(1)

Summary

The Martin Company proposes to conduct a research and development program leading to the design and construction of a test facility required in the development of a completely regenerative life support system to sustain man in extended operations in space. In this test facility, the required subsystems and their components ~~developed in more conventional laboratories~~ would be installed and checked out, and the energy balance of the system achieved ~~as well as the proficiencies of the subsystems + components,~~

J. G. Gaume, M.D.

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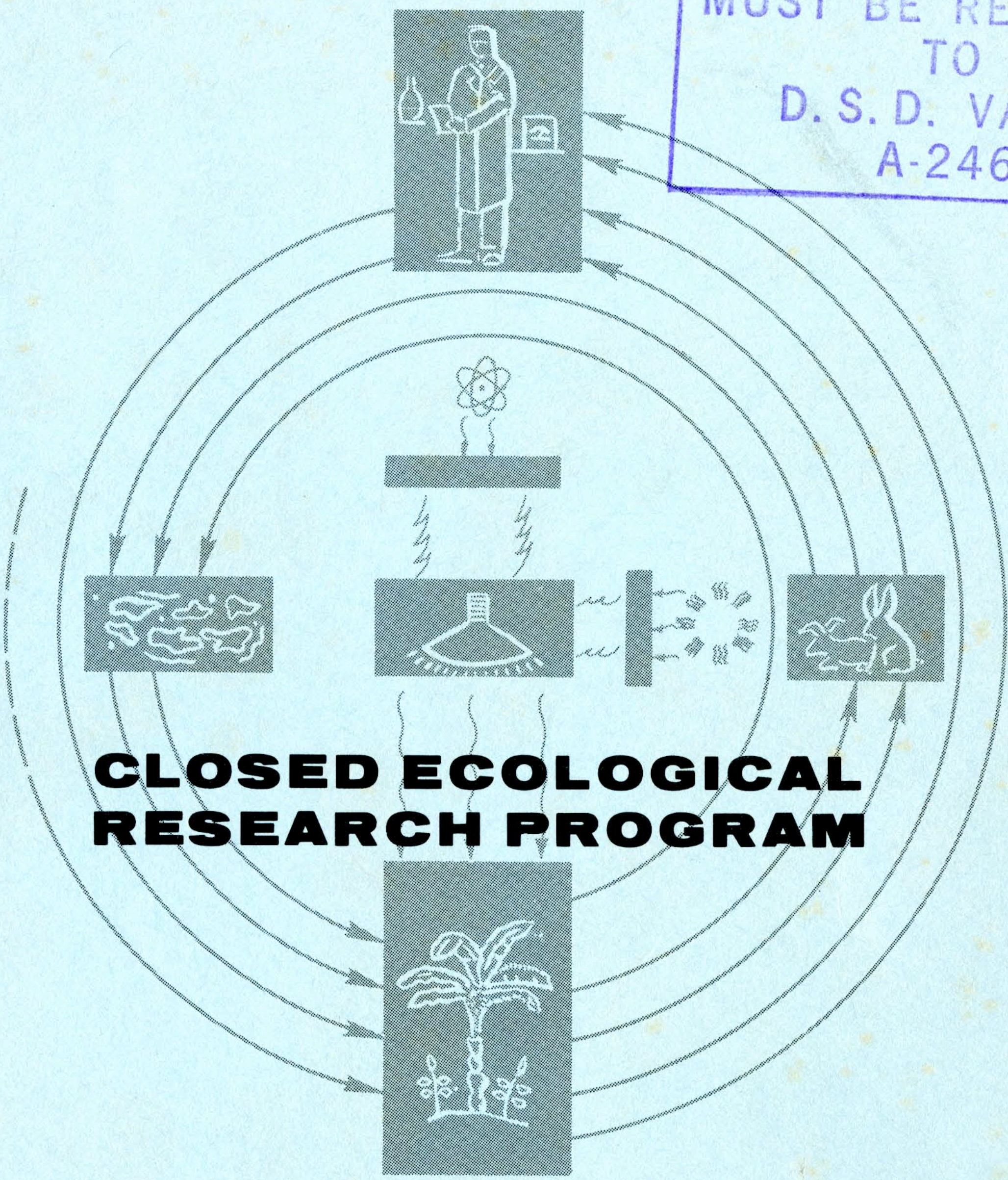

CLOSED ECOLOGICAL RESEARCH PROGRAM

DECEMBER 1959

MARTIN
DENVER

P-59-85 Copy No. 28

CLOSED ECOLOGICAL RESEARCH PROGRAM

December 1959

Approved

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CONTENTS

SUMMARY

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(1) The Martin Company proposes to conduct a research program, utilizing a closed ecological system to define the physiological and psychological design criteria for a system capable of supporting man in extended space missions.

Existing conventional laboratories provide facilities sufficient for only partial solution of the problems associated with the maintenance of man in space for extended periods of time. Components and subsystems developed in these laboratories must ultimately be integrated into a complete system and tested under simulated space conditions. The program proposed herein accomplishes this requirement. It is divided into phases starting with the required applied research to develop the closed ecological subsystem and extending through an operational program in which simulated deep long-term life support missions are conducted. In these latter exercises, emphasis will be placed on the *physical and physiological* ~~psychological as well as the physiological~~ requirements ~~for~~ *of* man. *The psychological aspects of the problem, although important, will ~~be~~ not be initiated in this facility until the operational phase.*

~~It is proposed to commence this program in March 1960.~~ The preactivation phase will *require approximately two years for completion.* ~~extend until the end of 1962.~~ The ecological chamber and the life support subsystems will be developed during this time.

During the activation phase, the subsystems will be installed in the closed ecological chamber, checked out functionally, integrated with the other subsystems and the complete life support system checked out. This phase will extend *through the next 18 months,* ~~until mid 1963.~~

The operational phase of the program will commence after completion of the activation phase *and will be a continuing program.* From this effort, data will be obtained that will be applicable for design of *long-term* manned systems operating in space.

Add: Research Results Statement

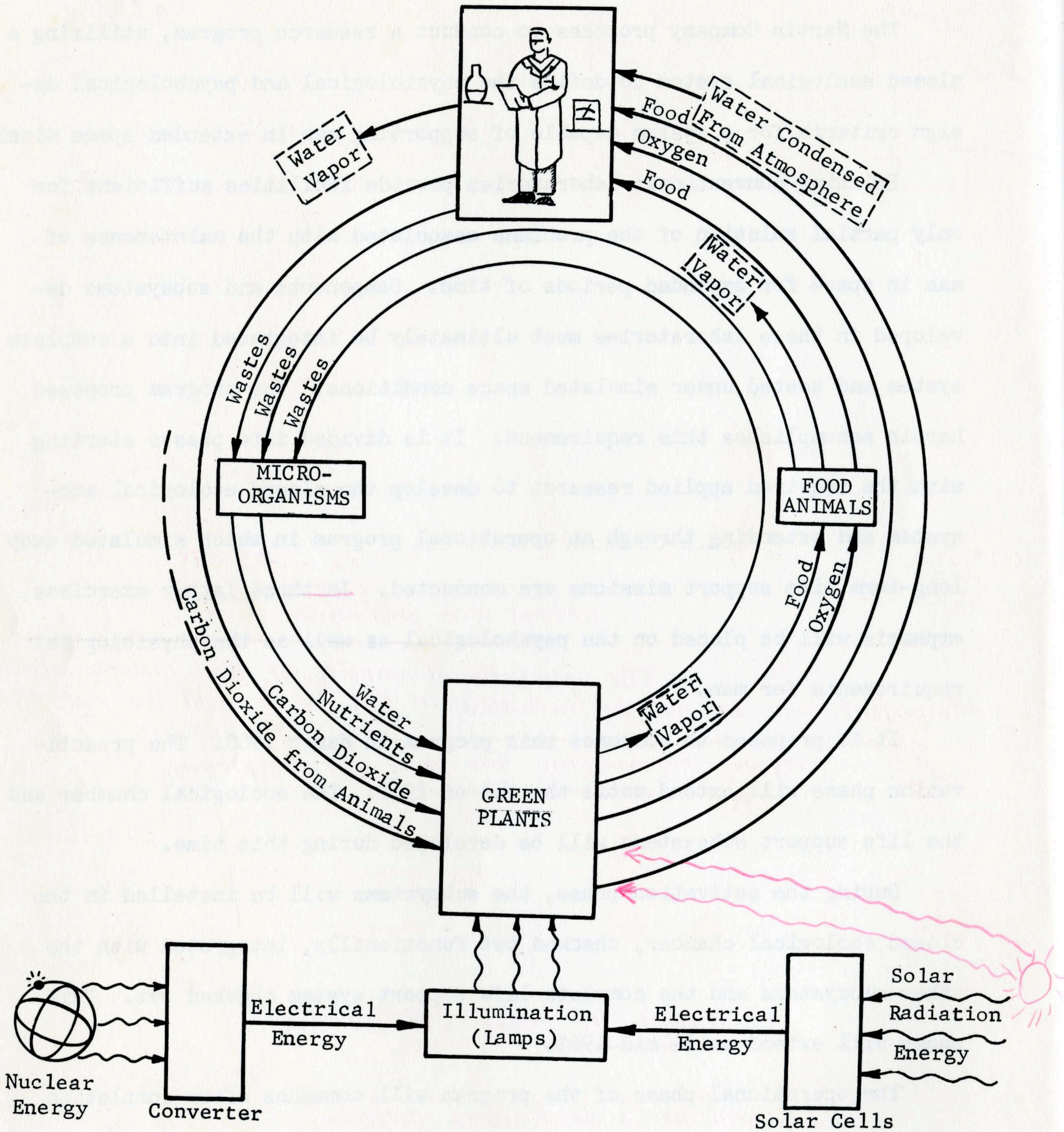


Fig. 1 Closed Ecology System

I. INTRODUCTION

With the advent of the ICBM and larger rockets, manned space flight is already in the initial stage. For manned space programs such as Mercury and Dyna-Soar I, the mission will be of such short duration that the life support system will use expendable constituents such as food, water, oxygen, and CO_2 absorbers. They will be supplied in quantities to perform the mission. However, for missions of longer durations, such as space stations, lunar exploration, or planetary exploration where it may take weeks, months, or years, a more efficient (weightwise) life support system is required.

Design criteria for the structure, guidance and control, and propulsion subsystems of space vehicles are now being defined. This proposal presents a research program to develop and operate a closed ecological system to define man's requirements for extended space missions to ensure his compatability with space vehicles.

The initial phase of this program will be carried out in the Space Medicine Laboratory now in operation at Martin-Denver. During the first year of the program, a 32 foot diameter spherical chamber will be designed and constructed to house five occupants and the necessary subsystems to make up the closed ecology. An outer vacuum shell approximately 64 feet in diameter will be placed around the spherical chamber later in the program to provide a near vacuum environment around the closed ecology. This shell will afford additional research capability for design criteria for equipment to be used on the outside of a space vehicle or in a lunar life support system.

This research program will be carried out by the Martin-Denver Space Medicine Section which is now staffed with the required specialists (see Personnel Qualifications) and with support as required from the pertinent engineering organizations.

Presently or in past

Space Medicine work now being conducted that is applicable to the closed ecological system includes:

1) Photosynthetic gas exchange system design and operation including algal research;

2) Waste processing and reutilization;

3) CO_2/O_2 separation; + concentration

4) ~~Ionized air research;~~

5) Hydroponics and ~~small animal food production;~~ plant pathology;

6) ~~Plant pathology;~~ Meat animal production;

7) Human engineering.

With the organized and integrated Space Medicine staff already at work on the basic subsystems for closed ecology, backed up by other scientific and technical staffs, this research program could be performed most economically and efficiently at Martin-Denver.

Other advantages in locating the program at Martin-Denver are:

1) The prevailing ambient atmospheric pressure of 12 psia. This reduction of 2.7 psi below sea level pressure presents structural advantages in design and construction of large reduced pressure structures. Also vacuum equipment requirements are reduced.

2) The low humidity prevailing in the area facilitates humidity and

corrosion control.

3) Most of the integrated support facilities necessary for successful operation of this new type laboratory are also in existance at Martin-Denver. See Appendix B.

It is proposed that the closed ecological research program commence as early as possible. ~~in March 1960.~~ Initial work will consist of developing the basic subsystems and the closed sphere chamber. Activation of the complete system would be accomplished ~~in mid 1962~~ two years after date of contract, with operation programs commencing ~~in early 1963.~~ 18 months after activation of the complete system.

II. RESEARCH PROGRAM

A. DESIGN PHILOSOPHY

A manned space capsule may be thought of as a "closed ecology". However, some confusion has been generated by assigning this term to systems which are designed for short-term maintenance of adequate human environment. If the designer of such a system is cognizant of the interactions between the physical, chemical, and biological environments and the human component, then, in a limited sense, the system may be thought of as an ecological system. In order for the term "closed ecology" to apply, it is necessary that the designer be aware of all material and energetic interactions between the manned component and the spatially limited environment; further, the design must incorporate provision for the complete and continuous recycling of the biologic matter confined in the system, and the system must be in a state of energy balance with the external environment.

A manned space cabin may be thought of as an isolated biophysical system in space. Initially, there will be a large store of potential energy in the fixed organic compounds contained in the human component, in the available food, and in molecular oxygen. After a period of time, this energy will have been radiated as heat, and the matter originally contained in the organic food and in molecular oxygen will have accumulated as carbon dioxide, water, nitrates, phosphates and other waste products. The potential energy contained in these substances will be low and, furthermore, will be unavailable to the human. In order to assure his continued existence, the man must either replenish his supply of high energy matter or reconstruct the high energy matter from material available as waste.

Since resupply will be extremely expensive and difficult, retention and use of the accumulated waste products must be considered. Theoretically, the waste material can be utilized by raising its potential energy level using solar radiation as a source of energy.

The advanced manned space system is envisioned as being a closed ecological system in which matter is continuously recycled, using incident solar radiation to provide the energy necessary to drive the process. In designing systems capable of converting solar to chemical energy, prime consideration must be given to the development of high rate capability in the smallest possible weight and volume configuration. Economy of matter will be critical, because resupply of useable material will be difficult and expensive. For this reason, material balance throughout the system will be important.

There are a number of cyclic systems operating simultaneously in support of human life on the earth. Although these can be studied individually, it is immediately apparent that they are interrelated.

It follows that an approach toward the achievement of a stable, balanced, closed ecology in which man represents the limiting active element might better be based on the concept of unit function than on the concept of material cycles. By unit function, it is meant that a system component such as man, a microbial culture, or a water recovery unit is defined in terms of material and energy inputs and outputs. The definition of material input and output must be specific not only as regards elemental composition but also with respect to the energy level (state of oxidation) of the matter.

The initial approach to the design of a closed ecology will be the definition of the unit function of man.

Man is maintained in his environment by accomplishing a continuous exchange of matter and energy between himself and his environment. The rates at which such exchanges occur are functions of the level of activity of the human.

The "standard values" assigned to the human component must be submitted to experimental verification and refinement. Furthermore, in order to compensate statistically for inherent individual variations, these experiments must be conducted with a sample of human subjects under conditions simulating the environment of the closed ecology.

Available data on the material output of man have been accumulated without specific regard to the problem of a tightly closed ecology. A change in diet, even one which continues to furnish the basic nutritional requirements of the human, may result in a profound change in the characteristics of excreted waste products. This results partly from the altered metabolic patterns induced in the human and partly from changes in the microflora of the intestine. It is, therefore, essential to conduct closed ecology experiments at the earliest possible time under conditions which simulate the proposed environment.

The human component represents the limiting functional unit in a closed ecology. In arranging for a suitable environment, the provision for adequate respiratory gas exchange is the first limiting factor encountered. In terms of a closed ecological system, the best solution to the problem is to introduce a photosynthetic plant into the sealed cabin. Such a system has been termed the photosynthetic gas exchanger. While apparently characterized by an initial weight-space requirement several times that of competing systems, it has the distinct advantage that when fully developed, it is regenerative and, therefore, requires the same amount of space and has the same weight over an indefinite period of time. This method takes advantage of the photosynthetic mechanism of green plants by which, simply stated, carbon dioxide and water are converted to organic compounds and molecular oxygen. Thus, it provides a point for efficiently injecting energy into the closed ecology. An analysis of the potential unit function of this component will allow for the specification of characteristics of other major and minor functional components and linking hardware.

The source of nutrient for the cultivation of algae in photosynthetic gas exchangers will undoubtedly be processed human wastes. The characterization of the optimum method for processing human wastes prior to their incorporation into the algal system represents one of the major research projects which must be undertaken in support of the closed ecology. Present knowledge does not dictate whether a biological waste processing system will be best or whether purely physical and chemical methods can be employed. A high temperature high rate anaerobic biological system is presently being developed in the Martin-Denver Space Medicine Laboratory.

It may not be possible to achieve adequate balance between the human component and one or several microbial populations. When the unit function of the human microbial and physical components have been defined, it will be necessary to conduct research aimed at defining the unit function of hydroponic cultures of higher plants and of small animal colonies. These components are not expected to be as efficient with respect to energy conversion or weight penalty as are the microbial components. However, this potential disadvantage ~~may~~ will be offset by the advantages of more complete recycling and better and more varied diet which would result from the inclusion of these additional components. Generally speaking, as the period of planned independent operation is increased, the number and kinds of components required in the ecological system will increase. These additional plants and animals must be chosen carefully and their unit functions very carefully defined, since their inclusion in an operational closed ecology must be based on the demonstration of their ability to provide an essential capacity not otherwise available.

In addition to the predominantly biological components, a closed ecological system will incorporate a number of strictly chemical or physical components. For instance, the waste processing system may function as a non-biological system. A portion of the air purification cycle will include a unit capable of catalytically oxidizing carbon monoxide and other noxious gases. Depending upon the degree of fixed nitrogen retention in the biological portions, it may be necessary to reoxidize continuously a portion of the molecular nitrogen in an electric arc. Water will be recovered by a physical process.

A basic study scheduled in the later phase of the work proposed here will be one which considers the mission requirements of the manned system and the proposed lengths of independent operation. This study should determine all physiological and psychological requirements essential to human function and not provided by the proposed system. These requirements must be defined in terms of basic function rather than in terms of traditional sociological or economic desirability. A man can function effectively for three days without thoroughly washing himself; but his general performance would most likely deteriorate to some extent if he were required to go three months without performing this function. However, we must be absolutely certain that soap, as such, is an essential material requirement for human cleanliness. Perhaps there is an equally adequate way of keeping clean which is consistent with the proposed closed ecological system. Supplementation of the system with truly essential material needs must be accomplished at the beginning of the mission or provided by some method of supply. As mission terms are increased, the extraterrestrial systems will become more and more complicated and will, thus, achieve higher levels of self sufficiency. The proposed ecological system laboratory will provide the basic facility for accomplishment of these studies.

B. RESEARCH PLAN

The development of a closed ecological system capable of supporting a human population will depend upon an effective concurrent program of biological research. The research to be accomplished can be identified in terms of three of the four phases of development of the complete system. These include: I. Preactivation Phase, III. Activation Phase, and IV. Operational Phase. Phase II is the design and construction of special tooling.

1. Preactivation Phase

During the Preactivation Phase, research programs already underway in the Martin-Denver Space Medicine Laboratories will be broadened and accelerated. The required human environment will be defined in terms of functional limits and optimum conditions. Such definition will include atmospheric requirements such as total pressure, partial pressures of oxygen and carbon dioxide, humidity, inert gas, noxious gases and required temperature. Methods for maintaining acceptable environmental conditions will be developed and will include consideration of emergency procedures, methods for identification and control of noxious gases, methods for providing for respiratory gas exchange, temperature, and humidity control.

mention our chamber system.

The human requirements for food and water will be specified in detail as end products of digestion, i.e., sugars, amino acids, fats, minerals, vitamins, etc. Any special problems in feeding peculiar to space operations will be considered. A plan for providing the complete nutritional requirements of the human component will be developed. The nutritional value of the algae produced by the photosynthetic gas exchanger will be determined. Supplementation and variety of diet by the inclusion of hydroponically grown plants and small animal colonies will be studied. Space requirements for each crop and animal colony will be determined.

A program of research will lead to the development of a waste recovery system. The kind and amounts of waste produced by the human component, animal colonies and food crops will be determined. A high rate process for converting these waste products to suitable nutrient for algae and higher plants will be developed. The study of the high temperature high rate anaerobic biological digestor presently underway will be continued. Other methods of waste processing including aerobic incineration will be considered. Methods will be investigated for processing recovered water to provide potable drinking water.

Concurrent with the preactivation research program, an engineering design and development program will translate experimental data into design criteria for five-man ecological system components. Human engineering aspects of component design will be considered. Fabrication or procurement of such components will follow.

2. Activation Phase

The second major research program is identified with the Activation Phase. During this phase of system development, the research program will consist of installing and testing various ecological system components in the closed ecological chamber (see Fig. 2). Subsystem and system testing will determine adequacy of the complete research tool. Tests will be conducted at ambient pressure and at reduced pressure.

Operational protocols will be established. Control systems will be checked out. Any cyclic deficiencies will be identified and corrected.

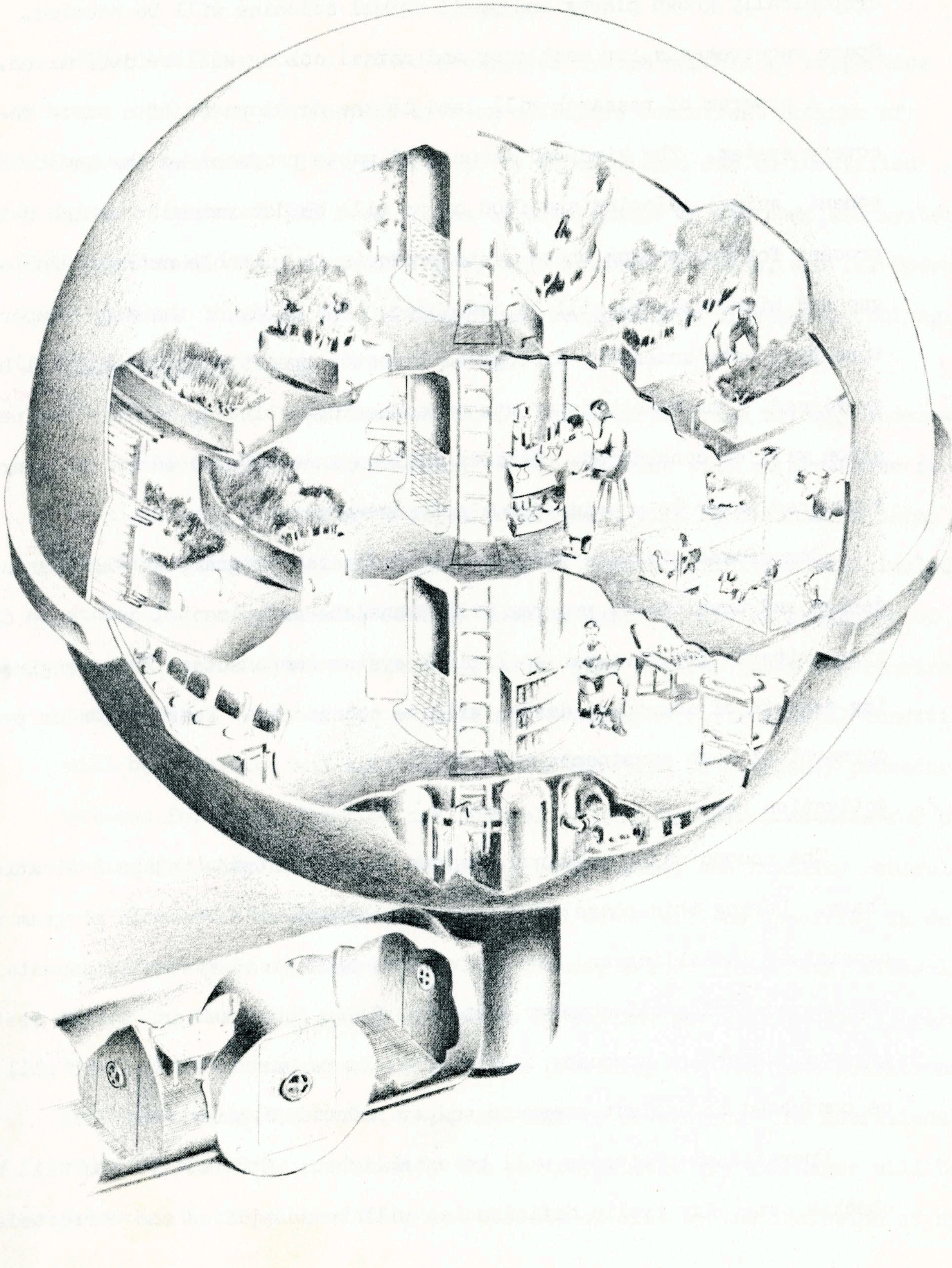


Fig. 2 Internal Arrangement of Closed Ecological Laboratory

The energy requirements of the complete system will be identified. Energy balance with the external environment will be established. Where necessary, components will be improved sufficiently to provide the desired capability. Emergency procedures and equipment will be tested and appropriately modified. The Activation Phase will culminate in the operation of the closed ecological system for the purpose of demonstrating the capability of the system.

3. Operational Phase

The ultimate aim of the Operational Research Phase is to establish design criteria for an operational closed ecological system in space. Study of the system in operation will provide engineering data necessary to optimize the efficiency and reliability of each component and to allow for design of light weight, gravity independent, completely automated subsystems. Figure 3 illustrates a complete closed ecological system laboratory.

Specific life support missions will be simulated in all possible aspects. The physiological, psychological, and ecological data accumulated during these experiments will be used for a series of parametric studies in which the complicated interactions of components and subsystems will be examined. Emphasis will be placed on the development of a knowledge of human factor limitations inherent in tightly linked closed ecological systems. Because of the complex nature of the system and the large amount of data to be accumulated, the use of the analog computer facility at Martin-Denver will be required.

Biometric consultation in experimental design and data analysis will be required. It is anticipated that WADC will wish to participate in the

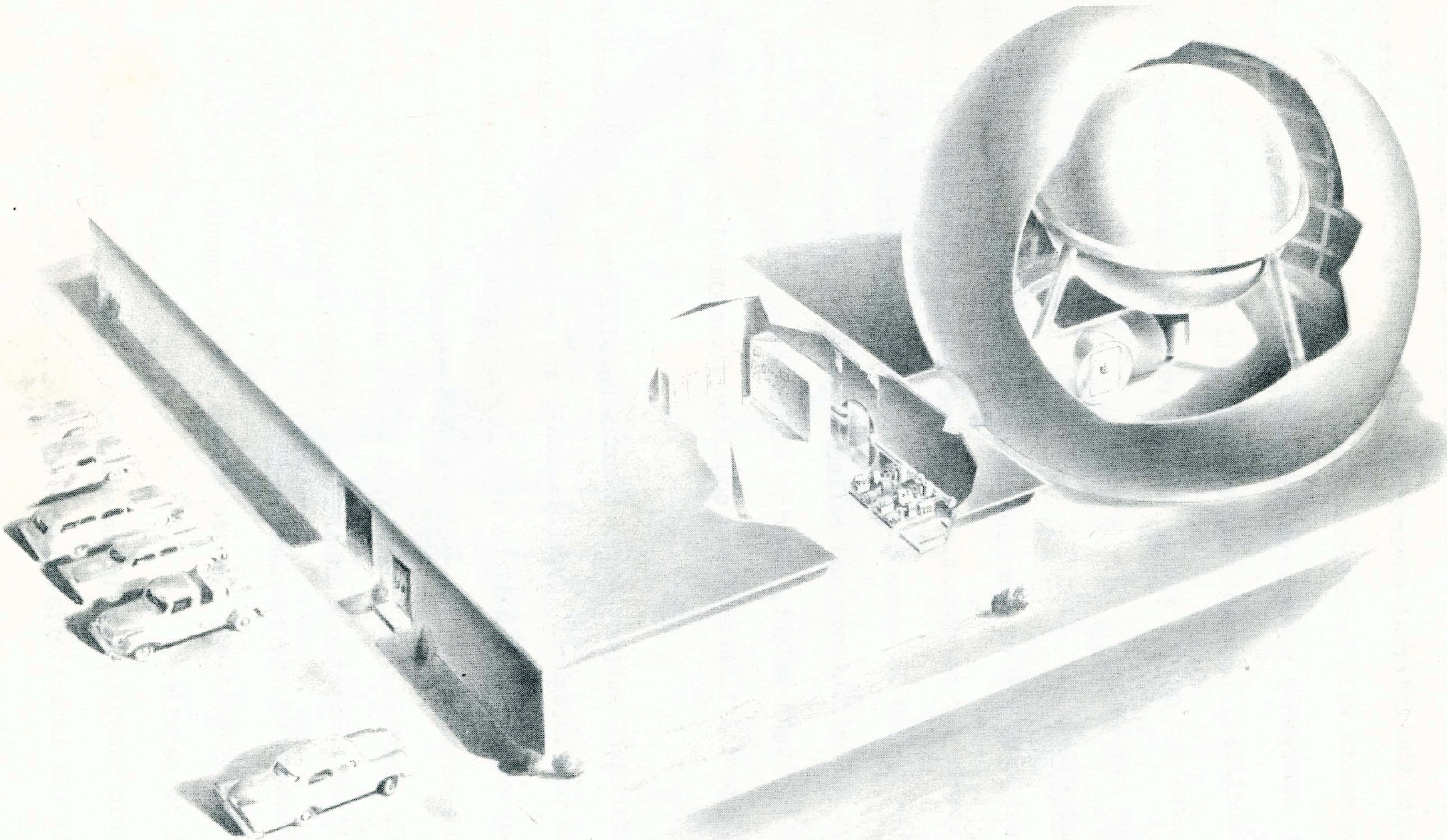


Fig. 3 Closed Ecological Laboratory, Complete Complex

Operational Research Program and to provide a limited number of scientific personnel to the program either on an assigned or consultative basis.

C. DESCRIPTION OF COMPONENTS

Following is a brief description of the components and subsystems to be used in this program. Figure 4 is a flow diagram of the integrated subsystems. The following paragraph numbers correspond to the numbers on the diagram.

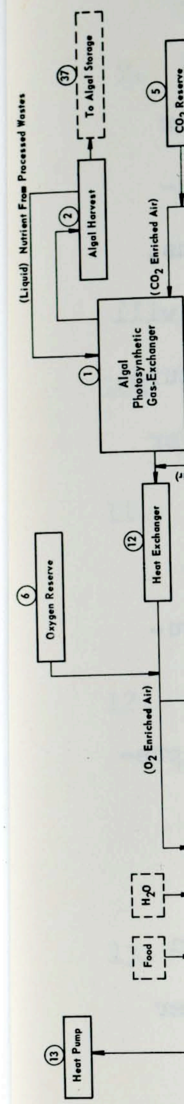
Atmospheric Control Subsystem -

1. Algal Photosynthetic Gas Exchanger

The photosynthetic gas exchanger will provide carbon dioxide uptake and oxygen production capability sufficient to satisfy all requirements for gas exchange for the simulator population. Gas exchange rate will meet respiration, food production, and waste processing requirements. This component will consist of a number of modular units to provide increased flexibility and reliability. The final design will be based on the results of a research program, currently in progress, which considers choice of algal strain, methods of illumination, methods of gassing, nutritional aspects of algae, and contamination control.

2. Algal Harvester (Centrifuge)

The algal harvest unit will separate algae from the liquid nutrient automatically at a rate equal to the production rate. Harvested algae will be processed for storage as food, and the liquid nutrient returned to the photosynthetic gas exchanger. Centrifugation is currently the method recommended, but a research project considering the use of a naturally produced flocculent is underway at Martin-Denver. Results of this project may reduce or eliminate the requirement for



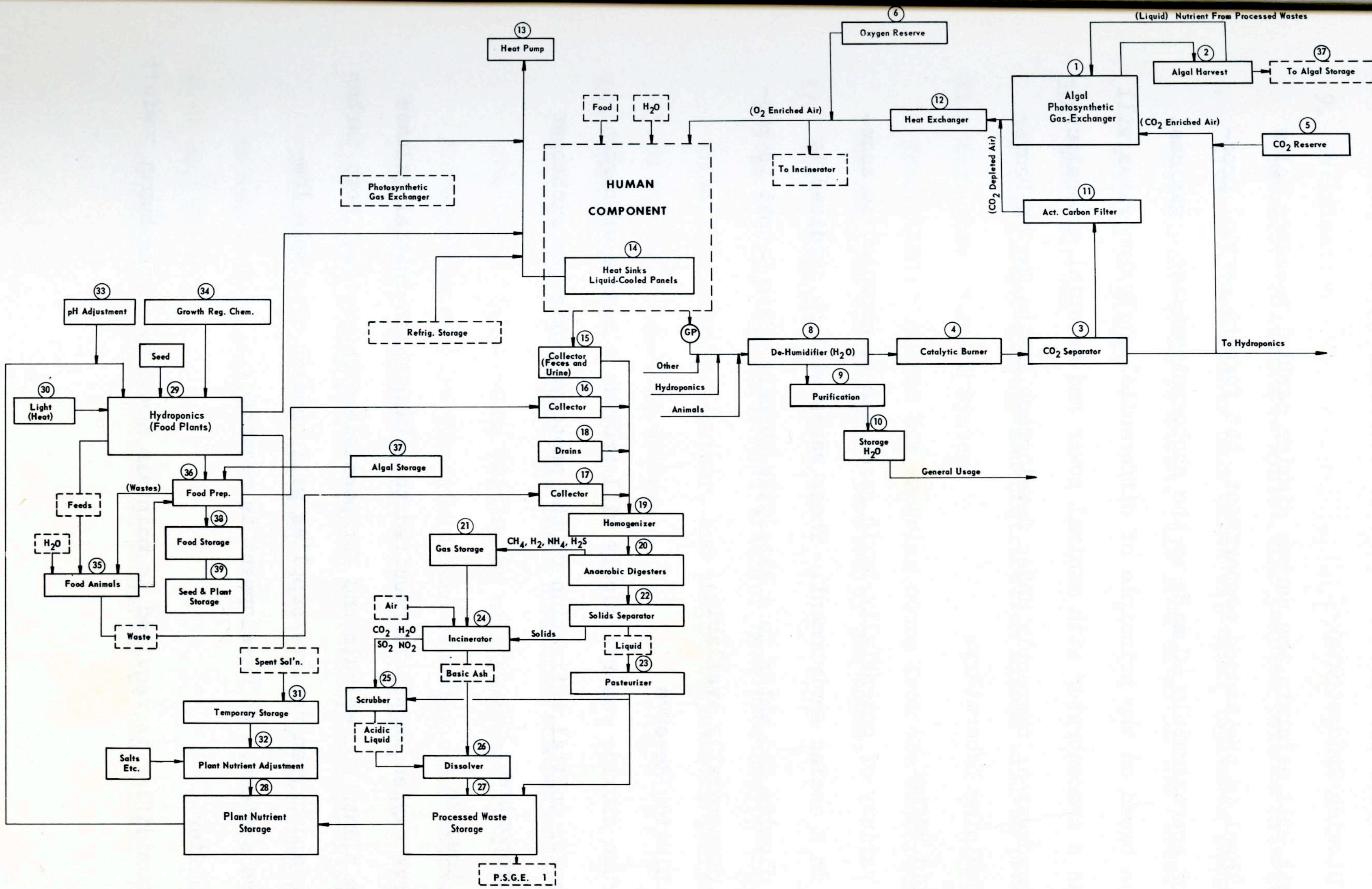


Fig. 4 Closed Ecology System - Flow Diagram

centrifugation.

3. Carbon Dioxide Concentrator

This unit will maintain the carbon dioxide partial pressure below a safe level in the manned compartment, but furnish partial pressures of approximately 40 mm Hg to the photosynthesizing organisms. A device based on the principle of differential diffusion rates will serve as a concentrator with minimal power and material expenditure. This component is currently under development in the Martin-Denver Space Medicine Laboratory.

4. Catalytic Burner

A wide variety of potentially toxic gases can be expected to accumulate in a sealed environment. These gases will be oxidized to carbon dioxide and water in a catalytic burner. Such a unit is presently commercially available.

5. Carbon Dioxide Reserve

The carbon dioxide reserve supply will provide a source of carbon dioxide for initial activation of the photosynthetic gas exchanger and hydroponicum.

6. Oxygen Reserve

A reserve oxygen supply is required to establish an initial balance between plants and animals and for possible emergencies. Both carbon dioxide and oxygen reserve supplies will consist of simple low-pressure systems. No development is required.

8. Dehumidifier

The dehumidifier is required to maintain humidity in the human comfort range; it will also serve as the water recovery system.

9. Purification

The water purification system will produce potable drinking water from the dehumidifier unit bleed-off tank. Suitable filtration and treatment will be provided. All free water in the closed system will be recycled.

10. Water Storage

A clean water storage and distribution system will be provided.

11. Activated Charcoal System

This standard method for removing odors from the atmosphere will be employed for odors not removed by the algae.

12. Heat Exchanger

The air heat exchanger will transfer heat produced by the human component, catalytic burner, and the photosynthetic gas exchanger to the heat rejection system.

13. Heat Pump

Surrounded by a vacuum, the inner spherical chamber will accumulate heat. Temperature regulation will be primarily a problem of transferring heat to the outside and reducing solar input. The proposed heat transfer system consists of liquid cooled panels or heat sinks located at the primary sources of heat production; heat is transferred outside the whole facility to a heat pump such as an evaporative cooler.

14. Heat Sink

Temperature will be controlled primarily by heat sinks. Heat will be taken up at its source by panels and heat exchangers and transferred by a liquid system to an exterior rejection system.

Waste Processing Subsystem -

15,16, 17,18. Collectors -

Waste collectors will control odors and transmit wastes to the processing system.

19. Homogenizer -

A waste homogenizer will prepare raw wastes for accelerated microbiological digestion by increasing available surface area through particle size reduction.

20. Anaerobic Digestion -

An accelerated anaerobic digestion unit will control temperature, pH, recirculation, and other factors to effect maximum microbiological conversion of wastes in a minimum time span. This unit is presently under development in the Martin-Denver Space Medicine Laboratory.

21. Gas Storage -

This unit will receive and store digester gas produced in the digester unit.

22. Solids Separator -

A solids separator will extract the material not liquified in the digester unit.

23. Pasteurizer -

This unit will inactivate any living organisms surviving the accelerated digestion process.

24. Incinerator -

An incinerator will use stored digester gas as fuel to oxidize the separated solids to ash.

25. Scrubber -

A scrubber unit will use clear pasteurized waste solution from the separator to take up the acidic oxide gases from the incinerator. This acidic solution from the scrubber will dissolve the basic ash from the incinerator.

27. Processed Waste Storage -

This unit will receive both pasteurized liquid from the separator and soluble minerals from the dissolver unit.

an alternate approach to waste processing is electrochemical.

Food Production Subsystem - Food will be provided from both plants and animals.

28. Plant Nutrient Storage -

Processed waste from storage will supply the plant nutrient storage system.

29. Hydroponics -

Plants selected for their efficiency in producing material edible to man and food animals and for compatibility with the environment will be grown by hydroponic methods for maxiuum efficiency. Hydroponic tanks, plant supports, and accessory equipment will be provided as necessary. Temperature and humidity will be controlled as required.

30. Light -

Special illumination systems will provide lighting necessary for plant growth. Design of this system will be based primarily on information currently available from the Department of Agriculture.

31. Temporary Storage -

Spent hydroponic solutions will go to temporary storage prior to testing and rebalancing of nutrient composition.

32. Plant Nutrient Adjustment -

A nutrient adjustment unit will reduce excess accumulations of salts; the imbalance of spent nutrient solution resulting from preferential absorption of elements by plants will be corrected.

33. pH Adjustment -

pH adjustment and control of plant nutrient solution will be provided as required by each crop requirement.

34. Growth Regulating Chemicals -

The basic nutrient solution will be supplemented as required by individual crops to accelerate harvest and increase yields.

35. Food Animals -

Certain animals, selected for their efficiency in producing edible animal protein and for their compatibility with the system, will be grown in the animal colony.

36. Food Preparation -

A food preparation center will trim harvested plants for storage, butcher food animals for storage, and prepare crew meals from stored algal, plant, and animal material. Suitable resultant wastes will be fed directly to various animals, which will be used as intermediate biological links in the overall system.

37. Algal Storage -

Algae harvested as a by-product of the operation of the photosynthetic gas exchange system will be a primary source of food for animals. Storage and processing facilities will be provided.

38. Food Storage

A food storage unit will accommodate harvested algal, plant, and animal materials, prior to daily usage.

39. Seed and Plant Storage

A refrigerated storage unit will ensure viability of seeds and plants that require a dormant period in their life cycle.

D. SPECIAL TOOLING

The R&D program outlined in Phase I includes the development of atmosphere conditioning, waste processing, and food production subsystems. Special tooling is required to integrate the Phase I subsystems into a closed ecological system and for conducting the test programs outlined in Phases III and IV. The special tooling consists of an inner spherical chamber, an outer vacuum shell, and support equipment (see Fig. 3).

1. Closed Ecological Chamber (Fig. 5)

The closed ecological chamber consists of an insulated, welded steel sphere, approximately 32 feet in diameter, supported on steel columns attached to an equatorial ring-girder. A vertical axial cylindrical core structure will be supported from this ring-girder by radial beams. The median deck will be supported by these beams. An upper level deck and a lower level deck will be supported by cantilevered beams from the core structure. The sphere is designed to operate at 5 psi absolute pressure. Preliminary design criteria for this inner sphere are shown in Appendix A.

The central core will serve as a utility-well for pipe, ducting, and wiring, and will contain an electric lift, for access to all three decks. The core will extend through the bottom of the sphere to grade, and will connect with an air-lock entry chamber.

The chamber will be fitted with a food preparation and storage area and crew quarters for five men. Basic area-lighting, sanitary and water piping, and electrical services will be included.

The basic heat-removal system will consist of a circulating-water manifold system within the inner sphere, with supply and removal lines to

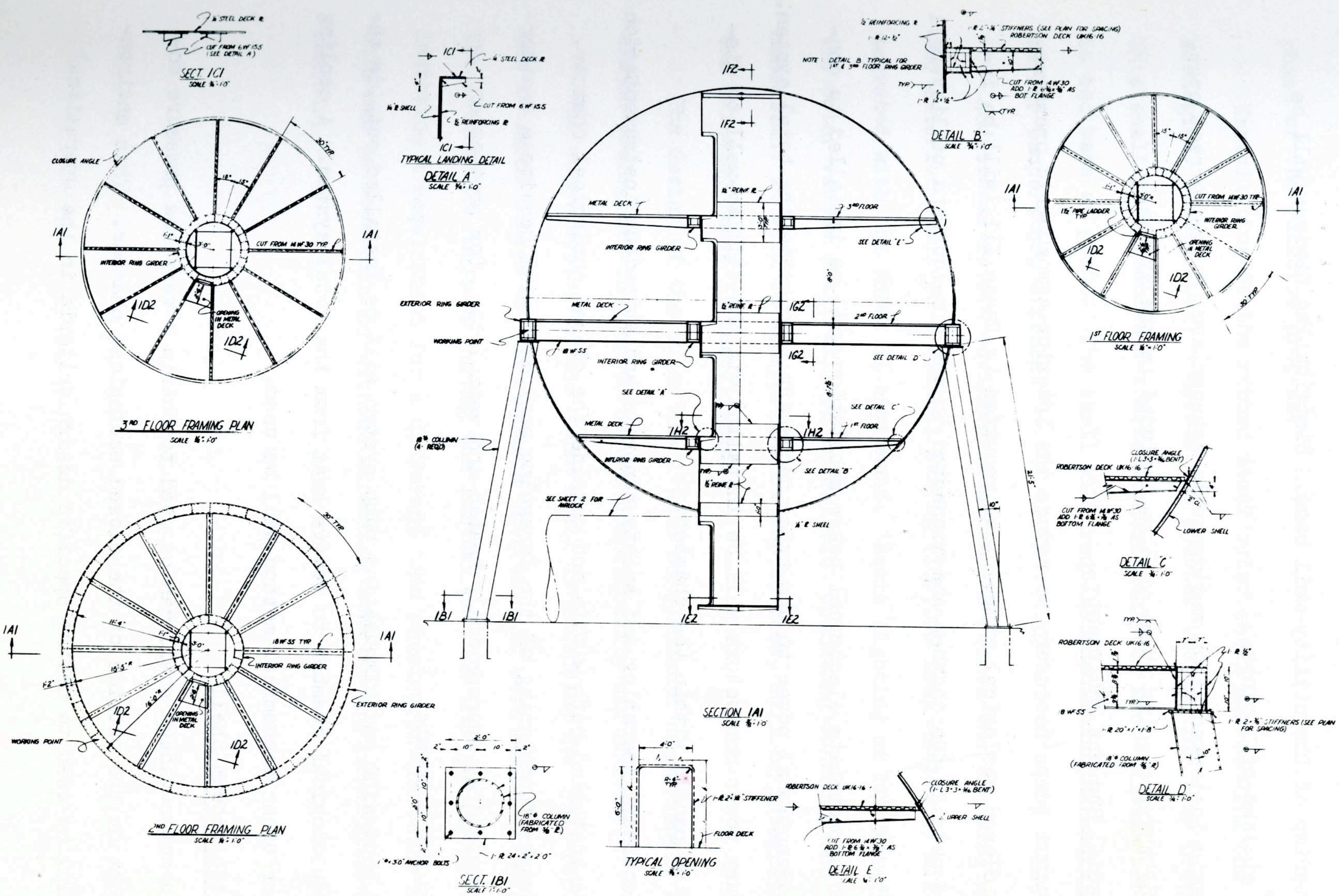


Fig. 5 Structural Arrangement, Closed Ecological Chamber

the exterior of the utility-well base. Distribution headers will be valved at take-off points.

Basic instrumentation and controls appropriate to the correct operation of the foregoing items will be included in the system.

2. Special Support Equipment

Vacuum pumps necessary to reduce the interior atmospheric pressure of the closed ecological chamber, as required in Phase III, will be installed outside the chamber and connected to the air-lock and utility-well system.

An appropriate electrical power substation will be installed to convert conventional power to the types necessary to operate the total system. Secondary power conductors will be installed via the utility-well to distribution panels within the chamber.

Necessary operating and safety controls and attendant instrumentation will be installed both within and outside the closed ecological chamber.

Proper functioning of the foregoing equipment will require a weather-tight enclosure, appropriately heated and ventilated, for protection against the elements.

A heat-sink and circulating pump system will be installed outside the closed ecological chamber to remove heat from the total system. A cooling tower or other economical method will be used.

3. Outer Vacuum Shell

An outer vacuum shell can be used to obtain a very low pressure environment on the outside of the closed ecological chamber. This environment will be used to define specific design criteria in the operational phase of the research program.

Installation of the ribbed steel outer shell surrounding the closed ecological chamber will complete the special tooling for this program. This shell is a truncated sphere approximately 64 feet in diameter sealed to the base at grade. The shell will require insulation to minimize exterior temperature effects.

Additional vacuum equipment adequate to reduce the pressure within the exterior shell to a nominal 8 mm Hg (100,000 feet altitude) will be integrated with the Phase II equipment. Basic lighting of the interior of the outer vacuum shell will be installed. Operating controls and instrumentation, as well as appropriate safety devices, will be integrated with the existing Phase II installation.

The design of the outer shell will be conducted concurrently with the closed ecological chamber to ensure compatability and economy.

The construction of the outer shell is scheduled for 1963 for use in the advanced phases of the research program. If work conducted during the Activation Phase or during the initial part of the Operational Phase indicates a requirement for a different time phasing of the outer shell, this can be accomplished without affecting work in the inner spherical chamber.

E. INSTRUMENTATION AND CONTROL

An integral part of each subsystem will be the instrumentation essential to data collection and to subsystem control.

Instrumentation for the atmospheric conditioning system will consist of continuous analysis and recording of air temperature, and absolute pressure and partial pressures of oxygen, carbon dioxide, and water vapor. Gas analysis points will be chosen so that the performance of each component in the subsystem may be continuously evaluated. Gas flow rates at various points will be sensed and recorded. pH, optical density, and conductivity of the algal suspension will be continuously recorded. Optical density data will control harvest rate, and conductivity data will control addition of nutrient. Since the gas exchanger will consist of a number of modules, multiple recording of these data or comutated channels will be employed. Temperature of the algal suspension will be adequately controlled by existing thermostatic techniques; it will, therefore, be locally indicated and not recorded.

Instrumentation for the waste processing subsystem will consist of pH metering and a number of gas and liquid pressure, temperature, and flow rate readings. Automatic analysis of the effluent will not be provided initially due to the high cost of the necessary equipment. Periodic chemical and biological analysis will provide necessary information and control data.

Instrumentation for the hydroponicum and small animal colony will consist of local indicators for temperature and humidity. A portable light meter will provide initial calibration of light intensity and subsequent period checks.

Electric power input will be metered and, where required, local watt-hour and elapsed time meters will accumulate data on energy consumption by individual components.

During the operational research phase, additional physiological and psychological instrumentation will be required. Detailed specification of these items will depend on the program developed during earlier phases.

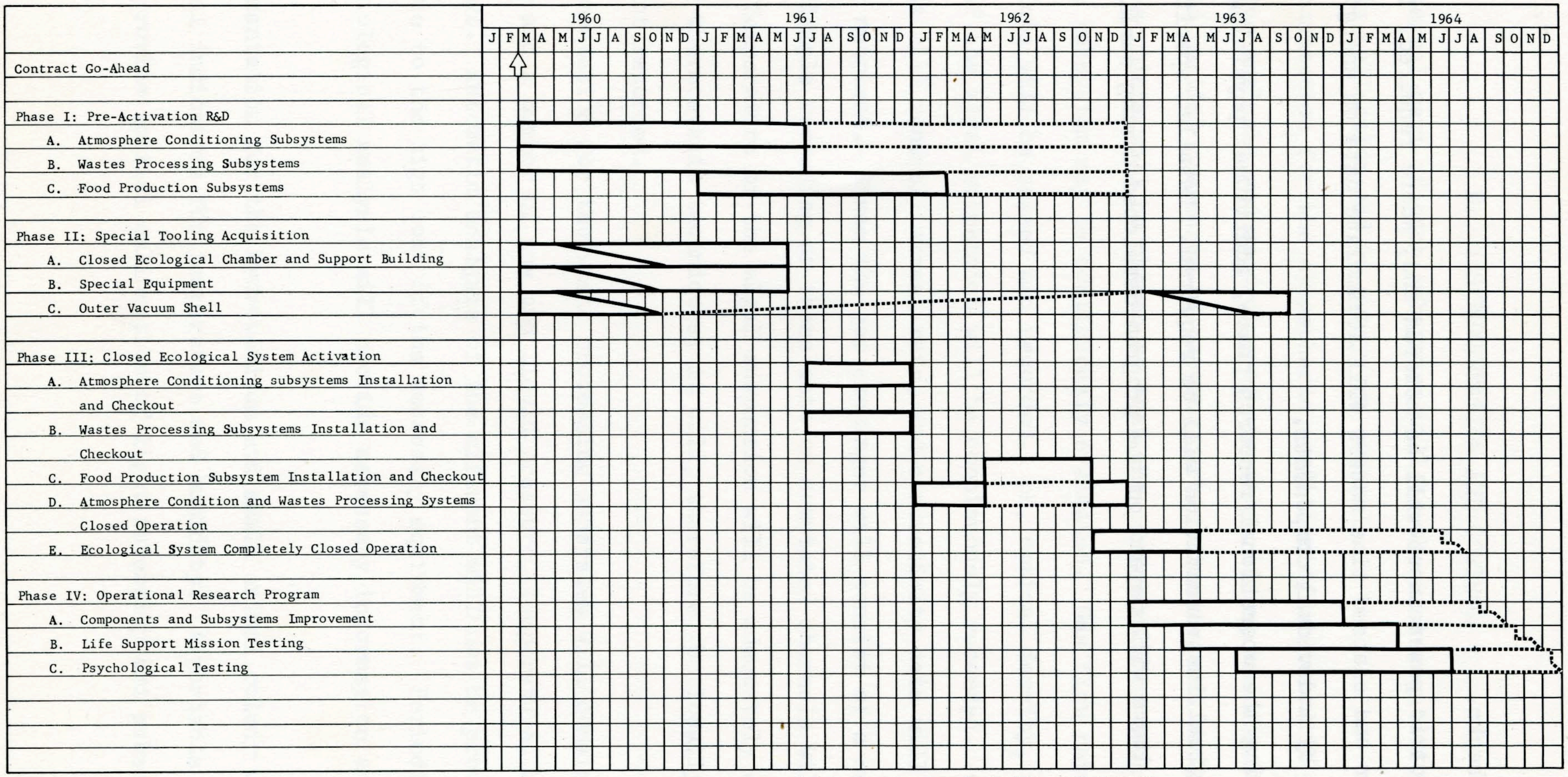


Fig. 6 Master Schedule for Closed Ecological Research Program

III. DEVELOPMENT PLAN

The development of a closed ecological system for manned space operations will be conducted in an orderly phased program (see Fig. 6). Four phases are proposed.

Phase I. Pre-Activation Research and Development

This phase will complete necessary research required to establish design criteria for system components, complete engineering required to fabricate or procure system components, and complete fabrication or procurement of such components.

This phase is divided into three catagories:

1) Atmospheric control subsystem;

2) Waste processing subsystem;

3) Food production subsystem.

The atmospheric control subsystem will be developed initially to balance the oxygen/carbon dioxide requirements for five men and the colony of food animals for a normal day. This device will be developed based on the current state of the art knowledge and is not intended for use in advanced closed ecology systems. Design modifications will be performed on the system throughout the research program to improve efficiency and reduce size. Data obtained from this program will be the basis for future designs.

A list of the components comprising the atmospheric control subsystem is contained in the Chapter II, "C. Description of Components". The algal photosynthetic gas exchanger, the algal harvester, and the carbon dioxide concentrator must be developed. The remainder of components for this subsystem will be modifications of available equipment. The Phase I development

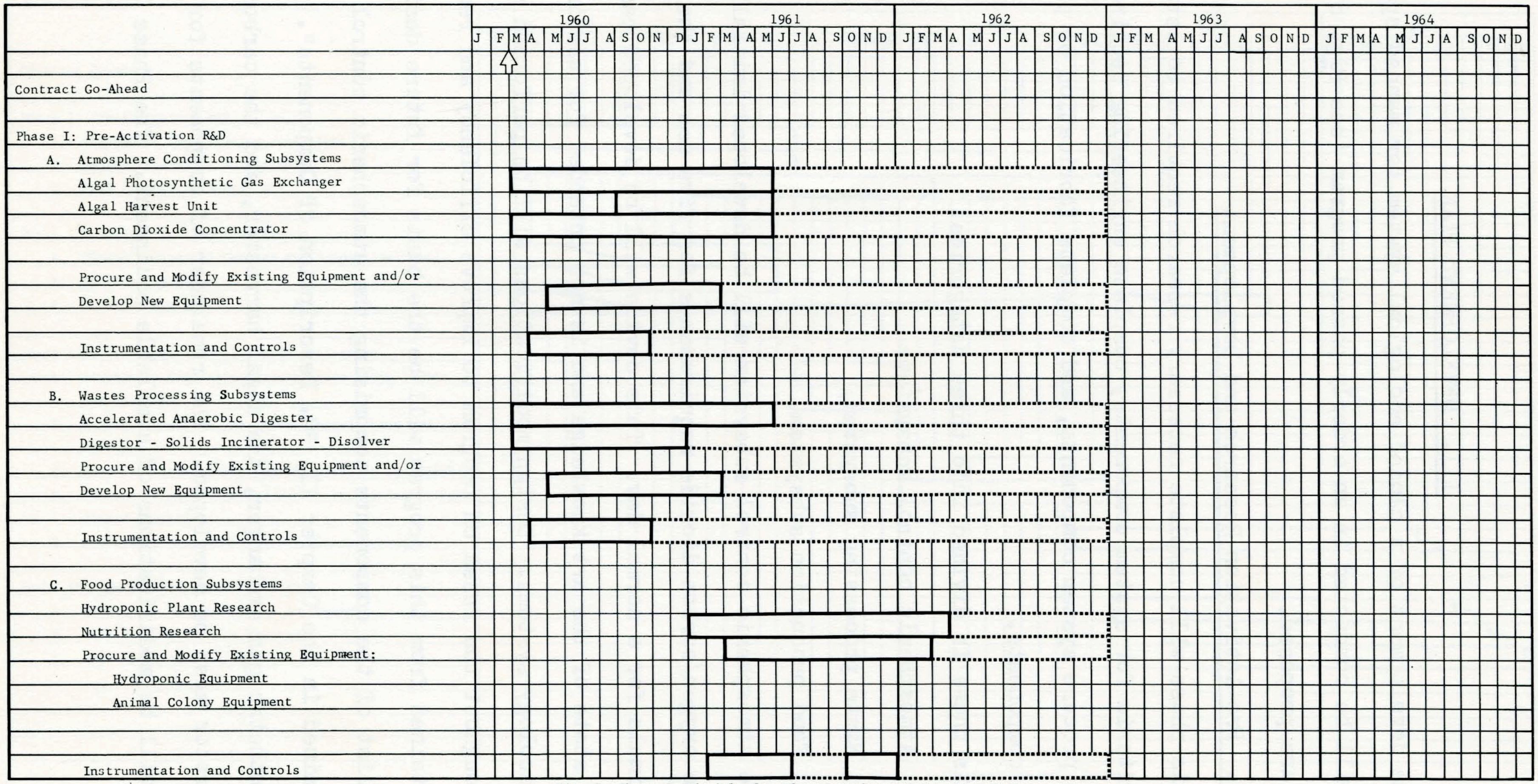


Fig. 7 Phase I Schedule for Closed Ecological Research Program

change or eliminate dates

schedule (Fig. 7) shows a development span of 15 months starting in March 1960 for the algal photosynthetic gas exchanger. The algal harvester development will extend over a 15 month period starting in September 1960 and ending in May 1961. The carbon dioxide concentrator development will extend over a 9 month period starting in March 1960 and ending in December 1960. Procurement and modification of the off-the-shelf items will commence in May 1960; these items are scheduled for use after March 1961.

The waste processing subsystem development philosophy is similar to that of the atmospheric control subsystem. The accelerated anaerobic digestion unit and the solids separator (incinerator and dissolver) must be developed. The digestion subsystem will be developed over a 15 month span starting in March 1960, and the separator over a 10 month span starting in March 1960. The procurement and modification of the off-the-shelf hardware will be accomplished in the same time span as that for the atmospheric control subsystems.

The development program for the food production subsystem, including the hydroponic and animal colony components, will commence in January 1961 and continue for 15 months. During this span, hydroponic plant and nutrition research will be conducted.

Procurement and modification of hydroponic and animal colony subsystems will start in March 1961 and continue for a year.

Instrumentation and control for the three subsystems contained in Phase I are shown in Figure 7.

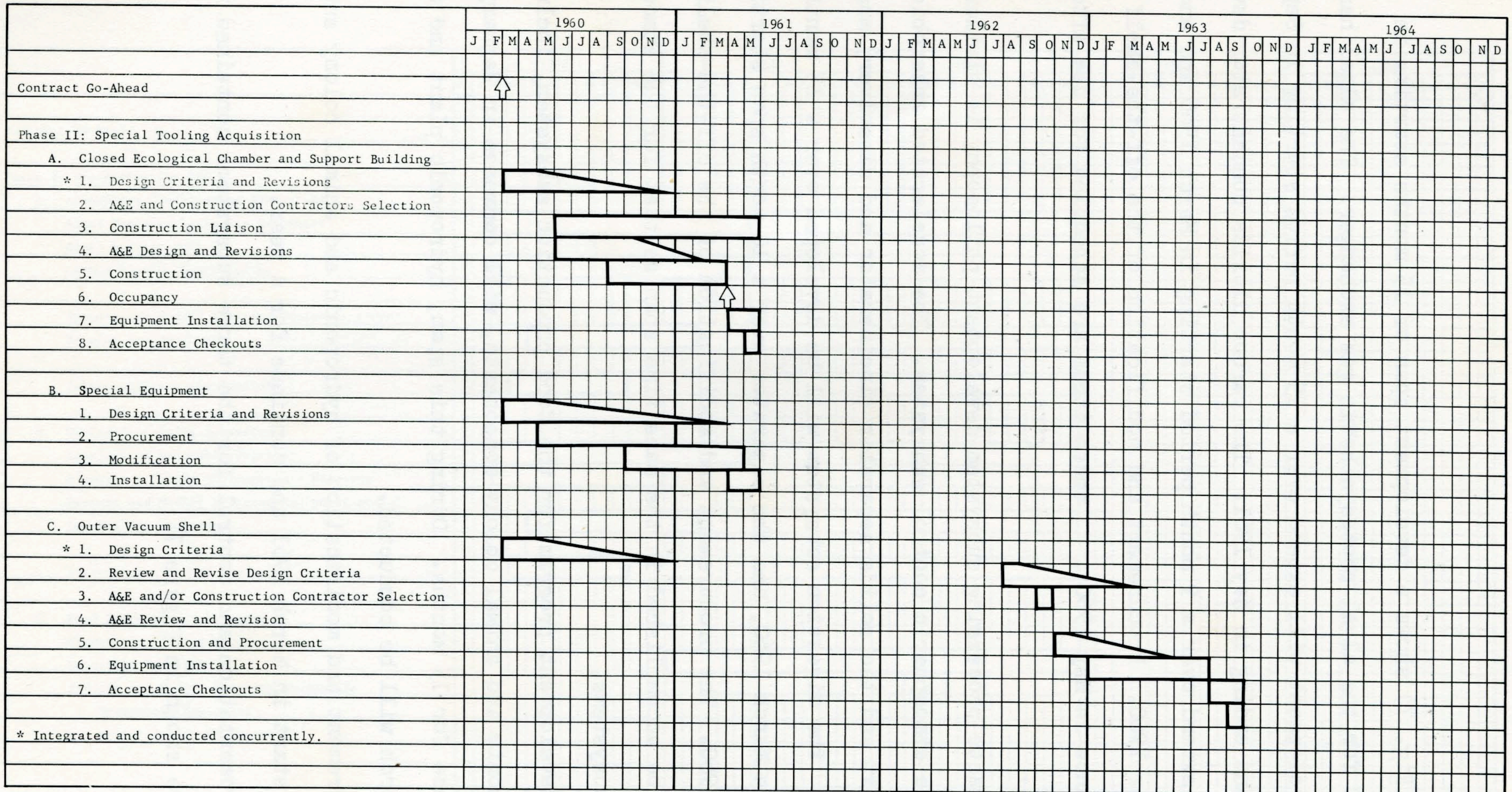


Fig. 8 Phase II Schedule for Closed Ecological Research Program

Phase II. Special Tooling Acquisition

Detailed design, procurement, construction, and installation of the closed ecology chamber and internal fittings, attached support equipment, and outer vacuum shell will be accomplished according to the schedule shown in Figure 8. Although the total engineering effort will be accomplished immediately, construction of the outer shell is not scheduled for initiation until 1963.

Phase III. Closed Ecological System Activation

During this phase, all components will be installed and systematically checked out. The system will be tested first with respect to gas exchange and waste processing and finally as a complete closed system both at ambient and at reduced pressures.

Phase IV. Operational Research Program

The Operational Research Program will be initiated in early 1963. It will include a systems and component improvement program, a series of life support mission simulation experiments, and a program of human factors experimentation. Figure 6, the master schedule, indicates the proposed time spans of Phases III and IV.

Personnel Qualifications - The following qualified personnel will be available to work on the program.

Robert H. Edgerley, Ph.D., Head, Physiology Unit, Space Medicine Section

Education:

Ph.D., Ohio State University, 1942; M.S., Ohio State University, 1939; B.S., Capital University, 1937.

Experience:

1955 to present: The Martin Company. Human Factors Specialist (Aviation Physiologist). Work in all areas of aviation and space physiology related to projects the company has had under way. These areas include temperature regulation in hot and cold environments, noise and vibration, accelerations, oxygen requirements, nutrition requirements, habitability, radiation physiology, anthropometry, decompressions, vision, research planning, and space medicine.

1954 to 1955: Toni Research Laboratories. Consultant on statistical design and analysis of experimental research.

1953 to 1954: Rheumatic Fever Research Institute of Northwestern School of Medicine. Research Associate on problems of connective tissue physiology.

1947 to 1953: Radiological Research Laboratories, Columbia University's College of Physicians and Surgeons. Research Scientist conducting basic research on the mechanisms of biological effects of ionizing radiations.

1946 to 1947: Assistant Professor of Zoology, University of Alabama. Taught courses in general zoology, comparative anatomy, human physiology, general physiology, and protozoology.

1943 to 1946: Aviation Physiologist, Army Air Corps.

Memberships:

Sigma Xi
American Association for the Advancement of Science
Aeromedical Association
American Astronautical Society

Publications:

"Effect of X-irradiation on Connective Tissue Ground Substance in Mice", American Journal of Physiology, 171(3):668-677, 1952.
"Effect of X-irradiation on Connective Tissue Ground Substance", American Journal of Physiology, 174(3):341-346, 1953.

John B. Fink, Ph.D., Head, Psychology and Human Engineering Unit, Space Medicine Section.

Education:

Ph.D., Indiana University, Physiological Psychology, Behavior Theory, Mathematical Models, 1953; M.A., Indiana University, Clinical Psychology, Behavior Theory, 1951; B.A., New York University, Biology, Psychology, Physical Science, 1948.

Experience:

1959 to present: Head, Psychology and Human Engineering Unit, Space Medicine Section, The Martin Company, Denver. Research, consulting, and design activities on human factors variables in the design of manned space vehicles and environments.

1958 to 1959: Senior Research Engineer, Human Engineering and Reliability, Convair-Astronautics, San Diego, California. Research, consulting, and design activities on human factors variables in the design of manned space vehicles and environments.

1957 to 1958: Medical Psychologist, University of California, Los Angeles, California. Research project on behavioral factors in psychiatric disorders.

1956 to 1957: Senior Design Engineer, Convair-Fort Worth, Texas. Research, consulting, and design activities on aircraft instruments, controls, communications, escape systems, cockpit and cabin layouts, compartment climate, weapons systems, and crew function and task analysis.

1956 to 1957: Faculty Lecturer (Human Engineering, Human Relations in Industry), Texas Christian University, Fort Worth, Texas.

1955 to 1956: Staff Research Psychologist, Psychology Department, University of Illinois, Aviation Psychology Laboratory, Aviation Psychologist, University of Illinois. WADC research contract on aircraft instruments and controls design, flight simulator design, and flight training programs.

1953 to 1955: Assistant Professor, Psychology Department, University of Louisville. Head of Experimental Psychology Program and Graduate Student Research Program. Director of Psychology Laboratory. Courses in Human Engineering, Experimental Psychology, Physiological Psychology, Behavior Theory.

1951 to 1953: Research Fellow, Indiana University. ONR contract on psychophysiological patterns of stress.

1951 to 1952: Instructor, Experimental Psychology, and Statistics, Indiana University.

1949 to 1951: Research Fellow, Indiana University. USAF research contract on bio-electric factors in muscle tension associated with operator controls behavior.

Memberships:

American Psychological Association
Aerospace Medical Association
Human Factors Society
American Rocket Society

Publications:

"Stimulus Generalization of a Muscle Action Potential Response", Journal of Experimental Psychology, 1951. "Decrement of a Learned Response as a Function of Several Stimulus Characteristics", Journal of Comparative Physiological Psychology, 1952. "Conditioning of a Muscle Action Potential Response", Journal of Experimental Psychology, 1953. "Conditioned Muscle Tension Activity in a Response Controls Situation", USAF School of Aviation Medicine Report, 1955. "The 'Fly To'-'Fly From' Problem in the Design of Aircraft Instruments", Convair-Fort Worth Report, 1957. "Acceleration Factors in Manned Flight", Convair-Fort Worth Report, 1957. "Human Factors in the Design of Space Vehicles", Convair-Astronautics Report, 1958. "A Systematic Approach to Human Engineering Analysis", Convair-Astronautics Report, 1958.

Robert D. Gafford, Ph.D., Head, Ecology Unit, Space Medicine Section

Education:

Ph.D., Stanford University, 1957; M.A., Stanford University, 1955; B.S., University of New Mexico, 1947.

Experience:

1958 to present: Head, Ecology Unit, Space Medicine Section, The Martin Company, Denver, Colorado. Directs program of biological research in support of the Space Medicine Program. General areas of interest include problems of cultivating microbial populations of potential benefit to manned space flight, and control of micro-organisms of potential danger to manned space flight.

1955 to 1958: Research Biologist, USAF School of Aviation Medicine, San Antonio, Texas. Worked on the biological effects of ionizing radiation and on problems of closed ecological systems in manned space operations.

Memberships:

American Astronautical Society
Sigma Xi
Society of American Bacteriologists
American Association for the Advancement of Science
American Rocket Society

Publications:

"Metabolism of Protocatechuic Acid by Neurospora", with S. R. Gross, Federation Proceedings, 14:463 (1955). "The Metabolism of Protocatechuic Acid by Neurospora", with S. R. Gross and E. L. Tatum, Journal of Biological Chemistry, 219:781 (1956). "The Lethal Effects of Gamma Radiation on Neurospora Conidia", Bacterial Proceedings, 57:50 (1957). "The Lethal Effects of Gamma Radiation on Neurospora Conidia", School of Aviation Medicine Report 57-61, July 1957. "The Observation of Two-Process Survival Curves in Gamma Irradiated Neurospora Conicia", Radiation Research, 8:248 (1958). "The Provision of Respiratory Gas Exchange for Small Primates by Use of a Photosynthetic Gas Exchanger, Preliminary Observations", with H. L. Bitter and R. A. Adams, School of Aviation Medicine Report 58-126, October 1958. "A Photosynthetic Gas Exchanger Capable of Providing for the Respiratory Requirements of Small Animals", with C. E. Craft, School of Aviation Medicine Report 58-124, November 1958. "Satellite Laboratory Program of Biological Research", with R. H. Edgerley, The Martin Company, Denver Division, November 1958.

James G. Gaume, M.D., Chief, Space Medicine Section

Education:

M.D., Creighton University, 1940; B.S., Kansas State University, 1936.

Experience:

1957 to present: Chief, Space Medicine Section, The Martin Company, Denver. Responsibility for Space Medicine and Human Factors in the development of all forms of space operations, as related to Martin projects, including space equivalent flight, satellite flight, lunar and planetary operations. Established human factors design criteria for various space vehicles, and life support systems. Organized and directs a staff of fifteen research scientists and engineers devoted to solution of space medicine problems.

1956 to 1957: Research Scientist, Space Medicine Department, USAF School of Aviation Medicine, San Antonio, Texas. Research on: sealed cabins and artificial atmospheres; effects of zero gravity on the human body; photosynthetic gas exchange systems.

1946 to 1956: Practice of General and Industrial Medicine, Ellinwood, Kansas. General practice of medicine and surgery. Teaching experience and clinical research.

1942 to 1946: USAF, Rated Flight Surgeon.

1941 to 1942: General medical practice.

Memberships:

American Medical Association
Aerospace Medical Association
American Rocket Society

Publications:

"Man's Flight into Space", Making the World of Tomorrow (International Relations Institute publication), St. Mary's University, San Antonio, Texas, September 1957. "Plants as a Means of Balancing a Closed Ecological System", The Journal of Astronautics (American Astronautical Society publication), Winter 1951. Vol. IV, No. 4, pp 72-75. "Design of an Algal Chamber Adaptable to a Space Ship Cabin", USAF School of Aviation Medicine, No. 58-61, May 1958. "Nutrition in Space Operations", Journal of Food Psychology, 1958, Vol. XII, No. 9, pp 433-535. "A Device for Simulation of Reaction Control Problems in Orbital Maneuvers", presented at 30th annual meeting of Aero Medical Association, Los Angeles, California, 29 April 1959.

Manfred M. Hein, Associate, Human Factors, Space Medicine Section

Education:

M.S., University of Colorado, 1959; B.S., Cornell University, 1950.

Experience:

1959 to present: Associate, Human Factors, The Martin Company, Denver, Colorado. Responsible for carrying out physiological studies in connection with manned space flight and advising engineering personnel regarding human factors in design of space vehicles.

1951 to 1958: Research Assistant, University of Colorado Medical Center, Department of Laboratory Medicine and Clinical Pathology. Responsible for carrying out physiological experiments in humans and animals as well as some in vitro systems. Chemical, isotopic and physical analysis of biological specimens and analysis of data in connection with experiments. Teaching medical technology and assisting in teaching of medical students. Supervised a four-member research laboratory.

1950 to 1951: Assistant Head, Animal Maintenance Department, Sloan-Kettering Institute for Cancer Research, New York. Supervision of animal caretakers, administrative work in connection with receipt of animals, food, and inventory.

Memberships:

Associate Member, Nuclear Medicine Society

Publications:

"The Blood Brain Barrier of Rats and Rabbits as Studied with Na^{22}", Ph.D. thesis, University of Colorado, in preparation. "Studies on the Administration of Atropine in Humans", with J. H. Holmes, Journal of Laboratory and Clinical Medicine, 48:819, 1956. "Measurement of Salivary Flow as an Indication of the State of Hydration in Renal Disease", with J. H. Holmes, J. Crandell and W. C. Dwyer, Journal of Laboratory and Clinical Medicine, 52:822, 1958.

Norman W. LeVora, Associate, Human Factors, Space Medicine Section

Education:

M.S., Ohio State University, 1956; B.S., Ohio State University, 1953.

Experience:

1959 to present: Associate, Human Factors, Space Medicine Section, The Martin Company, Denver, Colorado. Physiological studies in connection with manned space flight.

1957 to 1958: Gerontology Branch, National Institutes of Health, Baltimore City Hospitals, Baltimore, Maryland. Mechanics of limb movement portion of the Human Performance Project awarded to the Medical College of Virginia.

1957: Martin-Baltimore, Aero Medical Representative on Matador Project. Aero Medical Representative on Advanced Design Project 345.

1956 to 1957: Gerontology Branch, National Institutes of Health, Baltimore, same as above.

1953 to 1956: Research Assistant, Ohio State University, Aviation Medical Laboratory. Research on the redistribution of pulmonary blood flow during unilateral anoxia.

1952 to 1953: Research Assistant, Ohio State University Cancer Research Laboratory. Made therapeutic doses of I^{131} and P^{32}. Maintained three strains of cancer cells in mice and measured uptake of various drugs in cancerous and other tissues using radioactive labeled drugs.

Prior to 1952: Various part-time jobs including driving instructor, aircraft electrician, timekeeper, drug clerk, and funeral home assistant.

Memberships:

American Association for the Advancement of Science
Aero Medical Association

Publications:

"A Method for Measuring the Redistribution of Pulmonary Blood Flow During Unilateral Anoxia Using Radioactive Iodine", thesis for M.S. degree, 1953.

Hugh L. Pote, Ph.D., Plant Pathologist, Space Medicine Section

Education:

Ph.D., University of Illinois, 1958; M.S., Colorado State University, 1955; B.A., University of Denver, 1950.

Experience:

1958 to present: Plant Pathologist, Space Medicine Section, The Martin Company, Denver, Colorado. Conducts research on the growth of plants in an artificial environment.

1955 to 1958: Research Assistant, University of Illinois, Plant Pathology Department. Screening and evaluating new antifungal antibiotics.

1952 to 1955: Research Assistant, Western Crop Protection Laboratory, Colorado State University, Fort Collins, Colorado. Screening and evaluating new fungicides.

1951 to 1952: Research Assistant, Organic Chemistry Section, Denver Research Institute, University of Denver. Classified Air Force project.

1950 to 1951: Plant Operator, Julius Hyman and Company, Rocky Mountain Arsenal, Denver, Colorado. Conducted cracking and distilling operations of dicyclopentadiene.

1950: Research Assistant, Great Western Sugar Company, Denver, Colorado. Investigations on raffinose and glutamic acid.

Memberships:

American Association for the Advancement of Science
American Phytopathological Society
Gamma Sigma Delta Agricultural Society

Publications:

"Certain Metabolic Changes in Plants Caused by Dithiocarbamate Fungicides", thesis for M.S. degree, 1955. "Tetrin: A New Antifungal Antibiotic", thesis for Ph.D. degree, 1958. "An Apparatus for Testing Fungicides in a Soil Column", with W. D. Thomas, Jr., presented at Colorado-Wyoming Academy of Science, Colorado A & M College, May 1, 1954.

D. E. Richardson, P.E., Head, Bio-engineering Unit, Space Medicine Section

Education:

B.S., Michigan State College, 1938; Cass Technical School, Detroit, Michigan, Aeronautical Engineering, 1933.

Experience:

1958 to present: Head, Bio-engineering Unit, Space Medicine Section, The Martin Company, Denver, Colorado. Responsible for design of laboratory facilities, special research equipment and project proposals.

1956 to 1958: Project Engineer, The Martin Company. Design of plant and test facilities. Responsible for engineering of major chemical equipment and installations, and complete management of design and construction for a large product tank cleaning and testing facility, as well as complete chemical-milling facility.

1955 to 1956: Design Engineer, Stearns-Rogers Company, Denver. Layout and design of steam power plant piping and equipment.

1952 to 1955: Chemical Engineer for Huffman Microanalytical Labs, Wheatridge, Colorado. Designed and built new laboratory and facilities; did microanalytical research.

1951 to 1952: Engineering Draftsman for Stearns-Rogers Company, Denver. Steam Power Plant Department.

1949 to 1951: Production Manager for Millar Coffee Company, Denver, Colorado.

1945 to 1948: Chief Chemical Engineer for Industrial Laboratories, Denver. Materials Testing Consultants.

1942 to 1945: Chemical Engineer for Food, Plastics, and Dehydrating Plants in Denver. Responsible for research and development, quality control, instrumentation, facilities. Did complete design of a by-products plant for production of albumen. Designed and installed laboratory.

1939 to 1941: Plant Chemical Engineer for food manufacturing plants in Detroit, Michigan, and in Chicago, Illinois. Responsible for plant design, layout, process equipment and piping in addition to laboratory analysis work. Designed and installed complete laboratories.

Memberships:

National Society of Professional Engineers (registered Professional Engineer, Colorado No. 2644)

Professional Engineers of Colorado
American Water Works Association
Sewage and Industrial Wastes Association

Publications:

"Method of Testing Acid in Pickles and Pickle Products", with R. G. Switzer, Fruit Products, J. 18, No. 10, pp 292-293:313. "Rate of Diffusion of Salt from Pickles During the Freshening Process," with F. W. Fabian, Fruit Products, J. 18, 260-261, 281, 283. "Method of Wrapping Cheese and Product", with J. L. Michel and R. J. Chadbourne, Assignors to Martin Bros. Company, Denver, Colorado, U.S. Patent No. 2,342, 969, 29 February 1944.

Edward W. Romano, Hydroponics Specialist, Space Medicine Section

Education:

A.A.S. (Agronomy), State University of New York, 1951.

Experience:

1958 to present: Hydroponics Specialist, Space Medicine Section, The Martin Company, Denver, Colorado.

1957 to 1958: Plant Engineering Division, The Martin Company, Denver.

1952 to 1956: Worked under the supervision of a veterinarian as a technician in the U.S. Air Force.

1952: As suggested prerequisite, worked at Kansas State Artificial Insemination Bureau. While attending the State University, accomplished two years research and experimentation in Hydroponics. Initiated a 3-credit-hour Hydroponics course at the school.

1950 (summer): For summer credit, employed as Greenskeeper at Duchess Country Club to study turf management.

1948 (prior to entering school): As prerequisite, worked on dairy farm for management, operation, and maintenance.

Herbert G. Schafer, Design Specialist (Electrical and Electronics), Space Medicine Section

Education:

B.S., Carnegie Institute of Technology, 1934. Graduate studies in High Frequency AC and Microwave Theory at the University of Pennsylvania, and in Electromagnetics at the University of California (Los Angeles).

Experience:

1956 to present: Design Specialist, The Martin Company, Denver, Colorado. Responsibilities have included design of instrumentation, proposal writing, design of magnetic amplifiers for the Titan autopilot.

1953 to 1956: Martin-Baltimore, Design Specialist (Staff), Electro-Mechanical Department. Design of magnetic amplifier controls for Matador, LaCrosse, and Titan missiles, design of circuits for ground support equipment on Matador and LaCrosse missiles.

1950 to 1953: Convair, San Diego and Pomona, California. Senior Research Engineer, Electronics Department. Advance design on Terrier Anti-Aircraft Missile (later lots). Systems integration studies for Terrier missile (early lots). Advance proposal studies on Atlas Missile.

1946 to 1950: Naval Research Laboratory, Group Engineer, Interior Communications Section. Design and evaluation of shipboard instrumentation and communications including combat information centers and damage control systems. Advance research on magnetic amplifier theory and circuits. Development of control circuits utilizing magnetic amplifiers. Special assignment, installation and operation of nuclear measuring equipment in South Pacific area.

1943 to 1946: Naval Air Material Center, Philadelphia, Development Engineer. Development of subcarrier telemetering systems for airborne structural flight measurements, development of airborne television systems for instrument telemetering and reconnaissance applications.

1937 to 1943: Naval Air Material Center, Philadelphia, Test Engineer. Radio and electrical components for aircraft. Development engineer, accoustical measurements. Techniques for aircraft microphones and headphones, measurement techniques for noise control in aircraft, measurement of radio interference in military aircraft, and design of instrumentation and controls for high altitude chambers.

Memberships:

Institute of Radio Engineers
American Institute of Electrical Engineers

Publications:

"The Application of Solid-State Amplifiers and Control Devices in Modern Auto Pilot Circuits", with L. J. Johnson and S. E. Rauch, Proceedings of National Electronics Conference, 1956. "A Magnetic Amplifier Frequency Control, with L. J. Johnson, AIEE Transactions, 1950, Technical Paper No. 50-95. Several other classified and unclassified papers in the fields of aircraft communications, power systems, telemetering, structural flight testing, and missile systems.

APPENDIX A

PRELIMINARY DESIGN CRITERIA FOR THE INNER SPHERE

Sphere diameter -- 32 ft

Leak-tight construction at 7 psia internal and 5 psi external differential pressures

Three decks with 7-ft headroom clearance (excess headroom on top deck)

Central-core utility well with 4x4-ft lift

Interior temperature range -- +65° F to +80°F, with control $\pm 2^{\circ}$F of thermostat setting

Decks -- minimum depth constructed to be smooth, tight, and readily cleanable

Provisions to admit apparatus (maximum size: 4x4x6 ft)

Provisions for entry of electrical power cables:

115v, 60-cps ac;

230v, 60-cps ac;

480v, 60-cps ac;

400-cps ac;

28v dc.

Provisions for 1-in. lox supply line entry

Vacuum waste line for gases (used in regenerating absorber systems for products that must be discarded to external atmosphere)

APPENDIX B

EXISTING FACILITIES AT MARTIN-DENVER

Space Medicine Research Laboratory	Martin-Denver Space Medicine Laboratory facilities include: Algal research; Hydroponics and plant pathology; Physiological research; Waste processing and reutilization; Bio-engineering design and research instrumentation. In addition to these existing laboratory facilities, additional laboratory space is being provided.
General Purpose Laboratories	100,000 sq ft consisting essentially of electrical, electronic, and mechanical laboratories; instrument maintenance and calibration, and data processing areas.
Engineering Research Support Shop	Capable of both prototype development and repair and work in mechanical and electronic fabrication: Machining; Welding; Sheet metal fabrication; Engraving; Electronic console fabrication; Printed circuits; Repair of mechanical and electronic test items and test equipment.
Environmental Test Laboratory	Altitude capabilities to 250,000 ft: 18x22x22-in. chamber, Pressure recording and programming; 3x3x3-ft chamber, Pressure recording; Temperature programming and recording (range -120 to +350°F), Humidity programming and recording (range +350 to +185°F, R.H. 20 to 100%); 4x4x4-ft chamber, Pressure recording, Temperature programming and recording (range -120 to +350°F), Humidity programming and recording (range +35 to +185°F, R.H. 20 to 100%).

Altitude capabilities to 200,000 ft:
8x8x8-ft chamber,
Temperature programming and recording (range -120 to +350°F),
Humidity programming and recording (range +35 to +185°F, R.H. 20 to 100%);

10x10x8-ft chamber,
Pressure recording,
Temperature programming and recording (range +35 to +185°F, R.H. 20 to 100%).

Humidity:
8x8x8-ft humidity chamber,
Temperature and humidity programming and recording (range +35 to +185°F, R.H. 20 to 100%).

Temperature:
Low-temperature chamber, 34x16x15 in.,
Room temperature to -140°F,
One channel temperature recording;

Forced convection oven, 37x19x24 in.,
Room temperature to +260°C;

Radiant heat chamber, 3-ft diameter and 3 ft long,
Temperatures to 450°F combined with altitude to 50,000 ft. Fast rise time (450° in 90 sec, and 50,000 ft in 60 sec).

Sand and Dust Chamber (1):
Volume-4x4x4 ft,
Sand and dust velocity to 2300 ft/min,
Sand and dust density controlled,
Temperature controlled from 80 to 140°F

Salt Fog Chamber:
Volume-4x4x6 ft,
Salt fog per Martin-Air Force specifications.

Rain Chamber (1):
Volume-4x4x6 ft,
Rainfall to 4 in/hr.

Explosion Chamber (1):
3.5-ft diameter and 5 ft long,
Explosion testing at room temperature.

Tie-down pad for non-standard test setups (1):
12x18-ft area,
Steel I-beams imbedded in concrete.

Hydraulic Power Supply (1):
20 gpm at 3000 psi.

Vibration and Shock Measurements:
Endevco, Glenite, Massa, Statham or MB pickups.

Combined temperature and altitude environments can be performed in the altitude and temperature chambers.

One ATH chamber is built to take a 5000-lb shaker for combined testing.

Vibration Systems (5):
Force outputs-1250,3400,5000 and 12,500 lb;
Four units have randem complex or sinewave capabilities over the frequency range of 5 to 2000 cps.
One system has sinewave capabilities only, over the frequency range of 5 to 2000 cps.

Shock:
Two machines,
Output 40,000-lb thrust,
Shaped sawtooth pulses.

Cold Flow Laboratory

Three cells capable of component testing using RP-1, lox, liquid nitrogen, liquid helium, and gaseous nitrogen and helium. In addition, two cells capable of flow testing complete missile propellant system.

Factory

Machine shop;
Metal cleaning and finishing;
Electronics assembly.