STATEMENT OF WORK

PART I. LABORATORY RESEARCH PROGRAMS

The laboratory programs will be coordinated between the laboratories at Martin - Baltimore, and Martin-Denver with the use of RIAS for defining the algae cultures and as consultant. These programs will provide the data necessary to conduct a design study of the Photosynthetic Gas Exchanger of the Ecological System.

These tests must be conducted toward the objective of selecting the desired Algae strain and techniques for operation and construction of the Gas Exchanger which will conform to the environmental and operational requirements imposed by the completely closed and self sufficient ecology. Important examples of these requirements are the need to utilize Urea nitrogen and the need to provide O_2 and Algae at a maximum rate with least weight of the system.

The laboratory efforts will be divided among Martin-Baltimore and Martin Denver and RIAS. Martin - Baltimore will conduct tests leading to plots that can be used for engineering design. This will require large scale long duration tests (several weeks) and some modification of present equipment & instrumentation, e.g. for continuous flow. The longer time is necessary to come to equilibrium. Martin - Denver will conduct tests on a wider variety of variables to provide clues as to the values to be used for Martin - Baltimore tests and will also test varying techniques devised in the engineering program for comparison data. Martin - Denver will also conduct ancillary programs to provide data needed to establish the conditions of operation for Martin - Baltimore tests and process engineering, e.g. the determination and nutrient composition from human waste and the plant growth, etc using algae from Martin - Baltimore tests. RIAS will provide consultant and analytical

services for both Martin - Baltimore and Martin - Denver. The Nuclear Division or Brookhaven Laboratories will be asked to conduct any radiation effects tests that are deemed necessary. Human factors tests will be conducted at Martin - Baltimore since the larger unit exists here. It is contemplated that another large unit may be required toward the end of the program to verify small scale tests on revised techniques. Contracts to conduct this program should be forthcoming to enable construction of the unit.

M-D 30 liter planned soon 20-48" powergroove

Martin - Baltimore Program

1. A series of runs will be conducted with the algae system presently in operation but modified to close the nutrient cycle and a little later the gas cycle. Animals will be used to close the gas cycle until the advanced experimental model (Unit #2)is constructed. Modifications must be made for continuous operation before these cycles can be closed and adequate instrumentation to take the necessary readings must be provided.

The runs will be designed to measure the performance of the system while varying several parameters in accordance with random statistical techniques. The best algae from preceding tests will be used for these runs.

The variables to be studied in the closed cycle test will be the CO_2 concentration of inlet gas, nutrient formula composition, nutrient flow rate, gas flow rate, algae suspension concentration, and algae suspension temperature and P_H. The Process Design Study of Part II will define other desired data from tests so that they can be established in detail.

energy inputs

It is anticipated that these runs will be of sufficient duration to hold equilibrium conditions and determine the growth of bacteria on mutants and any tonic effluents under varying conditions. The recorded data should be sufficient for analysis determination of efficiencies, control of experiment and design and is expected to include:

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(1) Input power

(2) Inlet and outlet liquor temperatures

(3) Tank temperature

(4) Inlet and outlet gas temperature

(5) Inlet and outlet gas composition

(6) Inlet and outlet liquor composition including nutrients & minerals

(7) Rate of algae harvest, solids and liquids

(8) Inlet and outlet gas flow rate

(9) Inlet liquor flow rate

(10) Culture volume

(11) Inlet and outlet coolant temperature

(12) Coolant flow rate

The equipment will be tested first by closing the nutrient cycle only and using continuous harvesting. Once gas effluent composition over a period of time has been determined, the gas cycle can then be closed using animals of sufficient capacity. During initial tests the safeguard of a suitable device for CO removal will be used.

Probably not required ? Chlorella

2. The operation of the system in a small sample test when subjected to radiation will be investigated. Should such a test be feasible and provide meaningful data, it will be proposed in conjunction with the Martin - Nuclear Division radiation source as a part of an integrated program proposal if this source is suitable for such a test.

3. The operation of the system in a reduced pressure and high pressure environment will also be investigated for small scale tests. Test similarities may permit the apparatus to be the same as for the radiation tests and it, too, will be included in an integrated program proposal.

4. Upon completion of the study of various techniques of design of the gas exchanger a one man unit will be fabricated and tested in the laboratory

with a closed cycle. Animals will be used for the first tests of performance followed by tests with a man in the system. The performance of the man will be measured during these runs.

5. Small tests should be conducted using samples of algae solution to determine the effect on the solution of several metals in order to select a material for construction of the container.

Martin - Denver Program

1. A series of runs on the small system at Denver will be conducted to study the effects of the critical variables of CO_2 and O_2 concentration in the inlet gas stream, the gas flow rate and P_H on the characteristics of the algae strains recommended by RIAS. In particular, these tests should be conducted to determine the presence of toxic effluents in the gas or liquor discharge using a continuous harvesting cycle and the presence of mutants in the algae. A comparison of the several strains should be made to determine which strain will be selected for production tests at Martin - Baltimore. Samples will be provided for radiation tests.

2. A program of tests on the small equipment should be conducted to determine the effects of bacteria on the algae culture and the discharge gases. In conjunction with these tests, techniques for cleaning the algae system by chemical means should be tested.

3. Irradiated algae strains will be grown in the small scale apparatus to determine long term effects of radiation at various levels. This work will be proposed as part of the radiation tests.

4. Small scale tests on the various techniques devised in conjunction with Martin - Baltimore's engineering effort will be conducted to provide data for engineering evaluation and for determining relative effects on the algae culture performance produced by the various methods.

The engineering studies for which test equipments should be devised

will include:

(1) A Study of illumination intensity and spectrum

(2) A study of fluid flow variables including the length of the flow path, methods of producing turbulence, and possible staging techniques

(3) A study of methods for mixing gases and algae including the problems of producing this mixture under zero gravity conditions.

(4) A study of methods of continuous harvesting.

5. The breakdown of human waste for nutrients and techniques for producing nutrients fromexcess algae should be tested. A program for testing the several techniques for converting or decomposing human waste to nutrients for algae will be conducted using some equipment already constructed at Denver. The output of the waste treatment system will be used to feed small scale algae tests for initial experiments. Once a suitable nutrient formulation is devised sufficient nutrient will be produced to permit tests at Martin - Baltimore for production data from this formulation. Disposal of remaining solids will be studied. Fitzsimmons

6. The waste nutrient formulation will be tested in the small continuous system to measure effects on the algae culture in this operation prior to performing tests at Martin - Baltimore.

7. A program for determining the plans and animal or fish to be produced using algae and/or decomposed or converted human waste and which will provide a palatable and balanced diet. This program will select the plants and/or fish to be grown and test the techniques to be used for growing this food and will provide nutritional data for growing. The techniques to be tested will be devised in conjunction with engineering studies to be conducted at Martin - Baltimore.

RIAS Program

RIAS will assist these programs by providing a consultant service as to conditions of test and characteristics of algae. Various new strains will be studied to determine their characteristics and recommendations will be made for test. Samples of test cultures from Martin - Baltimore and Martin - Denver will be analyzed to provide data regarding their growth, the developments of mutants and bacteria and similar data regarding the peculiarities of algae growth and development during the previously described tests.

PART II

This part of the program will define the processes involved in the complete closed ecological system. These processes will be studied to permit selection of the operations to be performed and the characteristics of the equipment to perform these operations. A design study of each item of equipment will not be performed in detail. This study will be closely coordinated with Part I and conducted concurrently. The requirements established will be used to specify data required from tests and some of the input values for tests.

This complete system study will produce a development plan and will recommend that proposals be made for specific development items or research necessary to forward the development of the closed ecological system.

1. The environmental limits for design of the system will be established. These include the natural environment of the moon as far as it can presently be determined and the environment to be anticipated as the result of military operations.

The natural environment has been studied for previous lunar studies and should be defined in terms of this system. Data limits should be included for temperature magnitude and rate of charge, radiation flux and spectrum limits,

pressure magnitude and rate of charge, shock limits due to moon quakes, gravity and magnetic field values, meteoric impact frequency and energy for various size particles and other effects.

The military system environment requires the definition of nuclear weapons that may be used and their effects with ground and air burst. Data on shock, thermal effects, probable accuracy and yield, radiation flux and spectrum, magnetic field, penetration, fuzing effects, debris velocity, cratering and earth movement are necessary for design of the structure of the ecological system. Fragmentary and advanced weapons will be considered if data becomes available.

2. The Physiological requirements of man must be specified to permit the system design to be balanced. These will include O_2 and CO_2 rates, temperatures, toxicity of various elements in system, waste characteristic variation with diet, nutrient requirement limits and capacity, liquid requirements, trace compounds in exhalation and other factors found to influence design.

3. The Operational Requirements of the overall system that influence design and operation will be established. A few have been established in the introduction to this statement of work. This study requires the determination of Systems Applications and integration with the present concepts of operating and constructing a lunar base or space station. This study will include investigation of the use of the system for a moon base, space station and space vehicles; definition of the size, weight, logistic supply, structural, maintenance, reliability and other operational requirements or procedures; and defining emergency situations and requirements.

4. The structure required to enclose the system and provide environmental protection for the man will be defined.

A comparison of various types of structures will be made and their

effectiveness in restricting the environment to acceptable levels will be evaluated. Structure for human occupancy and for housing equipment to be installed on the moon will be studied. Both above ground and below ground structures will be defined.

For the structures selected the specific design problems will be defined and solutions established to prove feasibility. Both the structure itself and techniques of construction will be defined.

5. The steps of the processes and the effects of the variable in each step will be defined. The process steps will each be studied in conjunction with others to determine which processes will best meet the requirements.

For each of the cycles involved, i.e. gas, waste, algae-food, and liquor, the inputs and outputs of each step will be defined, the detailed process will be established for each step, the equipment requirements will be determined, the processes will be selected and programs defined to prove the processes and develop the equipment.

6. A system power study and heat balance will be conducted to establish power and radiation requirements.

7. The types of equipment for each step in the process will be compared and one type selected for each step. The approximate size and weight of each item should be defined to permit Part IV of the program to be accomplished.

8. The control system for the processes involved will be established. The elements requiring control will be established and methods of control and type of control equipment required will be selected. The control problem will be integrated with the process study to revise processes as necessary to permit adequate control. This problem is the most difficult since the cycles must balance and yet remain closed to the maximum degree. Current chemical processes rarely achieve both objectives.

9. An evaluation of the algae process in comparison with other systems for closing the loop will be made. Two systems in use are the stored gas and the air scrubber systems. Variation in the photosynthetic and waste cycles are possible and any concepts should be compared with the algae process. The comparison will consider the system weight vs time of operation, logistic supply requirements, power requirements, emergency characteristics, system weight vs number of personnel (capacity) and other pertinent parameters.

PART III

The most critical unit in the closed ecological system is the Photosynthetic Gas Exchanger. This unit possesses many design problems which must be studied prior to selecting the technique on which extensive performance tests should be conducted. These problems will be studied in some detail to provide data on which tests for the various techniques can be based and which, in turn, will permit the most satisfactory technique to be selected.

1. The design of the system for the gas exchanger unit must be established. Several techniques of passing the gas through the liquor will be compared and evaluated. These will include comparison of the multiple pass system of gas flow with staging systems. Methods which will be compared and analyzed for removing oxygen from the algae suspension will include gravitational separation, centrifugal separation and heat or pressure separation. The methods of introducing nutrient into the system will also be evaluated.

The variables to be considered will include the methods of flowing CO_2 into the liquor; the variation in flow with reduced or zero gravity field; variable CO_2 concentrations in inlet gas; use of counterflow, fluid spray or other methods of contact between gas and liquor; the effect of variation in pressure of the liquor, and variations in algae concentration.

The combined arrangement of the flow path, illumination source container and the system controls will be investigated to provide a coherent design of the unit. The study will be for a 25 man unit except for the test system design.

2. The design of the flow systems in the culture chamber will be defined. The flow of gases, liquors, and coolant will be defined and methods of providing mixing and the best turbulence will be devised. This design will select pump characteristics and type, and devise methods for the insertion of nutrients to provide best utilization by the algae.

3. The illumination of the chamber for greatest efficiency will be studied. This design must be coordinated with the flow path design and the test program to make best use of the power with least weight. A survey of available luminous devices will be conducted. Various illumination sources will be evaluated including fluorescent bulbs, electroluminescent sheets, flat bulbs, etc. to determine the most efficient design providing light of the proper spectrum for maximum algae growth and permitting the minimum space and weight for a gas exchanger unit of given capacity.

The illumination for laboratory tests will be specified. It will be necessary for RIAS to provide data regarding optimum absorption spectrum desired from such illumination.

4. The design of the package will be determined and will include the definition of solutions to the installation of power pump, seals, and cooling. The container materials will be defined for algae laboratory tests and selected from such tests. The design will include provisions for automatic recharging, cleaning and dumping of the contents and capabilities for remote adjustment and disconnect for maintenance will be provided.

5. The method of control of the process and techniques and equipment for providing this control will be defined. Process control by monitoring output gas and liquor and/by controlling fluid flow, temperature, pressure, nutrient

composition illumination and/or Algae concentration will be investigated. A suitable automatic system will be studied for feasibility.

6. A model unit for test of performance will be designed and proposed for continuation of the study. This unit will employ the techniques selected from the previous study and will be used to establish performance parameters for these combined techniques. It will also be used to conduct human performance tests since it is believed that it may be the first unit to provide adequate safeguards and control for such tests. This unit will have sufficient capacity for one man and the effort in this part of the study will be to adapt the larger design which is studied to the smaller unit.

PART IV

The feasibility of packaging and designing the ecological system into a payload capable of being transported to the moon is a desired end result of this study for SR 192.

1. The integration of the payload with the concept presently being considered for construction of the lunar base will be established by means of providing the design limits, payload applications and operational requirements for the ecological system. The techniques of integrating the ecological system with the overall concept of the lunar base operation and construction will be defined.

The payload application to space station and space vehicle use will also be investigated to establish the variation in operational requirements and their effect on the system arrangement.

2. The payload configuration will be defined into which the ecological system is to be installed. This will require investigation of the booster and propulsion requirements for the payload, the techniques for braking and soft landing on the moon, methods for movement of the payload on the moon, and

determination of the payload housing structure and shielding. These capabilities will be investigated to establish the techniques to be used and the problems of integrating them with a payload containing a complete ecological system.

3. The equipment selected for the ecological system in Part II of the study will be installed in the payload configuration. This layout will show how all elements of the system will be fitted together and how they will operate. The system operation will be studied to assure compatibility with functional and system operational requirements through all phases of the application of the system.

4. The power supply for the self contained payload will be selected based on a study of potential systems that can be developed and on the power requirements established in Part II of the study. This power source will also be installed as part of the payload to establish feasibility of constructing such a payload.

5. The concept of base construction using such a payload will be elaborated to provide the basis for a proposed system to construct a lunar base. This system proposal should be formulated after the results of the SR 192 study are available so that the base design will be compatible with potential missions determined through this study.

6. A small model of the payload will be constructed for the purpose of presentation of the system to the Air Force.