N86-19915

PLAN FOR CELSS TEST BED PROJECT

Dr. William M. Knott, Biological Sciences Officer
Biomedical Office, John F. Kennedy Space Center, FL 32899
FTS 823-3152, Commercial (305) 867-3152

Introduction

The concept of a Controlled Environment Life Support System (CELSS) is not new, and the survival of man in space has been demonstrated for 9 months by the Soviet Union. Most available data indicate that the problems with the long-term presence of man in space are those associated more with life support systems and less with the mechanical integrity engineered into the vehicles per se. As the duration of missions in space becomes longer and longer -- many months to years -- the need for constructing an integrated reliable life support system incorporating regeneration becomes increasingly crucial.

In order to develop a functioning CELSS, as represented in figure 1, test modules must be designed, constructed, integrated, and tested for performance and reliability. Such tests should be run in parallel with current basic research efforts. These tests will translate laboratory results into a chamber facility that integrates the essentials of plant growth and material recycling processes to show that it can be done on a practical scale. This effort is to be followed by a more sophisticated system that will accomplish manned tests of the CELSS as a life support system. Concurrently, space station experiments will determine whether there are fundamental problems with growing plants in weightlessness, and solve them or develop workarounds. Following the manned test of a ground-based engineering prototype, a space system will be developed, and its gravity-sensitive components tested on the space station as appropriate. That phase will be completed about 2000 A.D., so that engineers defining the 21st Century missions can work with hard data, and the design and development of CELSS systems for these missions can begin when required.

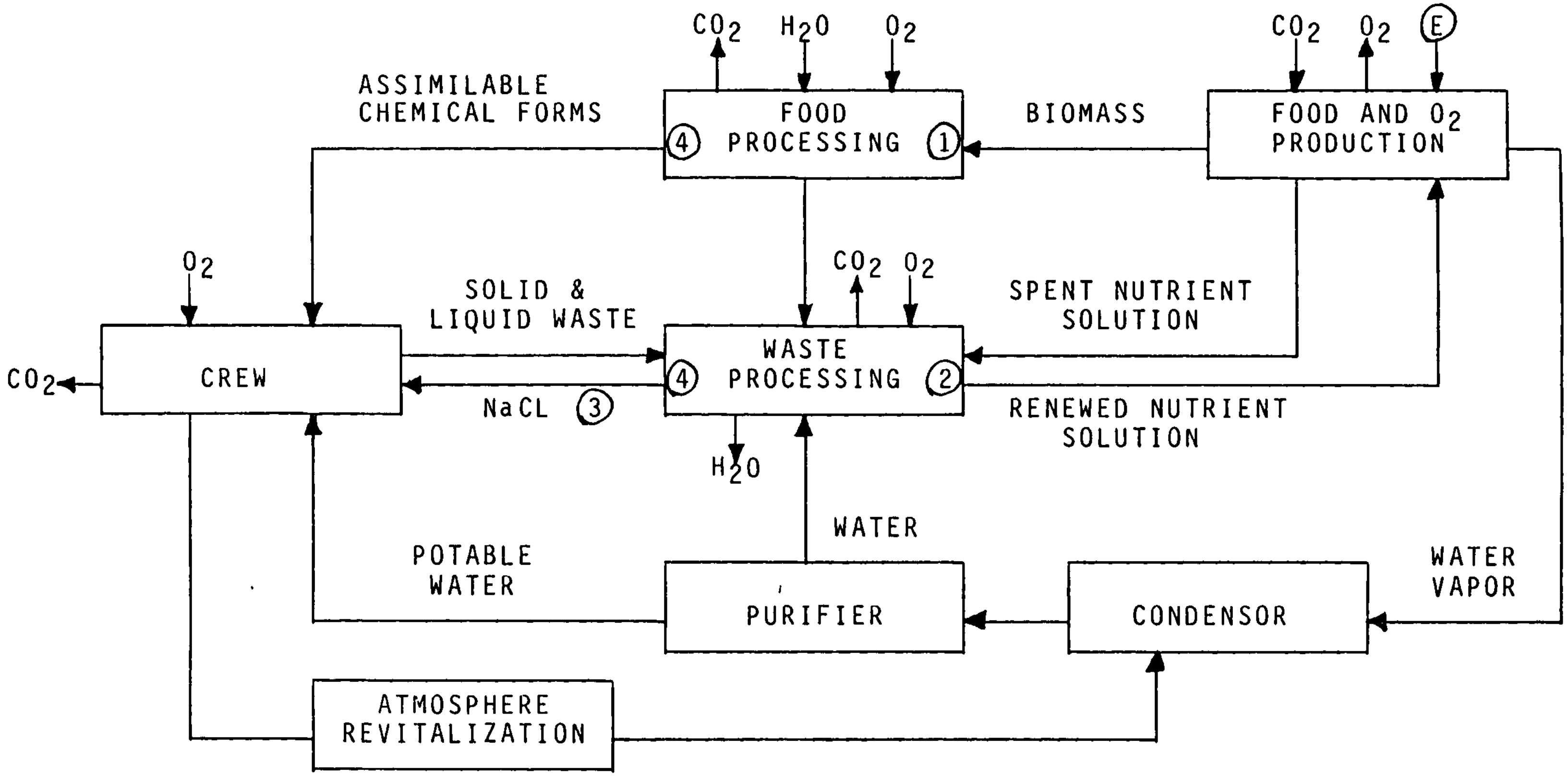
Four major components and two development areas are recognized as vital to the creation of a bioregenerative life support system:

COMPONENTS
1. Atmospheric regeneration
2. Food production
3. Food processing
4. Waste management

DEVELOPMENT AREAS
1. Engineering and control technologies
2. Analytical and monitoring capability

Kennedy
Space
Center

CELSS PROGRAM
PROCESS FLOW DIAGRAM



Research Emphasis During FY 85 and 86

1. Biomass Utilization
2. Nitrogen Management
3. Salt Partitioning
4. Subsystem Definition

FIGURE 1

The entire range of waste management options for reducing waste must be examined critically. The regeneration of waste water into a useable product will be a high priority in this project. Regardless of which biological system creates the reduced carbon ultimately destined for human consumption, processing will be essential. Current food processing techniques must be adapted, streamlined, miniaturized and effectively tailored to the needs of space. It is highly probable that a coupling of physical, chemical, and biological techniques for the treatment and segregation of waste and the efficient conversion of biomass to an edible substance will be the ultimate solution to the generation of a CELSS. An objective is to convert waste to useable foods, fuels, or other needed commodities such as atmospheric supplements.

Atmospheric regeneration must concentrate on maintaining a proper CO_2/O_2 balance under closed chamber conditions. Monitoring for the build-up of trace contaminants will be another major concern in researching this program component. Development of food production hardware will be closely coordinated with the atmospheric regenerative component. Food production can be accomplished with higher plants and/or photosynthetic microorganisms. Although not totally excluded, any animal component in food production during early phases of this project will be very limited. The growth of botanical biomass of dietary satisfaction to man, coupled with appropriate atmospheric regeneration, will be the principal objective of this project.

General: Project Technical Plan

The CELSS testbed project will achieve two major goals:

1. It will develop the knowledge and technology needed to build and test biological or combined biological physico-chemical regenerative life support systems.

2. It will fabricate, test, and operate ground based facilities to accomplish proof-of-concept testing and evaluation leading to flight experimentation.

The project will combine basic research and applied research/engineering to achieve a phased, integrated development of hardware, systems, and techniques for food and oxygen production, food processing, and waste processing in closed systems as follows:

1. Design, fabricate, and operate within three years a botanical production system scaled to a sufficient size to verify oxygen and nutrient load production (carbohydrates, fats, proteins) at a useable level.

CELSS PROJECT

MASTER SCHEDULE

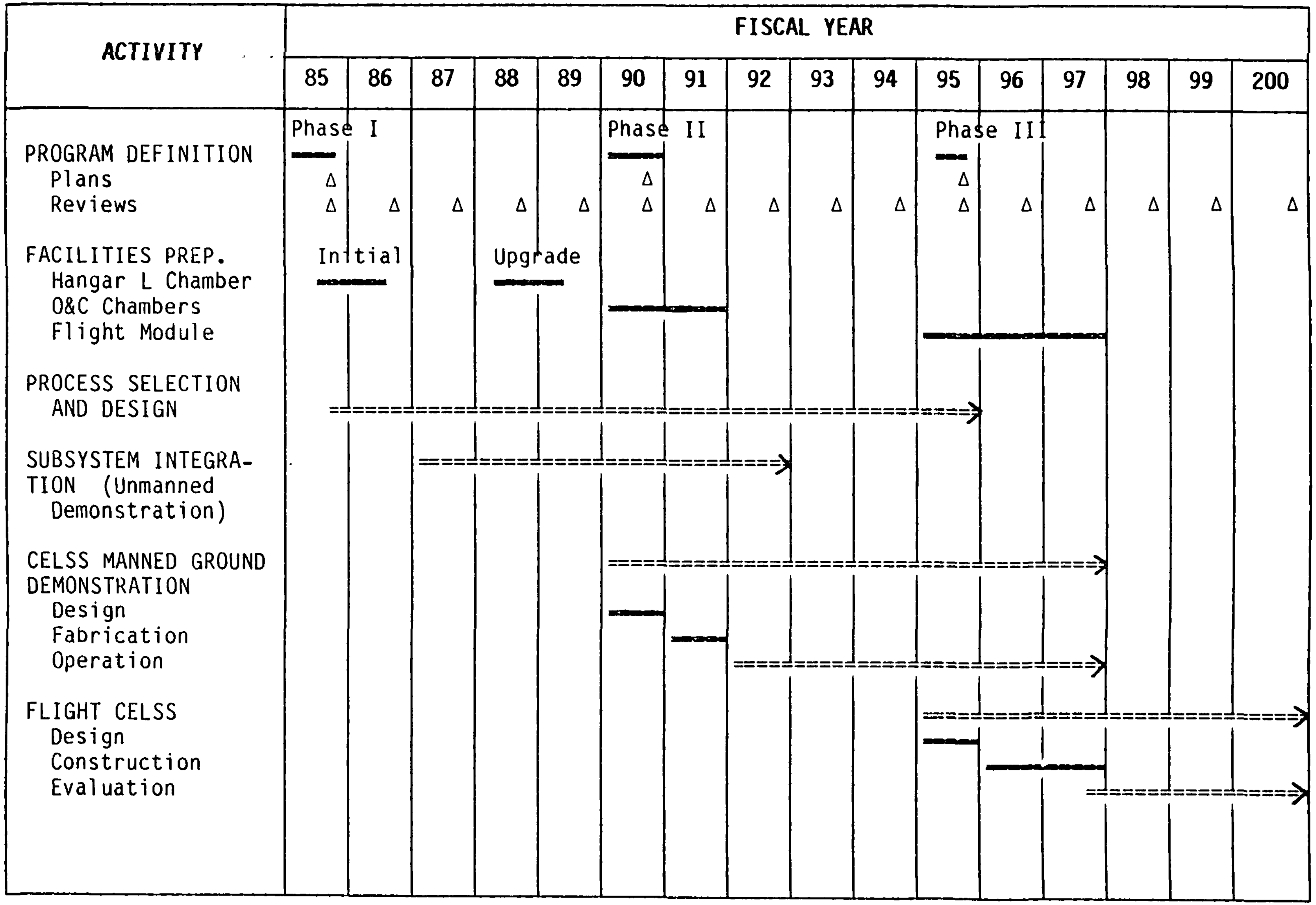


FIGURE 2

2. Develop within five years a waste management system compatible with the botanical production system and a food processing system that converts available biomass into edible products.

3. Design, construct, and operate within ten years a ground based candidate CELSS that includes man as an active participant in the system.

4. Design a flight CELSS module within twelve years and construct and conduct initial flight tests within fifteen years.

The testbed project will be divided into three phases with each phase conducted in series (Figure 2). The successful completion of one phase will be required before proceeding to the next. Each of the phases will be sufficiently distinct to produce important useful results even if the project is terminated prior to initiation of the subsequent phase. The three phases are:

1. Bioregenerative System Evaluation Test
2. Manned CELSS System Evaluation Test
3. FLight System Evaluation Test

Each of the three phases will take from 3-5 years to complete. A flight unit for testing in space will be completed within fifteen years.

This plan will be revised near the end of Phase I to review detailed objectives and approach to Phase II, and again during Phase II for Phase III.

Phase I: Bioregenerative Systems Evaluation Test, 1985-1990

The specific objectives of this portion of the program are:

1. Develop a closed chamber facility as a test bed for evaluating bioregenerative systems under ground based conditions.

2. Design and develop a higher plant production module and optimize it's efficiency for recycling and energy use. Incorporate microorganism production systems into the module as appropriate.

3. Operate the plant production module as a closed system for at least a six month period of time.

4. Determine the current status of food processing and water management systems and identify candidate systems for testing with the plant production module.

HYPOBARIC CHAMBER

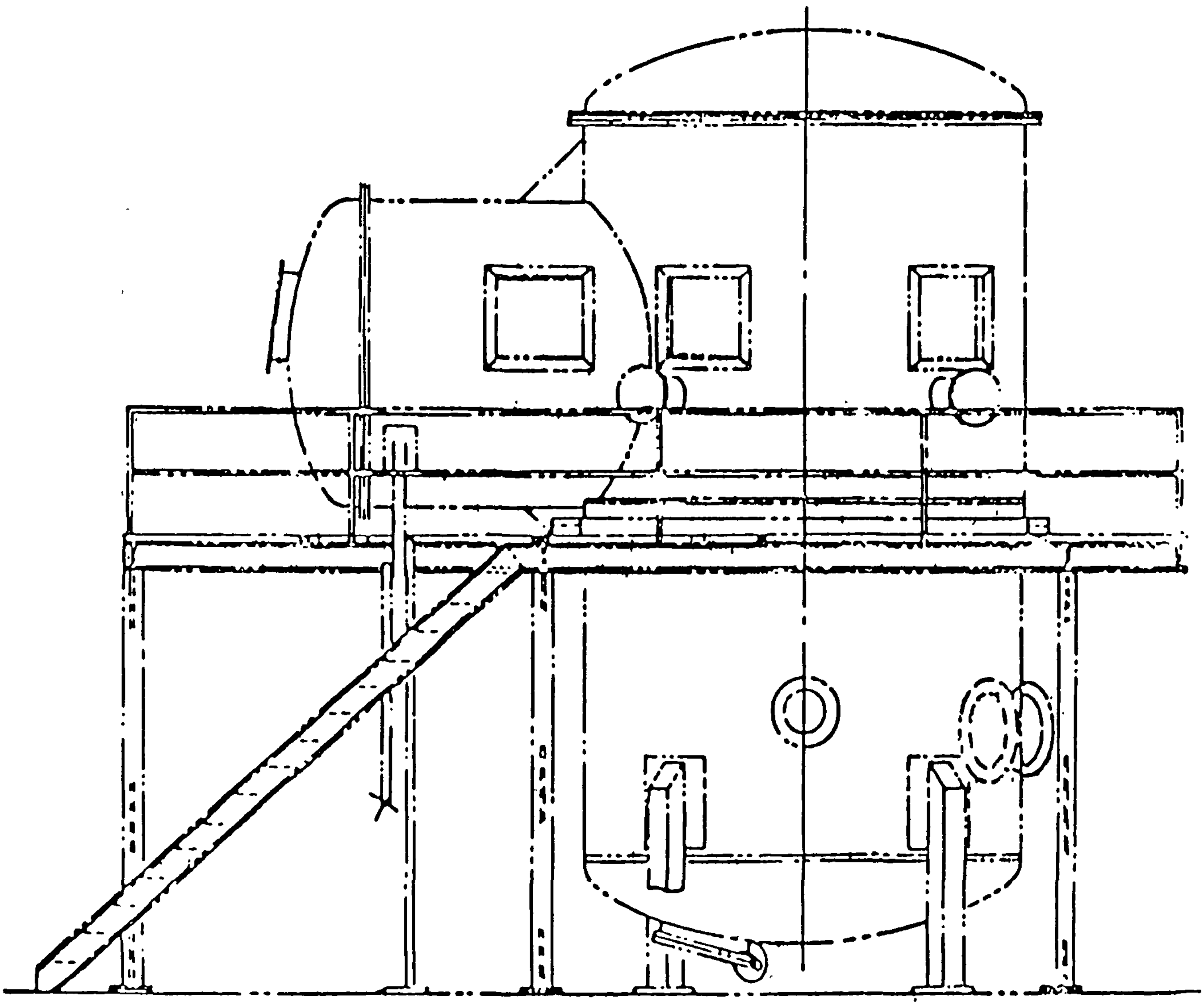


FIGURE 3

5. Develop selected food processing and waste management modules and test them as a part of an integrated system with the plant production module.

6. Design an integrated ground based CELSS with man as an integral part of the test facility.

This phase of the program will utilize a 6.7m x 3.6m cylindrical closed chamber facility in Hangar L. (figure 3). This hypoboric chamber (from the Mercury Program) will be modified to accomodate plant growth. Using this chamber, a plant production system will be developed and tested. Tests will be conducted with candidate higher plant species, concentrating on a single species community and later multiple species communities. Emphasis will be placed on engineering improvements during the tests, primarily concerning nutrient delivery systems, automated maintenance and harvest systems, lighting elements, and monitoring and control instrumentation. Chamber operations and systems integration will be accomplished through a NASA/Contractor team onsite at the Kennedy Space Center. The chamber will be refurbished and ready for testing by March, 1986 and plant studies will begin at that time. An AIBS advisory panel has been appointed to oversee this portion of the project.

A set of chamber tests will be initiated in April 1986 to establish the operational capability of the plant production systems and baseline mass and energy flux for the production module. Microorganism production systems will be developed and incorporated into the chamber tests as required. At least one extended time period ($\geq$ 30 days) test with multiple species crop community will be conducted during the first 2 years of the project.

As problems develop during chamber tests, decisions will be made to whether they can best be researched in the chamber or should be referred to other laboratories. Contracts will be developed with outside organizations on a specific problem solving basis as the test program dictates. Anticipated areas of research include definitive nutrient requirements, selected crop production, evaluating plant propogation techniques, plant monitoring instrumentation, microorganism culture systems, lighting systems, and higher plant nutrient delivery systems. Actual areas of research will be identified during the second year of the project and continuing for the remainder of Phase I. New concepts and equipment resulting from this research will be incorporated into the test facility as appropriate to improve the system starting with year 3.

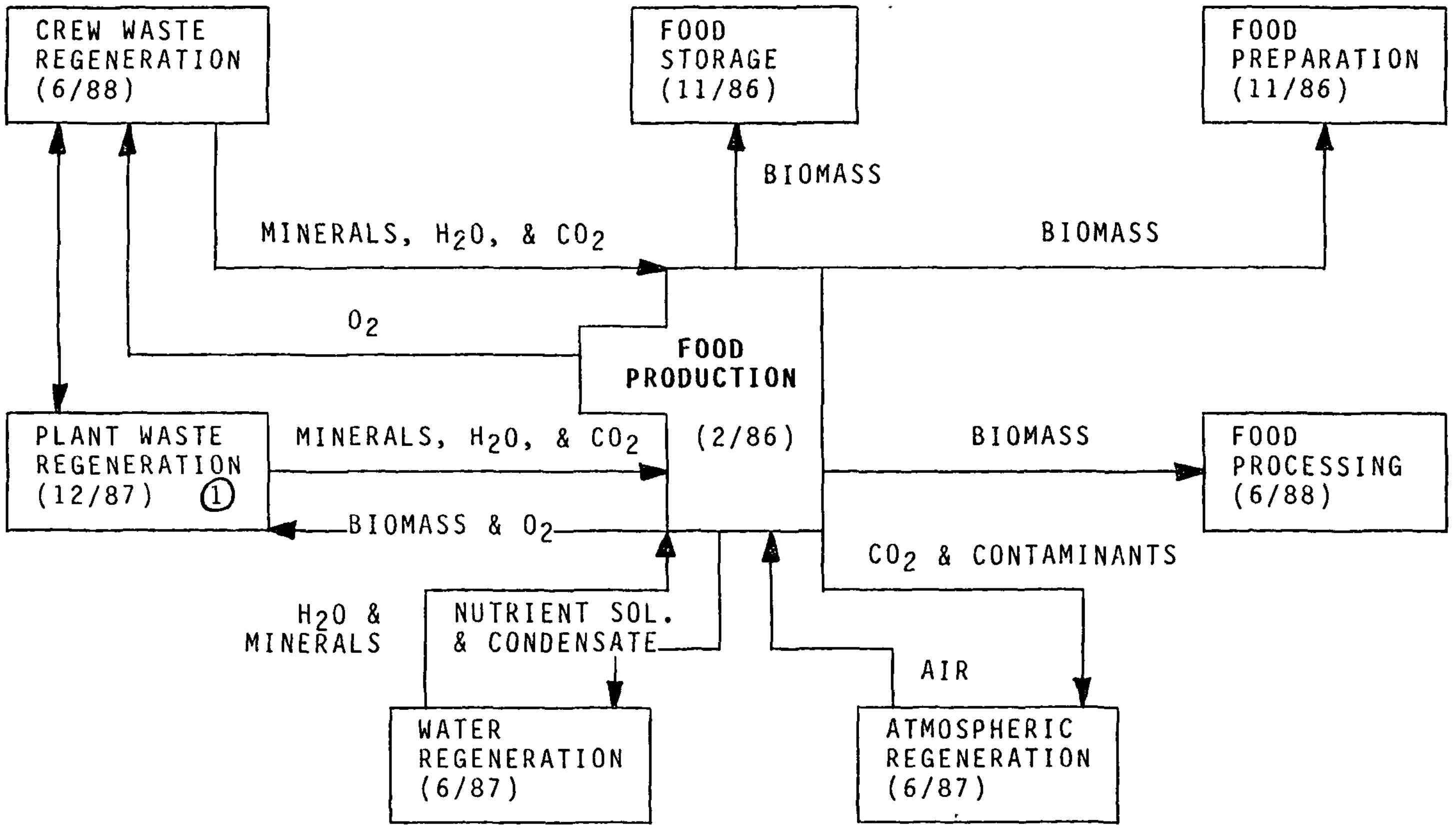
A functioning plant production system will evolve over this 3-5 year Phase I portion of the program. Tests will become longer in duration reaching a $\geq$ 90 day period by the end of this phase. An efficient, highly automated plant production module will be a product of this Phase I effort. The integration of food processing and waste management systems will also be done during Phase I. Food processing and waste management systems will be assessed while the food production module is being developed, and the best systems selected for evaluation. Food processing will concentrate on minimizing and converting plant wastes into reuseable components, and waste mangement will emphasize nitrogen cycling. This follow-on system selection will be accomplished with guidance from AIBS technical committees that will meet for the first time in August 1985. A revision to the project plan will be made by the end of 1985 that addresses in detail how the research and development of these systems will proceed.

The general approach to how the atmospheric control, waste management, and food processing components will be developed, integrated, and evaluated can be outlined. Systems to control gaseous contaminants in the atmosphere of the closed plant production facility will be the first addition to the chamber. It is anticipated that volatile hydrocarbons will be the major contaminants resulting from natural metabolic processes (e.g., methane, ethylene) and from outgassing of materials and equipment (e.g., thalates). Systems developed previously have included cyrogenic traps, incinerators, and carbon adsorption. Contaminant control systems must be interactive with atmospheric control systems. Exact requirements must depend on information gained from detailed analytical chemical studies of processes, materials, and equipment early in the operation of the plant procduction chamber. An atmospheric "finetuning" system will be added to the air handling ducts of the chamber during 1986.

A water recovery system will be integrated into the test that will recycle spent nutrient solutions and condensate from the chamber. The system will be derived from appropriate filtration and/or chemical treatment techniques. The ultimate objective of this system will be to improve the generation of water which is useful in sustaining plant growth in a timely and efficient manner. The water recovery system will be integrated with the chamber facility during late 1986.

Integration of a candidate waste management system with the plant production unit will be completed by late 1987. This system will be operated in laboratories adjacent to the chamber using primarily nonedible plant biomass. Human wastes could be added to the system later as appropriate to develop satisfactory operations. Much of the plant waste product could be recycled through the solid waste management system involving biodigesters, pyrolyzers, and/or incinerators. Unfortunately,

CELSS PROGRAM
COMPONENT INTEGRATION



(1) – Concentrate initially on nitrogen cycling and conversion into food

MONITORING AND CONTROL:
1. CO_2 and O_2
2. O_2 trace contaminants and viable nonedible particulates
3. Pressure, temp., humidity
4. Biomass (carbohydrates, proteins, lipids, & vitamins)
5. Water
6. Major nutrients
7. Energy (ie. electricity)

FIGURE 4

much of the engineering effort relative to these systems has centered on disposal rather than the recovery of water and chemicals. Additional information will be needed to choose and evaluate the optimum process once the most likely solid and liquid wastes are known. Design parameters are available for many physiochemical and biological solid organic waste treatment processes, but integrated, operational systems have not been completed. In addition, questions on mineral separation, recovery and conversion, vitamin recovery (or supplement), plus information on sanitation, safety, recycling time, and system by-products must be researched.

Food processing systems also will be developed in laboratories adjacent to the plant production chamber. Preparation and storage of edible food materials will be one part of this system. The more difficult part of this system will be that portion designed to convert nonedible plant biomass into an edible material. Candidate techniques to accomplish this conversion include microbial, chemical, and/or enzymatic systems. The development of food processing systems will begin in early 1986, and chamber tests will begin in late 1987 or early 1988. It should be stated perhaps, that plants selected for use in the system will be chosen, in part, for their high percentage of edible mass, thus minimizing this problem on the input side. Uneaten residue may, however, neutralize this hoped for advantage.

All candidate waste management and food processing systems will be interfaced with the plant production chamber facility and operated, tested, and evaluated. Tests and research will emphasize the integration of multiple subsystems into a total operational system. Measurements made during chamber tests will include CO_2 uptake and O_2 generation, moisture levels, nutrient uptake, nitrogen concentration, waste decomposition, and plant growth and productivity. Special attention will be given to the generation of contaminants under closed atmosphere and recirculating nutrient solution conditions. Improvement in the efficiency and reliability of the integrated systems to operate as a bioregenerative component will be the primary goal of this phase of the project. Tests will concentrate on mass and energy fluxes, and systems to improve recycling.

The final product of Phase I will be an integrated system that will produce food (major nutrients), produce O_2 and consume CO_2, and recycle essential waste and water components sufficient to maintain 3-4 people (figure 4). The goal is to make the system functional at a 4-5 KW maximum power level and 10 M^2 growing area per person. Phase II and III will follow in series after the completion of Phase I. General objectives for these later two phases have been established, but details of technical plans are scarce and, therefore, will not be discussed in this report.