of six exchanging in succession. The purpose of this project was oceanographic investigations in coastal areas, where biological and geological processes are particularly interesting. Marine life was abundant. The habitat's internal fittings were limited. The crew changes took place on the surface, the habitat surfacing every five or six days. Decompression time was limited to about ten hours.

Medusa II (Poland)

Poland's second under-water laboratory, the *Medusa II*, was completed in July 1968. A square habitat with about 14 m^3 internal capacity was launched from a ship, for the first trials to a depth of 30 m in the Baltic Sea. The habitat served as dwelling for three divers for 14 days.

Robinsub I (Italy)

During the tenth international Diving Sport Week on Ostica in July 1968, a small under-water house was sunk just off the island in 10 m water depth. The house was more or less a wire cage covered in plastic and the Italian Italo Ferraro lived in it for 48 hours.

Hebros II (Bulgaria)

The Bulgarians made considerable technical progress with their *Hebros II*, compared to their *Hebros I*. In contrast to *Hebros I*, *Hebros II* was designed not only to carry out purely scientific activities but also for economic studies. The main considerations were physiological and psychological studies under 4 bar pressure.

Sprut (USSR)

No metal was used in the construction of this habitat in 1968, even the floor was made of fabric and was flexible. A development of the *Octopus*, the project was for hydrochemical tests in which sea water samples were studied for their dissolved gas content, particularly oxygen.

BAH I (West Germany)

In September 1968, the West Germans installed the *BAH I* habitat in the Baltic. It was a simple straightforward design but unfortunately the project was over-shadowed by the death of Dr Horst Hartmann, who was part of the project, as a medical specialist. He died during a survey dive from the surface without having entered the habitat.

Ikhtiandr 68 (USSR)

The *Ikhtiandr 68* was installed in September 1968 off the Crimean coast, a construction with 15 m^3 water displacement. The station was 12 m under water and several teams lived there for eight days, mainly concerned with testing precise depth measuring equipment and geological equipment as well as studying ergonomics and the movement of humans under water.

Malter I and II (East Germany)

The first East German under-water dwelling called *Berlin I* was not developed until there was sufficient funds and personnel for it. A group of sport divers installed the *Malter I* in the Malter dam basin in November 1968. This habitat had room for two persons, sited at a depth of 8 m under water, and was very basic. On the other hand, the construction of the *Malter I* did prove that a small group of divers with limited funds could, with sufficient motivation and energy, design and install a basic dwelling.

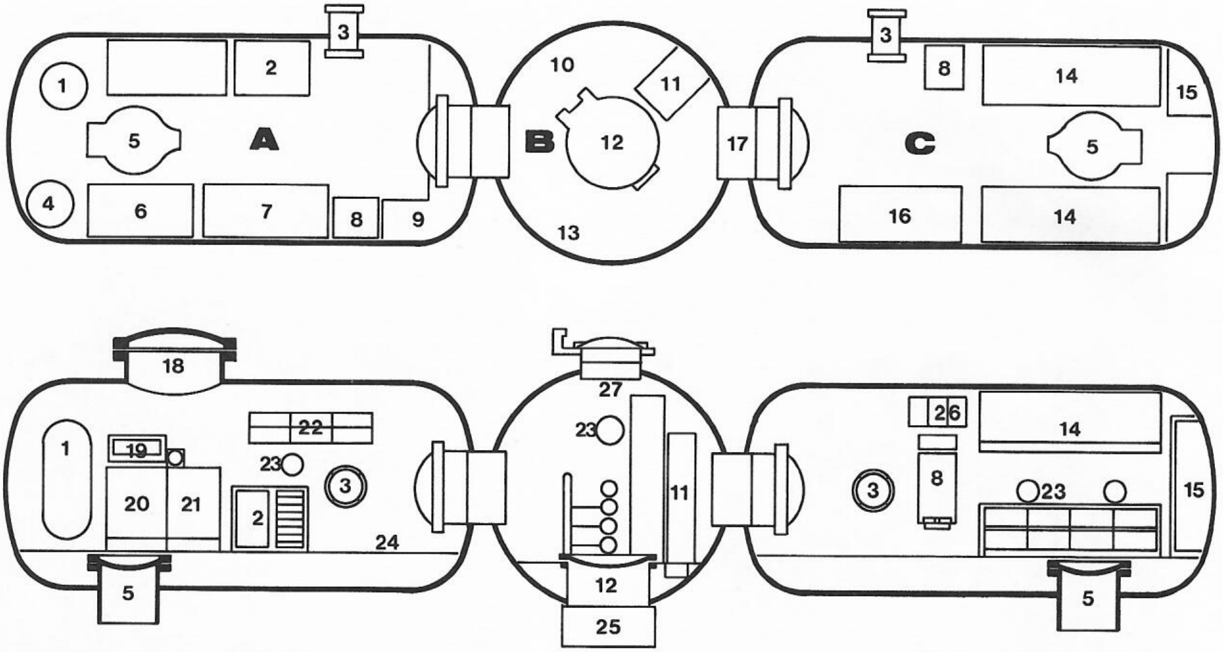

Fig. 6.49. Plan of the habitat *Aegir*.

1 hot water storage
2 galley
3 tool lock
4 cold water trunks
5 escape hatch
6 communications
7 laboratory sink
8 communications and dehumidifier
9 wet suit storage
10 shower
11 shower room
12 diving entry hatch
13 hookah breathing equipment
14 bunks
15 linen storage
16 WC
17 connecting tunnels
18 refitting hatch
19 infra-red oven
20 freezer
21 refrigerator
22 bulkhead storage space
23 observation port
24 deck plating
25 diving skirt
26 environmental control system
27 central sphere

Tektite I (USA)

This project was financed and supported jointly by General Electric Co., NASA, and the Ministry for the Interior. Four aquanauts lived for 59 days at a depth of nearly 13 m. The main purpose of the project was not to set up a record but rather to study human behaviour when subjected to living for long periods in relatively cramped quarters. The experiment was successfully brought to a conclusion without any major difficulties.

Sealab III (USA)

The biggest and most expensive under-water experiment of all times was ended before it really got started. Whereas many of the American

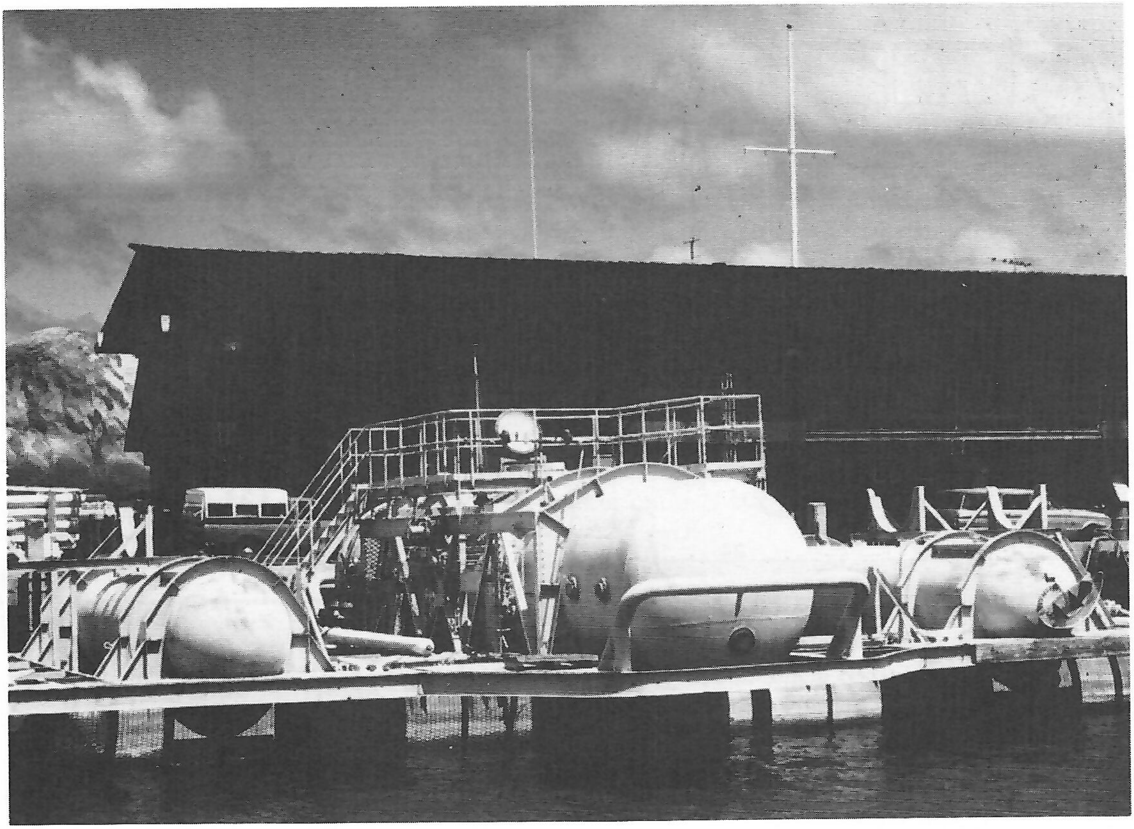

Fig. 6.50. The habitat *Aegir*.

space projects were carried out with incredible precision, this third *Sealab* programme seemed to be beset by bad luck. After various postponements, it was finally launched in February 1969. Technical problems required a four-man team of divers to dive down to the *Sealab* which was sited 183 m under water to carry out repairs. On the way from the diving bell to the habitat one of the divers, Berry Cannon, got into difficulties and died shortly afterwards in the bell. It was reported that his CO_2 absorbent container had not been filled. After this tragic accident, the project was terminated.

Robin II (Italy)

A successor to the *Robinsub I* project, this under-water station was very simple, being simply a transparent plastic container.

Aegir (USA)

One of the largest American under-water research centres located on the island Oahu in the Hawaiian Islands, the Makai Undersea Test Range incorporates a considerable installation on land including a big sea aquarium and a large under-water laboratory completed in early 1969 for working at depths down to about 150 m. This well designed

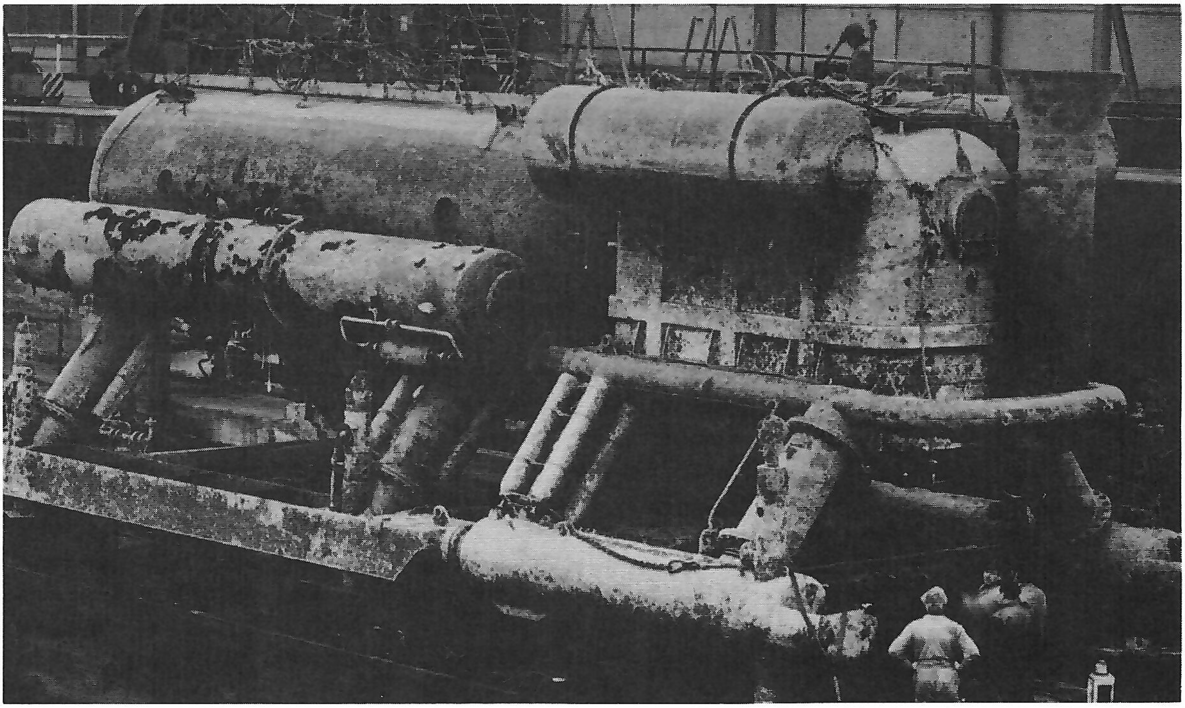

Fig. 6.51. The under-water laboratory *Helgoland* after recovery from the sea.

system has carried out successful projects and still holds the depth record of 158 m for known habitat installations. The facility is available for outside research.

UWL Helgoland (West Germany)

Ever since its first successful mission in 1969, the *Helgoland* has undertaken successive trials and experiments and also improved the general state of the art. Successive operations in the North and Baltic Seas as well as off the USA coast in 1976 have made *Helgoland* probably the most successful habitat to date. Scientists and technicians from all over the world have lived and run their experiments in this habitat for weeks and months. Although this habitat is now becoming outdated it has served its purpose by adding much to the knowledge of habitat operations.

Tectite II (USA)

The *Tektite II* programme used the same double cylinder habitat as the *Tektite I*. In 1970 the project involved 11 separate teams each of five aquanauts carrying out a large number of projects and tasks.

Shelf I (Bulgaria)

After *Hebros I* (1967) and *Hebros II* (1968) Bulgaria installed its first UWL, *Shelf I*, in the autumn of 1970. The laboratory was sited 21.5 m under water in the Black Sea. The experiments lasted seven days.

Edelhab I and II (USA)

Edelhab I was first sited in a fresh water lake at a depth of 10 m in 1968. It was designed and constructed by engineering students. After modifications and improvements in 1971 the laboratory was renamed *Edelhab II* and sited off the Florida coast south of Miami. For nearly three months oceanographic studies were carried out at 17 m depth by the Florida Aquanaut Research Expedition.

Asteria (Italy)

The Italian company, Galeazzi, installed a tower-shaped under-water habitat in Lake Garda in 1971. The main objective was diver training and testing technical instruments.

Seatopia (Japan)

Japan's interest in under-water technology was surprisingly limited when one considers its large coastal area. Except for a few brief reports about observation towers, small submersibles and under-water bulldozers, nothing much else was heard from Japan. Then in 1971 a large-scale habitat was announced and finally set up after some technical difficulties. The laboratory's shape was very similar to the American *Sealab II* and various features were also similar to other known designs.

Hunuc (South Africa)

Major difficulties arose while the habitat was being lowered and ballasted and before the habitat was occupied a storm destroyed it.

Lake Lab (USA)

The *Lake Lab* was a large igloo although a five-cornered shape. This small laboratory was designed for shallow waters at depths to 10 m and to be occupied by two divers for up to 48 hours. A mobile van on shore provided the support and to decompress the aquanauts surfaced and transferred to a decompression chamber.

Sub Igloo (Canada)

First installed in 1972, the *Sub Igloo* accommodated two or three people at a shallow depth of 13 m. The unit was made in the form of an acrylic dome, giving all-round visibility and designed for use under the ice pack.

La Chalupa (USA/Puerto Rico)

The use of portable pontoons with the under-water station was part of the Perry Oceanographics design with the advantages of quickly changing location by rapid launch and recovery. This compact laboratory consisting mainly of two chambers was first installed in Puerto Rico in 1972. The diving depth was 33 m with a team of five persons for two weeks. The safety installations and procedures were particularly good.

Galathee (France)

In 1977 a new beautifully shaped installation was designed. The *Galathee* was an elliptical house with huge observation panels for studying the under-water life in the Mediterranean.

Projects Being Designed and Constructed

One major project is currently progressing. It is the enormous *Chermomor 3* project now being developed by the Russians, a conventional laboratory as far as design goes but with a weight of about 300 tonnes In the USA NOAA had been planning to build the *Oceanlab*, a highly manoeuvrable submarine habitat, but the project has been abandoned.