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Crew Food Systems

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SUMMARY

The Advanced Life Support (ALS) chamber tests provided a unique opportunity to evaluate future space food systems and to assess potential problems associated with conversion of chamber-grown plants to edible foods. The JSC Space Food Systems Laboratory (hereafter referred to as the Food Lab) provided food support for all of the life support tests. The objective for the first two tests was to provide a nutritionally sound and acceptable food system with the limited food preparation and storage facilities in the chambers. Crew sensory evaluations, supermarket surveys, menu planning, and nutritional analyses were completed to accomplish the objective. The 15-day Phase I food system consisted of shelf-stable food and a microwave oven. Phase II evaluated an abbreviated International Space Station (ISS) food system with microwave ovens, a freezer, and a refrigerator. The objective of the Phase IIa mission was to evaluate a more advanced ISS food system. The food system for the 91-day Phase III test evaluated a potential regenerative food system. A 50 percent plant-based diet was tested for 81 days, and a menu with 90 percent of the calories derived from the approved crops to be grown was evaluated for 10 days. All of the objectives of the food systems were met and/or exceeded for all the tests.

The results of these food system tests established that a 50 percent frozen food system with microwave heating for food preparation was an optimum combination of food preservation technologies for maintaining an acceptable food system. This concept will continue to be followed for the ISS food system.

The 10-day BIO-Plex test verified that a menu can be developed from the basic crop list. This menu is acceptable for a crew for 10 days, and most of the nutritional requirements are attained. The drawback involves the fact that a plant-based diet is very labor intensive with excessive waste. Comprehensive research is needed in the areas of food processing and preparation in an enclosed environment.

Introduction

Food systems for the chamber studies became more complex, with additional objectives for each progressive chamber test. The JSC Food Lab provided food support for all of the life support tests. The food system being planned for the ISS is 50 percent frozen/refrigerated with microwave/convection heating for food preparation. The ALS chamber tests provided a unique opportunity to verify this concept with an isolated crew in a closed environment. The basic objective for the first test was to supply a shelf-stable food supply for one person for 15 days. Additional crewmembers were added for the subsequent missions and additional requirements were placed on the food system. Menus were planned based upon crew interviews, food questionnaires, and available food. Most of the food was procured from local supermarkets and passed into the chamber on a routine schedule. Crewmembers performed sensory evaluations on the food while in the chamber, and crew debriefs were held after each test to gain feedback.

Methods

Early Human Test Initiative (EHTI) Phase I

The food system for the Phase I test consisted of shelf-stable foods that were heated in a microwave oven. The menu was based upon food sensory evaluations conducted with the prime and back up crewmembers, food questionnaires, and crew interviews. Food from local supermarkets and Shuttle vendors was used to make up the diet. Recommended dietary allowances (RDA) were used as the dietary requirements (1).

Early Human Test Initiative Phase II

Facilities, Nutritional Requirements, Sensory Evaluations, and Menu

A combination freezer/refrigerator and two microwave ovens (600 watts each) were included in the chamber for the Phase II food system. The main objective of the food system was to evaluate the use of frozen food and microwave heating in an isolated environment as was being planned for the ISS. The prime and back-up crews completed food frequency and food questionnaires, and the results of the questionnaires were used to develop a supermarket survey to determine available foods. Two sensory evaluations on potential foods were conducted with the crewmembers using a nine-point hedonic scale where nine equals “like extremely” and one equals “dislike extremely” (2). Data from the sensory evaluations were used to develop a menu based upon crew preferences. Caloric requirements were calculated for each crewmember based on the World Health Organization (WHO) equations and the duration of the daily exercise (3). Macronutrient percentages

(carbohydrate, protein, and fat) were calculated based on the nutritional requirements for ISS missions up to 360 days (4). The menu was designed as a 10-day cycle to repeat three times during the 30-day chamber test. Each crewmember had a standard menu with some minor deviations to accommodate personal preferences. The crew was allowed to make substitutions to the menu during the test if desired. The daily menu included breakfast, lunch, dinner, and two snacks. The breakfast meal consisted of milk or juice, tea/coffee, fruit, and cereal or a bread product. The lunch meal consisted of a salad, a microwaveable lunch item or lunch-style food, a bread product, and a beverage. The dinner meal included a microwaveable dinner entrée, a microwaveable vegetable, and a dessert. Snacks included fruit, nuts, popcorn, granola bars, and yogurt.

The menu, including planned snacks, was approximately 2,200 kcal for the male subjects and 2,000 kcal for the female subject. Approximately 12 to 15 percent of calories came from protein, 50 to 55 percent from carbohydrate, and 30 to 35 percent from fat. The four test subjects were provided copies of their menus with the nutritional content, a list of commercial products available for substitution, and a sensory evaluation form to be completed during the test.

The food was made up of 16 percent fresh, 49 percent refrigerated/frozen, and 35 percent shelf-stable foods. Most of the food was stored outside the chamber and passed into the chamber through the airlock daily.

Advanced Human Life Support Enclosed System Study Phase IIa

Chamber Test as a Ground-Based Analogue for the ISS Food System

The main objective for the Phase IIa food system was to evaluate the proposed ISS food system by emulating it as close as possible in the chamber test. The food preparation hardware inside the chamber was the same as the Phase II test except the microwave ovens were 1,000 watts each instead of 600. The menu was developed by identifying commercial products that were comparable to the ISS food list in supermarkets and in the Nutritionist III database (5). A standard menu was created using the ISS standard menu and the commercial products version of the ISS food list. Prior to the test, two sensory evaluations were held with the crew. Approximately 20 commercial foods were evaluated at each session. The crewmembers were provided the ISS standard menu, the food list, food questionnaire, and a copy of their sensory results. This information was used by each crewmember to develop an individual 20-day cycle personal preference menu for the Phase IIa test. A follow-up meeting was held with the crew to discuss their personal menus, make minor nutritional adjustments, and determine the pantry contents. The pantry was a 20 percent planned overage that the crew could use for substitution. Caloric requirements and macronutrient percentages were calculated as in Phase II.

Each crewmember had a personalized menu, but on three occasions the crew shared a common "theme" meal at dinner. Menu analysis was performed using the Nutritionist III database (4). The menus consisted of approximately 3,000 kcal for the male subjects and 2,100 kcal for the female subject. Approximately 12 to 15 percent of calories came from protein, 50 to 55 percent from carbohydrate, and 30 to 35 percent from fat. The subjects were provided copies of their menus with nutritional content, a list of commercial products available for substitution, and sensory evaluation sheets to be performed during the test.

The food was made up of 15 percent fresh, 50 percent refrigerated/frozen, and 35 percent shelf-stable foods. Most of the frozen food was stored outside the chamber and passed into the chamber through the airlock. Forty days of shelf-stable food was stored inside the chamber prior to start, and was replenished on day 40. Sensory evaluations using the nine-point hedonic scale were completed every Friday by the crewmembers. The evaluation forms were passed into the chamber weekly.

Lunar-Mars Life Support Test Project Phase III

The overall objectives of the food system for Phase III were to:

a) Emulate a food system for a long-duration space mission
b) Determine the acceptability of the menu over the 91-day duration of the test
c) Examine the ease and sufficiency of food preparation and processing
d) Provide a safe food system which supplies a nutritious menu for the crewmembers
e) Render a food system that may be monitored and controlled to support medical experiments
f) Satisfy the physiological needs and the psychological food-related needs of the crew
g) Test a 10-day BIO-Plex menu to identify its acceptance in a closed-system environment that simulates long-term habitation in the ALS test bed facilities.

The objectives of the 10-day BIO-Plex portion of the study were to measure acceptance and determine if the nutritional needs could be met with a plant-based diet that incorporated a large portion of the ALS crops into the food system.

The Phase III 91-day food system was divided into two sections, the 81-day food system (September 19 to December 19, 1997) and the 10-day food system (October 20-29, 1997). The 81-day portion of the test provided a 50 percent plant-based diet (four or less servings of meat per week) utilizing a food system comprised of fresh, frozen, and thermostabilized foods. The Growth Apparatus for the Regenerative Development of Edible Nourishment (GARDEN), from Quantum Devices, Inc., Barneveld, WI, provided fresh Waldman's green lettuce. The GARDEN supplied the crew with four heads of lettuce every 10 days throughout the 91-day test,

including one harvest of lettuce during the 10-day BIO-Plex menu test.

A full-size, side-by-side refrigerator/freezer (67.6 x 31.5 x 32.5 in.) was provided inside the chamber. The unit held three days of frozen food and a one-week supply of fresh food, as well as several miscellaneous refrigerated food items. A chest freezer (29.5 x 41.5 x 22.5 in.) was available outside of the chamber for a one-week supply of frozen food storage. Storage was available for shelf-stable food items and dishware in a stainless steel cabinet (24 x 30 x 18 in.) inside the chamber. This cabinet also housed the microwave/convection oven. Additional space was located behind the television (37 x 86 x 12 in.) on the first floor; this storage space was used for shelf-stable food items and paper goods. A bread maker, blender, stovetop burner, and microwave/convection oven were provided in the chamber.

In addition, the Variable Pressure Growth Chamber at Johnson Space Center provided wheat during the test. The wheat berries were harvested and dried prior to the 10-day BIO-Plex menu. The dried wheat berries were processed into flour, mixed with other ingredients, and individually bagged for use in three bread recipes (whole wheat, soy, and sweet potato bread) that were prepared by the crew. These bags were transferred into the chamber for use during the last half of the test. A second harvest of wheat berries occurred after the 10-day test, and those berries were also processed into flour and used by the crew for bread baking.

The Phase III food system was developed with the aid of food frequency and nutrition questionnaires. The questionnaires helped to determine the selection of food items, recipes, and menus, and also defined food preferences, allergies, and habits. The caloric requirements for the Phase III food system were calculated, using a moderate activity factor, based on the World Health Organization (WHO) equations as follows:

Men (30 - 60 years): 1.7 (11.6W + 879) = kcal/day required
Women (30 - 60 years): 1.6 (8.7W + 829) = kcal/day required
W = weight in kg

81-Day Menu Development

A preliminary menu was designed, and the prime and back-up crew evaluated 38 items in two food evaluation sessions to determine the acceptability of the menu. Evaluations were performed using a nine-point hedonic scale, in which acceptability was rated with nine being “like extremely” and one being “dislike extremely” (2). In addition, nine vegetarian Meal Ready-to-Eat (MRE) products were evaluated. Five of the nine MREs were rated acceptable for use (average of six or above on the nine-point hedonic scale).

In August, a prime crewmember was replaced with a back-up. Due to this adjustment, some items on the menu were changed to accommodate the new crewmember.

The 81-day caloric requirements were calculated for the standardized menu, and the menu was finalized. This menu used three types of foods: fresh, frozen, and shelf-

stable. The fresh food items included fruits, vegetables, fresh chamber lettuce, fresh bread, and various prepared food items. The frozen food supply included frozen food entrees, vegetables, fruits, desserts, and various beverages. Shelf-stable food items were vegetarian MREs, snacks, canned items, boxed mixes, beverages, and condiments. The 81-day menu was designed as a 20-day cycle (Table 4.4-1) that would repeat four times.

The crewmembers were given a standardized menu. This minimized the time required for food preparation and processing; however, the menu did provide fresh food items that required extra preparation and frozen items requiring thawing/heating ahead of time.

At the halfway point, Halloween, and on a crewmember's birthday, special treats were provided. A special holiday meal was prepared for the crew to be served on Thanksgiving (November 26). This meal included a roasted turkey that was prepared in the JSC Food Lab as well as numerous additional typical holiday foods.

The 81-day menu was analyzed using the Nutritionist III Database (4). The baseline menu without beverages or snacks provided approximately 1,900 kcal per day. On average, the menu supplied 13 percent of the calories from protein, 64 percent of the calories from carbohydrate, and 23 percent of the calories from fat.

The four crewmembers were provided with a copy of the menu for each 20-day cycle during the 81-day portion of the test. Each crewmember also received a sensory evaluation form every Friday during the test to evaluate the menu. The menu and sensory evaluation score sheets were sent to the crew via electronic mail.

Table 4.4-1 *Twenty-day sample of the 81-day menu*

DAY 1: Friday, Sept. 19	**DAY 2: Saturday, Sept. 20**	**DAY 3: Sunday, Sept. 21**
Cereal	Cereal	Belgian waffles (2 waffles)
English muffin (1 muffin)	**Toast	Fruit yogurt (4.4 oz container)
Margarine (1 t.)	Margarine (1 t.)	Margarine (1 t.)
Jelly/jam	Jelly/jam	Syrup (1/4 cup)
Milk/juice (8 oz)	Milk/juice	Milk/juice
Coffee/tea	Coffee/tea	Coffee/tea
Broccoli pasta salad (1 cup)	Macaroni and cheese	Spicy black bean burger (1 patty)
Grilled chicken sandwich	Broccoli spears (2 spears)	Sandwich bun (1 bun)
**Lettuce/tomato/onion	**Baby red potatoes (2 potatoes)	Baked potato chips (12 chips)
Kiwi slices (1 kiwi)	**Blushing pears (1/2 cup)	Dill pickle spear
Beverage	Beverage	**Salad
		Beverage
Cheese manicotti w/ tomato sauce	Turkey	Garlic buttered baked fish fillet (1 fillet)
Breadsticks (1)	Mashed potatoes	**Pasta accents, garlic herb (1 c. cooked)
Salad	Peas	**Soy bread
*Strawberry cheesecake (1/6 cheesecake)	**Whole wheat bread	Margarine
Beverage	Margarine	*Chocolate eclair (1 eclair)
	*Cherry cobbler (1/4 cobbler)	Beverage
	Beverage	

*Items need advanced thawing/heating
**Items need preparation

Table 4.4-1 continued *Twenty-day sample of the 81-day menu*

DAY 4: Monday, Sept. 22	**DAY 5: Tuesday, Sept. 23**	**DAY 6: Wednesday, Sept. 24**
Oatmeal (1 packet)	Cereal	Pancakes (3 pancakes)
*Strawberries (2/3 cup)	**Toast	*Blueberries (3/4 cup)
Milk/juice	Margarine (1 t.)	Margarine (1 t.)
Coffee/tea	Jelly/jam	Syrup (1/4 cup)
	Milk/juice	Milk/juice
	Coffee/tea	Coffee/tea
Won ton soup (1 container)	Tuna noodle casserole	Vegetable soup (~1 cup prepared)
Vegetable egg roll	Crinkle cut carrots (2/3 cup)	Saltine crackers (5 crackers)
Rice, white	Cantaloupe slices	**Grilled cheese sandwich
Snow pea pods (1/2 pkg)	Biscuit (1 biscuit)	Kiwi slices (1 kiwi)
Beverage	Margarine	Blue Bell cup (1 cup)
	Beverage	Beverage
Eggplant parmigiana	Vegetable bowl w/teriyaki rice	Roasted turkey w/gravy
*Garlic bread (1/6 loaf)	Apricot halves (1/2 cup)	Cornbread dressing
Salad	**Soy bread	Cut, whole carrots (3/4 cup)
*Lemon meringue pie (1/6 pie)	Margarine	Tropical fruit salad (1/2 cup)
Beverage	*Coconut cream pie (1/5 pie)	**Sweet potato bread
	Beverage	Margarine
		Beverage

*Items need advanced thawing/heating
**Items need preparation

Table 4.4-1 continued *Twenty-day sample of the 81-day menu*

DAY 7: Thursday, Sept. 25	**DAY 8: Friday, Sept. 26**	**DAY 9: Saturday, Sept. 27**
Cereal	Cereal	Cereal
Fruit yogurt (4.4 oz container)	English muffin (1 muffin)	Banana
Milk/juice (1 cup)	Margarine (1 t.)	Milk/juice
Coffee/tea	Jelly/jam	Coffee/tea
	Milk/juice (1 cup)	
	Coffee/tea	
Bean & cheese burrito (1)	Four-cheese pizza (1/4 pizza)	Fettuccine alfredo
Fiesta corn (1/2 cup)	Mandarin oranges (1/2 cup)	**Baby red potatoes (2 potatoes)
Tortilla chips (9 chips)	Salad	California style veggies (3/4 cup)
Picante sauce (2 T.)	Raspberry jelly roll	**Soy bread
Chocolate chip cookies (3)	Beverage	Margarine
Beverage		Beverage
Grilled lemon pepper fish fillet (1 fillet)	Steak or chicken	Beef fajita pocket or Turkey/broc/cheese pocket (1 pocket)
**Scalloped potatoes (1 cup)	**White beans and rice (3/4 cup)	Red beans & rice (1 MRE)
Mixed vegetables (2/3 cup)	Asparagus spears (8 spears)	Red grapes
Biscuit (1 biscuit)	Red grapes	*Chocolate chip cookie dough sundae
Margarine	**Soy bread	Beverage
*Key lime pie (1 slice)	Margarine	
Beverage	Beverage	

*Items need advanced thawing/heating
**Items need preparation

Table 4.4-1 continued *Twenty-day sample of the 81-day menu*

DAY 10: Sunday, Sept. 28	**DAY 11: Monday, Sept. 29**	**DAY 12: Tuesday, Sept. 30**
French toast (2 pieces)	Cereal	Cereal
Sliced peaches (1/2 cup)	Plum	Plain bagel (1)
Margarine (1 t.)	Milk/juice	Cream cheese (2 T.)
Syrup (1/4 cup)	Coffee/tea	Jelly/jam
Milk/juice		Milk/juice
Coffee/tea		Coffee/tea
Quiche Florentine (1 quiche)	Tomato bisque	Fried chicken w/gravy
**Pasta accents, garden herb (1 c. cooked)	(~1 cup prepared)	Mashed potatoes
Red grapes	Saltine crackers (5 crackers)	Corn
Beverage	**Grilled cheese sandwich	**Soy bread
	Tropical fruit salad (1/2 cup)	Margarine
	Beverage	Jell-O (1 Jell-o cup)
		Beverage
Harvest burger (1 patty)	Country roasted turkey	Cheese lasagna
**Lettuce/tomato/onion	Rice pilaf	California style veggies (3/4 cup)
Cheese (1 slice)	Pineapple chunks (1/2 cup)	**Whole wheat bread
Sandwich bun (1 bun)	Dinner roll (1)	Margarine
Western beans (1 MRE)	Margarine	*Flaky coconut layer cake
**Coleslaw (1 1/2 cups)	Fruit freeze (1)	Beverage
Blue Bell cup (1)	Beverage	
Beverage		

*Items need advanced thawing/heating
**Items need preparation

Table 4.4-1 continued *Twenty-day sample of the 81-day menu*

DAY 13: Wednesday, Oct. 1	**DAY 14: Thursday, Oct. 2**	**DAY 15: Friday, Oct. 3**
Cereal	Oatmeal (1 packet)	Cereal
**Toast	Fruit yogurt	*Raspberries (3/4 cup)
Margarine	Milk/juice	**Toast
Jelly/jam	Coffee/tea	Margarine
Milk/juice		Jelly/jam
Coffee/tea		Milk/juice
		Coffee/tea
Cream of broccoli soup	Won ton soup (1 container)	Corn on the cob (1/2 ear)
Harvest burger (1 patty)	Oriental rice w/ veggies (1 package)	Black-eyed peas & okra (1 MRE)
**Lettuce/tomato/onion	Broccoli spears (2 spears)	*Blueberries (3/4 cup)
Sandwich bun (1 bun)	Mandarin oranges (1/2 cup)	Angel food cake
Escalloped apples (1/2 package)	Blue Bell cup (1 cup)	Beverage
Beverage	Fortune cookies (3 cookies)	
	Beverage	
Bean & cheese burrito (1 burrito)	Bow tie pasta w/creamy tomato sauce	Steak or chicken
**Rice, Spanish (1 cup)	Asparagus spears (8 spears)	**Baked potato
Green beans (2/3 cup)	Pineapple chunks (1/2 cup)	Mixed vegetables
Sherbet (1/2 cup)	**Sweet potato bread	Dinner roll (1 roll)
Beverage	Fruit freeze (1)	Margarine
	Beverage	*Lemon meringue pie (1/6 pie)
		Beverage

*Items need advanced thawing/heating
**Items need preparation

Table 4.4-1 continued *Twenty-day sample of the 81-day menu*

DAY 16: Saturday, Oct. 4	**DAY 17: Sunday, Oct. 5**	**DAY 18: Monday, Oct. 6**
Pancakes (3 pancakes)	Cereal	Cereal
Cantaloupe slices	English muffin (1 muffin)	**Toast
Margarine	Margarine (1 t.)	Margarine (1 t.)
Syrup (1/4 cup)	Jelly/jam	Jelly/jam
Milk/juice	Milk/juice	Milk/juice
Coffee/tea	Coffee/tea	Coffee/tea
Cheese enchilada	Turkey, ham & cheese pocket	Minestrone soup (1 MRE)
Mexican rice & beans	**Sweet potato	Saltine crackers (5)
Tortilla chips (9 chips)	Salad	**Blushing pears (1/2 cup)
Picante sauce (2 T.)	**Strawberry shortcake	**Salad
Strawberry parfait royale	Beverage	Beverage
Beverage		
Vegetable lasagna	Macaroni & cheese	Cheese ravioli in marinara sauce
Red grapes	Cauliflower (2/3 cup)	Garlic bread
Salad	Tropical fruit salad (1/2 cup)	Green beans (1/2 cup)
Chocolate pudding (1 pudding cup)	**Whole wheat bread	*Peach cobbler (1/4 cobbler)
Beverage	Margarine	Blue Bell cup (1)
	Beverage	

*Items need advanced thawing/heating
**Items need preparation

Table 4.4-1 continued *Twenty-day sample of the 81-day menu*

DAY 19: Tuesday, Oct. 7	**DAY 20: Wednesday, Oct. 8**
Oatmeal	Belgian waffles (2 waffles)
Kiwi slices	Peaches, sliced, raspberry flavored
Milk/juice	Margarine (1 t.)
Coffee/tea	Syrup
	Milk/juice
	Coffee/tea
Country fried chicken	Blackened chicken
Mashed potatoes	Rice
**Soy bread	Corn
Margarine	Chocolate pudding (1)
Jell-O	**Soy bread
Beverage	Margarine
	Beverage
Fettuccine alfredo w/broccoli pieces	Vegetable pizza
Crinkle cut carrots (2/3 cup)	*Strawberries
Breadsticks (1)	Green beans (1/2 cup)
Margarine	Chocolate mousse (1/5 mousse)
*Raspberries (3/4 cup)	Beverage
Beverage	

*Items need advanced thawing/heating
**Items need preparation

10-Day Menu Development

The 10-day BIO-Plex menu was designed to meet the NASA requirements which specified that at least 90 percent of the calories be derived from the NASA crop list (Table 4.4-2). The remaining 10 percent consisted of resupply items, such as fruit, beverages, and spices. Recipes for the 10-day BIO-Plex menu were selected from recipes that met the requirements or could be modified to meet them. The first requirement was that the recipe had to consist of mostly NASA crops or crop products. Another requirement was minimal preparation time or few preparation steps. These recipes were then evaluated for overall sensory acceptability using a nine-point hedonic scale. A sensory score of six or greater was considered acceptable for the menu. Items that could be prepared in the chamber were assigned to the crew. The remaining food preparation and processing activities were performed in the JSC Food Lab. Most of the preparation with the raw products was performed outside of the chamber, and the crew received partially prepared foods in labeled containers. The development of the menu for the 10-day test was a two-step process (6, 7).

Step 1: Selection and Screening of Recipes

Recipe selection was based on the following criteria:

a) Majority of ingredients derived from the recommended crop list (Table 4.4-2)
b) Limit the number of ingredients that would require resupply
c) Overall taste panel acceptability of six or greater on hedonic scale
d) Non-labor-intensive recipe preparation

Table 4.4-2 *NASA crop list*

Wheat	White Potato	Salad mix:
Peanut	Sweet Potato	lettuce, tomato,
Soybean	Rice	green onion,
		green leafy
		vegetables, herbs

Sources for the recipe search came from vegetarian cookbooks, the Internet, and soybean cookbooks. Recipes were initially screened through a laboratory tasting session. Spices and flavorings contribute minimally to the amount of the resupply needed to support the menu; therefore it was assumed that these items would be available in the quantities required. Some of the selected recipes were reformulated to include ingredients that would be available in the resupply supply or recommended crop list or its derivatives. Once the reformulation of the recipe was completed, a taste panel evaluated the recipes for degree of acceptability.

Ten to 25 panel members consisting of NASA and contractor employees ages 20 to 60 years old participated in the sensory analysis. A nine-point

hedonic scale (where one is "dislike extremely" and nine is "like extremely") measured each product for the degree of acceptability with regard to six attributes: appearance, color, odor, flavor, texture, and overall acceptability (2). The final criterion used for recipe selection was preparation time.

Step 2: Develop Menu Based on Requirements

After the recipes were selected, the 10-day menu was designed. Emphasis was placed on foods familiar to a Western diet since these foods had higher acceptability scores with the pool of potential crewmembers. Several requirements were considered in the design of the menu. The first requirement was that 90 percent of the calories come from the baseline crops. Sugar, oil, and other products that can be derived through processing of the baseline crops were acceptable and contributed to the 90 percent requirement. Another requirement was that the final menu would, at a minimum, meet the WHO caloric requirements for each crewmember (3). The RDAs were the basis for the remainder of the nutritional requirements (1).

The nutritional analysis, using the Minnesota Nutrition Data System software, was used to adjust the menu to better provide for the nutritional needs of the crew (9). If deficiencies were noted, foods rich in that nutrient were added or increased in quantity. Emphasis was placed on foods that did not require fortification or flavor enhancers, since these would be considered resupply items and decrease the self-sufficiency of the system. The menus were individualized where possible to meet crewmembers' specific nutritional requirements and personal preferences (Table 4.4-3). The other crewmember had additional snacks added to the menu to meet a higher caloric requirement.

Table 4.4-3 *Nutritional information for the 10-day BIO-Plex menu, crewmembers 1, 2, and 4*

Day	kcal	CHO (g)	Protein (g)	Fat (g)	% kcal from fat	Na (mg)	Ca (mg)	Fe (mg)
1	2204	380	51	65	27	3052	634	22
2	2140	330	82	66	28	3602	1076	31
3	2292	364	48	79	31	7049	434	22
4	2375	422	95	49	19	6273	1031	31
5	2443	384	85	75	28	4336	1121	26
6	2522	518	45	44	16	2115	575	17
7	2547	391	80	87	31	4838	886	26
8	2118	354	65	57	24	3164	819	26
9	2680	443	94	75	25	5272	741	30
10	2249	334	68	83	33	2771	808	24
Average	**2357**	**360**	**71**	**68**	**26**	**4247**	**812**	**26**
estimated need	2280 WHO	50-60% total kcal RDA	63-68 RDA	max 76 RDA	≤ 30 RDA	500-3500 RDA	800 RDA	RDA: male:10 female:15

The 10-day BIO-Plex menu was a 10-day cycle (see Table 4.4-4). Except for beverages, fruit, and bread, the majority of foods did not repeat. Two menus were developed for the 10-day test to meet the caloric needs of the crewmembers (a 3,000 kcal menu and a 2,280 kcal menu). The 3,000 kcal diet consisted of second helpings and additional snacks. The menu was planned so that all four crewmembers would have the same foods in different quantities.

Table 4.4-4 *BIO-Plex 10-day menu for crewmembers 1, 2, and 4*

Meal		Day 1		Day 2
Breakfast	41 g	Soybread*	110 g	Coffee cake*
	38 g	Strawberry jelly (C)	240 ml	Chocolate soy milk (C)
	240 ml	Orange juice, reconstituted (C)	38 g	Strawberry jelly (C)
	opt	454 g Coffee, rehydrated (C)	240 ml	Orange juice, reconstituted (C)
	opt	15 g Soymilk, plain (for coffee) (C)	opt	454 g Coffee, rehydrated (C)
	opt	15 g Sugar (for coffee) (C)	opt	15 g Soymilk, plain (for coffee) (C)
			opt	15 g Sugar (for coffee) (C)
Snack	105 g	Strawberries (C)	124 g	Applesauce (C)
Lunch	241 g	Vegetable stew	275 g	Hot and sour soup
	123 g	Baked potato (red potato)	250 g	Vegetable peanut stir fry
			158 g	Oven rice
	60 g	Soybean & red pepper sauce	47 g	Egg roll (frozen, homemade)
	opt	Green onion, chopped (1 small)	opt	10 g Mustard
	41 g	Soy bread*	480 ml	Beverage w/art. sweetener (C)
	124 g	Pears (C), juice pack		
	240 ml	Beverage with sugar (C)		
	70 g	No-bake cookies		
Snack	10 g	Pretzel sticks		
	70 g	No-bake cookies		
Dinner	312 g	Spinach lasagna	130 g	Tofu basil pasta sauce
	45 g	Skillet garlic bread (soy)*	226 g	on whole wheat fettucine noodles (C)*
	236 g	Lettuce salad *		
	32 g	Dressing, garlic & herb (C)*	67 g	Wheat bread*
			78 g	Cooked spinach
	78 g	Mixed veg: potatoes/ carrot/peas (C)*	65 g	Peanut cake*
			480 ml	Beverage: instant tea (C)
	78 g	Carrot cake*		
	480 ml	Beverage: instant tea (C)		

LEGEND: Common condiments not listed. Beverages with sugar and with artificial sweetener were powdered, fruit-flavored commercial products.
(C) = commercially available product
* = assembled or cooked in chamber
opt = optional

Table 4.4-4 continued *BIO-Plex 10-day menu for crewmembers 1, 2, and 4*

Meal		Day 3		Day 4
Breakfast	63 g	Sweet potato bread*	64 g	Wheat bread*
	38 g	Strawberry jelly (C)	240 ml	Chocolate soy milk (C)
	240 ml	Grape juice, reconstituted (C)	38 g	Strawberry jelly (C)
			240 ml	Orange juice, reconstituted (C)
	opt	16 oz. Coffee rehydrated (C)	opt	454 g Coffee rehydrated (C)
	opt	15 g Soymilk, plain (for coffee) (C)	opt	15 g Soymilk, plain (for coffee) (C)
	opt	15 g Sugar (for coffee) (C)	opt	15 g Sugar (for coffee) (C)
Snack			124 g	Pears, juice pack (C)
Lunch	354 g	Potato soup	435 g	Garlic lentil soup
	190 g	Crunchy confetti salad	134 g	Whole wheat bread*
	113 g	Fruit cocktail (C)	125 g	Tempeh-rice salad
	240 ml	Beverage with sugar (C)	124 g	Peaches, juice pack (C)
			opt	Strawberry jelly (C)
			240 ml	Beverage with sugar (C)
Snack			10 g	Pretzel sticks
Dinner	114g	Tempeh sandwich filling*	3 = 135 g	Soybean soft tacos (assembly)*: Tortilla
	126 g	Sweet potato bread*	129 g	Soybead filling (.5 c divided into 3)
	opt	Lettuce, tomato, onion, mustard		Toppings: lettuce, tomato, onion
	198 g	Marinated tomato & onions	104 g	Pico de gallo (C)
	163 g	Peach cobbler	75 g	Pineapple cake*
	480 ml	Beverage: instant tea (C)	480 ml	Beverage: instant tea (C)

LEGEND: Common condiments not listed. Beverages with sugar and with artificial sweetener were powdered, fruit-flavored commercial products.
(C) = commercially available product
* = assembled or cooked in chamber
opt = optional

Table 4.4-4 continued *BIO-Plex 10-day menu for crewmembers 1, 2, and 4*

Meal		Day 5		Day 6
Breakfast	144 g	Peanut butter bread*	110 g	Coffee cake*
	240 ml	Chocolate soy milk (C)	38 g	Strawberry jelly (C)
	38 g	Strawberry jelly (C)	240 ml	Grape juice, reconstituted (C)
	240 ml	Orange juice, reconstituted (C)	opt	480 ml Coffee, rehydrated (C)
	opt	480 ml Coffee, rehydrated (C)	opt	15 g Soymilk, plain (for coffee) (C)
	opt	15 g Soymilk, plain (for coffee) (C)	opt	15 g Sugar (for coffee) (C)
	opt	15 g Sugar (for coffee) (C)		
Snack	75 g	Peanut butter cookies	124 g	Applesauce (C)
Lunch	157 g	Spinach quiche, no cheese	582 g	Vegetable pizza
	41 g	Soybread*	225 g	Chocolate pudding
	236 g	Green salad*	240 ml	Beverage w/art. sweetener (C)
	124 g	Peaches, juice packed (C)		
	75 g	Peanut butter cookies		
	240 ml	Beverage w/art. sweetener (C)		
Snack	72 g	Peanut butter bread		
Dinner	315g	Tempeh cacciatore	431 g	Sweet and sour tempeh
	226 g	Whole wheat noodles*	158 g	Rice
	90 g	Skillet garlic bread (soy)	47 g	Egg rolls (frozen, homemade)
	236 g	Lettuce salad*	opt	10 g Mustard
	32 g	Vinaigrette dressing: Italian (C)	133 g	Peas (C)*
	72 g	Cooked spinach	113 g	Fruit cocktail, juice packed (C)
	163 g	Lemon custard pie	480 ml	Beverage: instant tea (C)
	105 g	w/Strawberries (C) on pie		
	480 ml	Beverage: instant tea (C)		

LEGEND: Common condiments not listed. Beverages with sugar and with artificial sweetener were powdered, fruit-flavored commercial products.
(C) = commercially available product
* = assembled or cooked in chamber
opt = optional

Table 4.4-4 continued *BIO-Plex 10-day menu for crewmembers 1, 2, and 4*

Meal		Day 7		Day 8
Breakfast	54 g	Plain bagel	144 g	Peanut butter bread*
	38 g	Strawberry jelly (C)	38 g	Strawberry jelly (C)
	240 ml	Orange juice, reconstituted (C)	240 ml	Orange juice, reconstituted (C)
	opt	480 ml Coffee, rehydrated (C)	opt	480 ml Coffee, rehydrated (C)
	opt	15 g Sugar (for coffee) (C)	opt	15 g Soymilk, plain (for coffee) (C)
	opt	15 g Soymilk, plain (for coffee) (C)	opt	15 g Sugar (for coffee) (C)
			124 g	Pineapple, can, juice packed (C)
Snack	240 ml	Beverage w/sugar (C)	240 ml	Grape Juice, reconstituted (C)
Lunch	296 g	Vegetable chowder	300 g	Vegetable carrot stir fry
	78 g	Spicy black bean burger (C)	158 g	On rice
			47 g	Egg roll (homemade, frozen)
	82 g	Soybread*		
	10 g	Mustard	opt	2 tsp. Mustard
	opt	Lettuce, tomato, onion	240 ml	Beverage w/art. sweetener
	170 g	Red potatoes (C)*		
	124 g	Apricots, juice packed (C)	192 g	Strawberry sorbet (C)
	213 g	Peanut butter pie		
	240 ml	Beverage w/art. sweetener (C)		
Snack	10 g	Pretzel sticks (C)		
Dinner	184 g	Spaghetti sauce*	89 g	Soybean ragout
	226 g	Whole wheat spaghetti noodles (C)*	158 g	Steamed rice, white
			133 g	Peas (C)
	45 g	Skillet garlic bread (soy)*	119 g	Spinach salad*
			32 g	Vinaigrette dressing (C)
	72 g	Cooked spinach	122 g	Choc-strawberry tofu trifle
	236 g	Salad with tomato & onion		
	32 g	Dressing: Italian (C)	480 ml	Beverage: instant tea (C)
	213 g	Peanut butter pie		
	480 ml	Beverage: instant tea (C)		

LEGEND: Common condiments not listed. Beverages with sugar and with artificial sweetener were powdered, fruit-flavored commercial products.
(C) = commercially available product
* = assembled or cooked in chamber
opt = optional

Table 4.4-4 continued *BIO-Plex 10-day menu for crewmembers 1, 2, and 4*

Meal		Day 9		Day 10
Breakfast	64 g	Wheat bread*	41 g	Soybread*
	3 Tbs.	Peanut butter, no salt, old-fashioned (C)	48 g	Peanut butter, no salt, old-fashioned (C)
	2 Tbs.	Strawberry jelly (C)	240 ml	Chocolate soy milk
	240 ml	Orange juice, reconstituted (C)	38 g	Strawberry jelly (C)
	opt	480 ml Coffee, rehydrated (C)	240 ml	Orange juice, reconstituted (C)
	opt	15 g Soymilk, plain (for coffee) (C)	opt	240 ml Coffee, rehydrated (C)
	opt	15 g Sugar (for coffee) (C)	opt	15 g Soymilk, plain (for coffee) (C)
			opt	15 g Sugar (for coffee) (C)
Snack	124 g	Pears, juice packed (C)		
Lunch	78 g	Spicy black bean burger (C)	180 g	Roasted garlic soybean hummus
	138 g	Wheat bread*	82 g	Soybread*
	10 g	Mustard	opt	Sandwich toppings: lettuce, tomato, green onion
	opt	Sandwich toppings: lettuce, tomato, green onion	opt	10 g Mustard
	130 g	Baked soybeans	204 g	Tabouli salad (C)
	124 g	Peaches, juice pack (C)	40 g	Dried apples (C)
	240 ml	Beverage w/art. sweetener (C)	233 g	Baked rice casserole
	137 g	Chewy brownies (C)	240 ml	Beverage w/art. sweetener (C)
Snack			137 g	Chewy brownies
Dinner	1 =	Chili bean burrito (assembly)*:	606 g	Pepper pizza
			236 g	Lettuce salad w/croutons
	45 g	Tortilla	163 g	Lemon custard pie
	159 g	Chili bean burrito filling	105 g	Strawberries (C) on pie
			480 ml	Beverage: instant tea (C)
	170 g	Red potatoes (C)*		
	104 g	Pico de gallo		
	236 g	Green salad*		
	32 g	Dressing: Italian (C)		
	480 ml	Beverage: instant tea (C)		

LEGEND: Common condiments not listed. Beverages with sugar and with artificial sweetener were powdered, fruit-flavored commercial products.
(C) = commercially available product
* = assembled or cooked in chamber
opt = optional

The crew completed sensory evaluation scores for each food item on a food tracking data sheet. The crew also utilized the nine-point hedonic scale for these evaluations. The crew provided estimates of plate waste on the food tracking data sheet. The crew circled which fraction, in one-quarter intervals, best described the amount of food remaining on his/her plate at the end of the meal. Food waste was either weighed by the crew during the 10-day test and then discarded, or it was passed out of the chamber to be weighed. The data was collected, and the trends were summarized. Time studies were done to determine the amount of time spent on preparation activities, which included cleaning, removing inedible biomass, chopping, slicing, and gathering ingredients (see Figure 4.4-1).

Discussion

Early Human Test Initiative Phase I

The Phase I food system for the crew of one consisted of shelf-stable foods that were heated in a microwave oven. Since there was only one test subject, limited data was available for analysis. The crewmember was satisfied with the diet for that length of time, but expressed a desire for more variety in the choice of foods.

Early Human Test Initiative Phase II

More food preparation equipment was included in the Phase II test to meet the food system objective of evaluating a 50 percent frozen/refrigerated food mix in an isolated environment. In general the food system was well accepted by the crew. The higher quality frozen dinners were more desirable, and beverages and juices were preferred to mask the taste of iodine in the water. Even though two microwave ovens were provided, food preparation took longer than expected. The crew maintained one common meal at dinner and enjoyed the special request items, both of which helped to improve morale. Recommendations for future missions were to increase the microwave capability and the frozen food storage in the chamber.

Advanced Human Life Support Enclosed System Study Phase IIa

The main objective of the Phase IIa food system was to evaluate the ISS food system by emulating it as close as possible in the chamber test. The microwave ovens were upgraded to 1000 watts to improve food preparation time. Overall the crew was very satisfied with the food system. The ethnic variety of the food selections was good. The crew reported that they missed toast and carbonated beverages. The frozen foods were bagged by day for transfer into the chamber, and this saved time. They would have preferred more fresh vegetables. The only fresh vegetables were prepackaged modified-atmosphere salads. They would have preferred that more of the frozen vegetables be served plain so that each individual could decide

what sauce to add. They always ate dinner together since it was easier to prepare one entrée for more than one person. The results from the weekly sensory evaluations inside the chamber were very positive, averaging between 7 (like moderately) and 8 (like very much). The overall daily average for all subjects was 7.85.

Lunar-Mars Life Support Test Project Phase III

The multiple objectives of the Phase III food system resulted in a much more detailed involvement in the test. The objective of the 81-day menu was to simulate a BIO-Plex mission where 50 percent of the food would be derived from chamber-grown crops (see Table 4.4-2). This 50 percent was defined as four or less servings of meat per week. The 10-day menu had 90 percent of the calories derived from the potential chamber-grown crops.

81-Day Menu Crew Debrief – Crew Assessment of Food System and Food Choices

A formal crew debrief was held for the 81-day menu. Three crewmembers (one male and two female) attended the debriefing. The general consensus of the crew was that the food system was very good. Some food fatigue was experienced toward the end of the test, especially toward the frozen food entrees. They would have preferred a menu that was a true 20-day cycle with fewer repeating food items. They would have preferred higher quality frozen food entrees. There were too many bean burritos and grilled cheese sandwiches. Overall, the crew followed the menu fairly closely, although they did make some changes. They did cook and prepare all items on the menu, but some substitutions were made by switching foods either to different times or to different days. One crewmember had a problem with low-fat entrees and felt they were not very tasty and required supplementation with butter. Some found themselves craving and using more salt than usual. Another member was concerned about the fat content of the menu and did not always eat according to the menu. Clearly these comments indicate that past eating habits influenced the crewmembers' perception of the chamber food system.

Cooking and preparing tended to be performed by one crewmember on a rotating basis. The crew usually ate meals together, especially at dinner. The presentation of the food was very important to the crew. There was a negative impact to all the paper, plastic, and cardboard that accompanied almost all the food.

The holiday meals were very gratifying, and surprises for long-duration missions will be very important because they boost morale. Thanksgiving was a very important meal because it gave the crewmembers a time to relax and enjoy their meal. Making the food items as "real" as possible is needed for future long-duration missions.

Different varieties of texture were missed. It would have been nice to have different varieties of cheese or chips that offered different textures. Snacks were craved quite frequently and associated with comfort food. However, not many snacks were eaten because snacks were not kept out nor were they readily available all of the time. The crew tended to snack together during certain periods such as movie time.

Large quantities of beverages were consumed because the relative humidity in the chamber was 40 percent and it was very dry. Typically 25 percent of the beverages were consumed as plain water and the rest as juice or fruit-flavored beverages. No one really liked the Ultra High Temperature (UHT) milk, and it was mentioned several times that real milk was missed. The UHT milk was mostly used for coffee and cereal. The crew did prefer the chocolate soymilk that was used during the 10-day menu more than the chocolate milk offered during the 81-day menu.

The menu had more than an adequate amount of desserts. It was suggested to alternate a low-fat dessert with a high-fat dessert. Another suggestion was to offer one large dessert that could be enjoyed for a couple of days. Bread was also an issue. Fresh bread was enjoyed, but it repeated too often in the menu; it was therefore not prepared as often as indicated by the menu. The sweet potato bread and wheat bread were enjoyed the most. The crew expressed that there was too much soy bread as they had developed taste fatigue after the 10-day BIO-Plex menu. The average sensory score for the 81-day menu was 7.3 (like moderately).

During the chamber test, three weighed-food record periods were conducted. The crew tended to finish all the food on their plates so they would not have to weigh leftovers. During this time they did not eat salad, bread, or anything that called for preparation because of the extra weighing. Snacking was also limited because of the weighing. The crew felt this biased their food records because their typical food consumption was altered.

The crew suggested a reevaluation of using the WHO (3) equation to calculate caloric requirements for the menu. They would rather have something that reflected the amount of calories that would be typically or realistically consumed, because the menu contained more calories than they felt comfortable eating.

10-Day Menu Crew Debrief

The 10-day menu crew debriefing was held via teleconference. The BIO-Plex menu overall was very acceptable. They reported that they enjoyed it and would miss it. The BIO-Plex meals were a pleasant change from the frozen entrees provided in the 81-day portion of the test.

The majority of the food items were familiar to the crew. They enjoyed the home-cooked nature of the meals. They missed items like milk, sour cream, butter spread, and steaks, and having a large variety of snack foods. They would have liked more sauces for the vegetables. The crew recommended different forms of bread rather than sliced bread all the time. One crewmember said that hamburger buns would have been a nice change.

All crewmembers indicated that variety was important to the menu. Variety was adequate for the 10 days, but, for a longer test, increased variety is recommended.

The crew did not experience food fatigue from the overall menu. Prior to the test, breakfast items such as waffles were replaced by various breads on the menu at the

request of the crew to decrease food preparation time in the mornings. Although this change was implemented, the crew recommended more variety with the breakfast items.

The limited choices of snack foods (no-bake cookies and egg rolls) contributed to food fatigue for these items. To improve variety, some of the crew would have liked to see snacks such as cereal and different types of vegetables.

Although one crewmember was aware of the NASA nutritional requirements and nutritional recommendations, none of the crewmembers used the requirements for their meal selection. One crewmember was concerned about the fat content of the menu. As a result, that crewmember avoided certain food items that were perceived to be high fat and thus influenced the consumption.

Crewmembers were not aware of the substitution options on the last page of the menu. The crew indicated that they would have liked the ability to substitute foods at will and to manage their own resources. This would have given them the opportunity to adjust the recipes to reflect their personal preferences. Also, the crew recommended that the menu be flexible enough to give them a choice to eat the leftovers, thereby utilizing the food more efficiently. The serving sizes were often too large.

The crew was satisfied with the BIO-Plex menu, and they did not feel underfed or feel any discomfort. The overall physical comfort level met the crew's expectations. There was a noticeable increase in the methane level and solid waste. However, this did not affect the crew's ability to complete their tasks. The crew commented that the measured volume of fecal waste was approximately doubled during the BIO-Plex menu test.

Overall, the crew acceptance of the food system was good. There were no significant changes in acceptability of the food throughout the 91-day test. The average sensory score for the 10-day menu was 7.0 on a hedonic scale of 1 - 9 (lowest acceptability to highest acceptability).

Nutritional Analysis

The nutritional analysis on the menu showed that the 10-day BIO-Plex menu met the caloric, carbohydrate, protein, and fat needs of the crew (see Table 4.4-3). Despite the lack of dairy products, the current recommended dietary allowance for calcium was met through other calcium-rich foods such as tofu and soybeans. However, it has been recommended that the RDA for calcium be raised to 1000 mg/day, and this menu would not meet this increased requirement (8).

The iron provided by the menu was higher than the respective RDAs for men and women. Iron overloading from this menu, however, may not be a problem due to poor absorption of iron from plant foods (10). Since iron overloading is a potential issue for space flight due to decreased turnover of red blood cells in microgravity, the iron bioavailability should be carefully considered during further development of the BIO-Plex menu (11).

The sodium content of the menu exceeded the nutritional recommendation for space flight, which is less than 3,500 mg/day (5). This level is recommended due to concerns related to the effect of high sodium intake on calcium metabolism. In addition to the sodium provided by the foods, the crew was allowed to add salt and pepper at the point of service. It was noted in the crew debriefing that at least one crewmember had used significant amounts of salt and soy sauce, which would have further increased the sodium levels in his/her diet. The issue of sodium content must be considered in the further development of the BIO-Plex diet, since this represents a potentially negative impact on the health of crewmembers.

All of the other RDAs were met except for vitamin D, vitamin B_{12}, and zinc. The 10-day menu provided 28 percent of the recommended vitamin D, 85 percent of vitamin B_{12}, and 74 percent of the recommended zinc. These are traditionally nutrients of concern for vegetarians. However, because of the short duration of the test, it was not considered critical to meet the requirements for these three nutrients. It is important to note that a final BIO-Plex menu developed for long-duration space flight, or for surface habitats on the Moon or Mars, would have to meet these requirements by use of fortified foods or other means. Vitamin D intake becomes even more important in situations such as these where the crewmember will not be exposed to sunlight.

Menu Preparation Times

Preparing meals for the BIO-Plex menu took longer than for the 81-day menu. One possible reason for the added preparation times was that the frozen microwaveable meals in the 81-day menu were very easy to prepare. Since the crew's experiment schedule was based on a five-day work week to match the supporting personnel outside of the chamber, the crew recommended weekends for food processing activities. The cooking was not difficult, but the cleaning was nearly impossible due to the water and cleaning equipment limitations inside the chamber. As a result, dishes and transport containers were cleaned in the JSC Food Lab. Food activities, like cooking pasta, used a large amount of water. It was recommended to consider water usage in future food system tests.

Table 4.4-5 contains the raw data collected for the time analysis. The data from this menu test indicates that a crew of four would spend an average of 4.6 crew hours per day in preparation and clean-up activities. This assumes the crew starts with ready-to-use ingredients. In the BIO-Plex facility and in other situations where a crew will be growing its own food, the time required for the actual processing of the crops into useable ingredients must be taken into account as well. Crop processing, food preparation, and clean-up activities will have an enormous impact on crew time, and efforts must be made to minimize the time required for all aspects of the food system. Bulk production of menu items and the automation of food processing and meal preparation are likely candidates to aid in time reduction.

Table 4.4-5 *Time required for total meal preparation in the 10-day BIO-Plex menu*

	CLEAN UP	MEAL PREPARATION		
	Total	Food Lab	20 ft Chamber	Total
Day/Meal	Time* (min)	Time* (min)	Time* (min)	Time (min)
PRETEST ACTIVITIES				
Food pre-preparation (egg rolls & cookies)	**15**	**122**		**122**
Daily food preparation activities for day 1	10	25		25
DAY 1				
Breakfast (all in 20 ft chamber)			25	25
Lunch	10	78	5	83
Dinner	15	30	45	75
Daily food preparation activities for day 2	15	72		72
Food pre-preparation (flour milling)	**15**	**45**		**45**
20 ft chamber end of the day clean up	20			
DAY 2				
Breakfast (all in 20 ft chamber)			20	20
Lunch	17	59	10	69
Dinner	10	08	50	58
Daily food preparation activities for day 3	11	58		58
20 ft chamber end of the day clean up	20			
DAY 3				
Breakfast (all in 20 ft chamber)			10	10
Lunch	10	30		30
Dinner	05	35	20	55
Daily food preparation activities for day 4	05	40		40
Food pre-prep. (tortillas)	**05**	**60**		**60**
20 ft chamber end of the day clean up	20			
DAY 4				
Breakfast (all in 20 ft chamber)			20	20
Lunch	06	39	5	44
Dinner	12	60	15	75
Daily food preparation activities for day 5	41	119		119
20 ft chamber end of the day clean up	20			

*These are partial times; meal preparation was split up between the Food Lab and the 20 ft. chamber

Table 4.4-5 continued *Time required for total meal preparation in the 10-day BIO-Plex menu*

	CLEAN UP	MEAL PREPARATION		
	Total	Food Lab	20 ft Chamber	Total
Day/Meal	Time* (min)	Time* (min)	Time* (min)	Time (min)
DAY 5				
Breakfast (all in 20 ft chamber)			10	10
Lunch	05	20	30	50
Dinner	05	35	35	70
Daily food preparation activities for day 6	07	90		90
Food pre-prep. (bagels)	**05**	**09**		**09**
20 ft chamber end of the day clean up	20			
DAY 6				
Breakfast (all in 20 ft chamber)			20	20
Lunch (all in 20 ft chamber)			45	45
Dinner	10	26	20	46
Daily food preparation activities for day 7	05	34		34
20 ft chamber end of the day clean up	20			
DAY 7				
Breakfast (all in 20 ft chamber)			10	10
Lunch	03	20	30	50
Dinner (all in 20 ft chamber)			40	40
Daily food preparation activities for day 8	05	65		65
20 ft chamber end of the day clean up	20			
DAY 8				
Breakfast (all in 20 ft chamber)			10	10
Lunch	30	30	15	45
Dinner	15	80	15	95
Daily food preparation activities for day 9	05	40		40
Food pre-prep. (tortillas)	**05**	**55**		**55**
20 ft chamber end of the day clean up	**20**			

*These are partial times; meal preparation was split up between the Food Lab and the 20 ft. chamber

Table 4.4-5 continued *Time required for total meal preparation in the 10-day BIO-Plex menu*

	CLEAN UP	MEAL PREPARATION		
	Total	Food Lab	20 ft Chamber	Total
Day/Meal	Time* (min)	Time* (min)	Time* (min)	Time (min)
DAY 9				
Breakfast (all in 20 ft chamber)			20	20
Lunch	05	35	20	55
Dinner	06	45	15	60
Daily food preparation activities for day 10	30	81		81
20 ft chamber end of the day clean up	20			
DAY 10				
Breakfast (all in 20 ft chamber)			15	15
Lunch	15	40	30	70
Dinner (all in 20 ft chamber)			40	40
20 ft chamber end of the day clean up	20			
MENU ENDING TOTALS	513	1294	645	1939
FOOD PRE-PREPARATION				
FOOD PRE-PREP TOTAL		291		
FOOD PRE-PREP CLEAN UP TOTAL	45			

*These are partial times; meal preparation was split up between the Food Lab and the 20 ft. chamber

Plate Waste Data

Figure 4.4-1 shows the waste data compiled by day. Total waste was comprised of preparation waste, plate waste, and leftovers. All percentages were determined in relation to the finished weight of the menu items. Preparation waste was the amount of waste generated each day during preparation of the menu items, and these percentages remained at low levels throughout the menu test. Plate waste data was determined by comparing what the crewmember actually ate to the planned serving size. The plate waste data shows wide day-to-day variation. Larger amounts of plate waste could be attributed to lower acceptability of menu items served on that day or excessive serving size(s). The high percentage of leftovers on many days suggested a need for better scaling of the recipes to the crew size.

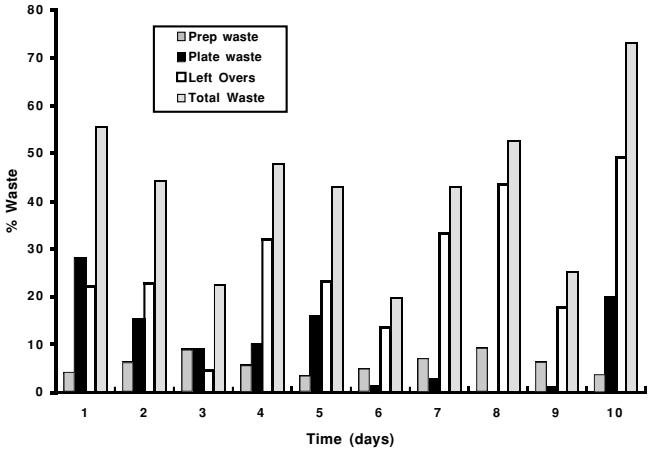

Figure 4.4-1 *Quantities of the different sources of waste monitored during the 10-day BIO-Plex diet*

Phase III Conclusions and Assessments

All of the objectives of the food system were met and/or exceeded for the entire 91-day test. This test rendered a food system that was monitored and controlled to support medical experiments, while satisfying the physiological and psychological food-related needs of the crew. This test also successfully incorporated a 10-day BIO-Plex menu, which integrated some food processing and meal preparation activities, into the 91-day test to increase closure of the recycling loop within the chamber system. Also, the test was successful in providing an acceptable plant-based menu for 10-day habitation in a closed-system environment. The nutritional needs were met, except for three nutrients (vitamin D, zinc, and vitamin B_{12}). These nutrients are typically low in vegetarian diets, therefore the need for fortified foods and/or supplementation of these nutrients may be necessary for long-duration tests.

Microbiological safety must be a consideration for transfers in and out of the chamber for future tests. It is a possible hazard to transfer food with body fluids and/or trash. Food should have dedicated transfer bins, rather than simply using the bin in which other items were transferred. Daily transfers were routinely limited, but separate transfer or separate bins for transfer must be evaluated for food products.

The amount of trash generated is a significant concern in a closed system, and this must be closely evaluated in future tests. The food packages and containers should be reevaluated to eliminate excess food-related trash.

The appropriateness of using the WHO equation to calculate caloric requirements must be evaluated. Specific requirements, constraints, and goals should be established three months prior to a test for future tests with food systems similar to the 10-day BIO-Plex test. Activities must be identified and scheduled to include rehearsals two months prior to a test so that the system will be complete before the beginning of the test.

The menu should be expanded from 10 days to 30 days to increase variety, and it also should be flexible enough to allow crews to utilize leftovers. A larger meal substitution base should be developed to prevent taste fatigue. Attention should be given to the participation of the crew in menu planning. A possible suggestion is that the crewmembers be able to plan their own menus under the direction of a registered dietitian using a preplanned menu as a guideline.

Recipes need to be reformulated for appropriate meal serving sizes in order to reduce leftovers. Realistic and manageable goals for handling the waste obtained from food processing, meal preparation, plate waste, and leftovers must be determined.

Education for the crew regarding the food system is essential. Nutrition education would be beneficial to prevent changes in diet or consumption based on misconceptions of nutrition. In future tests, when crews will be doing more extensive food preparation, it might also be useful to train the crew in basic cooking techniques to improve the quality of their meals.

The Importance of Ground-Based Analogues to Developing Food Systems for Space flight

The ALS chamber tests provided a unique opportunity to evaluate future space food systems and to assess potential problems associated with conversion of chamber-grown plants to edible foods. The results of these food system tests verified that a food system similar to the planned ISS Assembly Complete food system utilizing approximately 50 percent frozen and 50 percent shelf-stable food preservation technologies was at least moderately acceptable to a crew for an extended duration (81 days).

The 10-day BIO-Plex test confirmed that a menu could be developed from the basic crop list. This menu is acceptable for a crew for 10 days and meets most of the nutritional requirements; it is, however, a very labor-intensive diet with excessive waste. Comprehensive research is needed in the areas of food processing and preparation in an enclosed environment.

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