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# LIFE SUPPORT SYSTEMS FOR THE LUNAR BASE

by

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Some day in the near future man will contrive to place himself on the moon. To accomplish a step of this magnitude, plans are being made now to systematically develop the various types of life support systems that will be required for survival and useful performance in lunar exploration.

The life support system to be used in a particular lunar mission will be dictated by the requirements of the mission itself, with regard to the objectives and the duration. Without delineating the missions, it is possible to see that several types of systems, different in certain respects from each other, will be used. We can enumerate these types even now.

The first type of life support system will be used for short operations. It will consist of the vehicle used by the man, or men, to travel to the moon. Stored oxygen, food and water, and chemicals for absorption of carbon dioxide, odors and other noxious gases will be carried in sufficient quantity to last the duration of the mission.

As missions become longer the point will be reached where generation of oxygen from carbon dioxide, water, or materials at hand may be used to extend the length of the mission. The second type of system, then, would use physico-chemical methods to recover oxygen and water. Food would still be carried in sufficient quantity for the duration of the operation. This kind of system could be called an intermediate system and might best be used on the moon or another planet rather than in an orbital space station.

The third system is one which theoretically could be used indefinitely. It would be self-sustaining and would regenerate and purify its own atmosphere, produce its own food, and would re-utilize all its own wastes in producing food. In its essentials it would be a miniature replica of the closed ecology of the earth system - a terrella. The terrestrial ecology provides all that is necessary to life on earth, and the energy required to drive the processes is obtained from a source outside the system - the sun. In like manner, a miniature ecology would support life in the lunar base or lunar colony. Either solar energy or a nuclear power plant on the moon would provide power.

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## Atmosphere Regeneration

If we follow the earth's ecological pattern on the moon, the atmosphere of this third system would be regenerated by making use of the process of photosynthesis. Green plants give off varying amounts of oxygen during the photosynthetic period. The most efficient oxygen-producing plants present the largest amount of plant surface area per unit of weight or volume and contain the smallest proportion of nonphotosynthetic tissue. Hence, the choice of microscopic algae as the most suitable plant to produce oxygen. Certainly other factors are important too, but these seem to be the most important as long as payloads are weight-limited.

The choice of the best oxygen-producing alga has yet to be made. Each potential alga has a certain desirable characteristic. Some algae have several desirable characteristics in combination. But the best triple-function alga has not yet been selected. By "triple-function" I mean the ability to produce oxygen, to utilize wastes as nutrients, and to provide a dietary supplement. Further screening and research on the most suitable organisms must be done before a single best alga can be selected.

The design of a photosynthetic gas exchange system will depend on the organism selected, as well as on the environment in which it will be used. The Chlorella strains of algae are not exactly clean-growing; they stick to the sides of the culture vessels, piping, tubing, and to the lamp immersed in the culture to provide light energy for photosynthesis. Obviously, an organism with this characteristic would present larger problems in the maintainability of such a system. A surface coated with algae is deceptively dark and could easily fool a photocell which would be used to determine density. (See Figure 1.)

Use of these strains would create a greater requirement for down time, in order to scrub out the system. This alone would require a number of modular units in the system, one of which could be out of service during the cleaning period. The requirement would exist for a simple, easily dismantled design to minimize the down time.

The use of a clean-growing organism such as Anacystis nidulans or Synechococcus lividus, both blue-green algae, would minimize design problems and down time because these algae do not stick to surfaces as readily as do Chlorella or Scenedesmus. These blue-green algae are very good in this respect, but too little is known of their food value and content of toxic substances.

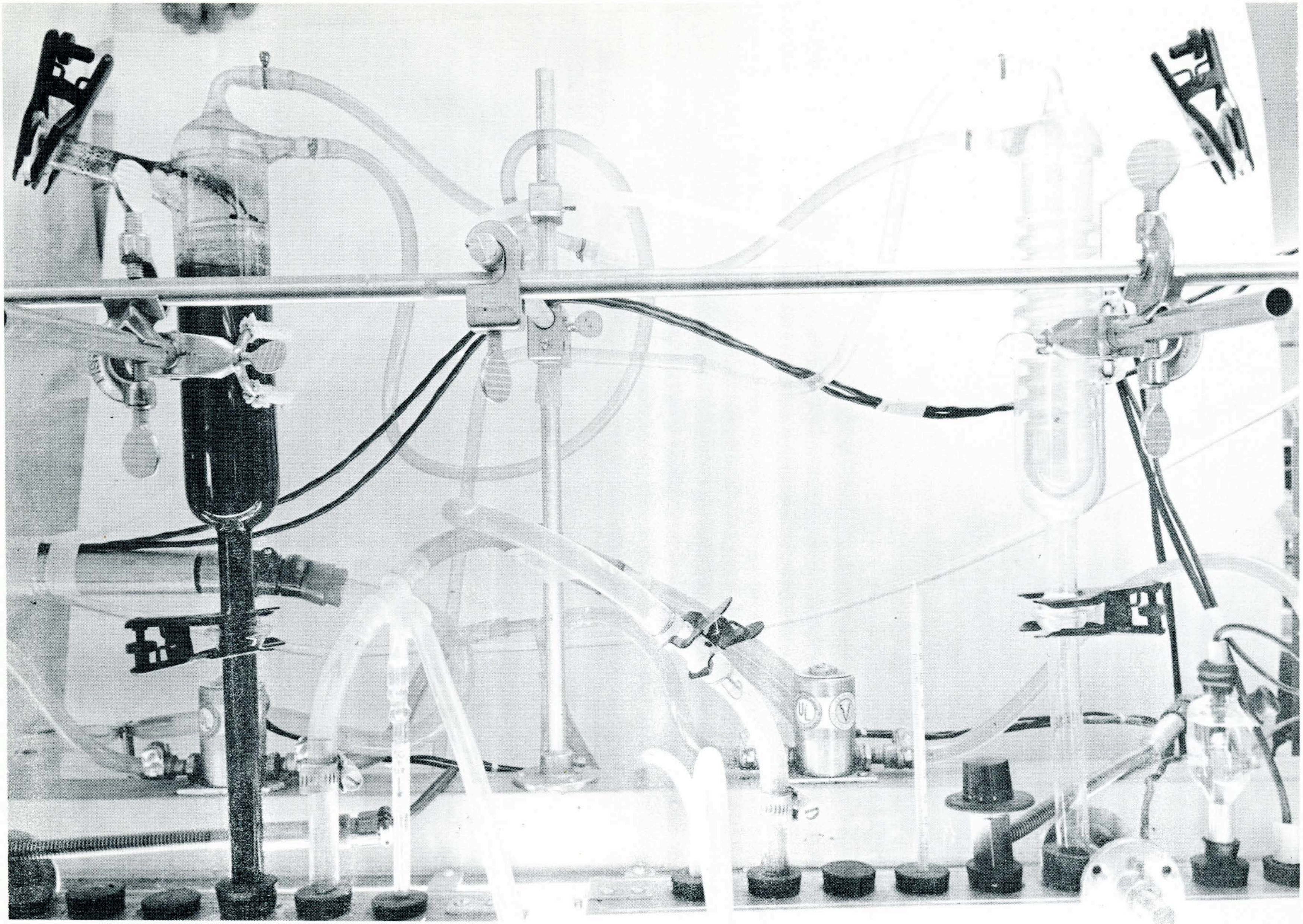

Fig. 1 Gas Outlets Above Two Identical Algal Culture Chambers. Left Chamber Contains Sorokin's Chlorella (40°C). Right Chamber Contains the Blue-Green Synechococcus Lividus (50°C).

Blue-greens are said to be more toxic than green algae. Toxic in what respect? And what are the evidences or symptoms of toxicity in animal or man? Assuming that they are more toxic, if these algae were used as food one might expect an increase in morbidity of gastrointestinal disorders among the crew members. At present we do not know a great deal about these toxic elements in blue-greens, and there may be some unsuspected toxic effects from eating green algae, too. Again, assuming toxicities in the form of allergies, gastrointestinal disorders, possible chemical effects on blood vessels, the gastric and intestinal mucosae and possibly other tissues, the curve on maintainability of the crew members goes up logarithmically.

Other problem areas in algaculture can be mentioned. These include the maintenance of the chemical composition of the nutrient solution. Can this be maintained by automation or must the solution be made up by a technician? Will chemical nutrients be used or can suitable nutrients be derived from the processed waste materials accumulating in the closed system?

What will be the source of light energy for photosynthesis? Different designs are required for use of solar energy and for artificial illumination. Both designs must be relatively trouble-free and easily reparable. The intensity and spectrum of light are important in algaculture. Each alga requires slightly different light characteristics for its proper growth. Too much light can be harmful to algae and can cause solarization, or bleaching. A solarized culture does not photosynthesize and oxygen production is reduced or stopped. Bleached algae, on the other hand, may be better as food than unbleached algae. Further investigations into the nutrient value of solarized algae are necessary.

Algae are susceptible to bacterial and protozoal contamination, or may be poisoned by an exposed bit of copper or other metals in the culture system. Contact with a bare metal can reduce the growth rate, thereby reducing oxygen production. A sick culture can be extremely serious in a closed system. If the sick culture cannot be cured by proper treatment, such as the addition of a deficient element, removal of a toxic element, correction of pH, or one of the other fifteen or twenty variables, the culture must be replaced. This means that preserved and viable stock cultures must be on hand for replacement of the sick culture. Here again, modular separate units would be desirable to negate the possibility of the whole system being rendered ineffective simultaneously.

## Food Production

In the long-term lunar life support system food will be provided in one of two ways: 1) by supply rocket from earth, or 2) by production within the life support system.

The first method will cost exorbitant sums of money to blast a few tons of food to the moon. The present Thor-Able booster is estimated by NASA to cost from $10 to $14 million per firing. Saturn firings are estimated by NASA to be approximately $20 million. With such costs in prospect, it behooves us to attempt to develop a system of food production within the lunar closed ecology. It would be designed to produce food for a specific number of crewmen. There would be no room for crop failures, but overproduction would be acceptable or desirable. Sealed in gas-tight containers, surplus foods could be stored outside in the natural deep-freeze of the moon - the shadow or shade.

For long-term lunar living a diet as completely normal as possible should be provided from both the nutritional and the psychological aspects. Motivation must be as high as possible, and a diet consisting solely of algae would not sustain or increase motivation. An algal diet would be comparable to eating nothing but grass or spinach. To keep the lunar explorer in a state of well-being, a normal diet of meat, vegetables, grains, and fruits must be supplied.

Meat protein can be supplied in the form of animals, fowl, fish and other aquatic forms of life. A minimum number of vegetables such as kale, peanuts, tomatoes, rice, and soybeans will provide basic requirements. Fruits, such as apples, pears, peaches, apricots, pineapples, cherries, and plums would provide additional interest in the menu.

The basic objectives in producing food on the moon are to glean the largest possible harvest in the shortest possible time from the smallest possible space and provide food of high quality at the same time. It is felt that the use of hydroponic techniques can be efficiently utilized in growing the food plants mentioned.

Since the growing of food plants involves photosynthesis as much as algaculture, the variables and the problems in higher plant systems are much the same. The design of these culture beds is less stringent, but other new factors are just as important. Pollination of plants is one of these. It might require the full time of two or more men to carry out pollination. Two bees could do the same job in a fraction of the time. Thus in order to assure adequate fruiting of plants, certain insects should be included in the system.

Most of the same problems that affect algae affect higher plants. These include deficiency diseases, toxic elements, too much light or too much continuous light, fungus disease, or insects. Undesirable insects in the closed life support system could be disastrous in a short time. Only desirable and useful insects can be permitted.

By controlling rigidly the temperature, light, humidity, and nutrient availability, growth rates of plants can be increased markedly. Tomatoes planted from seed can reach a height of 28 to 30 inches and flowering in 21 to 24 days. The fruit can be harvested in 48 to 50 days after planting from seed. By comparison the average garden tomato is harvested in 70 to 80 days. Similar increases in growth rates can be obtained with other plants - rice, soybean, kale, and peanut.

## Waste Processing

The third basic and critical part of the closed ecology as it has been described is the utilization of all waste products in the system. This includes carbon dioxide, liquid and solid excreta from man and animal, animal hides, bones, entrails, plant stalks, roots and leaves, wash water, soap, and detergents.

By proper planning in the design of the ecology, certain scavenger animals or fish can be used to consume remnants of butchered animals. Some animals can eat plant wastes alone or wastes mixed with grains and algae. Or, it might be necessary to process all wastes so that the end product will be a complete nutrient, or nearly so, for food plants and algae. However wastes are utilized, the cycle is completed and begins again.

Before any of us would be ready to subject ourselves on the moon to such a life support system as has been described, we would require that the parts of the system would be checked out and proven here on earth. In other words, a test facility must be built, systems designed, fabricated and installed, and each part tested as to its reliability. The size of the biological portions required for x number of men must be calculated, and installed. The entire system must then be put into operation with x number of men, and the interactions of the subsystems and their components studied. As design change requirements are noted the changes will be made. The test objective will be to balance the biological systems involved so that everything comes out even. Unquestionably, this is easier said than done.

One of the major projects of The Martin Company Space Medicine research program at Denver has been the design of a facility to develop this self-supporting system. The primary purpose of this research laboratory is to develop and test a closed ecology such as that described in this paper. The laboratory is suitable as a checkout facility for new and untried components.

Figure 2 shows the current Martin concept of a regenerative life support system structure designed to support five men. The concept includes a biological atmosphere exchanger, waste processing and food production systems, and crew quarters including areas for food preparation, sleeping, recreation, and sanitary facilities. Accessory equipment to monitor and control the various processes required are included in the system.

This research laboratory permits the integrated testing of these subsystems on which much work has been done as separate and individual problems. No matter how much research is done on these subsystems without attempting to integrate them into a single system, the reliability and the maintainability of the complete entity cannot be tested with any degree of assurance. The early attempts to put together the parts of a closed system will without doubt uncover problems which have not been considered in theoretical studies of the total problem.

The life support sphere as shown in Figure 2 is designed to be operated at a range of pressure from ambient to as low as 5 psi. Present concepts of closed life support systems make use of reduced pressures to ease the structural requirements and to reduce the amount of inert gas to fill out the atmospheric pressure requirements. Assuming that the biological portions of the system can be brought to balance with each other, a reduction in pressure to one-half or one-third of an atmosphere may very well upset the balance. These questions must be answered under simulated conditions and can be done only in a test facility such as has been described.

To increase the simulation capabilities of this laboratory, a vacuum shell can be constructed around the life support sphere (Fig. 3). This shell would provide a vacuum surround for the life support sphere, nearly simulating the vacuum of space. I say "nearly" because the pressure in the vacuum space would be in the order of 8 mm of mercury or 100,000 ft equivalent. An extremely high vacuum would not be necessary.

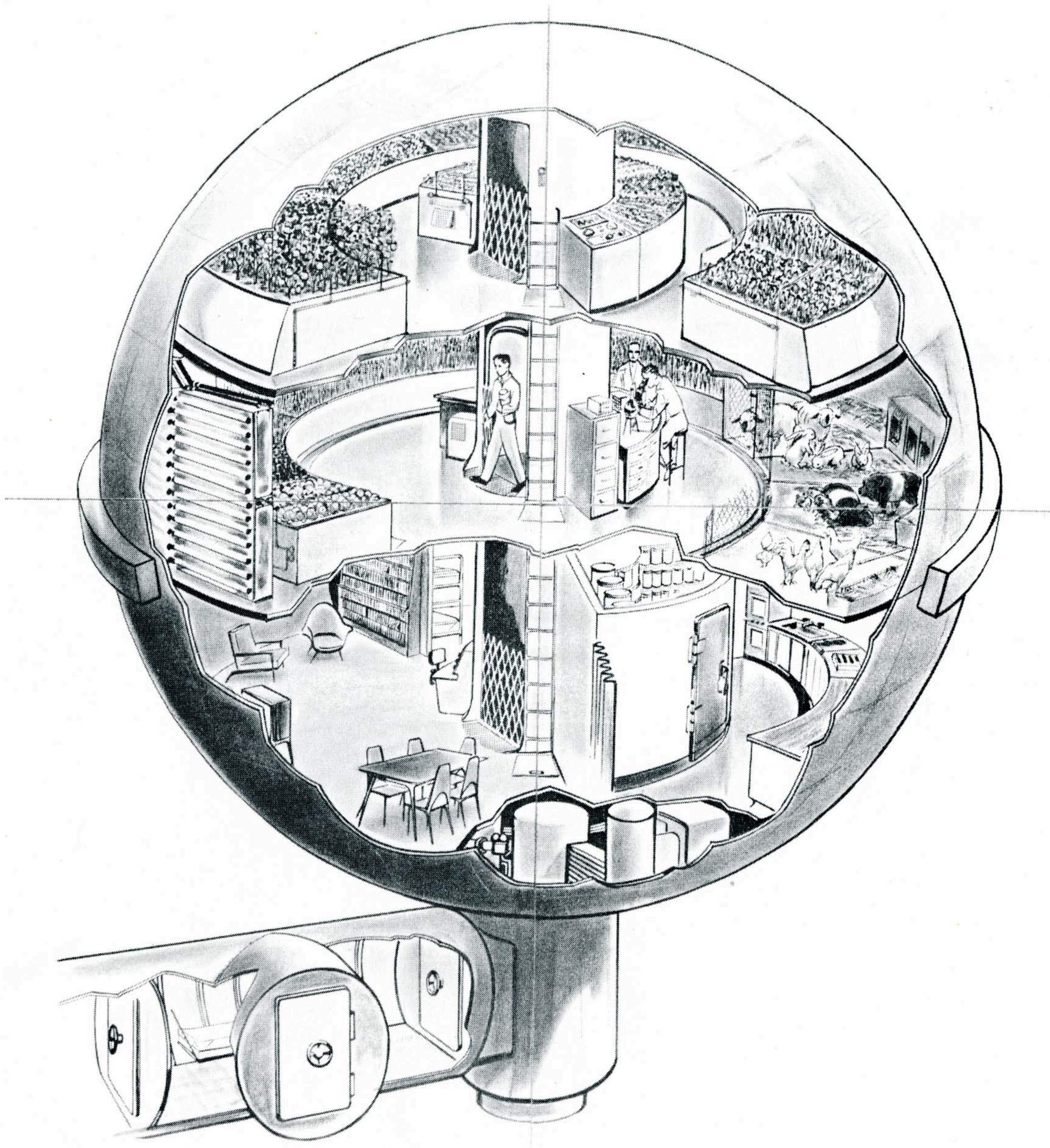

Fig. 2 Life Support Enclosure of the Lunar Housing Simulator Showing Entrance Lock and Internal Arrangement

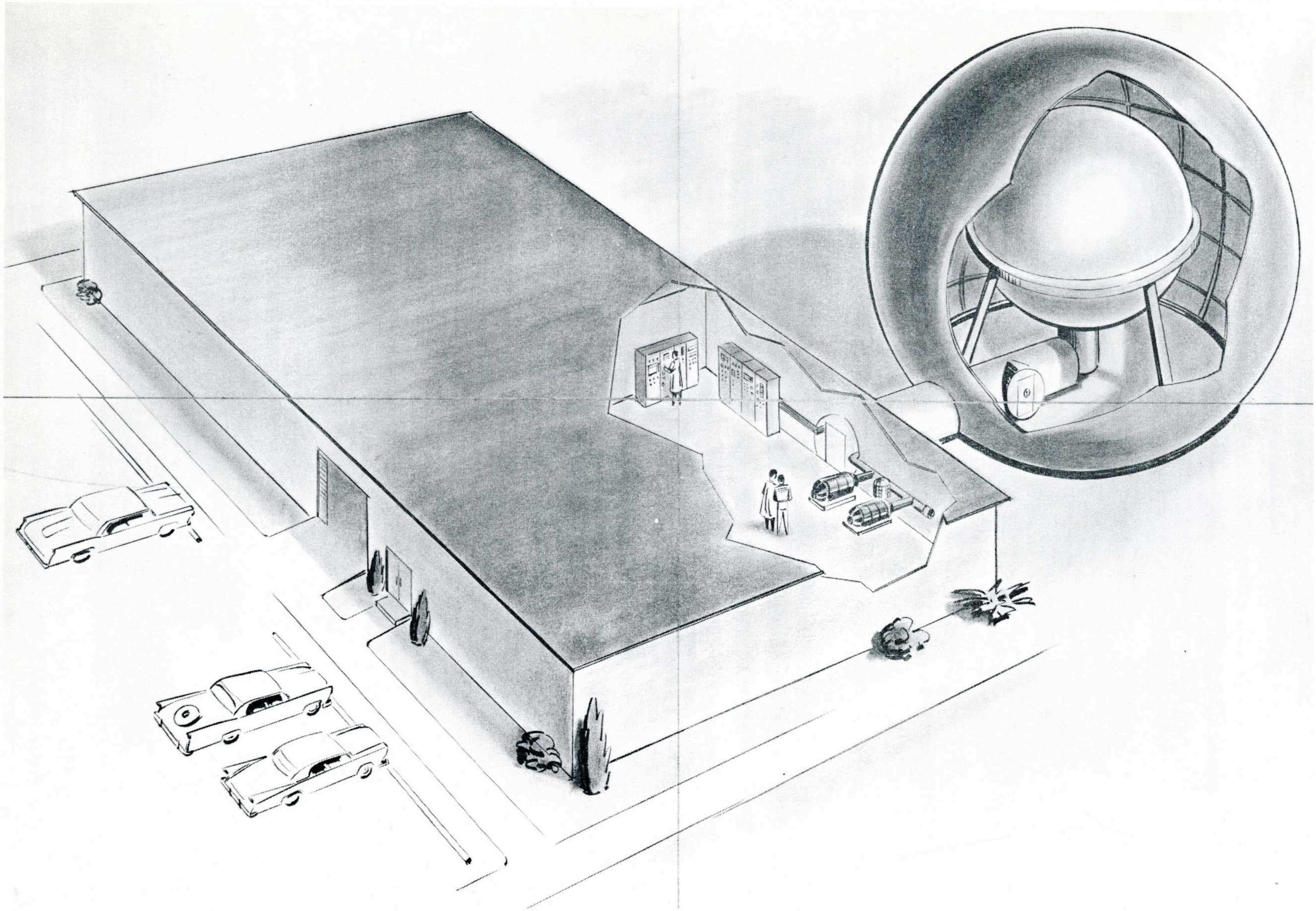

Fig. 3 Complete Lunar Housing Simulator Complex Showing Life Support Enclosure, Vacuum Sphere, Access Tunnel and Support Building

An air lock would provide access to the life support enclosure, to the vacuum space, or to the outside. By donning a full pressure suit, a crew member could enter the vacuum area and perform the physical work required to construct a lunar base. Of course, the gravity factor could not be simulated accurately, but what a man can do under one g, he can do much easier under 1/6 g.

The vacuum surround also provides the capability of checking out heat exchange theories and related problems expected to be encountered on the moon. The problems of leak detection and temporary and permanent repair techniques can also be tested and improved. Other ancillary engineering benefits can accrue from the availability of such a facility.

The support building shown in Figure 3 would contain pumping equipment, monitoring and control stations, support laboratories and shops that would be used to solve internal problems that could not be solved within the test enclosure. Monitoring of internal activities would be by closed TV circuit since both shells would be made of steel.

## SUMMARY

This paper has briefly reviewed the kinds of life support systems that would be required for lunar operations. It has discussed one concept of a research laboratory and test facility designed specifically to develop and test the various subsystems and components of the regenerative life support system. These steps are as mandatory for the development of the closed life support system as are the steps in a test program for any missile or space system. The time required to test the fully integrated system is such that an immediate beginning must be made to implement such a program.

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