FINAL REPORT

FEEDING SYSTEM DESIGN FOR ADVANCED ORBITAL FACILITIES

Contract No. NAS 9-9780

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FEEDING SYSTEM DESIGN FOR ADVANCED ORBITAL FACILITIES

Contract NAS 9-9780

INTRODUCTION

This report defines a conceptual design for a feeding system for 100 men in orbiting space facilities for periods up to 90 days. In formulating this concept, the primary objective is to provide food which maintains nutritional and psychological function in the environment of space. The areas of food preparation, food service, consumption, and cleanup have been studies and optimal recommendations are presented. While weight, volume, and power requirements are considered secondary criteria, secondary to food adequacy, still these factors have been considered in trading off secondary systems and individual components.

Previous feeding plans for space missions of shorter duration have emphasized conservation of weight, volume, and power while supplying sufficient sustenance to insure completion of the mission objective. This plan attempts to go beyond this concept by supplying appetizing food approaching the theoretical ideal of earth-based meals. Beside supplying adequate nutrition, this system should contribute to mission accomplishment by greatly improving the morale of the crew.

Recognizing the difficulties involved in preparing the varieties of foods required by such a system from basic ingredients under conditions of weightlessness, the recommended feeding system relies heavily on frozen, fully-prepared foods which need only be thawed and heated in one operation to make them ready for the table.

INTRODUCTION (continued)

These foods are produced today in great variety and have received high acceptance. This report recommends a particular baseline food system. It is not intended as a study of the spectrum of possible systems Recommendations are made in the area of suggested research in certain areas. Such research may lead to great improvements in the recommended system, or may well change the selection of certain equipment items, since equipment trade-offs in this report are based on best information available at this time. For example, advance in the state-of-the-art in dehydration technology may lead to complete elimination of use of frozen food.

OBJECTIVES

To provide a conceptual design for a feeding system for 100 men in orbiting space facilities which will be optimal in the areas of food acceptance, food preparation, food service, consumption, and cleaning.

To document the engineering and logistical data generated by the design effort so that such data may be used in evaluation of future concepts and studies.

LITERATURE REVIEW

The literature research was conducted by Whirlpool Life Support Systems Group personnel; the Whirlpool Information Center; and by the Aerospace Research Applications Center (ARAC), Indiana University Foundation, Bloomington, Indiana. Information was to be gathered on all aerospace feeding systems for multimanned missions in excess of 28 days duration.

The results of the research were not very fruitful but a number of references were uncovered that could be useful in the designing of such a feeding system. These references are also included in the Bibliography.

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DISCUSSION

Food and Packaging

Food Types and Categories

Food Interfaces. The basic factor in any feeding system is the food, and the type of food supplied (thermo-stabilized, frozen prepared, dry, chilled, etc.) will determine the requirements for storage facilities, preparation equipment, and other components of the feeding system. To determine the type of food most suitable for each of the general categories, such as beverages, sandwiches, vegetables, etc., it is necessary to consider the comparative merits of the different food types with relation to the stated objectives of the feeding system under consideration. This trade-off study cannot be conducted until objectives have been defined, and objectives have been differentiated from requirements, which must be met if the system is at all acceptable. Detailed definition of requirements and objectives is best accomplished by first studying the various interfaces in the system. The food interface chart presented in Figure 12 lists interfaces between the food and other system components, and the characteristics of the food that are influenced by each interface, and those that impose requirements on interfacing system components.

Food Requirements and Objectives. The requirements and objectives for food in the feeding system are presented in Figure 13.

FOOD INTERFACE CHART

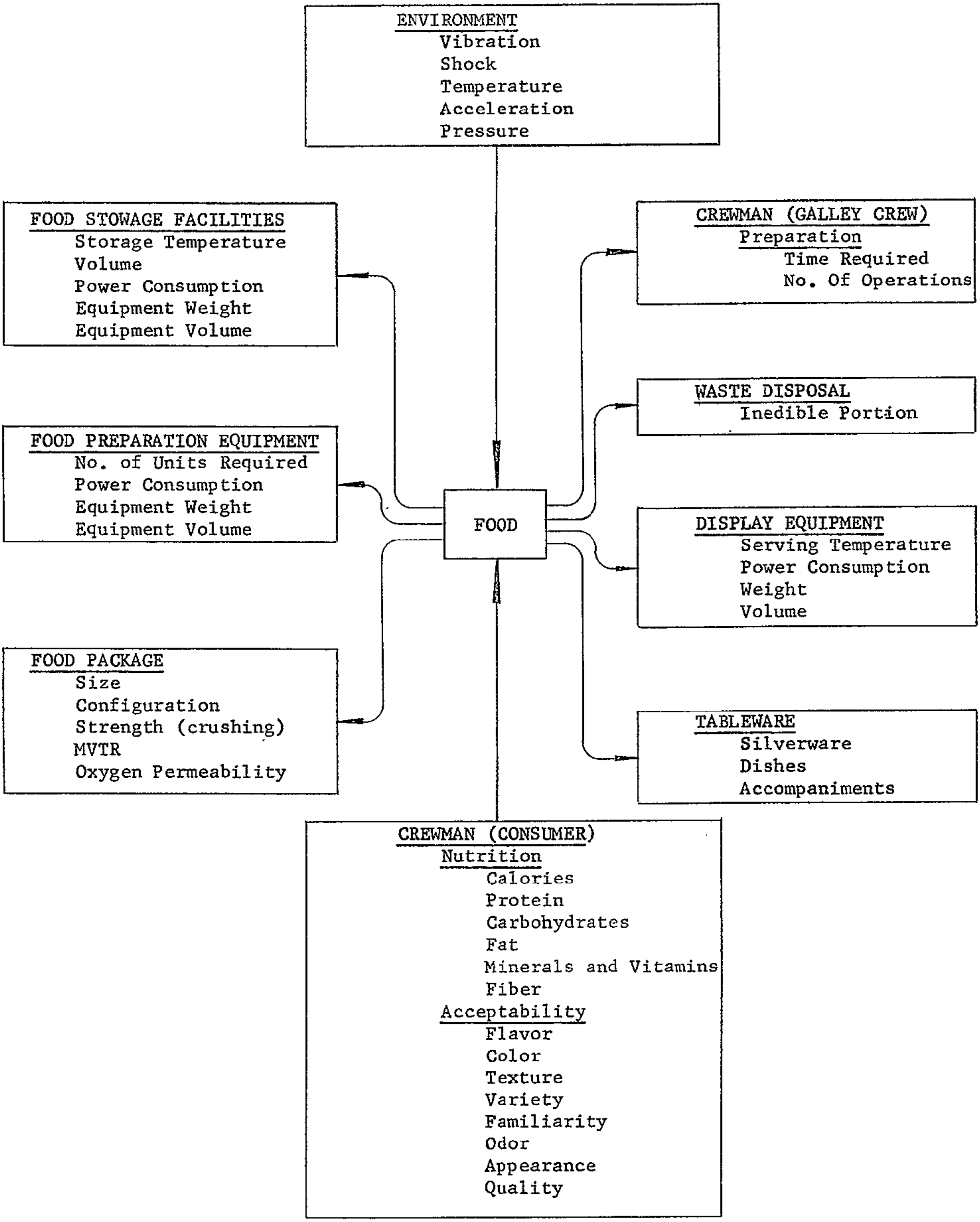


FIGURE 12

REQUIREMENTS AND OBJECTIVES FOR FOOD

REQUIREMENTS

Daily food intake shall provide adequate nutrition.

OBJECTIVES

High food acceptability shall be the primary consideration.

Food shall be stowed in facilities of minimum volume, requiring equipment of minimum weight and volume, and consuming minimum power, consistent with storage conditions required for food of maximum acceptability.

Food shall require a minimum of preparation equipment of minimum weight and volume, consuming a minimum of power, consistent with preparation requirements for food of maximum acceptability.

Food, when properly packaged and stowed, shall resist degradation by environment conditions, such as vibration, shock, temperature, acceleration and pressure.

Food preparation shall contain a minimum of inedible substances (bone, seeds, rinds, etc.) to minimize demands on waste disposal facilities.

Food shall impose a minimum requirement for weight, volume and power consumption of display equipment, consistent with maximum acceptability.

Food shall impose minimum requirements for food package weight, volume and complexity.

Food shall be consumed by use of a minimum number of dishes, implements and accompaniments, consistent with maximum acceptability.

Figure 13

<u>Trade-Off Considerations</u>. The trade-off factors listed in the trade-off analysis were selected to compare the relative merit of frozen and dehydrated foods. Factors such as safety and reliability were not included in the analysis because in a properly designed and properly operating system they should be about equal for both preservation methods. Therefore, they would not be useful in showing differences between the two preservation methods.

The trade-off factors were rated for each type of food as follows:

<u>Weight Rating</u>

1 equal to or better than fresh uncooked food

2 Slightly lighter than fresh uncooked food

3 75-25% lighter than fresh uncooked food

4 80% or more lighter than fresh uncooked food

<u>Volume Rating</u>

1 equal to fresh or freshly cooked

2 50% of fresh or freshly cooked

3 33% of fresh or freshly cooked

4 15% of fresh or freshly cooked

<u>Storage Requirements Rating</u>

1 highly controlled storage conditions $\pm$ 2°F

2 moderated controlled storage conditions $\pm$ 10°F

3 slightly controlled storage conditions $\pm$ 30°F

4 controlled only to eliminate extreme high and low temperature

Packaging Requirements Rating

1 not within the capabilities of current state-of-the-art technology

2 requires very special packaging, but within current technology; includes method for rehydration

3 requires excellent protection from oxygen based on 90-day resupply

4 requires very little protection from oxygen based on 90-day resupply

Rehydration Requirements Rating

1 requires 15 min. or more rehydration time or holding time

2 requires 5-10 min rehydration time

3 requires less than 5 min rehydration time

4 none

Heating Requirements Rating

1 requires specialized heating equipment

2 requires only heating

3 requires hot water plus heating

4 requires only hot water

Variety of Foods Available Rating

1 extremely limited, very few

2 limited

3 adequate for menu development

4 almost unlimited

<u>Acceptability Rating</u>

1 poor

2 fair

3 good

4 excellent

Each of the trade-off factors is weighted by assigning a multiplier number. These multipliers indicate the relative importance of the factor as it affects the design and development of the feeding system. For comparing each of the two preservation types against each trade-off factor, the assigned rating is multiplied by the factor multiplier.

Weight was given a factor of 2 because of the relative importance of the energy needed for launching the original vehicle and the resupply vehicle. Although volume is important, it is not currently considered as important as weight for this system. Therefore, volume was given a factor of 1. Storage requirements was given a factor of 2 because of the weight of, and the problems associated with the design of storage equipment. Packaging requirements were given a factor of 2 because of the importance of the package in maintaining the acceptability of the food and because of the importance of design in the acceptability of the eating system. Rehydration requirements and heating requirements were given factors of 1. Although these trade-off factors are important, they can relatively easily be designed into the food preparation area. Variety of food available and food acceptability were given factors of 3 because of their extreme importance in the development of a feeding system that will be highly acceptable on a long term basis.

Trade-Off Factors	Factor Multiplier	FOOD CATEGORIES											
		Entrees Extended Meat		Entrees-Other		Vegetables & Starches		Fruits		Fruit Juices		Milk	
		Frozen	Dry	Frozen	Dry	Frozen	Dry	Frozen	Dry	Frozen	Dry	Frozen	Dry
Weight	2	2	8	4	8	2	8	2	8	4	8	2	8
Volume	1	1	1	1	1	1	1	1	1	2	4	1	3
Storage Requirements	2	4	8	4	8	4	8	4	8	4	8	4	6
Packaging Requirements	2	6	4	6	4	8	4	8	4	8	4	6	4
Rehydration Requirements	1	4	2	4	2	4	2	4	1	3	3	4	1
Heating Requirements	1	2	4	2	4	2	4	--	--	--	--	--	--
Variety of Food Available	3	12	9	12	6	9	3	12	3	9	9	--	--
Food Acceptability	3	12	9	12	6	12	6	9	6	12	6	9	3
TOTAL		43	45	45	39	42	36	40	31	42	42	26	25

Selection of Food Types and Selection of Food Preservation Type Used

The selection of the food preservation types used for each of the food categories was chosen to give the highest degree of acceptability and greatest variety under the constraints imposed by other design considerations of the system, such as the length of time between resupply. In the selection of the preservation type to be used, it was assumed that even though some of the food may not be currently available in the form needed, by the time of flight the food would be available either commercially or by special order. It was also assumed that foods would be packaged and stored in near optimum conditions.

Below are given the reasons for the selection of the preservation type or types chosen for each of food categories in Table I. The foods will be discussed in the order that they appear in Table I.

Breakfast

Appetizer

Juice

Not all types of fruit juices are available frozen or as frozen concentrate; therefore, some canned juices must be used such as tomato, vegetable, apricot, and prune. The proportion shown in Tàble 1 was selected because citrus juices (frozen concentrate) are the most popular breakfast juices and therefore would be used most of the time.

Fruits

Not all fruits are available canned, therefore, to get maximum variety some frozen fruits must be used. Strawberries, blueberries, raspberries, and melon are examples of the fruits that would be supplied frozen.

Cereal

Hot and cold cereals are almost always dry. No other form was considered.

Entrees

Eggs

Frozen eggs are chosen because they are generally more acceptable psychologically than dry eggs.

Meats

Breakfast meats are to be frozen because they have a higher acceptability in this form.

Meats Extended

Frozen extended meats are more acceptable than dehydrated or canned.

Grilled Bread

Grilled breads are frozen because no other means of preservation is satisfactory.

Breakfast Breads

All breakfast breads are frozen because it is the only method by which they can satisfactorily be supplied.

Beverages

Hot

The hot breakfast drinks are all dehydrated because they are acceptable and are easier to handle at zero gravity than other forms.

Cold (Milk)

Frozen milk was chosen because in spite of the problems that may be encountered, it would be more acceptable than dehydrated or canned milk.

Accompaniments

Syrup

Syrup will be thermostabilized to extend shelf-life.

Jellies and Jam

Jellies and jam are thermostabilized because it is the only form available.

Salt and Pepper

Salt and pepper are naturally preserved dry.

Cream

Cream or cream substitutes are frozen to extend shelf-life.

Sugar

Sugar's natural form is dry.

Dinner (Lunch)

Salads and Relishes

The selection of preservation methods for the salads and relishes varies considerably depending on the resupply period. The shorter the resupply period, the greater the proportion of prepared refrigerated salad items that can be used For each of the resupply periods, 14, 30, and 90 days, the maximum amount of prepared salads are used. The mix between thermostabilized and frozen foods for the various categories under salads and relishes was used to give the maximum variety and acceptability.

Entrees

Sandwiches (fillings)

Hot

All hot sandwich fillings will be prepared frozen because it results in a highly acceptable product.

Cold

Ten percent of the cold sandwich fillings are supplied in thermostabilized form because a larger variety of products, such as, peanut butter, cheese and certain types of meat spreads are available in this form. The remainder of the cold sandwich fillings, mainly meats, are frozen.

Soup

Part of the soup is supplied frozen because this process yields, for some types, a more highly acceptable soup than the canned or the dried equivalent. The remainder is either single strength canned or dehydrated soup.

Meat, Extended

Meat, Substitutes

Meat, Grilled

Meat, Deep Fried

All these items are frozen because they have generally a higher acceptable than if they were canned or dehydrated.

Starches

All starch items are frozen because they yield a highly satisfactory product that is easily prepared at zero gravity.

Vegetables

Buttered

Creamed & Sauce

These vegetables are frozen prepared because they yield a more acceptable product than dehydrated or canned and also because a wide variety of vegetables is available frozen.

Baked and Steamed

Freezing is the only satisfactory way of preserving this type of vegetable.

Bread and Rolls

All bread type items are frozen because it is the only method by which they can satisfactorily be supplied.

Dessert

Ice Cream

Freezing preservation is the only way ice cream can be supplied without producing the product aboard the craft.

Puddings and Custards

Fifty percent of the puddings and custard is thermostabilized and fifty percent is frozen prepared. This proportion gives a large variety and good acceptability.

Fruits

See breakfast fruits.

Cake, Dessert Breads, Pie, Cookies

Part of these products will be formulated so that they will be stable at ambient temperature. Others will be preserved by freezing.

Beverages

Hot

Cold (Milk)

See breakfast beverages

Accompaniments

Catsup, Mustard, Dressings

These products are normally preserved by thermostabilization.

Butter, Jellies, Jam, Cream

See breakfast accompaniments

Snacks

Fruit (Bananas, Intermediate Moisture Fruits)

These products are normally stored dry.

Fruits, Apple

Refrigeration is the only method possible to extend fresh shelf-life.

Candy

Candy is normally stored dry.

Beverages

Hot

See breakfast beverages

Cold

The proportions were selected to give maximum variety and acceptability for snacks.

Sandwich Spreads

Proportions were selected on the basis of supplying a good variety of highly acceptable spreads.

Cookies

See Dinner (Lunch) cookies

Nuts

The nuts are stored chilled in increase shelf-life

Crackers

Normal method of storage is at room temperature, dry.

Given in Table I are the food preservation types selected to be used in the feeding system for the various menu categories. Also given in the Table for each menu category is the proportion that each preservation type will be used. Under each of the preservation types are two columns which indicate whether the food will be bulk packaged or individual portion -size packaged. In many cases figures are given in both columns indicating that the food item may be packaged either way.

TABLE I

PROPORTIONS OF FOOD TYPES IN VARIOUS CATEGORIES

B - Bulk Packaged

I - Individual Portion Size Packaged

(percentages appearing in parentheses under both B and I indicate optional choice)

FOOD CATEGORY	TYPE OF FOOD PROCESSING							
	Thermo-stabilized		Frozen Prepared		Dry		Chill	
	B	I	B	I	B	I	B	I
BREAKFAST								
Appetizer								
Juice	(35%)	(35%)	65%	-				
Fruit	(65%)	(65%)	(35%)	(35%)				
Cereal								
Hot					(100%)	(100%)		
Cold					--	100%		
Entree								
Egg			--	100%				
Meat (with Egg)			(100%)*	(100%)*				
Meat extended			--	100%				
Grilled Bread			100%	--				
Meat (with Bread)			(100%)*	(100%)*				
Breakfast Bread								
Toast			100%					
Quick Breads			--	100%				
Sweet Dough Breads			--	100%				

* - Sliced raw or partially cooked

TABLE I

FOOD CATEGORY	TYPE OF FOOD PROCESSING							
	Thermo-stabilized		Frozen Prepared		Dry		Chill	
	B	I	B	I	B	I	B	I
BREAKFAST (continued)								
Beverage								
Hot					--	100%		
Cold (milk)			--	100%				
Accompaniments								
Butter			100%					
Syrup	(100%)	(100%)						
Jellies and Jams		100%						
Salt and Pepper					100%			
Cream			(100%)	(100%)				
Sugar					100%			
DINNER (LUNCH)								
Salads and Relishes								
(See Subtable)								
Entrees								
Sandwiches (fillings)								
Hot			(100%)	(100%)				
Cold	(10%)	(10%)	(90%)	(90%)				
Soup (single strength)	(60%)	(60%)	(10%)	(10%)	(30%)	(30%)		
Meat Extended				100%				
Meat Substitutes				100%				

TABLE I

FOOD CATEGORY	TYPE OF FOOD PROCESSING							
	Thermo-stabilized		Frozen Prepared		Dry		Chill	
	B	I	B	I	B	I	B	I
DINNER (LUNCH) continued								
Entrees (continued)								
Meat, Roasted				100%				
Meat, Grilled or Broiled				100%				
Meat, Deep Fried				100%				
Starches								
Potatoes			(100%)	(100%)				
Grains				100%				
Pasta				100%				
Vegetables								
Buttered				100%				
Creamed and Sauce			(100%)	(100%)				
Baked and Steamed			(100%)	(100%)				
Bread and Rolls			(100%)	(100%)				
Dessert								
Ice Cream				100%				
Puddings and Custards	(50%)	(50%)	(50%)	(50%)				
Fruits	(65%)	(65%)	(35%)	(35%)				
Cake, Dessert Breads				100%				
Pie				100%				
Cookie			(70%)	(70%)	(30%)	(30%)		

TABLE I

FOOD CATEGORY	TYPE OF FOOD PROCESSING							
	Thermo-stabilized		Frozen Prepared		Dry		Chill	
	B	I	B	I	B	I	B	I
DINNER (LUNCH) continued								
Beverage								
Hot						100%		
Cold (milk)				100%				
Cold (cold drinks)						100%		
Accompaniments								
Catsup, Mustard	(100%)	(100%)						
Dressings	(100%)	(100%)						
Butter			100%					
Jellies and Jams		100%						
Cream			(100%)	(100%)				
Sauces	(50%)	(50%)	(50%)	(50%)				
Salt, Pepper					100%			
SNACKS								
Fruit (Bananas, Inter Moist. Fruit)					(5%)	(5%)		
Fruit (Apples, etc.)							95%	
Candy						100%		
Beverages								
Hot						100%		
Cold	(33%)	(33%)	(33%)	(33%)		33%		
Sandwich Spreads	(50%)	(50%)	(50%)	(50%)				

TABLE I

FOOD CATEGORY	TYPE OF FOOD PROCESSING: Thermo-stabilized		Frozen Prepared		Dry		Chill	
	B	I	B	I	B	I	B	I
SNACKS (continued)								
Cookies			(70%)	(70%)	(30%)	(30%)		
Nuts								100%
Crackers						100%		
SALADS AND RELISHES (14 Day Resupply)								
Vegetable Base	(10%)	(10%)					(90%)	(90%)
Fruit Base	(55%)	(55%)	(35%)	(35%)			(10%)	(10%)
Meat or Cheese Base			(100%)	(100%)				
Molded	(10%)	(10%)	(45%)	(45%)			(45%)	(45%)
Juice	(65%)	(65%)	(35%)	(35%)				
Relishes	(100%)	(100%)						
(30 Day Resupply)								
Vegetable Base	(50%)	(50%)					(50%)	(50%)
Fruit Base	(55%)	(55%)	(35%)	(35%)			(10%)	(10%)
Meat or Cheese Base			(100%)	(100%)				
Molded	(25%)	(25%)	(45%)	(45%)			(30%)	(30%)
Juice	(65%)	(65%)	(35%)	(35%)				
Relishes	(100%)	(100%)						
(90 Day Resupply)								
Vegetable Base	(85%)	(85%)					(15%)	(15%)

TABLE I

FOOD CATEGORY	TYPE OF FOOD PROCESSING							
	Thermo-stabilized		Frozen Prepared		Dry		Chill	
	B	I	B	I	B	I	B	I
SALADS AND RELISHES cont.								
(90 Day Resupply, cont.)								
Fruit Base	(55%)	(55%)	(35%)	(35%)			(10%)	(10%)
Meat or Cheese Base			(100%)	(100%)				
Molded	(45%)	(45%)	(45%)	(45%)			(10%)	(10%)
Juice	(65%)	(65%)	(35%)	(35%)				
Relishes	(100%)	(100%)						

NOTES:

Vegetable base salads can include beans (2 week storage life or 5 weeks with preservative); bean sprouts; cabbage (3 weeks storage life with preservative); sauerkraut; or potatoes (2 weeks storage life or 5 weeks with preservative). Fruit base salads can include melon balls; mixed fruits; or waldorf (refrigerated). Molded salads include gelatin (3 to 4 weeks storage life). Relishes can include pickles; olives; corn relish; pickled beets; or red cabbage.

Food Packaging

Package Interfaces. Food package interfaces are listed in Figure 14.

Requirements.

Capability of containing fully prepared foods during freezing process.

Capability to withstand maximum temperature required for heating (450°F).

Capability of serving as a dish during consumption.

Flexibility to adapt to selected waste disposal method (Compacting).

Compatability with electrostatic restraint system (electrically conductive).

Objectives

Minimum weight.

Minimum volume

Maximum convenience during handling, preparation, consumption, and disposal.

Trade-Off Considerations. In order to comply with the listed requirements and objectives there is only one possible choice for containers for the frozen prepared food. This choice is aluminum foil formed pans with suitable covers. Various competitive containers of pasteboard and plastic were briefly considered, however these materials will not stand the required reheating temperature and are not as suitable as aluminum for restraint in an electrostatic field.

Frozen milk and concentrated frozen fruit juices will be packaged in plastic bags since this presents a package which can be easily opened for insertion of the contents into a reconstituting centrifuge.

FOOD PACKAGE INTERFACES

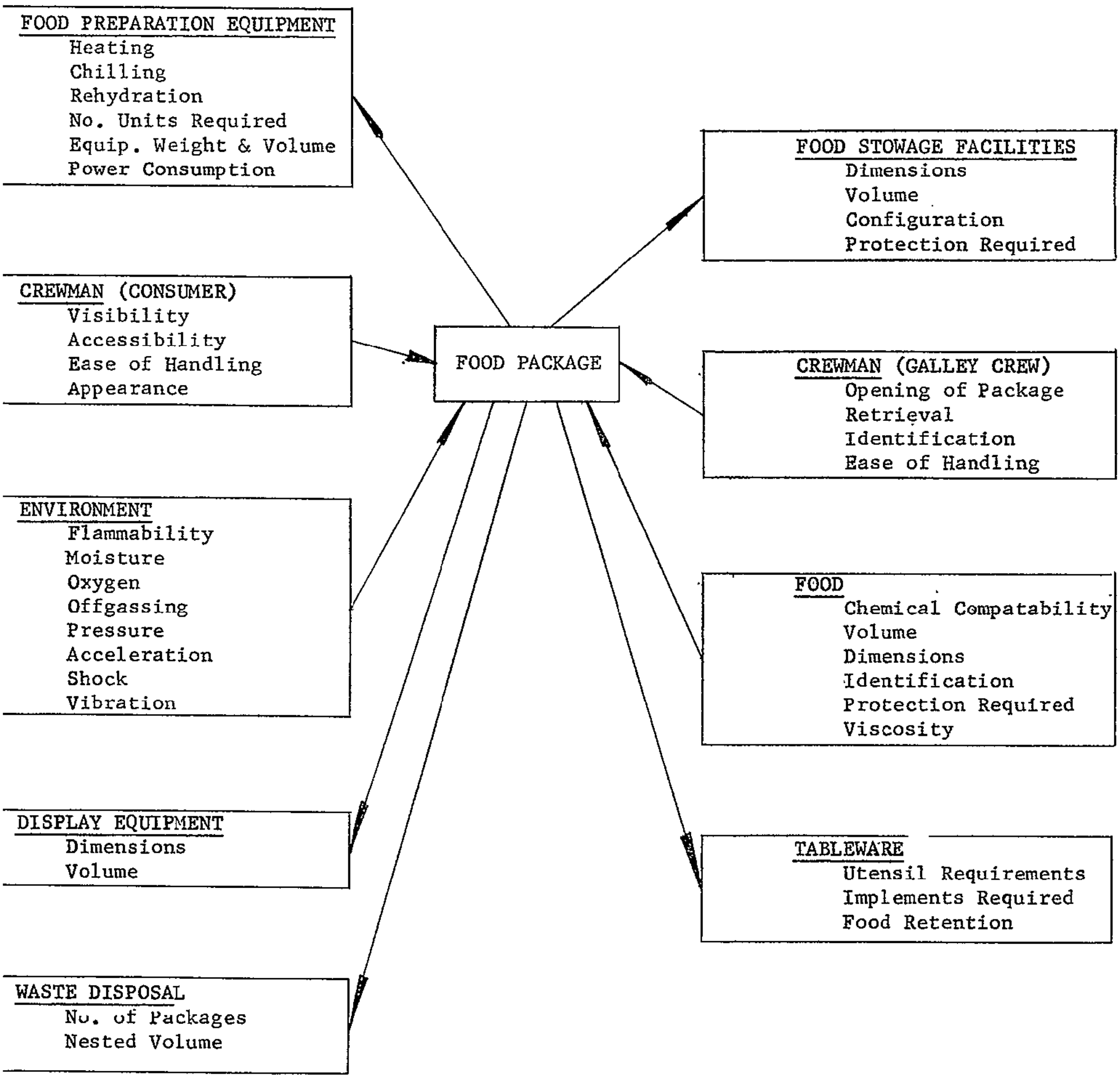


Figure 14

Selected Concept

Practically all portion size frozen foods are packaged in aluminum foil pans. Many of the commercially available pans are sized for two or more portions at the present time. It is assured that pans of any particular size can be made readily available when required for this projected program. For purposes of sizing serving pans and other equipment described in this report the particular pan sizes developed for the U.S.A.F. Foil Pack In-Flight system were adopted. These sizes are 4 1/2"x 3 5/8"x 1 1/2" for entrees and 2 1/4" x 3 3/4" x 1 1/2" for side dishes and desserts. A typical meal would consist of one large container and four small ones containing the meat entree in the large container, starch (potato, macaroni, etc.), vegetable, dessert, and a bread item in the four smaller pans.

Since the large container is practically equal in area to two small containers, they all nest conveniently in the cavities provided in the meal tray.

Food Stowage Equipment

Frozen Food Stowage Equipment Interfaces. Interfaces common to all types of food stowage equipment are listed in Figure 16.

Requirements

Adequate capacity (14-day resupply 212 ft^3, 30-day resupply 455 ft^3, 90-day resupply 1364 ft^3.)

Maintain temperature at -10°F or less.

Operable under zero gravity conditions.

Configuration compatible with deck shape.

Maintain performance for required life under specified conditions of atmosphere, noise microbiology, vibration, and relative humidity.

FOOD STOWAGE EQUIPMENT AND FACILITIES INTERFACES

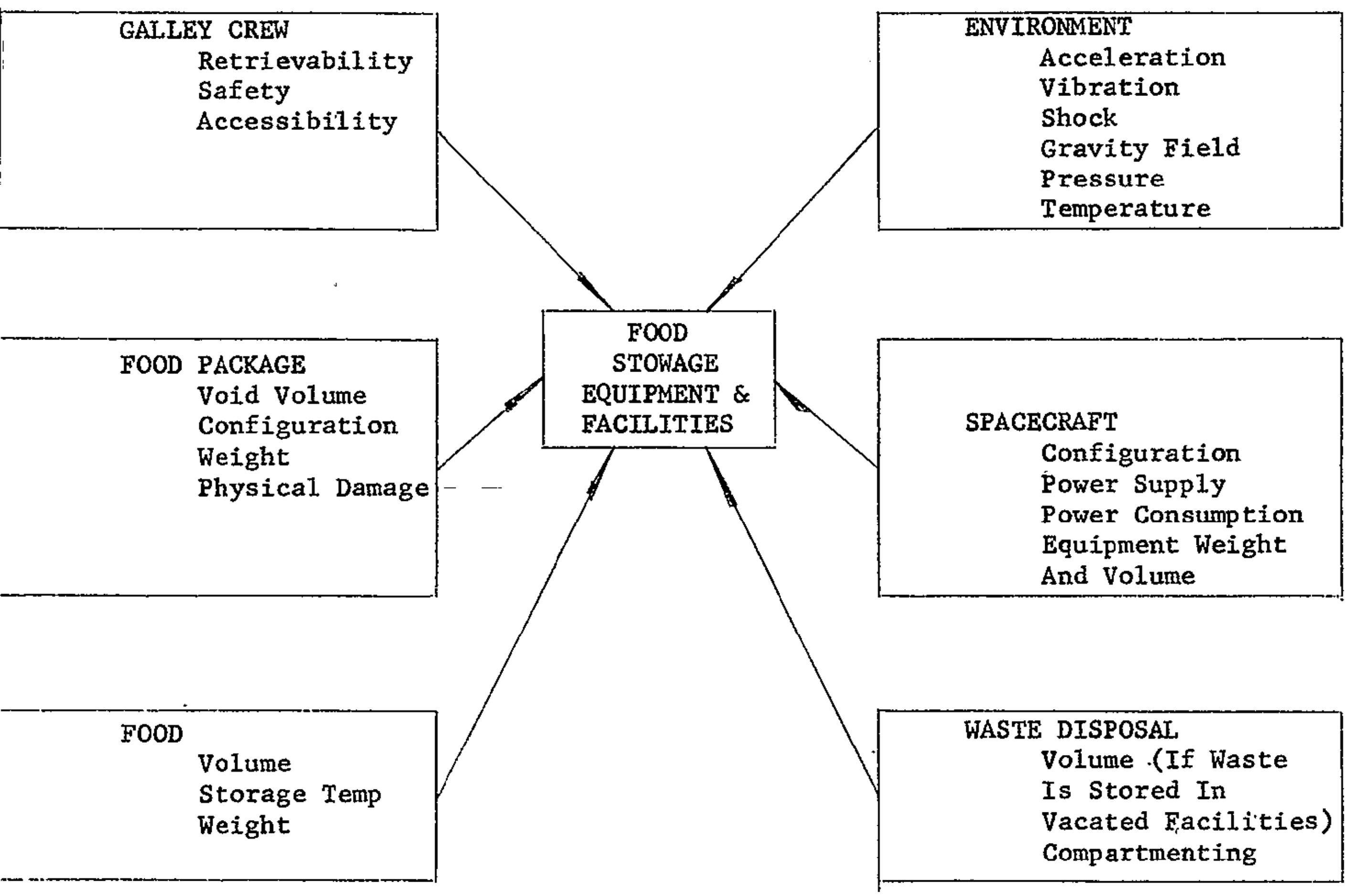


Figure 16

Requirements (continued)

Present no external surfaces accessible to crewmen at temperature less than 40°F or more than 150°F.

Objectives

Minimum power consumptions

Minimum weight

Minimum volume

Minimum requirement for, and maximum ease of, maintenance and repair.

Minimum hazard to safety of crewman.

Maximum reliability in providing the required temperature.

Minimum risk of development and application.

Maximum convenience in stowing and retrieving food items.

Complete compatibility with system interfaces.

Candidate Concepts

Water sublimination concept

Space radiator concept

Cryogenic liquid expansion concept

Thermoelectric concept

Vapor Compression concept.

Air cycle concept

Freezer Trade-off Analysis

The following trade-off analysis is presented in tabular form. A full explanation of the rating system employed and the rationale used to evaluate the candidate concepts follows the table.

FREEZER TRADE-OFF ANALYSIS

TRADE-OFF FACTORS	FACTOR MULTIPLIER	FREEZER CONCEPTS: WATER SUBLIMATION	SPACE RADIATOR	CRYOGENIC LIQUID EXPANSION	THERMO ELECTRIC	VAPOR COMPRESSION	AIR CYCLE
POWER REQUIREMENT	2	8	8	8	2	6	2
WEIGHT	2	8	8	2	4	6	2
VOLUME	1	4	4	1	3	3	1
MAINTENANCE & REPAIR REQ'MT	1	3	4	4	3	3	3
SAFETY HAZARD	3	9	12	12	12	12	12
RELIABILITY	2	6	6	6	6	6	4
DEVELOPMENT RISK	2	4	6	6	6	4	6
CONVENIENCE	2	8	8	2	8	8	6
SYSTEM COMPATABILITY	3	12	12	3	9	9	9
TOTAL SCORE		62	68	44	53	57	45
RANK		2	1	6	4	3	5

Trade-Off Factors

The trade-off factors listed in the trade-off table are considered adequate to compare the relative merits of the different freezer concepts considered for operation at zero gravity. They are the same as the stated objectives.

Ratings

Each freezer concept is rated against each trade-off factor on the following scale.

Poor - 1

Fair - 2

Good - 3

Excellent - 4

Factor Multipliers

Each trade-off factor is weighted by assigning a multiplier number as indicated in the table. These multipliers indicate the relative importance of the factor as it affects the functioning of the freezer as part of the entire system including all interfaces. In scoring each freezer concept against each trade-off factor, the assigned rating is multiplied by the factor multiplier.

Freezer Design

To establish a basis for comparison of the various freezer concepts the refrigeration load is defined by the following calculation.

Volume - 1364 cu. ft. frozen food (for 90 days)

Temperature - Holding at -10°F.

Area of insulated freezer walls - 900 sq. ft.

Thermal transmission, walls - V = .042 BTU/Sq. Ft./°F./Hr.
(Based on 4" polyurethane foam)

Refrigeration load:

Walls - .042 BTU x 900 ft.^{2} x 85°F. = 3,193 BTU/Hr. = 73,632 BTU/24 Hr.

Freezer Design (continued)

Air Change: (Assuming that opening the freezer door will admit

1300 cu. ft. or 97 LBS. of air in 24 hours.

97 LBS. x $85^{o}F$ x .2336 specific heat = 1926 BTU/24 hours.

Total Load = 76,632 + 1926 = 78,558 BTU/24 hours.

Freezer Concept Trade-Off

Sublimation of Water

It is assumed that, since all waste water will be reclaimed, and that much water will be reclaimed from the frozen foods consumed by the crew, that excess water will be available for purposes of refrigeration.

The enthalpy of water at $32^{o}F$ in passing from a solid to a vapor is 1075.8 BTU/LB.

Refrigeration load - $\frac{78558 \text{ BTU}}{1075.8 \text{ ''}}$ = 73 LBS. H_2O/24 Hr.

$\frac{73}{24}$ = 3.04 LB/HR = .365 GAL/HR

The concept of water sublimation as applied to refrigerating the frozen food load is visualized as passing a transfer fluid such as ethylene glycol through a coil in the frozen food compartment, circulating the fluid by pumping, on through a sublimator at the spacecraft hull. Sublimation of water into space vacuum will produce extremely low temperatures in the transfer fluid. Referring to Table 5, "Saturation: Solid-Vapor", page 76 of "Thermodynamic Properties of Steam Including Data for the Liquid and Solid Phases", J.H. Keenan and F.G. Keyes, it will be seen that ice sublimation at 0.0108 psi. absolute pressure produces a temperature of $-10^{o}F$. At 0.0019 psi. absolute pressure the resultant temperature is $-40^{o}F$. Since the absolute pressure in space vacuum is infinitely lower than these tabular pressures it follows that there will be no difficulty in achieving the required low

Sublimation of Water (continued)

temperature in the transfer fluid. The sublimator would be a small compartment adjacent to the storage compartment and equipped with closures permitting opening the sublimator to space vacuum or venting it to spacecraft ambient atmosphere. The sublimator would contain a heat exchanger in the form of a coil. The transfer fluid would pass inside this coil and water sublimation would occur on the outside surface. The coil would be covered with a wicking material extending into a water trough. With the outer closure of the sublimator closed, the inner vent would open to allow the sublimator temperature to rise above freezing while water was injected into the trough and wicked over the coil surface. Subsequent closing of the inner vent and opening of the outer closure would expose the wetted coil to space vacuum and sublimation of the water would occur. Sensing devices would control the pumping rate of the transfer fluid, water injection, and opening and closing of the sublimator closures.

For estimating purposes, the sublimator size and approximate weight is defined by the following calculation.

Refrigeration load $= \frac{78558 \text{ BTU}}{24 \text{ HR}} = 3{,}273$ BTU/Hr.

Heat Exchanger coil - Assume U=200 BTU/SQ. Ft./$^{\circ}$F/Hr., Temp Diff. = 15°

Then: U=200 x 15 = 3000 BTU/SQ.Ft./HR

Coil Area $= \frac{3273 \text{ BTU}}{3000 \text{ BTU}} = 1.10$ SQ. FT. or 159"^{2} Coil Surface

Six lineal feet of 3/4" O.D. copper refrigerating tubing would furnish adequate surface area.

It is estimated that this device could be housed in a box not more than 2'^{3} in size.

Weight of the entire system is estimated at 200 lbs.
The power requirement would be small since the only tasks involved are pumping the transfer fluid, operating automatic controls, and opening the sublimator closures. The rating is excellent, 4, and the score is 8.

Sublimation of Water (Continued)

The weight of 200 lbs. is considered excellent, 4, and the score is 8.

Volume of 2 cu. ft. is considered excellent, 4, and the score is 4.

Maintenance and repair is considered good, 3, and the score is 3.

Safety hazard is rated good, 3, since there are no anticipated hazards but the device is entirely new and untried. The score is 9.

Reliability is considered good, 3, and the score is 6.

Development risk must be considered high since the concept is entirely new. The rating is fair, 2, and the score is 4.

Convenience is considered excellent, 4, since the transfer fluid can be circulated in coils wherever needed without interfering with access to the useable freezer space. The score is 8.

System compatibility is considered excellent, 4, and the score is 12.

Space Radiator

The space radiator concept would employ the same basic heat collection system as that described for the water sublimation concept, a transfer fluid circulating through coils in the freezer space and carrying the heat to a space radiator or radiators. The radiator would be outside the hull and, if only one were employed, it would be necessary to provide an automatic shield to cover the radiator when rotation exposed it to the sun's rays. It might be necessary to use two radiators and automatically divert the transfer fluid to the one on the cold side of the hull. The automatic shield is the major problem in this concept. Success or failure of the actual flight system depend on the performance of this critical item.

Space Radiator (Continued)

Power requirement is the same as required for the sublimation system. The rating is excellent, 4, and the score is 8.

Weight is considered excellent, 4, and the score is 8.

Volume is small. The rating is excellent, 4, and the score is 4.

Maintenance and repair requirement should be very low for this system. The rating is excellent, 4, and the score is 4.

The safety hazard is very small, the rating is excellent, 4, and the score is 12.

Reliability is considered good, 3, and the score is 6.

Development risk should be good since there has been prior experience with space radiators. The rating is good, 3, and the score is 6.

Convenience with this simple system should be excellent, 4, and the score is 8.

System compatibility is rated excellent, 4, and the score is 12.

Cryogenic Liquid Expansion

This concept involves expanding or vaporizing liquid nitrogen in a heat exchanger coil in the freezer, then venting the nitrogen gas overboard. Since the total refrigerating effect in bringing liquid nitrogen to the boiling point and evaporating it would amount to 93 BTU/LB. (compared with enthalpy of 1075.8 BTU/LB. for water), and it would be necessary to carry a large supply of liquid nitrogen in heavy containers, the system sppears to be impractical, as is borne out in the trade-off.

Cryogenic Liquid Expansion (Continued)

Probably the only power requirement would be a small amount for operation of controls. The rating is excellent, 4, and the score is 8.

Weight is a serious fault in this system. The weight of the nitrogen and storage cylinders for the 90 day requirement is estimated at 19,000 lbs. The rating is poor, 1, and the score is 2.

An estimated 400 Cu. Ft. of storage space would be required for the nitrogen cylinders. The rating is poor, 1, and the score is 1.

Since there is very little mechanism in this system there should be very little maintenance and repair requirement. The rating is excellent, 4, and the score is 4.

There is practically no safety hazard with this concept, therefore, the rating is excellent and the score is 12.

Reliability should be good since there are few mechanical parts involved The rating is good, 3, and the score is 6. There is some chance of failing to connect new cylinders of gas when required.

Development risk is good, 3, and the score is 6.

Convenience is rated poor, 1, since it would be necessary to connect and disconnect gas cylinders at frequent intervals. The handling and storing of the gas cylinders would be most inconvenient. The score is 2.

System compatibility is rated poor, 1, since the manual handling of multiple gas cylinders imposes an unnecessary task on the crew and does not meet the requirement of maximum automation nor minimum number of crew members engaged in food preparation, since the refrigeration

Cryogenic Liquid Expansion (Continued)

must be considered as a part of the food preparation. The score is 3.

Thermoelectric Concept

The power requirement for thermoelectric refrigeration is roughly three times that of a compressor system. When compared with systems requiring only the power to operate a circulating pump and controls, thermoelectric must be rated poor, 1, and the score is 2.

Weight cannot be accurately estimated in the absence of a design for the system. However, large heavy metallic heat sinks would be involved and the rating cannot be higher than fair, 2, and the score is 4.

Volume can be considered good, 3, and the score is 3.

Thermoelectric couples may require replacement, but there are no moving parts so maintenance and repair is rated good, 3, and the score is 3.

There is no safety hazard involved. The rating is excellent, 4, and the score is 12.

Possible failure of thermoelectric couples or loss of intimate contact between the cold side of couple and heat sink reduces the reliability to a rating of only good,3, and the score is 6.

Development risk is only moderate and the rating is good, 3. The score is 6.

Thermoelectric Concept (Continued)

Convenience should be excellent, 4, and the score is 8.

System compatibility is considered good, 3. A rating of excellent might be considered except that there is some reasonable doubt about the system's ability to maintain the required temperature of -10°F in the freezer. The score is 9.

Vapor Compression

This concept involves a compressor, evaporator, expansion valve, condenser, and probably a space radiator to assist the condenser in disposing of the removed heat. Some doubt exists about the eventual success of this design in zero gravity operating conditions. In the absence of gravity difficulty will be encountered in accomplishing liquid-vapor separation, particularly in the condenser.

The power requirement is moderately high and is rated good, 3. The score is 6.

Weight can be considered good, 3, and the score is 6.

The volume of the components involved is greater than that of several other concepts considered. Volume is rated good, 3, and the score is 3.

Maintenance and repair is rated good, 3, and the score is 3.

The safety hazard is considered to be low, the rating is excellent, 4, and the score is 12.

Reliability is considered good, 3, and the score is 6.

Vapor Compression (Continued)

Development risk is considered only fair, 2, and the score is 4.

Convenience is rated excellent, 4, and the score is 8.

System compatibility is considered good, 3, and the score is 9.

Air Cycle

In this concept air is the refrigerant. The air is compressed, passed through a heat exchanger and expanded in a turbine. The air is cooled in passing through the turbine and circulated to the space to be cooled. Obviously such a system can be used to best advantage when there is useful work for the turbine to perform as in providing compressed air for jet engines in aircraft.

The power requirement for this concept is high. It is rated poor, 1, and the score is 2.

Weight will high because of the number of mechanical components involved. Rating is poor, 1, and the score is 2.

Volume is large because of the need for a turbine and a compressor. Also, the heat exchanger in the frozen food compartment would need to be a large air duct rather than a small fluid coil. Volume is rated poor, 1, and the score is 1.

Maintenance and repair is rated good, 3, because the components are relatively service free. The score is 3.

No safety hazard is involved. The rating is excellent, 4, and the score is 12.

Air Cycle (Continued)

Reliability is rated fair, 2, and the sc

Development risk is rated good, 3, since this system should operate well at zero gravity and has no serious design problem areas. The score is 6.

Convenience is rated good, 3, and the score is 6.

This concept is rated good, 3, on system compatibility since its disadvantages have been separately covered under weight and volume. The score is 9.

Selected Concept

The selected space radiator concept trades off as No. 1 selection. However, if there are disadvantages in this concept, known to NASA, based on actual mission experience, the No. 2 selection, Water Sublimation, can be considered. This points out one of the advantages of the trade-off method.

Chilled Food Stowage

Equipment Interfaces

Equipment interfaces are the same as those stated for the frozen food stowage.

Requirements

Adequate capacity (14-day resupply $14'^3$, 30-day resupply $27'^3$, 90-day re-supply $76'^3$).

Maintain temperature at $35^oF. \pm 3^oF$.

All other requirements same as for frozen food stowage.

Objectives

All objectives same as for frozen food stowage.

Selected Concept

Since the refrigeration system has been selected for frozen food stowage the obvious way to provide chilled storage is to make it an extension of the system.

As illustrated on the floor plan, a refrigerator is recommended at a location convenient to the food preparation counter in the galley. Capacity is 76 ft.^{3}, the maximum for 90-day resupply. The case will be aluminum, insulated with 2" of polyurethane. Refrigerant will be supplied to coils within the refrigerator for the circulating system in the frozen food stowage area. Suitable controls will throttle the refrigerant flow to maintain the required temperature in the refrigerator. It may be possible to tie the refrigerator into the ECS cooling rather than into the freezer depending on what is available in the specific spacecraft design.

Dry Food Stowage

Requirements

Adequate capacity (14-day resupply 85 ft^3, 30-day resupply 184 ft^3, 90-day resupply 558 ft^3.

Provision to retain contents at zero gravity.

Maintain temperature between 35^o and 85^{o}F.

Maintain integrity of food for required life under specified environmental conditions.

Configuration compatible with shape of deck.

Objectives

Minimum weight

Minimum volume

Minimum power

Minimum requirement for, and maximum ease of, maintenance and repair.

Minimum hazard to safety of crewman.

Maximum reliability in providing required temperature.

Maximum convenience in stowing and retrieving dry food items.

Trade-Off Considerations

Candidate concepts for dry food stowage would normally be traded off against factors which would be the same as the objectives stated above. However, due to the large volume of dry food to be considered, and the fact that refrigeration method has already been selected, there is a single obvious way to provide the stowage.

Selected Concept

The selected concept for dry food storage is a lightly insulated room as illustrated on the floor plan. This room, as illustrated, has a volume of $540'^3$. The required volume for 90-day resupply is $558'^3$, however, space is provided above the chilled food stowage. The $36'^3$ volume is adequate for 5 to 6 days supply of dry food which will then be conveniently available adjacent to the food preparation counter in the galley. This locker need be replenished from the store room only once every five days.

In order to prevent the temperature rising above the recommended maximum of 85$'$F. it is recommended that a refrigeration coil be placed both in the storage room and the galley locker. These coils can be an extension of the circulating refrigerant system in the frozen

Selected Concept (continued)

food storage area. Suitable controls can be devised to supply a limited amount of refrigerant to hold the dry food stowage area below 85°F.

Temperatures lower than the recommended 35°F. are not anticipated in the dry food stowage areas. However, anticipating emergency situations such as possible temporary failures of the E.C.S. system, it is recommended that suitably sized electric resistance heaters be installed in the dry food stowage areas. These heaters could be controlled automatically to supply heat only when needed to prevent the temperature dropping below 35°F.

Food Preparation Equipment

Interfaces

Interfaces common to all food preparation equipment are listed in Figure 15.

Reconstitution Equipment

Fruit Juice Rehydration

Requirements

Adequate capacity for maximum requirement (two units, each with a capacity of 1.5 gallons).

Operable at zero gravity.

Capability to rehydrate and/or mix dehydrated foods and frozen concentrates both hot and cold.

Capability to dispense reconstituted food and/or beverages into serving containers.

Maintain performance for required life under specified environmental conditions.

Present no external surface to crewman at temperatures less than 40°F or more than 150°F.

FOOD PREPARATION EQUIPMENT INTERFACES

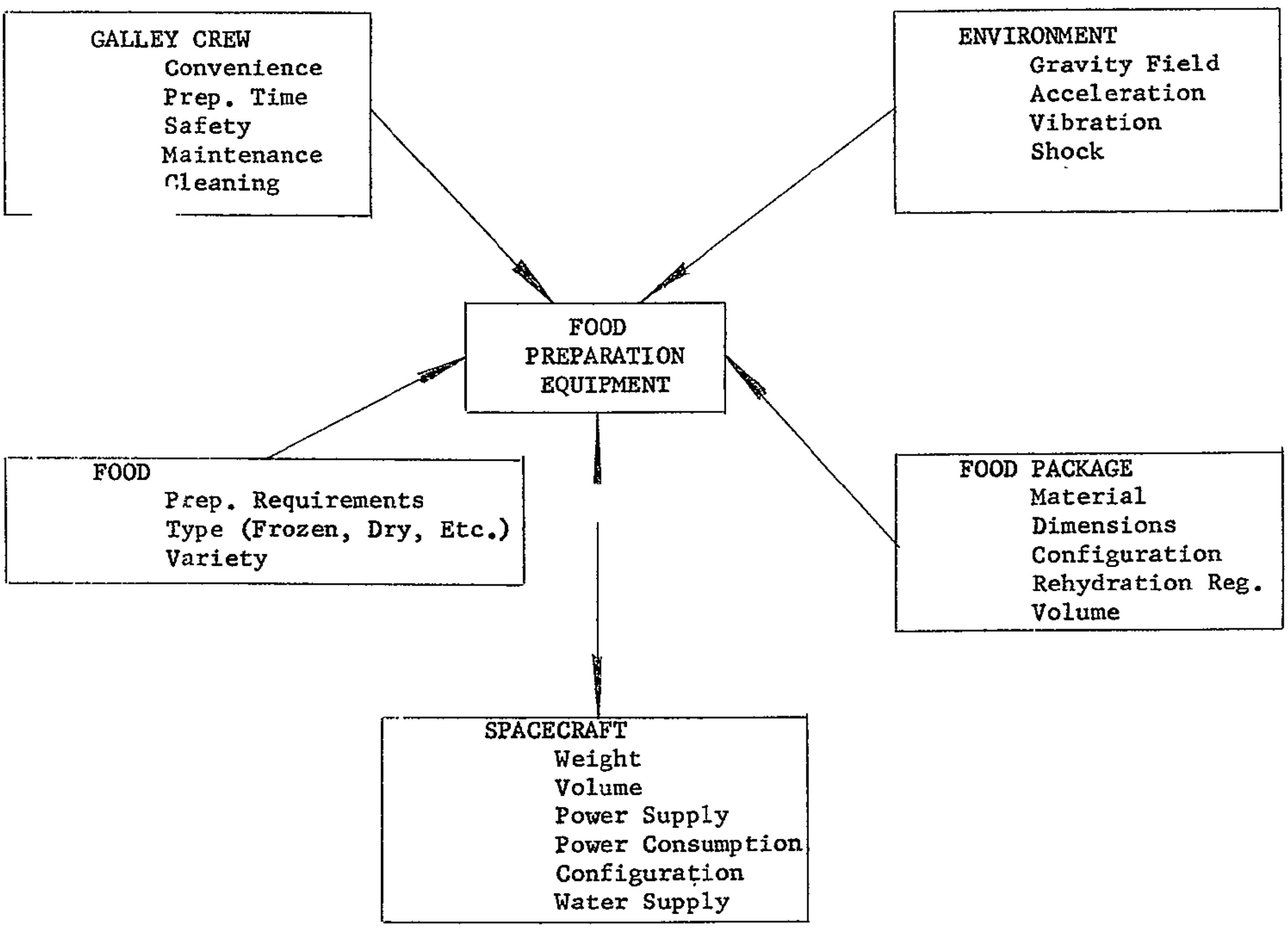


Figure 15

Objectives

Maximum efficiency

Maximum automaticity, within reasonable limits of resulting increases in power consumption, weight, and volume.

Minimum power consumption

Minimum weight

Minimum volume

Maximum convenience in operation.

Minimum requirements for maintenance and repair, and maximum convenience in maintenance and repair operations.

Minimum hazards to safety of operator.

Trade-Off Considerations

Candidate concepts considered included:

(a) Individual bags requiring addition of water and manual kneading.

(b) Multiple freeze packs hold twenty-five servings of concentrated frozen juice. These would require injection of water and manual kneading.

(c) Centrifuge which will accept frozen juice and water, then accomplish both reconstitution and loading of individual serving containers with maximum efficiency at zero gravity.

Selected Concept

The centrifuge displays so many obvious advantages over the manual concepts that it is recommended without further trade-off. The centrifuge can be cleaned by introducing hot water into the entry spout with the bowl rotating. Detergent may be introduced with the first hot water charge, followed by a hot water rinse. The fluid will be pumped through the entire device and can be discharged into the water recovery system.

Selected Concept (Continued)

Breakfast for 100 people requires 384 oz., (70 servings of 5 1/2 oz. each.) of reconstituted juice. This quantity requires 96 oz. of frozen concentrate, (3 quarts.) The concentrate will be packed in 1 pint plastic pouches, 6 required for one breakfast period.

In order to attain the objectives of maximum automaticity and maximum convenience in operation, and to satisfy the requirements of mixing reconstituted fluids and dispensing them into serving containers under conditions of zero gravity, concepts requiring manual manipulation have been rejected in favor of the centrifuge. Centrifuge is illustrated on Figure 1.

Two centrifuges of 1.5 gal capacity are recommended. Three one-pint packages of frozen juice will be opened and the contents placed in the centrifuge bowl, evenly spaced to minimize unbalance in the machine. The cover will be replaced on the centrifuge and rotation initiated to create gravity in the device. Nine pints of water will be injected in the entry spout on top of cover. After a sufficient time interval for reconstitution, the device will be allowed to pump out through a dispensing tube into the individual beverage dispensers. As illustrated on Fig. 2, the centrifuges will be provided with a pump-out device consisting of a stationary disc with a cross dilled exit passage connected to the beverage dispensing tube at the hub of the centrfuge. The disc will be only slightly smaller than the inside diameter of the rotating bowl so that fluid will be tapped off at the point of highest pressure.

Reconstitution Centrifuge

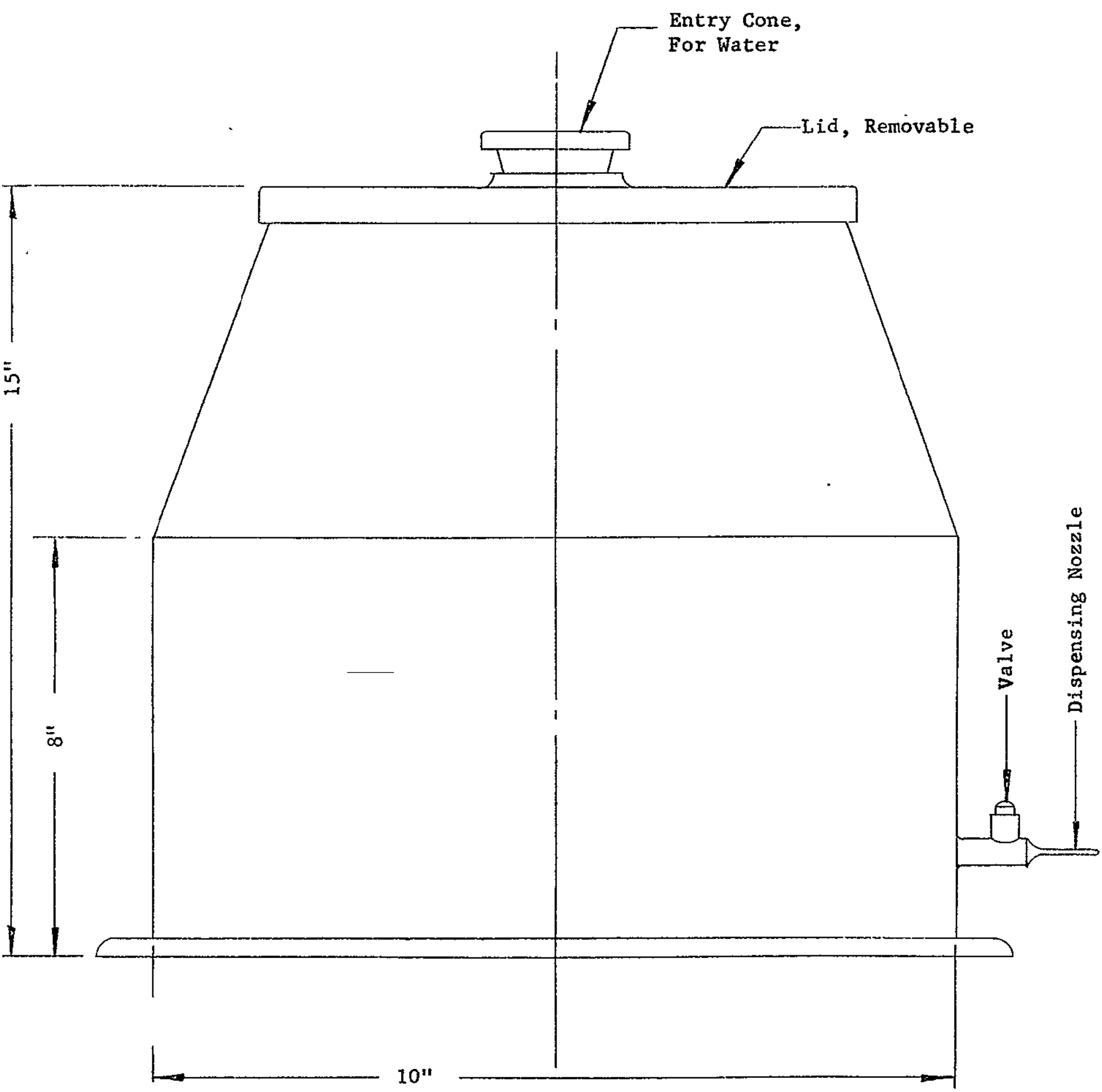
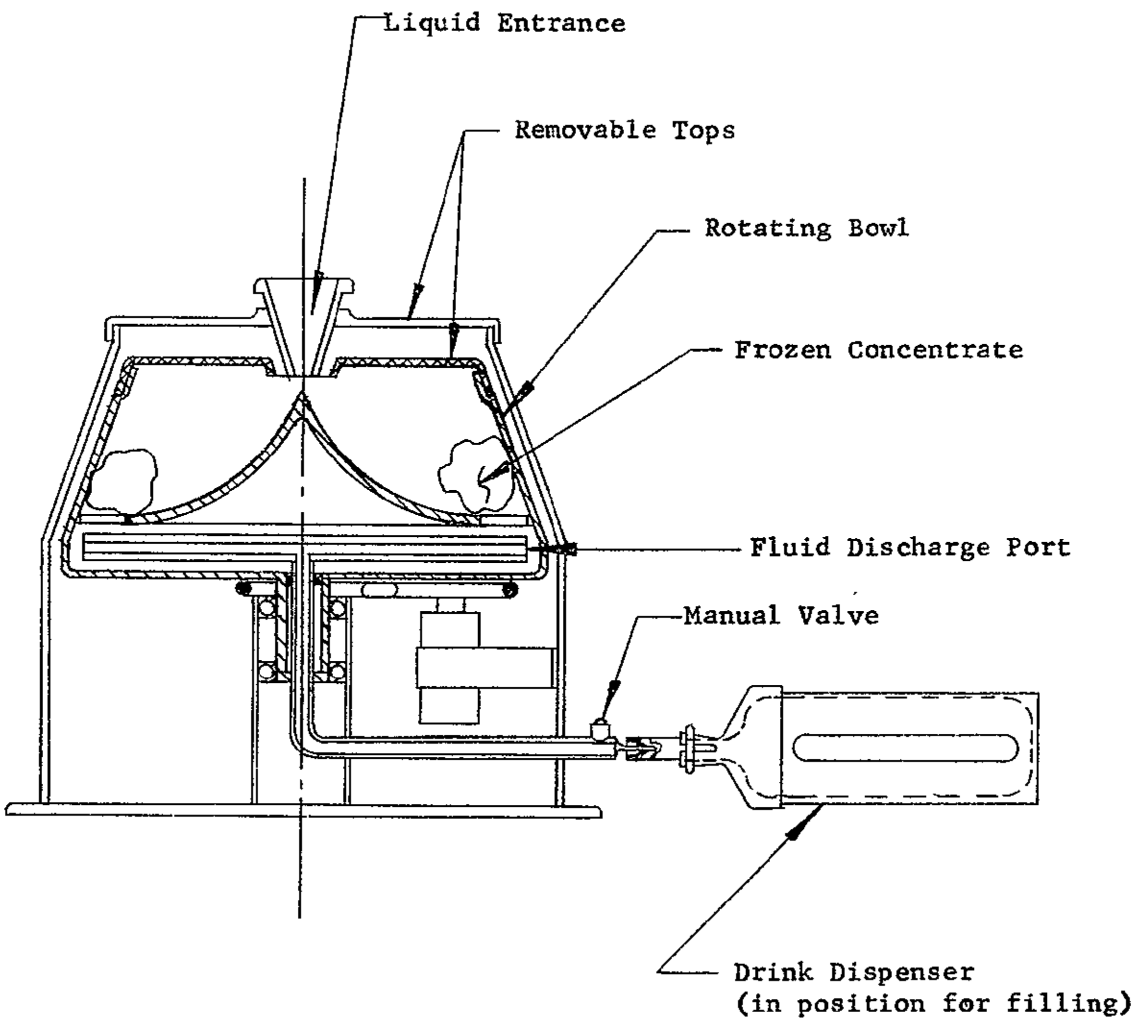


Figure 1
Capacity - 1.5 Gal.



Reconstitution Centrifuge

Capacity - 1.5 Gallons

FIGURE 2

Selected Concept (Continued)

Two centrifuges are recommended for the following reasons:

1. To provide flexibility to meet varying demands for reconstituted beverages.
2. Duplication of equipment improves availability when needed and allows for minor emergency repair or adjustment.
3. Reduced size improves convenience of loading etc.

Milk Reconstitution

Previous trade-offs dictate that milk will be provided in frozen whole state. A third centrifuge is provided for thawing, mixing, and dispensing the milk into drink dispensing pouches in the same manner as that employed in dispensing the reconstituted juices. It is recommended that the milk be provided frozen in one pint quantities in plastic pouches.

Hot Beverage Reconstitution

Requirements

Adequate capacity for maximum use requirement (one unit of 5 gallon capacity.) Operable at zero gravity.

Capability to rehydrate dehydrated coffee or tea with hot water.

Capability to dispense air-free hot water into serving containers containing concentrated dehydrated coffee or tea.

Maintain performance for required life under specified environmental conditions.

Present no external surface to crewman at temperatures higher than 150°F.

Objectives

Maximum efficiency.

Maximum degree of automaticity consistent with conservation of weight and power.

Minimum power consumption.

Minimum weight.

Minimum volume.

Maximum convenience in operation.

Minimum requirement for and maximum convenience in maintenance and repair.

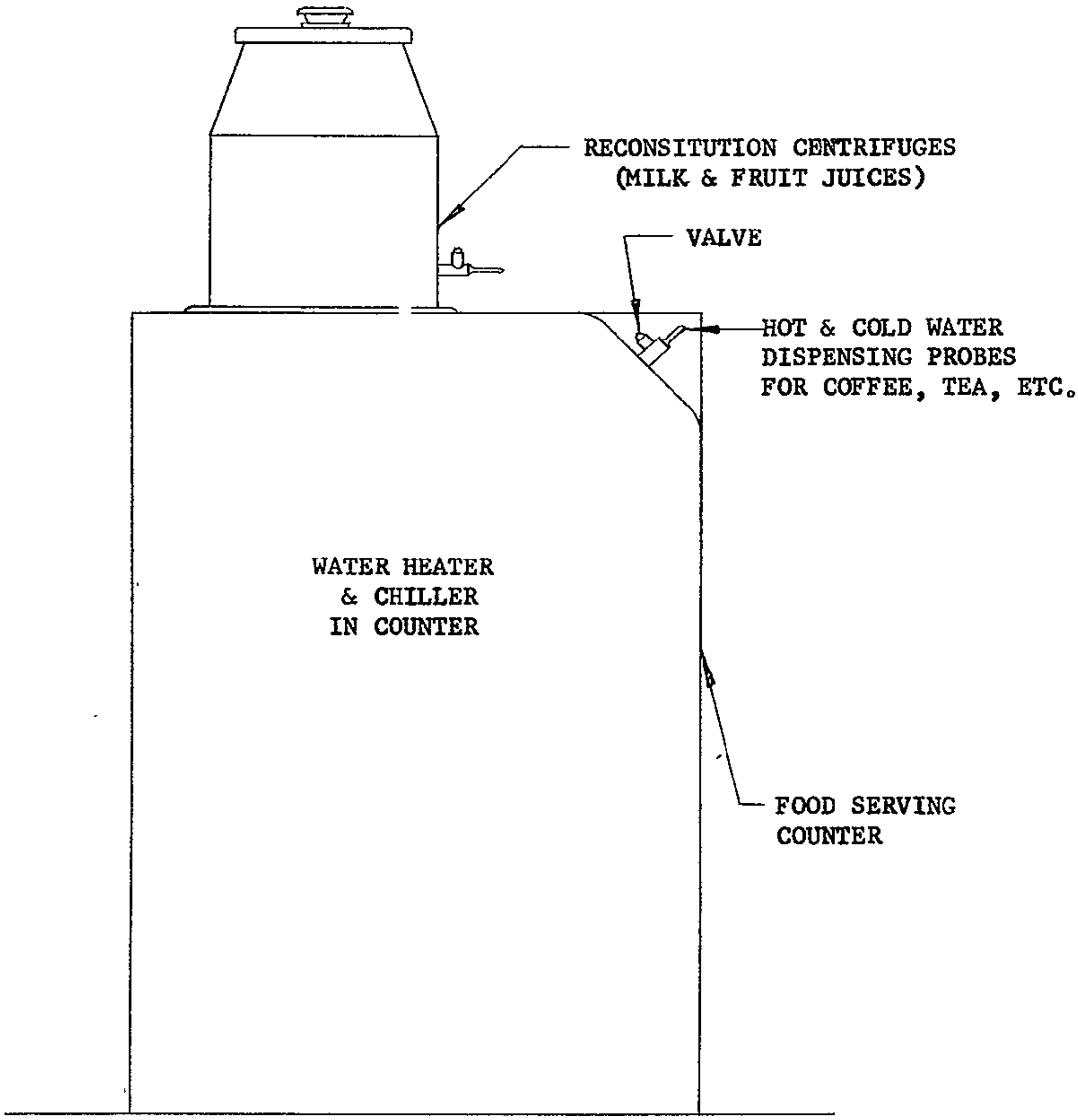
Minimum hazards to safety of operator.

Trade-Off Considerations

This subject cannot be treated as a trade-off in the ordinary sense of the term since one approach only will mate with the existing interfaces. The form in which coffee and tea are provided, dehydrated in the pouches of the drink dispensers, is dictated by considerations of weight, bulk, minimum handling, elimination of brewing equipment etc. Beverages in this form can be rehydrated and heated simply and with maximum efficiency in the following way.

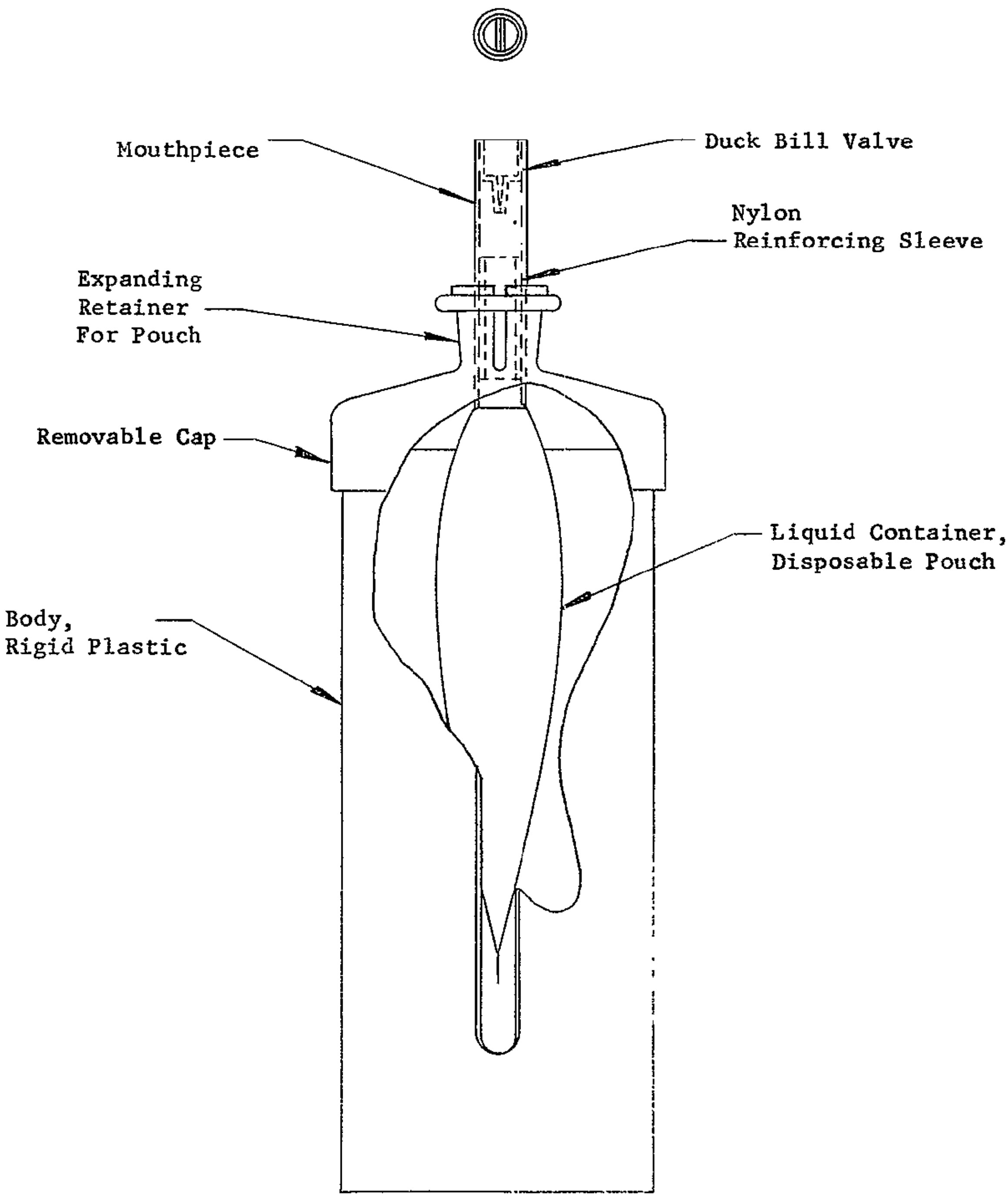
Selected Concept

The selected concept consists of a water heater with a simple measuring and dispensing conn[illegible]on to interface with the drink dispensing pouch which is pre[illegible]ged with a measured amount of dehydrated coffee or tea concentrate. This concept assumes that there will be a pressurized supply of substantially air-free water in the spacecraft. The water heater will be operable at zero gravity and is described in detail under Galley Arrangement and Accessory Equipment in this report. The water heater will be housed under the food serving



BEVERAGE RECONSITITUTION

FIGURE 4



<u>Drink Dispenser</u>

6 oz. Capacity

FIGURE 3

Selected Concept (Continued)

counter away from possible contact with the crewman. A dispensing tube will be attached to the hot water outlet and carried up through the counter top. A measuring and dispensing "gun" will be attached to this tube and will be supplied with a probe to fit the valve in the drink dispenser, Fig. 3. The disposable pouches will be labeled to indicate contents, "Coffee", "Coffee with Cream","Coffee with Sugar","Coffee with Cream and Sugar", "Tea", and "Tea with Sugar". The pouches will also be labeled to indicate amount of water required by number of actuations of the gun trigger.

It will be observed, from this description, that the same basic drink dispenser is recommended for all beverages including coffee and tea and well as fruit juices and milk. Choice of the beverage will be made by the consumer but the galley counterman will select the properly labeled pouch and accomplish the reconstitution. The hot beverage reconstitution device is illustrated as Figure 4.

Optional Equipment

A discussion of optional equipment for possible use during periods of normal gravity will be found on page 85.

Heating Equipment for Frozen Foods

Requirements

Adequate size for maximum heating requirement; (2092 In.^{2} of shelf space at 425°F., 425"^{2} of shelf space with temperature adjustable from 325°F to 450°F, and 425"^{2} of shelf space at 325°F). (As stated for 50 crewmen.) Operable under conditions of zero gravity. Maintain performance for required life under specified environmental conditions.

Requirements (Continued)

Capable of heating contents to desired temperature in 30 minutes or less, using a maximum of 100 watt-hours per pound of food.

Capable of handling portion size containers of specified sizes.

Present no external surfaces accessible to crewman at temperatures above 150°F.

Objectives

Maximum efficiency.

Minimum weight

Minimum volume.

Maximum convenience in operation.

Minimum requirement for, and maximum convenience in, maintenance and repair.

Minimum hazards to safety of operator.

Oven Concepts

The following concepts of ovens for heating of frozen, prepared foods were considered. Some of these concepts are obviously poor candidates for operation under the specified conditions but they are listed to establish valid reasons for dropping them from consideration. In the following paragraphs the various concepts are discussed in detail to establish the background data used in the oven trade-off table which follows.

Trade-Off Factors

The trade-off factors listed in the table are considered most applicable to define and compare the relative merits of different oven concepts to be employed at zero gravity.

Trade-Off Factors (Continued)

Ratings:

Each oven concept is rated against each trade-off factor by the following scale:

Poor	1
Fair	2
Good	3
Excellent	4

Factor Multipliers

Each trade-off factor is weighted by assigning a multiplier number as indicated in the table. These multipliers indicate the relative importance of the trade-off factor in relation to the functioning of the oven as a part of the entire system, including all interfaces.

In scoring each oven concept against each trade-off factor, the rating is multiplied by the factor multiplier.

OVEN TRADE-OFF ANALYSIS

TRADE-OFF FACTORS	FACTOR MULTIPLIER	OVEN CONCEPTS					
		FORCED CONVECTION	CONDUCTION	MICROWAVE	STEAM COOKER	RADIANT	THERMO-ELECTRIC
POWER REQUIREMENT	2	8	8	2	6	6	2
WEIGHT	2	6	4	2	4	6	4
VOLUME	1	3	2	1	2	3	2
MAINTENANCE & REPAIR REQ MT	1	3	3	3	2	3	2
SAFETY HAZARD	3	12	12	3	6	3	9
RELIABILITY	2	6	6	6	4	6	6
DEVELOPMENT RISK	2	6	6	8	2	6	4
CONVENIENCE	2	6	4	4	4	6	6
HEATING TIME	2	6	6	6	6	6	2
SYSTEM COMPATIBILITY	3	12	9	3	9	6	3
TOTAL SCORE		68	60	38	45	51	40
RANK		1	2	6	4	3	5

Forced Convection Oven

Since there will be no normal convection at zero gravity, convection will be forced by blowers. There will be three separate temperature zones in the oven to meet the requirements of the various frozen food items. One or more blowers with proper air ducting will provide the necessary air movement to accomplish efficient heat transfer to the food packages. By this method the food will be heated uniformly throughout the package. Air will be heated by electric resistance heaters.

The power requirement, based on comparable commercial equipment, is estimated at 11 KW/hour. Based on comparison of power requirements for other heating methods this is considered excellent and is rated 4. It is not possible to estimate heating times for frozen foods at zero gravity, therefore the figure of 11 KW/hour can only be compared with the power requirements for other types of heating equipment on the hourly basis. For instance, the estimate for the power requirement for microwave equipment for the same job is 40 KW/hour. Multiplied by the multiplier of 2 the score becomes 8. The weight of the forced convection oven is estimated at 550 lbs. This is considered good and is rated 3. Introducing the tabular multiplier of 2 produces a score of 6 on weight.

The volume is estimated to be 50 cu. ft. compared with the other equipment under consideration this is rated 3, good. Since the multiplier for volume is 1 the score is 3.

Maintenance and repair is rated 3, good, since the device is simple with only resistance heaters and blowers which are considered as relatively trouble-free. The factor multiplier in this case in only one because there will be maintenance people available on this mission. The resultant score is 3.

The safety hazard is considered excellent, 4, since there are no potential hazards such as high voltage or micro-waves. The factor

Forced Convection Oven (continued)

multiplier in this case is 3 and the resultant score is 12.

Reliability is rated good, 3, since resistance heaters and blowers of high reliability are readily available. Resultant score is 6.

Development risk is considered good, 3, since the basic design is well established and the only development required will be in the area of adapting shelving to package sizes and providing zero gravity restraints for the packages. The score is 6.

Convenience is rated good, 3, for several reasons. A convection oven provides even heat so that no special positioning of the food packages will be required. The oven cavities are large and will readily accept varying numbers of packages as the demand changes at various hours of the day. The resultant score is 6.

Heating time can only be estimated as we have no data on the operation of a forced convection oven operating at zero gravity. Logically we can assume that the heating time will be reasonably short since it is established that forced convection cuts heating time by as much as 50% compared with gravity convection at one gravity. On this basis heating time is rated good, 3, and the resultant score is 6. On system compatability the forced convection oven is rated excellent, 4, and since the multiplier is 3, the score is 12.

Conduction Oven

A conduction oven would be designed with cavities to fit the individual packages, cavities lined with resistance heater grids. If the cavities provide intimate contact with all surfaces of the packages the heat transfer would be quite efficient. Obviously many separate cavities would be needed for the large number of packages required per meal. At least 250 packages must be heated for one meal and, even if cavities could be provided to accept ten packages of a given size, twenty-five cavities would be required. These cavities must be separated and insulated from each other and the resultant oven would be very bulky. One of the problems inherent with this design is the necessity of sensing temperature at the package surfaces, to control the heating grids, to prevent scorching at food surfaces.

The power requirement is considered excellent assuming that intimate contact can be maintained between the packages and the resistance heaters. The rating is 4 multiplied by 2 to produce a score of 8.

Weight can only be estimated since this is a highly unconventional design. However, the large number of cavities required indicate that the weight will be somewhat higher than that of the convection oven and it is consequently rated as fair, 2. Multiplied by 2 the score is 4.

Volume is estimated to be only fair. The rating is 2 and the score is 2.

Maintenance and repair is considered to be good since the resistance grids are relatively trouble-free and, while individual wires may burn out, the grid is actually composed of a large number of individual circuits and should require little maintenance. The rating is good and the score is 3.

There is little safety hazard with this type of heating, therefore the rating is excellent, 4, and the score is 12.

This system is relatively simple and the reliability is rated good, 3. The score is 6.

There will be some development risk but it is considered relatively minor. The rating is good, 3, and the score is 6.

Loading and unloading twenty-five cavities is considered inconvenient. Therefore the rating for convenience is only fair, 2, and the score is 4.

Heating time is unknown but, again assuming intimate contact between heaters and packages, the heat transfer should be at least equal to that of forced convection. Therefore, a rating of good, 3, is established and the score is 6.

On system compatability this concept is rated good, 3, with a score of 9. The concept is not rated higher because of the extra time required to load and unload the cavities.

Total score for the conduction oven is 60 and its rank number is two.

Microwave Oven

The power requirement of microwave ovens is quite high. As an example; a commercially available unit with approximately 2 cu. ft. capacity has a power input of 6600 watts and a maximum output of 2000 watts. It is estimated that microwave equipment large enough to handle the heating of meals for fifty people at one time would demand an electrical load of 40 KW. On this basis power requirement is rated poor, 1, and the score is 2.

Weight is estimated at 1200 lbs., largely due to power conversion equipment and shielding. Weight is poor, 1, and the score is 2.

Volume is poor since much of the overall bulk consists of power conversion equipment and shielding. Rating is poor, 1, and the score is 1.

Maintenance and repair is rated good, 3, since this equipment has a fairly low incidence-of-repair record now. The score is 3.

There is some safety hazard with microwave equipment. If the door seals are regularly checked and integrity of the seal is maintained they are reasonably safe. A rating of poor, 1, was assigned and the score is 3.

The state-of-the-art in microwave oven design assures good reliability and the rating is good, 3. The score then is 6.

Development risk is considered negligible, largely because this method of heating does not require gravity for heat transfer. The rating is excellent, 4, and the score is 8.

Convenience is rated only fair, 2, because this method of cooking requires careful time regulation. Various food items would have to be marked for cooking time and careful selections made in assembling each batch of food items for insertion in the oven. The score is, therefore, 4.

Heating time in microwave ovens is proportionate to food mass. While single items heat in a minute or two, mass loading of the oven will raise the heating time to approximately the same as that of a convection oven. For this reason heating time is rated good, 3, and the score is 6.

The microwave oven must be scored low on system compatability since it will not accept metal frozen food containers. If plastic or other non-metalic containers were selected for the frozen foods, then the microwave oven could be rated much higher on system compatability.

The plan of freezing, storing, heating and serving the food in the same container, thereby eliminating dishwasing, practically dictates the use of aluminum foil containers. A second reason is that microwave heating has an inherent lack of uniformity of energy distribution resulting in uneven heating, frozen spots, and general low acceptability of the prepared food. For these reasons microwave ovens are rated poor, 1, and the score is 3. The rank is number 6.

Steam Cooker

The steam cooker offers a high rate of heat transfer. However, when considered for operation at zero gravity, many problems become apparent. It would probably be necessary to create a gravity field in the cooking chamber by rotation since convection will not be available. Normally steam cooking would not be acceptable for heating food in foil dishes because moisture droplets penetrate the pack covers. In this contemplated design centrifugal force could remove the droplets from the cover and, indeed, from the entire package, thus increasing the rate of heat transfer. Since design of this device is beyond the scope of the present project, only crude estimates based on best judgment can be offered as the basis of this concept tradeoff. The use of plastic or other non-metalic containers for the frozen food might improve the rating of the steam cooker.

The power requirement, estimated from performance data on commercial steamers, can be considered good, 3, and the score is 6.

Weight is estimated at 700 lbs. This is considered fair, 2, and the score is 4.

Volume is estimated at 65 cu. ft. This is considered fair, 2, and the score is 2.

Since there are more parts to maintain, boiler plus motor, and drive parts to rotate the cooking chamber, maintenance and repair requirement is rated only fair, 2, and the score is 2.

Introduction of a boiler into the spacecraft must be considered hazardous to some extent. Therefore, the rating is fair, 2, and the score is 6.

Reliability can only be considered fair since the concept is not designed. The rating is 2 and the score is 4.

Development risk must be considered to be high since there has been no previous work on steam cooking at zero gravity. The rating is poor, 1, and the score is 2.

A steamer will probably be less convenient than ovens that require only shelf loading. The rating is considered to be fair, 2, and the score is 4.

Steam cookers, except the high pressure type, are reported to be slow in thawing frozen food. The heating time, therefore, is considered fair, 2, and the score is 6.

System compatability should be good, assuming that the device can be designed to meet all interfaces. The rating is good, 3, and the score is 9.

The final score for the steam cooker is 45 and it ranks 4th among the considered concepts.

Radiant Oven

The radiant oven considered here would employ quartz plates emitting infrared rays (electromagnetic energy). Delivery of the radiation would be pulsed (intermittent) to prevent scorching of the food surfaces and to promote thorough heating of the entire package. For purposes of comparison with other heating methods a commercial "Recon" oven has been studied. This oven has a capacity of "400 portions" and shelf space equal to the requirements of the food list considered in this contract.

The power requirement is 15 KW which is considered good, 3, and the score is 6.

Weight is approximately 550 lbs., good, 3, and the score is 6.

Volume is 40 cu. ft. which is rated good, 3, and the score is 3.

Maintenance and repair is considered good, 3, and the score is 3.

Safety hazard is considered poor, 1, because of high temperatures generated by the quartz plates and consequent possibility of operator injury. The score is 3.

Reliability is judged good, 3, and the score is 6.

Development risk is rated 3 since this equipment is available subject to modification only. The score is 6.

Convenience is judged good, 3, and the score is 6.

Heating time is judged good, 3, and the score is 6.

System compatability is judged fair, 2, since special coloration may be required on food packages and the use of plastic packaging is not possible with this oven. The score is 6.

The total score for the radiant oven is 51 and it ranks third among the concepts considered.

Thermo-Electric Oven

The thermo-electric (Peltier) principle could only be considered seriously for a food-warming oven if it were also used as a source of refrigeration, so that the heat would be available as a by-product of the refrigeration system. For reasons discussed below, mainly high power requirement, this system is not recommended for refrigeration or heating. However, for trade-off purposes, some comparative ratings have been established for the trade-off table as follows:

The power requirement is roughly three times that of resistance heating. The rating is poor, 1, and the score is 2.

To provide the necessary heat it would be necessary to provide cascaded couples and a large metallic heat sink which would introduce additional weight. The weight must be considered only fair, 2, and the score is 4.

Volume can only be estimated. However, the required heat sink would add wasted space, so the volume rating is fair, 2, and the score is 2.

Maintenance and repair is considered only fair, 2, since the couples must be kept in repair as well as all the same equipment required to circulate the heat as in a forced convection oven. The score is 2.

Safety hazard is considered good, 3, and the score is 9.

Reliability is considered good, 3, and the score is 6.

Development risk must be considered only fair, 2, since much design effort would be required and there is some doubt about availability of suitable Peltier couples. The score is 4.

There is no reason to consider this oven any less convenient than a convection oven so the rating is good, 3, and the score is 6.

Heating time is really unknown. There is reason to believe that the temperature level attainable at the hot end of the couples will be considerably lower than that of resistance heaters and, consequently, the heating time will suffer. The rating is poor, 1, and the score is 2.

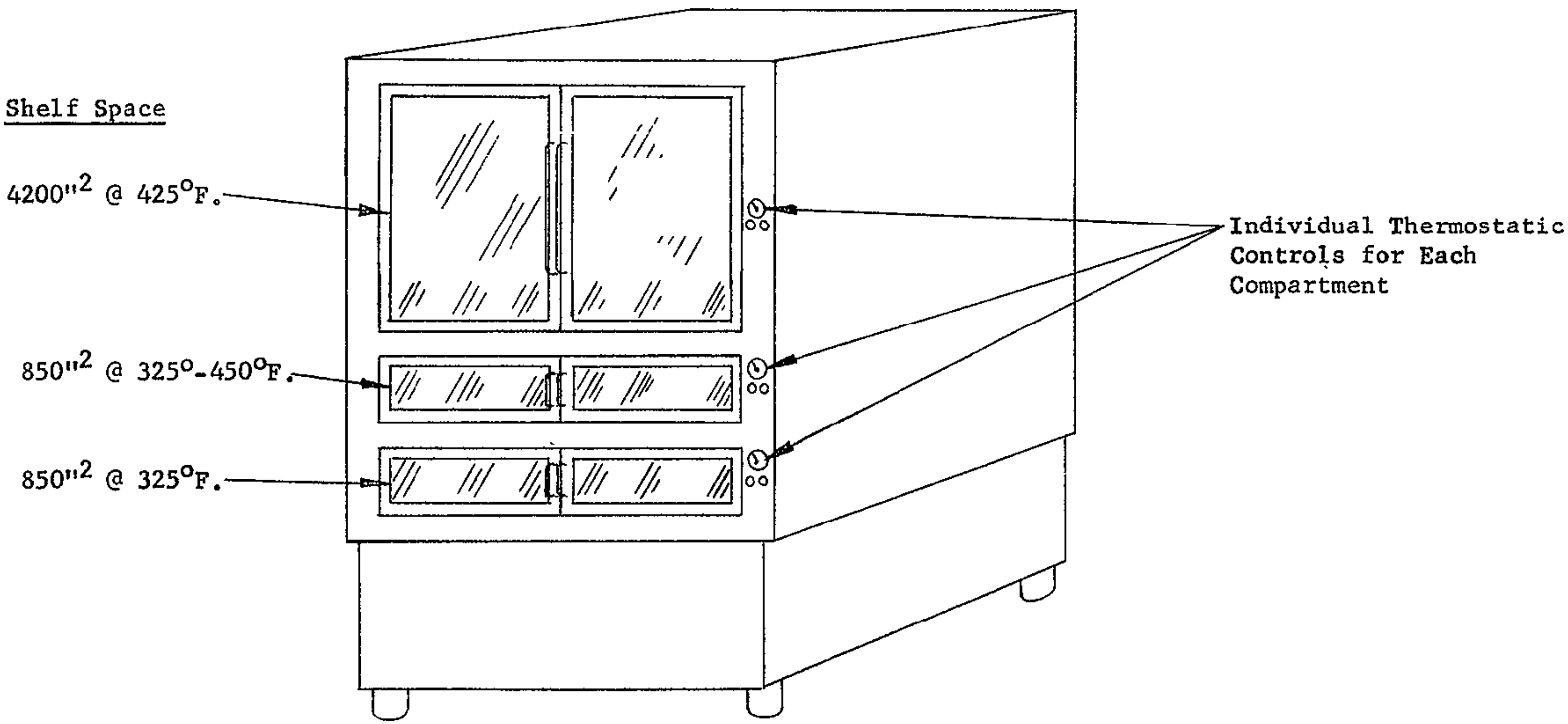
On system compatability there is no reason to believe that this method may require more power than the limit of 100 watt hours per pound of food. The rating is poor, 1, and the score is 3.

The total score for the thermo-electric oven is 40 and it ranks 5th among the concepts considered.

Selected Concept

The selected concept is the forced convection oven illustrated as Figure 18.

The oven is sized to permit preparation of 100 meals in one batch. This capability will allow preparing a meal for the entire complement, then holding portions at serving temperature to suit any staggering of meal periods or serving of single hot meals to crewmen at remote duty stations. Preparing meals in full complement batches insures most economical usage of available power.



Convection Oven

Figure 18

Toaster

Requirements

Adequate capacity (12 pieces per minute).

Capability to toast, brown or heat as required.

Operable under conditions of zero gravity.

Maintain performance for required life under specified environmental conditions.

Present no external surfaces accessible to a crewman at temperatures in excess of 150°F.

Objectives

Maximum efficiency.

Minimum weight.

Minimum volume.

Maximum convenience in operation.

Minimum requirements for maintenance and repair, and maximum convenience and repair operations.

Minimum hazards to safety of operator.

Candidate Concepts and Selection

There were two (2) concepts investigated, automatic pop-up and conveyorized, however the pop-up toaster was immediately eliminated from consideration as unable to fulfill the requirements of capacity and operability while maintaining the objectives. Additional invetigation was conducted to determine the proper heating element. Three element concepts were selected as potential candidates and analyzed: nichrome wire, quartz infrared tube, and tubular sheath. Nichrome wire elements have a potential element oxidation problem in an off-design mode and are readily susceptible to damage in the zero gravity environment. The

Candidate Concepts and Selection (continued)

quartz infrared tubes require significantly more power to reach the desired capacity, are susceptible to breakage of the quartz envelope, and due to the absence of natural convection will develop severe thermal stresses in the quartz at the ends of the heating tube. The tubular heating element, a coiled resistance wire encased by a metal sheath and packed with insulation, will not have the element oxidation problem if the ends of the sheath are properly sealed; the outside metal will also protect the heating element from damage. Tubular elements were selected as the heating concept for the conveyorized toaster.

Adequate features can be built into the design of this unit to control the element temperature by thermostatic dial, provide front or rear delivery of the toasted product and a heat sensing system permitting faster heat-up and toasting. The toaster will be approximately two feet high, one and one half feet wide and one foot deep. The estimated weight of the unit is 50 pounds. The toaster will be operated under an electrostatic resistraint field adjacent to the display counter where galley personnel may load the product from the rear of the unit and have the product delivered to the front which is easily accessible to the serving line.

Frozen Food Thawing Equipment

No special equipment for thawing frozen food is required with the recommended feeding system. Frozen, fully prepared items are best prepared by placing them directly in the preheated oven without previous thawing. Notable exceptions are, bread which can be thawed at ambient temperature, and sandwich meats which will be thawed in the refrigerator.

Display Equipment

Interfaces

Display equipment interfaces are listed in Figure 23.

Hot Food Display

Requirements

Capability to maintain hot foods at proper serving temperature (155°F to 165°F)

Adequate size to display hot food required for maximum of 50 crewmen at each meal period.

Capability to function under conditions of zero gravity.

Present no surfaces accessible to crewman at temperatures over 150°F

Maintain performance for required life under specified environmental conditions.

Provision to confine heat to food without excursion to atmosphere.

Objectives

Maximum efficiency.

Minimum power consumption.

Minimum weight

Minimum volume

Maximum convenience for servers and crewmen being served.

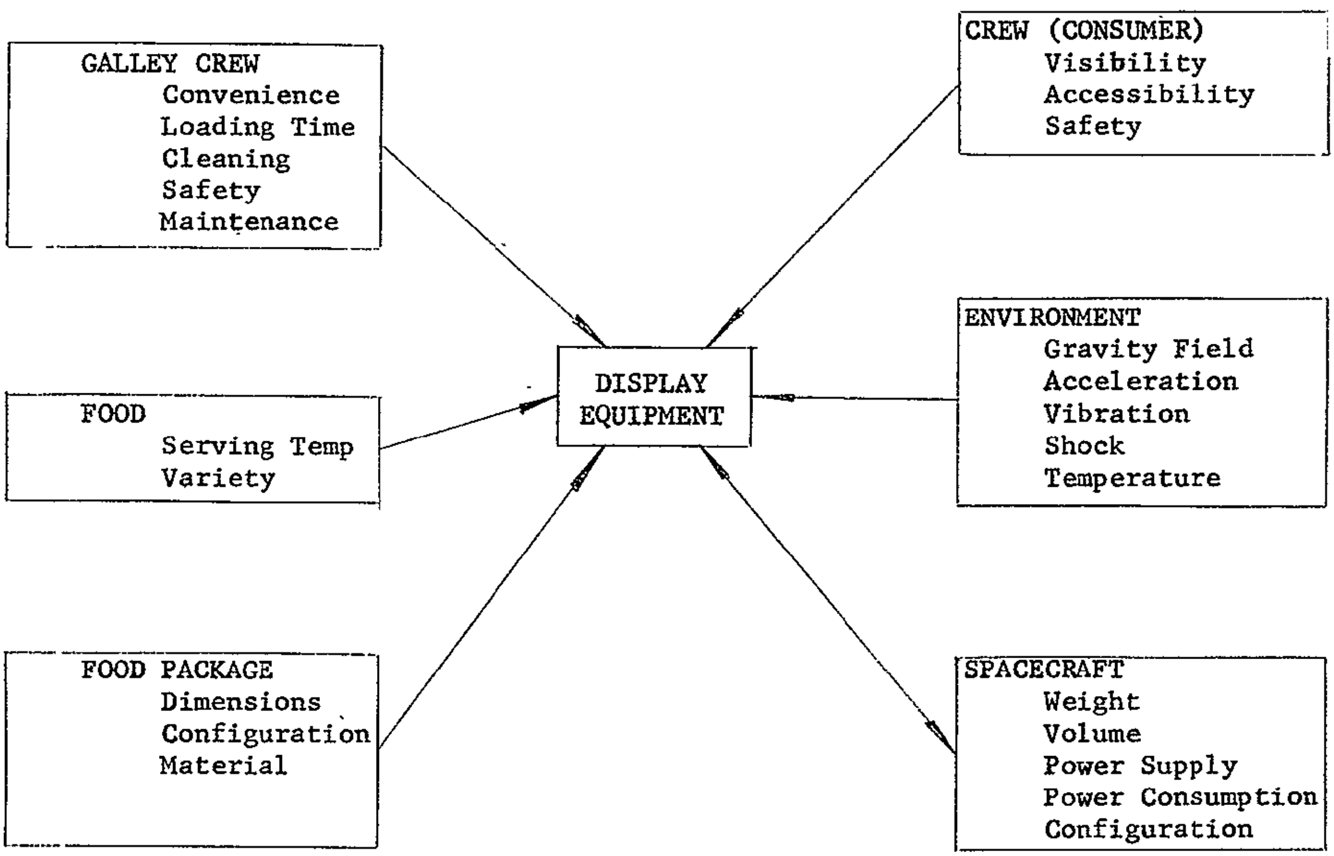
Minimum requirement for, and maximum convenience in maintenance and repair.

Minimum hazards to safety of crewmen.

Trade-Off Considerations

Only two concepts were considered for the hot food display; one approximating the conventional cafeteria "steam table" but adapted to zero gravity operation, the other a more elaborate approach similar to an automated

DISPLAY EQUIPMENT INTERFACES



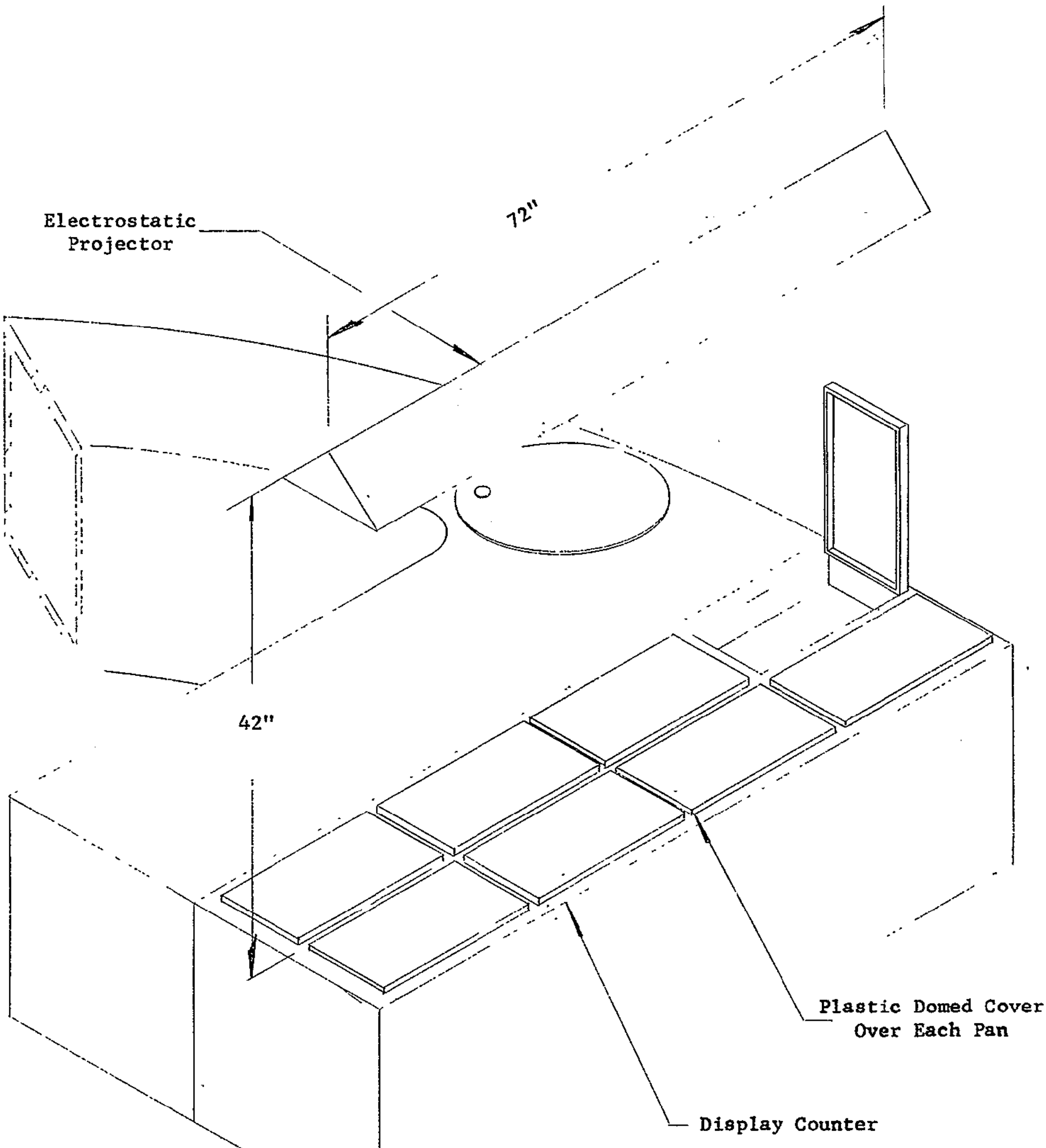
Trade-Off Considerations (continued)

vending machine. Since not more than 50 people are to be served at one meal period and there will be galley personnel to attend the display the automated approach is not justified.

Selected Concept

The selected concept is a serving table of the familiar cafeteria type but redesigned to suit the environmental conditions. The table is 36" high x 84" long x 29" wide. The table top is provided with wells to receive eight 12" x 20" serving pans. Six of the pans will be heated to display hot food and two are chilled for dessert items. Each 12" x 20" pan will display 12 entrees, or 24 side dishes, or 24 desserts.

One loading of the table will serve 25 crewmen. Since the table is directly in front of the serving counter it can be reloaded by galley attendants from the rear as required without interrupting the traffic flow in front of the counter. Six of the pans will be heated by glass plate resistance heaters. The pans will rest directly on the hot plates and the temperature will be thermostatically controlled. Each of the 12" x 20" pans can be covered with hinged, domed covers of transparent plastic to control thermal excursion. The display table is illustrated as Figure 5.



FOOD DISPLAY COUNTER

Figure 5

Cold Food Display

Requirements

Capability to maintain cold foods at proper serving temperature ($40 - 45^{\circ}F$)

Present no surfaces accessible to crewman at temperatures below $40^{\circ}F$.

All other requirements same as for hot food display.

Objectives

All objectives same as for hot food display.

Trade-Off Considerations

Since a central refrigeration system has already been selected, there are no valid reasons for consideration of more than one concept.

Selected Concept

The cold food items will be displayed in two 12" x 20" pans on the display table. These pans will rest on cold plates which will contain refrigerant circulated from the freezer circulating system. Thermostats and throttling valves can be designed to hold the pan bottom at the required temperature.

Meal Tray

Interfaces. Tray interfaces are listed in Figure 25.

Requirements

Adequate capacity for the largest planned meal.

Capable of retaining food and food packages under conditions of zero gravity.

Objectives

Minimum Weight.

Minimum Volume.

Maximum convenience in dining and cleanup.

Concept Description

The recommended meal tray is presented in Figure 6. The tray is constructed of pressed aluminum, a conductor well suited for use in the electrostatic restraint field. The interior of each large recess is lined with a lightweight thermal insulation. This will permit adjacent compartments to contain a hot or cold food package with minimum heat loss (or gain) through the tray. The recesses in the tray are sized to receive either one entree or two side dishes. The slide on cover serves a two-fold purpose: first, it prevents the inadvertent loss of any tray item while the crewman is moving between the serving counter, dining area and disposal area; and second, it allows the top of the meal tray to be partially exposed permitting access to a limited number of food products in products in the zero gravity environment. The cover will only be used during zero gravity periods. The simple design of the tray offers the easiest cleanup operation since there are no inaccessible areas and a wiping rag is all that is required. Construction of the tray, measuring approximately 16" x 8½" with the depth suitable for accepting the deepest food package, will permit

TRAY INTERFACES

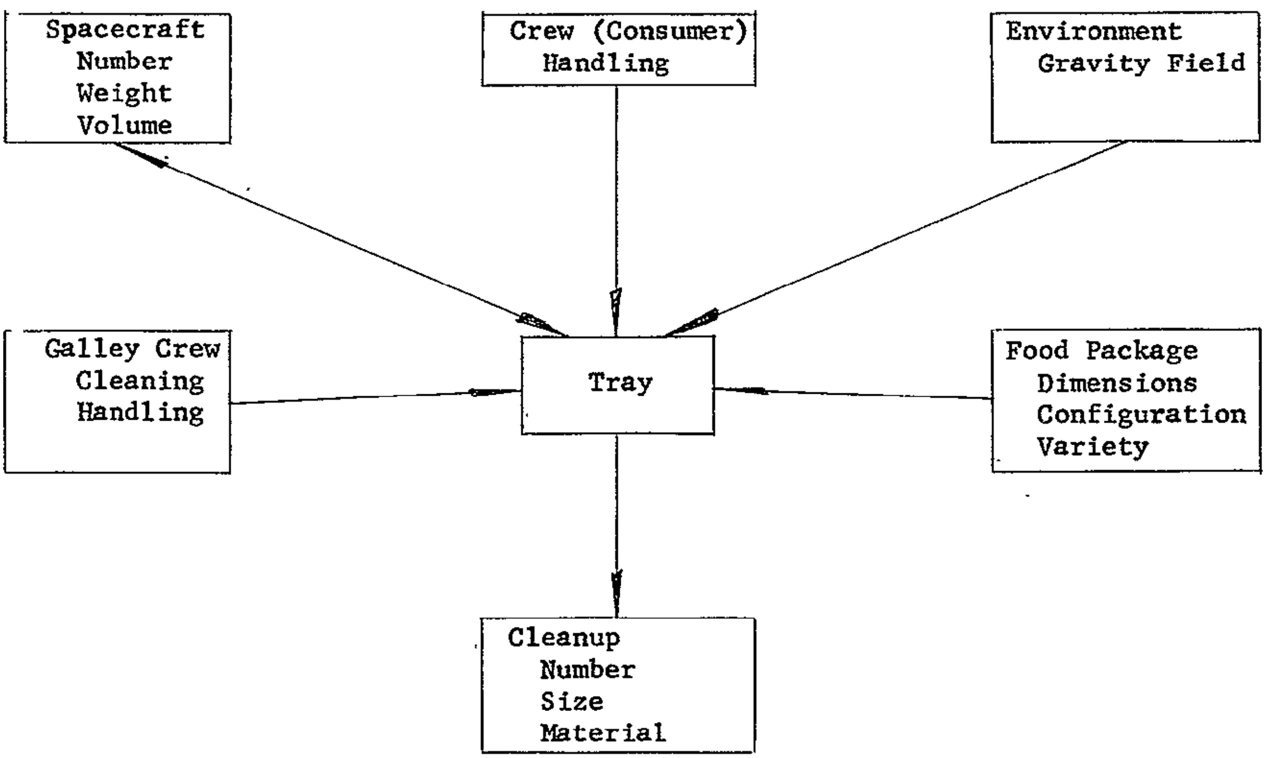
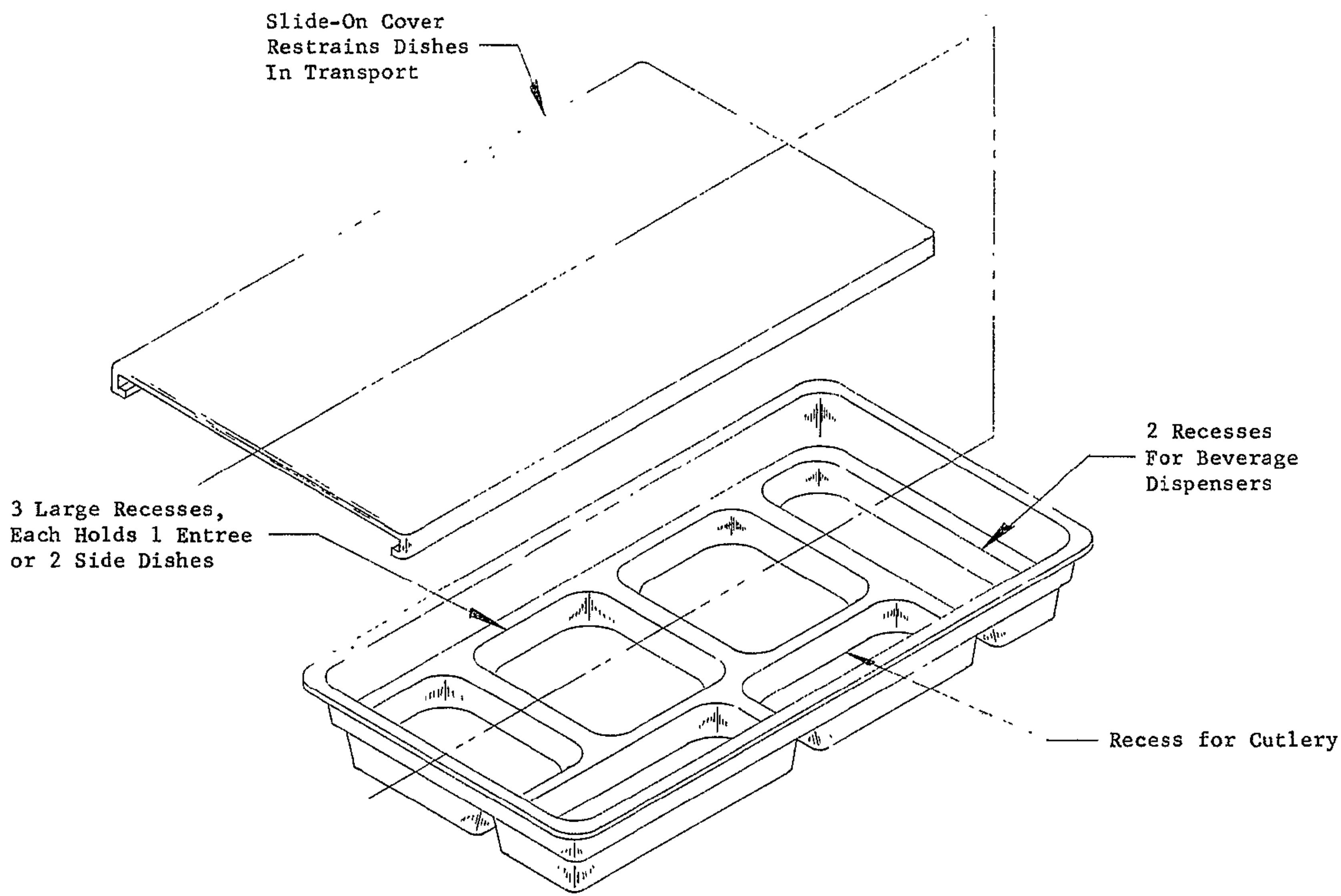


Figure 25



MEAL TRAY

FIGURE 6

them to be nested in the minimum volume, when not in use, since the recesses in the tray are tapered and, with proper orientation, slide into one another. As a possible alternate, the tray could be provided with a disposable liner so that wiping after use would not be required.

Eating Utensils

Interfaces. Eating utensil interfaces are listed in Figure 26.

Requirements

Anthropometrically compatable.

Interface with all food packages.

Functional under both gravitational and nongravitational environments.

Aesthetically acceptable.

Objectives

Minimum weight.

Minimum volume.

Maximum convenience and safety in use.

Candidate Concepts

Three concepts were evaluated as described below.

(1) Reusable conventional items--knives, forks and spoons made out of light metal and cleaned after each use.

(2) Disposable conventional items--light metal and two weights of plastic utensils of conventional design were investigated; any of the sets would be disposed of after use.

(3) Special multi-purpose items--Reusable utensils of unconventional design incorporating a combination of the fork and spoon and the fork and knife.

Tradeoff Analysis

The initial step was an investigation into disposable conventional eating utensils. Figure 17 presents an evaluation of the weight and volume penalties for utensils discarded after each meal and utensils

EATING UTENSIL INTERFACES

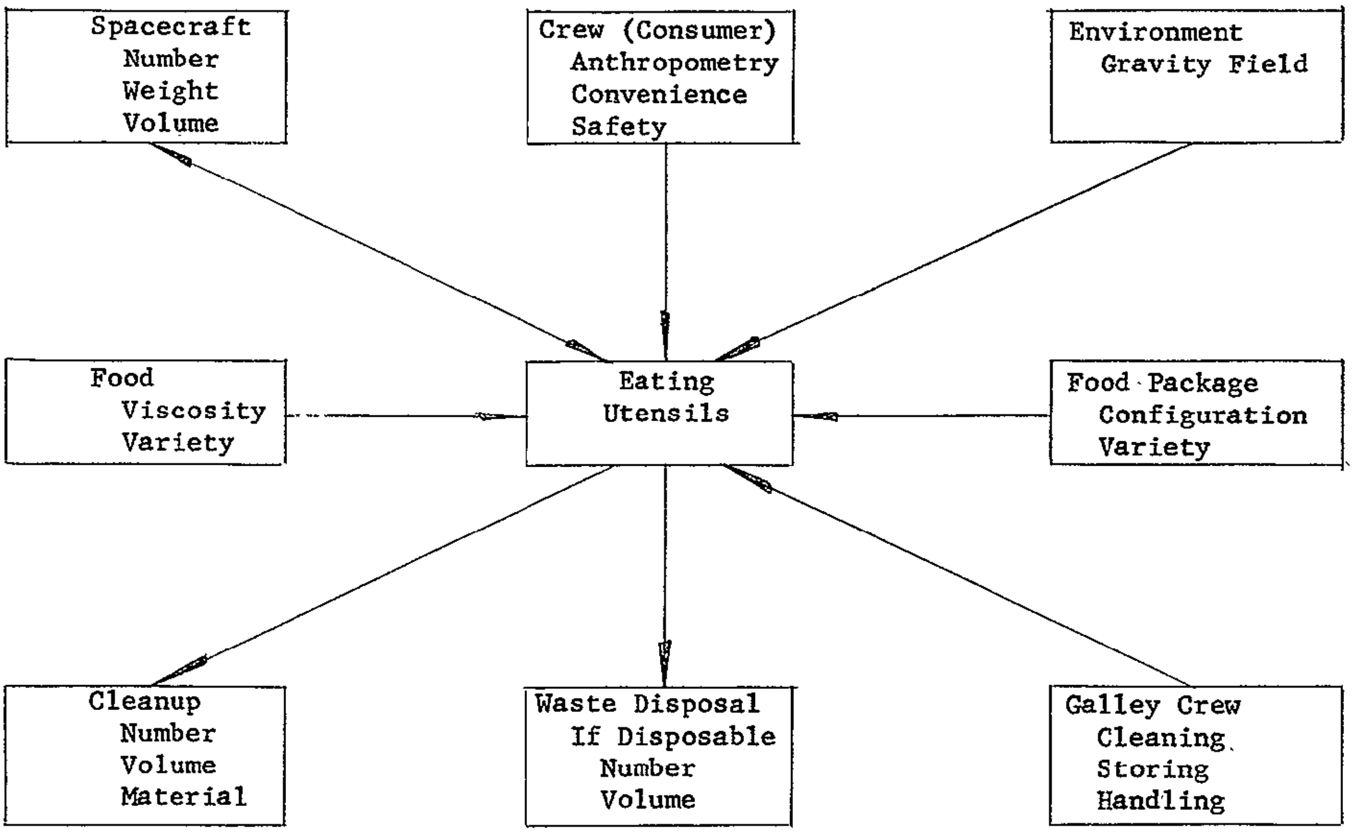


Figure 26

discarded once each day. Although the weight and volume penalties are excessive in either case, it is interesting to note the heavy and light plastic utensils require more weight and volume in the latter case. This was caused by the addition of disposable cleaning wipes required for one day reusable utensils. If the utensils are to be reused, metal utensils need not be replaced each day. Figure 17 shows that the weight and volume resulting from reusable metal utensils with disposable cleaning wipes: the cleaning wipes alone generate excessive weight and volume penalties to justify the need for a dishwasher. These penalties could possibly be reduced by washing and reusing the cleaning wipes; however, this procedure would only introduce another step into the cleaning operation. The tradeoff for a dishwasher is favorable since this expense is encountered only once, not on every resupply.

Since one of the basic requirements is to provide a familiar dining environment, it would be impractical to incorporate new and unconventional silverware. The combination or multi-purpose items require the developing of unconventional dining habits and were eliminated from consideration.

Selected Concept

Conventionally designed eating utensils are recommended. Because they will be used in an electrostatic restraint field, the handles of the utensils will be flat and provide a wide contact surface between the utensil and the table top. The items will be fabricated from silver since it provides a self-sanitizing surface due to the aligo-dynamic effect.

EATING UTENSIL DATA

Basis: 100 Men, Three Meals/Day, 90 Day Resupply

	Each Set		Total Resupply	
	Wt. (grams)	Vol. (in^3)	Wt. (lbs)	Vol. (ft^3)
Disposable Each Meal				
Light Metal	100	12	5950	188
Heavy Plastic	13	8	770	125
Light Plastic	7	7.5	418	117
Disposable Each Day*				
Light Metal	130	18	2580	94.0
Heavy Plastic	43	14	858	73.0
Light Plastic	37	13.5	730	71.4
Reusable*				
Light Metal	30	6	595	31

*Includes Cleaning Wipe for Each Meal

Figure 17

Beverage Containers

Interfaces. Beverage container interfaces are listed in Figure 27.

Requirements

Adequate capacity to contain specified quantites of coffee, tea, milk, or reconstituted fruit drinks (6 ounce capacity).

Capability of receiving, holding, and dispensing liquids in an air-free state.

Operable under conditions of zero gravity.

Provision for drinking without undue manipulation by operator.

Provision for handling by crewman without discomfort.

Capability of disposal without cleanup.

Objectives

Minimum weight.

Minimum volume.

Maximum convenience in operation.

Minimum requirement for cleanup.

Tradeoff Considerations

Candidate concepts included: frozen milk in individual bags equipped with a valve to receive a mouthpiece, individual bags containing dehydrated coffee or tea and equipped with valves for rehydrating and drinking, and the third approach which is the selected concept.

Selected Concept

The selected concept is adaptable to all beverages included in the menu. It consists of a disposable pouch fitted with a valve and mouthpiece and a rigid plastic holder for the pouch. The pouches are to be stored flat with all air evacuated. For milk or fruit juice, the pouches will be empty. For coffee or tea, they will contain the proper amount of the dehydrated concentrate. Sugar and dehydrated cream can be

BEVERAGE CONTAINER INTERFACES

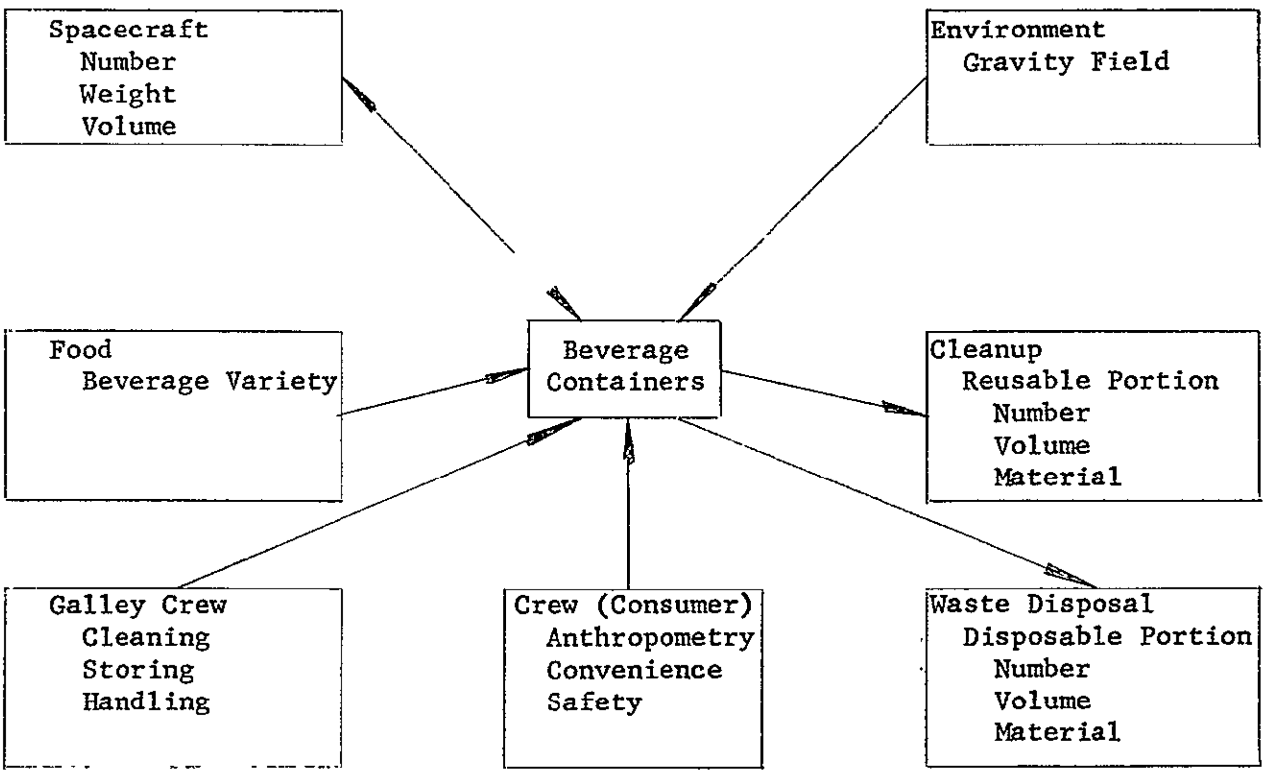


Figure 27

included in coffee or tea pouches properly marked to identify contents. The valve will permit entry of the dispensing probe of the centrifuge to fill the pouch with milk or fruit juice. For coffee or tea, the hot water dispensing probe will be inserted through the valve.

The pouch will expand or contract during filling and drinking to provide the required variable displacement for excluding air. For convenience in handling, the plastic holder is fitted with a removable cap secured by a quarter-turn lug locking arrangement. After removing the cap from the holder body, it will be simple to insert the pouch neck and secure it by engaging the the slip ring of the expanding retainer. This procedure will be reversed in removing the used pouch for disposal in the waste compactor.

Comfort in use is assured by the contour of the plastic holder which is cylindrical and will fit the hand like a drinking glass. The holder will also insulate the hand from the hot drink pouch.

Use of the dispenser practically eliminates cleanup as the pouches will be compacted with packaging trash and placed in frozen storage. The drink dispenser is illustrated as Figure 3 on page 53.

Optional Equipment

The recommended drink dispenser is designed for operation at either zero gravity or normal earth gravity. However, during periods of normal gravity, the use of regular cups or glasses may add to the acceptability of the beverages. Optional equipment might include a supply of conventional cups and glasses and an electric hot plate with conventional, tempered glass coffee dispensers. The centrifuges would dispense reconstituted fruit juice or milk into glasses. A bulk supply of concentrated, powdered coffee and tea would permit reconstitution of coffee and tea in the glass dispensers, using the hot plate to keep a supply ready for occasional demands. Optionally, coffee or tea could be prepared by the cup, using concentrate from the bulk supply and hot water from the water heater discharge.

Condiment Dispensers

Interfaces. Condiment dispenser interfaces are listed in Figure 28

Requirements

Operable within the environmental conditions.

Anthropometrically compatible.

Objectives

Minimum weight.

Minimum volume.

Maximum convenience in use.

Minimum cleanup operations.

Minimum maintenance (e.g., refilling).

Candidate Concepts

Five concepts for the condiment dispensers were investigated as described below:

(1) Pressurized container A reusable metal dispensing container similar in design and operation to an aerosol can with the following exceptions. The liquid to be dispensed is contained in a flexible package within the container rather than suspended in the gas. By attaching the flexible package to the dispensing valve, actuating the valve results in a positive displacement of the dispensed liquid by the entrapped gas. A valve installed on the body of the rigid container will allow the pressure to be vented, permitting the dispenser's screw top to be opened and an expended flexible package replaced. The dispenser can then be repressurized and is ready for use. This system is applicable to liquid or paste accompanyments only; salt, pepper, and other normally dry constituents would be required to be suspended in a solution. Dispenser refills would be individually packaged.

CONDIMENT DISPENSER INTERFACES

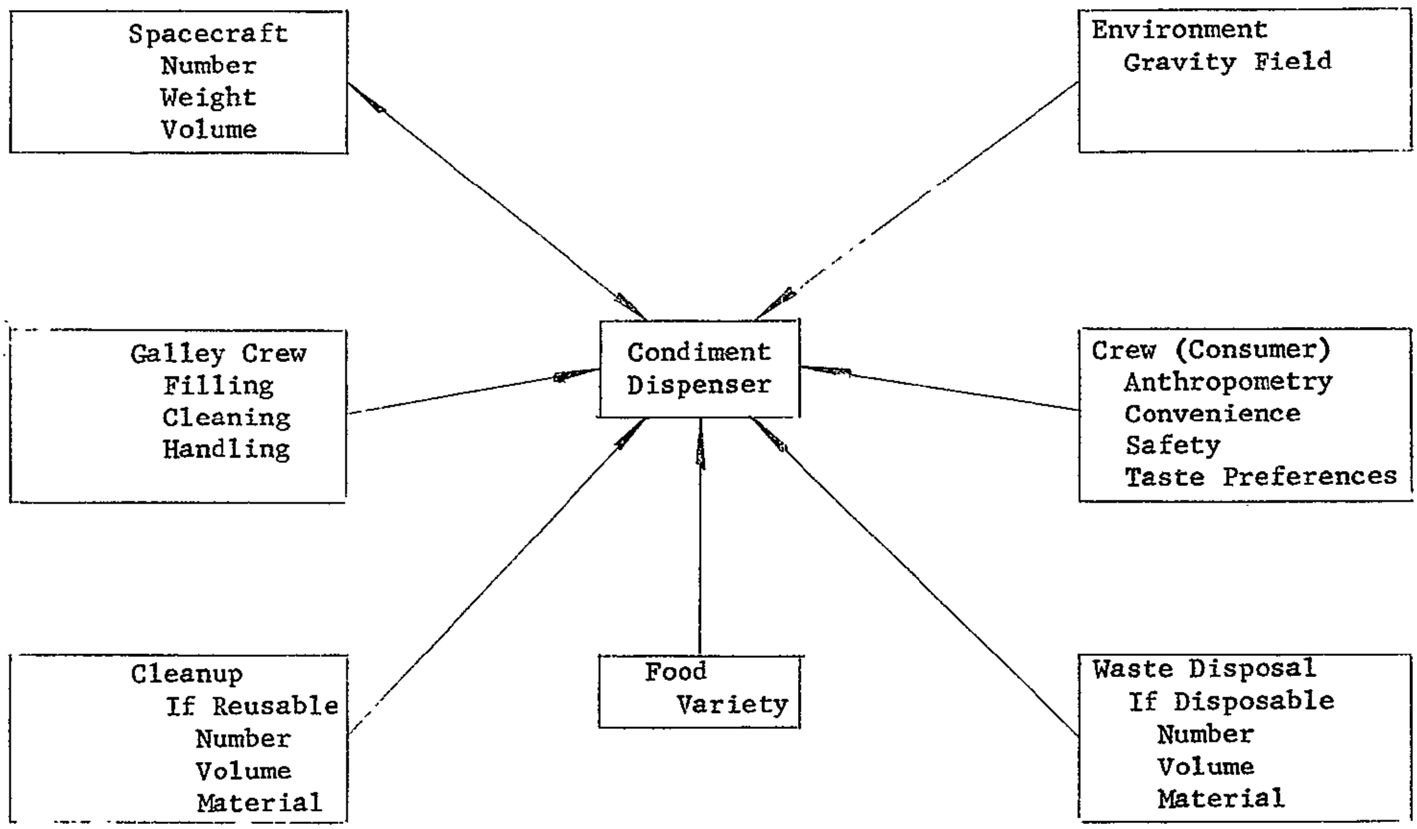


Figure 28

(2) Flexible squeeze bottle - A flexible plastic package with a flip-open spout or dispensing nozzle. Placing the spout in an upright position will open the dispensing valve; pressure, applied on the sides of the container by squeezing, would force the contents out of the nozzle to the desired location. Releasing the pressure on the package will allow the memory of the package to backfill through the nozzle, cleaning the dispensing flow channel. After the bottle has assumed its original position, the dispensing valve will be closed by placing the spout in a horizontal position. This bottle would be bulk filled from a central supply and is applicable to both liquid and dry condiments. The liquid refill operation would take advantage of the package's memory by reversing the normal dispensing technique and backfilling with the liquid to be dispensed. The geometry of the dispenser will insure separation of liquid and gas within the container by locating the liquid at the spout end since this is the area of minimum surface tension. Dispensing of the dry condiments is accomplished due to the existing velocity of the air and the impinging of the condiments. in the desired location.

(3) Squeeze tube - A flexible package which will dispense a paste product when squeezed. This design is similar to the conventional packages used to dispense toothpaste. The packages are not reusable and require dry products to be modified into a paste solution.

(4) Conventional shakers - Since all dining will be in an electrostatic restraint field, conventional dispensers can be used if appropriate caps are designed to fit over the containers when not in use or while being transported between refill area and the dining area. Dispensing

will be caused by momentum and acceleration forces generated by shaking the container over the food. Once leaving the container, the dispensed product will have the additional force of the restraint field acting upon it. This concept is not applicable to liquid or paste condiments.

(5) Individual packets - Individual packets of accompanyment items are familiar in the conventional forms and additional exploration is not required.

Trade-Off Analysis

Two trade-off analyses were conducted, one for normally liquid accompaniments and one for normally dry products. All factors were considered equally and weighted on a 1 to 4 scale, 4 being excellent and 1 poor. The trade off parameters are self-explanatory.

Trade Off Parameter	Liquid Pressurized Container	Condiment Flex. Squeeze Bottle	Configuration Squeeze Tube	Individual Packets
Total Weight (Dispenser & Refill Pouch)	2	4	2	1
Total Volume (Dispenser & Refill Pouch)	2	4	2	1
Cleanup	4	4	4	3
Refill Maintenance	3	3	4	4
Dispenser Metering	2	4	4	4
Aesthestically Acceptable	2	4	2	4
TOTALS	15	23	18	17

Normally Dry Condiment Configuration

Trade Off Parameter	Pressurized Container*	Flex. Squeeze Bottle	Squeeze Tube*	Conventional Shakers	Individual Packets
Total Weight (Dispenser & Refill Pouch)	2	4	2	4	1
Total Volume (Dispenser & Refill Pouch)	2	4	2	4	1
Cleanup	4	4	4	4	3
Refill Maintenance	3	3	4	3	4
Aethestically Acceptable	2	4	2	4	4
Dispenser Metering	1	2	1	4	4
TOTALS	14	21	15	23	17

*Paste or particular solution required

Selected Concept

The selected concept for liquid or paste condiment dispensing is the flexible squeeze bottle while dry condiment dispensing will incorporate conventional shakers. Typical designs for each of these dispensers are shown in Figure 7.

Since the dispensers will be used in an electrostatic restraint field, they will be fabricated with anodized aluminum wherever possible. The shaker design shown presents a frontal area to the emitter greater than the base diameter. This will increase the force exerted on the dispenser since the force is preportional to the area normal to the ion stream. Additional features incorporated into the concept include a spring cap with retaining clasp, level indicator operable in zero gravity since momentum and inertia forces will position the contents as it is set down after use, and an embossed letter to indicate the contents. The liquid dispenser will be of color coded plastic to indicate contents with a circular metallic base. The diameter of the base section will be larger than the plastic squeeze section to increase the restraining force.

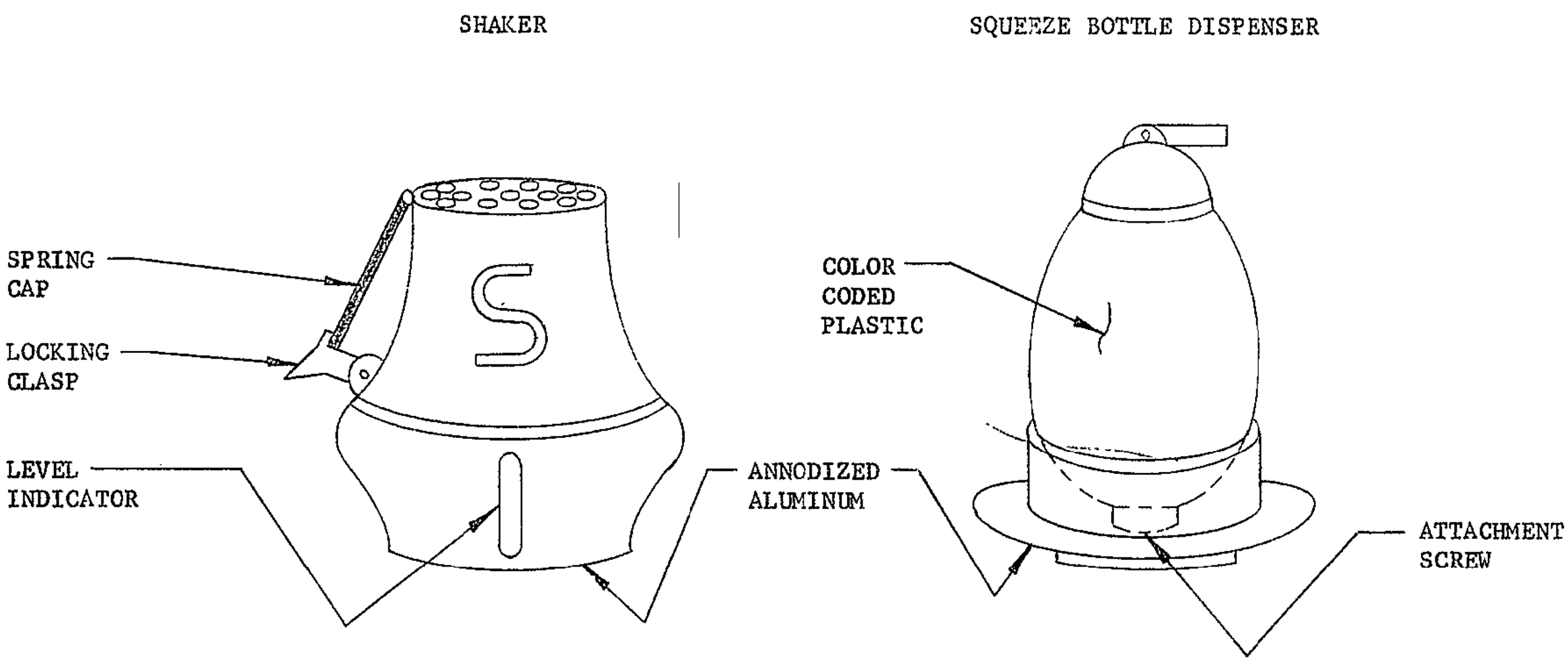

SHAKER
SQUEEZE BOTTLE DISPENSER
SPRING CAP
LOCKING CLASP
LEVEL INDICATOR
ANNODIZED ALUMINUM
COLOR CODED PLASTIC
ATTACHMENT SCREW

FIGURE 7

Galley Arrangement and Accessory Equipment

Floor Plan

Floor Plan Interfaces. Interfaces influencing galley arrangement are listed in Figure No. 24.

Requirements.

Adequate storage space for all food required for maximum duty tour (90-day resupply).

Adequate floor space to accomodate all equipment.

Provide proper orientation of equipment to facilitate stowage, preparation, cleanup, and waste disposal.

Adequate working space around and between equipment units.

Provision of proper aisleways to insure smooth traffic flow.

Adequate and comfortable dining area.

Provision for an accessible display area for food.

Objectives.

Maximum efficiency in use of available space.

Maximum convenience in stowage and retrieval of food and supply items.

Optimum traffic flow.

Maximum economy of time in preparation, serving, consuming, cleanup, and waste disposal

Trade-Off Considerations. The restrictions imposed on the floor plan by the volume of food required for 90-day resupply preclude trade-off of several systems. Certain equipment items of fixed dimension are required to prepare this food, serve it, and handle resultant cleanup and waste disposal. After initial trade-off of the various components and establishment

GALLEY ARRANGEMENT INTERFACES

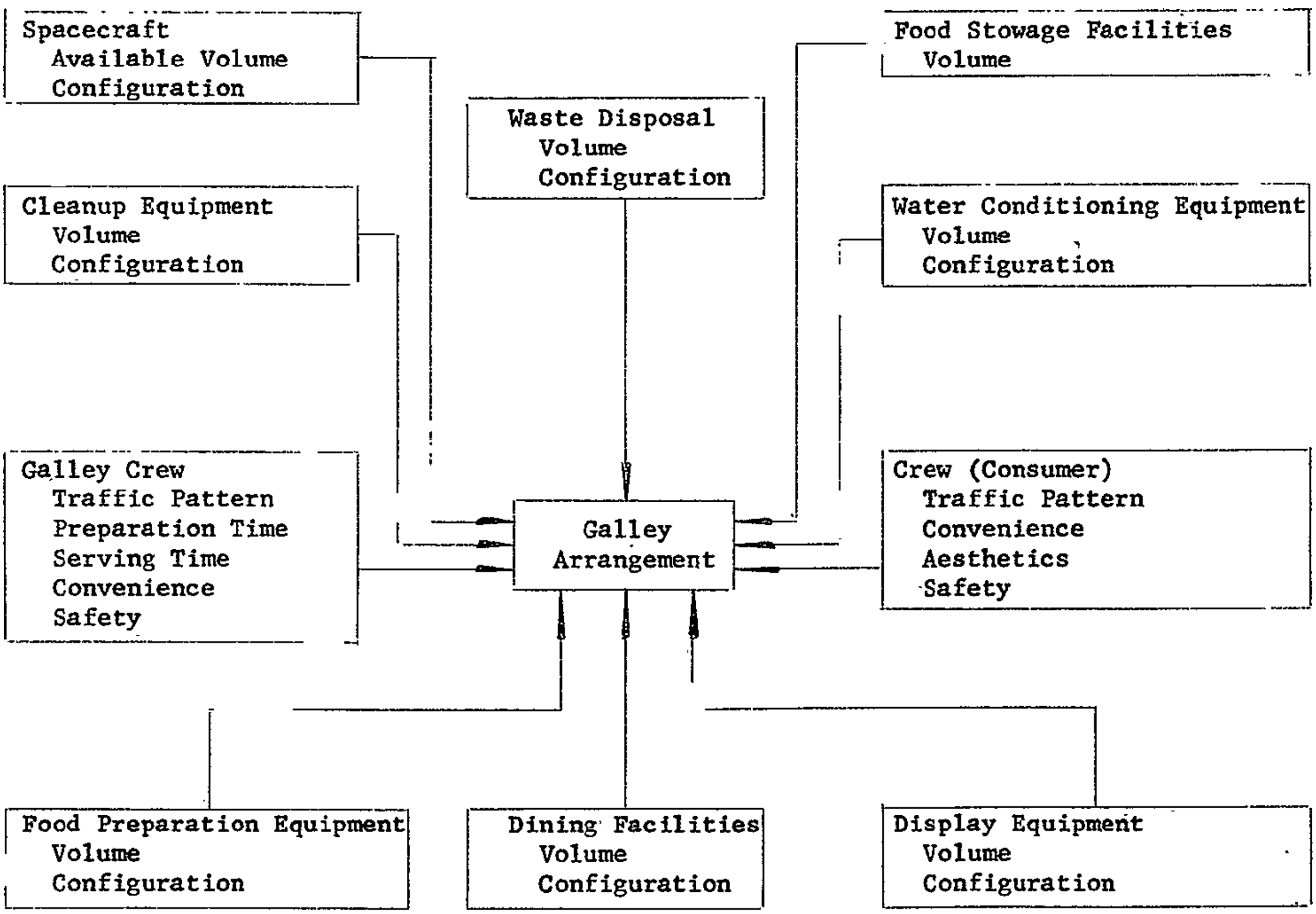


Figure 24

Trade-Off Considerations. (continued)

of the unit dimensions, the problem became one of arriving at the best placement of the components to insure maximum efficiency in system functioning.

Selected Concept. The final floor plan arrangement as represented on Figure 8 presents the plan suggested for 90-day resupply. No compromise was accepted in galley design since the system would not be acceptable if galley personnel were restricted in their work or if the equipment items were limited in capacity.

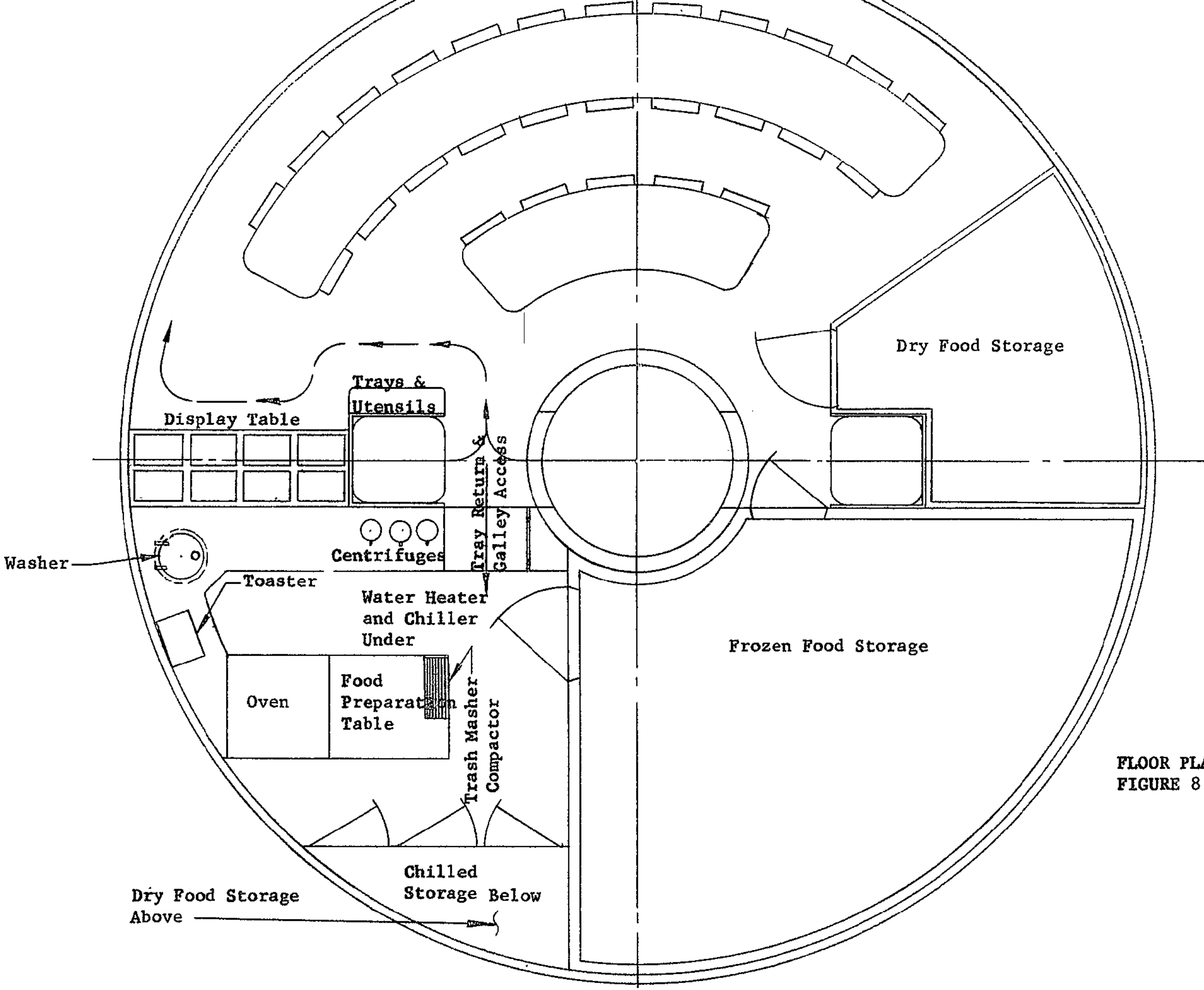
However, the bulk storage of this large food supply, which occupies more than 34% of the volume of the galley level, does compromise the provisions of dining area and lounge facilities. Seating as illustrated provides for only 27 persons without undue crowding. Lounge facilities are entirely eliminated in this plan. The impact of shortening the resupply intervals to 30 or 14 days is graphically illustrated in the Appendix, where it may be seen that for a 30-day resupply period, the food volume would be reduced to 11.48% of available volume in the galley level, or reduced to only 5.32% for 14-day resupply.

Attention must also be directed to the fact that food storage areas delineated on this floor plan are the bare minimum based on the assumption that food packages will be stacked floor to ceiling without provision of shelving, aisleways, etc.

Discussion of Floor Plan. Study of Floor Plan, Figure 8, will point out the many advantages of the recommended system.

Note that frozen and dry foods can be moved into their respective stowage areas directly from the elevator shaft in a matter of two or three steps.

Frozen food can be removed from the freezer through a door opening directly



FLOOR PLAN
FIGURE 8

Discussion of Floor Plan. (continued)

into the galley and immediately adjacent to the food preparation counter.

Approximately a five-day supply of dry food is stored directly in the galley adjacent to the preparation counter. The bulk stowage of dry food is farther from the galley, but the ready store in the galley need be replenished only once in five days. Dry foods will move directly from the food preparation table to the display table.

A suggested galley crew might include four men, at least during the meal preparation and serving period. If the four galley attendants are stationed as follows, there will be minimum need for them to move from their assigned stations. Three crewmen will be grouped, facing the three open sides of the preparation table. One will move chilled and dry foods from stowage to the preparation table. His movements can be limited to an about-face and one step in either direction. The second crewman will move frozen food from stowage to the preparation table. The third man will hand frozen food to the fourth man who will be stationed to load and attend the warming oven.

During the serving period, the No. 4 man will move heated food from the oven to the display table. The No. 3 man will turn to face the display table, where he will assist in filling the display trays or attend to dispensing of coffee, tea or milk from the centrifuges. During the breakfast period he may attend the toaster, producing toast or heated rolls on demand.

The No. 2 man will assist No. 3 in preparing and serving beverages or moving chilled foods to the display.

The No. 1 crewman may be released from duty during servingbut should be on standby to assist in cleanup.

Discussion of Floor Plan. (continued)

During cleanup, the food trays loaded with food packages will be returned to the galley at the entry gate counter. The No. 3 and No. 2 crewmen will receive the trays, empty their contents into the trash compactor, and slide the trays on the serving counter to the No. 4 crewman for wiping, if required, stacking, and eventual return to the tray storage rack.

The oven is of sufficient capacity to prepare 100 meals. Depending on the eventual assignment and definition of meal periods, it may be advisable to fill the oven, heat 100 meals, serve 50, then hold 50 at serving temperature. Some food will always be held at serving temperature to accomodate needs of crewmen assigned to duties demanding service at times other than regular meal periods.

Water Conditioning

Equipment Interfaces. Water heater and chiller interfaces are listed in Figure No. 19.

Water Heater

Requirements

Capability to provide five gallons of water at 170° F in 30 minutes (or to boost water to 170° F if hot water is otherwise available).

Operable under zero gravity conditions.

Maintain performance for required life.

Present no external surface accessible to crewman at temperature over 150° F.

Dispense hot water into beverage containers.

WATER CONDITIONING EQUIPMENT INTERFACES

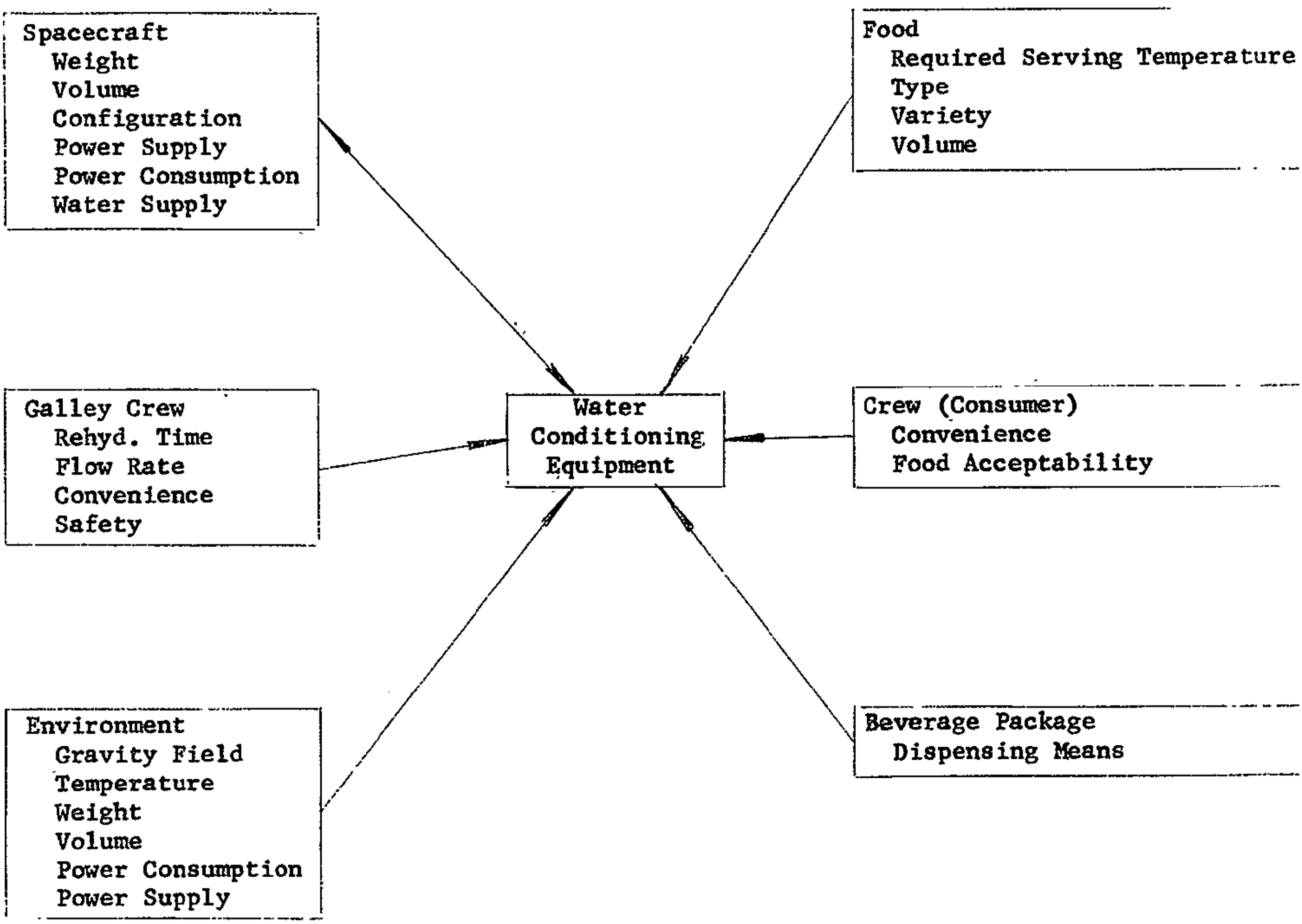


Figure 19

Water Conditioning (continued)

Objectives

Maximum efficiency

Minimum Power consumption

Minimum weight

Minimum volume

Minimum requirement for, and maximum ease of, maintenance and repair.

Maximum convenience in operation

Minimum hazards to safety of operator

Trade-Off Considerations

Only one concept has been considered for the zero gravity water heater. This choice was made on the basis of experiment and design efforts previously conducted at the Whirlpool laboratories.

Selected Concept

The water heater will be of tubular aluminum construction, using wrap-around electrical resistance heaters. Interior baffles will be perforated in such manner to provide turbulence in the flowing water. The water enters the bottom and exits the top of the heater. Entire unit will be thermally insulated and thermostatically controlled. The weight is estimated as 14-lbs. The electrical requirement is estimated at 850 watts.

Water Conditioning (continued)

Water Chiller

Requirements

Capability to provide two gallons of water at 35° F in 30 minutes at zero gravity.

No accessible surfaces at temperature lower than 40° F.

Dispense cold water into reconstitution centrifuge or directly in drink dispenser.

All other requirements are the same as the water heater.

Objectives

All objectives are the same as the water heater.

Trade-Off Considerations

Only one concept was considered since refrigeration is available from a central source provided by the food refrigeration system.

Selected Concept

The water chiller will be of the same cylindrical aluminum configuration as the water heater, using internal baffling designed to introduce turbulent mixing. The entire cylinder will be encased in a water jacket. The refrigerant used for heat transfer in the food freezer will be circulated through the water jacket. Heat will be transferred through the baffles and cylindrical body to the transfer fluid. Thermostatic control and a throttling valve will control flow of the transfer fluid to effect specified water temperature.

Facility/Utensil Cleanup

Interfaces

Facility/utensil interfaces are listed in Figure No. 20.

Requirements

Capability to wash knives, forks, spoons and wiping towels (the only items requiring washing).

Operable under conditions of zero gravity.

Maintain performance for required life under specified environmental conditions.

Prevent excursion of water to spacecraft atmosphere under conditions of zero gravity.

Objectives

Maximum efficiency

Minimum power consumption

Maximum degree of automaticity

Minimum weight

Minimum volume

Maximum convenience in operation

Minimum requirement for, and maximum ease of, maintenance and repair

Minimum hazards to safety of operator

Trade-Off Considerations

The recommended feeding system concept based on predominant use of frozen, fully prepared foods minimizes the need for dishwashing. Since the prepared foods are heated in and consumed from the original packages, a disposable aluminum foil dish, there will be no dishes or cooking utensils to wash. Silver knives, forks and spoons must be washed, and this can be accomplished in a centrifugal washer, as illustrated on Figure 9.

FACILITY/UTENSIL CLEANUP INTERFACES

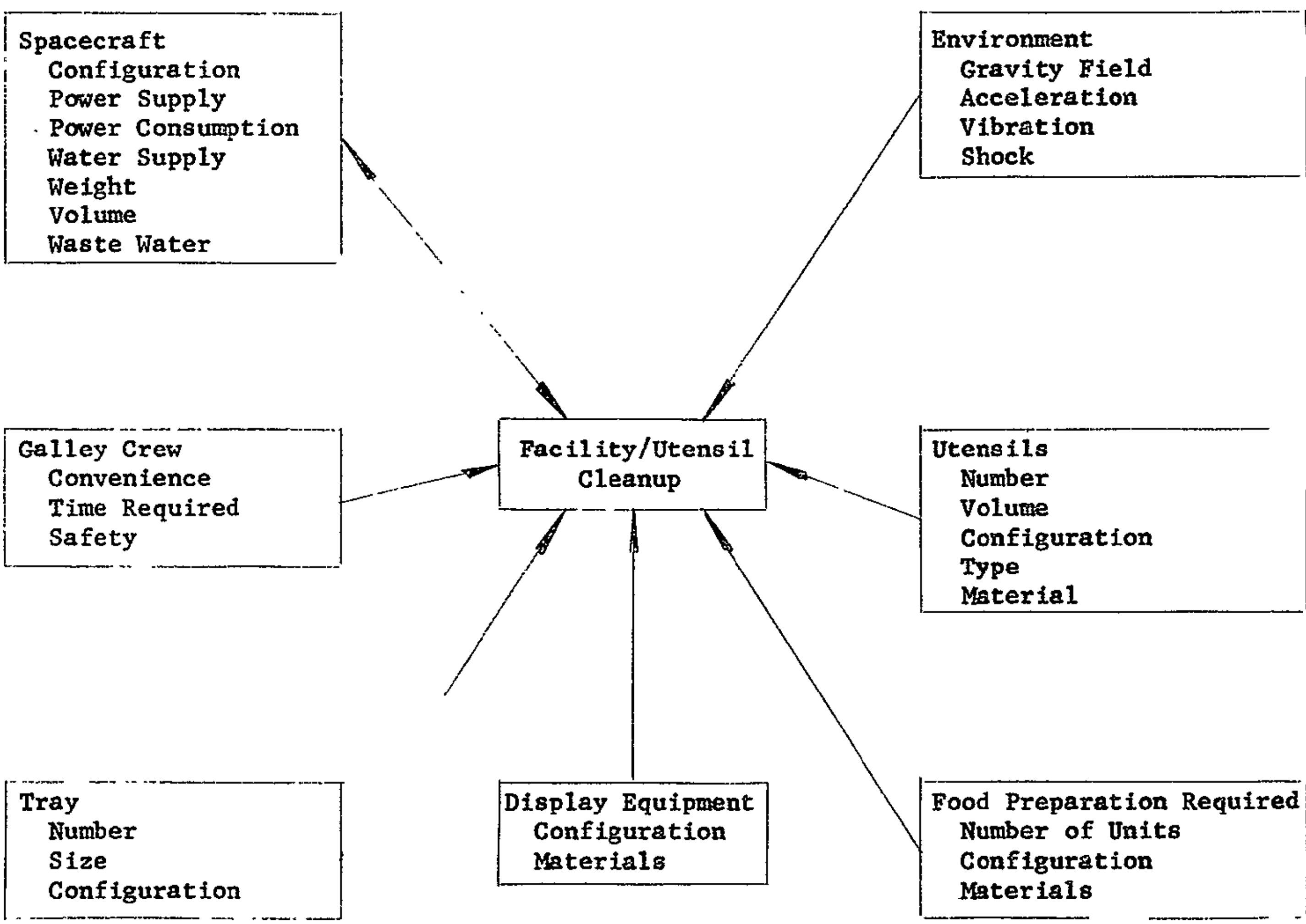
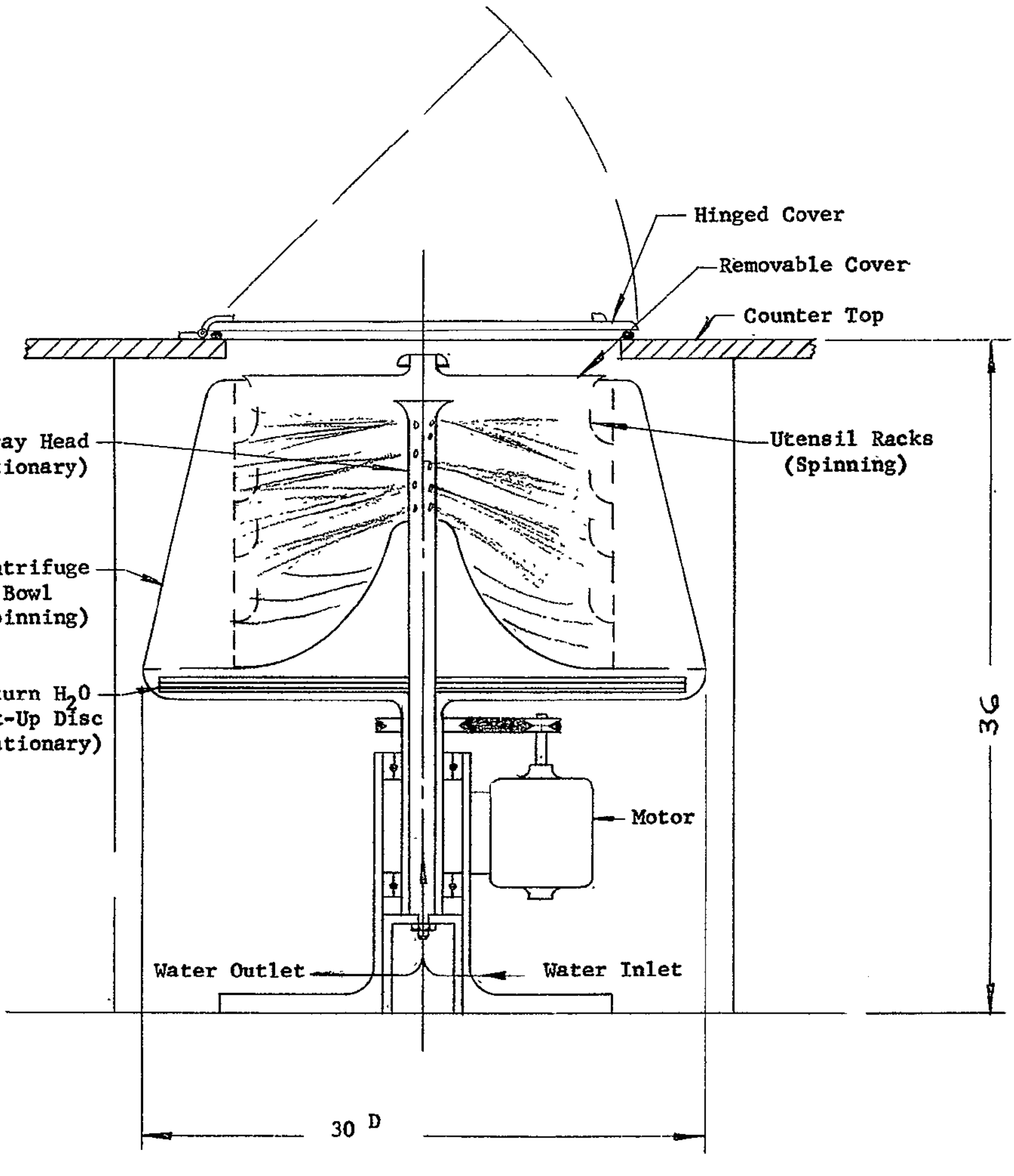


Figure 20



CENTRIFUGAL WASHER

Figure 9

Facility/Utensil Cleanup

Selected Concept

The centrifuge will be housed under the serving counter and will be loaded from the counter top. Access is through a hinged cover which can be raised to insert the eating utensils. Knives, forks and spoons will be held in pockets on a cylindrical screen which will revolve with the drum of the centrifuge. It is assumed that there will be a central system providing warm water under pressure. Water from this source will be piped into a stationary center post in the centrifuge. The post will be perforated to direct multiple streams radially toward the cutlery and onward to the periphery of the centrifuge bowl. The water will be collected in an air-free state under centrifugal pressure and picked up by a stationary disc at the bottom of the bowl. This disc will be provided with one or more radial passages which will carry the water, under centrifugal pressure, back to the stationary hub, and down a vertical passage connecting with the waste water reclamation system.

After washing, with the water shut off, the utensils can be allowed to spin until they are dry.

This machine can be automated so that the utensil washing and drying is accomplished automatically, the cycle being initiated by closing the lid.

The meal trays are used only to carry food in containers and should not require much cleaning. However, it is recommended that they be wiped with a damp towel when necessary. Trade-off indicates that the towels should be permanent; throw-away towels would introduce unessential weight and volume in the system. The centrifuge can also be used to wash these wiping towels. The towels can be positioned on the wire racks so that water will be forced through the material by centrifugal force. Spinning them after washing will dry them sufficiently for succeeding wipings.

Waste Disposal

Interfaces

Waste disposal interfaces are listed in Figure No. 21.

Requirements

Adequate capacity to compact waste material from at least one meal to minimum size.

Operable under conditions of zero gravity.

Maintain performance for required life span.

Objectives

Maximum efficiency

Maximum degree of automaticity

Minimum power consumption

Minimum weight

Minimum volume

Maximum convenience

Minimum requirement for, and maximum ease of, maintenance and repair.

Minimum hazards to safety of operator

Trade-Off Considerations

With the proposed system, using frozen, prepared food predominantly, the waste will consist mostly of packaging material. This practically dictates only one approach to waste disposal since the aluminum foil dishes are not prime material for oxidation. The approach is simply to collect waste at a central point to avoid confusion in the galley, compact the waste into smallest possible dimension, package it for convenient handling, and store it in the freezer, replacing consumed frozen food stores. Eventually, these waste packages will be sent back to earth on returning shuttle craft. If overboard dump is considered a more attractive disposal method, the compact waste packages should interface well with such a system.

WASTE DISPOSAL INTERFACES

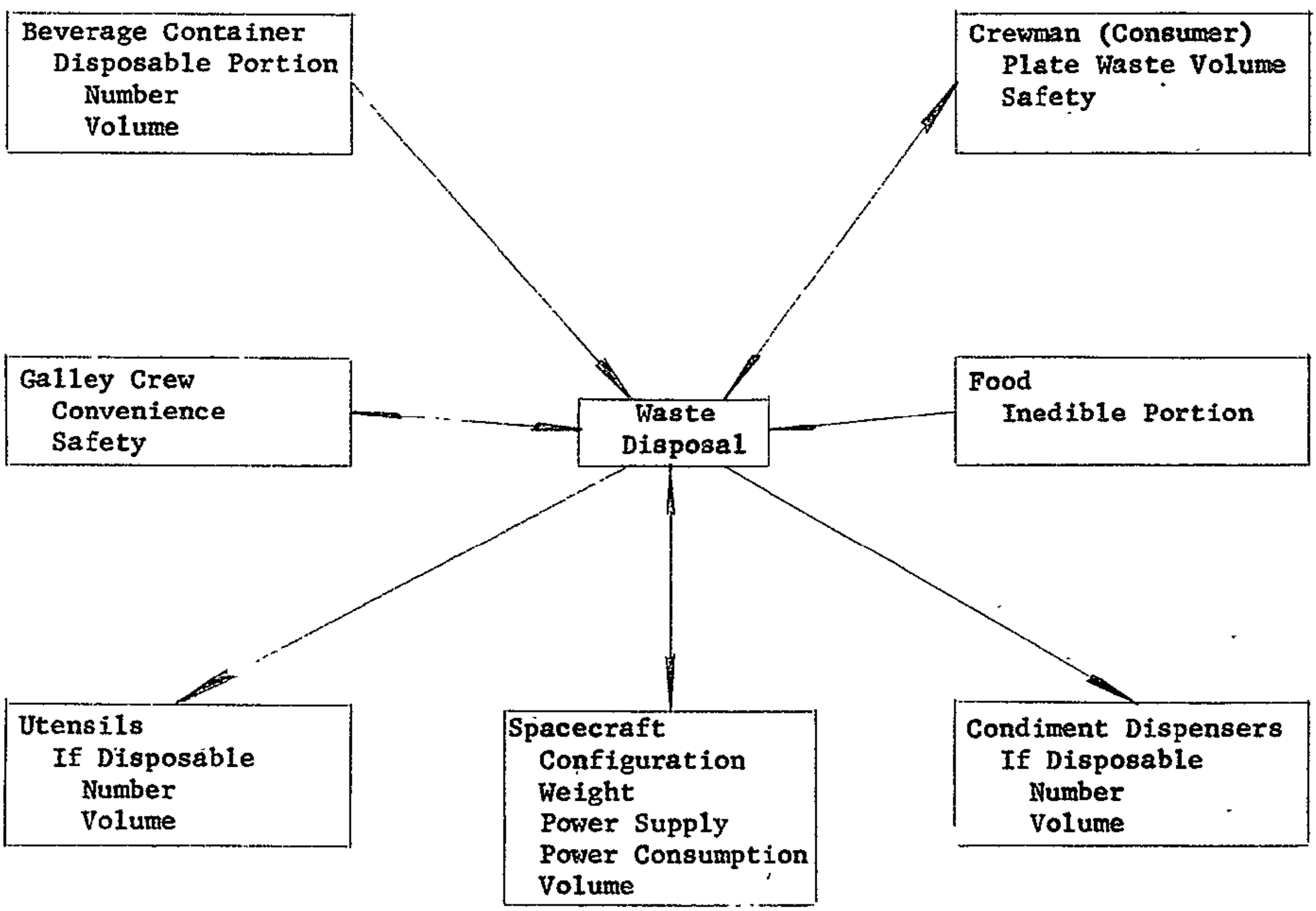


Figure 21

Waste Disposal (continued)

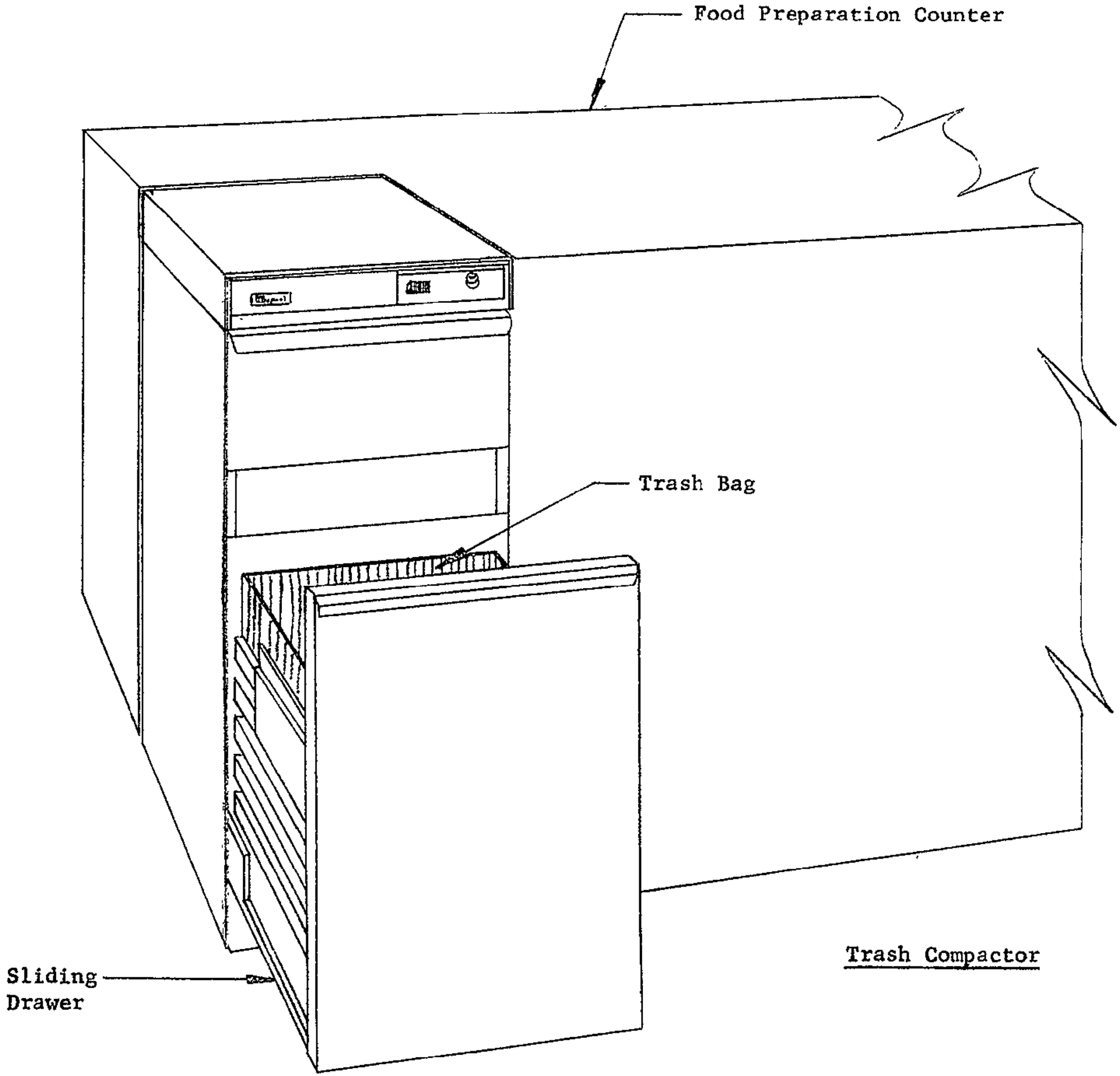
Selected Concept

The Whirlpool "Trash Masher" is now a commercially available trash compactor which will automatically compact 20 to 30 pounds of waste materials into a package approximately 9" x 16" x 18". This device can easily be modified for spacecraft application and is shown located at one corner of the food preparation counter. See Figure 10.

At this location it is convenient to the tray return point. The compactor is of counter-top height. In operation a front drawer is pulled open and trash placed in a heavy craft bag with polyethylene liner in the drawer. Closing the drawer automatically actuates a ram which compacts the trash.

It is estimated that the waste generated by serving 300 meals per day in this feeding system can be contained in three of the packages compacted by this device. This would entail removing one compacted package after each meal period and placing it in the freezer in space vacated by the consumed food.

Eventually, these compact packages are transferred to the resupply shuttlecraft and returned to earth. The estimated volume of this waste is 270 packages 9" x 16" x 18", or 405 $ft.^3$.



Trash Compactor

FIGURE 10

Restraint Under Zero Gravity Conditions

Interfaces

Restraint system interfaces are listed in Figure No. 22.

Requirements

Capability to restrain food portions and implements during preparation, serving, consumption and cleanup.

Maintain integrity for required life under specified environmental conditions.

Capability of application at all areas where required.

Operable with provided power supply.

Objectives

Minimum weight

Minimum volume

Minimum power consumption

Maximum convenience in use

Minimum requirement for manual manipulation

Minimum hazards to safety of operator.

Candidate Concepts

While some consideration was given to mechanical restraints, straps, clips, etc., this concept was abandoned because of its complexity and the requirement for much manual effort on the part of galley personnel and crewmen at time of consumption.

An alternate concept considered was the laminar air flow system. In using this approach, it would be necessary to provide perforated tables, hoods over the tables, and blowers to direct a considerable air flow above and

RESTRAINT SYSTEM INTERFACES

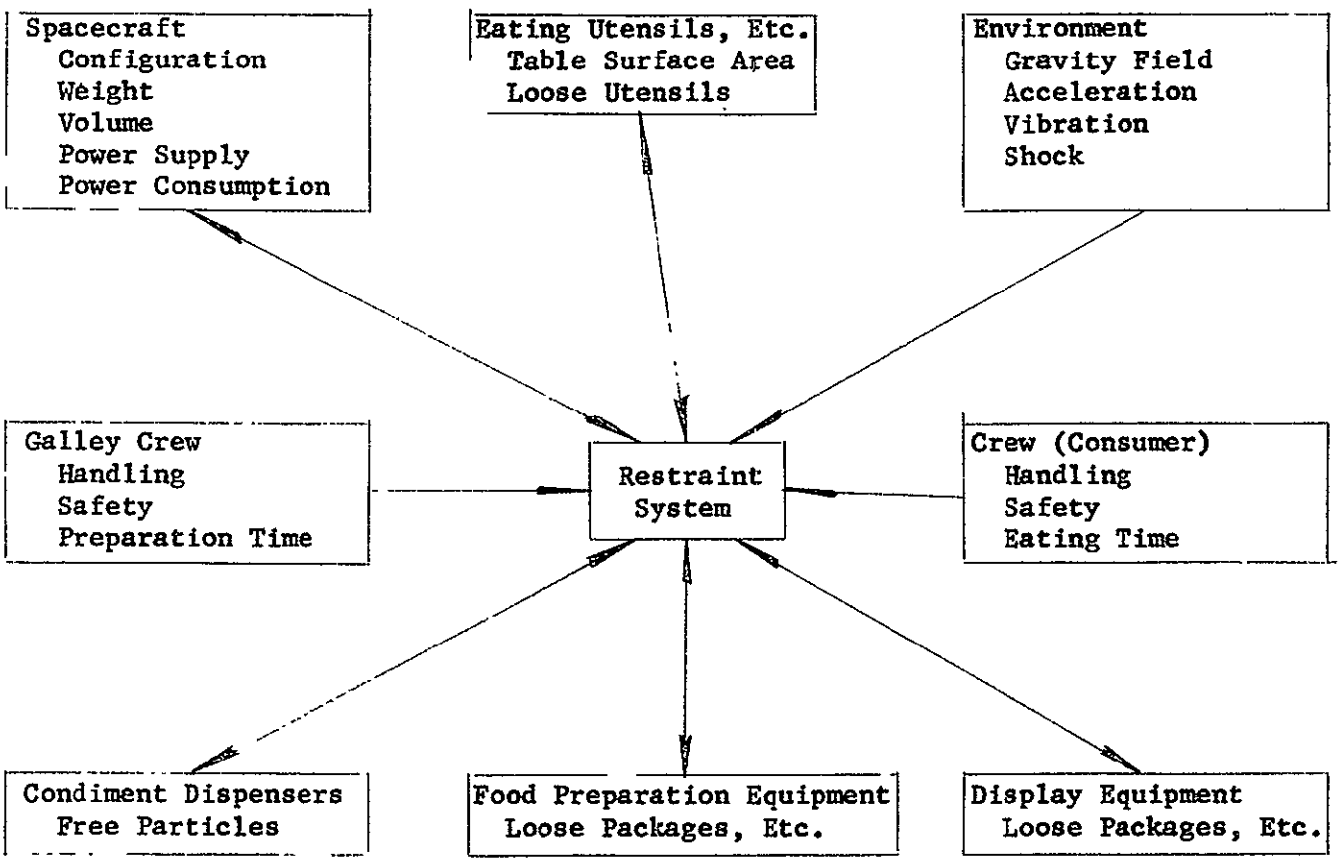


Figure 22

Candidate Concepts (continued)

downward through the table top. It appears to be quite obvious that this concept would be difficult to apply, would require a considerable amount of power, and would have definite weight and volume disadvantages. The third concept involves the use of electrostatic restraint fields.

Trade-Off Analysis

Under zero gravity conditions food handling during preparation, serving, consumption, and cleanup presents special problems. Food packages removed from the freezer are stacked on the preparation table for insertion into the oven. After heating, these packages are removed from the oven and placed in the heated pans on the display table. During these operations it is most desirable that the packages be restrained from floating by an automatic system, particularly because of the large number of packages to be handled. The galley personnel should be free to perform their duties without having to fasten clamps or other manual restraint devices. Again, during consumption, if the entire function of eating is to be a happy occasion, crewmen should be freed of any need to even think about restraining the food or implements on the dining table.

During cleanup and waste disposal operations, the efficiency of the galley attendants will be high if an automatic system handles the restraint problems without the need for manipulation of manual restraints. For reasons of automaticity, simplicity of operation, and conservation of weight, power, and volume, the electrostatic restraint field is the recommended concept.

Selected Concept

The provision of electrostatic restraint fields in the areas of food preparation food consumption, and cleanup automatically provides a degree of restraint that will allow the crewmen to perform their duties or consume their food under conditions approaching familiar earth gravity conditions.

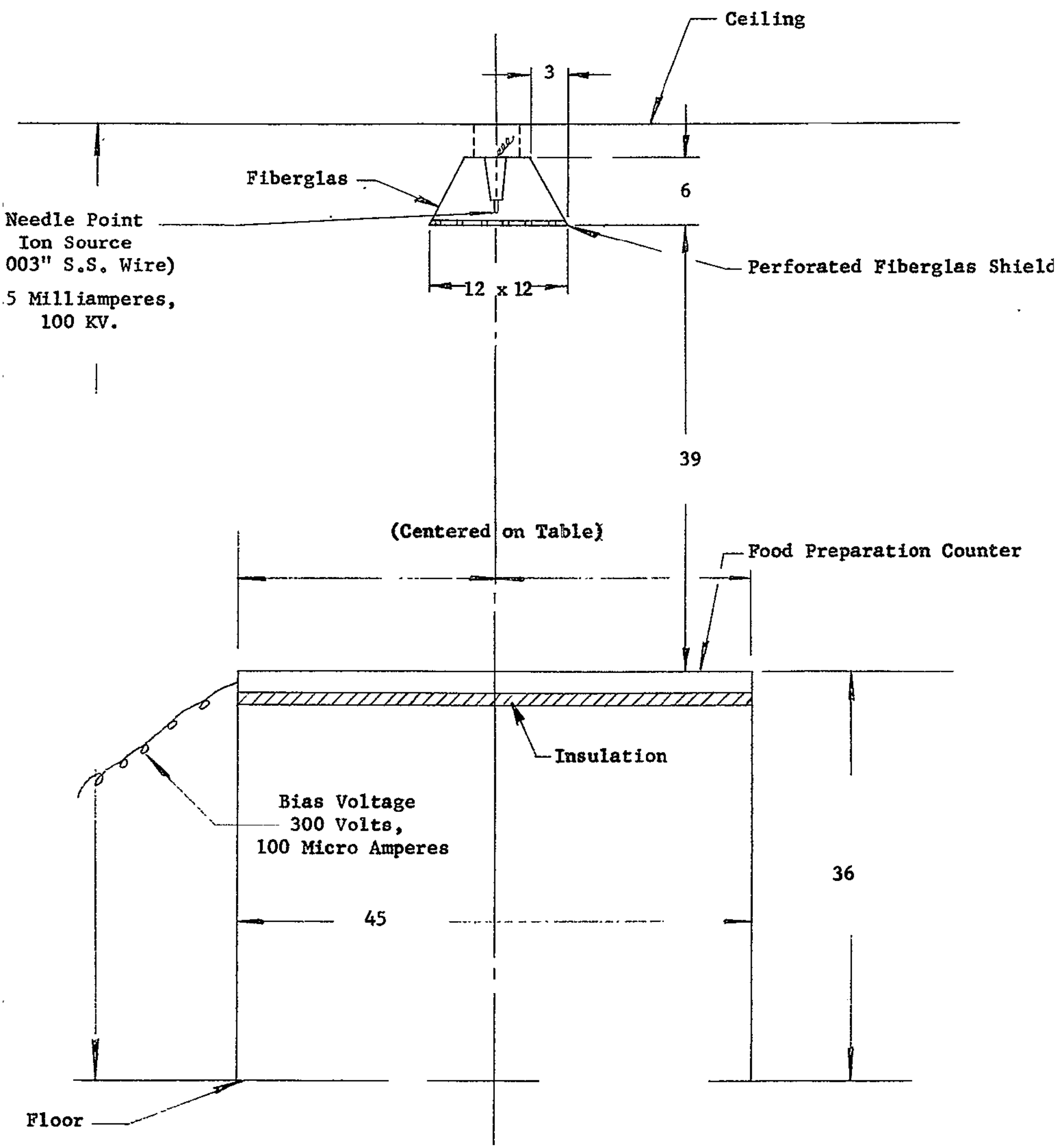
Selected Concept (continued)

The state-of-the-art on development of electrostatic restraint fields does not provide sufficient data to permit complete design of the equipment at this time. Mathematically predicted forces in the fields have been somewhat higher than the forces actually observed by experiment. However, the experimental results have been good enough to encourage further development and to indicate that this is a good, workable concept. (See report on NASA Contract NAS8-21385.) It will be recommended that further development be performed in this area.

General design of the recommended system has been established, and weight and power requirements have been estimated. It is recommended that restraint fields be provided over the food preparation table, the entire display and serving area, and over the dining tables.

The ion-beam projector over the food preparation table will be a single point source as illustrated on Figure No. 11. The shield must be non-conducting, and fiberglass is the recommended material. This projector should be elevated approximately 42-in. above the table top where it will not interfere with the vision of the food preparation people. The table top must be either porcelain enamelled steel or anodized aluminum. The table top must be insulated from the spacecraft structure and provided with a bias voltage of 300 volts at 100 milliamperes. The attractive force between this negatively charged table top and objects resting thereon, particularly conductive objects, is stronger than the ion-beam field between the tabletop and the projector.

Objects floating in the ion-beam field are encouraged to move toward the tabletop by the number of ions which they collect. The number of ions collected is proportional to the surface area of the object. Once placed on the tabletop, the object is restrained there by the ions collected by the object and discharged to the tabletop. Factors influencing this discharge, and consequently, the adhesive force, are the conductivity of the object, the area



ELECTROSTATIC RESTRAINT EQUIPMENT

Figure 11

Selected Concept (continued)

of surface in contact with the table, and the degree of intimate contact which is determined by the finish of the mating surfaces. Consequently, utensils and implements will be designed with these factors in mind.

The display table and adjacent serving counter is a large area which requires a restraint field. This will be supplied by a continuous wire 72-in. long. The wire will be .003" stainless steel, housed in a fiberglas, trough-shaped shield. This projector should be mounted 42-in. over the countertops.

The projectors over the dining tables will also be single .003 stainless steel wires in fiberglas troughs. These units will be 10-ft. long and will be provided as needed when table sizes and locations are finalized.

The power requirement for the ion beam transmitters is estimated as a total of 8 milliamperes for the dining tables, one milliampere at the display area, and .25 milliamperes at the food preparation table. The recommended voltage is 100 KV. Total power is then 925 watts.

The beam projectors are constructed with a perforated plastic shield below the ion source to eliminate possible shock hazard. Experimental results have shown that it is impossible to produce a noticeable shock by touching any object in the electrostatic field.

It is assumed that the principal power supply in the spacecraft will be 28 V.D.C. The power source for the electrostatic fields will be a solid-state oscillator and a Tesla coil producing 100 KV from the 28 VDC source. There will also be a bias voltage output of 300 volts at 1.0 milliamperes. This power supply could be housed in a box no larger than 12" x 12" x 24", and its weight should not exceed 75-lbs. Since the ion projectors are of very light construction, it can be seen that this concept will be quite light and economical of power.

EMERGENCY FEEDING SYSTEM

The emergency feeding system shall supply 30-days of food for 100 men and must comply with the following requirements:

a. Shall be calorically and nutritionally satisfactory for crew performance.

b. Shall not require electrical power for storage, heating.

c. Shall not require hot water for rehydration.

d. System shall be c ible of being used in the weightless conditions.

e. Fōod shall be stɛ : for a period of several years.

Whirlpool suggests that t emergency feeding system be similar to the Apollo feeding system. I naking this suggestion, Whirlpool assumes that water and water dispensir levices will be supplied in convenient locations for use with the food and r drinking. The Apollo system can supply the caloric requirements and probably most of the vitamin and mineral requirements. If additional vitamins and minerals are required, they can simply be supplied by supplementing the diet with pills or capsules.

The proposed emergency feeding system does not require electrical power for heating the food nor for maintaining a given storage temperature. However, it is important to point out that the dehydrated foods used in the Apollo feeding system may be degraded if subjected to temperatures above 100° F for extended periods of time. Although the rehydratable foods do not require hot water for rehydration, the acceptability of some of the foods would be enhanced by use of hot water.

The Apollo feeding system has demonstrated its capability of being used in weightless conditions. Therefore, Whirlpool recommends that Apollo-type packages be used. These packages not only provide acceptable eating methods, but also provide a good oxygen-moisture barrier for protection of the food.

Emergency Feeding System

This high degree of protection from oxygen and moisture will be needed to maintain the food in an acceptable condition for the required periods of several years. The Apollo dehydrated foods should be stable for a period of several years; however, storage studies of this length have not been conducted to determine the degree of stability.

The weight of the system will be approximately 2 lbs. per man per day, or 6,000 lbs. for 100 men for 30 days. The volume would be 200 cu. in. per man per day, or 347.2 cu. ft. for 100 men for 30 days. This volume is the minimum volume required if all the food was as efficiently packed as it is in the Apollo missions. The weight and volume figures given include the skin cleaning towel, chewing gum and germicidal tablets. However, these items only represent a small proportion of the total weight and volume, and the elimination of them would not greatly change the total weight or volume of the system.

RECOMMENDATIONS

Thawing

Upon request from NASA-MSC to develop a table of thawing times for various frozen foods, a rapid literature search was made to determine if there was much information published. The results of this search indicate that there is very little published information on the types of foods that may be used in a 100-man space station. The search indicated that the limited data in the literature are given for thawing at different conditions of temperature, humidity, air movement, etc. These data are meaningless for comparison of thawing rate of various foods unless they could be converted into one set of thawing conditions. Unfortunately, this cannot be done with any degree of accuracy.

The only way to obtain a table of thawing times of food of the type that may be used in the 100-man space station is to conduct laboratory tests. It is recommended that these times be determined and documented by a laboratory program.

Heating

There are no reliable data for heating time requirements for portion-size frozen foods at zero gravity. While it may be assumed that a forced convection oven will accomplish efficient heat transfer from the heat source to the food container at zero gravity, little is known about the resultant heat transfer in the actual food mass. It has been assumed that, at normal gravity, convection currents are the principal mode of heat transfer within the food. It follows, then, that these convection currents may be non-existent at zero gravity, and the heating time may be adversely affected. It is recommended that heating time for frozen foods be investigated at zero gravity by experiment with a small forced convection oven and also, if possible, by use of a conductive cavity oven.

Recommendations (continued)

Electrostatic Restraint

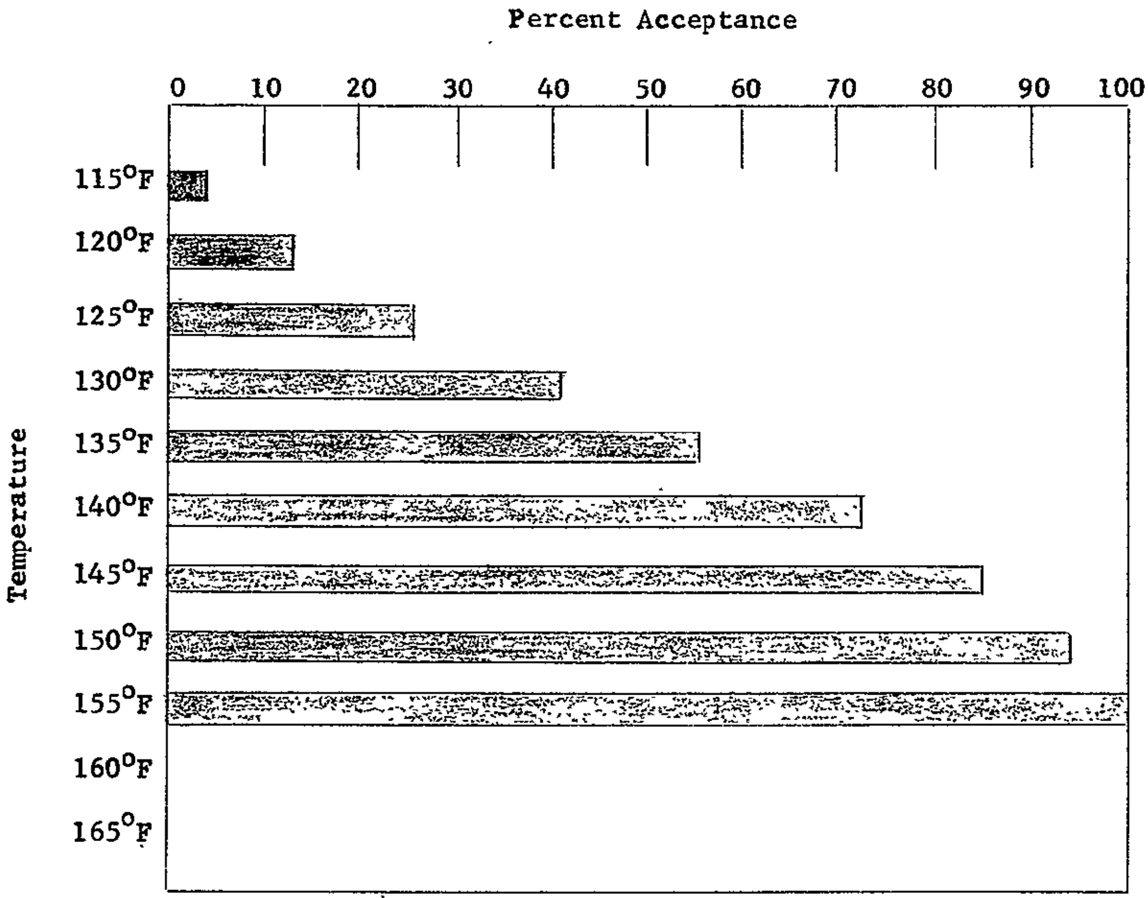
It is recommended that there be further investigation of electrostatic restraint fields, preferably by actual, small-scale experiment at zero gravity.

The present state-of-the-art is embodied in NASA report NAS8-21385, and this report suggests that further research will optimize the design, and that it is possible that far stronger forces may be achieved than those demonstrated thus far.

APPENDIX

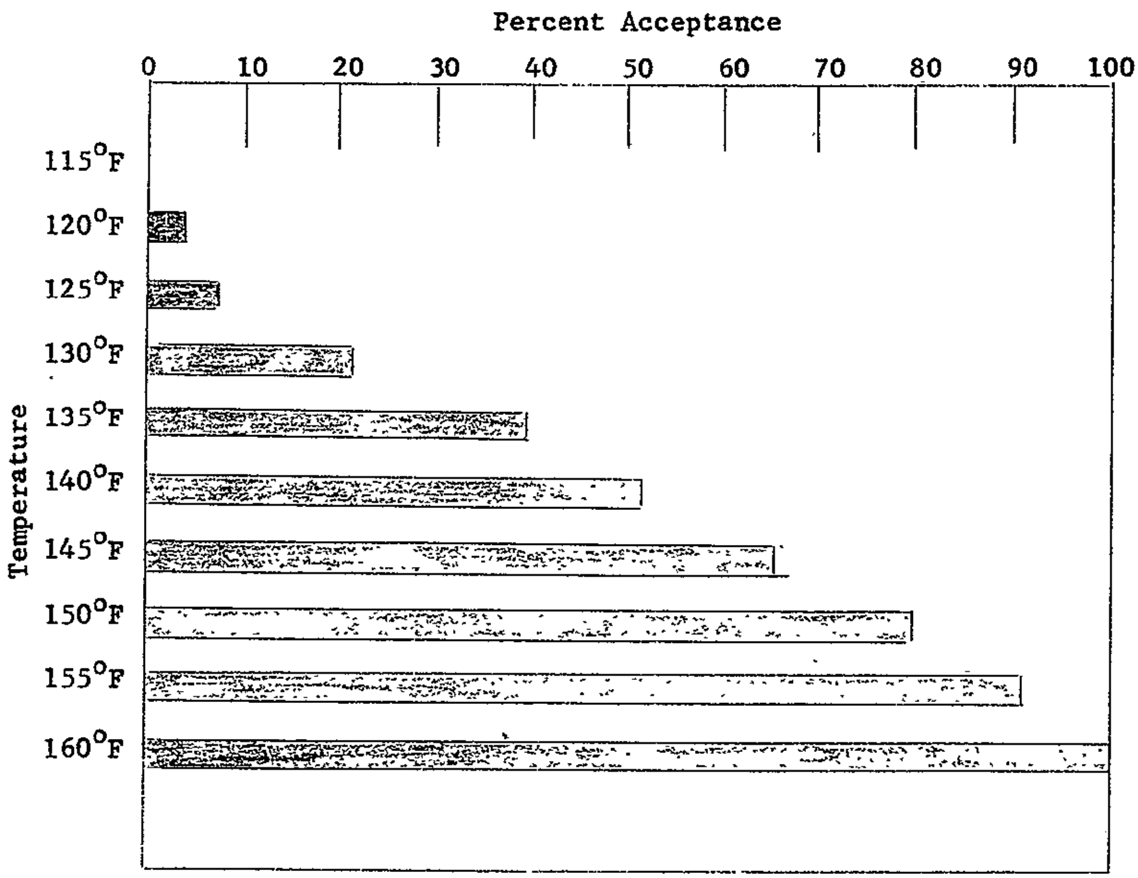
The following section contains charts and graphs presenting food serving temperatures, food volumes vs. resupply time, and factors affecting shuttle craft configuration.

SERVING TEMPERATURE PREFERENCE FOR MEATS



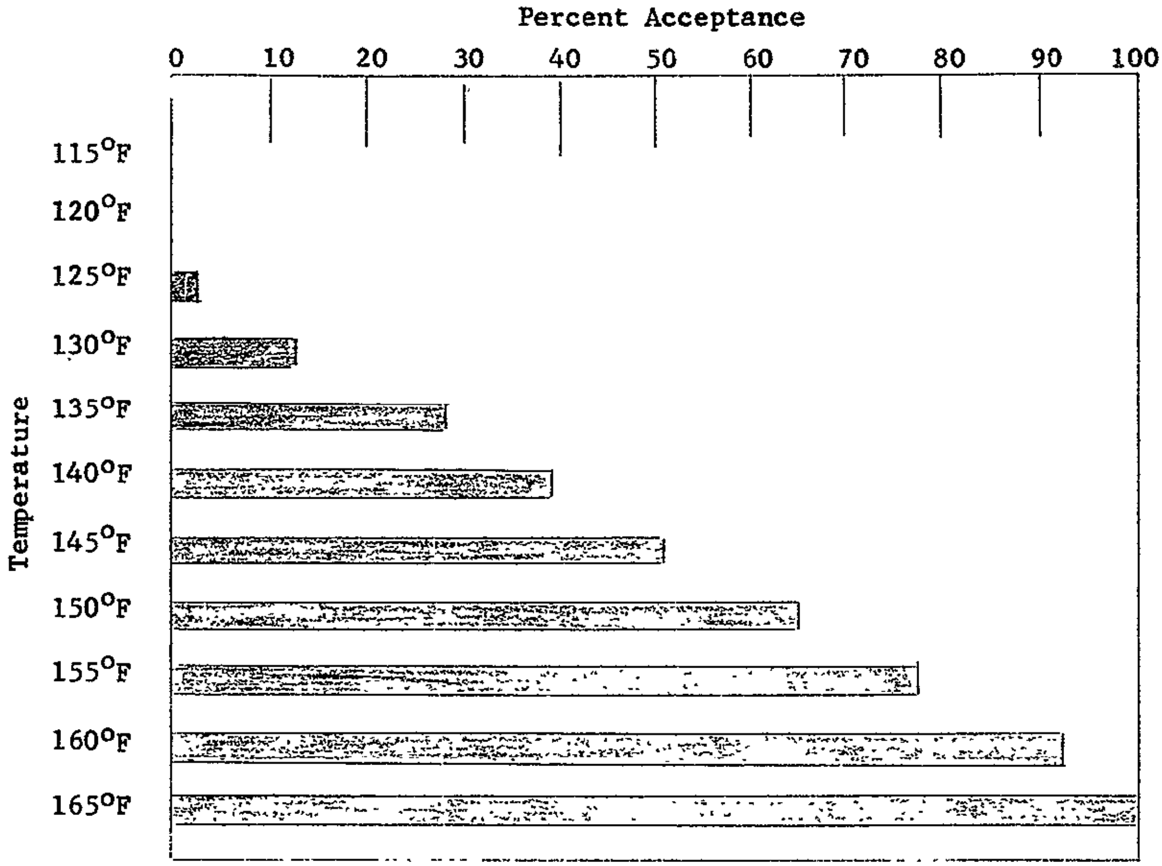
REF: "Food Temperature Preferences".
Journal of The American Dietic Association
Volume 43, September 1963

SERVING TEMPERATURE PREFERENCE FOR POTATOES



REF: "Food Temperature Preferences"
Journal of The American Dietic Association
Volume 43, September 1963

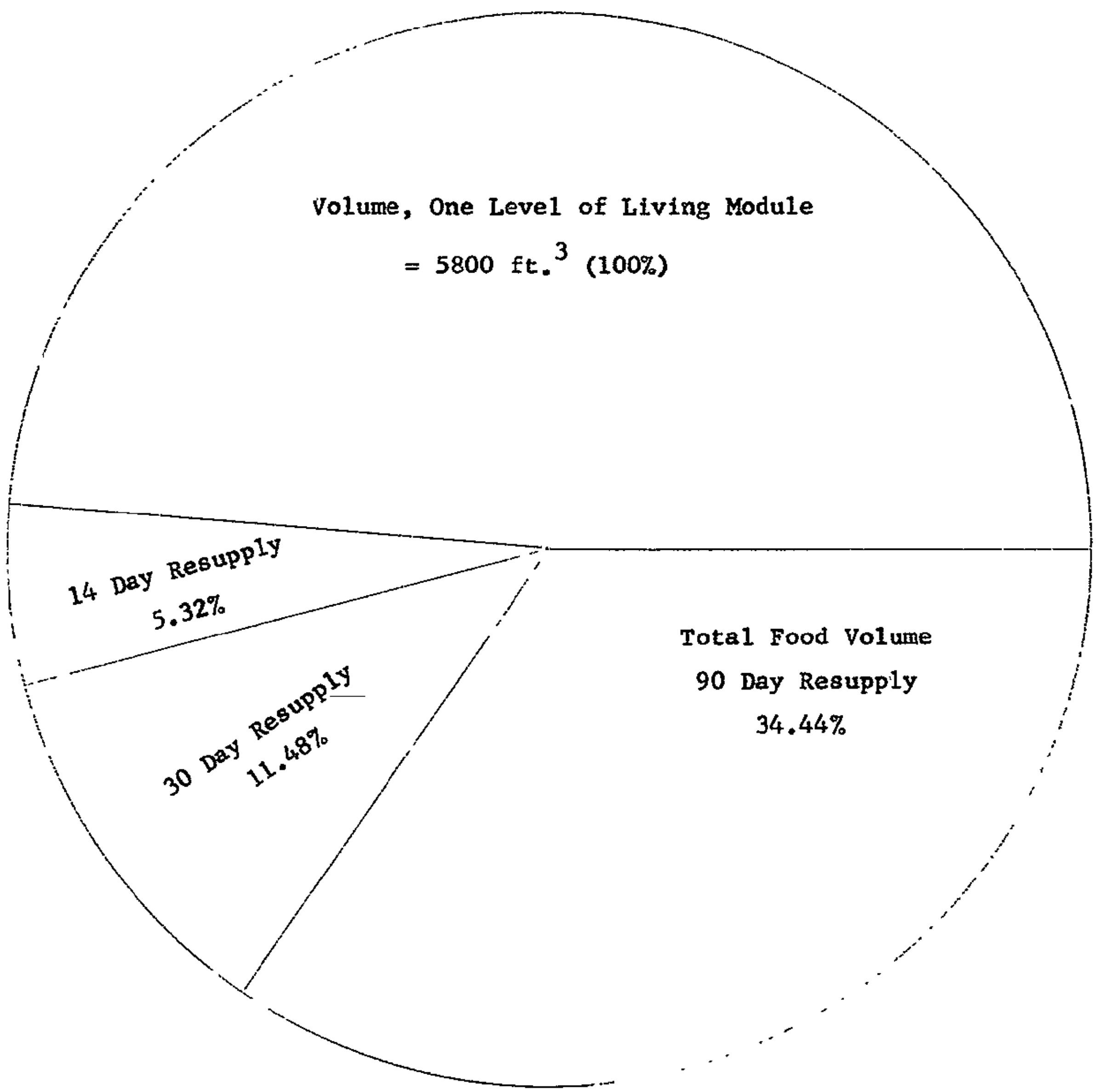
SERVING TEMPERATURE PREFERENCE FOR VEGETABLES



REF: "Food Temperature Preferences"
Journal of The American Dietic Association
Volume 43, September 1963

TOTAL FOOD STORAGE VOLUME VS RESUPPLY TIME

Based on 14 Day, 30 Day, and 90 Day Resupply Intervals
(Food Volume Represented as Percent of Total Cube of One Level
of Spacecraft Living Module)

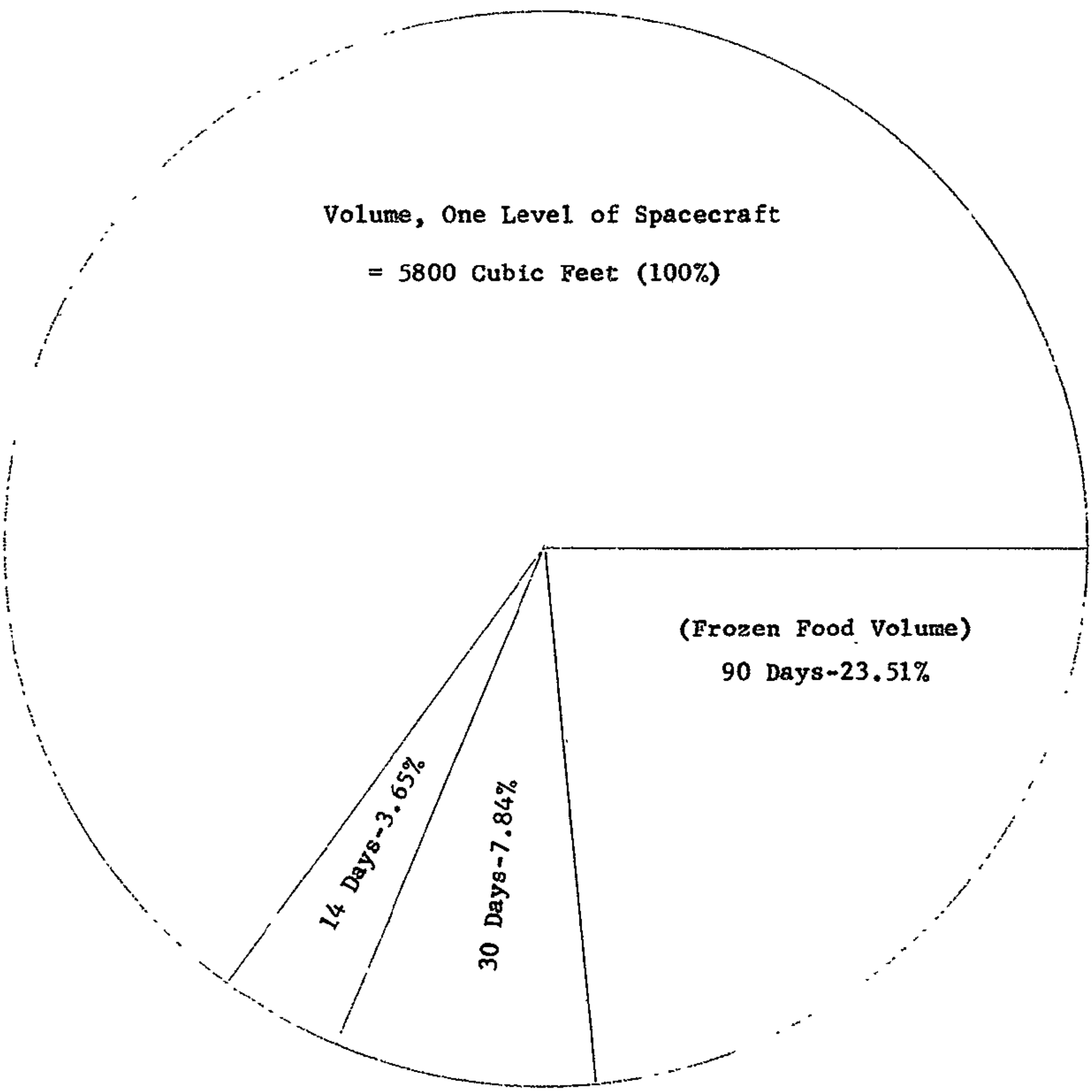


Total Food Volume, 90 Day Resupply - $\frac{1998}{5800}$ ft.^{3} x 100 = 34.45%

Total Food Volume, 30 Day Resupply - $\frac{666}{5800}$ ft.^{3} x 100 = 11.44%

Total Food Volume, 14 Day Resupply - $\frac{309}{5800}$ ft.^{3} x 100 = 5.32%

FROZEN FOOD STORAGE VOLUME VS RESUPPLY TIME



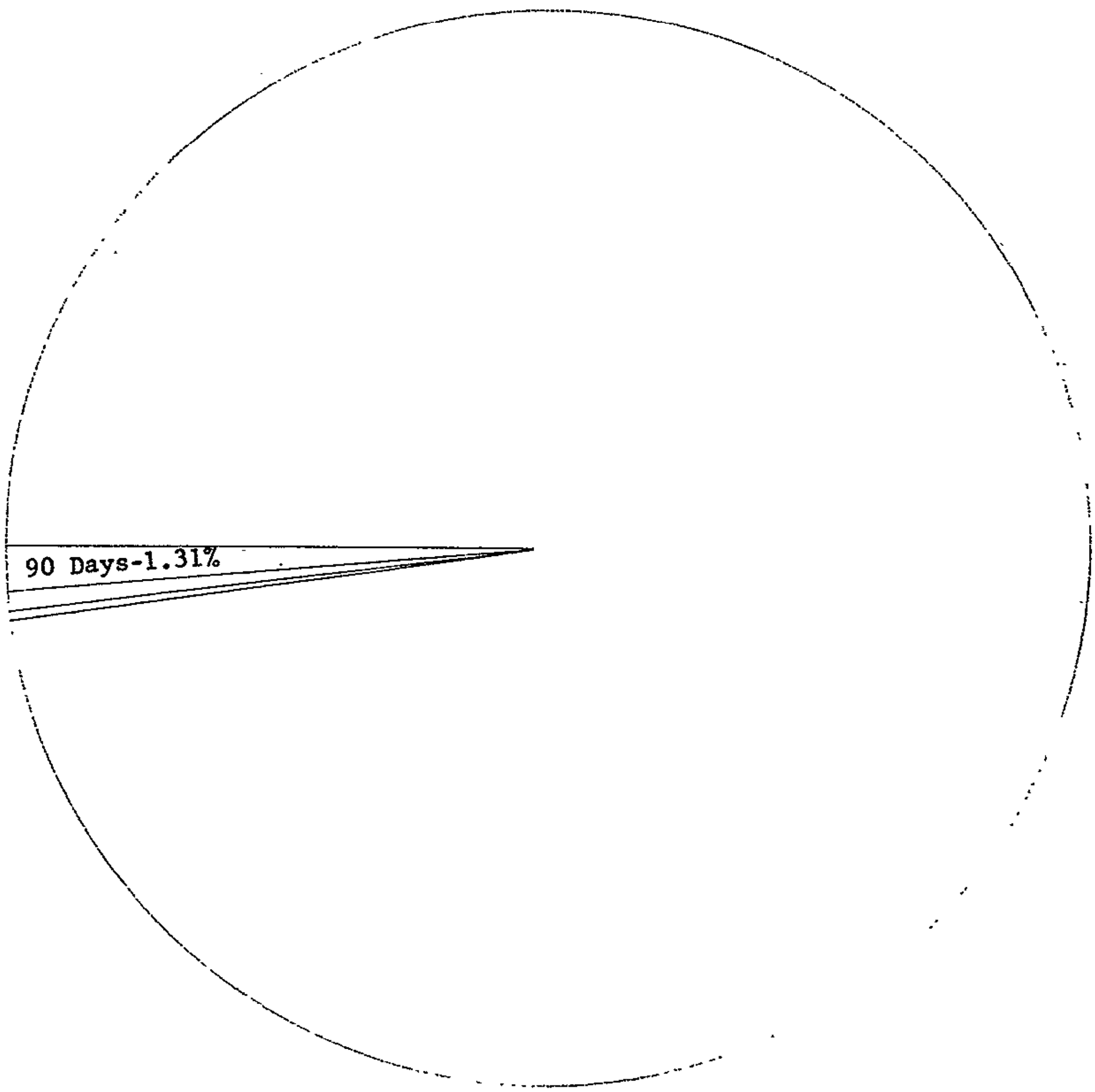
Total Cube = 829 ft.^{2} x 7 ft. = 5800 ft.^{3} (Total Cube, Galley Level)

90 Day Frozen Food = 1364 ft.^{3} = $\frac{1364}{5800}$ x 100 = 23.51%

30 Day Frozen Food = 455 ft.^{3} = $\frac{455}{5800}$ x 100 x 7.84%

14 Day Frozen Food = 212 ft.^{3} = $\frac{212}{5800}$ x 100 x 3.65%

CHILLED FOOD STORAGE VOLUME VS RESUPPLY TIME

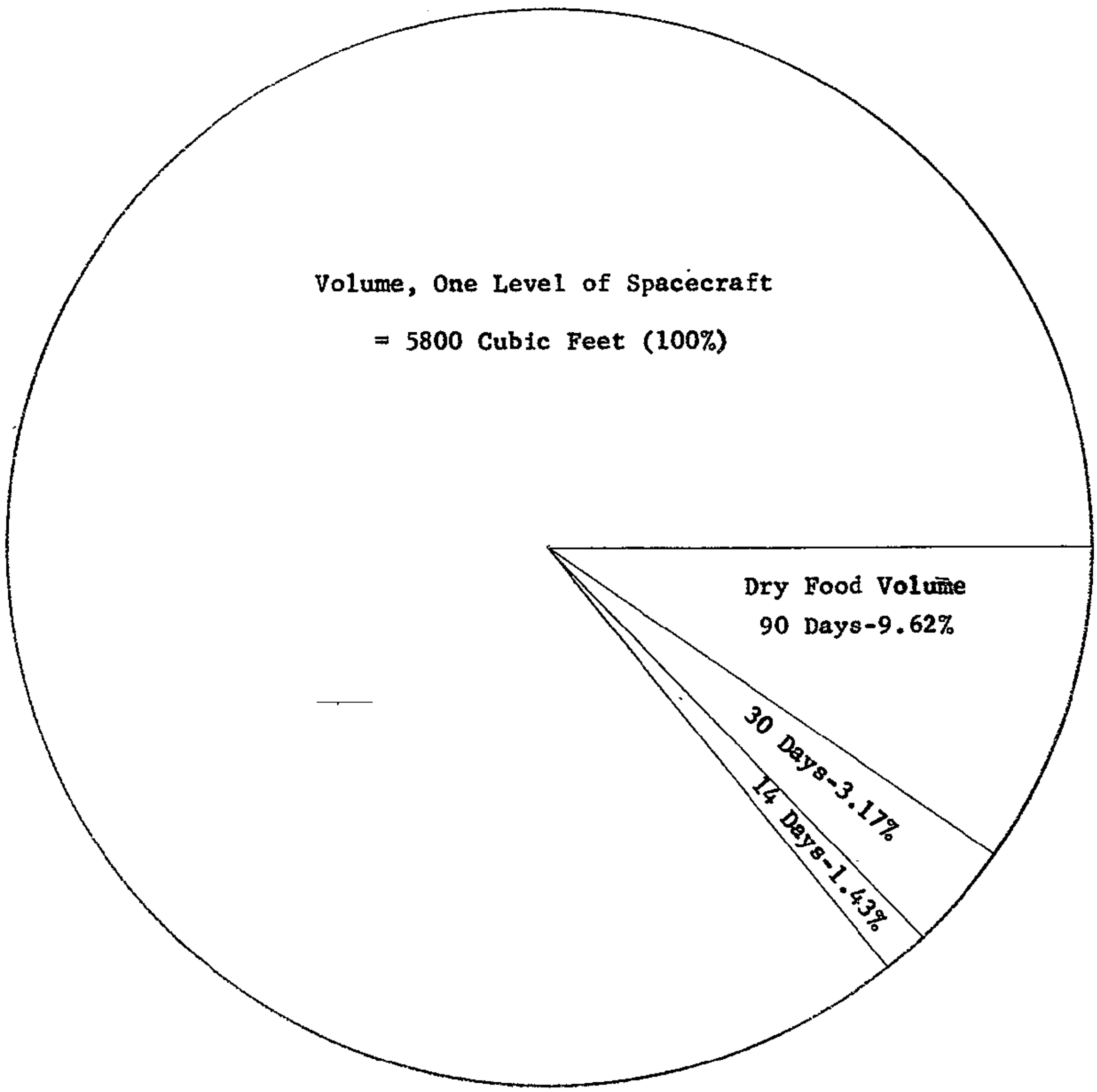


Chilled Food Volume, 90 Day Resupply - $\frac{76 \text{ ft.}^3}{5800} \times 100 = 1.31\%$

Chilled Food Volume, 30 Day Resupply - $\frac{27 \text{ ft.}^3}{5800} \times 100 = .465\%$

Chilled Food Volume, 14 Day Resupply - $\frac{14 \text{ ft.}^3}{5800} \times 100 = .241\%$

DRY FOOD STORAGE VOLUME VS RESUPPLY TIME



90 Days Dry Food = 558 $ft.^3 = \frac{558}{5800} \times 100 = 9.62\%$

30 Days Dry Food = 184 $ft.^3 = \frac{184}{5800} \times 100 = 3.17\%$

14 Days Dry Food - 83 $ft.^3 = \frac{83}{5800} \times 100 = 1.43\%$

INFLUENCE OF FEEDING SYSTEM ON SHUTTLE CRAFT DESIGN

Food Volume for 90-Day Resupply

Frozen Food		1,364 cu. ft.	at $-10^{o}F$
Chilled Food		76 " "	at $35^{o}F \pm 3^{o}F$
Dry Food		558 " "	at $35^{o} - 85^{o}F$
	Total	1,998 " "	

Food Volume for 30-Day Resupply

Frozen Food		455 cu. ft.	at $-10^{o}F$
Chilled Food		27 " "	at $35^{o}F \pm 3^{o}F$
Dry Food		184 " "	at $35^{o} - 85^{o}F$
	Total	666 " "	

Food Volume for 14-Day Resupply

Frozen Food		212 cu. ft.	at $-10^{o}F$
Chilled Food		14 " "	at $35^{o}F \pm 3^{o}F$
Dry Food		83 " "	at $35^{o} - 85^{o}F$
	Total	309 " "	

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Waste Storage Volume (On Return Trip)
(Store at 0^{o} to $-10^{o}F$)

90-Day Resupply

Estimated Volume	270 Packages 9" x 16" x 18"	=	405 cu. ft
Estimated Weight	270 Packages at30-lbs.	=	8,100 lbs.

30-Day Resupply

Estimated Volume	90 Packages 9" x 16" x 18"	=	135 cu. ft.
Estimated Weight	90 Packages at 30-lbs.	=	2,700 lbs.

14-Day Resupply

Estimated Volume	42 Packages 9" x 16" x 18"	=	63 cu. ft.
Estimated Weight	42 Packages at 30 lbs.	=	1,260 lbs.