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2. NUTRITION AND FOOD TECHNOLOGY FOR
A CONTROLLED ECOLOGICAL LIFE
SUPPORT SYSTEM
(CELSS)

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TABLE OF CONTENTS

	Page
List of Tables and Figures	vii
I. SUMMARY	1
II. INTRODUCTION	5
A. THE STUDY CONTEXT	5
B. STUDY OBJECTIVES	6
C. SCOPE OF WORK	6
III. NUTRITIONAL REQUIREMENTS	9
A. INTRODUCTION	9
B. THE MACRONUTRIENTS	10
C. THE MICRONUTRIENTS	15
D. FUTURE PROJECTS	18
IV. DIETARY GOALS	21
A. INTRODUCTION	21
B. USDA GOALS AS ADAPTED TO SPACE MISSIONS	21
C. ADDITIONAL GOALS FOR OPTIMAL NUTRITION IN SPACE	24
V. FOOD ACCEPTABILITY	25
A. INTRODUCTION	25
B. FACTORS INFLUENCING ACCEPTABILITY OF FOODS ON EARTH	25
C. FACTORS INFLUENCING ACCEPTABILITY IN CELSS	26
D. TASTE PHYSIOLOGY	28
E. AN APPROACH TO TESTING FOR THE ACCEPTABILITY OF FOOD PRODUCTS	29
VI. FOOD SERVICE SYSTEMS	31
A. OBJECTIVES	31
B. INTEGRATION OF FOOD PRODUCTION WITH CELSS	31
C. FOOD PREPARATION	38
D. MEAL SERVICE	47
E. CONCLUSIONS	49

TABLE OF CONTENTS (Continued)

	Page
VII. PRELIMINARY PROGRAM PLAN	51
LIST OF REFERENCES	53
APPENDIX A – MISSION SCENARIOS FOR CELSS	59
APPENDIX B – DATA BASE MANAGEMENT	71
APPENDIX C – GLOSSARY	75
APPENDIX D – BIBLIOGRAPHY	79

LIST OF TABLES AND FIGURES

Table No.		Page
1	Toxic Levels and Recommended Dietary Allowances for Trace Elements	17
2	Suggested Research Projects	19
3	Food Service Systems	32

Figure No.		
1	Characteristics of Food System	34
2	Food Production and Service System Components	36
3	Food Preparation Requirements	40
4	Fluid Immersion Cooker	44
5	Oven Cavity for Microwave/Forced-Convection Heating and Broiling	45
6	Direct Contact and/or Radiant Heating Surface Cooking Processor	46
7	Preliminary Program Plan	52

I. SUMMARY

Expanded space capabilities will provide the opportunity to engage in industrial-scale operations beyond the surface of the Earth. These operations will require the establishment of permanent manned space stations. Habitability of these stations could be achieved by complete resupply of the essentials from the Earth, by complete recycling of air, water and food, or by selective combination of both methods based on cost considerations. In this study for the National Aeronautics and Space Administration (NASA), Arthur D. Little, Inc., has considered food technology requirements and a nutritional strategy for a Controlled Ecological Life Support System (CELSS) to provide adequate food in an acceptable form in future space missions. Our objectives have been the establishment of nutritional requirements, dietary goals and a food service system to deliver acceptable foods in a safe and healthy form, and the development of research goals and priorities.

A CELSS in Space will differ from an Earth-based structure with a similar degree of closure for a variety of reasons, including the altered gravitational field, the type of food that could be grown, and physiological and psychological stresses. Previous missions have provided much practical information on the physiological effects of life in Space. In this study we have considered the effects of a CELSS in Space on the crew's nutritional needs and food requirements, and also identified where research will be needed to maintain crew members in the kind of physical condition considered normal by Earth standards.

For example, it is known that protein metabolism is altered in Space. However, further research is needed to determine optimal protein levels for the diet. Current indications are that protein levels may have to be reduced because of effects on calcium metabolism. Carbohydrate and fat levels seem to fluctuate without adverse effects within the limits of currently acceptable diets; however, this condition could change if one could manufacture large amounts of simple carbohydrates in a CELSS. Total energy requirements may increase slightly because of an increased work load and/or a decreased efficiency of utilization. Calcium requirements are not known — they will probably increase in an effort to reverse the loss of calcium from the bones. Even more important may be the ratio of calcium to phosphorous, which has been quite low to date. This area must be studied further in future missions. There is considerable concern about a toxic buildup of trace elements in a CELSS. For some elements there is a narrow safety margin between adequacy and toxicity. For others, these levels are not yet known. This concern is paralleled on Earth where there is increased USDA funding in this area. Results from Earth will help in the design and construction of a CELSS. Once built and tested, careful monitoring will be necessary to prevent problems of too much or too little of a required trace element. Requirements for some vitamins may be altered because of stress, gravitational changes, and changes in the foods. These levels can be met by resupply of supplements from Earth.

To form a bridge between nutritional needs and the food service system which provides foods to meet these needs, the following dietary goals have been established.

for space flights: (a) to establish access to a variety of foods; (b) to determine and maintain ideal weight for the crew; (c) to avoid too much sodium, by cutting out highly salted foods; (d) if alcohol is permitted, to drink in moderation; (e) to reduce protein intake; and (f) to reduce the calcium-to-phosphate ratio to the range of 1:1 to 1:2.

The acceptability of the diet regimen that will meet these goals will be very important to the physical and mental satisfaction of the crew. While there are no guaranteed methods of predicting acceptability, testing is extremely helpful to the selection of good food choices. This testing can and should be done during short-term missions and in ground-based settings. There is also a problem of taste differences which can and should be researched during short-term missions. Food choices will be affected by the composition of the crew, the food service, the manner of food preparation, the social setting, and the source of the food. This study presents a research approach to testing for the acceptability of food products.

To utilize the performance capabilities of a CELSS, the food service system must be designed for a specific mission and must: (a) fulfill dietary goals by delivery of the appropriate nutrients, (b) deliver acceptable foods with appropriate sensory attributes, (c) maintain health and safety standards, (d) provide for unique needs of the space environment and activity level of the crew, and (e) provide drinking water of potable quality.

Food production will be experimental at first and will expand slowly until it reaches a significant portion of the diet in very long-term missions in the future. This food production will result in less resupply and fewer waste storage problems because part of the waste products will be reutilized.

Preparation techniques could be developed to provide fresh-cooked foods from either resupplied or CELSS-produced products. Constraints of the Space environment on cooking devices are the absence of convection, the need to keep foods contained, and the difficulties of weighing, measuring and transferring materials. There are three major forms of cooking, or thermal processing, and these can be adapted to CELSS. Fluid immersion can prepare food by pressure cooking or deep fat frying. Roasting and baking can be done with a combination forced convection/microwave oven, perhaps with a browning unit attached. Direct contact and/or radiant heating can be utilized for grilling, pan frying, and other stove-top operations. Advanced technologies for cooking processes on Earth should be examined and adapted to a food preparation system for CELSS.

Meal service will vary with the type of mission. As the crew size increases, individualized preplanned meals will become impractical, and some kind of food service operation will be warranted. Menus will cycle, with choices offered as needed. Food monitoring systems can be utilized for inventory purposes and to insure adequacy of diet. Meal service can be solo or group, cafeteria or restaurant, with other options such as fast food or vending. Equipment will have to be developed specifically for this purpose. Waste-handling techniques will be developed as part of the CELSS. Some of these materials can be utilized for recycling. Whether or not materials are recycled, it is important to minimize waste in packaging and food processing at every level of planning and functioning of the CELSS.

A coordinated approach among many disciplines will be essential to the development of a CELSS. Sufficient lead time must be allowed for studying the various issues that will have to be resolved before space missions of longer than several months will be possible. The research projects identified in this study are the beginning of an incremental process. A CELSS will be the culmination of the information obtained from research projects and the experiences acquired from various short-term missions prior to the construction and utilization of a large-scale space station.

II. INTRODUCTION

A. THE STUDY CONTEXT

The utilization of space for economic, scientific, and societal missions is the dominant theme for the future direction of space activities. The existence of satellites for such utilitarian purposes as earth observations, meteorology and communications, as well as for scientific and defense purposes, is accepted as commonplace. These satellites have dimensions in the range of tens of meters and masses of tens of tons. Today, the population in space consists of a few astronauts on missions which extend, at most, over a six-month period. The constraints on expanded industrial uses of space will be removed with the advent of an effective space transportation system, which by analogy to the railroad, will make space accessible for a broad range of purposes.

Expanded space transportation capabilities will provide the opportunity to engage in large-scale orbital activities in permanent, manned space stations which are the stepping stones required to create the infrastructure for expanding industrial-scale operations beyond the surface of the Earth. Permanent, manned space stations will require evaluation of the logistics of resupplying space missions as crew size and mission duration increase, based on practical economic considerations.

Already in the late 1950's and early 1960's, it was recognized that regenerative systems using both biological as well as physical-chemical methods would be needed to control humidity, remove carbon dioxide and reclaim water. It was found that near-Earth space missions could be adequately supported by on-board storage and regenerative physical-chemical technology. The national commitment to develop a new space transportation system provided the impetus for renewed studies of biological life-support systems, including the possibility of developing a controlled ecological life-support system (CELSS) which would permit at least partial closure of air, water, and food cycles.

The development of a CELSS will require an increased understanding of diverse disciplines such as human physiology and psychology, social interactions and processes, energy flows, the ecology of interconnected biological and physical processes, and the maintenance of a biologically desirable environment. The areas which will require detailed studies are human nutrition and diet, as well as food service and food processing. Such studies will contribute to the good health and effective performance of crews during long space missions and permit the involvement of a broader segment of the population in space activities.

The results of these studies will be essential to guide the selection of foods to be supplied from Earth, stored in orbit and produced in CELSS, the design of the systems required for food production and waste processing in CELSS, and the selection of construction materials for and safety features incorporated in CELSS.

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B. STUDY OBJECTIVES

The objective of this study is to consider the food technology requirements and to formulate and define a nutritional strategy for CELSS so that the crew members will be provided with adequate nourishment and acceptable diets during future space missions. This involves the establishment of nutritional requirements, dietary goals and food service system requirements to deliver acceptable foods in a safe and healthy form, the development of research goals and priorities, and the development of a program plan to guide future study activities.

C. SCOPE OF WORK

To accomplish the objectives of the study, the following interdependent tasks have been addressed.

1. Data Base Management

The literature applicable to the objectives of this study was surveyed, selected documents acquired, and an annotated bibliography composed of references identified as valuable to the understanding of specific topics was created. The emphasis was not on a historical survey but on careful selection of those documents which were directly supportive of the specific tasks to be accomplished. (Information on the data base is presented in Appendix B. The bibliography is presented in Appendix D.)

2. Mission Scenarios

Potential space missions in low-Earth orbit and geosynchronous orbit were selected as representative of the technical and economic constraints of space flight operations which could influence crew requirements. These missions highlight the desirable characteristics of the CELSS parameters, including design life and food production and resupply, to provide a definite basis for establishing the nutritional and food service requirements. (The mission scenarios are presented in Appendix A.)

3. Nutritional Requirements

The information obtained from the data base was used to determine the nutritional requirements of the mission scenarios; to assess these nutritional requirements to identify the factors governing normal needs and those which could alter metabolic requirements due to reduced gravity conditions; and to develop the rationale for the recommended dietary allowances, including needs for energy, carbohydrates, salt, proteins, minerals, trace elements and vitamins. The changes in the recommended dietary allowances which might be appropriate for the expected working conditions in the mission scenarios were established; and the changes in these requirements as a function of time, and the effects of recycling on nutrients in CELSS were considered. Areas of uncertainty in the present understanding of nutritional requirements were identified and specific research projects to determine nutrient requirements more accurately and to guide CELSS design were established.

4. Dietary Goals

Goals were established to encourage the consumption of a diet which will lead to optimal health of the crew over extended time periods. These goals also were to serve as a bridge between nutritional requirements and the design requirements for the food service system and provide a basis for CELSS development. The dietary goals addressed food variety, sodium, animal fat, cholesterol, sucrose, protein, calcium, phosphorous intake, and provisions for dietary fiber.

5. Food Acceptability

The factors influencing food acceptability on Earth were considered as well as factors unique to CELSS, such as the food sources and food consumption patterns. Crew needs were identified, the changes in taste physiology which may influence attainment of dietary goals were assessed and an approach to testing the acceptability of food products was presented.

6. Food Service Systems

The characteristics of food systems were identified, including agricultural, microbial and animal products, chemical synthesis and waste processing. Food preparation techniques were evaluated on the basis of cooking processes and concepts for cooking equipment applicable to cooking processes such as fluid immersion, roasting and baking and direct contact and/or radiant heating were presented. Meal service options based on menu planning, meal preparation, meal service types and equipment were considered and requirements for meal service sanitation and waste handling outlined.

7. Workshop on Nutrition in Space

A Workshop was organized and held at the Cosmos Club in Washington, D.C. on May 19 and 20, 1980, to identify the level of current knowledge of nutritional requirements and known space-related factors, to explore the food and health differences between living in an Earth-gravity field and in near- or zero-gravity, and to define research needs and projects to assist in the formulation and definition of a nutritional strategy. The Workshop participants were people from academic institutions, government agencies, and the food industry with expert knowledge of and prior experience in nutrition and food service related to space missions and unique terrestrial requirements.

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III. NUTRITIONAL REQUIREMENTS

A. INTRODUCTION

Nutritional requirements of crew members during extended missions will be affected by the space environment. The factors which may impact nutritional requirements are:

- (1) *The Gravity Field.* The most persuasive and important effect which will impact nutritional requirements in CELSS is the partial- or zero-g environment.* It is highly unlikely that there will be a one-g environment in any of the missions which are under consideration. A reduced gravity field is known to affect calcium and nitrogen metabolism. This produces imbalances in homeostasis which affect nutrition requirements.
- (2) *A Closed or Partially Closed CELSS.* In any mission of 90 days or more, water and oxygen will most likely be recycled. There are also missions where different foodstuffs could be grown from recycled nutrients. Changes in the nutrient composition of the foods grown in CELSS will impact the nutritional requirements.
- (3) *Food.* The food supply for a CELSS could be provided at the start of the mission, resupplied during the mission, or grown in CELSS. Foods stored for long periods of time may lose important nutrients, which would negatively impact nutrient intake. Resupplied foods will be the least altered but will still need preparation and/or packaging for launch. Foods grown in CELSS will differ from foods grown on Earth because they will be grown with recycled nutrients which may either lack or have a surplus of essential nutrients. The effects of reduced gravity on the growth of foods have not been established.
- (4) *Increased Exposure to Cosmic Radiation.* Crew members would be exposed to cosmic radiation during extended missions and, therefore, risk radiation-induced health effects. Controlled diets might reduce such effects.
- (5) *Physiological Stress.* Crew members will be stressed during missions and will have to make physical, psychological, and social adjustments. The extent of the physiological effects of stress is not established, but it is known that stress can contribute to the loss of calcium and nitrogen from the body. Stress could alter the requirements for several vitamins and minerals, as well as for the macronutrients.

*In this report reduced-g environment designates near-zero-g conditions.

To date, missions have been carried out with foods supplied prior to launch and stored on board. These foods have been developed and improved as a result of experience during previous missions (Rambaut and Smith, 1977). In these missions, it was assumed that nutritional requirements in space would be similar to the ground-based Recommended Dietary Allowances (NRC, 1980). During the Skylab missions lasting 28, 59, and 84 days, nutrient balance studies were carried out, providing a basis to project nutrition requirements for extended missions. These studies showed that nutritional requirements were different for crews living in space and that there were problems with the intake of several key nutrients (Leach and Rambaut, 1975).

Nutritional requirements during extended missions have been reviewed in the literature (Calloway, 1975; Rambaut, 1980). The establishment of nutritional requirements for such missions is based on the following assumptions:

- (1) The Earth-normal nutritional requirements as defined by the RDA's are only a starting point in determining how much of each nutrient must be supplied. The RDA's assume that there is a large margin of safety built into the requirements. However, there is controversy concerning the role of many of the nutrients. Because the RDA's are based on current data, they will be used as a basis for establishing a nutritional strategy for CELSS.
- (2) The foods which will be provided for future missions should resemble terrestrial food products as much as possible, i.e., essential nutrients should be supplied in the form of easily recognized food products. The assumption here is that food consumption is a pleasurable experience to which the crew will be looking forward and that it will be an important aspect of time spent away from the work tasks. Considering the cost of space missions and training of crew members to perform required tasks, the cost of providing highly acceptable food will be minor by comparison. Therefore, nutritional requirements should deal with whole diets and not only formulated foods.

Nutritional requirements can be classified according to macronutrients and micronutrients. These requirements are discussed, results of studies are presented, areas of uncertainty are indicated, and further research is indicated in the following sections.

B. THE MACRONUTRIENTS

1. Proteins

The protein requirement for both men and women at normal gravity is 0.8gm/kg/day (NRC, 1980). This requirement may be altered in space due to stress, changes in gravity, and reduced activity.

Zero or reduced gravity causes a loss of muscle mass. This loss, well documented from previous missions (Hander *et al.*, 1971; Rambaut *et al.*, 1977b), is similar to that

seen in bed-rest studies (Margen and Calloway, 1966). The muscle loss, and the accompanying negative nitrogen balance, continues for about six weeks and then the rate of loss diminishes and finally disappears (Vorobyov *et al.*, 1976). Muscle loss can be minimized by regular exercise, which the Skylab crews performed (Thornton and Rummel, 1977).

The optimal amount of protein in a space diet may be different than the level presently recommended. On the one hand, a high-protein intake may help to offset the negative nitrogen balance caused by muscle wastage. On the other hand, studies with purified proteins have shown that increases in protein intake, within the range consumed in the United States, increase calcium excretion significantly (Allen *et al.*, 1979; Chu *et al.*, 1975; Margen *et al.*, 1974). A high-protein diet derived from a high-meat diet did not exhibit this effect (Spencer *et al.*, 1978). Once the requirement is known, it may be difficult to implement this level since intake chosen by astronauts during the Skylab mission was one and one-half to two times the requirement (Joseph Kerwin, Personal Communication). It may be necessary to limit protein intake, which could negatively impact the acceptability of foods unless vegetable substitutes for meat can be successfully utilized.

Work does not appear to increase the body's need for protein. However, extreme environmental or physiological stress increases nitrogen loss (Cuthbertson *et al.*, 1964), and there is evidence that less severe stress may do so as well (Mace, 1962). Transient increases in urinary nitrogen are seen in stressful conditions (Scrimshaw *et al.*, 1966). It is not known if increased dietary protein would compensate for losses due to stress. However, upon return to normal gravity, it may be beneficial to increase protein intake during the recovery period.

To establish optimal protein requirements, further research is required in the following areas:

- (a) Definition of the effects of stress and the accompanying hormonal changes on nitrogen loss; and
- (b) Balance studies to determine protein intake necessary in the space environment.

Balance studies should utilize more accurate techniques than those used previously. Techniques relying on the use of stable isotopes are available and could be adapted to space-flight conditions. (These techniques were discussed in the Workshop, May 1980, and are in the Proceedings, May 1981.)

2. Carbohydrates

Carbohydrates (starches and sugars) comprise 40%-50% of the calories in the American diet. In other countries, this percentage is even higher. In this country, the Department of Agriculture has recommended that, in a balanced diet, intake of sugar be decreased and starches increased, while keeping the total amount of carbohydrate the same.

There is inadequate information at this time on the utilization of carbohydrates during a mission. Carbohydrates could be resupplied, stored, and/or synthesized in CELSS to meet the needs of crews on a specific mission. There are no known limits or optimal levels for starch and sugar intakes, and the desirable levels for the Earth-normal diet have not been established. Healthy individuals can consume a wide variety of amounts and types of sugars and starches without obvious ill effect, except for caries. At the lower level, a diet with no carbohydrates is likely to lead to ketosis, protein breakdown, loss of sodium, and dehydration. These effects can be prevented by ingestion of 50-100 grams of digestible carbohydrate per day (Calloway, 1971). The upper limit of carbohydrate consumption is defined by the amounts of protein and fat which are necessary to the body. Because the limits to carbohydrate intake are so broad (even the brain and nervous system could function when supplied with fats, if necessary), it is not likely that these limits will be approached within the context of a palatable diet for the crew. Therefore, the requirements and ranges of intake for sugar and starch are assumed to be the same as Earth-normal.

To establish optimal levels for carbohydrate utilization, further research is required in the following areas:

- (a) If the available food supply deviates significantly from a normal diet due to chemical synthesis of glycerol or other specific sugars, it would be essential to study the physiological effects caused by large amounts of carbohydrates;
- (b) Similarly, it would likewise be necessary to determine the upper limits which can be tolerated. The determinations could be made in a one-g environment such as a clinical research laboratory or a ground-based demonstrator.

3. Fiber

Previously, fiber was not considered to be essential for short periods of time and therefore was not included as a requirement for diets on missions (Calloway and Margen, 1966). The early missions used low-residue foods. Recent missions have used foods with moderate to low fiber content. This type of diet will probably continue in the near future. The USDA recommends that a moderate amount of fiber be included in the diet, as there may be a negative correlation between food-fiber content and colon disease. Such a cause-and-effect relationship has not yet been proven and there does not appear to be a need for large amounts of fiber in the diet in a reduced-g environment. However, further research may lead to changes in these levels, particularly if data obtained in future missions indicate that there are beneficial health effects from more fiber in the food products consumed by the crew.

4. Fat

A wide latitude of fat intake is tolerated by the human body. At the low end, certain polyunsaturated fatty acids must be provided and these constitute the only

absolute nutritional requirement for fat. Linoleic and linolenic acid are essential for brain function, and 1%-2% of a total diet appears to be ample, forming a minimum fat requirement (Calloway, 1975). However, most diets supply much more than this. The typical American diet includes 30%-50% of total calories as fat. At the high end, it is possible to consume too much fat, e.g., more than 150 g per day, causing ketosis and sometimes diarrhea. Fat is a high-density vehicle for calories for energy utilization and, as such, it may be beneficial to resupply high-fat foods from Earth. If foods are to be grown or synthesized in a CELSS, little fat will be produced and the fat intake will be low, since foods grown easily in a hydroponic system are low in fats and oils. However, it may be possible to grow oil-containing vegetables such as soybeans.

When considering the type of fat to be included in the diet, consideration should also be given to the types of fat associated with cardiovascular disease. Evidence suggests that the average chain length of fatty acids should be about 16 carbon atoms, with 1.2 grams unsaturated for each gram of saturated fat (Rambaut, 1980).

Although there have been no known problems in fat metabolism, astronauts on previous missions demonstrated a craving for high-fat foods such as ice cream, meats, and butter or margarine (J. Kerwin, Personal Communication). On missions of one year or more, storage problems may be experienced with high-fat foods because of rancidity. Therefore, the most appropriate means of supplying fat most likely will be by resupply from Earth. Because of the need for unsaturated fats in the diet, hydroponic agriculture should be explored to produce vegetable oils for possible food production in CELSS.

Research in the area of fat utilization and requirements is needed in the following areas:

- (a) Determination of the efficiency of utilization of energy derived from carbohydrates versus fats;
- (b) Development of hydroponic growth of plants bearing oils; and
- (c) Verification and quantification of changes in perceived desirability of high-fat and low-fat foods.

5. Energy

The total energy consumption of crew members can be affected by: (a) changes in work output due to reduced-g, (b) changes in the metabolic efficiency of caloric (food) utilization, and (c) stress. The net difference determines the change in calorie intake requirements.

Food consumption measured on board many of the previous missions showed an initial decline of 15%. This decrease went beyond the nausea which occurs in approximately half of the astronauts for the first few days to one week. This reduction in food intake did not reflect a change in metabolic requirements, and resulted in

decreased body mass in all astronauts. This loss of weight was distributed through body fat, muscle, water, and to a small degree, minerals (Johnson *et al.*, 1974).

In the Appollo missions, calculations were made of calories consumed versus changes in body weight. These data indicated that although there was weight loss, the caloric requirements did not change significantly (Rambaut *et al.*, 1973). However, further studies during the Skylab missions of 28, 59 and 84 days demonstrated a significant net energy deficit when energy input compared to output was compared to those same data measured before and after flights (Rambaut *et al.*, 1977a). This could have been caused by difficulties in adjusting to reduced-g conditions; it could also have been caused by a decreased efficiency of energy utilization. There also is some evidence that metabolic efficiency may have been diminished. For example, the respiratory quotient (RQ) increased while subjects performed a standard bicycle exercise. Also, thyroxine levels increased following recovery from the mission. However, this loss could also be attributed to the fact that work was being done with a diminished muscle mass (Rambaut *et al.*, 1977a).

For whatever reason, there is a greater need for energy (i.e., total calories) than would have been anticipated from calculation of basal metabolic rate (BMR), activity levels, and work output. Energy needs may be increased in reduced-g because of the extra work needed to maintain a desired position. Extra calories are also consumed during stressful situations. For example, a student taking an examination uses a very modest increment of calories because of the work of the brain. However, a student taking an examination under stress uses a large number of calories (Scrimshaw *et al.*, 1966). The stresses experienced during a mission may account for the increased caloric need.

It is important to determine the reasons for the loss in body mass experienced during the first month of a mission. Water loss appears to be due to the redistribution of blood and to blood pooling which occurs in the first few days. Protein losses occur in the first few weeks and level off. The losses, similar to those experienced in bed rest, were the result of decreased use of leg and arm muscles. Both water and protein losses can be explained by the effects of reduced-g on muscle tone caused by the lack of physical work, particularly of lower body and leg muscles. The loss of fat, which accounts for more than 50% of weight loss, is harder to account for. Accumulated body fat serves as energy storage and would be just as essential in zero-g as in a one-g environment. However, energy storage may be less useful as the anticipated energy consumption decreases, and the reduced usage is perceived physiologically. The decrease in fat stores is also related to the decrease in food intake. It is known that decreased food intake is caused by decreased appetite. What is not known is whether decreased appetite is caused by deleterious physiological changes which lead, in turn, to decreased fat stores, or whether the need for food is actually decreased to a point where the appetite changes to allow for changing needs. Over the long run, appetite usually follows physiological needs, although it may take a while for the body to catch up to changes in such needs. This is an important topic for future research and will strongly influence nutritional requirements.

It is also important to accurately measure the energy needs of crew members engaged in specific work tasks to determine the amount of food which must be supplied. This measure can be used to determine the oxygen requirement as well. Energy based on caloric intake is an expensive component of food in a mixed diet; therefore, precise knowledge of energy (caloric) requirements is important to planning large-scale, long missions. Methods are available to measure the caloric requirements of crew members. Such measurements can determine whether the crew is metabolizing food as it does in Earth-normal situations and how much food will be necessary to sustain the crew members engaged in specific activities in reduced-g when tasked with heavy or light work loads. This research will have to be performed during future missions, as it cannot be effectively simulated in an Earth-based facility.

To establish optimal levels for energy utilization, further work is required in the following areas:

- (a) Determination of the efficiency of energy utilization of carbohydrates and fats in zero gravity;
- (b) Determination of basal metabolic and work-load requirements;
and
- (c) Determination of changes in appetite during long missions.

C. THE MICRONUTRIENTS

1. Minerals — Calcium (Ca) and Phosphorous(P)

Most of the body's calcium is present in the skeleton in a crystalline form of calcium phosphate. Bone is constantly being formed and resorbed. In an adult male, about 700 mg of calcium enters and leaves the bones each day (Whedon, 1964).

The small amount of calcium in the plasma is controlled very precisely, with diurnal fluctuations of only $\pm 3\%$ (Carruthers *et al.*, 1964). Hormonal control of plasma calcium is so tight that any loss will be made up immediately from the bone. Therefore, a hormonal imbalance can cause large amounts of calcium to be lost from the bone. Vitamin D also plays a role in calcium balance by causing it to be absorbed more effectively (DeLuca, 1974).

In space flights, calcium losses resulting in bone wastage, documented in several previous missions, are caused by increased urinary excretions of calcium as well as changes in aldosterone, anti-diuretic hormone (ADH), and renin (Leach and Rambaut, 1977). Over the long term, there is a risk of formation of renal stones as the excess calcium is dumped into the urine. Calcium loss is a major concern, and research to understand the causes of these losses and to find means to counteract them remains a high priority.

During the previous missions, calcium intake was maintained at 800 mg per day. Any deficits in intake were compensated for by calcium supplements. No

attempt was made to attain calcium equilibrium by increasing calcium levels to more than 800 mg per day, or by altering the balance between calcium, phosphate and/or magnesium, all of which have some effect on calcium equilibrium. Another factor important in the maintenance of calcium balance is the amount of protein intake. (Section III-B-1) Increasing exercise will minimize the calcium loss after a certain period of time and is expected to continue to be an essential part of the health maintenance of the crew.

The Ca:P ratio influences the absorption of calcium as well as its loss from bone, at least in experimental animals (Hegsted *et al.*, 1973; LSRO, 1975) The ideal Ca:P ratio should approach unity, although considerable variation (from 2:1 to 1:2) can be tolerated under normal circumstances. Thus, maintenance of this ratio may be a major challenge because Ca intake is relatively low and phosphate level is high. For example, the diets on Skylab varied in Ca:P ratio from 1:1 to as much as 1:4. These ratios are quite high and may accelerate the calcium loss from bones. There appears to be a conflict between what is acceptable (a high phosphate-low calcium diet), and what is optimal (Ca:P in the range of 1:1 to 1:2). This conflict may be resolved, to some extent, by ingestion of calcium tablets. More research should be performed under reduced-g and bed-rest conditions of the effects of a low Ca:P ratio on calcium absorption and bone loss, and on the effects, if any, of a change in diet in reversing this process. Several specific research projects are recommended to obtain data on the effects of Ca:P ratios. (See Workshop Proceedings.)

2. Trace Elements

Many trace elements are known to be essential to adequate nutrition: copper, chromium, iodine, iron, manganese, molybdenum, selenium, zinc, and fluoride (NRC, 1980). The recommended levels for these nutrients are given in Table 1. Also given are the threshold levels for toxicity from these same elements. In two cases, copper and selenium, the toxic levels are less than ten times in excess of the required amounts. Fluorine has a slightly wider margin of safety. Molybdenum can interfere with copper metabolism at fairly low levels. Chromium is known to be toxic; however, the threshold level for toxicity has not been determined (NRC, 1980).

Other trace elements — nickel, vanadium, silicon, tin, arsenic, and cadmium — are essential to other higher animals, but have not yet been proven to be essential to man. Many of these elements are known to be toxic at low levels. The trace elements in a CELSS will have to be carefully controlled to avoid toxic buildup of some elements through the recycling process. Since the design of the equipment for the CELSS is still in the conceptual stage, a monitoring system for analyzing trace elements, so that toxic buildup would not occur, should be included. Similarly, it is important to prevent depletion of trace elements through the filters, distillation apparatus and ion exchangers used in the water recycling process. The control of trace elements will depend on the specific materials, and designs, that will be incorporated in the water recycling system. There are already specific areas of concern, for example, cadmium toxicity. To date, there is no evidence which would indicate that requirements for trace elements will be any different for long-duration missions than for the Earth-normal situation.

TABLE 1
TOXIC LEVELS AND RECOMMENDED DIETARY ALLOWANCES
FOR TRACE ELEMENTS

Element	Toxicity	Recommended Dietary Allowance — mg
Copper	> 10 mg/day	2-3
Chromium	?	0.150
Fluorine	20 mg/day	1.0-1.5
Iodine	Up to 1 gm/day considered safe	0.15
Iron		
— Males	Food toxicity is low	10
— Females	Elemental toxicity can be lethal	18
Manganese	400 mg. Dust is toxic	2.5-5
Molybdenum	10-15 mg/day due to copper antagonism	0.25
Selenium	> 0.2 not recommended habitually	0.05-0.20
Zinc	2000 mg. Moderate excess aggravates copper problems	15

3. Vitamins

Vitamins are required in microgram or milligram amounts which can be easily resupplied from Earth if they are not present in adequate amounts in foods. Certain vitamins are particularly important in a CELSS. Vitamin D is essential to maintain calcium homeostasis. Because the crew may not be exposed to natural ultraviolet radiation, vitamin D should be supplied artificially. The required supply range to avoid deficiency or toxicity is narrow (400-1,000 International Units per day).

Data indicate that under stress the need for vitamins C and E and for folic acid is increased (H. Sauberlich, Personal Communication). Vitamin E reserves would be the first to be depleted, particularly if the atmosphere has an increased partial pressure of oxygen and/or if the diet is high in polyunsaturated fatty acids (Calloway, 1975). Also, oxygen and other atmospheric changes could affect hemoglobin levels, which could affect iron needs, particularly among the female crew members. Potential vitamin deficiencies should be monitored through a regular crew health assessment program.

If the foods consumed in space change radically from Earth-normal, the requirement for certain vitamins will also change. For example, energy needs are related to requirements for thiamine, riboflavin and niacin; high protein increases the need for vitamin B₆ — (2 mg/100 gm protein). Drugs also can alter the need for specific vitamins. With fat-soluble vitamins, an excess of supply can lead to toxicity.

In general, vitamins in CELSS could be supplemented by resupply from Earth as long as the system is adequately monitored to prevent either a deficiency or toxicity due to mission-specific circumstances.

D. FUTURE PROJECTS

Much work remains to be done to support the construction of a CELSS which will provide the nutritional needs of the crew. Many ideas for research projects thought to be necessary to the development of a CELSS have been introduced, both at the Workshop and in this report (see Table 2). Some ideas have been presented in considerable detail (see Workshop Proceedings*); others have been suggested in conceptual form. In addition, preliminary categories for research projects have been established in anticipation of establishing priorities for the research required to support CELSS development.

*Under separate cover.

TABLE 2
SUGGESTED RESEARCH PROJECTS

	Unique to CELSS Needs	Type of Facility				
		Lab	Clinic	GBD	Shuttle	SOC
Energy						
Test for tolerance of large amounts of glycerol; recycled foods	+		X	X		
Animal study on efficiency of food utilization in zero g	±				X	X
Measure energy utilization with 5 meals a day under various working conditions	±			X		
Measure RMR before and after mission	-				X	
Test utilization of glucose, glycogen and fatty acids at start and end of mission	-				X	
Determine energy needs for electrolyte maintenance	-				X	
Protein						
Determine optimal protein level by use of liquid diet; determine minimal level	+		X		X	X
Effects of protein level on Ca, P, Mg, N balance	±		X		X	X
Use of new methodologies to determine protein loss	±		X		X	X
Effect of stress on protein turnover	±	X	X	X	X	X
Effect of stress and hormone changes on nitrogen loss	-	X	X	X	X	X
Effects of low protein diets biochemically, hormonally, and effects on mineral metabolism and serum amino acid levels	-		X		X	X
Calcium						
Neutron activation analysis of man and/or dogs before and after mission to determine calcium turnover	+				X	X
Effect of increased dietary calcium on bone mineral content during a mission	+				X	X
Effect of protein or fat restrictions on calcium loss	+		X		X	X
Effect of Vit D ₃ administration on bone loss in bed rested patients	±		X			
Compare changes in body composition seen with changes in dietary levels of Ca, P, Mg, N, and ratios of Ca/P/N, Ca/Mg, and Ca/fat	±		X		X	
Measure parathyroid hormone, Vit D ₃ , calcitonin, corticosteroid and alkaline phosphatase levels in man	-		X		X	
Trace Elements						
Determine concentration and/or dilution factors of trace elements in CELSS	+	X		X		X
Develop procedures for selective removal of toxic elements	±	X		X	X	
Determine rate of utilization and excretion of minerals in zero g	±			X	X	X
Determine trace elements excreted with lost calcium	±		X			
Assessment and Monitoring						
Develop measurement techniques which correlate nutritional status with performance: strength, vision, immune competence	±		X		X	X
Determine effect of nutritional status on performance in space	±				X	X
Physiological Stress						
Effect of working environment on stress levels	+			X	X	X
Establish appropriate methodologies to assess mental and physical performance	+				X	X
Impact of stress on requirements for vitamins C and K	±			X	X	X
Training methods to improve handling of stress	±			X	X	X
New methodologies to studies stress-related blood parameter changes in zero G: hemoglobin, blood lipids, iron, folacin, and trace elements	±				X	X
Effects of illness and death on crew behavior	-				X	X
Food Acceptability						
Training for taste testing of actual food products before, during, and after mission	+				X	X
Evaluate changes in taste performance during extended missions	+					X
Determine limits of tolerance for recycled foods or engineered foods in a ground based setting	+			X		
Training for taste testing of standard solutions in space	±				X	X
Evaluate acceptability of limited menus for extended periods	±			X		X
Determine the effect of the environment (light, color, design, etc.) on perception of acceptability	±			X		
Evaluate salivary gland activity	-				X	X
Food Technology						
Adapt cooking processes to meet free-fall conditions	+			X	X	X
Develop equipment to measure, weigh, and prepare foods in space	+			X	X	X
Establish food preparation and service techniques	+			X	X	X

+ = most likely important to CELSS needs.
± = may be important, depending on the exact nature of the project and the type of CELSS.
- = not likely to be critical to CELSS needs.

Notes:
GBD = Ground-based Demonstrator
SOC = Space Operations Center

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IV. DIETARY GOALS

A. INTRODUCTION

Dietary goals will be established for extended missions as a basis for encouraging and monitoring the consumption of food to assure optimal health and performance. In an emergency, the body may tolerate wide variations from an optimal diet, but during extended missions it will be necessary to refine the diet to accommodate the altered environmental constraints. Therefore, dietary goals form a bridge between nutritional requirements and the food service system which will be designed to produce the food.

The USDA has issued a series of guidelines to encourage the general population to eat a better balance of foods to improve long-term health effects. These general guidelines suggest the following: eat a variety of foods, cut down on sodium, cut down on animal fats and cholesterol, cut down on sucrose, and eat more dietary fiber (USDA, 1980).

B. USDA GOALS AS ADAPTED TO SPACE MISSIONS

(1) *Eat a variety of foods.* Man needs about 40 different vitamins, minerals, amino acids, essential fatty acids and an adequate supply of calories (from carbohydrates, fats, and proteins) for proper body functioning. These nutrients are in the foods consumed and some (vitamins and some minerals) can be provided in the form of supplements.

No single food item supplies all the essential nutrients in the amounts needed. The greater the variety, the less likely that there will be a deficiency or an excess of any single nutrient. Variety also reduces the likelihood of being exposed to excessive contaminants in any single food item.

In reduced-g, inactive crew members may eat little food so that extra attention must be paid to ensure that the diet is high in nutritious foods and low in foods which provide calories but very little else. Sufficient exercise and increased metabolic activity would mitigate this problem.

In an Earth-normal situation, the best way to assure variety and a well-balanced diet is to select different foods each day from the basic food groups. In a mission this may be more difficult because of the limited menu available. Also, the nutrient value of the foods may be reduced during food processing and storage. If a few simple foods are produced in CELSS, there will be a desire to maximize consumption of these foods to justify their production on economic grounds. However, with frequent sources of resupply, with good food processing, careful menu planning, and supplementary vitamins when necessary, it will be possible to assure adequate amounts of all known nutrients.

20

(2) *Maintain ideal weight.* It is well known that people who are more than 25% over their ideal weight have increased frequencies of chronic disorders such as high blood pressure and diabetes, and increased levels of blood lipids. All of these are associated with increased risks of heart attack and stroke. In the Earth-normal situation, a large proportion of the adult population makes attempts at weight reduction and, to a lesser extent, weight gain.

In a mission, selection criteria will most likely include ranges for acceptable weight which will rule out those individuals with a high risk of developing disease due to overweight. The crew should be monitored during a mission for signs of significant changes in body mass. There are two reasons for this: (1) rapid weight change can signal a medical problem which would have to be treated; (2) a large weight change would increase the difficulty of readjusting to one-g upon return to Earth.

(3) *Avoid too much fat, saturated fat and cholesterol.* High blood cholesterol levels are associated with increased risk of heart attack. Americans tend to choose diets high in saturated fats and cholesterol and therefore tend to have high serum cholesterol levels. Individuals within this population usually have greater risk of heart disease than people eating low-fat, low-cholesterol diets. While there is some correlation between consumption of saturated fat and cholesterol and risk of heart disease, the exact importance of each factor has not been established scientifically. Consequently, there is controversy about the levels of saturated fats and cholesterol which should be recommended for healthy Americans.

In a mission, this guideline may be easy to fulfill because of the large number of processed and formulated foods that will be incorporated into the diet. The fat level in these foods can be controlled or altered. However, astronauts have craved foods that are high in animal fats, such as meat, ice cream and butter, so there may be a conflict between what crew members will prefer to eat and the optimum diet for their health.

(4) *Eat foods with adequate starch and fiber.* To cut back on fats, it is necessary to meet caloric needs by increasing carbohydrates. In particular, complex carbohydrates are recommended because in addition to calories, they provide more essential nutrients than simple carbohydrates, i.e., sugars.

USDA also recommends an increase in dietary fiber through addition of complex carbohydrates. Dietary fiber is generally defined as the sum of the indigestible carbohydrate and carbohydrate-like components of foods, including cellulose, lignin, hemicelluloses, pentosans, gums and pectins. These nondigestible fibers provide bulk in the diet and aid elimination. Although there is no demonstrated metabolic requirement for dietary fiber, its physiological significance has not been adequately explored.

Dietary fiber consumption has decreased in developed countries, including the United States, since the turn of the century. It has been claimed that the incidence of a number of diseases, most notably diverticulosis, cardiovascular disease, colonic cancer, and diabetes, is inversely related to dietary fiber consumption. Many hypotheses have been proposed to explain a possible role of a lack of fiber in the development of these diseases, but they have not been proven experimentally (Spiller and Amen, 1976; Roth and Mehlman, 1978).

Because of the lack of conclusive data, it is not yet possible to recommend a specific level of fiber intake for the Earth-normal situation. Rather than marked dietary changes, moderate increases in dietary fiber consumption achievable by increased consumption of vegetables, fruits and whole-grain cereal products are suggested (NRC, 1980).

Further research is required to assess the risks of a low-residue diet over long periods of time. It will be possible to increase the amount of fiber in the diets by increasing the amount of complex carbohydrates. This could make waste recycling in CELSS more difficult, so it is important to determine the effects of low-residue diets over long periods of time so that a desirable fiber level can be established.

(5) *Avoid too much sugar.* The major health hazard of too much sugar consumption is dental caries. The risk of caries is related to the frequency of eating sweets — especially if these are between-meal snacks which stick to the teeth. Frequent snacks of sticky foods and day-long consumption of soft drinks may be harmful to the teeth. In reduced-g, sticky foods are popular because they do not produce crumbs; these foods may be highly cariogenic. Careful hygiene is particularly important in a mission because of these factors.

Reduction in sucrose intake may decrease acceptability of foods. For example, if water is recycled, soft drinks may be more acceptable than deionized or distilled water (both have a flat taste). When the effects of increased intake of sucrose on health are better known, it will be easier to develop appropriate diets in the context of a CELSS. If the chemical synthesis of glycerol or other simple sugars becomes feasible in a CELSS, the health effects of consumption of these components as a function of quantity and time will have to be determined.

(6) *Avoid too much sodium.* The major hazard of excess sodium intake is for persons who have high blood pressure. These individuals comprise approximately 17 percent of the adult population. In populations with low sodium intakes, high blood pressure is rare. In contrast, in populations with high sodium intakes, high blood pressure is common. Low-sodium diets might help people who are prone to high blood pressure from developing it.

The typical American diet contains about 6 grams of sodium per day. Diets for previous missions have contained similar high levels, generally delivering 5 to 6 grams per day. It is important to keep sodium levels moderate because of the need to avoid blood pressure increase and difficulties associated with retaining too much fluid in the body.

The space shuttle program allows for the free use of salt solutions and also provides some highly salted foods (C. Stadler, Personal Communication). It will be possible to control sodium intake by not providing such highly salted foods, as previous crews have not craved salt. Reduced sodium intake levels are unlikely to result in lowering food acceptability.

(7) *If alcohol is permitted, drink in moderation.* Alcoholic beverages tend to be high in calories and low in other nutrients. Moderate drinking can frustrate efforts to achieve an ideal weight in people who are otherwise consuming acceptable amounts of food.

Heavy drinking causes more serious problems such as cirrhosis of the liver and poor intake of foods, which, in turn, causes vitamin and mineral deficiencies.

There is no indication that an alcohol consumption policy is being developed for missions. The effects of alcohol consumption in reduced gravity will need to be established and compared with effects in an Earth-normal situation.

C. ADDITIONAL GOALS FOR OPTIMAL NUTRITION IN SPACE

In addition to the above-named goals which are adapted from the USDA Dietary Guidelines, two other goals emerge from the research done on prior missions:

(1) *Determine optimal protein level and reduce protein intake to conform to this level.* This could have two beneficial effects. The first is to reduce excess water retention. The second is to reduce calcium losses. It is known that high levels of protein lead to negative calcium balance. (See Section III-B-1.) It is also known that when the astronauts on Apollo and Skylab selected their own menus, the protein intake of some of the men was as much as 150 to 200 grams a day (J. Kerwin, Personal Communication). This level corresponds to 600 to 800 calories of protein on a 3300-calorie diet, or 18 to 24 percent of the total diet.

(2) *Reduce the calcium-to-phosphate ratio.* This will require both a decrease in the amount of phosphate (decreased consumption of meats and nonphosphate-containing soft drinks) and an increase in the intake of calcium (dairy products and tablets). Since phosphates are present in a wide variety of foods, the emphasis will be on increasing the intake of calcium. Reduction of the calcium-to-phosphate ratio to a range of 1:1 to 1:2 could improve calcium retention by the body.

These dietary goals should be considered as guidelines and most likely will be amended as more is learned about diets to achieve optimal health in space missions. The evolution of dietary guidelines for extended missions will parallel their evolution on Earth. Data which meet Earth-normal conditions should be re-interpreted in light of the results of research to be carried out in support of nutritional experiments for future missions as part of the CELSS development program.

V. FOOD ACCEPTABILITY

A. INTRODUCTION

Adequate food consumption in a CELSS will be necessary to maintain optimal health, achieve desired performance, and ensure the effective functioning of the crew during extended missions. It is also critical to the crew's social and psychological well-being. The diet must provide a source not only of energy and adequate nutrition, but also of the intrinsic pleasurable factors of sensory satisfaction, comfort, companionship, and social interactions.

No scientific method has yet been developed that will predict precisely what group of people will want to eat which foods at a specified time during a given period. There is no reliable method to determine with a desirable degree of accuracy the level of acceptance of a food product by a population. Progress has been made in developing methods to test the acceptability of specific foods with selected groups of people. These methods, however, while applicable to rating acceptability of foods in unusual circumstances have not been applied to extended mission planning and CELSS development. The challenge that CELSS presents, therefore, is the development of suitable acceptability test procedures applicable to the selection of foods and beverages to be served to the crew engaged in specific missions.

The basic lesson from past experience with various diets over extended periods of time under stressful or unusual conditions, including combat, expeditions, prisons and hospitals, is that the higher the level of distraction and/or threat to life, the less important is the issue of food acceptability. When the distractions were low, as for example in nuclear submarine duty or on oil drilling platforms in the Arctic, foods which were acceptable under standard testing conditions became unacceptable. Clearly, any acceptability testing as part of a nutritional strategy for CELSS would have to be done under carefully simulated conditions taking into account previous terrestrial experience with food acceptability.

B. FACTORS INFLUENCING ACCEPTABILITY OF FOODS ON EARTH

1. Perception

Food acceptability can be defined as the measure to which a food, beverage or confection gives continued satisfaction. Among the components that influence satisfaction are the perceptual aspects, i.e., the way the food smells, tastes, chews, feels, looks and the extent to which it satisfies preconceptions of its healthfulness and safety. In addition to being acceptable, foods and beverages have to impart a certain degree of familiarity and not appear to be bizarre or unusual. Also, a fresh appearance — indicated by color and texture — is a highly important characteristic of foods.

2. Serving

The presentation of the food or beverage influences the degree of acceptability. As part of a given menu cycle, for example, it would be desirable to avoid serving beef stroganoff with creamed celery and a custard with little texture and color differentiation, because such a combination would have limited eye appeal. Suitable and attractive dinnerware on which the food is tastefully arranged and easily handled, and attractively styled utensils are important. Above all, to avoid monotony there must be a variety in both the content of the meals and the serving temperature of the foods and beverages. Finally, individuals may desire a change in the ambience and a choice as to whether or not to eat in a social setting, e.g., mess hall.

3. Preparation

Acceptability of a given food or beverage can be influenced by the manner in which it is prepared, not only to meet the required end result, i.e., type of cooking and degree of cooking, but also in terms of the cutting, slicing, removal of fat or waste. If the type of food to be served requires preparation near the area in which it is consumed, great care has to be exercised to keep these operations as pleasant and attractive as possible.

4. Psychological Needs

Eating involves various degrees of psychological preparation which may be influenced by family and ethnic customs, peer group behavior and social pressures.

Food acceptability and the resulting food selection behavior may not necessarily lead to individual choice of nutritious and well-balanced diets. Basic foods (e.g., bread, potatoes, meat) can be acceptable over a long period of time even when served repeatedly. Most novel or unusual food products, e.g., different ethnic foods, have a short lifetime, after which they begin to lose acceptability. Changes in food acceptability occur only slowly. Therefore, foods should be selected to maintain acceptability over a long period (e.g., hamburger), while recognizing short-term acceptability of those foods which are served to provide variety, to reward, or to promote positive social interactions. (Rozin, 1977, also see Workshop Proceedings.) A limited menu may be acceptable for a short time but acceptability and morale would deteriorate if the variety of food is not increased for an extended period.

C. FACTORS INFLUENCING ACCEPTABILITY IN CELSS

1. Source of Foods

To meet requirements a suitable combination of Earth-produced foods, conventional foods, and foods produced in CELSS may be desirable. Even if a CELSS is nearly self-sufficient, supplies of stored water and conventional foods would be needed during the start up of food production and as a reserve in case the food production system should fail. The types of foods that could be supplied include:

Conventional: fresh vegetables, fruits, baked goods, etc., freeze dried, thermally stabilized, or frozen.

Unconventional: cultured animal and vegetable products, produced hydroponically from conventional plants, or from algae, microbes, or aquaculture.

2. Consumption Patterns

Crew members will be eating basically a similar diet, although the caloric level and the time of consumption of the various food items may vary, depending on crew duties and energy consumption requirements. This diet will include snacks, beverages, and regular meals which may be served in a dining hall setting as well as being available on demand or in fast food service situations. To achieve increased food acceptability, it will be important to introduce food variety with different ways of preparing foods, different types of flavorings, textures, appearances, aroma, temperatures, and presentation.

3. Unique Crew Needs

Reduced-g and different crew activity levels create unique physical and psychological needs that will have to be satisfied. The physical needs, for example, will include a reduced-calorie diet for some of the less mobile workers. Unfortunately, reduced-calorie diets tend to be less appealing. The physical limitations dictated by the reduced-g may make the simple mechanics of eating difficult and frustrating for some crew members. The psychological need to maintain a continuity in life style may have to be provided by food service facilities designed to provide a social setting for the crew members.

4. Composition of the Crew

Crew members who are to be served may include members with different ethnic backgrounds. However, until the probable ethnic composition can be defined, considerations of food acceptability should be based on U.S. food acceptance patterns.

The types of activity being performed by the crew may lead to some segregation of food composition and thus different food acceptability criteria. For example, the composition of the crew could be as follows:

Staff Division	Percentage of Crew	Age Group
Administrative Personnel	10	35-40
Construction Crew		
performing manual and remotely		
controlled assembly tasks	60	25-35
Service Personnel	30	35-45

Approximately 90% of the inhabitants could be construction workers and service personnel who, as a group, may demand a different variety than the 10%

administrative personnel who, as a group, may be more amenable to eating recycled or unconventional food items. Permission acclimation to the food to be served during the mission would be necessary for all crew members.

5. Food Attributes

In the selection of foods that will be acceptable, certain attributes should be avoided, such as satiation, flatulence, and other physiological changes, including overstimulation. For example, the use of foods high in sulphur content, e.g., onions and garlic, while acceptable on Earth, may have to be limited in CELSS. Similarly, consumption of alcoholic beverages, while being acceptable on Earth, will have to be controlled but not necessarily eliminated.

D. TASTE PHYSIOLOGY

To meet nutritional requirements and attain the dietary goals, data will have to be obtained on the degree to which appetite will be affected by the reduced-g environment. There have been many anecdotal reports of changes in taste perception in past missions. For a long time, the hypothalamus has been associated with the hunger and satiety centers of the brain. The destruction of the ventromedial area of the hypothalamus is associated with a tendency toward increased feeding; conversely, destruction of the lateral area leads to aphagia which is partially but never completely overcome (Anand and Brobeck, 1951; Mabel *et al.*, 1966). These "centers" are, however, only a part of the feeding stimuli; while the hypothalamus influences feeding control, it does not itself substantially control food intake either in the long or short term. Higher control resides at least to some extent in the pituitary (Morrison, 1977; DeWys, 1977).

On Earth, changes in taste perception can occur as the result of physiological functions. Such a change is evident in many patients with neoplastic disease. Studies on taste profiles of cancer patients show an increased sugar threshold and a decreased urea threshold. These taste perceptions change the patient's acceptance of foods, leading to decreased food consumption, which exacerbates the cachexia (DeWys, 1975; Carson and Gormican, 1977). In addition, the decreased appeal of the foods leads to decreased gastric secretions and poorer digestion.

Gorshein (1977) has shown that hypophysectomized patients have exactly the opposite response to taste as do cancer patients; namely, an increased urea threshold and decreased sugar threshold. These observations support the hypothesis that the pituitary gland plays an important part in higher-level control over the development of taste abnormalities. These studies lead to the possibility that drugs which affect the pituitary could affect taste perceptions and appetite.

One can hypothesize from these studies that flavors can be altered to compensate for these changes. Similarly, if there are physiological alterations in taste due to factors such as absence of gravity, increase in stress, etc., foods could be altered to compensate for these changes. It is important to evaluate and quantify these findings, and to design experiments to obtain further data during future missions.

E. AN APPROACH TO TESTING FOR THE ACCEPTABILITY OF FOOD PRODUCTS

1. Food Taste Changes

To maintain optimum nutrient intake and optimal health, it is not enough to provide nutritious foods. It is also essential that the food be palatable so that it is eaten. This is not a major problem in a normal Earth situation. In a mission, many factors relating to nutrient intake would change. The food will be processed differently; it will be stored, prepared, and served differently. Food produced in a CELSS will be different; it may include, for example, plants genetically engineered to flourish in a reduced-g environment. Finally, as previously indicated the same food may taste different. It is therefore important that changes in food taste be evaluated both qualitatively and quantitatively so that the flavor system of the foods which will be developed for future missions can be constructed to assure a high degree of food acceptance.

The following types of experiments could be carried out:

- *Testing of standardized solutions to detect the presence of any physiological changes in the taste buds.* In this study, the taste of various concentrations of a solution containing four basic tastes — bitter, salt, sweet, and sour — could be evaluated. These tests could be performed by crew members in Earth-normal conditions, and during a future Space shuttle mission.
- *Evaluation of changes in taste preference of foods during extended missions.* Information on taste changes can be verified and quantified using a model of acceptability testing which has been developed by Arthur D. Little, Inc., and applied over many years to foods developed for the consumer market.

2. Research on Acceptability of Specific Foods

Research conducted already in 1953 by Arthur D. Little, Inc., led to the development of five criteria for general flavor acceptability (Sjostrom and Cairncross, 1953). These guidelines were developed from an evaluation of a broad variety of consumer products. They encompass national and regional brands, as well as those products which enjoy only minimum brand and flavor acceptability as determined by market share. The following criteria for flavor acceptability are based on general characteristics of acceptability, and not specific preferential characteristics:

- Flavor should develop rapidly in the mouth.
- Flavor must be appropriate to the product.
- The flavor should be fully blended and complex.
- Off-notes, which are bound to appear, should occur neither first nor last in the spectrum.
- There should be a rapid disappearance of flavor from the mouth.

Several of these criteria have been found to be very important to the long-term acceptability of a food product, especially the complexity and fullness of flavor, the appropriateness of flavor, and the rapid disappearance of flavor in the aftertaste.

The entire research protocol — i.e., definition, diagnosis, and test — is an iterative one. By using objective and descriptive sensory equipment methods, coupled with consumer testing under carefully controlled conditions, it should be possible to develop highly acceptable food products for specific missions.

a. Definition of Acceptability Parameters

As a first step, acceptability must be defined in as exact parameters as possible. These include a description of the product, of the population to be served by the product, and the manner in which the product will be presented to the target population.

b. Diagnosis

The diagnostic task requires trained or expert panel evaluations of the sensory properties of the products. The output of this work is a series of analytical descriptions of each product's aroma, aftertaste, color, texture, and feel in the mouth. In addition, competitive products and experimental variations are subjected to critical evaluations.

c. Testing

Once the analytical definition of the sensory attributes of the food product has been established, the impact or importance of these attributes on a preselected groups of consumers must be determined, because the overall combination of sensory effects influences the product acceptability. This is done on the basis of a series of tests which simulate the conditions under which the product is consumed. At this time, the product would be consumed under actual conditions of use, recognizing the importance of the total effect of the environment.

The aim of the test method is to correlate the consumer responses with the analytical findings. If both sets of data are positive, there is a high probability that an acceptable food product has been developed. If the consumer response is less than positive, the product can be modified by using the analytical data as a guide.

VI. FOOD SERVICE SYSTEMS

A. OBJECTIVES

The objectives of a food service system are to:

- Fulfill dietary goals by delivering the appropriate nutrients in the form of both meals and snacks;
- Deliver acceptable foods with appropriate sensory attributes;
- Maintain health and safety standards; and
- Provide for unique needs of the mission and activity level of the crew.

The food service system should be designed for a specific mission and to utilize the performance capabilities of a CELSS. The two mission scenarios that were developed in this study (Appendix A) serve as the basis for investigating an approach to food service systems.

There are a number of options for supplying food, depending on the duration of the mission, specifications of acceptable foods, the menu cycle, and the food-service system (Table 3). To provide the nutritional requirements, a combination of conventional (terrestrially produced) and unconventional (produced and recycled in a CELSS) foods will be selected. Stored supplies of water and conventional foods will be needed during the start-up of food production and as an emergency reserve to provide sustenance if the CELSS food production systems fail.

It is assumed that a CELSS for a GEO construction base could be designed to meet the requirements of such a long-term mission. However, even with recycling capabilities, stored food and food resupplies would still be required. A CELSS for a near-term LEO SOC would primarily function with stored foods, although limited recycling of some foods may be possible.

B. INTEGRATION OF FOOD PRODUCTION WITH CELSS

Depending on the mission and the development of the technology, the CELSS may be partially open or fully closed. (See Appendix A.) Because a partially closed CELSS will require increased resupply of food, make-up water, and atmospheric constituents, it may be more desirable in a GEO CELSS to provide for nearly complete closure for water recycling and atmosphere regeneration. The degree to which CELSS-produced foods will be used will depend upon the innovations in food production. For example, using one set of assumptions, wheat may be the most cost-effective food that could be cultivated and grown (Mason, 1980), while other foods (vegetables and fruits) could be produced in limited quantities.

Based on the experience gained to date in the US and USSR space programs, modifications of conventional, freeze-dried, thermally stabilized, and frozen convenience foods could provide the basis for a food service system (Figure 1). However, to

TABLE 3

FOOD SERVICE SYSTEMS

System Components	Options	LEO (By 1990)	GEO (By 2000)
Food Types – Earth Supply	Stored Conventional Food – Fresh – Shelf Stable (Canned, Dehydrated, IMF or Irradiated) – Frozen	Earth Supplied	To be determined
Food Types – Produced by CELSS	– Bacteria/Algae – Plants (Space-Adapted, Sprouts, Hydroponics) – Aquaculture – Animal Husbandry Including Invertebrates	Experimental	Limited
Menu Planning	Advance vs Spontaneous Individual vs Group Minimum Tolerable Menu Cycle Conventional vs Nonconventional Foods	Advance Individual 1 to 2 Weeks Conventional Foods	Limited Choice Group, To be determined, Conventional and Nonconventional Foods
Diet Familiarization	Pre-Mission	Pre-Mission	Pre-Mission

TABLE 3 (Continued)

System Components	Options	LEO (By 1989)	GEO (By 1998)
Service Modes:			
Preparation	Self vs Staff Preparation Scratch Cooking vs Prepared Foods Inventory Control and Supply Management	Self Prepared Simple	Staff Limited Scratch Programmed
Service Types	— Restaurant, Cafeteria, Vending, Self — Cash, Subsistence	Self Subsistence	Mostly Cafeteria Both
Eating	Congregate vs Individual	Congregate	Both
Intake Monitoring	Self vs Staff Implemented	Self	Staff
Waste Handling	Stored vs Recycling	Mostly Stored, Water Recycled	Mostly Recycled

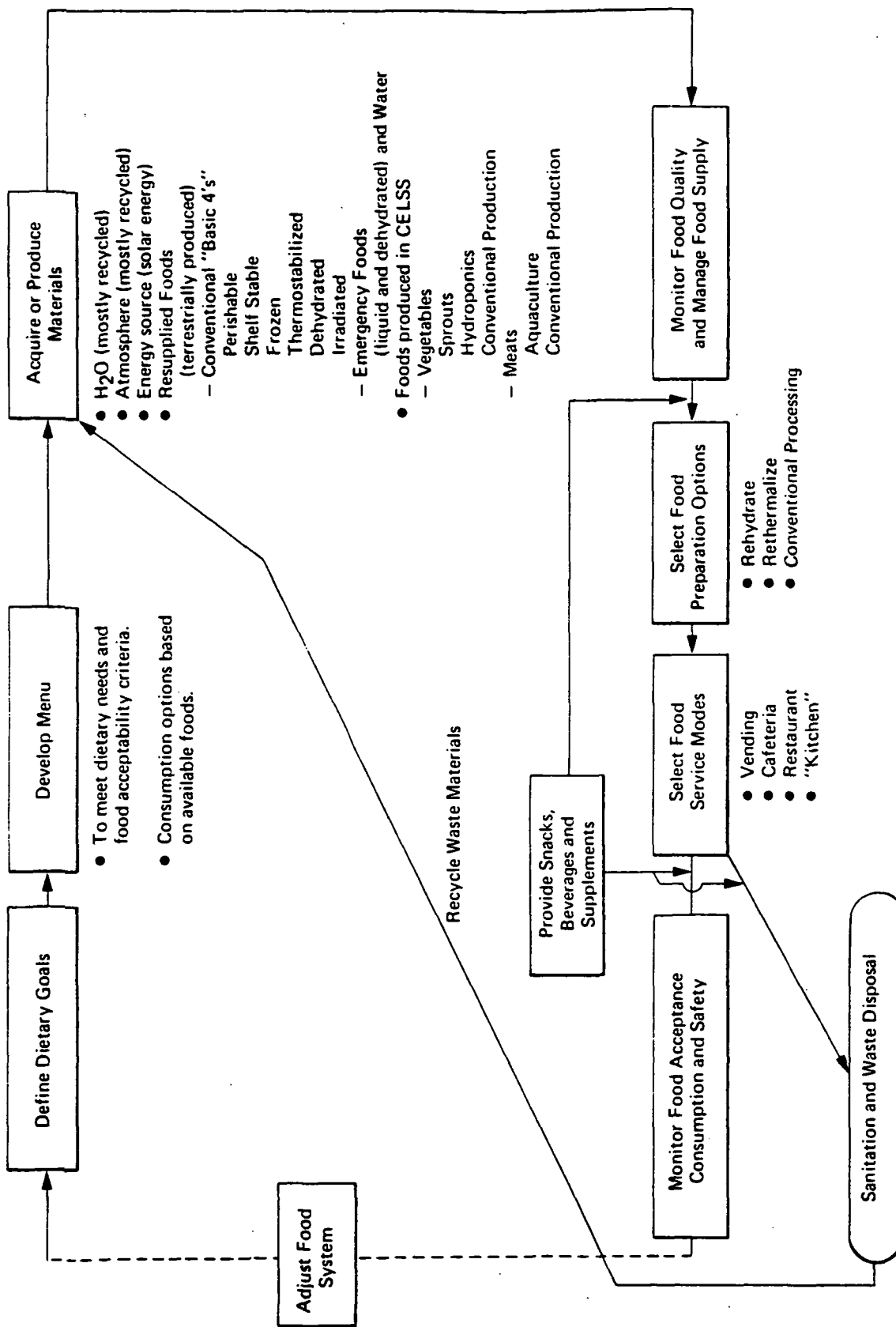


FIGURE 1 CHARACTERISTICS OF FOOD SYSTEM

take advantage of the CELSS recycling capabilities and to reduce cost, the production of foods should be investigated. (See Appendix A.) Figure 1 also identifies the steps in the planning, production, preparation, service, and monitoring of a food system. The system should be designed to meet the defined dietary goals through the development of an adequate menu, the selection of appropriate foods, and consideration of consumption options, in line with the food production capabilities of CELSS, and the various food preparation, service and monitoring options.

For those foods which will be produced in CELSS and recycled, a pattern emerges (Figure 2). The food preparation system starts with the development of a production plan, the acquisition of the appropriate raw materials, either from recycling or from resupply, growing of food, harvesting, storage, prepreparation, service, cleaning, evaluation and monitoring of the production system.

1. Agricultural Products

The breakeven time for growth of different foods will vary according to mass, area, growth rate, edible portion and several other factors (Spurlock and Modell, 1980). This agriculture could be large and complex, or simple and experimental, depending on the needs of the CELSS. Such agriculture can be regarded also as a change of routine for the crew which provides a significant but limited part of the food supply. The sprouting of seeds, such as soybean, alfalfa, and mung beans, is a simple cottage industry and requires only moderate temperature and atmospheric control. No illumination is required in the sprouting stage and a small mass and volume of starting material (seeds) will yield a six- to ten-fold increase in mass. Sprouted vegetable seeds provide an excellent source of fiber and textural contrast. Sprouts could provide a bland matrix to use as a starting material or carrier for additional unconventional foods. Although the effect of reduced-g on the sprouting process is not known, it is apt to be less on sprouted seeds than on any other food system.

Successful experiments in Argentina, Newfoundland, and at the Environmental Research Laboratory in Tucson, Arizona, indicate that certain vegetables could be grown hydroponically (A. Rahman, 1978; M. Jensen, 1980). There is considerable experience with the hydroponic growth of lettuce, tomatoes, and cucumbers. Because of the need to optimize environmental conditions during growth, a CELSS may be of advantage in conjunction with waste processing (Meissner and Modell, 1979). An experimental program on the possible effects of reduced-g on seed and vegetable culture performed as part of future Space Shuttle missions could answer several key questions to determine the feasibility of this approach.

It is highly unlikely that soil-based production of vegetables would be feasible in a CELSS, although at some future date extra-terrestrial soil-based production of grains and vegetables may be feasible. Because grains and vegetables lack essential amino acids they would have to be supplemented by specific amino acids to balance the protein content of the food product.



2. Microbiological Products

A number of microbiological systems show promise for future food production (Lyman, 1967). Photosynthetic systems such as algae may be useful in atmospheric regeneration in near-term applications and will become more attractive for CELSS if useful nutrients can be obtained from the biomass produced. At present, the quality and acceptability of foods derived directly from algae pose problems for human ingestion (Calloway, 1969; Calloway and Waslein, 1971). But there is the possibility of using algal products as nutrients for plants or animals in a more complicated food chain, especially in aquaculture. Some bacteria (e.g., hydrogeonomas) are interesting candidates for use in a CELSS primarily because the growth process is not photosynthetic, making suspension-bulk culture in reduced-g possible. Nitrogen requirements for growth may be provided entirely by urea (recovered from urine). The biomass produced may have a protein content approaching 50%, which is too high for direct human consumption, but bacterial culture could be of interest in advanced systems using relatively complex food chains.

3. Chemical Synthesis Products

Another system which could be used for food production in a CELSS is the direct chemical synthesis of some nutrients (e.g., carbohydrates), such a system, which may become feasible in the near future (Lyman, op cit), might also be used to provide inputs to other types of food production, including production of fertilizers or feeds for use in agricultural systems.

4. Animal Products

Animals should be the last of the food chain to be considered for production in a CELSS. The energy required per calorie of food produced is greater than that for grain or vegetable food sources. Furthermore, the volume, environmental control, and waste disposal requirements are greater. However, if protein intake is reduced in future missions, a large proportion of animal foods could be produced. Reduced protein is one area where dietary goals and CELSS food production capabilities would complement one another.

Fish, shrimp, and small marine animals provide the most efficient biological recycling mechanism for the production of high-quality protein from aquatic plants, algal or bacterial products, or agricultural, food preparation, and human waste. In aquaculture, the mass of the system (water is the carrying medium) is the limiting factor. Research is needed to determine the species which would maximize productivity in this type of a system.

Small animals such as rabbits or chickens may eventually be raised. However, in the near term, it is not likely that animals will be raised for other than experimental purposes.

To develop candidate food production systems, extensive research, including experiments in reduced-g, would be needed. Detailed systems analysis would be

required to determine which of the above systems or combinations would provide the most cost-effective acceptable technology and/or food qualities for CELSS. Each food option would need to be analyzed to determine the mass and volume requirements for equipment and supporting systems, the biomass inventory needed for a given production, the efficiency of energy conversion, the worker time requirement and the degree to which specific foods could be incorporated in a food service system to meet nutritional requirements.

5. Waste Recycling Products

There is an assumption in the design and function of a CELSS that the waste recycling process should be as complete as possible. This goal would require the investigation and development of simple food chains which could utilize bacteria, algae and solar energy to produce foods from waste materials. The resulting foods should be capable of being incorporated in a diet to meet desired nutritional and dietary goals. The food production cycle would have to include harvesting, storage, preparation, service and cleanup. Appropriate technologies to separate nonusable from usable wastes will be required. Approaches towards the development of such technologies are being investigated.

C. FOOD PREPARATION

Assuming that both conventionally and CELSS-produced foods would be available, optimum food preparation techniques would have to be developed.

Both of the Space habitats described in the mission scenarios are near-zero-g facilities. If this environment is found to be unacceptable for operations such as food production, a partial-g environment could be provided by one or more of the following approaches:

- Small centrifuges to create a partial-g field to meet limited food preparation needs;
- Large low-g centrifuges inside a pressure vessel, big enough and rotating slowly enough so that personnel can work inside them for limited periods (The rotation of a pressurized work chamber such as that used in the "Flash 18" aseptic processing might prove feasible.); and
- Rotating sections of the habitat, either connected to the near-zero-g areas by rotating pressure seals or attached by cables to the main habitat (so that EVA would be required to reach them).

If any of these systems are required, the additional mass and cost would be charged to the CELSS, which would reduce its economic viability. In its initial stages, the CELSS will most likely be designed for near-zero-g operation, with centrifugal systems introduced only where essential. However, future missions may utilize a CELSS containing partial-g or even one-g. Food preparations for these missions would

be similar to a conventional system such as used on an oil rig or submarine. The assumption is made that the CELSS will operate in reduced-g (near-zero-g).

Many, but not all, of the effects of reduced-g (in terms of habitability and CELSS design requirements) are predictable by an exercise of the imagination, but gravity is such a pervasive feature of life on Earth that it is easy to overlook even obvious consequences of its absence. Several characteristics of the reduced-g environment include:

- *There is no convection mechanism for heat transfer.* Steady flames are possible only if combustion products are removed by artificial means (e.g., a fan). It is not possible to boil liquids by application of localized heat to a vessel (although it may be possible to bring a liquid close to the boiling point by such means if it is stirred continuously during heating).
- *Liquids and particulate materials must be kept in closed containers.* In particular, closed cups (perhaps with a straw for drinking) are needed for beverages, and dry foods such as cookies should not be served on conventional plates. However, experience in Skylab suggests that viscous and adhesive foods such as stews can, with care, be served in bowls and eaten with a spoon.
- *Many ordinary food preparation operations may require special equipment.* It may be difficult or impossible to pour liquids or dry ingredients such as salt and sugar from one container to another or to transfer them with a spoon. For example, chopping of onions or other ingredients would have to be carried out in closed containers.
- *Ingredients cannot be weighed by conventional scales.* Mass could be measured by inertial devices (such as the resonant spring-mass system used in Skylab), but there may be difficulties because of sloshing or other motion of the sample relative to its container.
- *Restraints are required for all personnel at work stations.*

Figure 3 shows the food sources and preparation requirements as well as the methods of heat application for either cooking or rethermalizing which would have to be developed for the food preparation system.

1. Pre-Preparation of Foods

The behavior of foods stored in reduced-g is not well known, for example, how to open and empty a can of peas. Tasks such as cleaning, peeling, trimming, and capturing the waste and rinse water could present significant challenges. Also, weighing or volumetrically measuring quantities of flour or other ingredients used in baking or for making other staples such as pasta could be difficult.

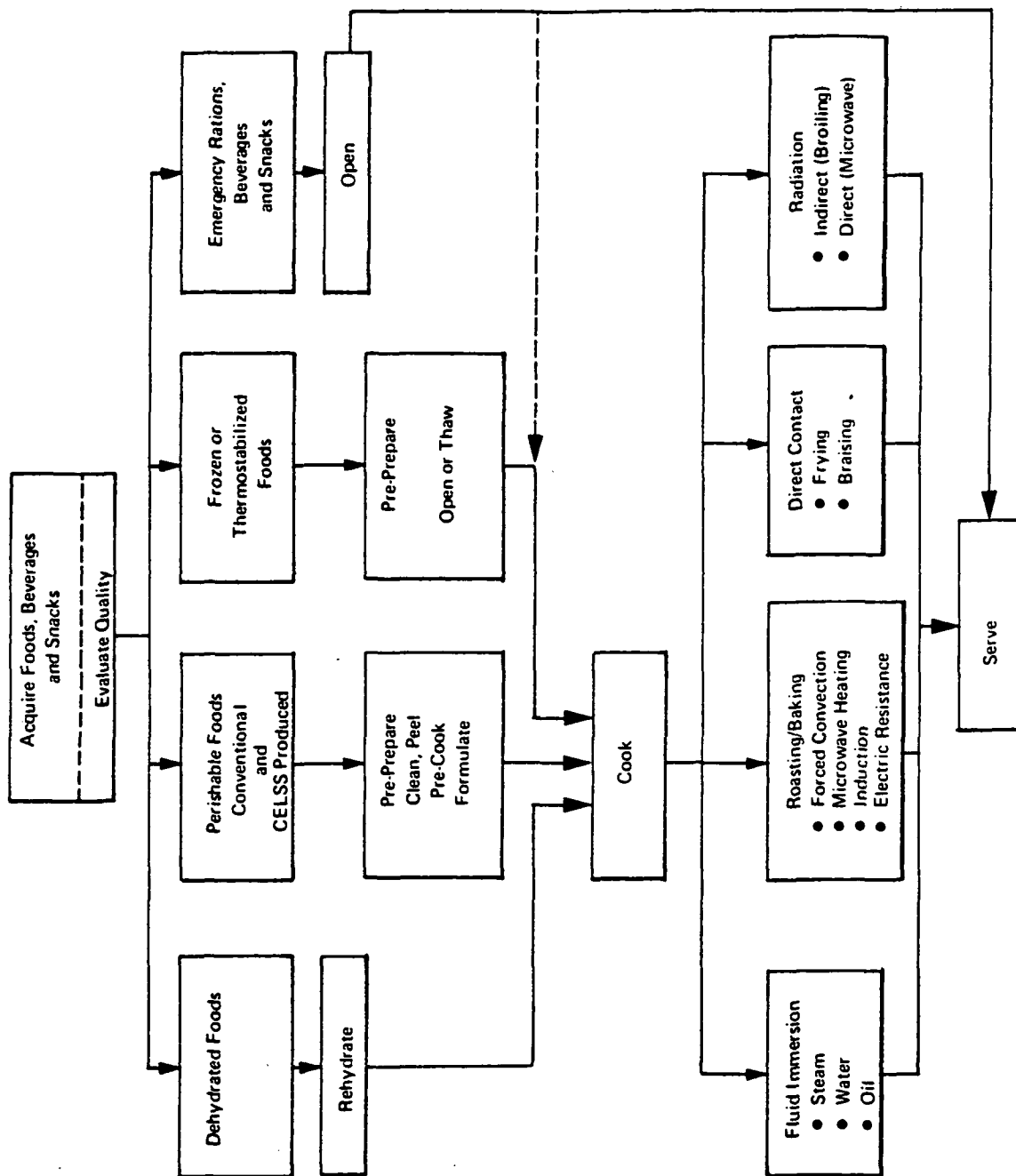


FIGURE 3 FOOD PREPARATION REQUIREMENTS

However, it is quite possible that these challenges could be solved with ingenuity and the experience obtained from previous missions. Key experiments could be carried out in future Space Shuttle missions to confirm the extent of practical difficulties and to indicate how to develop devices for pre-preparation of foods and train crew members in performing the necessary tasks.

2. Cooking Processes — Effects on Foods

There will most likely be some food preparation in long-term missions, due to the decreased acceptability of packaged and highly processed foods. Cooking of fresh foods, when feasible, provides better taste, better nutrition and a wider variety of menus. Foods are cooked, i.e., exposed to the effects of heat, to make them more attractive, more palatable, safer to eat, easier to chew, and in some cases to make their nutrient content more readily available.

Heat is transferred to foods by conduction, convection and direct radiation or heat exchange via the oven walls. An oven is used to bake, roast, or broil meats, and bake selected vegetables, grain and fruit products and combinations (e.g., casseroles). The oven process includes defrosting and warming foods to consumption temperatures.

Cooking processes cause both physical and chemical changes in foods. These changes result generally from temperature increases within the foods, which increase molecular activity and chemical interactions. Such physical and chemical changes affect flavor, texture and appearance, and the nature of these changes determines the success or failure of the cooking process. Success is closely related to the time and temperature of the process and the chemical composition of the foods.

Meat cuts are generally composed of muscle fiber, fat, and bone. There are so many possible variations it is safe to assume that an individual meat portion that is oven processed varies to some degree in chemical composition and therefore requires specific conditions for optimum processing. The composition and general physical/chemical structure of meats is continuously altered during the processing, causing chemical reactions that depend on the time as well as on the temperature of the process.

The oven process of baking is equally complex. Baked goods may be aerated or non-aerated protein structures in which sugar, starch, fats, and flavoring agents are suspended or dissolved. The protein and starch constituents, derived from flour, provided the strength or ability to retain gas and maintain structure.

Heating (baking) batters or doughs in an oven generates and expands gases, evaporates water, gelatinizes the starch, and coagulates the protein.

Fruits and vegetables are plant products, and from a cooking standpoint may be viewed as a single class. Like all other plant tissues, their cells are enclosed in walls of cellulose. Each cell is connected to adjacent cells by a layer of carbohydrate-cementing substance called protopectin.

When heat is applied to fruits and vegetables, they undergo softening and become more digestible as a result of partial disintegration of the cellulose and swelling of starch granules; gross changes also occur in pigment coloration, in the formation of acids, and in the release of sulfur compounds.

Heat processing affects, and sometimes develops, flavor, both desirable and undesirable. Hot water leeches out soluble flavoring components, such as sugar and salts, evaporates the more volatile flavoring compounds, and decomposes the more thermally sensitive components. On heating (in raw cabbage, for example), a sulfur-containing compound decomposes to form hydrogen sulfide, the objectionable odor of cooking cabbage.

Most vegetable processing operations involve the addition of moist heat to the product to assure that the product does not dehydrate and to accelerate the desired effects. Baking such products as potatoes, squash, or vegetable/cereal/meat casseroles utilizes internal moisture for this purpose.

All these are examples of the complexities of cooking processes that must be considered when food service systems for CELSS are being conceptualized.

3. Technologies Applicable to Cooking Processes

a. Evolution

Over the years, the evolution of technologies for cooking foods has been closely tied to available energy resources: first wood and charcoal, which were subsequently replaced by coal, which in turn was supplanted by gas and electricity when these energy sources became widely available. Changes in lifestyle have led to the development of timed controls and self-cleaning ovens and, more recently, the wide acceptance of microwave cooking, resulting in a dramatic decrease in food preparation times. Escalating energy costs have led to the development of more efficiently heated and smaller oven cavities.

New developments, such as induction stovetop cooking, are energy-conserving because the heat is produced directly in the vessel containing the food, reducing cooking times and resulting in a cleaner cooking process. Forced convection is being used in commercial ovens to distribute the heat more evenly, obtain the desired heating rate, and prepare foods. Small ovens with forced convection heating have been introduced as stand-alone appliances capable of cooking small portions of food without heating the traditionally large oven cavity.

b. Oven Cooking Parameters

The following parameters have to be considered for oven cooking processes.

(1) *Time/Temperature Controls.* Time/temperature control is required to produce successful foods. Every non-manufactured food product differs to some extent,

and oven controls of sufficient sensitivity to prepare a wide range of foods are still being improved. Time/temperature controls should be considered in conjunction with microprocessor and sensor technology. The final, or finishing, food preparation steps of manufactured or prepared foods which are portion-controlled and require only heating, or a minimum amount of cooking, could be aided by sensors that would assure proper finish points for frozen, refrigerated, or shelf-stable foods. A microprocessor could be used to "store" cooking sequences that have been developed. This would allow the "cook" to improve cooking sequences on the basis of individual preferences.

(2) *Heat Transfer.* Temperature gradients create the need for continued operator attention and manual operations such as turning meats to assure proper "doneness" and reduce sticking. An atmosphere of steam within the oven cavity can serve as a heat transfer medium.

The variability of the heat imparted to food during the operating time limits the effectiveness of an oven as a good processing mechanism. If heat is applied not just to the bottom but also to the sides of the food, heat requirements can be reduced and efficiency and control increased.

Forced air convection is used widely in institutional and commercial ovens. Many cooking operations are based on dehydration of food, and forced air convection can accelerate that process.

(3) *Hydration.* If water is included in a forced air system, a controlled-humidity atmosphere can be maintained. When dehydration is undesirable, this type of atmosphere will retard it in addition to accelerating heat transfer. Steam in an enclosed system can also function as a food process control and time saver.

(4) *Environmental Consideration.* The use of microwave heating in a CELSS would require meeting allowable levels for continuous human exposure to microwaves. The generation of magnetic fields may also result in, as yet, undefined environmental effects.

(5) *Energy Conservation.* Although the potential for reduction in energy use for cooking may be small, the concern with energy usage will favor the development of cooking methods to reduce energy consumption. Effective use of input power in heating the food rather than the oven cavity and a programmed heating cycle to make the most effective use of the available heat for the desired stages of food processing will assist in reducing energy consumption, while maintaining the desired food quality. It may also be possible to utilize reclaimed heat from condensers in the CELSS.

c. Cooking Equipment Concepts

Several technologies developed for terrestrial cooking processes could be modified for use in a reduced-g environment. The following concepts for cooking appliances indicate the approaches which could be considered to meet cooking process requirements: fluid immersion, roasting and baking and direct contact or radiant heating.

(1) *Fluid Immersion.* Figure 4 shows a concept based on the principle of a pressure cooker or fryer which could meet a broad range of cooking or rethermalization requirements by immersing the food product in water, steam, or oil to obtain the required heat transfer. A retaining basket positions the food product and assures immersion under reduced-g conditions. The heat source could be electric resistance or induction. Induction heating would have the advantage that the energy is efficiently transferred directly to the cooking module without the usual hot elements and the time delay associated with electric-resistance heating during the heating cycles. An airlock would isolate the cooking process from the interior environment. The vent could be part of a heat recovery system to utilize the energy input to the cooking module efficiently. The cooking module would be supplied with a safety valve to control the allowable pressures. Sensors and controls would regulate the time and temperatures required for processing specific food products.

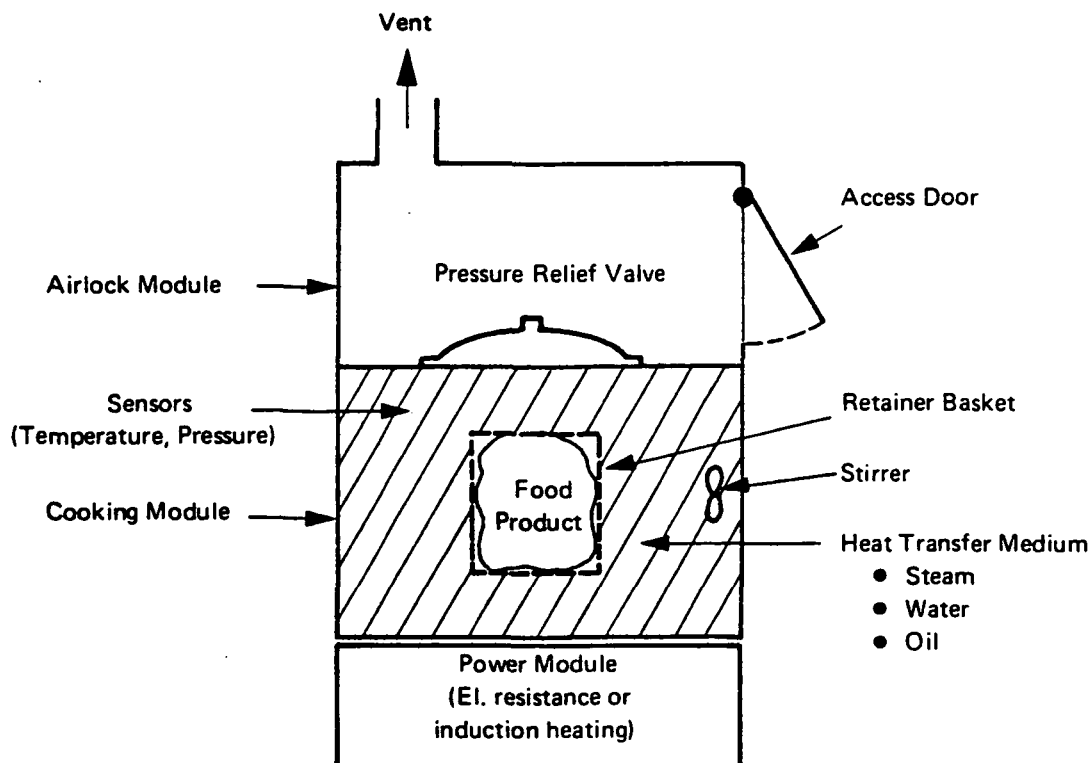


FIGURE 4 FLUID IMMERSION COOKER

(2) *Roasting and Baking.* In a reduced-g environment forced convection would be required for baking or roasting in an oven cavity. Figure 5 shows a combination microwave/forced-convection oven which could be designed to meet cooking process requirements beyond immersion heating, including browning, and duplicate the cooking processes used for a wide variety of food products heated in similar ovens on Earth. A moisture barrier could be included to heat food products with a high moisture content as an option to immersion cooking. Broiling could be accomplished by positioning the food product in a fixture at the desired distance from a broiling element. The element would be heated either by electrical resistance or induction.

Sensors to measure the temperature of the food product and its moisture content could be combined with microprocessor controls to process the food products according to programmed cooking sequences to reduce the variability of the cooking process and assure that the finished product would be acceptable.

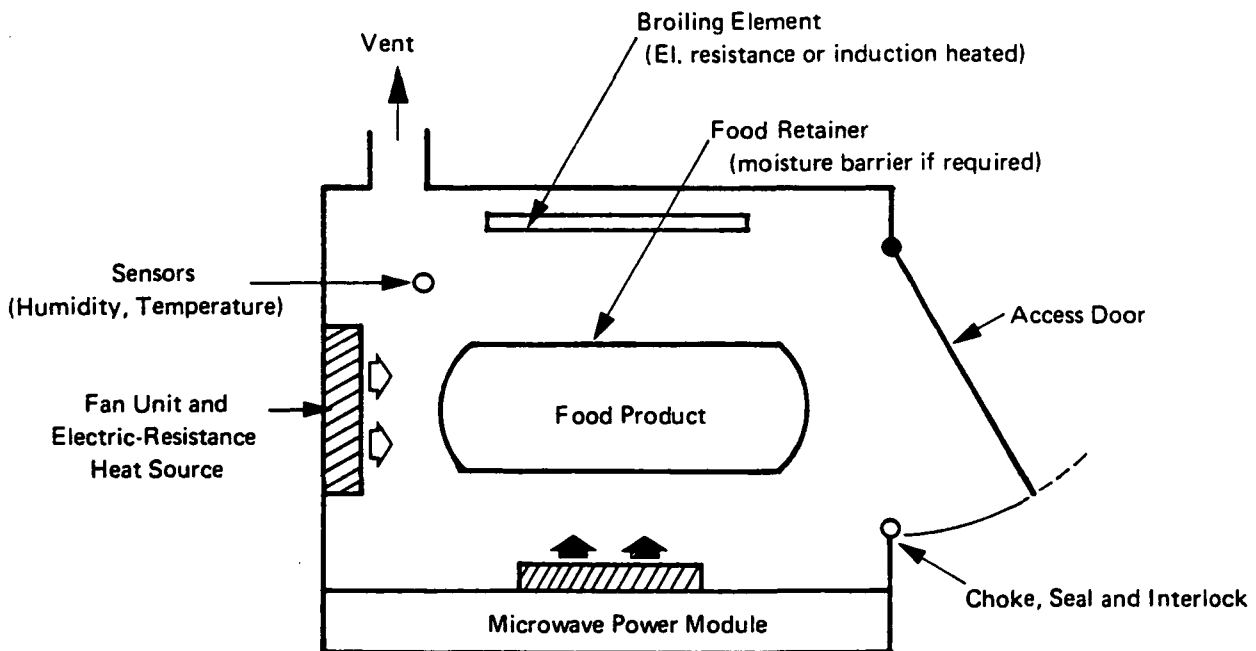
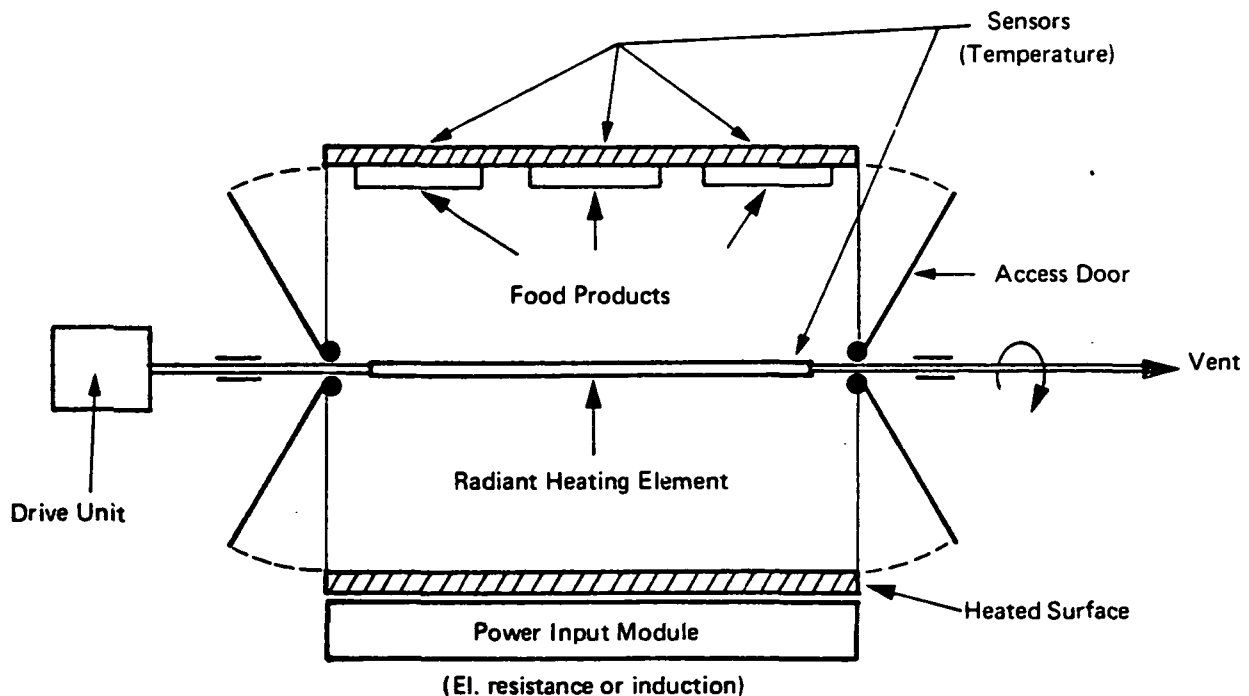


FIGURE 5 OVEN CAVITY FOR MICROWAVE/FORCED-CONVECTION HEATING AND BROILING

(3) *Direct Contact and/or Radiant Heating.* Grilling, frying and similar stovetop processes require heat to be transferred to the food product by direct conduction and/or radiant heating. Typically, the food is heated in a pan or on a hot surface with gravity maintaining adequate contact between the heated surface and the food. In a reduced-g environment this would not be possible. Furthermore, the action of steam forming at the food-surface interface or vapors from the cooking oil used as a heat transfer medium and release agent would propel the food product away from the heated surface. Figure 6 shows the concept of a rotating grill which could create a near-one-g field to confine the food product and provide for conductive heat transfer. The contact surface could be electric-resistance- or induction-heated and a radiating element would be provided at the center. Induction heating of the contact surface could simplify the appliance, as rotating electrical brushes for power transfer would not be required. The cooking surface would be enclosed and access doors would be provided to perform the required cooking operations.

Cooking appliances for use in reduced-g will require considerable development and adaptation so that they can be effectively integrated with CELSS-produced food products. The rapid development of advanced technologies for cooking processes on Earth should be supportive of the efforts to develop a food preparation system for CELSS.



**FIGURE 6 DIRECT CONTACT AND/OR RADIANT HEATING
SURFACE COOKING PROCESSOR**

D. MEAL SERVICE

1. Menu Planning

The type of mission and the meal service options available will greatly influence the menu planning function. Shorter missions could be completely preplanned for each individual on the basis of premission familiarization and choice of diet as in prior missions. It is likely that a wider variety of foods and meal preparation and service modes would be available in future missions. For longer missions, or missions where a variety of meal preparation options would be available, individually preplanned diets are probably not practical nor desirable. Meal service options could include individual and/or team preparation of foods as well as the selection of *a la carte* offerings from a cafeteria or other type of food service operation. Food intake monitoring may be desirable to assure that each individual receives an adequate diet. This could be important if a blend of conventional and nonconventional foods is used, since such a blend may not be acceptable to some individuals, either for sensory, psychological, or physiological reasons.

2. Meal Preparation

There are a number of options with respect to meal preparation irrespective of the food types available. Depending on the crew size and projected meal times, there may be options for an individual preparing meals, a team preparing meals for a small group, or complete meal preparation by a specifically designated food service staff. Depending on the equipment and foods available, the complexity of the meal preparation operation can range from simple rethermalization of convenience foods to cooking of fresh meats and vegetables from either conventional or nonconventional sources. If self-service is considered, crew members would have to be trained in acceptable meal preparation techniques as well as portion control to maintain adequate management of necessarily very limited supplies. However, the psychological impact of being able to prepare one's meals or working as a team to prepare and eat meals might be so satisfying as to outweigh the desire to implement an efficient meal service with a staff-run commissary. In any event, the consumption of a variety of foods by crew members would have to be monitored to assure that nutritional requirements are met and adequate food supplies are maintained.

3. Meal Service Types

A number of food service types are available depending upon the crew size, work schedules, and physical facilities of a specific mission. For missions where there is more than one service form available, consideration should be given to whether all meals should be provided as a subsistence item. If fast food and/or white tablecloth options are available, it might be desirable to provide for social options, which are psychologically beneficial. Possible meal service options include fast food, vending machines, individual or group (i.e., family style), and cafeteria or white tablecloth restaurant formats. Any of the above options could be made part of a mission plan. Their feasibility would be determined on the basis of available mass, volume, labor requirements, compatibility with mission objectives and cost.

Consistent with the desired meal service options, there are basically only two types of eating patterns. These are either congregational eating or eating alone and could be part of any of the meal service options.

4. Meal Service Equipment

The meal service equipment, including dinnerware, would have to fit with the available meal service options and be compatible with sanitation and solid waste disposal capabilities of the CELSS. Because of the volume requirements of disposable dinnerware and waste recycling limitations, it is likely that reusable dinnerware and utensils would be necessary. It may also be desirable to develop specially designed dinnerware to permit food consumption in reduced-g environments. Dinnerware, utensils, and meal service equipment should be fabricated from easily cleanable and durable materials and should be of such construction as to minimize cleaning requirements. The design philosophy which may be appropriate for this equipment could be adapted from dining equipment developed for the handicapped. Experience with such equipment should provide valuable guidance for the design and utilization of equipment in reduced-g missions.

5. Meal Service Sanitation and Waste Handling

Meal service sanitation, food storage, food preparation, and dining areas must be designed to be easily cleanable. The use of detergents and sanitizers should be kept to a minimum to improve the potential for recycling of the fluid waste streams. Although it will be necessary to provide for some chemical sanitization of food contact surfaces, it would be desirable to use simple detergents for soil removal and rely mostly on the use of hot water or a sterilizer for sanitization of utensils, dinnerware and meal service equipment.

To minimize the impact of liquid-carried waste, it will be necessary to provide for scrupulous management of all types of food waste. Depending upon the type of recycling system, waste disposal could vary from incineration of food waste along with other organic material such as feces and urine, to complete recycling of the food waste for use as a nutrient source. The waste materials could be concentrated to form a sludge which could be used for growing crops. Sludge at a level of 10% has been added to soil-grown crops of grains and vegetables. However, the sludge may contain toxic trace elements such as zinc, nickel and cadmium. Depending on the growth medium and system design, some of these trace elements may be taken up by plants which, if part of the CELSS food chain, would be ingested by the crew. Trace elements tend to migrate to organs, particularly to the liver and spleen. Generally, they are not detectable in muscle of animals. A detailed evaluation of trace element contamination of food produced in a CELSS based on recycled wastes will be required to assure that food will be safe for human consumption.

A significant source of solid waste bulk is the packaging material associated with food service. This material may displace a large volume and represent up to one-third of the weight of terrestrial food products. Innovative food preservation or packaging techniques such as ice glazing of frozen foods and the coating of refrigerated perishable

foods with edible glazes should be considered. Depending on the mission, it may be possible to recycle cellulose-based packaging materials for use either as a direct source of fiber in the diet or as a medium for culturing foods.

E. CONCLUSIONS

A properly designed food service system can make living in a CELSS enjoyable and healthful. Foods will have to be provided to crew members in a cost-effective manner. This may include resupply of individual food items, resupply of bulk foods which would be processed and cooked on board, and/or the eventual growth of foods from recycled waste materials. The environment within the CELSS and the type of food supplied will be very important to the health and general well-being of the crew. Each particular food system will be designed to meet the needs of the specific mission for which it is designed. However, pilot studies can and should be started now utilizing the constraints imposed by the mission scenarios to provide sufficient lead time to plan for optimal systems for future missions.

Specific projects include:

- (1) Determination of the optimal food service system for missions described in the mission scenarios (Appendix A), utilizing information from oil rigs, submarines, or other useful analogous situations;
- (2) Development and testing of cooking equipment designed to meet free-fall conditions; and
- (3) Experiments on the Space Shuttle to test equipment designed to measure, weigh, and prepare foods, and to establish food preparation and service techniques.

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VII. PRELIMINARY PROGRAM PLAN

Based on the considerations of nutritional requirements and food technology for CELSS, a preliminary program plan has been prepared (Figure 7). The plan elements are divided into ground-based and space-based activities. The ground-based activities include: establishing the priority of research projects to determine nutrition requirements; establishing dietary goals; determining food acceptability under simulated conditions; designing a food service system, including prototype, fabrication and testing; and establishing a ground simulator test program. This ground testing program would obtain information on acceptable diets, food service systems, and food preparation in a setting which would approximate important aspects of a manned operational facility containing a CELSS.

The space-based program includes shuttle experiments which would be designed to be carried out on an "as available" basis. The experiments would range from simple activities to increasingly more extensive experiments in support of research objectives (Table 2). A space operations center could provide an opportunity to perform more extensive experiments which would be designed to obtain information not obtainable in the ground simulator test program.

The tasks in the program plan elements would be completed over a ten-year period. The information obtained from each element would provide a basis for planning the next step. The detailed definition of the program plan will depend on the mission scenario that will best represent future program directions whether involving the shuttle, a space operation center, or other activities requiring manned operations and a CELSS during an extended period in orbit.

The program plan will have to be integrated with advances made in the nutritional field and food technology to ensure effective use of all information which would maximize the performance, health, and psychological well being of the crews for future Space missions.

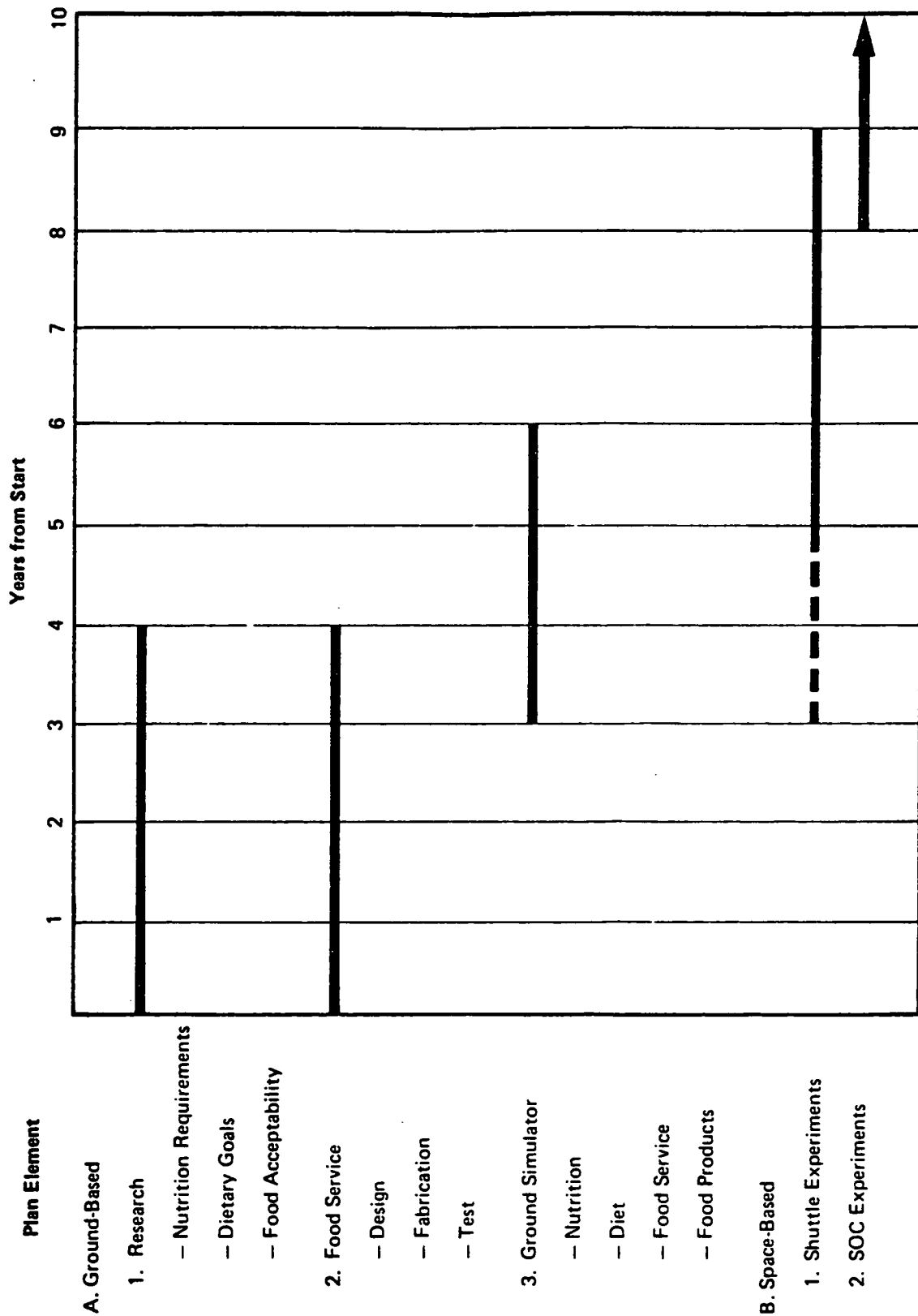


FIGURE 7 PRELIMINARY PROGRAM PLAN

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APPENDIX A

MISSION SCENARIOS FOR CELSS

1. INTRODUCTION

In order to formulate a nutritional strategy for a controlled ecological life support system (CELSS), a plan must be developed that meets nutritional goals under conditions imposed by the technical and economic constraints of spaceflight operations and by the characteristics of the CELSS itself. The range of potential space missions for which the CELSS might be attractive was restricted to Earth orbit, so that extreme remoteness is not a factor in the choice between the CELSS and stored/resupplied food systems.

From an economic point-of-view, the CELSS will be justified when its capital costs are less than the discounted value of the stream of costs for resupplying food which it replaces. The cost effectiveness thus depends on the design life of the facility. In general, the breakeven life (i.e., the design life beyond which the CELSS has an economic advantage over food resupply) increases as the cost of space transportation decreases. For a given transportation cost, the breakeven life increases with the mass of the CELSS (per crewmember). On the basis of these considerations, and available data concerning potential space missions, we propose two scenarios for possible base-line missions as a point of departure in partially or completely assessing closed life support systems.

The facilities involved in these proposed scenarios are: 1) a small space station in low Earth orbit (LEO), supported by the Space Transportation System (STS: the space shuttle); and 2) a major construction facility in geosynchronous orbit (GEO), supported by a Heavy-Lift Launch Vehicle (HLLV) and advanced Orbital Transfer Vehicles (OTV's). The LEO space station is a relatively near-term possibility, but the GEO space base requires advanced technology and a large-scale commitment to industrial activities in orbit and is, therefore, unlikely to be built until the end of the century. Advances in technology are expected to make access to the GEO base, when it is operational, considerably easier and cheaper than to the type of LEO station which could be built in the near future. Therefore, freight costs from Earth to the GEO base are an order of magnitude less than to the LEO station. A more massive CELSS is thus more economically feasible for the LEO case than for the GEO system, and its design life-time may be shorter. It is likely, therefore, that the LEO habitat would be used as a test-bed for the CELSS, leading to development of a lighter second-generation system for use in GEO. Economies-of-scale should also help in designing a higher-performance system for supporting industrial activities in GEO.

If a high-thrust OTV is used (e.g., for personnel or priority cargo), a launch opportunity from LEO to GEO (or GEO to LEO) occurs once every revolution of a staging facility in (equatorial) LEO, and the transit time is about 3.5 hours. Compared to the LEO station, the extra time required to get to or from the GEO base is less than 5 hours. The GEO base is therefore not much more remote than the LEO station in terms of accessibility.

2. LEO SPACE STATION

This facility does not represent any specific mission but uses data from a number of NASA studies of LEO space stations, for example, the Space Operations Center (SOC).¹ Typical habitat parameters of interest to the CELSS are listed in Table A-1. The choice of orbit is determined by the capabilities of the STS, and the module size is chosen to fit within the STS cargo bay. Figure A-1 is an artist's conception of what the SOC might look like. The missions it could support include:

- construction of large, complex space systems,
- development of the capability for permanent manned operations in space,
- materials processing and space manufacturing,
- on-orbit assembly, launch, recovery, and servicing of manned and unmanned spacecraft, and
- research in life sciences, earth observation applications, and space physics and astronomy.

Almost all of these missions require non-rotating or zero-g conditions so that the crew must spend most of its working time in zero-g. Experience-to-date suggests that frequent transfers between zero-g and normal gravity are likely to be more debilitating than residence in zero-g, so crew quarters also are taken to be zero-g. The crew rotation period is chosen as three months, a conservative value based on Skylab experience.

The crew (8 persons) will consist primarily of professional astronauts and scientists. They will undergo stringent selection procedures, be strongly motivated and will exhibit considerable self-discipline. Their duties may include strenuous tasks such as space-suited extra-vehicular activity (EVA), as well as daily exercises to maintain health conditions. In terms of their caloric intake, as well as the physiological effects of free fall, they are, therefore, classed as active rather than sedentary workers.

3. GEO CONSTRUCTION BASE

Data for this case are taken from design studies by Boeing Aerospace Company of a construction base for the Solar Power Satellite (SPS).² The construction base's habitat parameters are shown in Table A-1. Figure A-2 is an artist's rendering of the Solar Power Satellite Construction base. The base length in this illustration is 3.5 km. (Because of the scale, the crew's quarters are indiscernible.)

To reach GEO, cargo is first launched to LEO in the HLLV, a large, reusable, two-stage winged vehicle using conventional technology, with a net payload-to-orbit of 360 metric tons (mt). Crewmembers are carried in the Personnel Launch Vehicle

1. Covington, C. and Pilaud, R.O., "Space Operations Center; Next Goal for Manned Space Flight?" *Astronautics and Aeronautics*, Vol. 18, No. 9, 1980, pp. 30-37.

2. Boeing Aerospace Company. *Solar Power Satellite System Definition*, Volume II, Phase 2, Final Report: *Reference System Description*. Prepared for NASA Johnson Space Center under Contract No. NAS9-15636, Report No. D180-25461-2, November 1979.

TABLE A-1
HABITAT PARAMETERS

	LEO Space Station	GEO Construction Base
Orbit: Altitude	350 km	35,900 km
Inclination	28.5°	Equatorial
Internal g-level	0	0 (some partial-g possible)
Module size: Diameter (m)	4.5	17
Length (m)	18	23
Normal Orientation	Local/Vertical	POP
Return to Earth (hours)	1-16	10-24
Facility Life (years)	10	30
Crew Rotation (months)	3	12
Crew Size	8	500
Worker Stress Categories: Active	8	150
Sedentary	0	350
Age Distribution	25-50	20-60
Gender	M/F	M/F
Crew Selection	Stringent	Moderate
Nationalities	U.S.	International
Launch Vehicles	STS	HLLV/ COTV/ POTV
Specific Launch Cost (1979 \$):		
Personnel (\$/Person)	150,000	250,000
Fast Freight (\$/kg)	850	120
Slow Freight (\$/kg)	—	45
Operational Date	1989	1998
Sample Mission	SOC	SPS Construction

(PLV), a derivative of the Shuttle, with a canister having accommodations and life support for 80 passengers in the payload bay. Transport time from Earth is about 1 to 3 hours. From LEO, cargo bound for GEO is moved by the Electric Orbital Transfer Vehicle (EOTV), a large solar-electric, low-thrust vehicle with a payload of 4000 mt, taking about three months for the transfer time. Crewmembers are transported to GEO in the Personnel Orbital Transfer Vehicle (POTV), a rapid transit system (chemical propulsion) with a passenger capacity of 80 and a transfer time of approximately five hours. The POTV can also be used for priority cargo, with a payload capacity of 90 mt.

The GEO construction base is a large structure with maximum dimensions of 3.5 x 3.5 x 0.7 km, sized to meet the requirements for building two SPS's per year, each with a terrestrial output of 5 gigawatts (GW).³ The crew habitability modules are

3. Gigawatt (GW): one million kilowatts (10⁶ watts).

attached to this structure and sized to fit the HLLV. Since the SPS is not stressed for rotation, the construction base must be in free fall. For the same reasons as in the case of the LEO space station, the crew's quarters are also in zero-g. The crew rotation period is assumed to be 12 months because, by the time this facility will be built, longer stay times in zero-g may have been shown to be feasible.

The nominal orientation of the construction base is with one axis along the perpendicular to the orbital plane (POP) and the other axes stationary in inertial space. This orientation, together with the fact that satellites in GEO are in virtually continuous sunlight, may allow continuous insolation for photosynthetic processes in the CELSS, if desired.

The number of workers at the GEO construction base will increase rapidly to about 400 during the first four years of operation, and will then grow more slowly to 1000 after 20 years, to meet maintenance requirements for operational SPS's. A much wider variety of personnel will be employed than in the LEO space station, including astronauts, engineers, technicians, and administrative and support personnel. Extra-vehicular activity will be minimal, construction operations normally being carried out in shirt-sleeve conditions in a sealed canister, using remote manipulators. Most of the crew should therefore be classed as sedentary workers. It may be more difficult to maintain conditioning through regular exercise with such a variegated group.

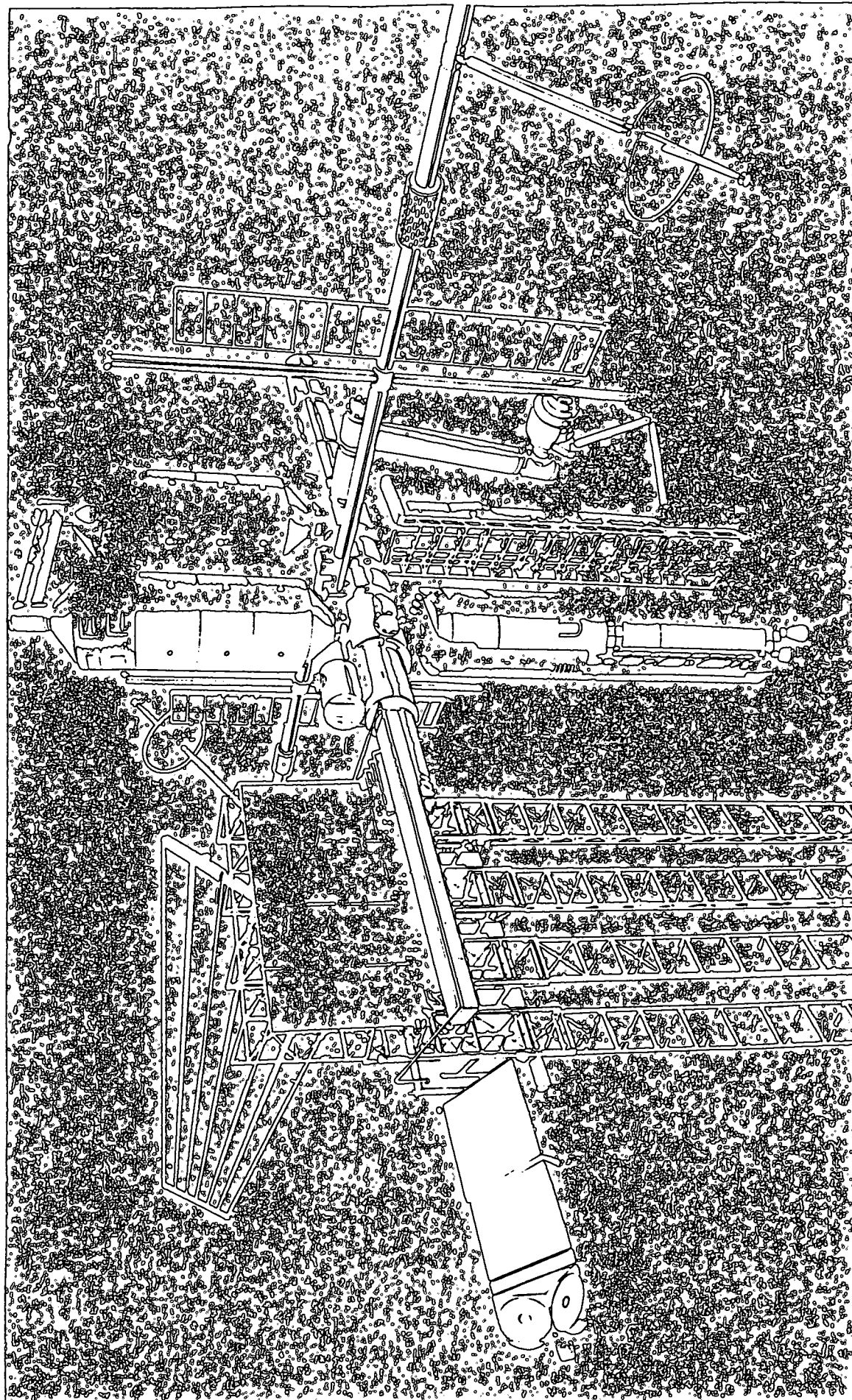
The implications of the proposed mission descriptions to the CELSS are discussed in the following section.

4. CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEMS

Figure A-3 is a simplified schematic of the CELSS. In a partially-closed system, some of the flow paths shown may be missing, with a corresponding increase in the inputs (resupply of food and make-up of water and atmospheric constituents). For both the LEO and GEO scenarios considered here, nearly complete closure of the atmospheric and water-regeneration loops may be assumed. The most critical issue for consideration is that of food supply.

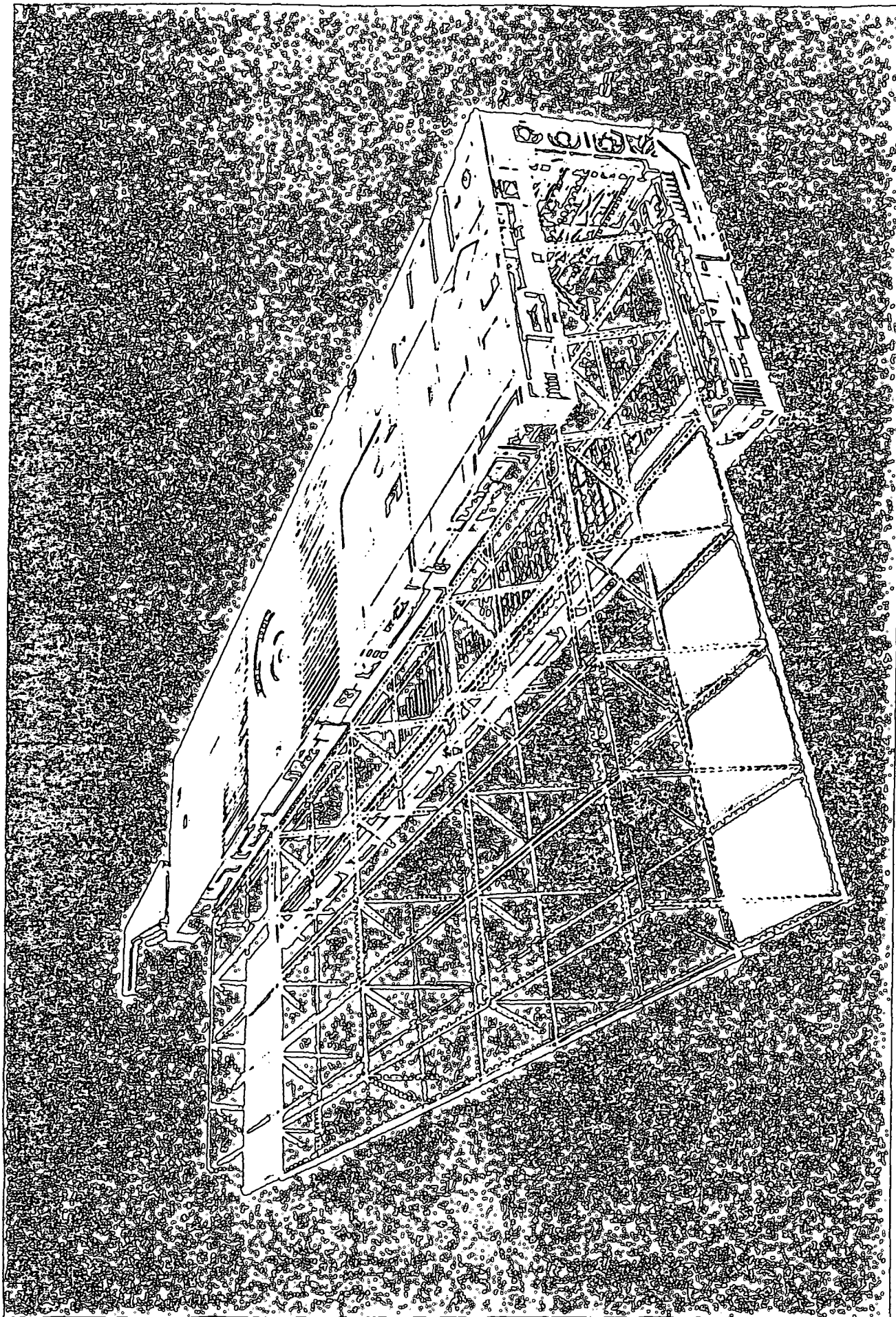
a. Food Supply Options

There are a number of options for supplying food, depending on the duration of the mission, specifications of acceptable foods, the menu cycle, and the food service system. In order to provide the necessary security (i.e., freedom from health hazards and fail-safe food availability), nutrients will probably be delivered as a combination of conventional-terrestrial foods and some unconventional items, developed to facilitate recycling in the CELSS. Supplies of stored water and conventional foods (in limited variety) will be needed during the start-up of food production and as an emergency reserve to allow sustenance until resupply, should the production systems fail.



Source: NASA

FIGURE A-1 SPACE OPERATIONS CENTER



Source: NASA

FIGURE A-2 SOLAR POWER SATELLITE
CONSTRUCTION BASE: ARTIST'S CONCEPTION

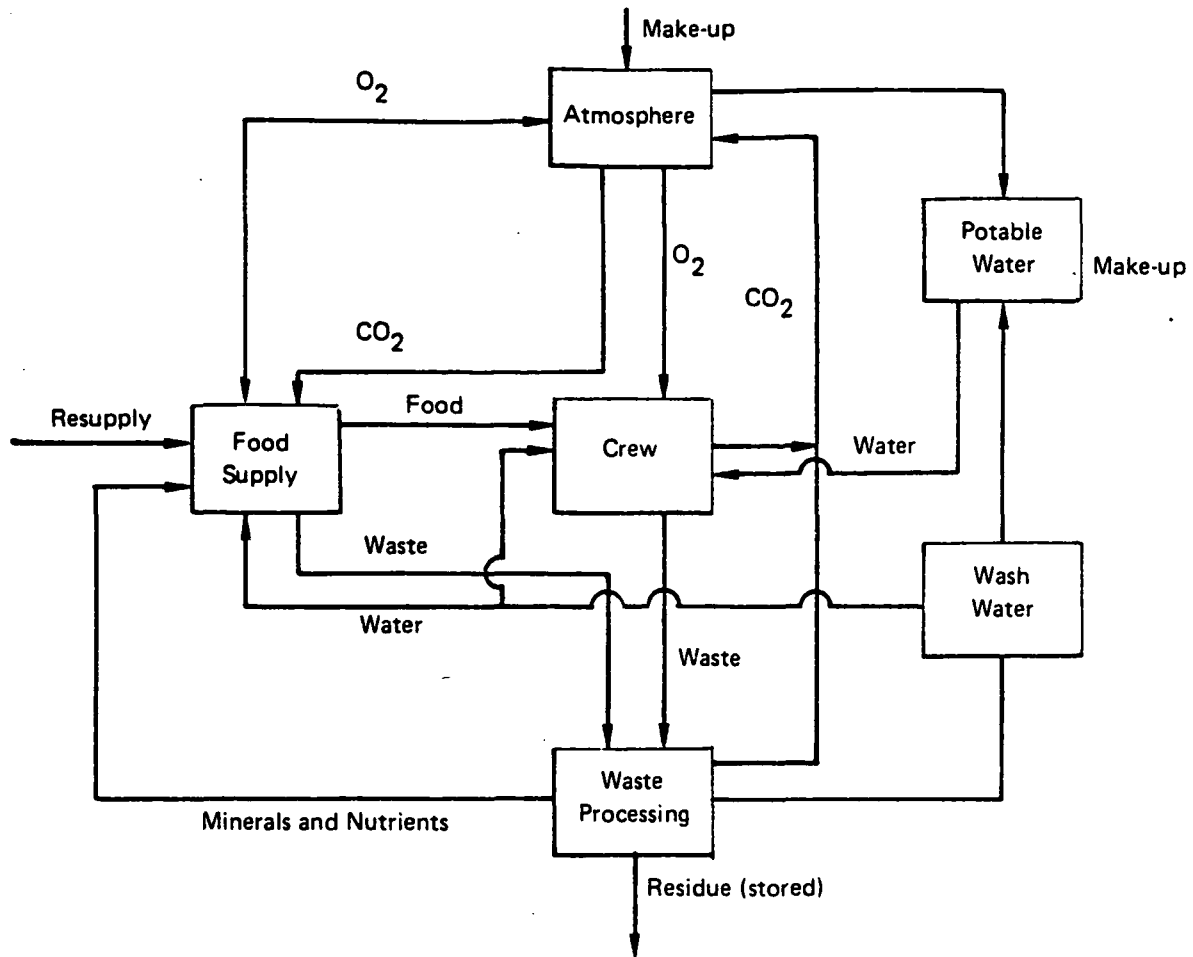


FIGURE A-3 SIMPLIFIED CELSS SCHEMATIC

The systems which could be used for food production in the CELSS include the following:

(1) *Chemical Synthesis*

Direct chemical synthesis of some nutrients (e.g., sugar) may be feasible, especially in the GEO base. Chemical synthesis might also be used to provide inputs to other types of food production (e.g., fertilizers for use in an agricultural system).

(2) *Microbiological Systems*

(a) *Algae.*

Photosynthetic systems such as algae may be useful in atmospheric regeneration for near-term applications (e.g., the LEO station) and will become much more attractive for the CELSS if useful nutrients could be obtained from the biomass produced. Food quality and acceptability may pose problems for

human ingestion of foods derived directly from algae, but the possibility also exists (especially in the second-generation GEO system) of using algal products as one step in a more complicated food chain (e.g., as nutrients for plants or animals).

(b) *Bacterial Cultures.*

Some bacteria (e.g., hydrogenomas) are interesting candidates for use in the CELSS, primarily because the growth process is not photosynthetic (making culture in bulk possible). Nitrogen requirements for growth may be provided entirely by urea (recovered from urine) and the biomass produced may have a protein content approaching 50%. Here again, it seems probable that bacterial culture will be of most interest in advanced systems using relatively complex food chains.

(3) *Higher-Plant Agriculture*

Fruits, vegetables, and other plants may be grown as part of the CELSS system, although difficulties due to the effects of zero-g could occur. Optimal atmospheric CO₂ concentrations could be maintained in agricultural areas. Insolation could also be available nearly continuously (in GEO) at higher flux levels than on Earth. The achievable productivity thus may be considerably higher than that found in the most advanced forms of terrestrial greenhouse agriculture. Hydroponic cultures using a low-mass matrix or root support probably will be the technology of choice. Plant-breeding experiments in zero-g (e.g., in the LEO space station) may result in plant species for these applications.

(4) *Animal Husbandry*

(a) *Aquaculture*

Fish and other small marine animals provide an efficient biological recycling mechanism, producing high-quality protein from aquatic plants, algal or bacterial products, or waste from agriculture and food preparation. A principal problem with aquaculture for the CELSS application is that of keeping the mass of the system within acceptable limits, given the relatively high density of water. Research is needed to determine, or to breed, species which maximize productivity per unit volume.

(b) *Higher animals*

Small animals such as rabbits or chickens may be raised in zero-g. Zero-g husbandry of larger animals, however could pose serious problems. It is not expected that animals will be raised except for experimental purposes in the near-term LEO space station.

b. Analyses Required

To provide candidate food-production systems for the CELSS, extensive research, including zero-g experimentation, will be needed. Detailed systems analyses will be required to determine which of the above systems, or which combination of them, would provide the most cost-effective and acceptable technology for supporting the LEO station and the GEO base. Each food option must be analyzed to determine mass and volume requirements for equipment and supporting systems, the biomass inventory needed for a given production, and the efficiency of energy conversion. A brief summary of the CELSS parameters in LEO and GEO is given in Table A-2.

TABLE A-2

CELSS PARAMETERS

	Low Earth Orbit (by 1990)	Geosynchronous Orbit (by 2000)
	Experimental CELSS	Second Generation CELSS
Degree of Closure	To be determined	To be determined
Internal g-Level	0	0 (plus centrifuges, if necessary)
Water and Atmosphere	Recycled	Recycled
Waste	Recycled	Recycled
Chemical Resynthesis	Some (e.g., sugar)	Some (e.g., sugar)
Bacteria	Developmental: Microbial Synthesis	Bacteria-based food chain
Plant Husbandry	Simple	More complex (partial food chain)
Animal Husbandry	Experimental	To be determined
Aquaculture	Experimental	Some

5. CONCLUSIONS

To provide a definite basis for discussing the CELSS, we have proposed two mission scenarios as examples of Earth-orbit application in which resupply of all consumables may be cost-ineffective. The CELSS for these two missions would have the following characteristics:

Near-term LEO space station:

- First-generation system, higher in mass (per crew-member) than later systems.
- Recycling of water and regeneration of atmosphere.
- Zero gravity.
- Chemical resynthesis of sugar.
- Possibility of simple plant husbandry.
- No animal husbandry (including aquaculture), except for experimental purposes.
- May not be cost-effective by itself but would pave the way for improved systems.

GEO construction base:

- Fully operational CELSS.
- Recycling of water and regeneration of atmosphere.
- Zero gravity unless partial gravity reduces CELSS cost.
- Chemical resynthesis of sugar(s).
- Cost-effective use of partial food chain such as bacteria - algae - plant-food for hydroponic agriculture.
- Possibility of animal husbandry (including aquaculture).

Development of all the necessary processes for the zero-gravity CELSS will require a major effort, including ground-based research, experiments in LEO, and extensive engineering studies.

APPENDIX B

DATA BASE MANAGEMENT

1. OBJECTIVES

The objectives of the data base management were to survey the literature, acquire the documents selected, and create a selective data base composed of references valuable to understanding specific topics. The emphasis was not on a historical survey because applicable nutrition and food service system reports were already reviewed.

2. METHODOLOGY

The literature search involved accessing every major computerized data base, supplemented by manual searches and by information from the project team regarding documents that were not available from conventional sources.

The historical survey was useful as a starting point to obtain references on specific nutritional and technical issues. The NTIS data base was used as a first step in the search. The terms that were used for information retrieval were:

Nutrient Requirements	— Energy Metabolism
Health Problems	— Water Requirements
	Carbohydrates
	Protein
	Vitamins
	Fiber
Closed Ecological Systems	— (i.e., — Controlled Ecological
	Life Support Systems)
Food Acceptability	
Food Safety	
Food Service System	
Space Missions	

We accessed the works of the Federal agencies and institutions as follows:

USDA	— has its own data base;
	CRIS — Current Research
	Information System
NASA	— via Aerospace Medicine
	Aerospace Biology STAR
FDA	— NTIS, direct contacts
NIH	— MEDLAR (medical Index)

AID	— National Agricultural Library (Agricola) and direct contacts.
USN	— (i.e., submarine studies) — NTIS or DDC (Defense Documentation Center) — recently declassified documents.
USAF	— Same as USN
USACE	— Same as USN
Private Research Groups	— (i.e., New Alchemists) — NTIS, through direct contacts.
Academic Institutions	— NTIS, Dissertation Abstracts
Industrial Organizations	— NTIS, direct contacts.
Archival Information	— NTIS

Other data bases and indexes that were searched included: Chemical Abstracts, Engineering Index (for Food engineering), Bio Abstracts, and Toxline (for food safety).

As the documents became available, they were classified and evaluated. Each document had a review sheet which was completed and returned to the data base manager. Based on these sheets, a bibliographic data base was compiled that was specific to CELSS issues.

3. RESULTS

The literature surveys produced more than a thousand documents. By careful review by the expert in the particular area, only those documents (approximately 100) which were considered valuable to the specific nutritional topics were selected. An annotated bibliography (72 references) was compiled as background information on CELSS for the Workshop, as well. This bibliography is attached (Appendix C). The references are arranged by author.

To facilitate access to the existing files, the design and implementation of a computerized data base for CELSS is described in the following section.

4. COMPUTERIZED DATA BASE MANAGEMENT SYSTEM FOR CELSS

CELSS as a subject area has a substantial amount of literature associated with it. As the concept of the CELSS evolves, it is reasonable to assume that this literature will grow at an increasingly rapid rate. It is at this stage in the CELSS development that an information retrieval system should be designed that will store currently available information in an efficient and retrievable manner and permit the incorporation of future studies, contracts, and publications. This information would then be readily available to government, industrial, and academic researchers, both in the United States and abroad.

The design and implementation of a data base management system to handle current and future information associated with the CELSS could consist of the following three phases:

PHASE I

- Define the content and requirements of a CELSS data base.
- Assess the commercially available data base software packages in relation to these requirements and identify the optimum package for the CELSS data base system.
- Create a CELSS subject thesaurus (based on the NASA Thesaurus SP-7050), supplemented with medical and nutritional terms.
- Create an author authority.
- Create a management system for regular, monthly updating.

PHASE II

- Implement the Data Base Management software package selected in Phase I.
- Update data base author files and thesauri.
- Establish procedures for conducting searches for users.

PHASE III

- Expand the data base to include abstracts.
- Evaluate the reports and other information within the data base and make hierarchical subject arrangement possible.
- Present plans to expand data base functions and to create a holding library.

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APPENDIX C

GLOSSARY

anorexia:	lack or loss of the appetite for food
apogee:	the point farthest from the Earth in the orbit of the moon or of a man-made satellite (opposite of perigee)
booster (launch vehicle):	any of the early stages of a multi-stage rocket; a rocket system that launches a spacecraft or other payload
burn:	firing of a rocket engine
burnout (brennschluss):	the point at which missile fuel is completely burned up and the missile enters its free-flight phase
CELSS:	Controlled Ecological Life Support System
de-orbit:	leave orbit in order to reenter the Earth's atmosphere
EVA:	Extra Vehicular Activity — activity of an astronaut outside a vehicle in Space
free-fall, weightlessness, zero-g:	unchecked fall of a body through Space; sensation of gravitation is absent; applies to any Space vehicle whenever rocket engines are not firing
GEO:	Geosynchronous Earth Orbit — orbit with radius 42300 km, and period of 24 hours
geostationary orbit:	equatorial geosynchronous orbit; satellite is fixed relative to Earth
geosynchronous orbit:	see GEO
gigawatt:	one million kilowatts (10^9 watts)
GLOW:	Gross Lift-Off Weight — weight of a launch vehicle at lift-off
gustation:	the act of tasting or the sense of taste
gustatory:	pertaining to the sense of taste

HLLV:	Heavy Lift Launch Vehicle — class of very large boosters which will be used for space industrialization
hypochondria:	morbid anxiety about one's health, often associated with numerous and varying symptoms which cannot be attributed to organic disease
IMF:	intermediate moisture foods
irradiated food:	preserved by ionizing radiation
"kick in the apogee":	burn to circularize an elliptical orbit
LEO:	Low Earth Orbit — circular Earth orbit at an altitude generally between 200 and 1000 km
nystagmus:	an involuntary rapid movement of the eyeball which may be horizontal, vertical, rotary, or mixed (i.e., of two varieties)
orbit insertion:	burn to establish desired orbital parameters
osteoporosis:	a bone disease characterized by a reduction in bone density accompanied by increasing porosity and brittleness; associated with loss of calcium from the bones
parenteral:	brought into the body through a way other than the digestive tract; i.e., by intravenous injection
perigee:	the point nearest to the Earth in the orbit of the moon or a man-made satellite
rad:	a dosage of absorbed radiation equal to the absorption of 100 ergs of energy per gram of material
re-entry:	return of a Space vehicle into the earth's atmosphere
rem:	a dosage of any ionizing radiation that will produce a biological effect approximately equal to that produced by one roentgen of X-ray or gamma-ray radiation
semi-major axis:	one-half maximum diameter of an elliptical orbit

SOC:	Space Operations Center — A design study for a semi-autonomous facility in LEO, supported by the STS. It could provide electrical power and/or attitude control for docked spacecraft, act as a supply depot for fuel and other consumables to be used by orbital transfer vehicles, and housekeeping support for attached laboratories for scientific or industrial purposes.
SPS:	Solar Power Satellite — Beaming solar energy to Earth in the form of microwaves from a satellite in geostationary orbit.
STS:	Space Transportation System — the NASA Space Shuttle
TPN:	Total Parenteral Nutrition — supplying all nutrient needs via intravenous injection of predigested nutrients

APPENDIX D

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— types of cooking service factors-p.11
— evaluation of 14 food service factors-p.11

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Tigranian, R.A., and Ushakov, A.S., "Peculiar Characteristics of Crewmembers' Metabolism on the Second Expedition Aboard Orbital Station Salyut-4." Institute of Biomedical Problems, USSR Ministry of Health, Moscow, USSR, *Aviation, Space, and Environmental Medicine*, Vol. 49, No. 1, September 1978, 1074-1079.

COMMENTS: Lots of detailed preflight and postflight measurements of metabolic parameters.

Turner, T.R., and Sanford, D.J. *Skylab Food Systems*. NASA Johnson Space Center, Houston, TX. Report No. NASA TM X-58139, October 1979, 39p.

United States Department of Agriculture. *Nutrition and Your Health. Dietary Guidelines for Americans*. USDHEW, Home and Garden Bulletin No. 232, 1980.

Ushakov, A.S., and Flasova, T.F., "Free Amino Acids in Human Blood Plasma During Space Flights." Institute of Biomedical Problems, USSR Ministry of Health, Moscow, USSR.

Ushakov, A.S.; Ivanova, S.M.; and Brantova, S.S., "Some Aspects of Energy Metabolism in Human Blood Erythrocytes under Hypokinesia and During Space Flights." *Aviation, Space, and Environmental Medicine*, Vol. 48, No. 9, September 1977, 824-827.

COMMENTS: Good article on E-metab Salyut-4.

Vlasov, S., "Prototype of a Space House." *Tekhnika Molodegchi*, No. 4, 1874, 28-29. NASA Technical Translation F-15,846.

COMMENTS: Description of a partial CELSS. Gives some feeling for the complexity involved in such a project.

Vorobyov, E.I., *et al.*, "Preliminary Results of Medical Investigations Carried Out During the Second Expedition of the Orbital Station Salyut-4." *Kosm. Biol. Aviakosm. Med.*, Vol. 10, No. 5, Sept./Oct. 1976, 3-18.

COMMENTS: Salyut-4 63 day flight demonstrates man's adaptation to weightlessness. Relative stabilization occurs after 1.5 mo. indicating no change that would prevent a further increase in the duration of future missions.

Voronin, G.I., and Polivoda, A.I. *Life Support of Spacecraft Crews*. Joint Publication Research Service Report No. JPRS 46,173. "Mashinostroyeniye," Publishing House, Moscow, Russia, 1967, 211p.

COMMENTS: Strictly engineering considerations.

Webb, P.; Troutman, S.J.; Frattali, V.; Dwyer, Jr.; Moore, T.O.; Morlock, J.F.; Smith, R.M.; Ohta, Y.; and Hong, S.K., "Energy Balance During a 24-Day Dry Heliox Saturation Dive to 18.6 ATA (Hana Kai II)." *Undersea Biomedical Research*, Vol. 3, 1976, A25.

COMMENTS: Increased energy needs during hyperbaric situation is unexplained.

West, B.B.; Woods, L.; Harger, V.F.; and Shuggart, G.S. *Food Service in Institutions*. 5th Edition, New York, John Wiley, 1977.

COMMENTS: Basic text.

Whedon, G.D., "The Combined Use of Balance and Isotopic Studies in the Study of Calcium Metabolism." *Proceedings VI International Congress on Nutrition*. Edited by C.F. Mills and R. Passmore, E&S Livingston, Ltd., Edinburgh, 1964, 425-438.