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Interim Report

For the Period

December 1, 1979 to January 31, 1981

Contract NAS 9-16008

EVALUATION OF ENGINEERED FOODS FOR CLOSED ECOLOGICAL LIFE SUPPORT SYSTEM (CELSS)

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I. INTRODUCTION

The present contract is part of two phase effort to develop a system of conversion of locally regenerated raw materials and of resupplied freeze-dried foods and ingredients into acceptable, safe and nutritious engineered foods.

The First Phase of the proposed research is to last two years and has the following objectives:

1) Evaluation of feasibility of developing acceptable and reliable engineered foods from a limited selection of plants grown in the GBCD, supplemented by microbially produced nutrients and a minimum of dehydrated nutrient sources (especially those of animal origin).

2) Evaluation of research tasks and specifications of research projects to adapt present technology and food science to expected space conditions. In particular, problems arising from unusual gravity conditions, problems of limited size and the isolation of the food production system, and the opportunities of space conditions are to be considered.

3) Development of scenaria of agricultural production of plant and microbial systems, including the specifications of processing wastes to be recycled.

The Second Phase of the proposed work, if approved, would last three years, initiate upon the completion of the first phase, and include experimental production of engineered foods from specified ingredients.

The present interim report is devoted to work accomplished during the first 14 months of the First Phase. This report consists of the following parts:

I. Introduction

II. Mass balance of food supply, generation, processing and consumption in PCELSS.

III. Summary of work in progress.

Appendix I: Waste Treatment in Partially Closed Environment Life Support System (PCELSS).

Previously (on November 30, 1980) we submitted a detailed report of an analysis of the feasibility of utilization of engineered foods in PCELSS, entitled: Engineered Foods in PCELSS - An Analysis

II. MASS BALANCE OF FOOD SUPPLY, GENERATION, PROCESSING, AND CONSUMPTION IN PCELSS (SCENARIO II)

A. INTRODUCTION

To calculate the overall mass balance of food supply, generation, processing, and consumption we needed to adjust slightly the USDA 1974 Thrifty Food Plan, shown in Table 1, according to Scenario II of Partially Closed Ecological Life Support System (PCELSS). In this scenario, it is assumed that most of the plant food products (except three fruits) are regenerated hydroponically in the space habitat. All foods derived from animals are freeze-dried and periodically resupplied from earth. All present calculations are based on the assumptions listed below. As the knowledge of actual possibilities and constraints of the space habitat improves, so will the precision of such calculations.

B. ASSUMPTIONS

1) The adjusted Thrifty Food Plan (according to PCELSS Scenario II criteria) together with resupplied vitamin and mineral supplementary pills (see miscellaneous item, Table 2) present a nutritionally adequate and acceptable diet. In the adjusted diet, corrections were made only to the total needed amount of flour. Those fractions of food ingredients such as oil, sugar, and milk which are used in preparation of other processed foods (e.g. bread, crackers, etc.), are taken from their calculated supply in original diet and therefore, no corrections or adjustments have been made for these items.

2) The total population of the space habitat is 50. For diet calculations, a male 20-54 years old was chosen as standard.

This conservative assumption prevents any underestimating of the total needed food.

3) Considering the limitations with regard to food resupply frequency and food regeneration in space habitat (manpower, equipment, storage area, etc.), all our calculations are based on "monthly" consumption. However, food resupply and regeneration patterns could be adapted according to desirable programs including the following:

a) Food resupply from earth 2-6 times per year.

b) Harvesting of agricultural products (e.g. soybean, sugar beet, wheat, etc.) 2-4 times per year.

c) Harvesting of agricultural products for fresh consumption or minor preparations before consumption (e.g. vegetables and fruits) 12-24 times per year.

4) Freeze-dried foods resupplied from earth, except butter and miscellaneous items, contain 3% moisture (wet basis). These foods are in ready-to-use shape upon rehydration.

5) Raw materials regenerated in space habitat "farm" and then delivered to the first storage room (grains, vegetables, fruits, etc.) are pre-cleaned as normally observed in wholesale trade. These operations are to be defined by the "Production" planning groups.

6) For sugar extraction and refining, conventional processing is assumed. For oil extraction from soybean, however, an aqueous extraction (to minimize chemical use) with only about 65% recovery is assumed. All products made from wheat will use "whole-wheat flour" prepared as in standard wheat milling technology. This decreases the solid waste and needed equipment.

7) The original Thrifty Food Plan allows discard of 5% of the "edible" food as "spoilage and plate waste". Our calculations for food waste during processing and preparation does not include this 5% and is based on data shown in Appendix I. Estimation of solid and liquid wastes will improve by further measurement of waste materials of plant foods resembling those grown hydroponically in space as well as clarifications of details of food processes which will be used in space. There are at present several industrial operations utilizing hydroponics.

8) Liquid waste from "food" preparation (washing, cooking, etc.) is assumed to be 280 ml/lb. Cleaning of utensils and kitchenwares has not been taken into account. For our assumed conditions preservation of the locally harvested items for extended storage has not been considered. If population of the colony is over 100 people, then some degree of mechanization will be required to decrease the labor involved in food preparation. Freezing or canning might be required to avoid shortages of some of the commodities produced on board.

C. CALCULATION OF FOOD MASS BALANCE FOR RESUPPLY, REGENERATION, PROCESSING, AND CONSUMPTION

1) Adjustment of Thrify Food Plan according to PCELSS scenario II criteria (Table 2).

2) Calculation of monthly food products "resupplied" from earth and "regenerated" on board for 50 inhabitants (Tables 3A and 3B).

3) Schematic of overall food mass balance in space habitat (Figure 1).

TABLE 1. —Thrifty Food Plan

Family member	Amounts of food for a week [1]													
	Milk, cheese, ice cream [2]	Meat, poultry, fish [3]	Eggs	Dry beans and peas, nuts [4]	Dark-green, deep-yellow vegetables	Citrus fruit, tomatoes	Potatoes	Other vegetables, fruit	Cereal	Flour	Bread	Other bakery products	Fats, oils	Sugar, sweets
Child:	*Qt*	*Lb*	*No*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*	*Lb*
7 months to 1 year	5.0	0.39	1.2	0.15	0.41	0.55	0.09	2.49	[5] 1.02	0.02	0.08	0.04	0.04	0.19
1-2 years	3.3	.83	3.3	.17	.22	.89	.65	2.26	[5] 1.02	.31	.78	.24	.11	.30
3-5 years	3.5	.55	2.5	.28	.20	.92	.88	2.28	1.03	.37	.94	.53	.38	.74
6-8 years	4.2	1.27	2.4	.49	.22	1.10	1.23	2.50	1.12	.62	1.42	.79	.51	.94
9-11 years	4.9	1.61	3.4	.53	.28	1.52	1.48	3.38	1.34	.81	1.82	1.10	.60	1.20
Male:														
12-14 years	5.2	1.79	3.6	.67	.23	1.45	1.59	3.30	1.22	.81	2.07	1.13	.77	1.21
15-19 years	5.1	2.35	4.0	.43	.32	1.70	2.10	3.43	.98	.90	2.36	1.46	1.00	1.05
20-54 years	2.6	3.03	4.0	.44	.39	1.80	2.62	3.69	.89	.92	2.29	1.33	.95	.88
55 years and over	2.4	2.45	4.0	.25	.51	1.85	1.75	3.77	1.09	.80	1.90	1.12	.79	.94
Female:														
12-19 years	5.4	1.80	3.8	.28	.42	1.74	1.22	3.61	.72	.76	1.49	.84	.51	.74
20-54 years	2.8	2.41	4.0	.27	.52	1.86	1.51	3.39	.90	.67	1.41	.67	.57	.57
55 years and over	2.8	1.84	4.0	.19	.60	2.02	1.26	3.73	1.12	.68	1.30	.58	.37	.45
Pregnant	[6] 5.2	2.69	4.0	.42	.56	2.17	1.89	4.03	1.13	.58	1.41	.66	.59	.58
Nursing	[6] 5.2	3.00	4.0	.38	.57	2.36	1.92	4.27	.98	.63	1.56	.82	.80	.75
Total														

[1] Amounts are for food as purchased or brought into the kitchen from garden or farm. Amounts allow for a discard of about 5 percent of the *edible* food as plate waste, spoilage, etc. For general use, round the total amount of food groups for the family to the nearest tenth or quarter of a pound. In addition to groups shown, most families use some other foods: coffee, tea, cocoa, soft drinks, punches, ades, leavening agents, and seasonings.

[2] Fluid milk and beverage made from dry or evaporated milk. Cheese and ice cream may replace some milk. Count as equivalent to a quart of fluid milk: natural or processed Cheddar-type cheese, 6 ounces; cottage cheese, 2½ pounds; ice cream or ice milk, 1½ quarts; unflavored yogurt, 4 cups.

[3] Bacon and salt pork should not exceed ⅓ pound for each 5 pounds of this group.

[4] Weight in terms of dry beans and peas, shelled nuts, and peanut butter. Count 1 pound of canned dry beans, such as pork and beans or kidney beans, as .33 pound.

[5] Cereal fortified with iron is recommended.

[6] For pregnant and nursing teenagers, 7 quarts is recommended.

Table 2. Thrifty Food Plan adjusted according to PCELSS (scenirio II) criteria. Products marked with an asterisk (*) are resupplied from earth.

Food Products	Amount $(\text{person}^{-1} \cdot \text{week}^{-1})$		Weight $(\text{g} \cdot \text{person}^{-1} \cdot \text{day}^{-1})$	Comment
*MILK PRODUCTS	2.6 Qt	2461 g	351.6	For fluid milk, ref (2) item 1320
fluid milk			271.6	For conversion to cheddar cheese
cheese			15.0	see foot note (2) of Thrifty Food Plan (Table 1). See also ref (2)(item 646e). No ice cream
*MEAT PRODUCTS (boneless)	3.03 lb	1370 g	195.7	For beef, ref (2) item 352b (round steak)
beef			100.0	For pork, ref (2) item 1715b (loin)
pork			20.7	For chicken, ref (2) item 685c
poultry			100.0	(40% refuse for bone and skin)
fish			15.0	For fish, ref (2) item 795b
*EGGS	4.0	228 g	32.6	Ref (2) item 968b (large egg = 57 g) (12% refuse for shell)
DRY BEANS, PEAS, & NUTS	0.44 lb	200 g	28.6	Ref (2), item 154a Note: the 28.6 g of dry beans may be replaced by an equivalent amount of soy protein concentrate from soy oil generated in space habitat
DARK GREEN & DEEP YELLOW VEGETABLES	0.39 lb	177 g	25.3	Ref (2) item 483 (broccoli as example)
TOMATOES	1.8 lb	816 g	116.6	Assume no citrus fruit For tomatoes ref (2) item 2282
POTATOES	2.02 lb	916 g	153.9	Ref (2) item 1785 (15% difference between hand and mechanical trimming is added).
OTHER VEGETABLES & FRUITS	3.69 lb	1674 g	239.1	
carrot			12.0	Ref (2) item 619
greens			10.0	Ref (2) item 2169
peas			20.0	Ref (2) item 1515 (replaced for canned vegetable)
cabbage			10.0	Ref (2) item 512b
lettuce			15.0	Ref (2) item 1258a (iceberg)
asparagus			8.0	Ref (2) item 46a (raw spears)
onion			20.0	Ref (2) item 1412a
green beans			10.0	Ref (2) item 182a
green pepper			20.0	Ref (2) item 1545a

Food Products	Amount $(\text{person}^{-1} \cdot \text{week}^{-1})$		Weight $(\text{g} \cdot \text{person}^{-1} \cdot \text{day}^{-1})$	Comment
mushroom			10.0	Ref (2) item 1354a
celery			10.0	Ref (2) item 637a
others (cucumbers)			44.1	Ref (2) item 942a
strawberries			8.0	Ref (2) item 2217a
cantaloupe			10.0	Ref (2) item 1358a
grapes			10.0	Ref (2) item 1084a
raisins			22.0 (98.5 of grapes)	Ref (2) item 1846a. To produce 22 g raisins (m.c. = 18%) we need 98.5 g grapes (m.c. = 81.6%)
FLOUR				
variable uses	0.92 lb	417 g	59.6	Ref (2) item 2435. Whole wheat flour (100% extraction) is used for all purposes.
cereal			56.4	
bread			84.3	
other bakery			8.35	
TOTAL:			208.7	
CEREAL	0.89 lb	404 g	57.7	Ref (2) item 2456 Ref (3) assuming 10% added sugar and 1% added salt. For 57.7 g cereal, 5.7 g sugar, 0.6 g salt, and 51.4 g flour (m.c. = 3.5%) or 56.4 g flour (m.c. = 12%)
BREAD	2.29 lb	1039 g	148.4	Whole wheat bread (Matz, 1960, p. 252) based on dough formula: water 35.2%, flour 56.8%, salt 1.1%, sugar 2.0%, dry skim milk 1.1%, shortening 1.7%, yeast 1.7% For bread, we need 84.3 g flour (12% m.c.)
OTHER BAKERY PRODUCTS	1.33 lb	603 g	86.1	In this category, for the sake of simplicity, we collected 3 different groups of food products. For crackers we used formula based on ref (4): 8.35 g flour, 0.25 g sugar, 0.17 g salt, 1.7 g butter, 2.5 g milk. For rice, ref (2) item 1875 For peanut butter assume 10.0 g shelled peanuts and 0.02 g salt ref (5)
cracker			10.0	
rice			66.1	
others (peanut butter)			10.0	
FATS & OILS	0.95 lb	431 g	61.6	Butter, ref (2) item 505
*butter			30.8	Soybean, ref (2) item 2139 (Composition: fat 18%, protein 34%, water 10%). Assume 65% oil extraction by non-solvent aqueous method ref (6).
soy oil			30.8 (from 263 g soybean)	

Food Products	Amount (person^{-1} · week^{-1})		Weight (g · person^{-1} · day^{-1})	Comment
SUGAR & SWEET	0.86 lb	390 g	55.7 (from 446 g beets)	Ref (7&8) based on 12.5% sugar extraction from beets
*MISCELLANEOUS			20.0	Salt, spices, yeasts, baking powder, emulsifiers, antioxidants and vitamin & minerals supplementary pills.

Table 3A. Monthly food product deliveries to PCELSS from earth (50 inhabitants)

A	B	C		D		E	F	G	H
Food Product	net amount consumed (kg)	Water		Solid		freeze-dried food supplied with 3% water (kg) ($D_b \div 0.97$)	water remaining in supplied food (kg) ($E - D_b$)	water to rehydrate foods in space ($C_b - F$)	Comment
		a	b	a	b				
		%	amount (kg)	%	amount (kg)				
MILK PRODUCTS									
fluid milk	407.4	87.4	356.1	12.6	51.3	52.9	1.6	354.5	We assumed an average moisture content of 3% for all freeze-dried foods (except butter) which are supplied from earth. For water and solids content see ref (2)
cheese	22.5	37.0	8.3	63.0	14.2	14.6	0.4	7.9	
butter	46.2	15.5	7.2	84.5	39.0	46.2	7.2	0.0	
MEAT PRODUCTS									
beef	150.0	66.6	99.9	33.4	50.1	51.7	1.6	98.3	
pork	31.1	57.2	17.8	42.8	13.3	13.7	0.4	17.4	
poultry	90.0	71.0	63.9	29.0	26.1	26.9	0.8	63.1	
fish	22.5	64.6	14.5	35.4	8.0	8.2	0.2	14.3	
EGGS	43.0	73.7	31.7	26.3	11.3	11.6	0.3	31.4	
MISCELLANEOUS	30.0	3.0	0.9	97.0	29.1	30.0	0.9	0.0	We assumed that butter and miscellaneous items do not need to be rehydrated in space
TOTAL:	842.7					255.8		586.9	

Table 3B. Monthly food production in PCELSS (50 inhabitants)

A	B	FOOD C		FOOD D		WASTE* E		WASTE* F		G	H
		water		solid		solid		liquid			
		a	b	a	b	a	b	a	b		
Food Product	amount (kg)	%	amount (kg)	%	amount (kg)	%	amount (kg) (B x 0.01Ea)	%	amount (kg) (B x 0.01Fa)	net amount consumed (kg) (B-Eb)	Comment
DRY BEANS, PEANS & NUTS	0	0	0	0	0	0	0	0	0	0	42.9 kg of dry beans is replaced by equivalent amount of soy protein concentrate from soy oil production
DARK GREEN DEEP YELLOW VEGETABLES	38.0	89.1	33.9	10.9	4.1	21.3	8.1	170.0	64.6	29.9	For water and solid %, see ref (2) For solid and liquid wastes (% and amount) we assumed the previous 14 reported experimental values. Appendix I.
TOMATOES	174.9	93.5	163.5	6.5	11.4	10.7	18.7	143.0	250.1	156.2	No citrus fruits are supplied or generated.
POTATOES	230.9	79.8	184.3	20.2	46.6	28.5	65.8	110.0	254.0	165.1	
OTHER FRUITS & VEGETABLES											
carrot	18.0	88.2	15.9	11.8	2.1	17.9	3.2	69.0	12.4	14.8	
greens (spinach)	15.0	90.7	13.6	9.3	1.4	16.0	2.4	714.0	107.1	12.6	
peas	30.0	78.0	23.4	13.0	6.6	63.1	18.9	177.0	53.1	11.1	
cabbage	15.0	92.4	13.9	7.6	1.1	44.5	6.7	248.0	37.2	8.3	
lettuce	22.5	95.5	21.5	4.5	1.0	21.6	4.9	101.0	22.7	17.6	
asparagus	12.0	91.7	11.0	8.3	1.0	20.0	2.4	400.0	48.0	9.6	
onion	30.0	89.1	26.7	10.9	3.3	20.0	6.0	100.0	30.0	24.0	Solid and liquid waste are assumed
green beans	15.0	90.1	13.5	9.9	1.5	24.4	3.7	232.0	34.8	11.3	
green pepper	30.0	93.4	28.0	6.6	2.0	18.0	5.4	100.0	30.0	24.6	
mushroom	15.0	90.4	13.6	9.6	1.4	10.0	1.5	300.0	45.0	13.5	
celery	15.0	94.1	14.1	5.9	0.9	24.2	3.6	392.0	58.8	11.4	
others (cucumber)	66.2	95.1	63.0	4.9	3.2	22.9	15.2	62.0	41.0	51.0	
strawberries	12.0	89.9	10.8	10.1	1.2	10.5	1.3	66.0	7.9	10.7	
cantaloupe	15.0	91.2	13.7	8.8	1.3	50.0	7.5	0.0	0.0	7.5	

Table 3B. Monthly food production in PCELSS (50 inhabitants) (cont.)

A	B	FOOD C		FOOD D		WASTE* E		WASTE* F		G	H
		water		solid		solid		liquid		net amount consumed	
		a	b	a	b	a	b	a	b		
Food Product	amount (kg)	%	amount (kg)	%	amount (kg)	%	amount (kg) (B x 0.01Ea)	%	amount (kg) (B x 0.01Fa)	(kg) (B-Eb)	Comment
grapes	15.0	81.6	12.2	18.4	2.8	34.0	5.1	100.0	15.0	9.9	Solid waste from Ref(2) liquid waste assumed
raisins (as grapes)	223.9	81.6	182.7	18.4	41.2	34.0	76.1	100.0	223.9	147.8	(33 kg raisins from 147.8 kg cleaned grapes)
FLOUR (for variable uses, cereal, bread, and other bakery products) As wheat	313.1	12.0	37.6	88.0	275.5	0.0	0.0	200.0	626.2	313.1 (flour)	Liquid waste is assumed for washing of wheat
RICE (as paddy)	141.7	9.6	13.6	90.4	128.1	30.0	42.5	0.0	0.0	99.2	To obtain 99.2 kg cleaned rice we need 141.7 kg rice paddy
PEANUTS	22.4	1.8	0.4	98.2	22.0	33.0	7.4	0.0	0.0	15.0	
SOY OIL (as soybean)	449.3	10.0	44.9	90.0	404.4	12.2	54.8	55.0	247.1	394.5 (46.2 kg oil)	11.7% oil extraction from cleaned soybeans by aqueous extraction. Liquid waste is assumed.
SUGAR & SWEET (as sugar beet)	814.9	79.0	643.8	21.0	171.1	17.9	145.9	434.0	3537.0	669.0 (83.6 kg sugar)	12.5% sugar extraction from cleaned beet. For solid waste we assumed the value for carrot. Liquid waste is assumed.
TOTAL	2734.8		1599.6				507.1		5745.9	1179.2	

*5% of discard of the "edible" food as spoilage and plate waste has already been considered in Thrifty Food Plan and is not included in our calculations for waste.

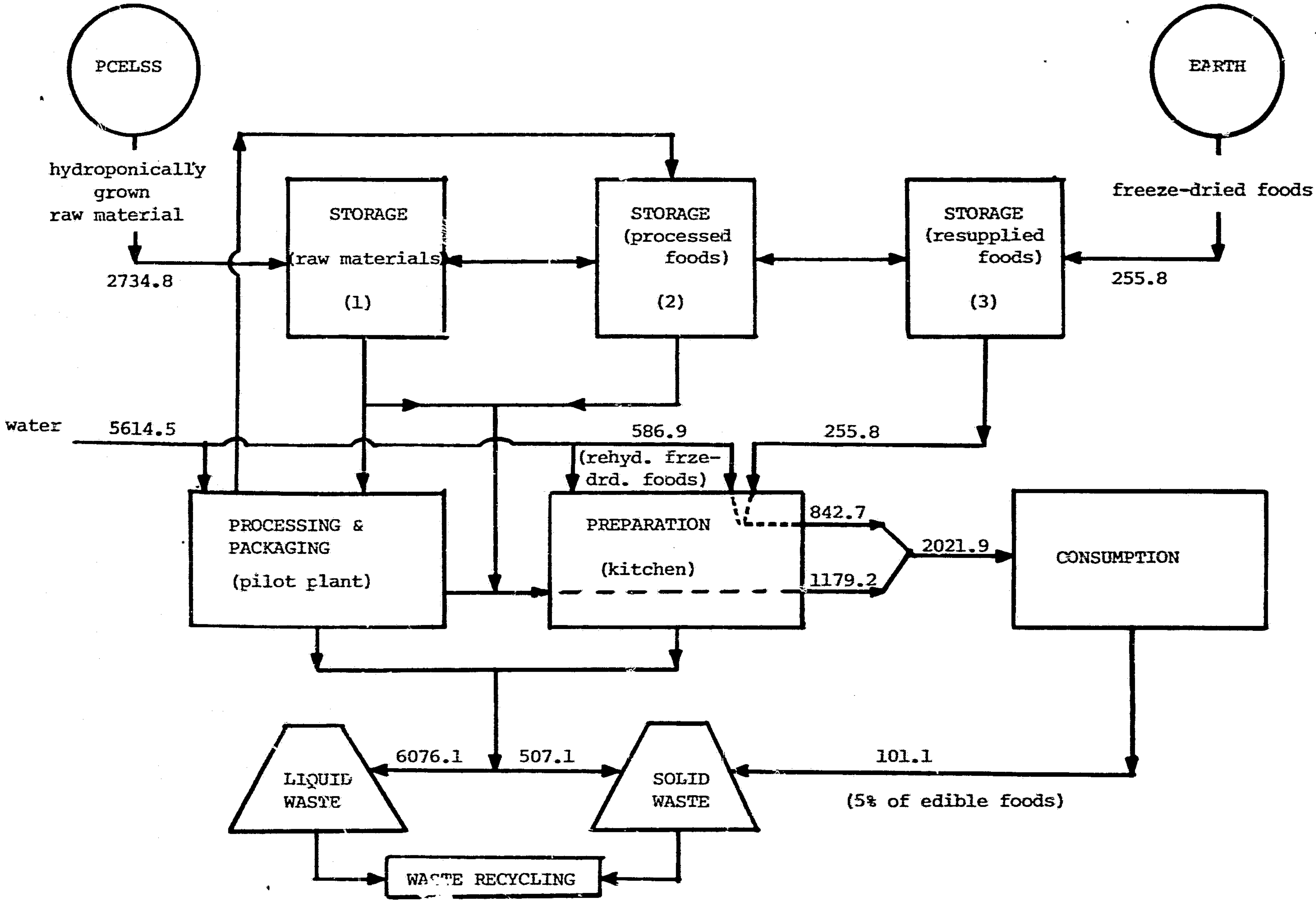

Fig. 1. Overall mass balance of monthly food resupply, regeneration, processing, and consumption in kg for 50 people in space habitat (PCELSS, Scenario II)

III. SUMMARY OF WORK IN PROGRESS

1) We are presently developing stepwise details (flow sheets) of food processes which could be used in space habitat (e.g., wheat and rice milling, bread baking, sugar extraction, aqueous oil extraction, soy protein texturization, etc.) taking into account the limitations and possibilities of such space colony.

2) We are preparing the mass balance for each of the above processes with respect to all inputs (raw food materials, water, chemicals, etc.) and all outputs (products, solid, liquid, and gas wastes). The required energy for these processes will also be calculated.

3) We are taking steps to obtain information about currently available equipment for all steps of food processes used in space habitat. This information shall be analyzed, and the potential for utilization will be evaluated.

4) Plans will be developed for design of a food pilot plant to be used in a ground based control demonstrator (GBCD) closely simulating space environment.

5) We shall proceed to develop a detailed outline of research and development needs to achieve a functional use of engineered foods in a space habitat. Assuming a target date for initial deployment of such a habitat late in the 20th century we shall develop the plan for development of the needed food component in terms of <u>engineered</u> foods.

6) A detailed plan for testing the feasibility of the engineered foods in the Second Phase of present work, to be initiated at the conclusion of the First Phase will be developed.

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A P P ~ N D I X   I

Waste Treatment in Partially Cl(sed Environment Life Support Systems (PCELSS)

Introduction

An extensive literature survey has been carried out in order to establish the amounts and composition of solid and liquid waste originated in food processing operations.

Particular emphasis has been given to vegetable products although information has also been collected for fruits, dairy products, eggs, poultry, beef, beet sugar and refined oils. When inadequate data was reported in the literature, some information was obtained from industrial sources.

Although overall size and composition of waste streams as presented in the literature or obtained from industrial sources may provide us with an idea of the magnitude of these parameters, broken down information for food operations is highly desirable in many cases but unfortunately very rarely available. In the case of root vegetables for instance, broken down information is critical and extrapolation of overall process information as practiced on earth to CELSS would be highly subjected to error. Differences in the state of the raw material would give origin to great discrepancies. As much as 5% of the raw material might be soil in root vegetables commonly processed by industry as opposed to the same type of vegetables if grown in hydroponic solutions.

A series of factors need also to be carefully considered when determining levels and composition of waste materials.

1. Plant size and percentage of plant capacity utilized.

   In general, larger plants present a more efficient use of water. A similar trend has been observed in regard to percent of used plant capacity.

2. Type of commodity and quality of the raw material.

   It is commonly accepted that information available for one product cannot be extrapolated to another. Each product is different. The condition of the raw material has a definite influence on the size and composition of the waste streams.

3. Product style.

   Differences in preparation equipment are associated with the style of the product. These differences in equipment will result in differences in the use of water and the level of pollutants. For example, corn-on-cob presents less water consumption than cream style or whole kernel corn. Sliced snap beans use more water than any other style.

4. Technology available and water use.

   The particular type of technology available at a plant influences the generation of waste. Modern technology has been geared towards the minimization of pollution. Operations such as peeling, blanching, transport of solids, etc., can be carried out using different methods, which will result in marked differences in size, as well as composition of waste materials. Water reuse is another factor that needs to be carefully considered.

5. Waste management.

   Food processing facilities may produce different amounts of waste material using the same type of technology. The control, management exerts over waste-producing operations at a plant, will result in differences on waste materials.

BASIS FOR THE FORMULATION OF THE WASTE MODEL

a. Size of population. The size of the population will affect to some extent the size and composition of the waste materials. A very small population has been selected for preliminary calculations.

b. Diet scenario. As previously mentioned, the particular commodities involved will determine the overall composition of the waste model. Diet scenarios have been planned based on the 1978 thrifty diet (USDA) and the 1977 Ames study base diet It should be mentioned that the thrifty diet considers only products easily obtained at not an excessive cost.

The potential food supply scenarios considered were as follows:

I. Food Resupply.

All foods are generated on earth and periodically resupplied to the habitat.

II. PCELSS-no animals.

Most or all the vegetable foodstuffs are grown on board. All foodstuffs derived from animals are periodically resupplied from earth.

III. PCELSS-limited animal population.

All of the vegetable foodstuffs are grown on board. Staples derived from animals (e.g., dairy products and eggs) are produced on board from a small animal population. Meat and fish are periodically resupplied from earth.

IV. CELSS.

All vegetable and animal foodstuffs are produced on board. Vitamins and trace diet elements that are not contained in sufficient quantity by foodstuffs are carried on board as diet supplement capsules.

Food supply has been divided into four basic groups.

1. Milk group: milk, cheese, ice cream.

2. Meat and alternates group:

   meat, poultry, fish

   eggs

   dry beans and peas, nuts

3. Vegetable and fruit group:

   dark green, deep yellow vegetables

   citrus fruit and tomatoes

   potatoes

   other vegetables and fruits

4. Bread and cereal group:

   cereal

   flour

   bread

   other baking products

Additional groups include:

5. Fats and oils

6. Sugar and sweets

Vegetables

Major steps for water use as well as generation of solids and dissolved residuals.

1. Washing and rinsing

   As much as 50% of the total liquid stream comes from these operations. These particular sources of waste material require special considerations.

Since plants will be grown in nutrient solutions much of this volume of water will not be required. The proximate analysis of these streams will be very different particularly in the case of root vegetables. Most metals found in vegetables originate from the soil in which they are grown. Plants absorb metal traces with higher concentrations usually observed in the peel. Fluctuations in the composition of the solid and liquid waste are due in part to the origin of the raw material.

2. Sorting

3. Peeling

High concentration of suspended solids are originated in this operation. It varies with the type of peeling and whether or not the vegetables have been blanched or lye-treated prior to peeling.

4. Blanching

Although small in volume the blanch water represents the largest portion of the soluble components in the liquid waste of an entire food processing operation. This operation is optional, depending on whether or not some food preservation is required.

5. Processing

Cooling waters and defrost waters are among others the most important sources of liquid waste in vegetable processing operations (optional).

6. Cleanup water

Washing of equipment, utensils, cookers, floors and general food preparation areas are major contributors of waste materials in food processing operations.

PREPARATION OF MODEL SYSTEM NO. 1
FOOD SUPPLY SCENARIO #2. HYDROPONIC PLANTS

Materials

Materials for the preparation of this waste model system for the case when hydroponic plants are grown on board and the remaining components of the diet are resupplied from earth, were obtained as follows:

Waste materials originated during fruit and vegetable preparation or processing were obtained in our laboratories. Special attention was paid to the case of root vegetables. For these materials, some preliminary washing was carried out to remove soil adhered to the surface iese preliminary washings were discarded.

It should be mentioned at this point, that waste materials from fruits and vegetables were collected manually. This would most likely be the case of a space colony with a very small population on board.

- Soy hulls and meal were obtained from:

A. E. Staley Manufacturing Co., Decatur, IL. (217)423-4411

The soy meal obtained had been solvent extracted. We were unable to obtain mechanically extracted soy meal, although we do not anticipate serious differences in composition between these two types of soybean meals.

- Wheat bran and shorts, which are the waste products originated in standard wheat milling operations, were obtained from:

ADM Milling Co.
Box 7007
Shawnee Mission, KS 66207
(913) 381-7400

- Rice polish, bran and hulls were obtained from:

Uncle Ben's Food, Inc.
13000 Westheimer
Houston, TX 77077
(713) 497-1970

Oats by-products including hulls and midds were obtained from:

The Quaker Oats Company John Stuart Res. Laboratories 617 West Main Street Barrington, IL 60010 (312) 381-1980	and	Con-Agra Company Omaha, Nebraska

Preparation procedure

The following procedure was used for the preparation of a representative waste model system originated during food processing and preparation.

In order to minimize chemical changes during storage upon arrival or preparation, solid and liquid waste were kept at 5°C.

The proportions used for the preparation of this preliminary model system were as indicated in Table 1. These values were obtained using literature and industry information.

During the process of collecting waste materials from fruits and vegetables, some experimental information was obtained and compared to the estimated values (Table 2). Discrepancies were expected in part due to the different levels of production as well as due to variations in the raw material. Literature and industry data has been obtained with much higher levels of production, resulting in different amounts of waste materials. However, it was considered useful to partially determine what fluctuation would be expected as affected by production levels.

For the preparation of this preliminary model system, waste materials originated during sugar manufacturing and oil processing were kept separated from the remaining components of the model system.

The ingredients of the model system were thoroughly blended to a slurry. This slurry was then placed in trays at -40°F and then freeze-dried to a final moisture content of 1-2%.

After dehydration, the material was passed through a vertical cutting machine (Hobart 15 Model). The material was reduced in size to ∿ 500 microns plus fibers.

After thorough blending of the pulverized material, this material was canned under vacuum in #10 type cans containing approximately 2 lbs of material.

A flow diagram of the preparation of the waste model is given (Fig. 1).

WASTE MODEL SYSTEM PREPARATION

FLOW DIAGRAM

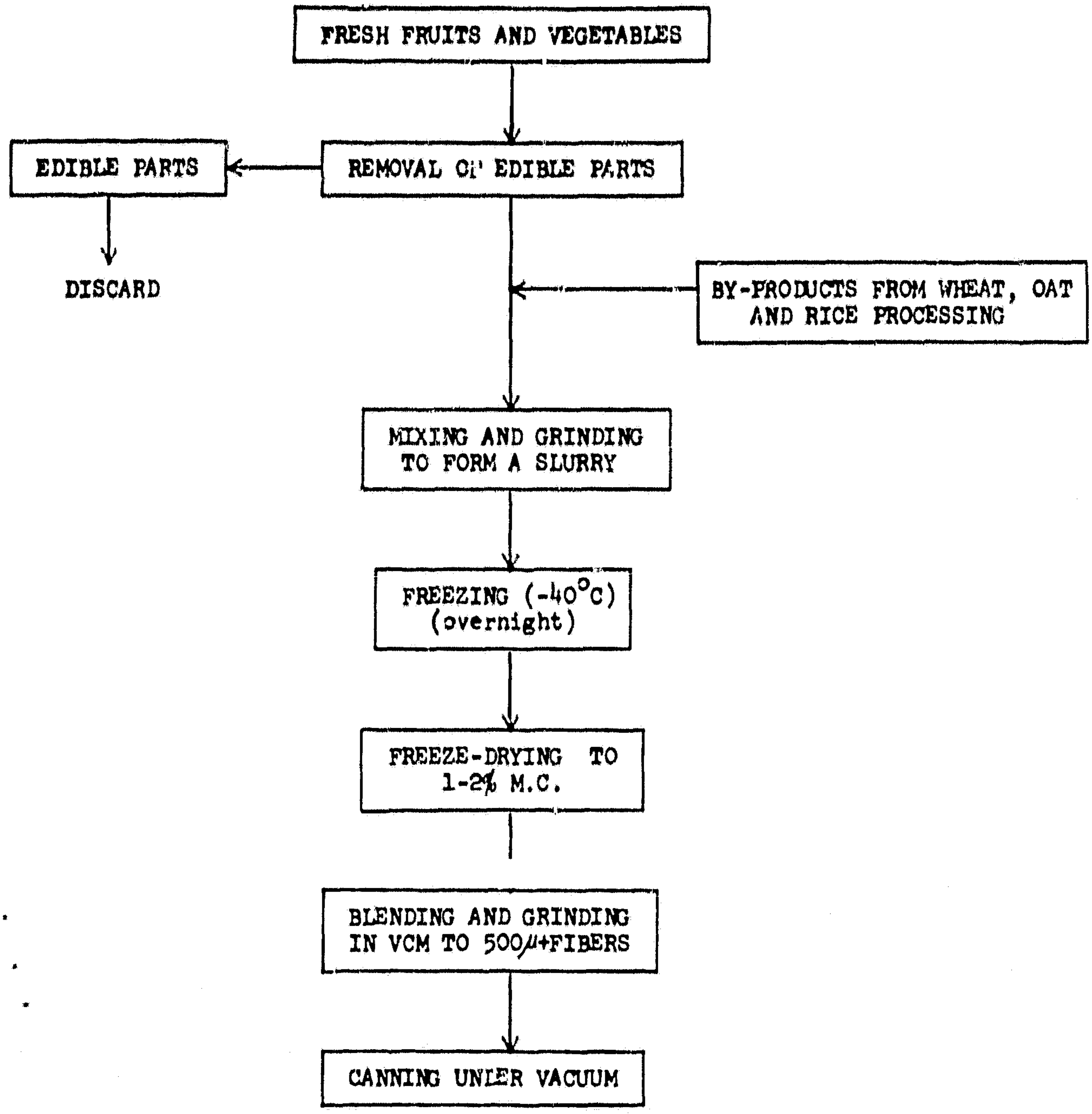

Figure 1.

Table 1. Composition of waste model system No. 1 as estimated from data obtained from the literature and industry sources.

	amount * g/day/person	% solid waste	solid waste g/day/person	solid waste dry weight	liquid waste gal/day/person
Asparagus	7	20(33)	1.8	0.1	0.008
Broccoli	18	20	4.5	0.2	0.035
Carrots	12	11(52)	1.5	0.2	0.013
Greens	26	16(40)	5.0	0.[illegible]	0.051
Potatoes	131	25(30)	43.7	9.6	0.144
Green beans	34	20	8.5	0.9	0.014
Beets	-	-	-	-	-
Cabbage	9.4	35	5.1	0.5	0.019
Celery	10	11	1.2	0.1	0.012
Cucumbers	5	10	0.6	0.0	0.002
Lettuce	10	26	3.5	0.2	0.020
Onions	-	-	-	-	-
Peas	7.5	64(79)	13.3	3.4	0.011
Lima beans (dry)	28	∿64	∿49.8	45.8	-
Apples	32	8	2.78	0.4	-
Bananas	20	32	9.4	2.8	-
Peaches	31	13	4.6	4.1	-
Tomatoes	59	9(16)	5.8	0.4	0.030
Oranges	59	27	21.8	4.7	-
Strawberries	32	10	3.3	0.1	0.035
Peanuts	10	33	4.9	4.4	-
Wheat	151	27.5	57.3	49.9	-
Oats	60	45	49.1	44.3	-
Rice	90	30	38.6	35.5	-
Soy	29		29 (hulls)	219	-
Soy(oil) (soy 361g)	65		209 (meal)		0.040
beets			0.65(bleach)	.65	
Beets (sugar) (477g)	62	.	19 (lime)	∿19	1.00
			398 (pulp)	19	
			24 (molasses)	20	
Bread		2	3.3	2.1	0.064
Food preparation					0.045
Spent oils (15%)					(0.003)
			1019.1	487.9	1.54

* Amounts given correspond to the edible parts.

Assumptions for the estimates of Table 1.

-Calculations were made based on the "1974 Thrifty Diet"

-Milk products, meats, eggs and fruits (except strawberries and tomatoes) were considered as being resupplied from earth.

-It has been assumed that the solid waste is originated in food preparation (processing) and that solid waste originated from damaged or spoiled raw material is minimum. Values of % solid waste given in parentheses would correspond to the case when irregularities in the raw material are observed.

-Conventional oil and sugar processing was assumed. In the case of oil refining, the liquid waste includes acidulation of the soapstock.

-Corrections or adjustments to the amounts of wheat and oil were done to account for the flour and oil used in the making of bread and crackers.

-Liquid waste from cooking was assumed as being 280 ml/lb and spent oils about 15%.

-Where the items "Pasta or rice" appear on the given diet, only rice was considered for the calculations.

-The solids content in the liquid waste is approximately 0.2-2% for most processes in the food industry; exact values will depend on the specific commodity.

-We have assumed that oil recovery from soybeans using aqueous extraction is close to 100%. However, aqueous processing using standard technology would extract $\sim$65% of the oil only. Therefore, requiring larger amounts of raw material to satisfy the amount of oil requested. Although aqueous extraction presents a much less efficient method for oil recovery as compared to solvent extraction (recoveries in the 95% range), aqueous extraction would be the recommended method due to the minimization in the use of chemicals.

-In the case of flour, we have assumed that standard wheat milling technology would be used. However, considering the case of a space colony, whole wheat bread would probably be the preferred choice. Preparation of whole wheat bread would contribute to minimize waste, since the whole grain is used.

Option

-If the 28 g/day/person of dry lima beans are substituted by soymeal the total amount of solid waste would be:939 g/day/person (409.4 g/day/dry weight)

-Cleaning of utensils or kitchenware has not been taken into account.

In Appendix II, some estimates are given for the ultimate analysis of waste materials originated in the colony under food supply scenario II.

So far we have considered that all the food required by the space colony is produced or harvested as needed, and that food preservation is not a factor of importance. However, if we consider a population in the colony of over 100 people, we believe that some degree of mechanization will be required to decrease the labor involved in food preparation. We also feel that either freezing, preferably, or canning might be required to avoid shortages in the supply of some of the commodities produced on board. These two factors will affect the type and size of the liquid and solid waste streams.

In the following section some factors to be taken into account in fruit and vegetable processing will be mentioned. These factors apply when mechanization and preservation techniques are used.

Table 2. A comparison between experimental and estimated values for solid and liquid waste originated during fruit and vegetable preparation.

Waste from:	Solid Waste (%)		Liquid Waste ml/g Edible	
	Expt.	Est.	Expt.	Est.
Asparagus	---	20	4.00	4.23
Broccoli	21.3	20	1.70	7.19
Carrots	17.9	11	0.69	4.00
Greens	---	16	7.14	7.25
Potatoes	28.5	25	1.10	4.06
Green beans	24.4	20	2.32	1.52
Cabbage	44.5	35	2.48	7.48
Celery	24.2	11	3.92	4.44
Cucumbers	22.9	10	0.62	1.48
Lettuce	21.6	26	1.01	7.40
Onions	---	---	---	---
Peas	63.1	64	1.77	5.42
Lima beans (dry)	50.0	64	---	---
Apples	21.5	8	---	---
Bananas	36.9	32	---	---
Peaches	13.7	13	---	---
Tomatoes	10.7	9	1.43	1.88
Oranges	23.3	27	---	---
Strawberries	10.5	10	0.66	4.04
Peanuts	27.0	33	---	---
Wheat	---	27.5	---	---
Oats	---	45	---	---
Rice	---	30	---	---

Table 3. Composition of solid waste (dry matter) used to prepare the waste model system No. 1 (as canned).

Waste from:	Waste fraction dry (%)
Asparagus	0.04
Broccoli	0.11
Carrots	0.11
Greens	0.22
Potatoes	4.59
Green beans	0.41
Cabbage	0.24
Celery	0.04
Cucumbers	0.01
Lettuce	0.08
Peas	1.64
Lima beans (dry)	21.87
Apples	0.21
Bananas	1.35
Peaches	1.98
Tomatoes	0.19
Oranges	2.22
Strawberries	0.06
Peanuts	2.11
Wheat	24.27
Oats	21.57
Rice	16.68
	100.00

Where feasible, waste streams have been broken down into individual streams coming from each one of the food processing operations and overall results estimated.

In order to conserve on water usage or reduce pollutant levels, a series of assumptions have been taken into account. In the case of vegetables for example:

1. To reduce amounts as well as loads of waste. Steam blanchers rather than hot water blanchers have been considered.
2. Air-cooling using blancher condensate as opposed to water cooling has been selected to reduce the organic waste load of the blanching and cooling effluents.
3. Dry size graders rather than hydrograders have been chosen.
4. Use of dry belt conveyors and/or negative air for transport rather than fluming.
5. Utilization of air transport methods for dry-cleaning.
6. In the cases in which peeling is required, such as in the case of potatoes, carrots, beets, etc., steam-peeling has been considered as the most suitable way to accomplish this stage. A short exposure steamer presents the following advantages: a) high capacity, b) no chemicals are required, c) labor savings, d) low maintenance, e) less liquid waste, f) high increased yield as compared to other peeling methods, g) versatility and h) minimum heat ring.
7. Definition of processing involved.

Table 4. Amounts of solid and liquid waste originating during preservation of fruits and vegetables by freezing (industrial values).

	solid waste %	liquid waste gal/ton	Comments
Asparagus	33	2083	steam-blanched
Broccoli	33	2375	steam-blanched, cut
Carrots	21	1940	short-exposure steamer, cut
Greens	16	2660	chopped
Potatoes	30	2500	short exposure steamer, cut
Green beans	21	1390	cut
Celery	∿ 15	2230	cut
Peas	64	2500	-
Tomatoes	16	1300	"canned"
Strawberries	10	2000	-

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Table A, Concentration ranges of essential nutrient elements in plant tissue.

Nutrient Element	Forms Absorbed	Concentration in Plant
		%
Carbon (C)	CO_2	45
Hydrogen (H)	H_2O	6
Oxygen (O)	O_2, CO_2, H_2O	43
Nitrogen (N)	NH_4^+, NO_3^-	1 to 6
Phosphorus (P)	$H_2PO_4^-, HPO_4^=$	0.05 to 1
Potassium (K)	K^+	0.3 to 6
Calcium (Ca)	Ca^{++}	0.1 to 3
Magnesium (Mg)	Mg^{++}	0.05 to 1
Sulfur (S)	$SO_4^=$	0.05 to 1.5
		ppm
Iron (Fe)	Fe^{++}, Fe^{+++}	10 to 1000
Manganese (Mn)	Mn^{++}	5 to 500
Copper (Cu)	Cu^{++}	2 to 75
Zinc (Zn)	Zn^{++}	5 to 200
Boron (B)	H_3BO_3	2 to 75
Molybdenum (Mo)	$HMoO_4^-$	0.1 to 50
Chlorine (Cl)	Cl^-	25 to 25,000

(After Walsh et al., 1976)