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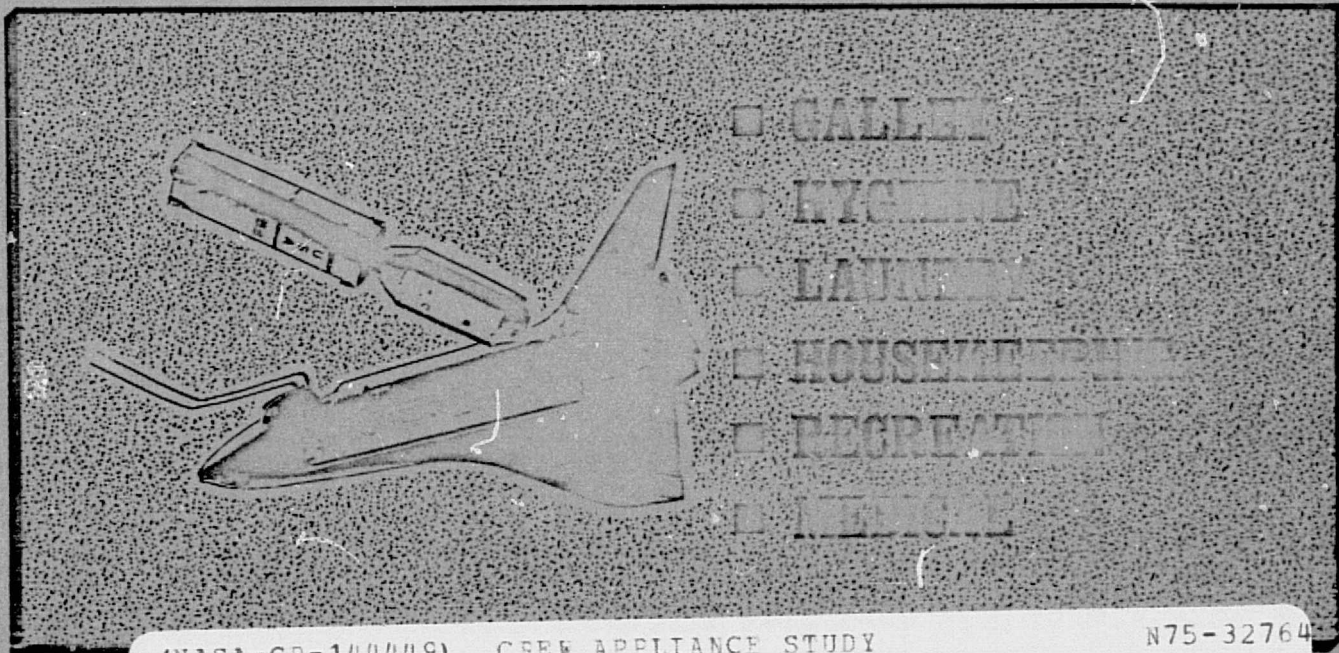
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144449

FINAL REPORT

CREW APPLIANCE STUDY



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FINAL REPORT

Contract NAS 9-13965

August 29, 1975

Prepared for

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D2-118572

REVISIONS

REV. SYM	DESCRIPTION	DATE	APPROVED

ABSTRACT

The crew appliance study was performed for NASA-JSC by the Boeing Aerospace Company under Contract NAS 9-13965. A detailed study of crew appliances was initiated because they generally require large amounts of electrical power, have high heating or cooling requirements, and are users of liquid/gas consumables. These crew appliance interface requirements can significantly impact the design of a manned space vehicle environmental control and life support system (ECLSS). This study identified, by means of a thorough literature search, viable crew appliance concepts. Trade studies were performed of these concepts for food management, personal hygiene, housekeeping, and off-duty habitability functions to determine which best satisfy the Space Shuttle Orbiter and Modular Space Station mission requirements. In conjunction with these studies, models of selected appliance concepts not currently included in the G-189A Computer Program subroutine library were developed and validated. Development plans of selected appliance concepts were generated for future NASA-JSC reference. As an extension to the basic contract, a Shuttle freezer conceptual design was developed and a test support activity was provided for regenerative environmental control life support subsystems.

KEY WORDS

Clothes Washer	Refuse Management
Crew Appliances	Shower
Dishwasher	Shuttle Orbiter
Food Management	Spacecraft Environmental Control
Modular Space Station	Waste Collection
Off-Duty Activities	Refrigerator/Freezer
Personal Hygiene	

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1.0 CREW APPLIANCE STUDY SUMMARY

This report documents the results of the Crew Appliance Study conducted under Contract NAS 9-13965. Three main tasks were considered during the study:

- (1) Task 1.0 - Concept Study
- (2) Task 2.0 - Preparation of Mathematical Models
- (3) Task 3.0 - Generation of Development Plans

The concept study task, documented in Crew Appliance Concepts Report (Reference 1), provided a literature search to identify space-oriented crew appliance concepts; collected, categorized, and documented the available vehicle oriented appliance data; and developed an optimized appliance system for both the Shuttle and Space Station vehicle missions. Mathematical modeling of the selected appliance concepts and verification of the resulting math models were accomplished during the preparation of mathematical models task. Results of this are reported in the Crew Appliance Computer Program Manual (Reference 2). The generation of development plans task identified future appliance concept development activities. In addition to this basic study effort, a Regenerative Environmental Control Life Support subsystem hardware test support activity and a Shuttle freezer conceptual design were accomplished and developed as an extension to the basic Crew Appliance contract. The freezer design study effort is described in the Shuttle Freezer Conceptual Design report (Reference 3).

1.1 TASK 1.0 - CONCEPT STUDY

The literature search produced an abstract file pertaining to 299 appliance-related documents which were file coded according to subject content. A brief description of each document's contents and its worthiness to the appliance study were included. These documents and 382 others reviewed during the study were compiled to form an appliance subject bibliography. Contained in Appendix A of the Crew Appliance Concepts Report, the bibliography has been placed in a computerized format which can be accessed remotely on a time-sharing computer.

Appliance concepts introduced in the literature search and found to be technically reasonable were included in the list of concepts to be reviewed for inclusion in the appliance system. A total of 135 concepts were identified and categorized. All the available engineering parameters relating to the 135 concepts were compiled and summarized in an Appliance Concept Function Matrix. These matrices were constructed for both the Shuttle and Space Station mission operations with the basic appliance functional parameters being adjusted to reflect the mission requirements.

Various appliance concepts in each habitability function category were traded to determine which concept best satisfied the mission requirements for a particular function. Factors such as weight, volume, electrical power and thermal requirements, reliability, safety, and cost were weighed. The quality of the trade task was enhanced by the use of a Boeing-developed computerized trade routine which easily allowed a variation of weighting factors to be repeatedly assigned and assessed. Concepts which were found in the trade task to best satisfy the Shuttle and Space Station mission requirements are tabulated in Table 1.1-1 and Table 1.1-2, respectively.

Appliance concepts identified in the trade program formed the basic optimum appliance system. This system was further optimized by alternating concepts until the conceptual system was within the vehicle requirements or until each requirement deficiency was reduced to a minimum. Final selected concepts for each habitability function in the Shuttle and Space Station appliance systems are tabulated in Table 1.1-1 and Table 1.1-2, respectively.

TABLE 1.1-1
SUMMARY OF SHUTTLE CREW APPLIANCE CONCEPT SELECTION

HABITABILITY SUBSYSTEM	HABITABILITY FUNCTION	APPLIANCE FUNCTION	CONCEPT CHOSEN	FIRST RATED CONCEPT	SECOND RATED CONCEPT
FOOD MANAGEMENT	FOOD STORAGE	REFRIGERATED	Space Radiator	Space Radiator	Thermoelectric
	FOOD PREPARATION	WARMING	Heating Trays	Heating Trays	Convective Oven
	GALLEY CLEANUP	DISH CLEANUP	Reusable Dishes and Utensils with Disposable Wet/Dry Wipes	Reusable Dishes and Utensils with Disposable Wet/Dry Wipes	Reusable Dishes and Disposable Utensils with Disposable Wet/Dry Wipes
PERSONAL HYGIENE	WASTE COLLECTION	FECAL COLLECTION	Dry John System Disposable Bags	Apollo System	Skylab System
		URINE COLLECTION		Apollo System	Skylab System
		VOMITUS COLLECTION		Disposable Bags	Intimate Adaptor
	BODY CLEANSING	PARTIAL BODY WASHING	Disposable Wet Wipe	Disposable Wet Wipe	Skylab-Type Disposable Washcloth
PARTIAL BODY DRYING		Disposable Dry	Disposable Dry	Electric Dryer	
PERSONAL GROOMING	SHAVING	Safety or Windup	Safety or Windup	Safety or Windup	
	DENTAL CARE	Toothbrush w/Dentifrice	Toothbrush w/Dentifrice	Electric Toothbrush	
HOUSEKEEPING	EQUIPMENT CLEANUP	SURFACE WIPING	Disposable Wet/Dry Wipes	Disposable Wet/Dry Wipes	Skylab-Type Disposable Cloth
	REFUSE MANAGEMENT	MANUAL COLLECTION	Disposable Trash Bag	Disposable Trash Bag	Disposable Receptacles
		VACUUM COLLECTION	Skylab-Type Electric	Vacuum-Vented	Skylab-Type Electric
		REFUSE DISPOSAL	Storage Bin/Container	Storage Bin/Container	Vacuum Storage
CLOTHING/LINEN MAINTENANCE	CLOTHES WASH/DRY	Disposable Clothes	Disposable Clothes	Mechanical w/Clothes Line	
OFF-DUTY ACTIVITIES	ENTERTAINMENT	MUSIC	Cassette Record Recorder	*	*
		LIBRARY	Books	*	*
		TELEVISION	Commercial Type	*	*
		GAMES	Cards, Handball, Etc.	*	*
PHYSICAL CONDITIONING	EXERCISERS	Exer Gym, Hand Exerciser	*	*	

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TABLE 1.1-2

SUMMARY OF SPACE STATION CREW APPLIANCE CONCEPT SELECTION

HABITABILITY SUBSYSTEM	HABITABILITY FUNCTION	APPLIANCE FUNCTION	CONCEPT CHOSEN	FIRST RATED CONCEPT	SECOND RATED CONCEPT
FOOD MANAGEMENT	FOOD STORAGE	REFRIGERATED FROZEN	Space Radiator Space Radiator	Space Radiator Space Radiator	Thermoelectric Thermoelectric
	FOOD PREPARATION	WARMING	Heating Trays	Heating Trays	Convective Oven
	GALLEY CLEANUP	DISH CLEANUP	Water Spray Wash/Elec. Heat Dry	Reusable Dishes and Disposable Wet/Dry Wipes	Reusable Cups & Dishes - Disposable Utensils and Disposable Wet/Dry Wipes
PERSONAL HYGIENE	WASTE COLLECTION	FECAL COLLECTION	Dry John System Disposable Bags	Apollo System	Skylab System
		URINE COLLECTION		Apollo System	Skylab System
		VOMITUS COLLECTION		Disposable Bags	Intimate Adaptor
	BODY CLEANSING	SHOWER	Collapsible Reusable Wipes	Collapsible Reusable Wipes	Mechanical Skylab-Type Disposable Washcloths
PARTIAL BODY WASHING		Reusable Wipes	Reusable Wipes	Disposable Dry Wipes	
PERSONAL GROOMING	SHAVING	Windup	Windup	Vacuum Driven	
	HAIRCUTTING	Razor Comb Vacuum Collection	Razor Comb Vacuum Collection	Power Clipper Vacuum Collection	
	NAIL CARE	Manual Clipper	Manual Clipper	Nail File Vacuum Collection	
	DENTAL CARE	Toothbrush w/Dentifrice	Toothbrush w/Dentifrice	Electric Toothbrush	
HOUSEKEEPING	EQUIPMENT CLEANUP	SURFACE WIPING	Reusable Wet/Dry Wipes	Disposable Wet/Dry Wipes	Sponge Skylab-Type
	REFUSE MANAGEMENT	MANUAL COLLECTION	Disposable Bags	Disposable Bags	Disposable Recepticles
		VACUUM COLLECTION	Skylab-Type (Electric)	Skylab-Type (Electric)	Vacuum Vented
		REFUSE PROCESSING	Compactor (Air Pressure)	Compactor (Air Pressure)	Compactor (Vacuum)
	REFUSE DISPOSAL	Storage Bin/Container	Storage Bin/Container	Vacuum Storage	
	GARMENT/LINEN MAINTENANCE	CLOTHES WASH/DRY	Water Spray Agitation Plus Electric Dry	Disposable Clothes	Water Spray Agitation Plus Clothes Line
OFF-DUTY ACTIVITIES	ENTERTAINMENT	MUSIC	Cassette Recorder	*	*
		LIBRARY	Books	*	*
TELEVISION		Commercial Type	*	*	
GAMES		Cards, Handball; Etc.	*	*	
	PHYSICAL CONDITIONING	EXERCISERS	Exer Gym, Hand Exerciser	*	*

1.1 (Continued)

Requirements for the Shuttle Appliance System were sufficiently defined; and the optimized system developed in this study is well within these defined thermal, electrical, weight and volume requirements. The maximum instantaneous heat rejection load of the optimum system to the Shuttle ECLSS is 464 watts (1583 Btu/hr) less than the specified requirements.

Appliance requirements described in the NASA Modular Space Station Study (Reference 4) were used for comparison with the optimized Space Station characteristics. Because of insufficient definition of heat rejection and electrical power data in some areas, it was possible only to totally compare weight and volume. The optimized system was selected to provide a balanced system whereby heat rejection and electrical penalties were paid, where necessary, to eliminate high weight and volume-type appliance concepts. The resulting optimized Space Station appliance system is within the weight and volume system requirements (Modular Space Station Study). Maximum instantaneous heat rejection load of the conceptual system to the ECLSS is 1501 watts (5122 Btu/hr) directly to the coolant and 2716 watts (9268 Btu/hr) as heat leakage to the cabin.

1.2 TASK 2.0 - PREPARATION OF MATH MODELS

Computer subroutines were developed to model the thermodynamic behavior of the selected appliance concepts within the G-189A ETCLS system simulation computer program (Reference 5). The optimum appliance concepts selected from the trade studies discussed in Paragraph 1.1 are shown in Tables 1.1-1 and 1.1-2 for Shuttle Orbiter and Modular Space Station. Some of these concepts did not require a new G-189A subroutine since (1) a routine is already available, (2) no thermal/mass exchange is involved, or (3) operation of the component is so simple it requires only a minor addition to the G-189A (GPOLY) routine logic. Appliances in this category are as follows:

o Reusable dishes, wet and dry wipes	None needed
o Vomitus collection	None needed
o Partial body washing, wet wipes	Simple GPOLY logic only required
o Partial body drying, dry wipes or electric dryer	None needed (or a simple heater using G-189A routine ALTCOM)
o Wet shave	GPOLY logic required for water usage only
o Windup razor	None needed (or a simple heater using G-189A routine ALTCOM if electric)
o Toothbrush	GPOLY logic required for water usage only
o Vacuum refuse collection	GPOLY logic only required, or G-189A routine ALTCOM for an electric heater
o Tape recorder, TV	GPOLY logic only required, or G-189A routine ALTCOM for an electric heater

For the remaining appliances, six new G-189A subroutines have been written, some of which will model more than one type of appliance. These subroutines are generally described as follows:

1.2 (Continued)

<u>Subroutine Name</u>	<u>Description</u>
CHILLR	(simulates a thermally insulated locker cooled either by an externally chilled fluid or a self-contained refrigeration unit) * Freezer * Refrigerator
FTRAY	* Food warming/serving tray (Skylab-type)
ROSMOS	* Reverse osmosis waste water treatment unit
SHOWER	* Spacecraft whole body shower
WASDRY	* Clothes washer * Clothes dryer * Combined clothes washer/dryer * Dishwasher/dryer * Towel/cloth drying rack
WASTE	* Dryjohn * Urinal

These subroutines allow analysis of future spacecraft ECLS systems involving crew appliances using the G-189A program. Subroutines have been written in generalized terms to allow easy accommodation for changing appliance designs. Their performance predictions have been correlated with test data where available, and excellent agreement has been obtained. Where test data were not available, the results were compared with independent analysis and found to be reasonable and accurate. The new subroutines have been used to model the selected optimum appliances in all-up G-189A simulations of the Shuttle Orbiter and Modular Space Station ECLSS. The results from these runs demonstrate their operational status within the G-189A computer program.

1.3 DEVELOPMENT PLANS

Concurrent with the crew appliance study activity, possible areas of development were noted for the selected appliance concepts. The majority of the appliances are state-of-the-art due to the nature of the optimization techniques used in the trade program. Generally those appliances identified as requiring development were the ones chosen for Space Station to maximize the thermodynamic, electrical power, and consumables requirements. The partial body washing and fecal/urine collection appliances would have required a development plan; however, NASA-JSC has initiated study efforts to develop these concepts.

Appliances identified as requiring further development were the food storage refrigerator/freezer, the garment/linen maintenance clothes washer/dryer, whole body shower, and dish cleanup dishwasher. In most cases, a preprototype unit of each of these appliances has already been initiated by NASA-JSC and therefore the development plans generated are an adjunct to these efforts to improve the performance of these appliances. The development plans generated provide a recommended technical approach which is accompanied with a development schedule. These plans are a result of the literature survey conducted during the study, consultation with NASA-JSC technical monitors, and the whole body shower test support activity experience.

1.4 TEST SUPPORT

The test support phase as an extension to the Crew Appliance contract has provided assistance to NASA-JSC during the buildup of an Advanced Regenerative Environmental Control Life Support System (RECLSS) laboratory for testing RECLSS subsystems. This test support activity has included technical assistance during laboratory buildup, definition of RECLSS subsystem testing and real time test support. The laboratory buildup has progressed to support seven RECLSS subsystems during the contract period. The definition of RECLSS subsystem testing has included the generation of RECLSS test requirements, plans, and preparation sheets for four of the seven subsystems. Direct test support activities, thus far, have included functional and verification testing of the Oxygen Generation Subsystem and functional testing of the Vapor Compression Distillation and Humidity Control Subsystems.

The Oxygen Generation Subsystem was successfully run for a total of 100 hours. The continuous verification test was interrupted by a manually initiated shutdown occurring 66 hours into the test. The shutdown was dictated by loss of water flow to the electrolysis module. Subsequent data analysis confirmed the shutdown was caused by a blockage of the water flow orifice. The subsystem was restarted and completed the remaining 34 hours of continuous testing without further incidents. All parameters operated within designed specification limits. The subsystem required numerous modifications prior to this successful long-term, 100-hour verification tests; the most notable modification being the addition of a pump head bleed system. The bleed system allowed the subsystem to operate without short-term vapor-locking of the fluid pump. A more detailed discussion of the subsystem modifications and test data analysis is contained in the Quick Look Test Report released by NASA-JSC.

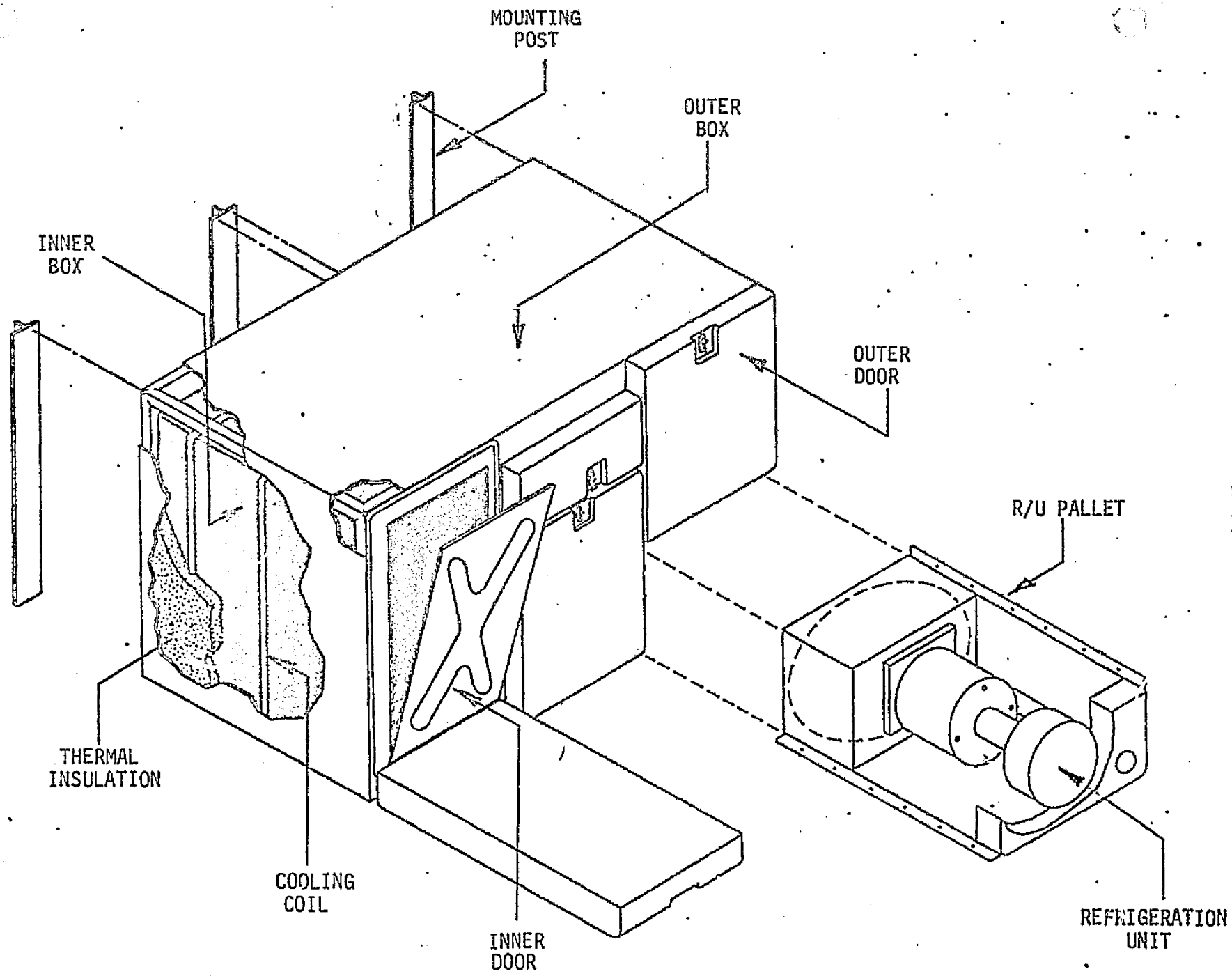
1.5 SHUTTLE FREEZER CONCEPTUAL DESIGN

As an extension to the Crew Appliance contract, a study was conducted to develop a conceptual "kit" freezer to be used to store food and medical samples on long duration Shuttle missions. The design developed is a portable unit weighing 70 pounds which can be transported fully assembled through Orbiter side hatch and mounted in the crew compartment on the storage module support system. A storage volume of 4.6 cubic feet with a capacity of 215 pounds of packaged food or 128 pounds of medical samples can be maintained at an average temperature of -10°F . Refrigeration is provided by an air-cooled unit utilizing a Stirling cycle principle to develop 75 watts of cooling with a peak electrical power requirement of 211 watts. A description of the freezer design is given in Reference 3.

Results of thermal analyses conducted to evaluate the steady state and transient storage volume temperature distributions and critical stored item and component temperatures are presented. Data are also given which describe the effects of coolant tubing spacing on wall temperature distribution.

Drawings were prepared to provide a detailed illustration of the mechanical and structural concepts employed in the freezer design and to validate packaging schemes and dimensional tolerances. Stress analyses of critical structural areas were made to insure freezer structural integrity could be maintained during all phases of the Shuttle mission.

The primary elements of the Shuttle conceptual freezer developed in this study are illustrated in the drawing shown in Figure 1.5-1.



1-9

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Figure 1.5-1. Shuttle Freezer Conceptual Design Features

1.6 DELIVERED ITEMS

Deliveries made during the contract are summarized in Table 1.6-1. The overall program schedule and major event milestones met are illustrated on page 1-14.

TABLE 1.6-1

DELIVERED ITEMS MARCH 7, 1974 TO AUGUST 29, 1975

<u>TITLE</u>	<u>DRL LINE ITEM No.</u>	<u>DRD No.</u>	<u>DATE DELIVERED</u>
Report, Crew Appliance Study Plan	*	-	March 27, 1974
Progress Report No. 1, Crew Appliance Study	4	MA-010TA	April 8, 1974
Progress Report No. 2, Crew Appliance Study	4	MA-010TA	May 8, 1974
Progress Report No. 3, Crew Appliance Study	4	MA-010TA	June 7, 1974
Progress Report No. 4, Crew Appliance Study	4	MA-010TA	July 8, 1974
Progress Report No. 5, Crew Appliance Study	4	MA-010TA	August 9, 1974
Bibliography-Crew Appliance Study	-	-	September 9, 1974
Progress Report No. 6, Crew Appliance Study	4	MA-010TA	September 9, 1974
Progress Report No. 7, Crew Appliance Study	4	MA-010TA	October 7, 1974
Progress Report No. 8, Crew Appliance Study	4	MA-010TA	November 8, 1974
Shuttle Orbiter Freezer Kit Preliminary Thermal Design Requirements	-	-	November 15, 1974

*Delivered in accordance with Program Schedule

TABLE 1.6-1 (Continued)

DELIVERED ITEMS MARCH 7, 1974 TO AUGUST 29, 1975

<u>TITLE</u>	<u>DRL LINE ITEM No.</u>	<u>DRD No.</u>	<u>DATE DELIVERED</u>
Progress Report No. 9, Crew Appliance Study	4	MA-010TA	December 9, 1974
Preliminary Concept Study Report	1	SE-542T	December 20, 1974
Progress Report No. 10, Crew Appliance Study	4	MA-010TA	January 6, 1975
Progress Report No. 11, Crew Appliance Study	4	MA-010TA	February 10, 1975
Study Plan Addendum	*	-	February 10, 1975
Progress Report No. 12, Crew Appliance Study	4	MA-010TA	March 10, 1975
Trip Report-Oxygen Generation Subsystem Electrolysis Module Failure Analysis at G.E.	-	-	March 14, 1975
CO ₂ Collection/ Humidity Control Subsystem Test Plan	-	-	March 18, 1975
Shuttle Freezer Study- Mid-term Briefing Document			March 21, 1975
Progress Report No. 13, Crew Appliance Study	4	MA-010TA	April 7, 1975
Interim Crew Appliance Computer Program Manual	*	-	April 28, 1975

*Delivered in accordance with Program Schedule

TABLE 1.6-1 (Concluded)

DELIVERED ITEMS MARCH 7, 1974 TO AUGUST 29, 1975

<u>TITLE</u>	<u>DRL LINE ITEM No.</u>	<u>DRD No.</u>	<u>DATE DELIVERED</u>
Progress Report No. 14, Crew Appliance Study	4	MA-010TA	May 7, 1975
Progress Report No. 15, Crew Appliance Study	4	MA-010TA	June 9, 1975
Shuttle Freezer Study - Conceptual Design Review			June 27, 1975
Progress Report No. 16, Crew Appliance Study	4	MA-010TA	July 7, 1975
Progress Report No. 17, Crew Appliance Study	4	MA-010TA	August 21, 1975
Shuttle Freezer Conceptual Design	-	-	August 22, 1975
Crew Appliance Computer Program Manual	3	DM-166T	August 29, 1975

2.0 CREW APPLIANCE STUDY

The crew appliance study was funded under Contract NAS 9-13965 by the Crew Systems Division of NASA JSC to develop conceptual crew appliance systems which will satisfy the mission requirements for the Shuttle Orbiter and the Modular Space Station.

Major crew appliances generally require large amounts of electrical energy; have high heating or cooling requirements; and are users of liquid/gas consumables. These crew appliance interface requirements can significantly impact the design of a manned space vehicle environmental control and life support system (ECLSS). The objective of this study is to analyze crew appliances to minimize the thermodynamic, power, weight, volume, and utilities support required for the ECLSS using an optimization technique to derive the most efficient mix of appliances. Crew appliance costs were heavily factored in favor of the state-of-the-art concepts; however, all appliance concepts considered during the study were of a sound design.

Three main tasks of the study which were divided into the six phases are described briefly in this section. The six phases are:

- | | | |
|--|---|----------|
| (1) Compilation and organization of source documentation
(Paragraph 2.1.1 - source documents) | } | Task 1.0 |
| (2) Appliance concept description development (Paragraph 2.1.2,
Concept Study) | | |
| (3) Selection of optimum appliance concepts (Paragraph 2.1.2,
Description of Selected Appliances) | | |
| (4) Development of math models of selected crew appliances
(Paragraph 2.2.1, Math Model Descriptions) | } | Task 2.0 |
| (5) Validation of developed math models (Paragraph 2.2.2,
Math Model Validation) | | |
| (6) Generation of appliance development plans (Paragraph 2.3.1,
Future Development Plans) | } | Task 3.0 |

In addition to the above tasks, an extension was made to the contract to develop a conceptual design of a freezer.

2.0 (Continued)

In order to thoroughly achieve the objectives of the study, all of the available appliance-related reference data were compiled from various library and contractor sources during Phase 1. A review of these references produced a list of documents which were considered most applicable to the appliance functions. These references were categorized and indexed and an abstract of each document written on an index card. The compendium of these index cards has been delivered to NASA JSC and is on file with J. R. Jaax, Building 7.

A bibliography of all document titles which are pertinent to the crew appliance study was compiled and published as Appendix A to the Crew Appliance Concepts document (Reference 1). The bibliography was ordered by three methods: (1) consecutive reference number, (2) alphabetically, and (3) index codes and computerized to catalog the large number of references and to provide easy retrieval of information. A description of the procedures used to retrieve information from the bibliography using a remote computer terminal was also documented in the Crew Appliance Concepts report. The source documentation effort is described in Section 2.1.1.

Data derived from the referenced documents provided a basis for the Phase 2 appliance concept descriptions development. The Crew Appliance System was organized into Habitability Subsystem, Habitability Function, and Appliance Function; and the most feasible concepts were identified for each function. This organization is shown schematically in Figure 2.0-1. Engineering data derived for each appliance were normalized to the established Shuttle Orbiter and Modular Space Station reference missions. These data were entered into an Appliance Concept Function Matrix to provide direct comparisons of concepts which serve a particular appliance function.

Concepts contained within each Appliance Function were traded using a parameter weighted technique designed to reflect the Shuttle Orbiter and Space Station vehicle appliance requirements. A computer program was developed and used to perform the trade studies. In addition to the concept

2.0 (Continued)

operational requirements considered, cost, reliability, maintainability, and safety were also factored into the trade program. The advantages of a computerized trade study are rapid turnaround time for parameter changes, changes in weighting distribution, and mission resupply time. The detailed engineering data utilized for the trade studies, the Appliance Concept Function Matrix, and the trade study program results are presented in Appendices B and C of the Crew Appliance Concepts document. The concept study results are described in Section 2.1.2.

During Phase 3, appliance concepts with the highest rating (results of Phase 2) in each of the appliance functions were optimized on a subsystem and a system level. The appliance system optimization study identified appliance function deficiencies by a comparison of the top rated concept requirements to the vehicle requirements derived from source documentation and by including crew time, crew performance, and usage time considerations.

The trade program and optimization technique used for this study not only provide the optimized appliance systems for the Shuttle Orbiter and Modular Space Station, but can be used with some manipulation for other vehicle programs. In addition, direct comparisons of appliance systems other than the ones chosen by the study can be readily made utilizing the data presented within these documents. The description of selected appliances is presented in Section 2.1.3.

The Phase 4 appliance concept math modeling task was performed to develop computer subroutines to simulate the selected optimum appliances thermodynamic performance. These routines were incorporated into the G-189A ETCLS system simulation computer program (Reference 5) and will allow analysis of spacecraft ECLS systems containing crew appliances. Six new G-189A subroutines were written, some of which will simulate more than one appliance concept. They were constructed in a flexible format and with generalized input to accommodate continuing changes in the appliance concept designs. These

2.0 (Continued)

routines are written in standard Fortran V language and are operational on the NASA JSC SRU 1108 EXEC II computing system. The component operation and math models are described in Section 2.2.1.

In Phase 5, the new appliance subroutines were run, both individually and in all-up Shuttle Orbiter and Modular Space Station ECLS systems, to verify their accuracy and operational status within the G-189A program environment. The results have been correlated with test data where available, and excellent agreement was obtained. Where test data were not available, the results were compared with independent analysis and found to be reasonable and accurate. This verification effort is described in Section 2.2.2.

During Phase 6, four development plans were generated for appliances which indicated a need for further development. These development plans present a proposed technical approach accompanied by a schedule to achieve the recommended development activity. The development plans generated are contained in Sections 2.3.1 through 2.3.3.

As an extension to the Crew Appliance Study, the task of developing a conceptual design for a "freezer kit" to be placed aboard the Shuttle Orbiter was assigned to the Boeing Aerospace Company. The resulting freezer conceptual design provides for frozen storage of whole food items as well as medical samples that can be readily installed on board the vehicle for selected orbital missions. In conjunction with Boeing's work, LTV Aerospace was assigned the responsibility to investigate potential refrigeration units for cooling and to provide a conceptual design compatible with the freezer requirements. The freezer conceptual design is discussed in detail in Section 2.1.4.

2.1 TASK 1.0, CONCEPT STUDY

This task identified existing space-oriented crew appliance concepts using source documentation located as a result of a thorough literature survey. These data provided the basis to generate the appliance functions matrices to tabulate critical data and to perform a system level integration and optimization trade study. The results of the system optimization study defined the optimum crew appliances system which satisfied the Shuttle Orbiter and Space Station requirements with minimum impact to the ECLSS and vehicle configuration.

2.1.1 Source Documentation

The results of the literature search conducted during the crew appliance study are contained within the bibliography published in Appendix A of the Crew Appliance Concepts report. A total of 682 references are included. Each reference was catalogued according to the type of appliance or vehicle to which it was related. For this purpose, a filing index was constructed to include all the types of appliances, vehicles, and related technology used during the crew appliance study, as shown in Figure 2.1-1. A generalized data handling program, COMPOSIT'77, available on the Commander-II System of Com-Share timesharing computer located at Ann Arbor, Michigan, was used to store, manipulate, and retrieve this information. For each reference, the following data were stored:

- o Reference Identification Number
- o Title
- o Author(s)
- o Date (month/day/year)
- o Publishing Organization
- o Contract Number
- o NASA JSC Library Number
- o Other Document Numbers
- o Index Codes (from Filing Index, Figure 2.1-1)

1.0	<u>VEHICLE REQUIREMENTS</u>	4.0	<u>HOUSEKEEPING</u>
1.1	SHUTTLE ORBITER	4.1	EQUIPMENT CLEANING
1.2	SPACELAB	4.2	TRASH COLLECTION
1.3	MODULAR AND 33-FOOT SPACE STATION	4.3	TRASH PROCESSING/DISPOSAL
1.4	SKYLAB	4.4	LAUNDRY (DISPOSABLE/REUSABLE CLOTHING, WASHER/DRYER)
1.5	SPACE TUG	4.5	WASH WATER PROCESSING
1.6	MANNED ORBITING LABORATORY (MOL)	4.6	MICROBIAL CONTROL
1.7	RESEARCH AND APPLICATIONS MODULE (RAM)	4.7	ANALYTICAL
1.8	SPACE STATION/BASE	5.0	<u>RECREATION</u>
1.9	APOLLO APPLICATIONS PROGRAM (AAP)	5.1	AUDIO
1.10	LUNAR BASE	5.2	VISUAL
1.11	APOLLO	5.3	EXERCISE
1.12	LUNAR MODULE (LM)	6.0	<u>MEDICAL</u>
1.13	INTERPLANETARY MANNED MISSIONS	6.1	EXPERIMENT MANAGEMENT
2.0	<u>FOOD MANAGEMENT</u>	6.2	PREPARATION, PRESERVATION, AND RETRIEVAL EQUIPMENT (REFRIGERATORS/FREEZERS/OVENS)
2.1	FOOD STORAGE (REFRIGERATOR/FREEZER/ STORAGE MODULES)	6.3	RADIOBIOLOGY
2.2	FOOD PREPARATION	6.4	DENTISTRY
2.3	FOOD CLEANUP (DISHWASHER/DRYER, WIPES)	6.5	MINOR SURGERY
2.4	WORK/DINING AREAS	6.6	ANALYTICAL
2.5	ANALYTICAL	7.0	<u>APPLIANCE-RELATED TECHNOLOGY</u>
3.0	<u>PERSONAL HYGIENE</u>	7.1	HEAT PIPES
3.1	FECAL COLLECTION/TRANSFER/PROCESSING	7.2	ULTRASONIC
3.2	URINE COLLECTION/TRANSFER/PROCESSING	7.3	MICROWAVE
3.3	VOMITUS COLLECTION/TRANSFER/PROCESSING	7.4	LASER
3.4	PARTIAL BODY WASHING/DRYING	7.5	MICROBIOLOGICAL PROCESSES
3.5	WHOLE BODY SHOWER	7.6	DIALYSIS AND MEMBRANES
3.6	DENTAL	7.7	THERMOELECTRIC DEVICES
3.7	SHAVING	7.8	FUEL CELLS
3.8	HAIR/NAIL	7.9	ELECTROPHORESIS
3.9	GENERAL PERSONAL HYGIENE ITEMS	7.10	LIGHT PIPES AND FIBER OPTICS
3.10	MICROBIAL CONTROL		
3.11	ANALYTICAL		

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2-7

Figure 2.1-1. Crew Appliance Subject Filing Index

7.11 SPECIAL THERMAL INSULATION AND ISOLATION
7.12 BATTERIES
7.13 TANKS
7.14 MONITORING
7.15 METAL BELLOWS
7.16 FILTERS
7.17 CRYOGENIC COOLING
7.18 SEALS
7.19 SOLAR COLLECTOR
7.20 VALVES
7.21 SPACE RADIATORS
7.22 REFRIGERATION

Figure 2.1-1. Crew Appliance Subject Filing Index (concluded)

2.1.1 (Continued)

The computer program is a highly flexible tool for collection, sorting, storage, analysis, and retrieval of generalized data in optional formats. Using this program, a complete alphabetized and sorted listing of the entire crew appliance bibliography was obtained.

The resulting bibliography published in the Crew Appliance Concepts report was composed of three parts.

Part I lists the title, date, publisher, and reference identification number for each reference. The references are arranged in numerical order by identification number. The first 299 references are numbered 1 through 299 consecutively, and represent the references reviewed in detail and used during the crew appliance study. The following 383 references are numbered 1001 through 1383 consecutively. These references were located during the literature search but were not directly used for the crew appliance trade study.

In Part II, all the references are listed in alphabetical order by title. With each reference is listed all the information described previously which is stored for it in the computer.

Part III has all the references sorted by their index code(s) from Figure 2.1-1 and listed alphabetically in a shortened form (title, date, and reference identification number). Examples of each of the bibliography sections are given in Figure 2.1-2. Thus, one can readily find (in Part III) every reference collected for any given appliance or vehicle category in the filing index (Figure 2.1-1). More detailed information about the references thus located may then be found by examining the long form for the same reference in Part II.

The information accumulated for all the references in the Crew Appliance Bibliography described above is permanently stored on Com-Share magnetic tape 5398.BOEING.APPL(D=1600, T=9). These references may easily be searched,

PART I - NUMERICAL REFERENCE LISTING

0001 = EUROPEAN SPACE RESEARCH ORGANIZATION SPACE SHUTTLE-SPACELAB DISCUSSIONS, , 04/17/73, NASA-JSC

0002 = SPACE SHUTTLE SYSTEM SUMMARY, ROCKWELL DOC. SSV73-45(R), 07/00/73, ROCKWELL

0003 = SPACE SHUTTLE SYSTEM TECHNICAL REVIEW, ROCKWELL DOC. SSV73-26, 04/16/73, ROCKWELL

0004 = SPACE SHUTTLE PROGRAM REVISED CABIN STUDY, ROCKWELL DOC. SSV73-13, 03/13/73, ROCKWELL

0005 = ORBITER VEHICLE END ITEM SPEC. FOR THE SPACE SHUTTLE SYS., PART 1, PERFORMANCE AND DESIGN REQUIREMENTS, SPEC. NO. MJO70-0001-1, 12/07/73,

PART II - ALPHABETICAL REFERENCE LISTING

0189 A BASELINE PROTOCOL FOR PERSONAL HYGIENE-FINAL REPORT
ANDR, FAIRCHILD
08/31/71, NAS 9-11509, FRD 3989, T71-15411
3-10

1001 A BIOMEDICAL PROGRAM FOR EXTENDED SPACE MISSIONS
ANDR, NASA-JSC
05/00/69, , T73-11082
6-0

0229 A DEVICE FOR STORING AND DISPENSING BITE-SIZE FOOD CUBES
J L MOORE, J R WATKIN, H O ROTH, WHIRLPOOL
07/13/71, FA1609-69-C, SAM-TR-71-33, N72-15485
2-1

1002 A MICROBIAL SURVEILLANCE SYSTEM
A K PRYOR AND C R MC DUFF, FAIRCHILD
00/00/68, ,
6-0

PART III - REFERENCES SORTED BY FILING INDEX

2.0 FOOD MANAGEMENT

A MICROWAVE HEATING SYSTEM FOR EXTENDED SPACE MISSIONS, 12/69, 1003

A STUDY OF THE REACTION KINETICS FOR SEVERAL SPACECRAFT LIFE SUPPORT SYSTEMS, 00/00, 1008

ACCEPTANCE TEST FOR LM OXYGEN BACTERIA FILTER, 03/68, 1010

ADVANCED METHODS OF RECOVERY FOR SPACE LIFE SUPPORT SYSTEMS, 00/73, 1013

ANALYSIS OF SELECTED CONSTITUENTS IN SPACE FOOD, 00/00, 1019

Figure 2.1-2. Examples of the Crew Appliance Bibliography Sections

2.1.1 (Continued)

sorted, rearranged or added to by using the COMPOSIT'77 program. User instructions for operating the program are also provided in the bibliography published in the Crew Appliance Concepts Report.

2.1.2 Concept Study Results

An Appliance Concept Function Matrix was developed to describe the physical and operational parameters for each appliance concept. Formatting of the matrix was designed to include and properly present parameters which have an impact on a vehicle ECLSS. Appliance concepts included in the matrices were organized within an appliance system to facilitate indexing of each concept. Appliance concept data presented in the matrices were adjusted to reflect Shuttle Orbiter and Modular Space Station mission requirements. The Shuttle Orbiter and Modular Space Station baseline mission and timeline were developed using the latest available reference data.

2.1.2.1 Mission Baseline Description

Shuttle Orbiter and Modular Space Station baseline missions are presented in Figures 2.1-3 and 2.1-4, respectively. Mission timelines for the two spacecraft are shown in Figures 2.1-5 and 2.1-6. The Shuttle Orbiter mission baseline was referenced from the 1973 fourth quarter Rockwell International mission description (Reference 6). The Modular Space Station mission baseline was compiled from McDonnell Douglas, Rockwell International, Hamilton Standard, and NASA JSC study reports.

The Shuttle Orbiter baseline mission provides for a maximum of six crewmembers for 7 days. Vehicle capability must, however, be based on the nominal mission plus contingencies in order to specify a complete appliance concept. Shuttle Orbiter contingency is specified as 96 hours for up to 10 crewmen. The appliance study was, therefore, based on a 42 man-days nominal mission plus 40 man-days contingency or 82 man-days (20.5 days with a nominal four-man crew). The timeline used as a baseline for daily crew activity was based on the mission requirements (Reference 6).

SHUTTLE MISSION BASELINE

- o 150,000 POUND ORBITER
- o BASELINE MISSION
 - 42 MAN-DAYS (3-6 MALE/FEMALE CREW FOR 7 DAYS)
 - 4 MAN NOMINAL MISSION
- o VEHICLE SYSTEM CAPABILITY
 - 42 MAN-DAYS + 96-HOUR CONTINGENCY FOR UP TO 10 CREWMEN (40 MAN-DAYS)

SHUTTLE IMPOSED REQUIREMENTS ON THE APPLIANCE SYSTEM

- o ALL MISSIONS WILL USE SAME HABITABILITY FUNCTIONS
- o GRAVITY - ZERO TO ONE EARTH GRAVITY
- o ATMOSPHERE
 - PRESSURE 14.7 PSIA
 - COMPOSITION 3.2 PSIA O₂
11.5 PSIA N₂
 - CO₂ CONCENTRATION 0-7.6 mm Hg
- o TEMPERATURE
 - RANGE (DRY BULK) 65°-80° F
 - 4 MEN (DESIGN PT.) 70° F
 - 10 MEN (DESIGN PT.) 80° F
 - DEWPOINT 39°-61° F
- o OPERATIONAL LIFE
 - 10 YEARS/100 ORBITAL MISSIONS/REPLACEABLE UNIT CONCEPT
- o GENERAL
 - GAS VENTING ALLOWED/NONPROPULSIVE
 - LIQUID VENTING SHALL BE MINIMIZED/NONPROPULSIVE
 - JETTISON OF SOLIDS/SOLID WASTES SHALL NOT BE ALLOWED.
 - NO MEDICAL SAMPLING REQUIRED OF FECES/URINE

SHUTTLE TIMELINE

- o NOMINAL CREW TIMELINE (SEE FIGURE 2.1-5)
 - WORK (INCLUDING OFF-DUTY) - 13 HOURS
 - EAT - 3 HOURS
 - SLEEP - 8 HOURS
- } REFERENCE 7

Figure 2.1-3. Shuttle Baseline Mission

SPACE STATION MISSION BASELINE

- o 20,000 POUND MODULES (MAXIMUM)
- o BASELINE MISSION
 - 6-MAN CREW (MALE/FEMALE)
 - 90/180-DAY RESUPPLY
- o VEHICLE SYSTEM CAPABILITY
 - 1080 MAN-DAYS + 96 HOUR CONTINGENCY FOR UP TO 12 MEN

SPACE STATION REQUIREMENTS IMPOSED ON THE APPLIANCE SYSTEM

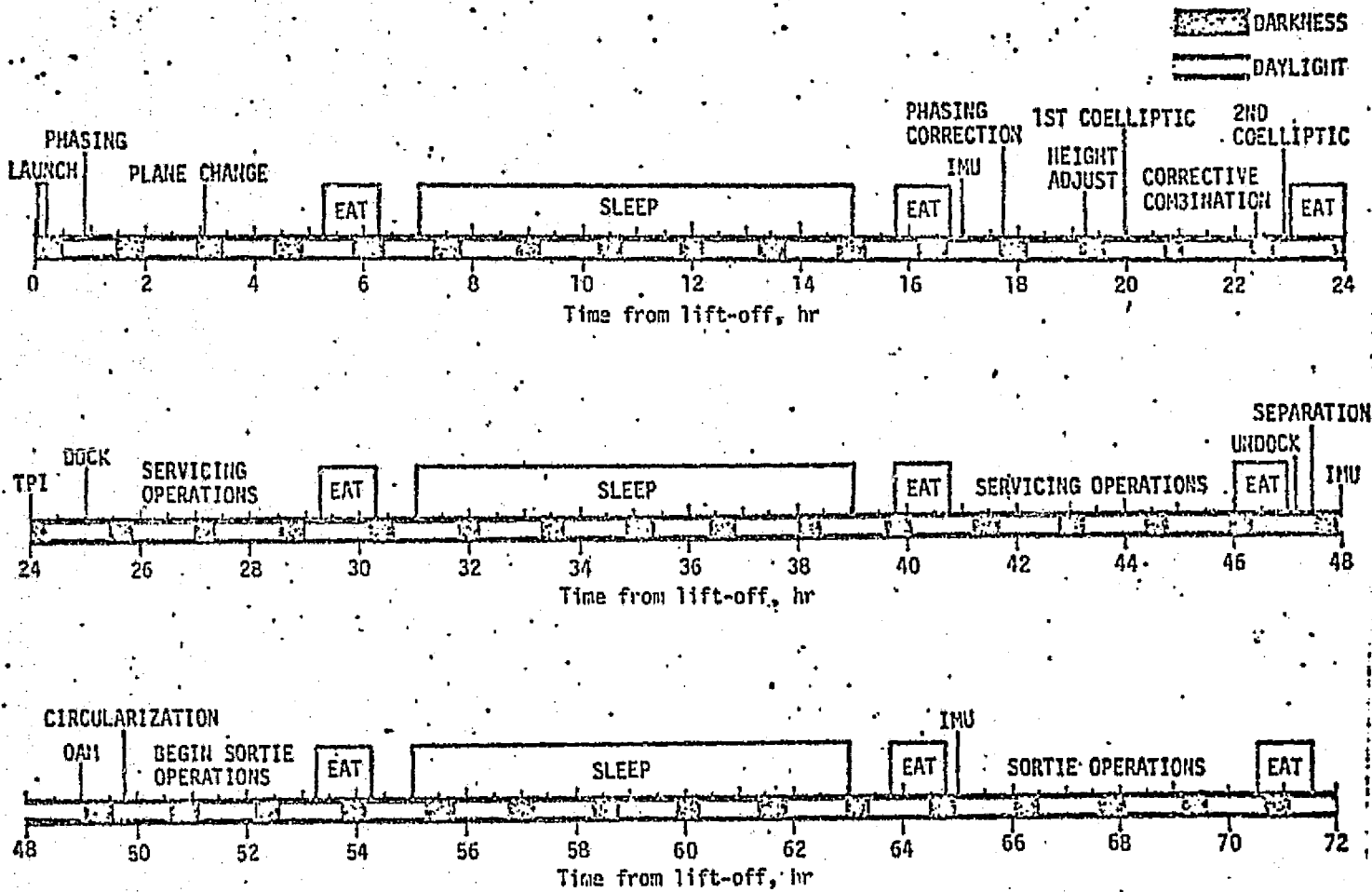
- o GRAVITY - ZERO
- o ATMOSPHERE (LIVING QTR's)
 - PRESSURE 14.7 PSIA
 - COMPOSITION 3.2 PSIA O₂
 - 11.5 PSIA N₂
 - CO₂ CONCENTRATION
- o TEMPERATURE (LIVING QTR's)
 - RANGE (DRY BULK) 65° -75° F
 - DEWPOINT 39° -62° F
- o OPERATIONAL LIFE
 - 10 YEARS/SCHEDULED MAINTENANCE
- o GENERAL
 - GAS VENTING ALLOWED/NONPROPULSIVE
 - LIQUID VENTING SHALL BE MINIMIZED/NONPROPULSIVE
 - JETTISON OF SOLIDS/SOLID WASTES SHALL NOT BE ALLOWED

SPACE STATION TIMELINE

- o NOMINAL CREW DUTY CYCLE
 - SEE FIGURE 2.1-6

Figure 2.1-4. Space Station Baseline Mission

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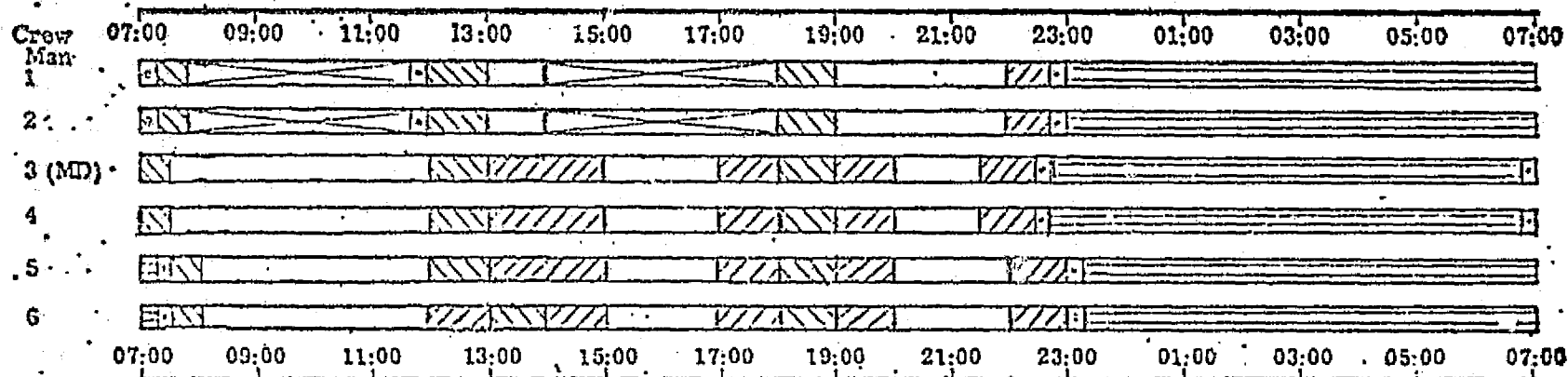
(a) Launch to 72 hours.

Figure 2.1-5. Shuttle Orbiter Timeline

2-14

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Daily Time - Earth Schedule



Daily Times - Earth Schedule

Codes







-  = Washroom/Tollet
-  = BIOMED/Exercise
-  = Work
-  = Sleep
-  = Recreation, light work
-  = Eat

Figure 2.1-6. Space Station Timeline

2.1.2.1 (Continued)

The Modular Space Station baseline mission uses a nominal six-man crew for 180 days. Mission contingency is based on 96 hours for six men. A total vehicle capability of 1104 man-days or 184 days was used for the appliance study. Space Station resupply period was assumed to be 180 days. The timeline used as a baseline for daily crew activity was based on the mission requirements and was taken from Reference 8. This timeline was modified as required to incorporate the various appliance functions involving crew time during the Crew Appliance System Optimization phase of the study. Also, timelines were altered to reduce the appliance system peak thermal and power demands on the vehicle systems.

In addition to the ECLSS imposed appliance restrictions, liquid and gas venting from appliances was minimized or eliminated and jettison of solids/solid wastes was not allowed. Gas or liquid venting, when allowed, was assumed to be nonpropulsive. The Shuttle Orbiter personal hygiene appliance concepts do not include hardware required to provide medical sampling of crewman feces/urine.

2.1.2.2 Appliance System Description

Development of a crew appliance system organization was necessary to thoroughly and orderly categorize all of the appliance concepts. The system organization is summarized in Figure 2.0-1. The Crew Appliance System was subdivided into three major groupings: Habitability Subsystem, Habitability Function, and Appliance Function. The five habitability subsystems are food management, personal hygiene, housekeeping, off-duty activity, and medical. These subsystems were further subdivided into 13 crew habitability functions and appliance functions then identified for each. A total of 33 appliance functions were included in the study.

Engineering data were derived for each concept listed in the Appliance Function section using the reference data described in Paragraph 2.1.1, NASA JSC and MSFC personnel, and crew appliance/space vehicle contractors.

2.1.2.2 (Continued)

New concepts were also added as they were identified during the study. A total of 135 individual appliance concepts considered during the study are listed in Figure 2.1-7 by title.

Appliance concept engineering data were normalized to the Shuttle Orbiter and Modular Space Station baseline mission requirements. These data were arranged and are presented in Appendices B and C of the Crew Appliance Concepts Report by individual appliance concept descriptions and work sheets. Appendices B and C apply to Shuttle Orbiter and Modular Space Station, respectively. The work sheets provided identification of each crew appliance concept weight, volume, electrical power, and thermal requirements.

In addition to these basic data, the solid/gas/liquid expendables requirements and operational penalties, if applicable, were computed and were also presented in the work sheets. A schematic or outline drawing, in most cases, and a summary of the references from which the engineering data were derived accompany each concept description.

2.1.2.3 Appliance Concept Function Matrix

Engineering data derived for each appliance concept described in the previous Paragraph 2.1.2.2 were formulated into an Appliance Concept Function Matrix. The results of these concept analyses are summarized, by appliance function, in the matrices included in Tables 3-1 through 3-29 for Shuttle and Tables 3-30 through 3-59 for Space Station in the Crew Appliance Concepts Report.

The Appliance Concept Function Matrix was developed, organized, and compiled to completely assess each concept's impact on the space vehicle mission operation and particularly on the vehicle ECLSS and to provide the necessary data for trade studies.

- 2-18
- 1.0 FOOD MANAGEMENT
 - 1.1 FOOD STORAGE
 - 1.1.1 Ambient Food Storage
 - 1.1.1.1 Rigid Containers
 - 1.1.1.2 Flexible Containers
 - 1.1.2 Refrigerated Food Storage
 - 1.1.2.1 Space Radiator
 - 1.1.2.2 Thermoelectric
 - 1.1.2.3 Air Cycle Turbine/Compressor
 - 1.1.3 Frozen Food Storage
 - 1.1.3.1 Space Radiator
 - 1.1.3.2 Thermoelectric
 - 1.1.3.3 Air Cycle Turbine/Compressor
 - 1.2 FOOD PREPARATION
 - 1.2.1 Food Rehydration
 - 1.2.2 Food Warming
 - 1.2.2.1 Heating Trays (Skylab)
 - 1.2.2.2 Oven - Hot Air Convection (Electric Heat)
 - 1.2.2.3 Oven - Microwave
 - 1.3 GALLEY CLEANUP
 - 1.3.1 Dishwasher/Dryer Combination
 - 1.3.1.1 Hot Water Spray - Centrifuge Drying
 - 1.3.1.2 Hot Water Spray - Air Spray Dry
 - 1.3.1.3 Hot Water Spray Wash - Force Hot Air Electric Heat Dry
 - 1.3.1.4 Hot Water Spray Wash - Forced Cold Air Desiccant
 - 1.3.1.5 Hot Water Spray Wash - Forced Hot Air Dry - Thermal Storage
 - 1.3.1.6 Ultrasonic Wash - Centrifuge Drying
 - 1.3.1.7 Ultrasonic Wash - Forced Hot Air Electric Dry
 - 1.3.1.8 Ultrasonic Wash - Force Cold Dry Air - Desiccant, Electrically Desorbed
 - 1.3.1.9 Ultrasonic Wash - Force Hot Air Dry - Thermal Storage
 - 1.3.1.10 Manual Wash - Manual Wipe Dry
 - 1.3.2 Dishwasher/Dryer with Dishes
 - 1.3.2.1 Hot Water Spray - Centrifuge Drying
 - 1.3.2.2 Hot Water Spray - Forced Hot Air Electric Heat Drying
 - 1.3.2.3 Hot Water Spray - Forced Air/Desiccant/ Electrically Heated
 - 1.3.2.4 Manual Wash - Manual Wipe
 - 1.3.2.5 Disposable Cups - Reusable Metallic Utensils and Dishes
 - 1.3.2.6 Disposable Cups and Nonmetallic Dishes - Reusable Metallic Utensils
 - 1.3.2.7 Disposable Cups and Nonmetallic Utensils - Reusable Metallic Dishes
 - 1.3.2.8 Disposable Cups and Nonmetallic Utensils and Dishes
 - 1.3.2.9 Reusable Cups and Metallic Utensils and Dishes
 - 1.3.2.10 Reusable Cups and Metallic Utensils - Disposable Nonmetallic Dishes
 - 1.3.2.11 Reusable Cups and Metallic Dishes - Disposable Nonmetallic Utensils
 - 1.3.2.12 Reusable Cups-Disposable Nonmetallic Utensils and Dishes
 - 2.0 PERSONAL HYGIENE
 - 2.1 WASTE COLLECTION/TRANSFER
 - 2.1.1 Fecal Collection/Transfer

Figure 2.1-7. Crew Habitability and Appliance Functions and Concepts

- 2.1.1.1 Dry John
- 2.1.1.2 Dry John - Anal Wash
- 2.1.1.3 Germicide - Wet John
- 2.1.1.4 Integrated Vacuum Decomposition
- 2.1.1.5 Flush Flow O₂ Incineration
- 2.1.1.6 Pyrolysis/Batch Incineration
- 2.1.1.7 Wet Oxidation
- 2.1.1.8 Semiautomatic Bag System (Skylab)
- 2.1.1.9 Dry Bags (Apollo)
- 2.1.2 Urine Collection/Transfer
 - 2.1.2.1 Standup Urinal
 - 2.1.2.2 Commode Urinal
 - 2.1.2.3 Intimate Male Adapter Urine (Skylab)
 - 2.1.2.4 Aperture Urinal
 - 2.1.2.5 Liquid/Gas Flow Cuff Type (Apollo)
- 2.1.3 Vomitus Collection/Transfer
 - 2.1.3.1 Disposable Intimate Personal Adapter (Mates with Commode)
 - 2.1.3.2 Reusable Intimate Personal Adapter, Lined (Mates with Commode)
 - 2.1.3.3 Disposable Portable Collector
 - 2.1.3.4 Reusable Portable Collector
- 2.2 BODY CLEANSING
 - 2.2.1 Whole Body Shower
 - 2.2.1.1 Vacuum Pickup
 - 2.2.1.2 Air Drag (Evaporative)
 - 2.2.1.3 Mechanical (Towel Pickup)
 - 2.2.1.4 Collapsible
 - 2.2.2 Partial Body Washing
 - 2.2.2.1 Disposable Wet Wipes
 - 2.2.2.2 Reusable Wet Wipes
 - 2.2.2.3 Disposable Wipes (Prepackaged)
 - 2.2.2.4 Automatic Sponge
 - 2.2.2.5 Reusable Washcloths
 - 2.2.2.6 Disposable Washcloths (Skylab)
 - 2.2.3 Partial Body Drying
 - 2.2.3.1 Reusable Dry Wipes
 - 2.2.3.2 Disposable Dry Wipes
 - 2.2.3.3 Electric Dryer
- 2.3 PERSONAL GROOMING
 - 2.3.1 Shaving
 - 2.3.1.1 Wet Shave - Safety Razor and Cream
 - 2.3.1.2 Dry Shave - Electric Razor/Vacuum Collection
 - 2.3.1.3 Dry Shave - Windup Razor (Skylab)
 - 2.3.1.4 Dry Shave - Vacuum Motor-Driven Razor
 - 2.3.1.5 Wet Shave - Safety Razor/Vacuum Collection
 - 2.3.2 Hair Cutting
 - 2.3.2.1 Electric Clipper/Vacuum Collection
 - 2.3.2.2 Razor-Comb/Vacuum Collection
 - 2.3.3 Nail Care
 - 2.3.3.1 Manual Nail Clipper/Bag Collection
 - 2.3.3.2 Metal Nail File/Vacuum Collection
 - 2.3.4 Dental
 - 2.3.4.1 Toothbrush with Dentifrice
 - 2.3.4.2 Water Pix
 - 2.3.4.3 Electric Toothbrush with Dentifrice
- 3.0 HOUSEKEEPING
 - 3.1 EQUIPMENT CLEANING
 - 3.1.1 Surface Wiping
 - 3.1.1.1 Disposable Wet/Dry Wipes

Figure 2.1-7. Crew Habitability and Appliance Functions and Concepts (continued)

- 3.1.1.2 Reusable Wet/Disposable Dry Wipes
- 3.1.1.3 Disposable Wet/Dry Wipes (Prepackaged)
- 3.1.1.4 Automatic Mop
- 3.1.1.5 Reusable Cleaning Cloths/ Disposable Dry Wipes
- 3.1.1.6 Disposable Cleaning Cloths/Disposable Dry Wipes
- 3.1.1.7 Disposable Wet Wipes/Reusable Dry Wipes
- 3.1.1.8 Reusable Wet/Dry Wipes
- 3.1.1.9 Reusable Cleaning Cloths/Dry Wipes
- 3.1.1.10 Disposable Cleaning Cloths/Reusable Dry Wipes
- 3.1.1.11 Sponges
- 3.1.1.12 Sponges/Skylab Wetting Unit
- 3.2 REFUSE MANAGEMENT
- 3.2.1 Manual Collection
- 3.2.1.1 Waste/Trash Bags
- 3.2.1.2 Waste Receptacles/Reusable
- 3.2.1.3 Waste Receptacles/Disposable
- 3.2.2 Vacuum Collection
- 3.2.2.1 Portable Vacuum/Electric (Skylab)
- 3.2.2.2 Portable Vacuum/Electric (Commercial)
- 3.2.2.3 Portable Vacuum/Space Venting
- 3.2.3 Refuse Transfer
- 3.2.4 Refuse Processing
- 3.2.4.1 Compactor
- 3.2.4.2 Shredder
- 3.2.4.3 Incinerator
- 3.2.4.4 Integrated Vacuum Decomposition
- 3.2.4.5 Flush Flow O₂ Incineration
- 3.2.4.6 Pyrolysis/Batch Incineration
- 3.2.4.7 Wet Oxidation
- 3.2.5 Refuse Disposal/Storage
- 3.2.5.1 Vacuum Storage

- 3.2.5.2 Storage Bin/Container
- 3.2.5.3 Restorage/Biological Stabilized
- 3.2.5.4 Trash Rocket
- 3.3 GARMENT/LINEN MAINTENANCE
- 3.3.1 Garment/Linen Washing
- 3.3.1.1 Mechanical Oscillations
- 3.3.1.2 Fluidic Agitation
- 3.3.1.3 Piston Agitation
- 3.3.1.4 Cyclic Valve and Pump
- 3.3.1.5 Diaphragm Actuated - One Directional Squeeze
- 3.3.1.6 Diaphragm Actuated - Two Directional Squeeze
- 3.3.1.7 Water Spray Agitated
- 3.3.1.8 Ultrasonic
- 3.3.1.9 Manual Washboard
- 3.3.1.10 Plain Recirculation
- 3.3.2 Garment/Linen/Drying
- 3.3.2.1 Forced Hot Air - Electric
- 3.3.2.2 Forced Hot Air - Heat from Thermal Storage Unit
- 3.3.2.3 Force Cold Dry Air - Desiccant - Vacuum Regenerable
- 3.3.2.4 Force Cold Dry Air - Desiccant - Heat Regenerable
- 3.3.2.5 Vacuum Dry
- 3.3.2.6 Thermal Vacuum Dry - Electric Heat
- 3.3.2.7 Thermal Vacuum Dry - Thermal Storage/ Radiant Heat
- 3.3.2.8 Clothesline - Forced Convection
- 3.3.2.9 Clothesline - Forced Convection plus Electric Heat
- 3.3.3 Garment/Linen Washer/Dryer-Disposable Clothes
- 3.3.3.1 Fluidic Agitation/Forced Hot Air - Electric Heater

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Figure 2.1-7. Crew Habitability and Appliance Functions and Concepts (continued)

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3.3.3.2	Fluidic Agitation/Forced Hot Air - Thermal Storage Heated	4.2.2	<u>Hand Exerciser</u>
3.3.3.3	Fluidic Agitation/Forced Air Drying - Clothesline	5.0	<u>MEDICAL</u>
3.3.3.4	Fluidic Agitation/Forced Air Drying - Clothesline	5.1	STERILIZATION
3.3.3.5	Water Spray Agitation/Forced Hot Air - Electric Heater	5.1.1	<u>Autoclaves</u>
3.3.3.6	Water Spray Agitation/Forced Hot Air - Thermal Storage Heater	5.1.1.1	Moist Heat
3.3.3.7	Water Spray Agitation/Forced Air Drying - Clothesline	5.1.1.2	Dry Heat
3.3.3.8	Water Spray Agitation/Electrically Heated - Clothesline	5.1.1.3	Ethylene Oxide
3.3.3.9	Disposable Clothes	5.2	PHYSICAL MONITORING
3.4	WASH WATER PROCESSING	5.2.1	<u>Ergometer</u>
4.0	<u>OFF-DUTY ACTIVITIES</u>		
4.1	ENTERTAINMENT		
4.1.1	<u>Music</u>		
4.1.1.1	Cassette Player/Recorder		
4.1.2	<u>Library</u>		
4.1.2.1	Books		
4.1.3	<u>Television</u>		
4.1.4	<u>Games</u>		
4.1.4.1	Handball		
4.1.4.2	Dart Board		
4.1.4.3	Cards		
4.2	PHYSICAL CONDITIONING		
4.2.1	<u>Exer-gym</u>		

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Figure 2.1-7. Crew Habitability and Appliance Functions and Concepts (concluded)

2.1.2.3 (Continued)

The matrix identifies the appliance concepts in the first column, see example, Figure 2.1-8. Usage time is specified in uses per day and hours per use in order to provide rate data for future work. The consumables and flow requirements columns specify the type of fluid, amount consumed per use, flow rate, pressure, and temperature required of the ECLSS by the appliance concept. Thermal requirements are divided into coolant and heat leak requirements for use in estimating the appliance concept impact on ECLSS thermal designs. The coolant thermal requirement was defined as latent and sensible heat required to be removed at an appliance/ECLSS coolant interface. Heat leak thermal requirement is the latent and sensible heat required to be removed at the ECLSS cabin heat exchanger. The electrical power requirements identify the peak and average AC and DC power requirements for each appliance concept. These data can be used to aid the selection of a vehicle power system including inverters. Weight and volume requirements specify the total weight and volume for each appliance concept including its solid, liquid, and gas expendables requirements which are mission dependent. Development cost is specified by the appliance concept availability; i.e., available, state of the art, etc., and cost indicator which is based on the appliance concept complexity. The resupply column applies only to the Modular Space Station. Resupply is the consumable weight necessary for the appliances to function for an additional 180 days. The remainder of the data matrix described previously are based on the referenced mission of 184 days for Space Station and 20.5 days for the Shuttle Orbiter. A more detailed description of each of these parameters is contained in the Crew Appliance Concepts Report.

The matrix for each appliance function with its accompanying set of concept descriptions and work sheets, located in Appendices B and C of the Crew Appliance Concepts Report, provide a complete background for the derived appliance data. These data were used as the basis for the trade studies conducted to select the optimum crew appliance concepts.

APPLIANCE CONCEPT FUNCTION MATRIX

INDEX NO. 1, 2, 3 REFRIGERATED FOOD STORAGE (SPACE STATION)

CONCEPT NO.	USAGE TIME	CONSUMABLES AND FLOW REQUIREMENTS		THERMAL REQTS		ELEC. PWR. REQTS		WT/VOL. REQTS		DEVELOPMENT COST	RESUPPLY					
		USES/DAY	TYPE	AMT. USED	FLOW	PRESS	TEMP	COOLANT	HT LEAK			PK PWR	AVG PWR	WEIGHT	VOLUME	AVAIL
		(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)
		(LB/USE)	(*)	(PSIG)	(DEG F)	(BTU/HR)	(BTU/HR)	(WATTS)	(WATTS)	(LBS)	(CU FT)	(#)	(#)	(LBS)		
1	.000 .000	B	.0000 (.0000)	.00 (.00)	.0 (.0)	4.4 (40.0)	52. (179.)	0. (0.)	50.0 .0	.0 (0)	134.1 (300.0)	.62 (22.00)	1	0	.0 (.0)	
2	.000 .000						130. (443.)	-9. (-30.)	.0 225.0	.0 (0)	152.9 (337.0)	.71 (25.10)	2	25	.0 (.0)	
3	.000 .000						2061. (7039.)	835. (2168.)	11000.0 .0	.0 (0)	235.9 (520.0)	2.04 (72.00)	3	70	.0 (.0)	

APPLIANCE CONCEPT

NO.	CONCEPT NAME
1	SPACE RADIATOR
2	THERMOELECTRIC
3	AIR CYCLE-TURBINE/COMPRESSOR

- (*)
- 1 - CABIN AIR (CIRCULATED), LITERS/SEC (FT³/MIN)
 - 2 - CABIN AIR (LOST), KG/HR (LB/HR)
 - 3 - OXYGEN (LOST), KG/HR (LB/HR)
 - 4 - COOLING WATER (CIRCULATED), KG/HR (LB/HR)
 - 5 - WATER (LOST), KG/HR (LB/HR)
 - 6 - NITROGEN (CIRCULATED), KG/HR (LB/HR)
 - 7 - NITROGEN (USED), KG/HR (LB/HR)
 - 8 - FREON (CIRCULATED), KG/HR (LB/HR)
 - 9 - WATER (PROCESSED), KG/HR (LB/HR)

- (**)AVAILABLE
- (***)COST INDICATOR
- (1) AVAILABLE 0-25%
 - (2) STATE OF THE ART 25-50%
 - (3) SOME DEVELOPMENT REQUIRED 50-75%
 - (4) EXTENSIVE DEV. REQUIRED 75-100%

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Figure 2.1-8. Example - Appliance Concept Function Matrix

2.1.3 Description of Selected Appliances

Shuttle and Space Station requirements for crew appliances were developed from the source documentation discussed in Paragraph 2.1.1. Requirements for each habitability subsystem were developed from the component habitability function requirements, and the resulting subsystems requirements were combined to form the basis of the total appliance system requirement of each spacecraft. Basic appliance system requirements defined are: heat rejection, electrical power, weight, and volume. The rationale behind each habitability function requirement, and the appliances which are included, are discussed in detail in the Crew Appliance Concepts Report. Optimum appliance concepts were selected using a weighed trade-off study and were further optimized by a comparison of the appliance functional requirements to the appliance subsystem and system requirements.

2.1.3.1 Vehicle Crew Appliance Requirements

The Shuttle Orbiter vehicle requirements for crew appliances were determined exclusively from those described in Reference 9. Most of the data documented in Reference 9 were developed for a baseline mission of 42 man-days (14 men and three days); therefore, alterations were made to the requirements data to make it representative of the 82 man-day mission assumed for this study.

The resulting Shuttle appliance system requirements are tabulated in Table 2.1-1. The total requirements listed at the bottom of the table represent the summation of all the subsystem requirements developed in the following paragraphs with the exception of heat rejection and electrical power. For these requirements, it was assumed that the heating and electrical loads for the housekeeping subsystem (electric vacuum cleaning) would not be imposed coincidentally with those of food management and personal hygiene.

The Space Station vehicle appliance requirements listed in this section were determined from those described in Reference 4. Most of the data documented in this reference were developed for a baseline mission of 180 man-days

TABLE 2.1-1
SHUTTLE APPLIANCE SYSTEM REQUIREMENTS

HABITABILITY SUBSYSTEM	HEAT REJECTION		ELECTRIC POWER			WEIGHT	VOLUME
	COOLANT	HT LEAK	PEAK	AVG	DEMAND	KG (lbs)	M ³ (ft ³)
	WATTS (Btu/hr)	WATTS (Btu/hr)	WATTS	WATTS	WATT-HR DAY		
FOOD MANAGEMENT	8.4 (28.6)	721.9 (2463.9)	893.0	TBD	1201.0	38.4 (84.7)	0.170 (6.0)
PERSONAL HYGIENE		165.0 (563.1)	805.0	TBD	636.6	588.4 (1297.2)	1.546 (54.6)
HOUSEKEEPING		60.1 *(205.2)	*80.0	60.0	120.0	41.0 (90.4)	0.521 (18.4)
OFF DUTY		165.4 (564.4)	250.0	TBD	740.0	85.5 (188.5)	0.283 (10.0)
* OMITTED FROM TOTAL							
SYSTEM TOTAL	8.4 (28.6)	1052.2 (3591.2)	1876.0		3175.0	753.0 (1660.0)	2.523 (89.1)

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2.1.3.1 (Continued)

(six men and 30 days); therefore, alterations were made to the data to make it representative of the 1104 man-day mission assumed for this study.

Resulting Space Station appliance system requirements are tabulated in Table 2.1-2. Total requirements listed at the bottom of the table represent the summation of all the subsystem requirements developed in the following paragraphs. The same format used to describe the Shuttle requirements with appliances grouped into subsystems was also used for these requirements.

2.1.3.2 Weighted Trade Study

Optimum appliance concepts were selected from the Appliance Concept Function Matrices described in Paragraph 2.1.2 using the results of a weighted trade-off study. In addition to the operational parameters summarized in the Appliance Concept Function Matrix, the appliance concept reliability, maintainability, and safety were also included as evaluation criteria for selecting the optimum concept. Crew preference, convenience, and usage time were not factored into the trade study so that the optimum choice could be based only on "hard" data. Crew considerations are taken into account during the final appliance subsystem and system optimization study. The above-mentioned selection parameters were each apportioned points to make up a weighting distribution. Once the weighting distribution was established, the appliance concept selection then depended on the rationale used to ratio each parameter to its point allotment. A computer program was developed utilizing the weighting distribution and the appliance concept selection rationale to automatically perform the weighted trades and determine the relative ratings of the appliance concepts.

Selection of the optimum appliance concept utilizing a weighting technique requires that the trade parameter weighting distribution be consistent with vehicle requirements and program goals. Numerous references were consulted to develop the weighting distribution technique, and finally an

TABLE 2.1-2

SPACE STATION APPLIANCE SYSTEM REQUIREMENTS

HABITABILITY SUBSYSTEM	HEAT REJECTION		ELECTRIC POWER			WEIGHT	VOLUME
	COOLANT	HT. LEAK	PEAK	AVG	DEMAND	KG (lbs)	M ³ (ft ³)
	WATTS (Btu/hr)	WATTS (Btu/hr)	WATTS	WATTS	WATT-HR DAY		
FOOD MANAGEMENT		958.0 (3269.7)	TBD	958.0	TBD	532.2 (1173.3)	6.313 (222.9)
PERSONAL HYGIENE		299.0 (1020.4)	TBD	299.0	TBD	287.3 (633.3)	2.852 (100.7)
HOUSEKEEPING		14.0	TBD	14.0	TBD	267.5 (589.8)	2.580 (91.1)
OFF-DUTY		TBD	TBD	TBD	TBD	170.1 (375.0)	3.398 (120.0)
SYSTEM TOTAL		TBD	TBD	TBD	TBD	1257.1 (2771.4)	15.142 (534.7)

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2.1.3.2 (Continued)

analytical comparison was made to a previous study (Reference 10) to provide a proper weighting distribution. The study, Reference 10, provided an in-depth trade study of various clothes washer concepts. Study results selected, as the optimum concept, a water spray agitated clothes washer for a Space Station having a resupply period of 230 days. The appliance concept selection program was adjusted to use a 230-day resupply period. Selection program runs were made for disposable clothes and eight clothes washer concepts using four different weighting distributions. The results of these runs were plotted to determine which distribution would select water spray agitation as the optimum concept. An even weighting distribution (all parameters having the same point value) was used as the basis for comparison to three independent weighting distributions. The weighting point distributions were varied to accentuate the more important parameters -- cost, weight, volume, and thermal requirements. The weighting chosen was selected to place the heaviest emphasis on cost. A detailed description of the weighting distribution rationale is contained in the Crew Appliance Concepts Report.

2.1.3.3 Crew Appliance System Optimization

Results of the weighted trade study provided an initial list of appliance concepts which individually best satisfy the electrical, weight, and volume requirements for the Shuttle and Space Station missions with a minimum thermal penalty to the spacecraft's ECLSS. The optimized appliance systems, which will, as an aggregate of these concepts, or alternates, provide appliance systems which best satisfy each vehicle's requirements.

Optimization of the Shuttle and Space Station appliance systems was initiated by first assembling the habitability subsystem with appliance concepts chosen in the trade studies. Heat rejection, electrical power, weight, and volume characteristics of the optimum subsystem were compared to the vehicle subsystem requirements; and when deficiencies existed, concepts were exchanged to reduce them. In some instances, crew convenience was an overriding factor in the concept selection. Once the deficiencies were reduced to a minimum, the subsystems were incorporated into the total appliance system.

2.1.3.3 (Continued)

Characteristics of the optimized appliance system were compared to the total spacecraft appliance system requirements, and again the appliance concept selection was reviewed to reduce system deficiencies where they existed. The optimum crew appliance system is comprised of the final appliance concepts chosen in this process. Procedures used in the process are discussed in detail for the Shuttle and Space Station in the Crew Appliance Concepts Report. Detailed descriptions and performance data of the concepts chosen and those considered in the trades are included in Appendices B and C of the above mentioned Concepts Report.

The final selected concepts for each habitability function in the Shuttle and Space Station appliance systems are tabulated in Table 1.1-1 and Table 1.1-2, respectively, located in the Summary, Paragraph 1.0. A brief description of each of the selected concepts for the Shuttle and Space Station is contained in Paragraphs 2.1.3.4 and 2.1.3.5, respectively. A summary of thermodynamic, electrical power, weight, volume, and consumables and flow requirements is contained in Table 2.1-3 for the Shuttle and in Table 2.1-4 for the Space Station vehicle.

2.1.3.4 Selected Shuttle Appliance Concepts

The appliance system selected for the Shuttle Orbiter is described in the following paragraph. A summary of thermodynamic, electrical power, weight, volume, and consumables and flow requirements for each of these selected appliances is contained in Table 2.1-3.

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TABLE 2.1-3 SHUTTLE APPLIANCE CONCEPT SUMMARY FUNCTION MATRIX

HABITABILITY SUBSYS	HABITABILITY FUNCTION	APPLIANCE FUNCTION	CONCEPT CHOSEN	USAGE TIME	CONSUMABLES AND FLOW REQUIREMENTS					THERMAL REQMTS		ELEC PWR REQMTS		WT/VOL	REQMTS
				USES/DAY HRS/USE	TYPE (*)	AMT. USED- -KG/USE- (LB/USE)	FLOW * (*)	PRESS -MPHG- (PSIG)	TEMP -DEG C- (DEG F)	COOLANT -WATTS- (BTU/HR)	HT LEAK -WATTS- (BTU/HR)	PK PWR AC DC -WATTS-	AVG PWR AC DC -WATTS-	WEIGHT -KG- (LBS)	VOLUME -CU M- (CU FT)
FOOD MANAGEMENT	FOOD STORAGE	REFRIGERATED	SPACE RADIATOR	.000 .000	8	.0000 (.0000)	.00 (.00)	.0 (.0)	4.4 (40.0)	9. (30.)	41. (141.)	50.0 .0	- .0	8.9 (19.6)	.04 (1.44)
	FOOD PREPARATION	WARMING	HEATING TRAYS	3.000 2.000						0. (0.)	197. (672.)	.0 660.0	.0 197.0	36.6 (80.6)	.14 (4.80)
	GALLEY CLEANUP	DISH CLEANUP	REUSABLE DISHES & UTENSILS WITH DISPOSABLE WET/DRY WIPES	3.000 .333						0. (0.)	0. (0.)	0.0 .0	.0 .0	15.5 (34.2)	.03 (1.20)
PERSONAL HYGIENE	WASTE COLLECTION	FECAL/URINE COLLECTION	DRY JOHN SYSTEM	4.000 .150	1 6	.0000 (.0000)	9.44 (20.00)	.0 (.0)	21.1 (70.0)	0. (0.)	200. (683.)	675.0 62.0	440.0 52.0	107.3 (236.5)	.85 (30.00)
		VOMITUS COLLECTION	DISPOSABLE BAGS	.560 .016						0. (0.)	0. (0.)	.0 .0	.0 .0	.5 (1.2)	.00 (.01)
	BODY CLEANSING	PARTIAL BODY WASHING	DISPOSABLE WET WIPES	40.000 .037						0. (0.)	0. (0.)	.0 .0	.0 .0	43.5 (96.0)	.06 (2.20)
		PARTIAL BODY DRYING	DISPOSABLE DRY	40.000 .056	5	.0111 (.0245)	.00 (.00)	.0 (.0)	.0 (.0)	0. (0.)	0. (0.)	.0 .0	.0 .0	19.6 (43.3)	.17 (5.89)
	PERSONAL GROOMING	SHAVING	SAFETY OR WINDUP	4.000 .100						0. (0.)	0. (0.)	.0 .0	.0 .0	1.0 (2.1)	.00 (.08)
				4.000 .100						0. (0.)	0. (0.)	.0 .0	.0 .0	.5 (1.0)	.00 (.02)
	DENTAL CARE	TOOTHBRUSH WITH DENTIFRICE	16.000 .082						0. (0.)	0. (0.)	.0 .0	.0 .0	6.4 (14.0)	.03 (1.20)	

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TABLE 2.1-3 SHUTTLE APPLIANCE CONCEPT SUMMARY FUNCTION MATRIX (CONT.)

HABITABILITY FUNCTIONS	HABITABILITY FUNCTION	APPLIANCE FUNCTION	CONCEPT CHOSEN	USAGE TIME USES/DAY HRS/USE	CONSUMABLES AND FLOW REQUIREMENTS				THERMAL REQMTS		ELEC PWR REQMTS		WT/VOL REQMTS		
					TYPE (*)	AMT. USED -KG/USE- (LB/USE)	FLOW * (*)	PRESS -MMHG- (PSIG)	TEMP -DEG C- (DEG F)	COOLANT -WATTS- (BTU/HR)	HT LEAK -WATTS- (BTU/HR)	PK PWR AC DC -WATTS-	AVG PWR AC DC -WATTS-	WEIGHT -KG- (LBS)	VOLUME -CU M- (CU FT)
HOUSEKEEPING	EQUIPMENT CLEANUP	SURFACE WIPING	DISPOSABLE WET/DRY WIPES	15.000 .037						0. (0.)	0. (0.)	.0 .0	.0 .0	39.1 (86.3)	.08 (2.80)
	REFUSE MANAGEMENT	MANUAL COLLECTION	DISPOSABLE TRASH BAGS	.000 .000						0. (0.)	0. (0.)	.0 .0	.0 .0	6.6 (14.6)	.09 (3.05)
		VACUUM COLLECTION	SKYLAB-TYPE ELECTRIC	5.000 .082						0. (0.)	77. (262.)	.0 115.0	.0 -	13.8 (30.4)	.02 (.79)
		REFUSE DISPOSAL	STORAGE BIN/CON- TAINER	.787 .041						0. (0.)	0. (0.)	.0 .0	.0 .0	8.7 (19.2)	.38 (13.28)
	GARMENT/ LINEN MAINTENANCE	CLOTHES WASH/DRY	DISPOSABLE CLOTHES	.000 .000	9	.0000 (.0000)	.00 (.00)	.0 (.0)	.0 (.0)	0. (0.)	0. (0.)	158.0 .0	.0 .0	51.7 (114.0)	.61 (21.50)
OFF-DUTY ACTIVITIES	ENTERTAIN- MENT	MUSIC	CASSETTE RECORDER	2.000 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	29.2 (64.3)	.04 (1.49)
		LIBRARY	BOOKS	2.000 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	.5 (1.0)	.01 (.33)
		TELEVISION	COMMERCIAL TYPE	2.000 2.000						0. (0.)	120. (409.)	120.0 .0	.0 .0	22.7 (50.0)	.12 (4.27)
		GAMES	CARDS, HANDBALL, ETC.	.500 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	.4 (.8)	.00 (.07)
	PHYSICAL CONDITIONING	EXERCISES	EXER GYM, HAND EXERCISER	4.000 1.000 4.000 .000						0. (0.)	0. (0.)	.0 .0 .0 .0	.0 .0 .0 .0	.6 (1.3)	.01 (.24)

(*) 1 - CABIN AIR (CIRCULATED), LITERS/SEC (FT³/MIN)
 2 - CABIN AIR (LOST), KG/HR (LB/HR)
 3 - OXYGEN (LOST), KG/HR (LB/HR)
 4 - COOLING WATER (CIRCULATED), KG/HR (LB/HR)
 5 - WATER (LOST), KG/HR (LB/HR)

6 - NITROGEN (CIRCULATED), KG/HR (LB/HR)
 7 - NITROGEN (USED), KG/HR (LB/HR)
 8 - FREON (CIRCULATED), KG/HR (LB/HR)
 9 - WATER (PROCESSED), KG/HR (LB/HR)

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TABLE 2.1-4 SPACE STATION APPLIANCE CONCEPT FUNCTION MATRIX SUMMARY

HABITABILITY SUBSYS.	HABITABILITY FUNCTION	APPLIANCE FUNCTION	CONCEPT CHOSEN	USAGE TIME USES/DAY HRS/USE	CONSUMABLES AND FLOW REQUIREMENTS					THERMAL REQMTS		ELEC PWR REQMTS		WT/VOL REQMTS	
					TYPE (*)	AMT. USED -KG/USE- (LB/USE)	FLOW * (*)	PRESS -MMHG- (PSIG)	TEMP -DEG C- (DEG F)	COOLANT -WATTS- (BTU/HR)	HT LEAK -WATTS- (BTU/HR)	PK PWR AC DC -WATTS-	AVG PWR AC DC -WATTS-	WEIGHT -KG- (LBS)	VOLUME -CU M- (CU FT)
FOOD MANAGEMENT	FOOD STORAGE	REFRIG-ERATED	SPACE RADIATOR	.000 .000	8	.0000 (.0000)	.00 (.00)	.0 (.0)	4.4 (40.0)	52. (179.)	0. (0.)	50.0 .0	- .0	136.1 (300.0)	.62 (22.07)
		FROZEN	SPACE RADIATOR	.000 .000	8	.0000 (.0000)	.00 (.00)	.0 (.0)	-23.3 (-10.0)	715. (2442.)	-665. (2271.)	50.0 .0	- .0	589.7 (1300.0)	2.70 (95.50)
	FOOD PREPARATION	WARMING	HEATING TRAYS	3.000 2.000						0. (0.)	295. (1007.)	.0 990.0	.0 295.0	54.9 (121.0)	.20 (7.20)
	DAILEY CLEANUP	DISH CLEANUP	WATER SPRAY WASH/ELEC. HEAT DRY	3.000 2.000	9	13.6080 (30.0000)	.00 (.00)	.0 (.0)	.0 (.0)	247. (842.)	371. (1268.)	167.0 326.0	- -	81.5 (179.6)	.69 (24.50)
PERSONAL HYGIENE	WASTE COLLECTION	FECAL/URINE COLLECTION	DRY JUNK SYSTEM	6.000 .167	1 6	.0000 (.0000) .0000 (.0000)	9.44 (20.00) .00 (.00)	.0 (.0) .0 (.0)	21.1 (70.0) 21.1 (70.0)	0. (0.)	200. (683.)	675.0 62.0	440.0 52.0	144.2 (318.0)	.95 (33.70)
		SOLIDUS COLLECTION	DISPOSABLE BAGS	.840 .015						0. (0.)	0. (0.)	.0 .0	.0 .0	7.0 (15.5)	.00 (.13)
	BODY CLEANSING	SHOWER	COLLAPSIBLE	6.000 .250	5	2.7216 (6.0000)	.00 (.00)	1292.9 (25.0)	41.1 (106.0)	77. (264.)	292. (997.)	85.0 -	- 85.0	103.8 (228.7)	1.57 (55.30)
		PARTIAL BODY WASHING	REUSABLE WIPES	60.000 .037	5	.3901 (.8600)	.01 (.02)	1551.4 (30.0)	.0 (.0)	105. (360.)	278. (948.)	500.0 .0	360.0 .0	21.6 (47.7)	.15 (5.20)
		PARTIAL BODY DRYING	REUSABLE WIPES	60.000 .037						37. (125.)	292. (997.)	.0 .0	.0 .0	75.2 (165.6)	.25 (8.80)
	PERSONAL GROOMING	SHAVING	WINDUP RAZOR	6.000 .100						0. (0.)	0. (0.)	.0 .0	.0 .0	.5 (1.0)	.00 (.02)
		HAIRCUTTING	RAZOR COMB VACUUM COLLECTION	.430 .099						0. (0.)	3. (11.)	.0 115.0	.0 -	.7 (1.5)	.01 (.2)
		NAIL CARE	MANUAL CLIPPER	.430 .050						0. (0.)	0. (0.)	.0 .0	.0 .0	.2 (.5)	.00 (.00)
		DENTAL CARE	TOOTHBRUSH WITH DENTIFRICE	6.000 .330						0. (0.)	0. (0.)	.0 .0	.0 .0	78.5 (173.0)	.27 (9.60)

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TABLE 2.1-4 SPACE STATION APPLIANCE CONCEPT FUNCTIONAL MATRIX SUMMARY (CONT.)

HABITABILITY SUBSYS	HABITABILITY FUNCTION	APPLIANCE FUNCTION	CONCEPT CHOSEN	USAGE TIME	CONSUMABLES AND FLOW REQUIREMENTS					THERMAL REQMTS		ELEC PWR REQMTS		WT/VOL REQMTS	
				USES/DAY HRS/USE	TYPE (*)	AMT. USED -KG/USE- (LB/USE)	FLOW * (*)	PRESS -MMHG- (PSIG)	TEMP -DEG C- (DEG F)	COOLANT -WATTS- (BTU/HR)	HT LEAK -WATTS- (BTU/HR)	PK PWR AC DC -WATTS-	AVG PWR AC DC -WATTS-	WEIGHT -KG- (LBS)	VOLUME -CU M- (CU FT)
HOUSEKEEPING	EQUIPMENT CLEANUP	SURFACE WIPING	REUSABLE WET/DRY WIPES	15.000 .037	5	2.5946 (5.7200)	.00 (.00)	1551.4 (30.0)	51.7 (125.0)	105. (360.)	278. (948.)	500.0 .0	360.0 .0	33.3 (73.5)	.22 (7.70)
	REFUSE MANAGEMENT	MANUAL COLLECTION	DISPOSABLE BAGS	.000 .000						0. (0.)	0. (0.)	.0 .0	.0 .0	153.1 (337.6)	.64 (22.51)
		VACUUM COLLECTION	SKYLAB-TYPE ELECTRIC	5.000 .082						0. (0.)	77. (262.)	.0 115.0	.0 .0	13.8 (30.4)	.02 (.86)
		REFUSE PROCESSING	COMPACTOR (AIR PRESSURE)	5.200 .017	1	.0000 (.0000)	.00 (.00)	1810.0 (35.0)	21.1 (70.0)	0. (0.)	0. (0.)	.0 10.0	.0 10.0	55.9 (123.2)	.21 (7.41)
		REFUSE DISPOSAL	STORAGE BIN/BIN/CONTAINER	1.000 .032						0. (0.)	0. (0.)	.0 .0	.0 .0	44.3 (97.6)	16.57 (585.00)
GARMENT/LINEN MAINTENANCE	CLOTHES WASH/DRY	WATER SPRAY AGITATION PLUS ELEC. DRY	2.000 5.000	9	49.8960 (110.0000)	.00 (.00)	.0 (.0)	.0 (.0)	198. (675.)	1470. (5020.)	237.0 227.0	.0 .0	239.3 (527.5)	1.31 (46.25)	
OFF-DUTY ACTIVITIES	ENTERTAINMENT	MUSIC	CASSETTE RECORDER	3.000 2.000						0. (0.)	30. (102.)	30.0 .0	30.0 .0	66.4 (146.4)	.08 (2.98)
		LIBRARY	BOOKS	3.000 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	6.3 (13.8)	.00 (.50)
		TELEVISION	COMMERCIAL TYPE	3.000 2.000						0. (0.)	120. (409.)	120.0 .0	.0 .0	22.7 (50.0)	.12 (4.27)
	GAMES	HANDBALL		.500 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	.4 (.8)	.00 (.07)
		DARTBOARD/DARTS		.500 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	.8 (1.8)	.00 (.04)
		BINOCULARS		.500 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	5.4 (12.0)	.00 (.17)
		CARDS		.500 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	3.0 (6.7)	.00 (.17)
CALCULATOR		.500 2.000						0. (0.)	0. (0.)	.0 .0	.0 .0	3.0 (6.6)	.00 (.13)		

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TABLE 2.1-4 SPACE STATION APPLIANCE CONCEPT FUNCTIONAL MATRIX SUMMARY (CONT.)

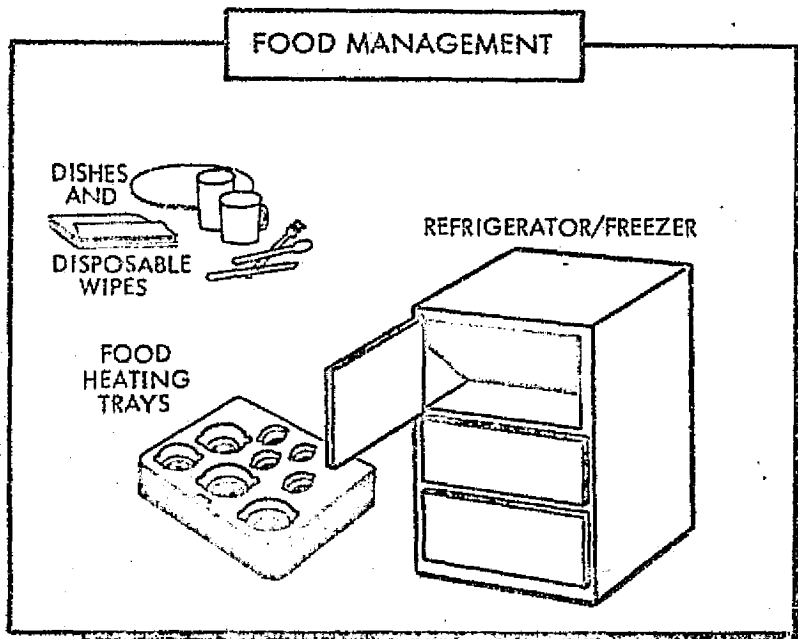
HABIT- ABILITY FUNCTIONS	HABITABILITY FUNCTION	APPLIANCE FUNCTION	CONCEPT CHOSEN	USAGE TIME	CONSUMABLES AND FLOW REQUIREMENTS					THERMAL REQMS		ELEC PWR REQMS		WT/VOL REQMS	
				USES/DAY HRS/USE	TYPE (*)	AMT. USED -KG/USE- (LB/USE)	FLOW * (*)	PRESS -MMHG- (PSIG)	TEMP -DEG C- (DEG F)	COOLANT -WATTS- (BTU/HR)	HT LEAK -WATTS- (BTU/HR)	PK PWR AC DC -WATTS-	AVG PWR AC DC -WATTS-	WEIGHT -KG- (LBS)	VOLUME -CU M- (CU FT)
OFF-DUTY ACTIVITIES	PHYSICAL CONDITION- ING	EXERCISERS	EXER-GYM	6.000 1.000						0. (0.)	0. (0.)	.0 .0	.0 .0	.9 (2.0)	.01 (.36)
			HAND EXER- CISER	6.000 .000						0. (0.)	0. (0.)	.0 .0	.0 .0	.2 (.5)	.00 (.04)

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- (*)
- | | |
|---|--|
| 1 - CABIN AIR (CIRCULATED), LITERS/SEC (FT ³ /MIN) | 6 - NITROGEN (CIRCULATED), KG/HR (LB/HR) |
| 2 - CABIN AIR (LOST), KG/HR (LB/HR) | 7 - NITROGEN (USED), KG/HR (LB/HR) |
| 3 - OXYGEN (LOST), KG/HR (LB/HR) | 8 - FREON (CIRCULATED), KG/HR (LB/HR) |
| 4 - COOLING WATER (CIRCULATED), KG/HR (LB/HR) | 9 - WATER (PROCESSED), KG/HR (LB/HR) |
| 5 - WATER (LOST), KG/HR (LB/HR) | |

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REFRIGERATED STORAGE - SPACE RADIATOR
 The refrigerator/freezer is simply an insulated food storage box, with coolant from the spacecraft ECS radiators routed through tubing within the refrigerator walls. This concept was used for the Skylab refrigerator. The Shuttle refrigerator was sized proportional to the above Skylab data based on the refrigerator food capacity. The wall insulation was 10.16 cm (4.0 in) thick. It was assumed that the radiator coolant would be of sufficiently low temperature for this concept to be feasible.

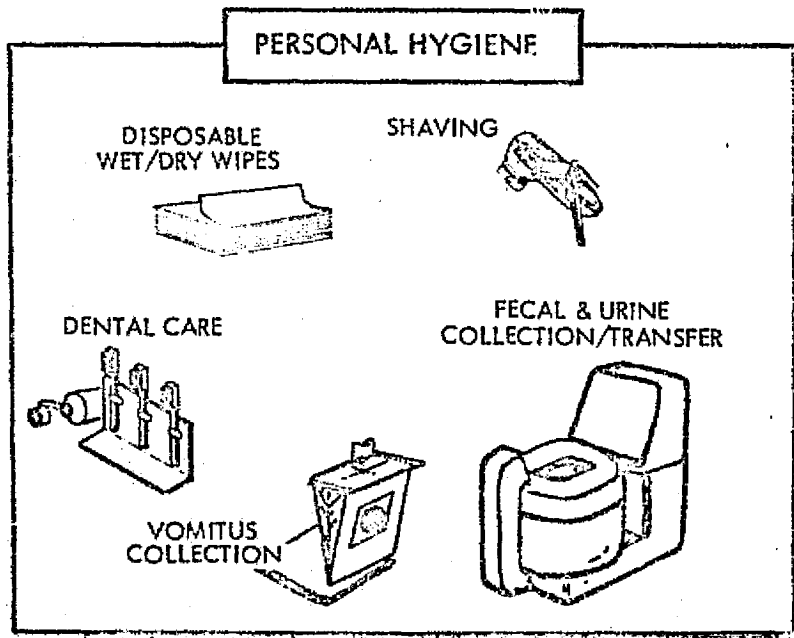
FOOD WARMING - HEATING TRAYS (SKYLAB)
 The heating trays consist of an insulated food tray with three heating cavities surrounded by imbedded electrical resistance heating elements. This concept was used on Skylab, and the actual Skylab weight/volume/power data were used for the study. A heating time of 1 1/2 to 2 hours is required to warm the food. Two hours was used for computing thermal penalties to the cabin cooling circuit. Each Skylab heating tray weighed 10.9 kg (24 lb).

DISH CLEANUP - REUSABLE DISHES AND UTENSILS WITH DISPOSABLE WET/DRY WIPES
 The reusable dishes and utensils were assumed to be metallic dishes and utensils. No food packaging penalty was used for this system. Two wet wipes and one dry wipe were assumed used to clean the dishes per man.

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2.1.3.4 (Continued)



FECAL/URINE COLLECTION/TRANSFER - DRY JOHN

The dry john commode assembly serves as a waste collector and feces/urine storage/processing unit. The seat is similar to the terrestrial type with modifications necessary for zero-gravity usage. The feces are transferred to the storage/processing section (collector) via the fecal transfer duct. The fecal transfer duct contains provisions for entrainment airflow for separating and moving the stool from the anus to the collector. Air positioning jets shown on the schematic are used to assist the user in positioning properly on the seat. This portion of the system was not considered part of the appliance, since recent tests have shown the jets are not necessary. The interface between the transfer duct and the feces collector is the collector valve. The valve is manually actuated and seals the collector after use to permit vacuum drying of the feces. A slinger is incorporated to maximize the feces and wipes area exposed to vacuum by depositing the feces and wipes on the wall of the collector. Entrainment air and air removed by the vacuum pump are passed through filters and returned to the cabin. A vacuum pump was assumed to satisfy the vehicle requirement of no venting external to the spacecraft.

VOMITUS COLLECTION/TRANSFER - PORTABLE DISPOSABLE COLLECTOR (AIRLINE TYPE)

The portable disposable collector is a light flexible bag with a drawstring closure device. The bag is used on all airlines and is made of thin gage plastic. The crewman can store the bag in a clothes pocket where it will be ready for use at any time. The bag is unfolded and grasped near the opening by both hands and held against the face enclosing the nose and mouth. Proper placement of the bag against the face provides the seal. The bag is sealed after use by tying a knot in the closure cord and discarding the bag and contents into the feces collector.

PARTIAL BODY WASHING - DISPOSABLE WIPES (SKYLAB)

The disposable wipes are made up of prepackaged wipes which were used on Skylab. The wipes are contained within a package to eliminate water evaporation during storage. The units are used and discarded.

PARTIAL BODY DRYING - DISPOSABLE DRY WIPES

The disposable dry wipe consists of wipes made of 4 ply "wet strength" paper. The paper wipes are 12 X 18 inches and are discarded after two uses. The wipe usage is based on 10 times per day per man. The wipes are disposed of by depositing into a vacuum drier to remove excess water. The dried wipe is then deposited into the refuse system. The weight and volume of the wipe dispenser was included as part of the appliance.

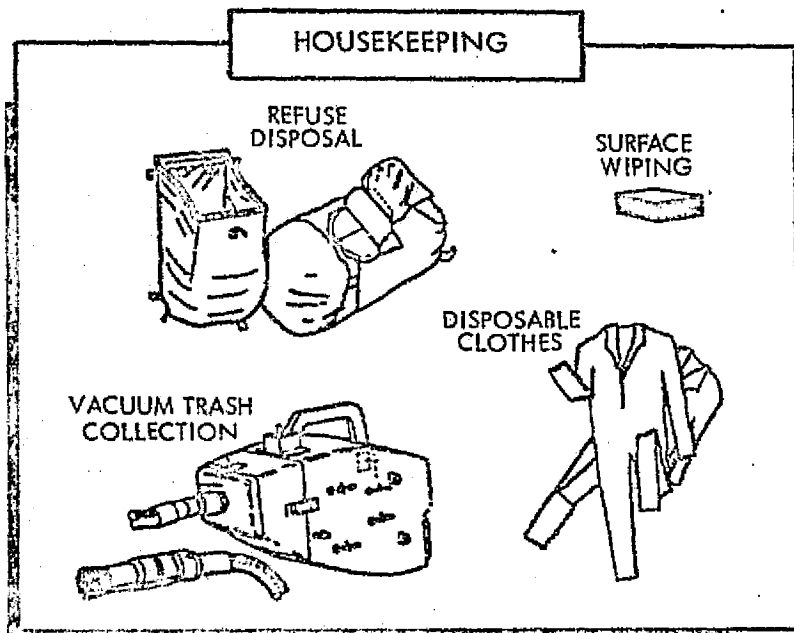
SHAVING - DRY SHAVE-WINDUP RAZOR (SKYLAB)

The windup razor dry shaver consists of a mechanical windup motor shaver with a hair particle reservoir. The unit was used on Skylab and the weight and volume used were the same as the flight weight unit.

TEETH BRUSHING - TOOTHBRUSH WITH DENTIFRICE

The toothbrush with dentifrice consists of a terrestrial type toothbrush with dentifrice. The dentifrice is digestible to be nonhazardous if accidentally swallowed and is dispensed by a roll-up tube. Mouthwash is also provided in a soft plastic "squeeze bottle." One squeeze bottle per each crewman is provided for hygiene reasons. The mouthwash is used to mix with the dentifrice and is expectorated into a sink or fecal collector. This appliance has flown on Apollo

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SURFACE WIPING - DISPOSABLE WET/DRY WIPES (PREPACKAGED)
 The disposable wet/dry wipes consist of prepackaged wet wipes which were used on Skylab. The wet wipes are contained within a package to eliminate water evaporation during storage. The dry wipes are dispensed from a 196 count container. The wet and dry wipes are used for cleanup and discarded.

MANUAL COLLECTION - WASTE/TRASH BAGS
 The waste/trash bags employ trash bags and disposable bags for refuse collection. This appliance uses the bag concept used on Skylab. The trash containers are mounted on the back side of collector doors. The collector areas are located in the food management, personal hygiene, and other areas where significant amount of bulk refuse is generated. The study assumed 3 collectors for Shuttle. Trash entry into the bag is through the front of the collection door through a slit in the bag. The refuse collection was based on its uncompressed volume. Disposable bags were applied for uncompressible trash. The disposable bags are held during use by snaps located at various locations throughout the vehicle. Both types of bags have bag closure devices to seal the bag after filling.

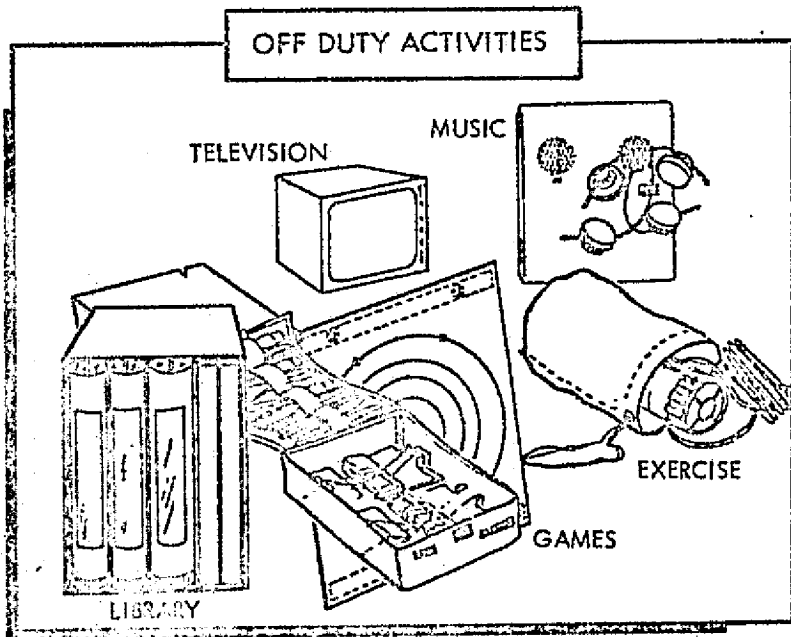
VACUUM COLLECTION - PORTABLE VACUUM/ELECTRIC (SKYLAB)
 The portable vacuum/electric is identical to the vacuum used on Skylab. The vacuum has a hose and pickup attachments to assist in vacuum pickup. The unit has a strap and handle for carrying/using the unit. Vacuum cleaner bags were assumed to require changing once per week (.142 cycles per day).

REFUSE DISPOSAL - STORAGE BIN/CONTAINER
 The storage bin/container employs a locker to store the refuse. Sterilant capsules were assumed for retarding the bacterial growth. The refuse was assumed to be collected by bags (Skylab, or equivalent) and transferred to the storage locker. A concept provides a sterilant capsule for each bag of refuse stored in the locker. The capsules used for the study were 2.25 grams each with a volume of .33 cubic inches. The walls of the storage locker were assumed to be aluminum. Sizing of the locker was based on the refuse volume including the storage bags.

GARMENT/LINEN - DISPOSABLE CLOTHES
 No clothes washer/dryer is used, and soiled clothing are simply disposed of and replaced by new ones. An average wear rate of .484 kg (1.066 lb) clothing/towels/washcloths was used per man per day. A packaging weight factor of 1.3 was applied to the disposable clothes weight. Bulk density of the clothes, including packaging, was assumed to be 0.0119 cu m/kg (0.190 cu ft/lb).

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MUSIC - CASSETTE PLAYER/RECORDER

The cassette player/recorder includes the following equipment: (1) tape player/recorder, (2) headsets, (3) microphone kit, (4) power cord/converter, (5) batteries, (6) cassette kit, and (7) wardroom speakers. The tape player can be used on conventional batteries or via a converter from 28 VDC to 6 VDC on spacecraft power. The tape recorder plays cassettes and is provided with a speaker and an adaption to headsets for private use.

LIBRARY - BOOKS

Books consist of individually selected off-the-shelf paperback books taken on the mission. The books are stored and when in use are provided with a cover for nonflammability. The covers are fabricated from Beta cloth.

VISUAL RECREATION - TELEVISION

The television provides programmed television programs to the crewmen. The data presented were based on 15-inch Panasonic. The Sony is also very similar to this model. The unit does not provide the means for use of video tape.

GAMES - HANDBALL/CARDS

The handball appliance provides three hand balls, one pyrell, one sponge, and one rubber hand ball. The balls are covered with a nonflammable Fluorel covering. One commercial ball is coated with Fluorel. The pyrell NERF ball was dipped in ammonium-dehydrogen phosphate and coated with Fluorel. The third ball is a toy ball coated with Fluorel. The balls are packaged in a sponge rubber container.

The card game provides card decks and card deck retainers for card playing in zero-g. The card retainer is constructed using a flexible strap with a magnet at each end. The assembly is covered with Beta cloth. The cards are standard cards manufactured using a lamination of three layers of Scheufelin paper E-20. Each deck is stored in an aluminum container for nonflammability. Four decks of cards were assumed for Shuttle.

EXERCISERS - EXER-GYM/HAND EXERCISER

The exer-gym is a commercial grade manufactured by Exer-Genie. The unit provides exercise by means of varying rope tension to produce the desired push/pull restraint forces. Exer-gym works by putting each foot in the strap loops and pulling rope with one or two hands. A storage container is provided for the exer-gym. The study assumed four exer-gyms were provided for Shuttle.

The hand exerciser is provided to keep hand and arm muscle condition. The hand exercisers are shaped to fit the hand and are used as a "squeeze" type exerciser for maintaining grip strength. The units are coated with Fluorel for nonflammability. The study assumed four hand exercisers were provided for Shuttle.

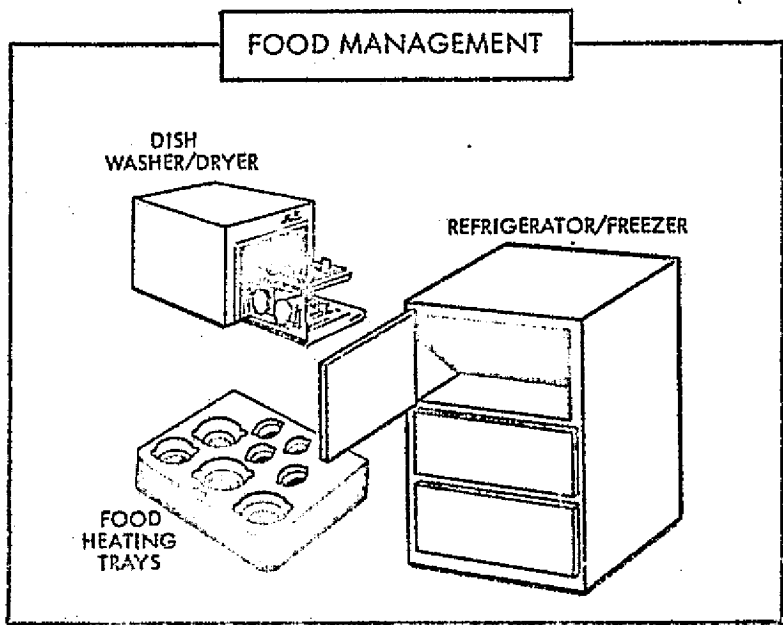
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2.1.3.5 Selected Space Station Appliance Concepts

The appliance system selected for the Shuttle Orbiter is described in the following paragraph. A summary of thermodynamic, electrical power, weight, volume, and consumables and flow requirements for each of these selected appliances is contained in Table 2.1-4.

2.1.3.5 (Continued)



REFRIGERATED/FREEZER STORAGE - SPACE RADIATOR

The refrigerator/freezer is simply an insulated food storage box, with coolant from the spacecraft ECS radiators routed through tubing within the refrigerator walls. This concept was used for the Skylab refrigerator. The Space Station refrigerators/freezers were sized proportional to the Skylab data based on the refrigerator/freezer food capacity. The wall insulation was 10.16 cm (4.0 inch) thick. It was assumed that the radiator coolant would be of sufficiently low temperature for this concept to be feasible.

FOOD WARMING - HEATING TRAYS (SKYLAB)

The heating trays consist of an insulated food tray with three heating cavities surrounded by imbedded electrical resistance heating elements. This concept was used on Skylab, and the actual Skylab weight/volume/power data were used for this study. A heating time of 1 1/2 to 2 hours is required to warm the food. Two hours was used for computing thermal penalties to the cabin cooling circuit. Each Skylab heating tray weighed 10.9 kg (24 lb).

DISHWASHER/DRYER COMBINATION - HOT WATER SPRAY WASH-FORCED HOT AIR ELECTRIC HEAT DRY

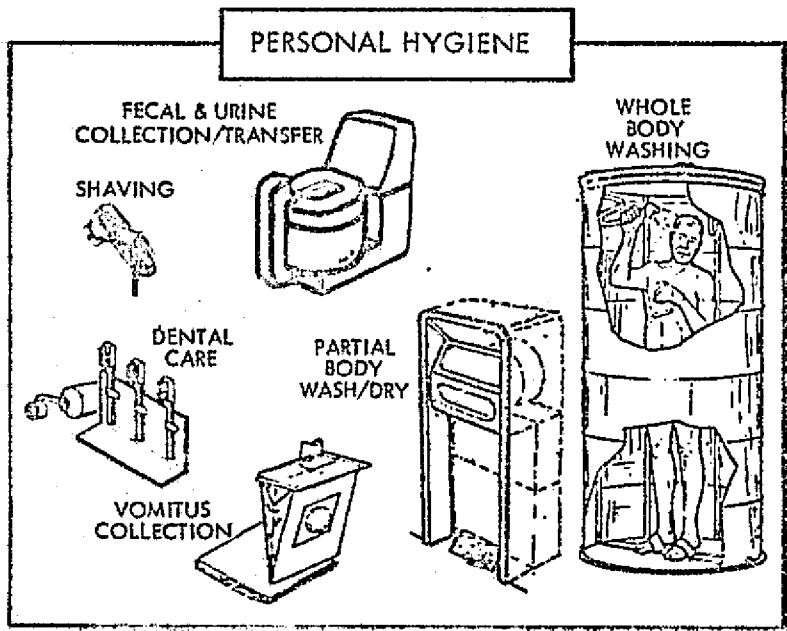
Dish washing is accomplished by spraying hot water (with an 8 psig pump head) over the dishes in a slowly rotating drum. Drying is accomplished by a circulating flow of air over the dishes which is heated by an electrical heating element. The heater also heats the dishes by radiation. Heater size was based on a 1 hour drying time.

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2.1.3.5 (Continued)

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FECAL/URINE COLLECTION/TRANSFER - DRY JOHN

The dry john commode assembly serves as a waste collector and feces/urine storage/processing unit. The seat is similar to the terrestrial type with modifications necessary for zero-gravity usage. The feces are transferred to the storage/processing section (collector) via the fecal transfer duct. The fecal transfer duct contains provisions for entrainment airflow for separating and moving the stool from the anus to the collector. Air positioning jets shown on the schematic are used to assist the user in positioning properly on the seat. This portion of the system was not considered part of the appliance, since recent tests have shown the jets are not necessary. The interface between the transfer duct and the feces collector is the collector valve. The valve is manually actuated and seals the collector after use to permit vacuum drying of the feces. A slinger is incorporated to maximize the feces and wipes area exposed to vacuum by depositing the feces and wipes on the wall of the collector. Entrainment air and air removed by the vacuum pump are passed through filters and returned to the cabin. A vacuum pump was assumed to satisfy the vehicle requirement of no venting external to the spacecraft.

VOMITUS COLLECTION/TRANSFER - PORTABLE DISPOSABLE COLLECTOR (AIRLINE TYPE)

The portable disposable collector is a light flexible bag with a drawstring closure device. The bag is used on all airlines and is made of thin gage plastic. The crewman can store the bag in a clothes pocket where it will be ready for use at any time. The bag is unfolded and grasped near the opening by both hands and held against the face enclosing the nose and mouth. Proper placement of the bag against the face provides the seal. The bag is sealed after use by tying a knot in the closure cord and discarding the bag and contents into the feces collector.

WHOLE BODY SHOWER - COLLAPSIBLE (SKYLAB)

The collapsible shower was used on Skylab. The shower stall is folded down for use to minimize space. The shower enclosure consists of two end ring closures and a translucent Beta cloth skirt with stiffening rings. One end ring attaches to the floor and the other to the ceiling when the shower is in use. Water is delivered through a nozzle with vacuum pickup of water. The waste water is centrifugally separated and routed to the water waste management system. Six pounds of water were assumed per shower. One towel per crewman per shower is used for drying.

PARTIAL BODY WASHING - REUSABLE WET WIPES

The reusable wet wipe appliance is a sponge bath technique used to clean local areas of the body. A wetting and soaping unit, with hand holes is supplied for the function. The unit has a water supply outlet, a storage area for soap and a fan for providing water entrainment during use. A centrifugal separator is provided upstream of the blower to collect used water. Water temperature is controlled by mixing hot with cold water in a temperature controlled mixing valve. The crewman first "soaps up" the wipe in the wetting unit, then uses it to clean the required areas of the body. The wipe is wrung out and rinsed inside the wetting unit. The rinsed damp wipe is used to wipe excess soap from the body. A final rinse and wringing out of the wipe is accomplished and reused. Reusable wipes are provided on a per man basis. The wipe is washed and dried using a washing machine and dryer. After 60 washings, the wipe is discarded and replaced. The reusable wipes are 10 inches square of 4 ply "wet strength" paper.

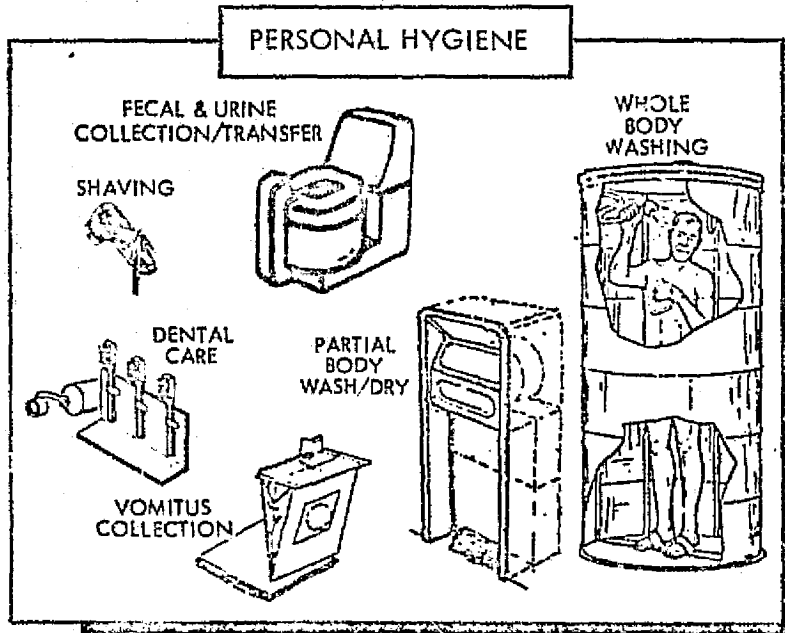
PARTIAL BODY DRYING - REUSABLE DRY WIPES

The reusable dry wipe appliance consists of wipes made of terrycloth. The terrycloth wipes are 15 X 30 inches and are used 10 times per day before washing. The concept includes the weight and volume of the wipe dispenser. The towels are washed and dried after one day of usage and are discarded after 60 washings. The concept is penalized for the washer/dryer function required to recycle the wipes. The terrycloth wipes are smaller and lighter than the terry towels used for whole body drying after showering.

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2.1.3.5 (Continued)

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SHAVING - DRY SHAVE-WINDUP RAZOR (SKYLAB)

The windup razor dry shaver consists of a mechanical windup motor shaver with a hair particle reservoir. The unit was used on Skylab and the weight and volume used were the same as the flight weight unit.

HAIR CUTTING - RAZOR-COMB/VACUUM COLLECTION

The comb/vacuum collection unit consists of a razor comb with a hand-held vacuum pickup device. The concept requires two men to operate which is a disadvantage from the crew time aspect. The unit used for vacuum collection is the power module used on Skylab.

NAIL CARE - MANUAL NAIL CLIPPER/BAG COLLECTION

The manual nail clipper/bag collection unit consists of a terrestrial type nail clipper enclosed by a bag to contain nail clippings. The bag incorporates a finger cuff and ring to form a seal around the finger during nail cutting. The collection bag is transparent to observe nail clipping.

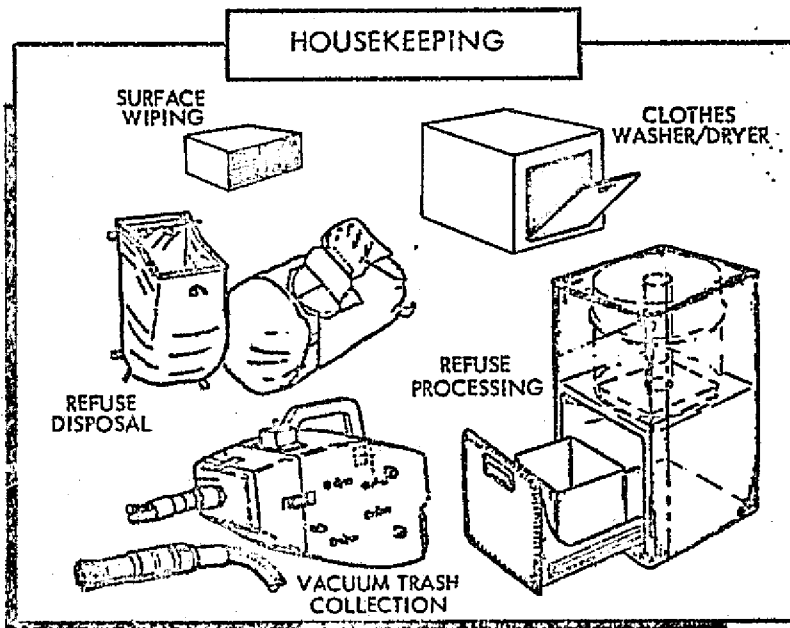
TEETH BRUSHING - TOOTHBRUSH WITH DENTIFRICE

The toothbrush with dentifrice consists of a terrestrial type toothbrush with dentifrice. The dentifrice is digestible to be nonhazardous if accidentally swallowed and is dispensed by a roll-up tube. Mouthwash is also provided in a soft plastic "squeeze bottle." One squeeze bottle per each crewman is provided for hygiene reasons. The mouthwash is used to mix with the dentifrice and is expectorated into a sink or fecal collector. This appliance has flown on Apollo.

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2.1.3.5 (Continued)

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SURFACE WIPING - REUSABLE WET/DRY WIPES

The reusable wet/dry wipes are used for equipment cleaning and drying. Terrycloth reusable dry/wet wipes are used a maximum of 5 times before washing. A wetting unit with hand holes is supplied for the function. The wetting unit has a water supply outlet and a fan for providing water entrainment during use. A centrifugal separator is provided upstream of the blower to collect used water. Water temperature is controlled by mixing hot with cold water in a temperature controlled mixing valve. The crewman wets the wipe, uses it for area cleanup (disinfectant soap is located at the wetting unit) and can be rewetted if necessary for cleanup. The wipe is wrung out in the wetting unit and is washed and dried after one day of usage and is discarded after 60 washings. The dry wipes are provisioned 3 per day for a maximum of 15 cleanup functions. The concept is penalized for the usage of a washer/dryer for recycling the cleaning and drying cloths.

MANUAL COLLECTION - WASTE/TRASH BAGS

The waste/trash bags employ trash bags and disposable bags for refuse collection. This appliance uses the bag concept used on Skylab. The trash containers are mounted on the back side of collector doors. The collector areas are located in the food management, personal hygiene, and other areas where significant amount of bulk refuse is generated. The study assumed 15 collectors for Space Station. Trash entry into the bag is through the front of the collection door through a slit in the bag. The refuse collection was based on its uncompressed volume. Disposable bags were applied for uncompressible trash. The disposable bags are held during use by snaps located at various locations throughout the vehicle. Both types of bags have bag closure devices to seal the bag after filling.

VACUUM COLLECTION - PORTABLE VACUUM/ELECTRIC (SKYLAB)

The portable vacuum/electric is identical to the vacuum used on Skylab. The vacuum has a hose and pickup attachments to assist in vacuum pickup. The unit has a strap and handle for carrying/using the unit. Vacuum cleaner bags were assumed to require changing once per week (.142 cycles per day).

REFUSE PROCESSING - COMPACTOR-AIR PRESSURE

The air pressure compactor uses air pressure against a piston for refuse compaction. The compactor is used for dry and moist compactible refuse. The unit provides a sterilant to the waste to prevent bacterial growth. The refuse is placed into a waste storage bag in the compactor. The compactor is actuated and compression of the refuse is accomplished using cabin air pressure of 40 psi. The piston used for the study was 9 inches square which results in 4000# of compaction pressure. The uncompressed refuse volume per day 2.45 FT³/day for Space Station was divided by the compactor volume of .47FT³ to determine the uses per day. Prior to tying the waste storage bag liner a sterilant capsule is placed into the bag. After tying, the capsule is broken releasing the sterilant gas.

REFUSE DISPOSAL - STORAGE BIN/CONTAINER

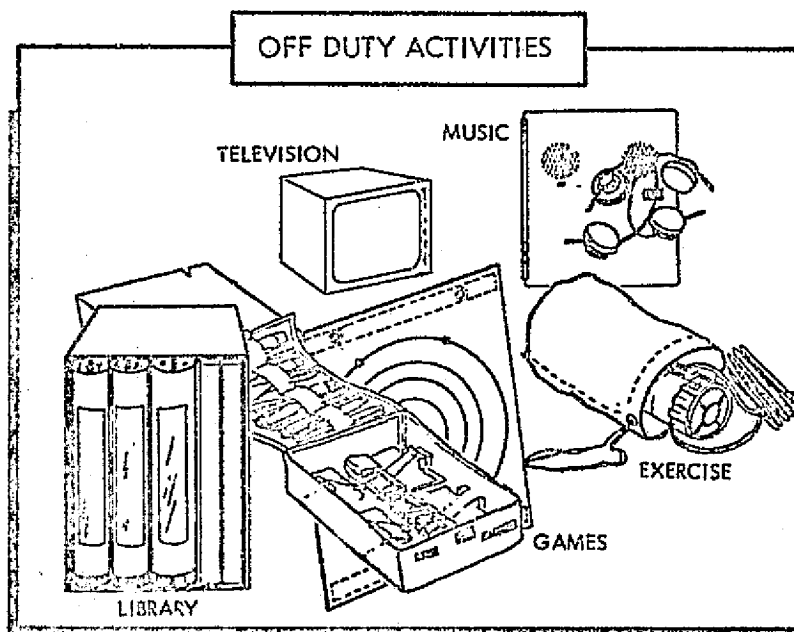
The storage bin/container employs a locker to store the refuse. Sterilant capsules were assumed for retarding the bacterial growth. The refuse was assumed to be collected by bags (Skylab, or equivalent) and transferred to the storage locker. A concept provides a sterilant capsule for each bag of refuse stored in the locker. The capsules used for the study were 2.25 grams each with a volume of .33 cubic inches. The walls of the storage locker were assumed to be aluminum. Sizing of the locker was based on the refuse volume including the storage bags.

GARMENT/LINEN - WATER SPRAY AGITATION/FORCE HOT AIR-ELECTRIC HEAT

The clothes washer cleans using a high velocity jet of water which is sprayed into a wire mesh drum from the outer circumference. The drum is slowly rotated to allow continuous removal of the water. A high speed spin cycle is used to remove the excess water after washing and rinsing. Clothes drying is accomplished using a jet of air spray at 60°C (140°F) which is directed into the clothes from outside the drum. The clothes are contained in a wire mesh drum which is rotated slowly in a direction counter to the air inlet. A prototype clothes dryer has been constructed utilizing this concept.

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2.1.3.5 (Continued)



MUSIC - CASSETTE PLAYER/RECORDER

The cassette player/recorder concept includes the following equipment: (1) tape player/recorder, (2) headsets, (3) microphone kit, (4) power cord/converter, (5) batteries, (6) cassette kit, and (7) wardroom speakers. The tape player can be used on conventional batteries or via a converter from 28 VDC to 6 VDC on spacecraft power. The tape recorder plays cassettes and is provided with a speaker and an adaption to headsets for private use.

LIBRARY - BOOKS

Books consist of individually selected off-the-shelf paperback books taken on the mission. The books are stored and when in use are provided with a cover for nonflammability. The covers are fabricated from Beta cloth.

VISUAL RECREATION - TELEVISION

The television provides programmed television programs to the crewmen. The data presented were based on 15-inch Panasonic. The Sony is also very similar to this model. The unit does not provide the means for use of video tape.

GAMES - HAND BALL/DART BOARD/DARTS/CARDS/BINOCULAR KIT/CALCULATOR

The handball appliance provides three hand balls, one pyrell, one sponge, and one rubber hand ball. The balls are covered with a nonflammable Fluorel covering. One commercial ball is coated with Fluorel. The pyrell NERF ball was dipped in ammonium-dehydrogen phosphate and coated with Fluorel. The third ball is a toy ball coated with Fluorel. The balls are packaged in a sponge rubber container.

The dart board appliance utilizes darts and board with velcro for a zero-g dart game. Twelve darts were provided with the heads covered with velcro hooks and attach to the board by means of velcro pile/hook attachment system. A dart holder container was provided as part of the concept. The system did not work well on Skylab (darts were not stable), so redesign of this system would be required prior to flight.

The card game provides card decks and card deck retainers for card playing in zero-g. The card retainer is constructed using a flexible strap with a magnet at each end. The assembly is covered with Beta cloth. The cards are standard cards manufactured using a lamination of three layers of Scheufelin paper E-20. Each deck is stored in an aluminum container for nonflammability. Eight decks of cards were assumed for Space Station.

The binocular kit provides binoculars for viewing distant objects such as earth and satellites. The binoculars are "trinovid" 10 X 40, manufactured by E. Leitz, Inc. Velcro attachment strips are provided for attachment when used in specified areas.

The calculator appliance provides a Hewlett-Packard HP-65 programmable pocket calculator. The calculator is an electronic slide rule with programmable tapes for special programs. The study assumed six units were supplied for Space Station.

EXERCISERS - EXER-GYM/HAND EXERCISER

The exer-gym is a commercial grade manufactured by Exer-Genie. The unit provides exercise by means of varying rope tension to produce the desired push/pull restraint forces. Exer-gym works by putting each foot in the strap loops and pulling rope with one or two hands. A storage container is provided for the exer-gym. The study assumed six exer-gyms were provided for Space Station.

The hand exerciser is provided to keep hand and arm muscle condition. The hand exercisers are shaped to fit the hand and are used as a "squeeze" type exerciser for maintaining grip strength. The units are coated with Fluorel for nonflammability. The study assumed six hand exercisers were provided for Space Station.

2.1.4 Shuttle Freezer Conceptual Design

Crew Systems Division was requested by the Life Sciences Directorate to determine the feasibility of a freezer for the frozen storage of whole food items as well as medical samples which would not be permanently mounted, but which could be readily installed on board the Shuttle for selected orbital missions. The development of the freezer conceptual design, which is described in detail in Reference 3, is summarized in this section.

Primary design requirements of the freezer are that it be a portable appliance which can be easily installed and removed, that it provide storage capacity and restraint for a designated amount of food and medical samples, and that the storage space be maintained at a particular thermal environment. The design must be such that it has a minimum of interface requirements with Shuttle systems and require no penetration of the Orbiter cabin pressure wall. Food and medical samples must be stored to provide isolation from one another. And the freezer must operate in the environment of the Orbiter crew compartment. The design mission duration is 30 days and the number of crew members is seven (7).

Frozen foods to be stored in the freezer are common foods such as meats, vegetables, fruits, and ice cream which will augment the normal Shuttle crewman's diet of rehydrated foods. The food volume and weight requirement is derived from an average of two (2) frozen servings per day per crewman for an entire 30-day mission (a total of 420 servings). Each serving will have a packaged dimension of 4" x 4" x 1". The total launch food weight and volume requirements derived from these specifications is 215 pounds and four (4.0) cubic feet, respectively.

Food will be held at -40°F prelaunch and stowed in the freezer initially at this temperature. The freezer will maintain food items at an average temperature of from 0°F to -20°F .

2.1.4 (Continued)

Samples of each crewmember's urine and feces are to be collected during the entire Orbiter mission duration and stored in the freezer for return to earth. Urine samples are collected continuously from all crewmen and placed into the freezer once a day. Feces samples are to be placed into the freezer as they are collected. Total medical sample weight and volume stored in the freezer during a 30-day mission are 128.3 pounds and 2.63 cubic feet, respectively.

2.1.4.1 Freezer Volume Optimization

Because of the critical space limitations of the Orbiter crew compartment and the shape constraints created by the Orbiter side hatch opening and potential mounting configurations, an optimization effort was conducted to provide a freezer envelope which would make the most efficient use of the space available. This optimization was accomplished by first determining the most efficient freezer compartmentation arrangement and then defining the envelope within which the freezer must be designed. The storage volume was divided into four individual compartments with volumes of .06, 1.00, 1.40, and 1.60 cubic feet.

The fill and empty sequence begins with the 0.6 ft³ empty volume being filled with medical samples as the smallest food storage volume (1.0 ft³) is being emptied. These volumes are sized such that a food storage volume is completely empty as the sample volume is completely full; then medical samples are placed into the empty food storage volume. This sequencing is continued during the duration of the mission with the remaining three food storage volumes.

2.1.4.2 Freezer Envelope Definition

Two dimensional constraints were considered in defining the freezer envelope: (1) the crew equipment storage module dimensions and (2) the side hatch opening. Equipment storage modules have standard external dimensions and

2.1.4.2 (Continued)

mounting fixtures and are to be mounted in arrays on both the forward and aft bulkhead of the Orbiter crew compartment. Location and arrangement of the modules are illustrated in Figures 2.1-9(a) and 2.1-9(b). The modules are mounted on posts, which extend from the Orbiter floor to ceiling, using fasteners located at each corner of each module. As seen in Figure 2.1-9(b), when in place the storage modules form the forward bulkhead of the crew compartment. Each module is independently mounted and can be individually removed; however, if a module is omitted, a close out panel must be installed to insure the composite strength of the entire storage module system. Modules are independently supported (do not rely on the floor or other modules) and are separated from adjacent modules by 3/8 inch on all sides.

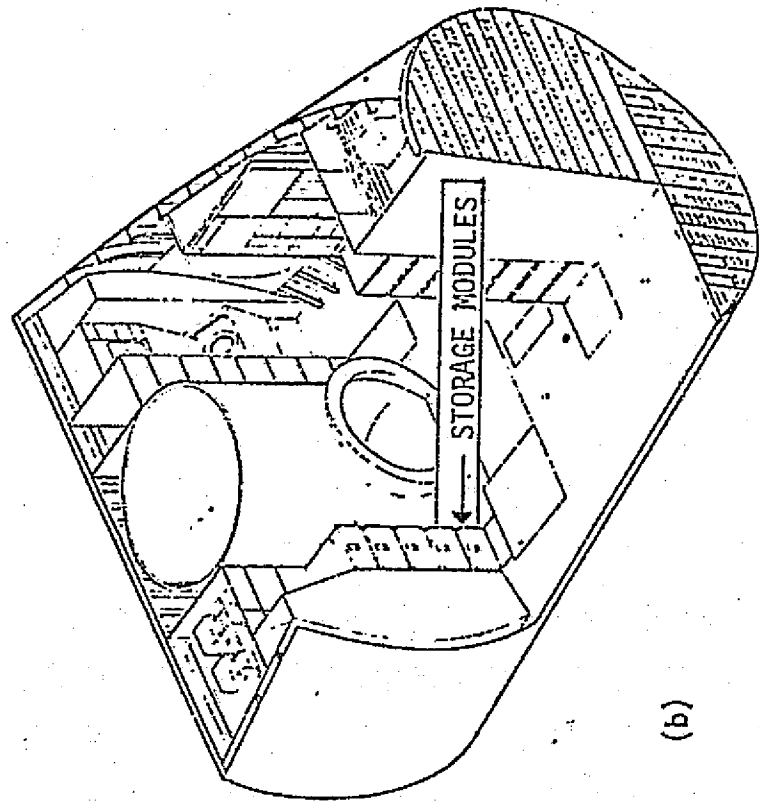
The volume which can be passed through the Orbiter side hatch is defined by a 25" x 25" x 50" rectangular volume. This limited the freezer dimensions to the equivalent volume of four storage modules.

2.1.4.3 Freezer Refrigeration System Description

The freezer refrigeration system includes the storage volume to refrigeration unit (R/U) heat transmission system and the refrigeration unit. Since the onboard Orbiter liquid cooling temperatures are not low enough to provide the desired storage temperature, the refrigeration system must therefore utilize a mechanical refrigeration device. Several options are available to transfer the heat gained in the storage volume to the refrigeration unit (R/U). These options can be divided into three basic types: (1) circulating cooling medium, (2) circulating refrigerant and (3) directly connected R/U. These types are illustrated schematically in Figure 2.1-10 with two identified options (A and B) for each type.

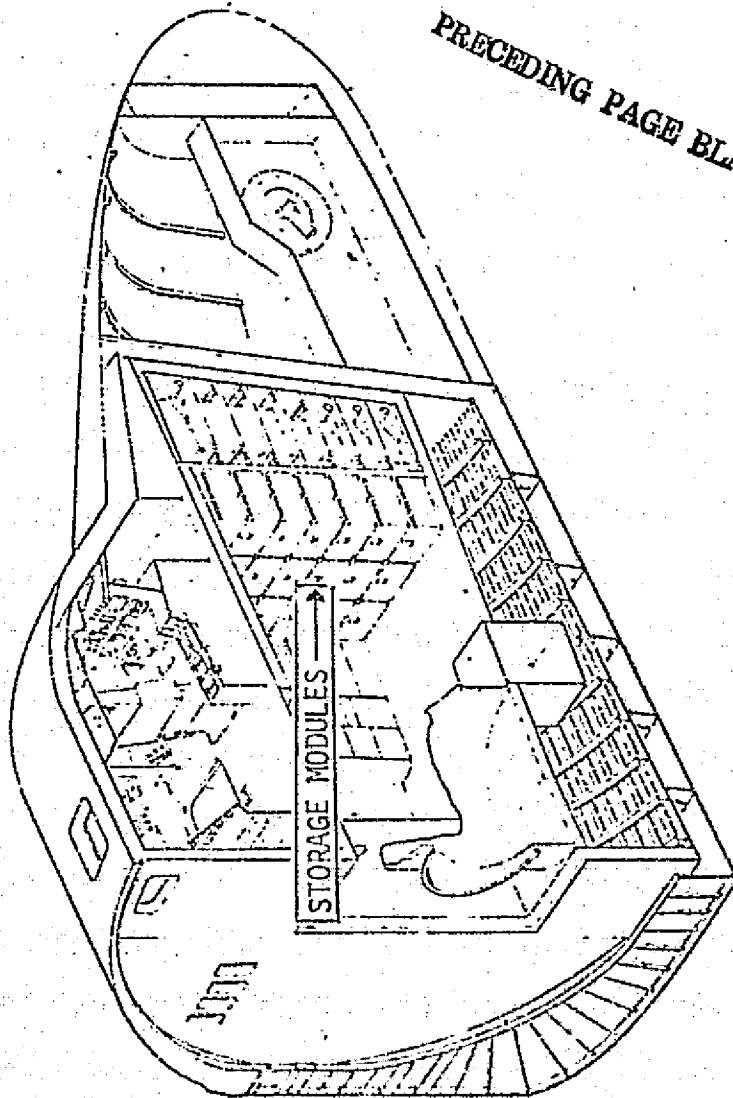
Of the six types of heat transmission presented, type IB is eliminated because of higher volume requirement necessary for the three individual connective systems (fans and finned heat exchangers) and the inherent higher

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(b)

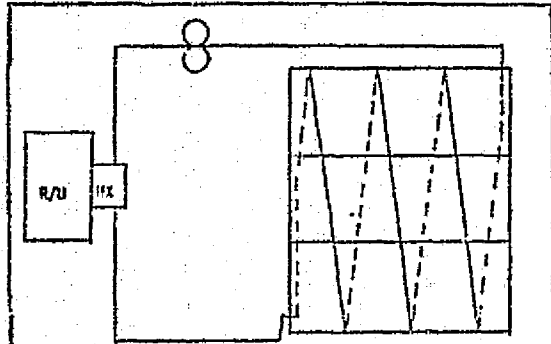
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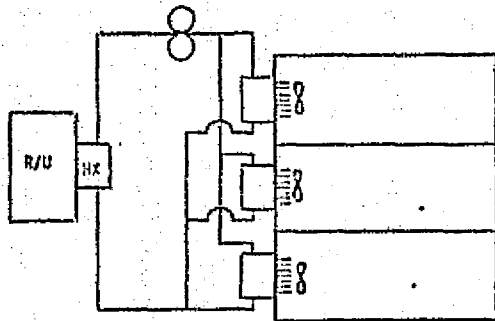
(a)

Figure 2.1-9 Crew Compartment Configuration

CIRCULATING COOLING MEDIUM
TYPE I

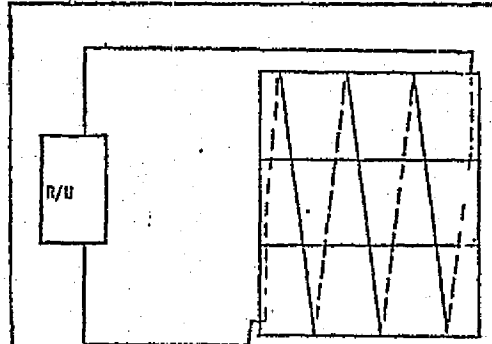


- A. TUBULAR DISTRIBUTION
 ○ EXTERNAL COOLANT LOOP

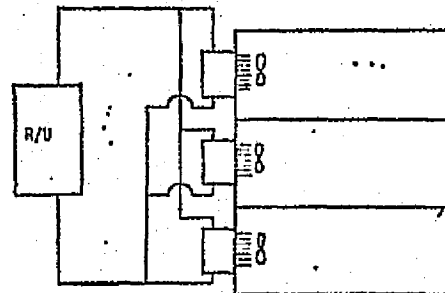


- B. COLD PLATES WITH FORCED CONVECTION
 ○ EXTERNAL COOLANT LOOP
 ○ INDIVIDUAL COMPARTMENT TEMPERATURE CONTROL

CIRCULATING REFRIGERANT
TYPE II

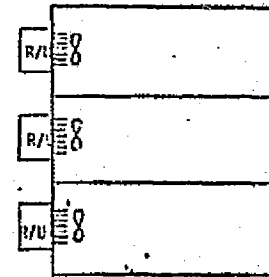


- A. TUBULAR DISTRIBUTION
 ○ COOLANT INTEGRAL TO R/U - NO EXTERNAL PUMP REQUIRED

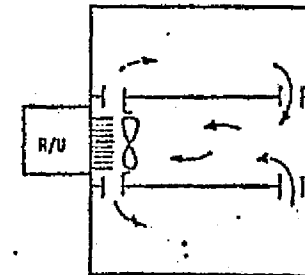


- B. COLD PLATES WITH FORCED CONVECTION
 ○ COOLANT INTEGRAL TO R/U - NO EXTERNAL PUMP REQUIRED
 ○ INDIVIDUAL COMPARTMENT TEMPERATURE CONTROL

DIRECT CONNECTION - FORCED CONVECTION
TYPE III



- A. ISOLATED COMPARTMENTS
 ○ LIMITED TO THERMOELECTRIC
 ○ INDIVIDUAL COMPARTMENT TEMPERATURE CONTROL
 ○ MULTIPLE R/U



- B. COMMON CIRCULATION
 ○ SINGLE R/U

Figure 2.1-10. Storage to R/U Heat Transmission Options

2.1.4.3 (Continued)

electrical power consumption and weight. Both options in type II are eliminated due to the potential safety hazard presented in circulating the R/U refrigerant outside the sealed volume of the R/U. And the type IIIB is eliminated since it violates the requirement for isolation of medical samples from food. Therefore, types IB and IIIA are the systems best suited for storage volume to R/U heat transmission.

2.1.4.4 Refrigeration System Trade Study

A screening of potential R/U concepts was conducted by LTV Aerospace to identify those concepts which were applicable to the requirements of the Shuttle freezer performance. Refrigeration concepts considered by LTV and a critique of each is tabulated in Table 2.1-5. Of these concepts, three were chosen for continued evaluation:

- o Thermoelectric
- o Stirling Cycle
- o Vapor Cycle

The working gases for the Stirling cycle and the vapor cycle are helium and ammonia, respectively.

A performance description, which covered the operating range required by the Shuttle freezer, was derived for each of these concepts using three R/U heat sink approaches: (1) cabin air at 80°F, (2) water cooling at 80°F, and (3) water cooling at 45°F. Preliminary estimates of the thermal leakage and thermal perturbation rates were made to determine the peak and average cooling rates to be developed by the R/U. Using these values the thermal loads weight and electrical power requirements of the three R/U types were derived for each mode of cooling.

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TABLE 2.1-5. REFRIGERATION UNIT CANDIDATES

REFRIGERATOR		MISSION SUITABILITY	HARDWARE DEVELOPMENT STATUS	FIXED ELEMENTS		COP	SAFETY PROBLEMS	COSTS		COMMENTS
				WEIGHT	VOLUME			DEVELOPMENT	RECURRING	
CYCLE REFRIGERATORS	STIRLING	GOOD	SOME UNITS AVAILABLE SUITABLE FOR ZERO G USE	GOOD	GOOD	GOOD	NONE	FAIR	MORE EXPENSIVE THAN VAPOR COMPRESSION	DEVELOPMENT IS NEEDED BUT COSTS SHOULD BE REASONABLE
	VM	QUESTIONABLE	SOME UNITS AVAILABLE SUITABLE FOR ZERO G USE	GOOD	GOOD	FAIR	NONE	FAIR	MORE EXPENSIVE THAN VAPOR COMPRESSION	CONSIDER ONLY IF VERY LONG LIFE AND LOW POWER CONSUMPTION ARE NEEDED
	BRAYTON	NOT A VIABLE CANDIDATE								LOW COP AND NEEDS DEVELOPMENT FOR THIS TEMPERATURE
VAPOR CYCLE (V-C) REFRIGERATORS		GOOD	<ul style="list-style-type: none"> NO DEVELOPMENT OF APPROPRIATE SIZE EQUIPMENT FOR ZERO G EXISTING HARDWARE WHICH TOO LARGE OR IS NOT SUITABLE 	GOOD	GOOD	VERY GOOD	FLUIDS FOR CYCLE	MORE EXPENSIVE THAN STIRLING	MORE EXPENSIVE THAN V-C	<ul style="list-style-type: none"> NEEDS DEVELOPMENT OF A ZERO G COMPRESSOR MAY BE ABLE TO MODIFY A STIRLING MACHINE
ABSORPTION/ ABSORPTION REFRIGERATORS		NOT A VIABLE CANDIDATE								SEVERAL FACTORS MAKE THIS CHOICE UNCOMPETITIVE
THERMOELECTRICS (T/E)		GOOD	PRODUCTION UNITS AVAILABLE FOR SPACECRAFT USE	EXCELLENT		POOR	NONE	NONE	EXCELLENT	COP MAY REQUIRE EXCESSIVE POWER AT THIS LOAD AND TEMPERATURE
EXPENDABLES		NOT A VIABLE CANDIDATE								PENALTY FOR CONSUMABLES IS TOO HIGH FOR ONE YEAR RESUPPLY
DIRECTIONAL SPACE RADIATORS		QUESTIONABLE SUITABLE FOR ORBIT MISSION PHASE ONLY	SPACE QUALIFIED	POOR	POOR	EXCELLENT	MINOR	FAIR	FAIR	<ul style="list-style-type: none"> SYSTEM SUFFERS FROM HIGHLY COMPLEX INTERFACES QUESTIONABLE FEASIBILITY WITHOUT ORIENTATION CONSTRAINTS

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2.1.4.4 (Continued)

The combination of three R/U concepts and three heat sink options provided nine (9) individual R/U systems which could be traded. The engineering data along with the more intangible characteristics such as reliability, safety, and maintenance factors were used as inputs to a computerized trade program developed for the Crew Appliance Concepts study (Reference 1).

The results of freezer concept trade are tabulated in Table 2.1-6. Briefly, the table illustrates (from left to right) each weighing factor (or criteria) being evaluated and the minimum and maximum of the nine values investigated with an arbitrary maximum number of points (PTS) assigned to each factor. The number of points awarded for each of the nine concepts is tabulated in columns labeled 1 through 9. The curve for determining the points awarded is a straight line of value (lbs. ft³, watts, etc.) versus points having a negative or positive slope depending upon the contribution of the factor to the Shuttle performance. For example, weight is a negative factor, therefore the point assignment line will be negative; whereas, reliability is a positive asset and the line will be positive.

The total points listed reflect the summation of those points determined for each factor for each concept. The maximum number possible is 85.

The final rating shown on the last line is the ratio of the point summation to the maximum possible points (85) shown in percent. The Stirling cycle system utilizing 45°F water cooling provides the highest rated concept. However, because of a location restriction which could be imposed on a water cooled system, NASA directed that preliminary design studies of the freezer be conducted using a cabin air cooled system. Of the air cooled concepts the Stirling cycle rated highest. It was therefore decided to proceed with a freezer preliminary design utilizing the air cooled, Stirling cycle concept to satisfy the R/U function.

TABLE 2.1-6. CREW APPLIANCE SELECTION MATRIX FOR FREEZER

SELECTION MATRIX FREEZER (SHUTTLE)

FACTOR	MIN VALUE	MAX VALUE	PTS	CONCEPT								
				1	2	3	4	5	6	7	8	9
WEIGHT	76.000	151.00	15	.00	5.17	5.76	3.68	5.86	6.66	7.45	7.35	7.25
POWER	38.000	363.00	15	.00	12.11	10.00	5.08	12.85	11.07	10.54	13.43	11.69
VOLUME	9.2000	9.2000	10	.00	.00	.00	.00	.00	.00	.00	.00	.00
THERMAL	130.00	1238.0	15	.00	12.12	10.01	5.06	12.86	11.07	10.54	13.42	11.69
RELIABILITY	.97617	.99465	5	.00	.58	1.65	2.18	2.80	3.85	2.18	2.80	3.88
MAINTENANCE	.99998	1.00000	5	.00	.63	1.74	1.83	2.51	3.57	1.83	2.51	3.62
SAFETY	.00000	1.0000	5	.00	.00	5.09	.00	.00	5.00	.00	.00	5.00
DEV COST	35.000	80.000	15	8.44	.00	2.81	8.44	.00	2.81	8.44	.00	2.81
TOTAL PT	.00000	85.000	85	8.44	30.60	36.97	26.27	36.88	44.04	40.98	39.51	45.95
RATING	.00000	100.00	100	9.93	36.00	43.50	30.91	43.38	51.81	48.21	46.47	54.05

APPLIANCE CONCEPT NO.	CONCEPT NAME
1	THERMOELECTRIC-CABIN AIR COOLING
2	VAPOR COMPRESSION-CABIN AIR COOLING
3	STIRLING CYCLE-CABIN AIR COOLING
4	THERMOELECTRIC-WATER COOLING (80 DEG.)
5	VAPOR COMPRESSION-WATER COOLING (80 DEG.)
6	STIRLING CYCLE-WATER COOLING (80 DEG.)
7	THERMOELECTRIC-WATER COOLING (45 DEG.)
8	VAPOR COMPRESSION-WATER COOLING (45 DEG.)
9	STIRLING CYCLE-WATER COOLING (45 DEG.)

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2.1.4.5 Refrigeration Unit Design

Once the Stirling cycle concept was chosen as the type of system to be used as the refrigeration unit, LTV Aerospace was assigned the responsibility to size and package the unit for the freezer and to determine its performance requirements. A detailed description of the theory and design of the Stirling cycle unit can be found in Reference 12.

After sizing of the external freezer envelope and satisfying the storage volume requirements, the remaining volume was allocated to thermal insulation and the refrigeration unit. Calculations were made to determine the maximum insulation thickness possible with enough volume remaining to accommodate the R/U. An insulation thickness of approximately 2.0 inches was used and a volume with dimensions of 9" x 12" x 20" was allocated to the R/U. Based on these conditions, the maximum design thermal load to the refrigeration unit was 75 watts. This value includes heat leakage, effects introduced by compartment door openings and warm medical samples, and heat from the cooling liquid pump. Characteristics of the conceptual Stirling cycle refrigeration unit devised by LTV are listed in Table 2.1-7.

2.1.4.6 Mechanical Design and Structural Analysis

The function of the freezer structure is to provide support and restraint to stored items and to the R/U. In addition, it also provides thermal insulation of the stored volume from the ambient environment and acts as a thermal conductor to the circulating coolant. Because the freezer is to use the crew equipment storage module mounting system, the freezer structural configuration was heavily influenced by the module design. A cutaway illustration identifying the basic mechanical design features of the freezer concept is shown in Figure 1.5-1.

The freezer design consists of a number of individual elements of which some serve functions other than structural. The structure is basically two boxes, one inside the other and thermally insulated from one another.

TABLE 2.1-7
REFRIGERATION UNIT PERFORMANCE

o	Refrigeration Cycle	:	Stirling
o	Cooling Rate	:	75 watts from Coolant 15 (\approx 70 watts excluding the pump)
o	Refrigerant	:	Helium
o	Power Consumption	:	
	- Regulated 28 VDC (Best estimate)	:	176 watts (Range 115 to 200 watts)
	- 200 VAC 400 Hz 3 \emptyset Regulated AC	:	30 watts (Fan)
			<hr/>
	TOTAL		206 watts
o	Coolant 15 Heat Exchanger		
	- Pressure Drop At		
	Flowrate = 105.3 lb/hr	:	$\Delta P = 0.22$ psi
	Flowrate = 210.6 lb/hr	:	$\Delta P = 0.44$ psi
o	Mass Properties		
	- Weight of Unit	:	20 lbs
	- Center of Gravity	:	12.7 in. from Front Face, Center of 5" x 12" plane
o	Life		
	- Refrigeration Unit System	:	8000 hours
	- Maintenance Interval (Helium servicing, replacement of motors, etc.)	:	2000 hours

2:1.4.6 (Continued)

Fasteners which attach the freezer to the storage module mounts are located on the outer box. The outer box is effectively suspended within the inner box by foam-on-place polystyrene. Connection between the inner and outer boxes is made at the front of the freezer by a one-piece framework on which the door seals and hinges are mounted. Minor attachments between the two boxes are made in back of the inner box. The refrigeration unit is located on a pallet which attaches to the outer box.

An analysis was conducted to determine if the proposed design is adequate to maintain the proper structural rigidity and integrity during the various phases of the Shuttle flight envelope. The primary items investigated were (1) mounting fastener loads, (2) thermal insulation deformation and (3) inner box restraint. This analysis indicated the proposed freezer structure was adequate for all imposed loads encountered during the Shuttle mission.

2.1.4.7 Freezer Thermal Analysis and Evaluation

Two thermal models were constructed using the SINDA (Systems Improved Numerical Differencing Analyzer) thermal analyzer computer program to select and verify the thermal design of the freezer. The first was a simplified two-dimensional representation of a single slice through the freezer. Its purpose was to examine the effect of spacing between the coolant tubing. The second model was a detailed three-dimensional nodal network of the entire freezer, with capability for varying and analyzing the effects of coolant tubing routing, medical sample insertion, refrigeration unit size and control scheme, structural thermophysical properties, and other pertinent design details.

The two-dimensional model neglects corner and end effects and assumes a semi-infinite plane with embedded coolant tubes spaced at regular intervals. Due to symmetry, it was necessary to model only one-half a section between

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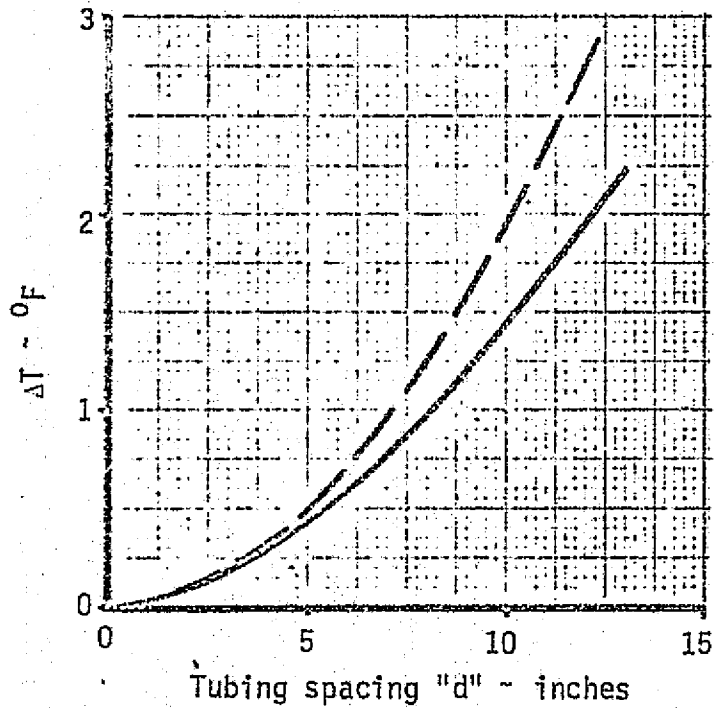
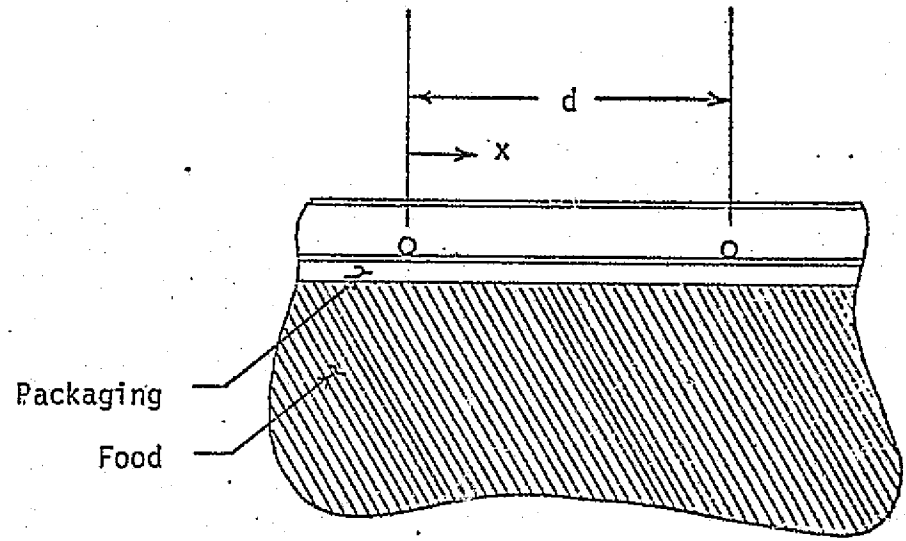
two cooling tubes. A -10°F coolant temperature was held constant in the tubing, with 80°F ambient conditions. Steady state runs were made assuming a distance between coolant tubes from 2 to 12 inches.

The effect of tubing spacing on the food temperatures is shown in Figure 2.1-11(a) for a food thermal conductivity of $1.0 \text{ Btu/hr-ft-}^{\circ}\text{F}$. An air/packaging gap was included in the model between the food and wall. The effective thermal conductivity of this gap was varied between 1.0 (equal to that for the food) and 0.0 to determine the maximum and minimum effects of this variable. The results in Figure 2.1-11(b) show a maximum food temperature variation between coolant tubes of 1.0°F with an eight (8) inch tubing spacing. After considering other temperature gradients throughout the freezer due to coolant warmup, edge effects, attach points, internal conductive aluminum spacer walls, etc., this spacing was chosen as a general guideline in initially routing the coolant tubing.

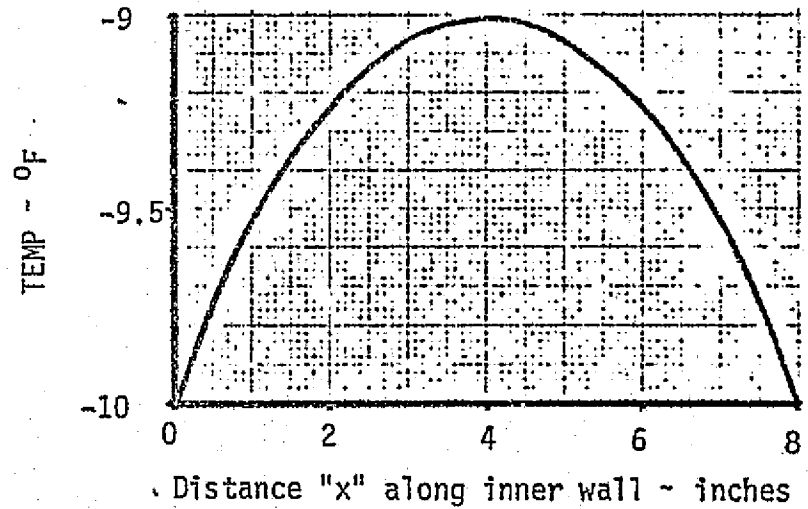
The three-dimensional model was developed to aid in selection of materials, configuration, and mating of the storage compartment with the refrigeration unit, and to provide verification of the final thermal design. The model comprises 169 nodes and 656 conductors, and was constructed with generalized inputs to accommodate continuing design changes. The model accounts for all corner and edge effects, structural hard attach points, control scheme, and effects of door opening and medical sample insertion.

Transient results from the model are shown in Figures 2.1-12 and 2.1-13 for an 80°F ambient temperature. The input conditions for this case were selected as representing worst-case design criteria. The maximum effect of five door openings, beginning at 3 hours time, is seen in Figure 2.1-12. This effect includes the sensible and latent heat from an assumed 0.5 cubic feet of air exchange with ambient surroundings for each door opening. The temperature effect from this is minimal, and the total energy input is negligible. At a time of 6 hours, a combined one-day's sample of urine

- - - - - $k_{\text{packaging}} = 0$
 _____ $k_{\text{packaging}} = k_{\text{food}}$



(a) Max Temperature Increase Along Inner Wall



(b) Temperature Profile Along Inner Wall (d = 8 in.)

Figure 2.1-11. Effect of Coolant Tubing Spacing on Food Temperature

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2-58

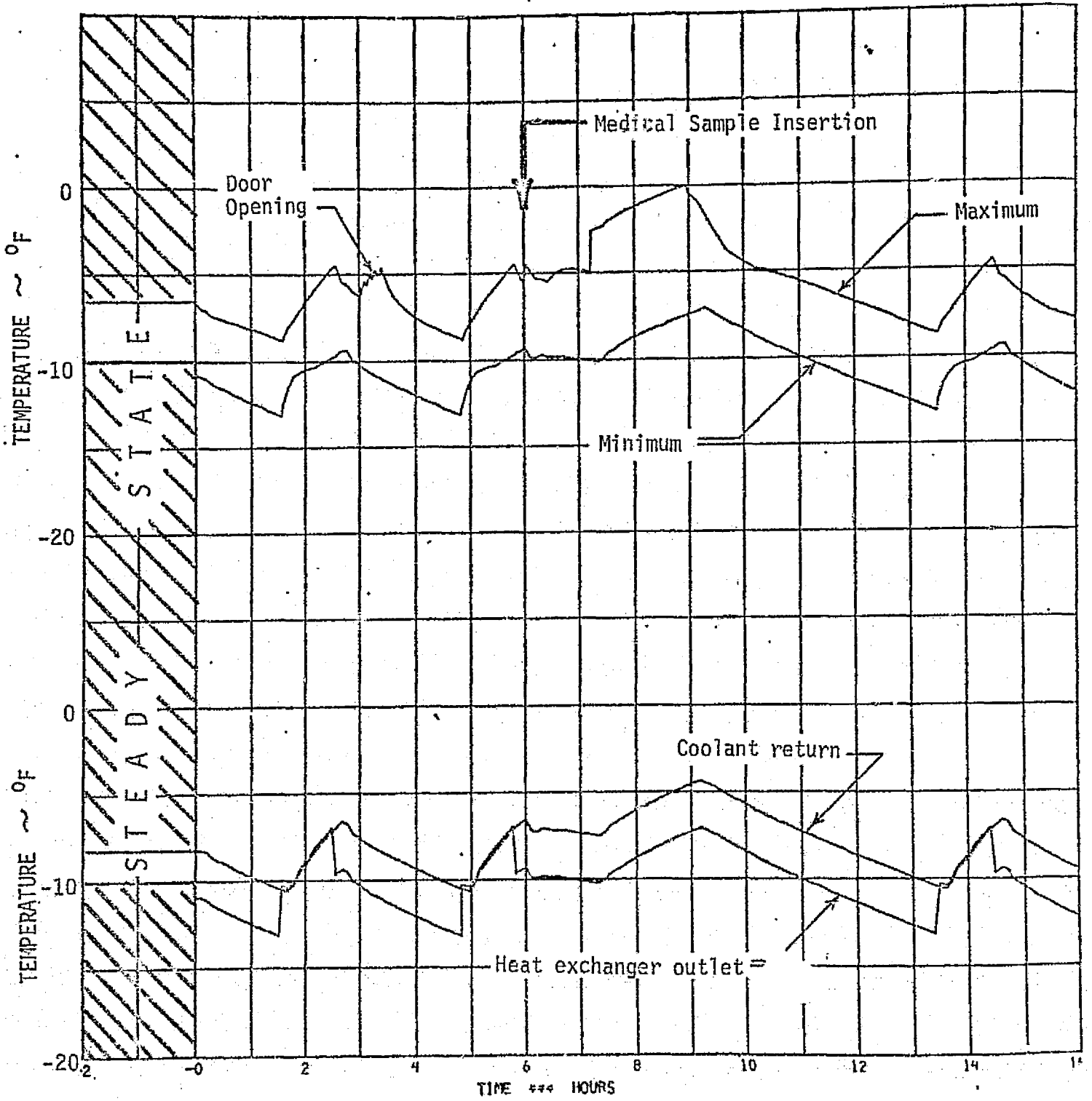


Figure 2.1-12. Transient Freezer Thermal Response Under "Worst-Case" Conditions

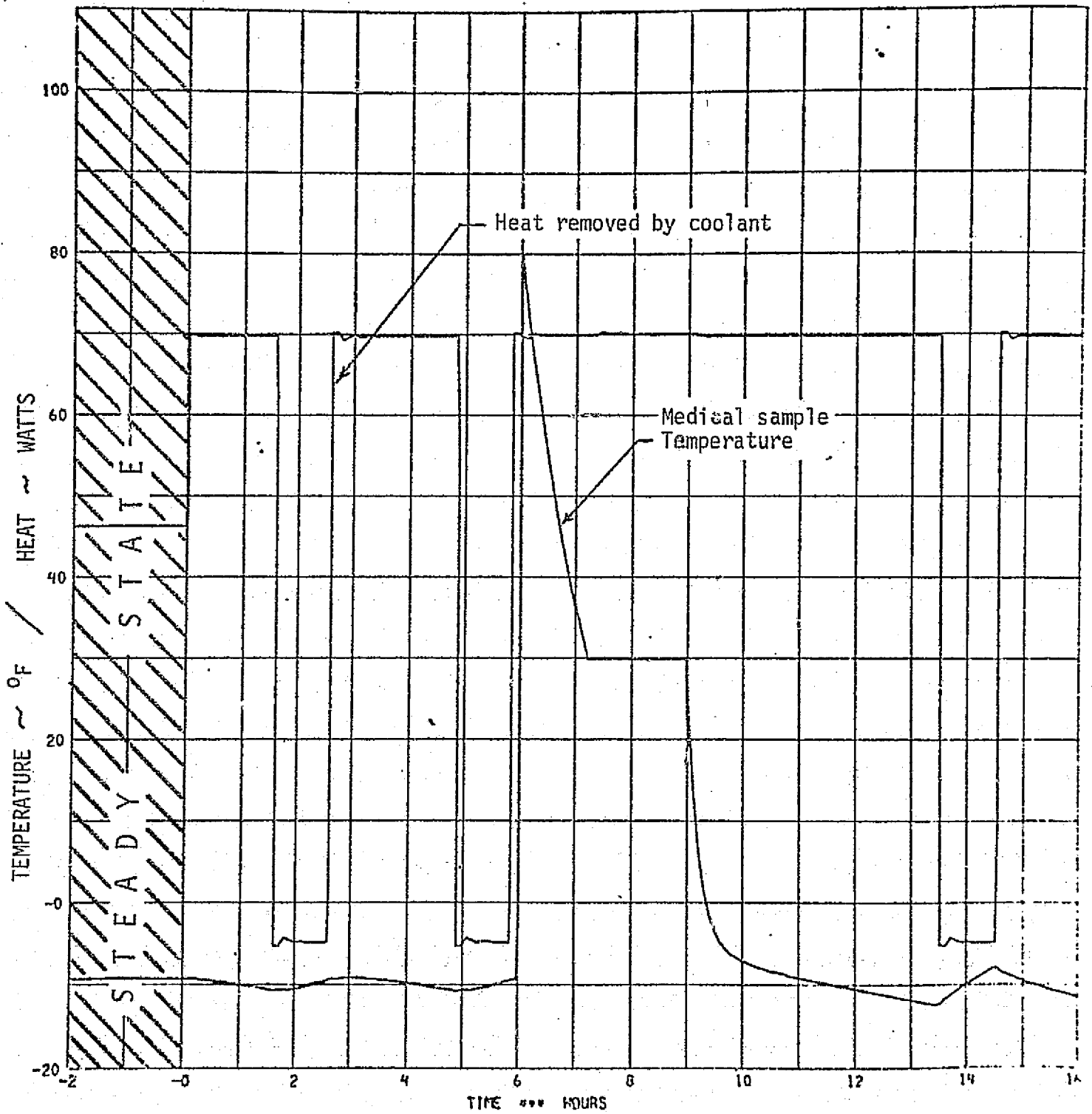


Figure 2.1-13. Transient Medical Sample Temperature and Coolant Heat Removal under "Worst-Case" Conditions

2.1.4.7 (Continued)

and feces for seven men was inserted directly adjacent to cooling tubes at the rear cold wall of the freezer. This sample was initially at 80°F and contained a total of 2.15 pounds of water. The sample cool-down profile is shown in Figure 2.1-13 (for a urine freezing temperature of 30°F), and the effect on adjacent samples and the freezer coolant return temperature is shown in Figure 2.1-12.

In Figures 2.1-14 and 2.1-15 are shown the results of a baseline case for comparison with no medical sample insertion or door openings. Again, ambient temperature was assumed 80°F. The refrigeration unit duty cycle (fraction of the total time it is turned on) for this case was found to be 69 percent. Another run with identical conditions except for 70°F ambient temperature resulted in a steady state duty cycle of 62 percent.

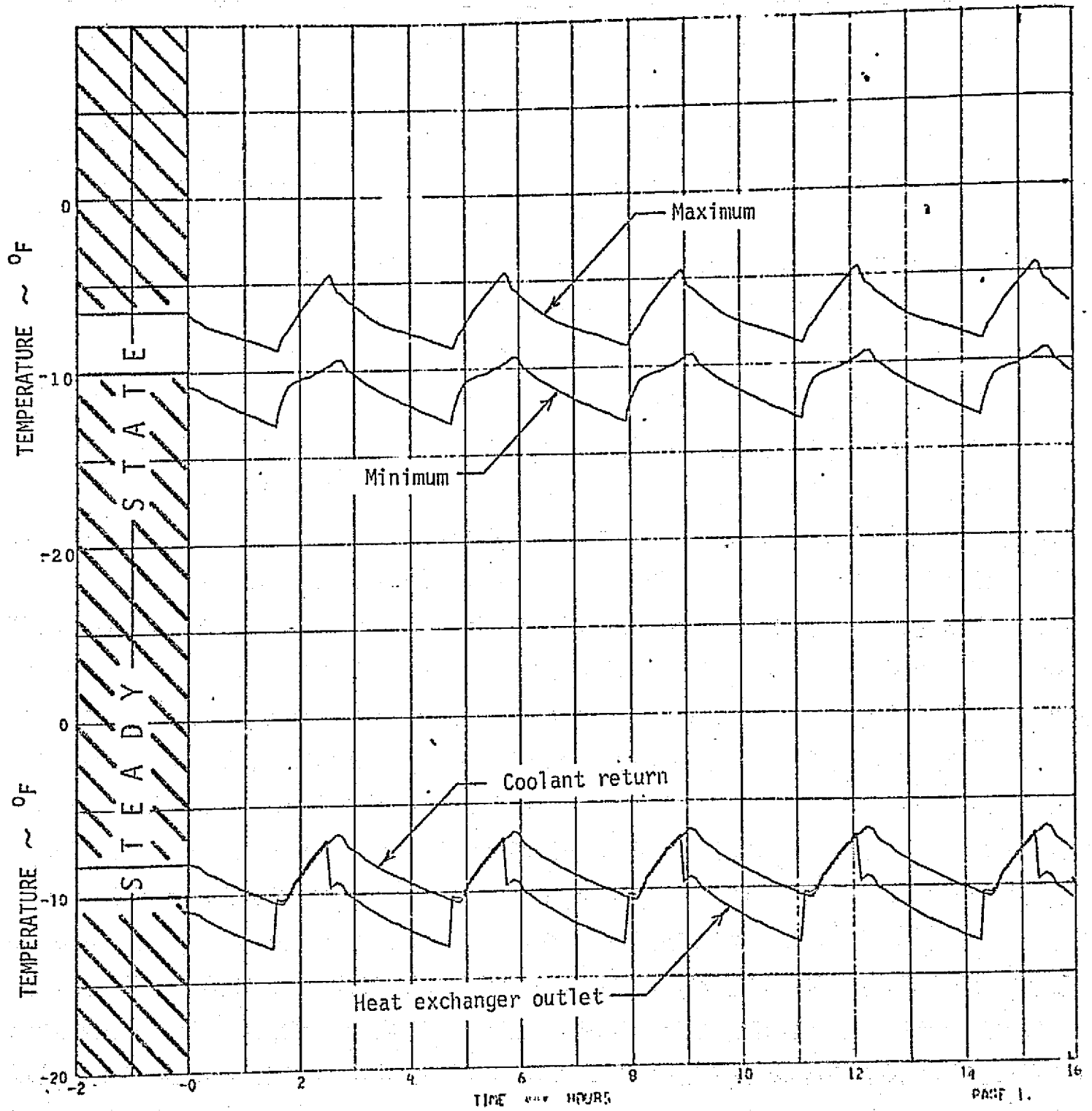


Figure 2.1-14. Transient Freezer Thermal Response With No Door Opening or Medical Sample Insertion

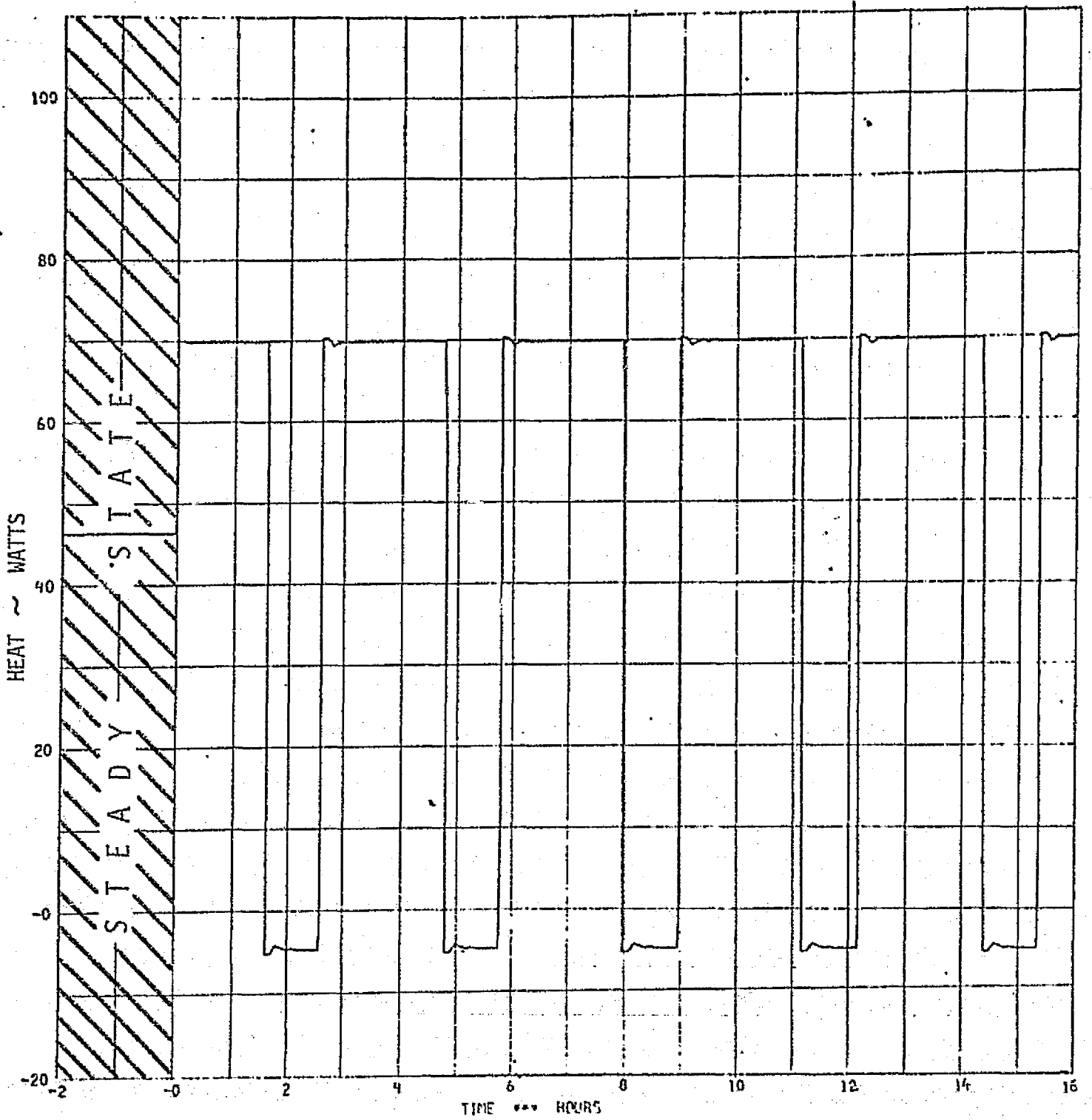


Figure 2.1-15. Freezer Transient Coolant Heat Removal With No Door Openings or Medical Sample Insertion

2.2 TASK 2.0, PREPARATION OF MATH MODELS

Future spacecraft analysis effort will require simulation of crew appliances using the G-189A ECLSS Computer Program, Reference 5. This program provides system level ECLSS performance simulation by performing mass and energy balances throughout all the interactive components and flow loops comprising a total system. Use of the G-189A program requires a subroutine for each component in the system. These subroutines are all similar in that a standard format of G-189A flow and thermodynamic data form the input for each. The input data for a given component are taken from the output data from the upstream component. The subroutine then must modify these input data in a manner which reflects the performance of the component it models, and present the output data in the required G-189A format. The program allows the user to control or modify the solution as it progresses by calling two subroutines, GPOLY1 and GPOLY2, immediately prior to and following each component solution. These routines may be used, for example, to alter fluid flow paths, turn components on or off, reevaluate component model data based on the current solution results, and compute and store parameters for later plotting.

The optimum appliance concepts selected from the trade studies in Section 2.1 are shown in Tables 1.1-1 and 1.1-2 for Shuttle Orbiter and Modular Space Station. Some of these concepts do not require a new G-189A subroutine since (1) a routine is already available, (2) no thermal/mass exchange is involved, or (3) operation of the component is so simple it requires only a minor addition to the GPOLY routine logic. Appliances in this category are as follows:

- | | |
|--|--|
| o Reusable dishes, wet and dry wipes | None needed |
| o Vomitus collection | None needed |
| o Partial body washing, wet wipes | Simple GPOLY logic only required |
| o Partial body drying, dry wipes or electric dryer | None needed (or a simple heater using G-189A routine ALTCOM) |

2.2 (Continued)

- | | |
|----------------------------|--|
| o Wet shave | GPOLY logic required for water usage only |
| o Windup razor | None needed (or a simple heater using G-189A routine ALTCOM if electric) |
| o Toothbrush | GPOLY logic required for water usage only |
| o Vacuum refuse collection | GPOLY logic only required, or G-189A routine ALTCOM for an electric heater |
| o Tape recorder, TV | GPOLY logic only required, or G-189A routine ALTCOM for an electric heater |

For the remaining appliances, six new G-189A subroutines have been written, some of which will model more than one type of appliance. These subroutines have been designated as G-189A component subroutines number 66 through 71, and are generally described as follows:

<u>Subroutine Number</u>	<u>Subroutine Name</u>	<u>Description</u>
71	CHILLR	(simulates a thermally insulated locker cooled either by an externally chilled fluid or a self-contained refrigeration unit) * Freezer * Refrigerator
66	FTRAY	* Food warming/serving tray (Skylab-type)
69	ROSMOS	* Reverse osmosis waste water treatment unit
67	SHOWER	* Spacecraft whole body shower

2.2 (Continued)

<u>Subroutine Number</u>	<u>Subroutine Name</u>	<u>Description</u>
70	WASDRY	<ul style="list-style-type: none"> * Clothes washer * Clothes dryer * Combined clothes washer/dryer * Dishwasher/dryer * Towel/cloth drying rack
68	WASTE	<ul style="list-style-type: none"> * Dryjohn * Urinal

The subroutines have been written in conventional Fortran V language and are operational on the NASA JSC SRU 1108 EXEC II computer system. They are described in the "Crew Appliance Computer Program Manual", Reference 2, with detailed math model descriptions, solution methods, user's input instructions, results of verification runs, and demonstration of their operation in all-up Shuttle Orbiter and Modular Space Station ECLSS simulation runs. A brief description of the component operation and mathematical model used for the new appliance subroutines is given in Section 2.2.1. Each subroutine was checked for accuracy and operational status within the G-189A program by performing selected verification runs. These runs are described in Section 2.2.2.

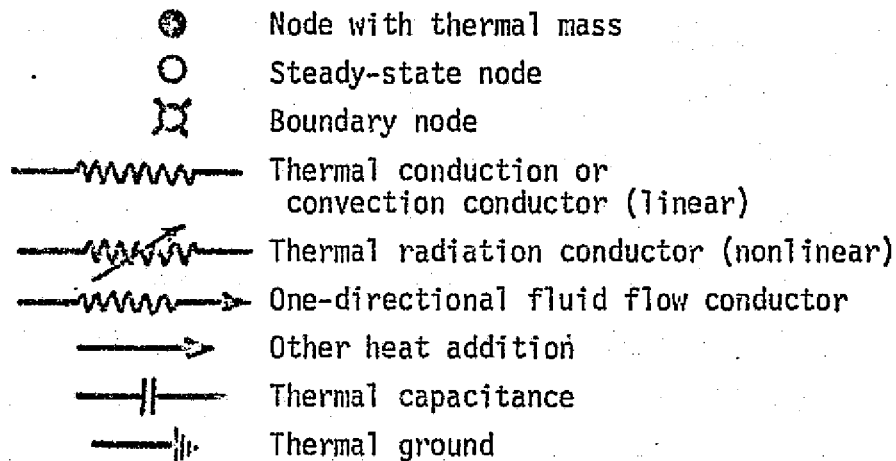
2.2.1 Computer Routine Development

In this section are included brief descriptions of the component operation and math model used for each of the new appliance subroutines. Complete subroutine descriptions are presented in detail in the "Crew Appliance Computer Program Manual", Reference 2, Chapter 3. The basic approach was to develop new subroutines only for the specific appliance components not already included in the G-189A component subroutine library. For example, for the clothes washer/dryer, the WASDRY subroutine models the thermal/mass

2.2.1 (Continued)

exchange in the agitator or drum only, with the peripheral pumps, valves, accumulator, etc., to be simulated by available G-189A component routines.

A major part of each appliance subroutine is the thermal model used to simulate the heat transfer within the appliance and between the appliance and its surroundings. An equivalent electrical resistor/capacitor nodal network was used in each case for this purpose. These nodal models are shown for the various appliances in the following sections using these symbols:



Nodes having thermal mass are solved by equating the net heat input to the change in heat storage. A thermal capacitance is specified for these nodes, as defined by the relation

$$C = mc_p$$

where :

C = nodal thermal capacitance

m = nodal mass

c_p = specific heat

2.2.1 (Continued)

Steady-state nodes are used to model gaseous fluid or other special nodes having negligible thermal mass. These nodes are in thermal equilibrium with their surroundings; that is, their temperature is computed such that the heat in is equal to the heat out. Boundary node temperatures are not computed in the subroutines. They must be input by the user and may be held constant or varied during a run based on the progressing solution.

The nodes are interconnected by thermal conductors evaluated in the following ways:

$$G = \left\{ \begin{array}{ll} kA/\ell & \sim \text{solid conduction} \\ h_c A_s & \sim \text{fluid convection} \\ \dot{m}c_p & \sim \text{fluid flow} \\ \sigma A_s \mathcal{F} & \sim \text{radiation} \end{array} \right.$$

where

- G = thermal conductor
- k = material thermal conductivity
- A = "window" area between nodes
- A_s = surface area of node
- ℓ = length between nodal centers
- \dot{m} = fluid mass flow rate
- h_c = convection heat transfer coefficient
- σ = Stefan-Boltzmann radiation constant
- \mathcal{F} = radiation interchange factor

The first three conductors are referred to as linear and transfer heat proportional to the first power temperature difference ($T_j - T_i$). The fourth conductor is radiation which transfers heat as a function of the fourth power temperature difference ($T_j^4 - T_i^4$). Some conductors are

2.2.1 (Continued)

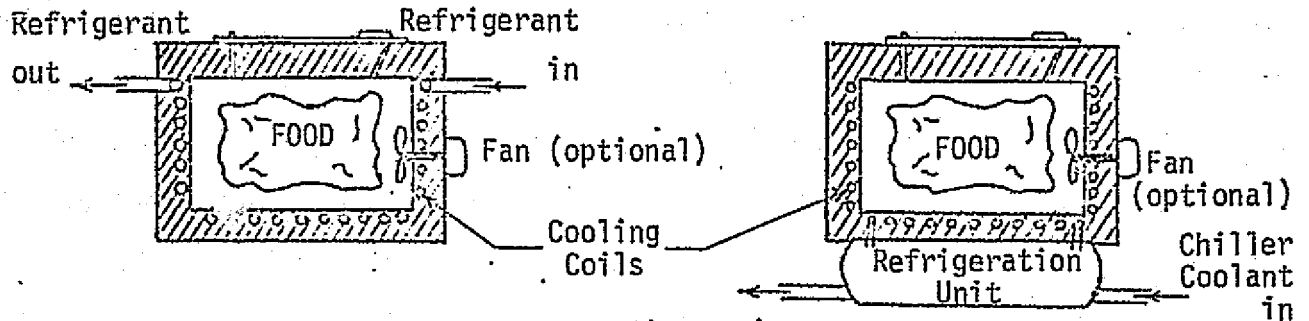
designated as "one-directional" elements, meaning that heat is transferred through them in one direction only. This feature is typically used for fluid flow simulation, in which the stored energy travels downstream only, and also used for satisfying certain boundary conditions at a line of symmetry within a model.

2.2.1.1 CHILLR Subroutine Description

The CHILLR subroutine, designated as G-189A No. 71, will simulate a refrigerator or freezer cooled either by an externally chilled coolant (e.g., from a radiator coolant circuit) or by a self-contained refrigeration unit. The model is generalized and may be used to simulate the configurations shown in Figure 2.2-1.

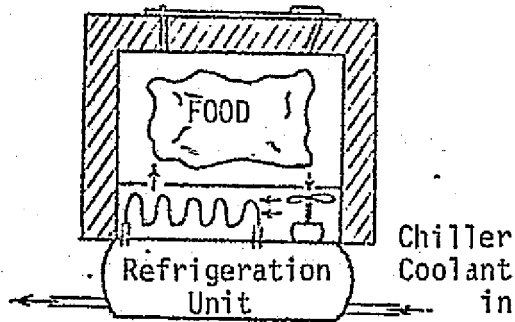
The thermal model in either case is shown in Figure 2.2-2. In addition to the thermal network shown in the figure, the locker inner walls and contents are thermally connected to the ambient surroundings using the standard G-189A subroutine QSURR. This routine models the heat exchange from an arbitrary structure to ambient via insulation, thermal shorts, and conduction/convection/radiation paths. The output from the QSURR subroutine defines the heat loss from the internal structure to ambient, which is designated as q_{surr} in Figure 2.2-2.

The CHILLR subroutine has been used to simulate the Shuttle food and medical sample freezer kit described in Reference 3. Excellent correlation between the subroutine results and independent detailed freezer thermal analysis has been obtained. The model data used for that freezer design are included directly in the subroutine as default input data.

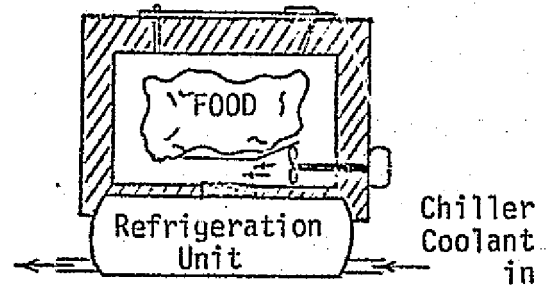


(a) Cooled by externally chilled liquid

(b) Self-contained refrigeration unit with wrapped cooling coils

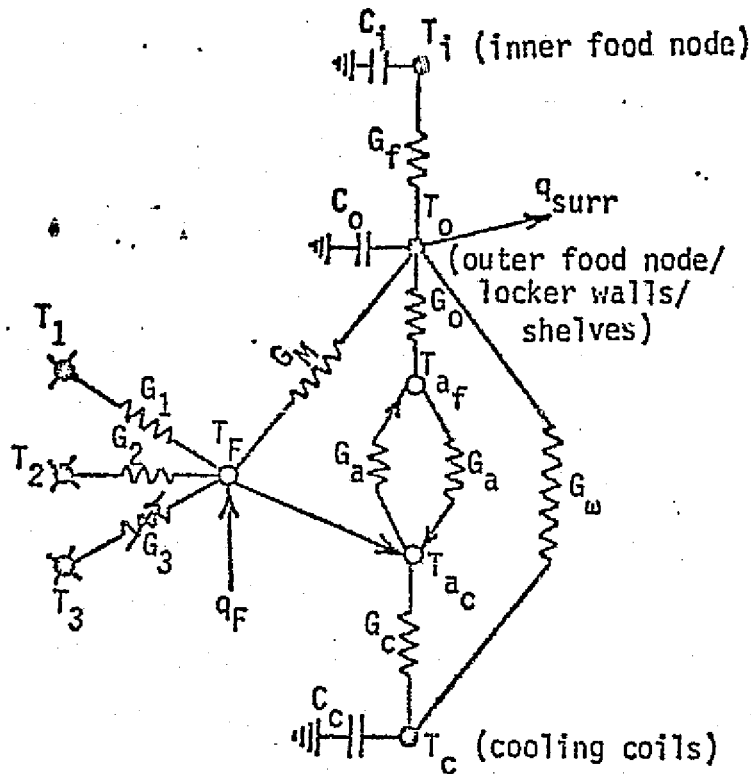


(c) Self-contained refrigeration unit with cooling coil interface

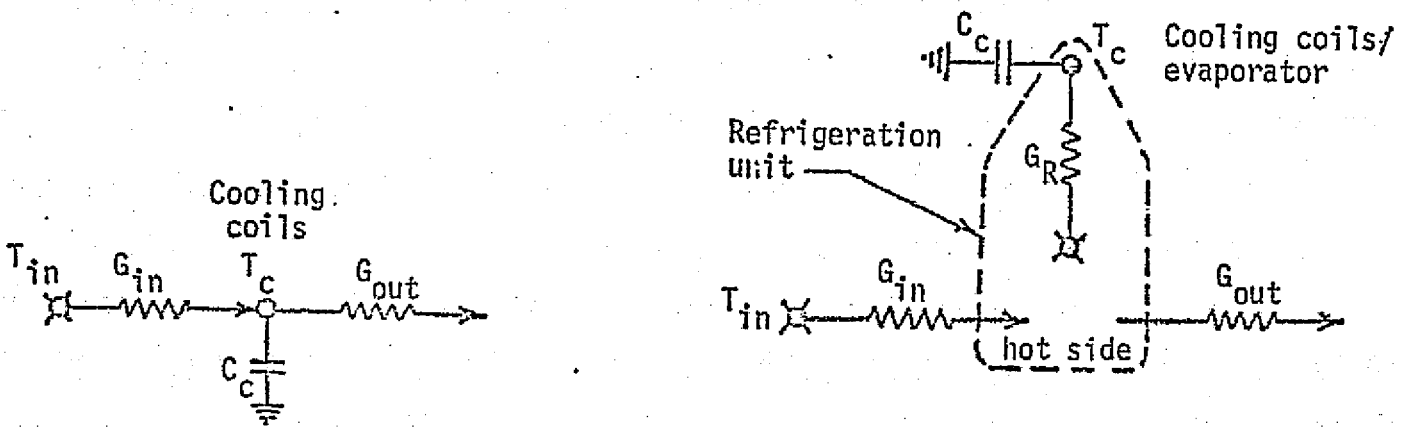


(d) Self-contained refrigeration unit with cold plate interface

Figure 2.2-1. CHILLR Component and Flow Schematic



(a) Thermal model of refrigerator/freezer locker including cooling coils



(b) Thermal model of refrigerator/freezer chiller side, including cooling coils - assuming externally chilled coolant fluid

(c) Thermal model of refrigerator/freezer chiller side, including cooling coils - assuming self-contained cooling unit

Figure 2.2-2. Thermal Model of Refrigerator/Freezer Locker (a) and Chiller (b) and (c)

2.2.1.2 FTRAY Subroutine Description

The FTRAY subroutine, designated as G-189A No. 66, simulates the performance of Skylab-type food warming/serving tray. A typical food tray, shown in Figure 2.2-3, had eight recessed food cavities, of which three had embedded thermostatically controlled electrical resistance heaters to warm the food. The thermal model used for a single food warming cavity is shown in Figure 2.2-4. The cavity is assumed cylindrical and is subdivided into five food nodes of equal volume. In addition to the thermal network shown in Figure 2.2-4, the food is thermally connected to the ambient surroundings using the G-189A subroutine QSURR. The subroutine has been correlated with actual Skylab test data and excellent agreement obtained.

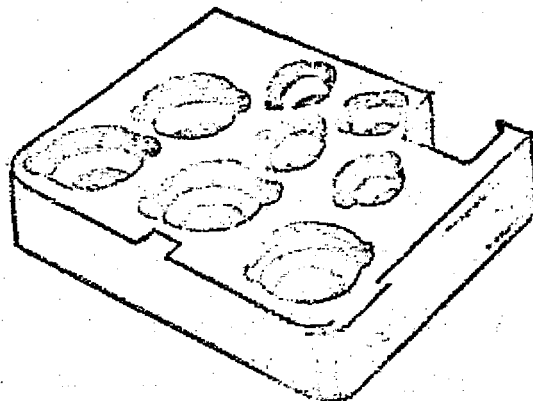


Figure 2.2-3. Typical Skylab-type Food Warming/Serving Tray

Any number of heated food cavities may be simulated by a single G-189A component using FTRAY. The routine determines the performance of a single food cavity and assumes all others are identical. If some food trays have different input data or time schedules, they must be simulated by separate G-189A components.

2.2.1.3 ROSMOS Subroutine Description

The ROSMOS subroutine, designated as G-189A No. 69, simulates a reverse osmosis process used for removing impurities from waste water. Fluid is forced by static pressures across a membrane in a direction opposite to which it would normally flow due to osmotic pressure alone. Most of the impurities are filtered out by the membrane, thus leaving a purified water

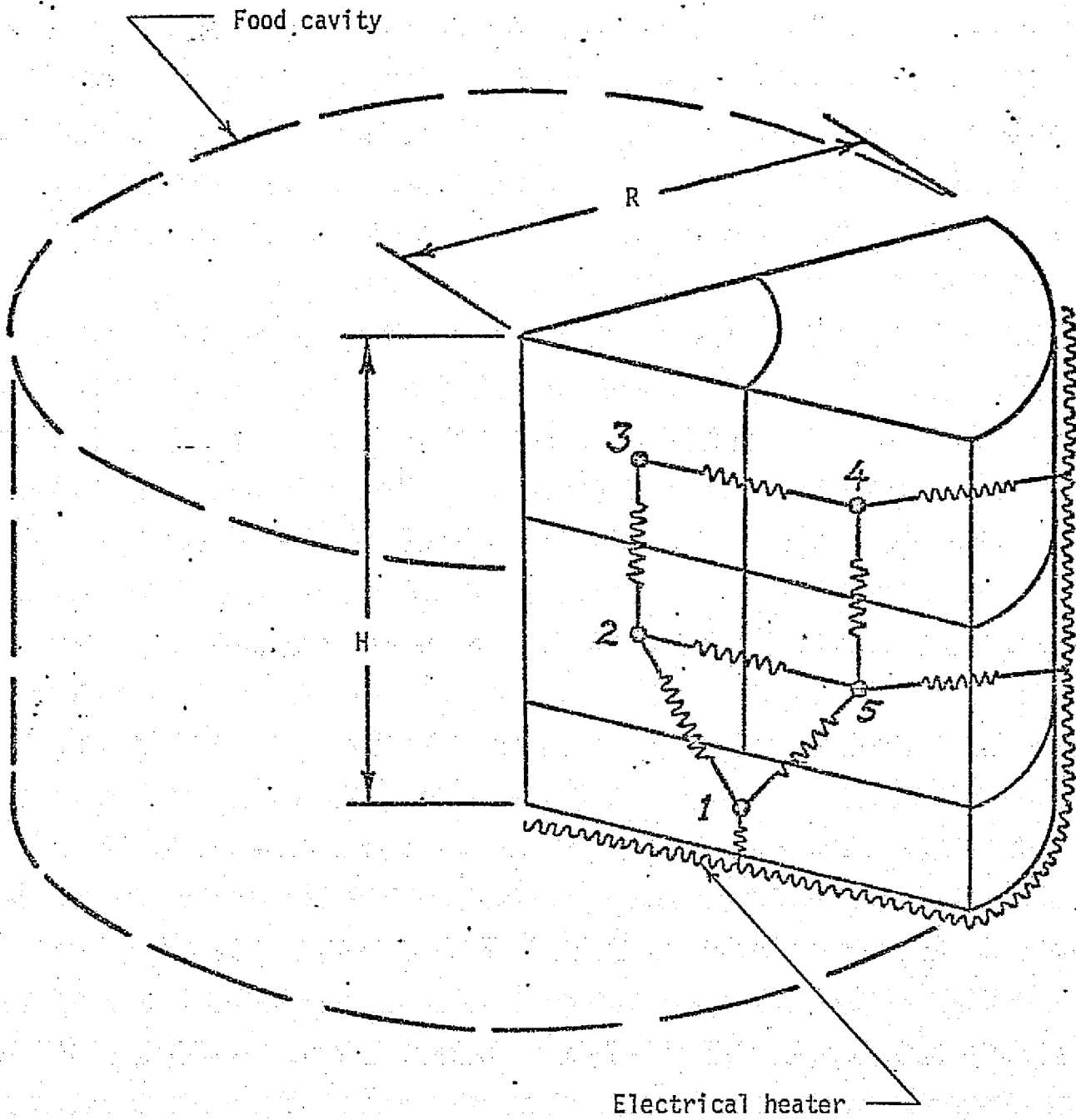


Figure 2.2-4. Thermal Model of a Single Food Warming Cavity

2.2.1.3 (Continued)

flow through the unit. This technique is in use commercially in many water and waste treatment applications and is being developed to recycle space-craft waste water. The subroutine will simulate the performance of an arbitrary type of reverse osmosis unit, shown in Figure 2.2-5, if test or design performance data for that unit are available. Only a single-stage unit may be simulated by a single component, but multistage operation may be achieved by connecting more than one unit together.

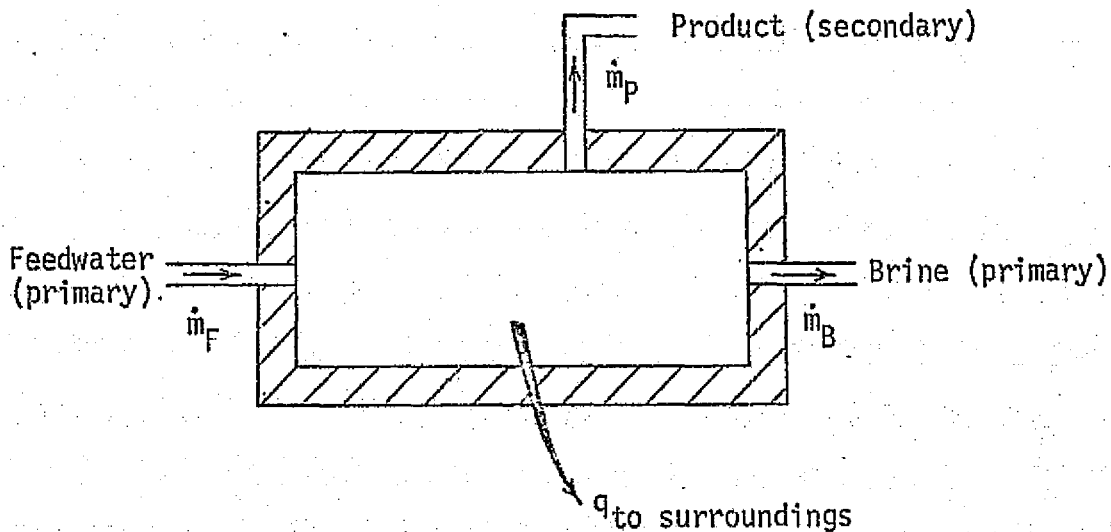


Figure 2.2-5. ROSMOS Component Flow Schematic

2.2.1.3 (Continued)

Since a particular spacecraft reverse osmosis unit design has not been determined, the subroutine was written in general terms to handle any unit for which some design or test data are available. The input design data are adjusted for the off-design conditions present during a run. The thermal balance of the reverse osmosis unit with ambient surroundings is handled using the standard G-189A subroutine QSURR.

The flow balance across a reverse osmosis module may be analyzed from two viewpoints of interest. First, one can consider the overall net effect of all the different types of solute impurities, lumped together and treated as a single homogeneous impurity. This approach is used in determining overall water balances and initial sizing and design of water recovery components. Secondly, one can consider the effect of the reverse osmosis module on each different type of impurity present in the water with its own individual rejection factor. This subroutine uses the former "overall" approach for handling the total flow balance, and will also apply the second approach as an option for handling any number of individual impurities desired.

2.2.1.4 SHOWER Subroutine Description

The SHOWER subroutine, designated as G-189A No. 67, models the thermal and evaporative mass exchange in a shower stall, as shown in Figure 2.2-6. The G-189A subroutine QSURR is used to model the thermal exchange between the shower stall frame and ambient environment. Evaporation is modeled by mass transfer equations as a function of air inlet flow rate, humidity and properties. The effect of the shower occupant is included by standard metabolic equations based on input metabolic rate and the respiratory quotient. The thermal nodal network assumed for the shower component is shown in Figure 2.2-7 for the occupied and unoccupied cases. The shower is assumed to be occupied if and only if there is flow inlet to the primary (air) side. When the water is turned on, the total (primary and secondary) water inlet and outlet

2.2.1.4 (Continued)

flowrates are equal. When the water is turned off with air flow only, the outlet water vapor flow is equal to the inlet flow plus the amount of water evaporated.

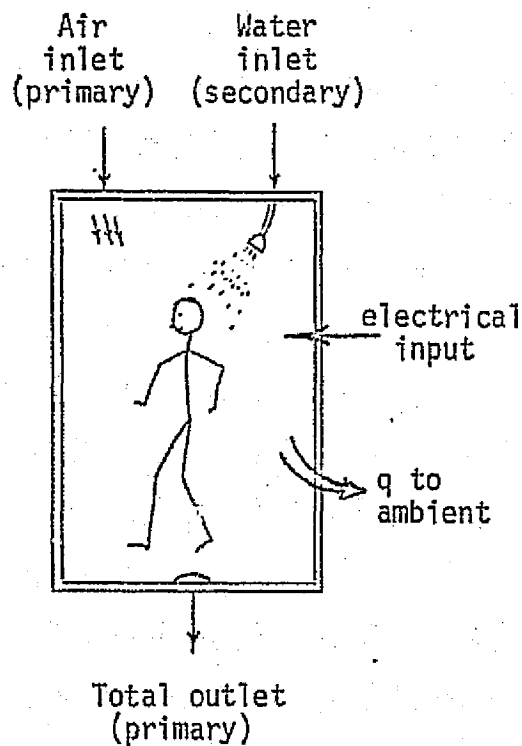


Figure 2.2-6. Shower Model Flow Schematic

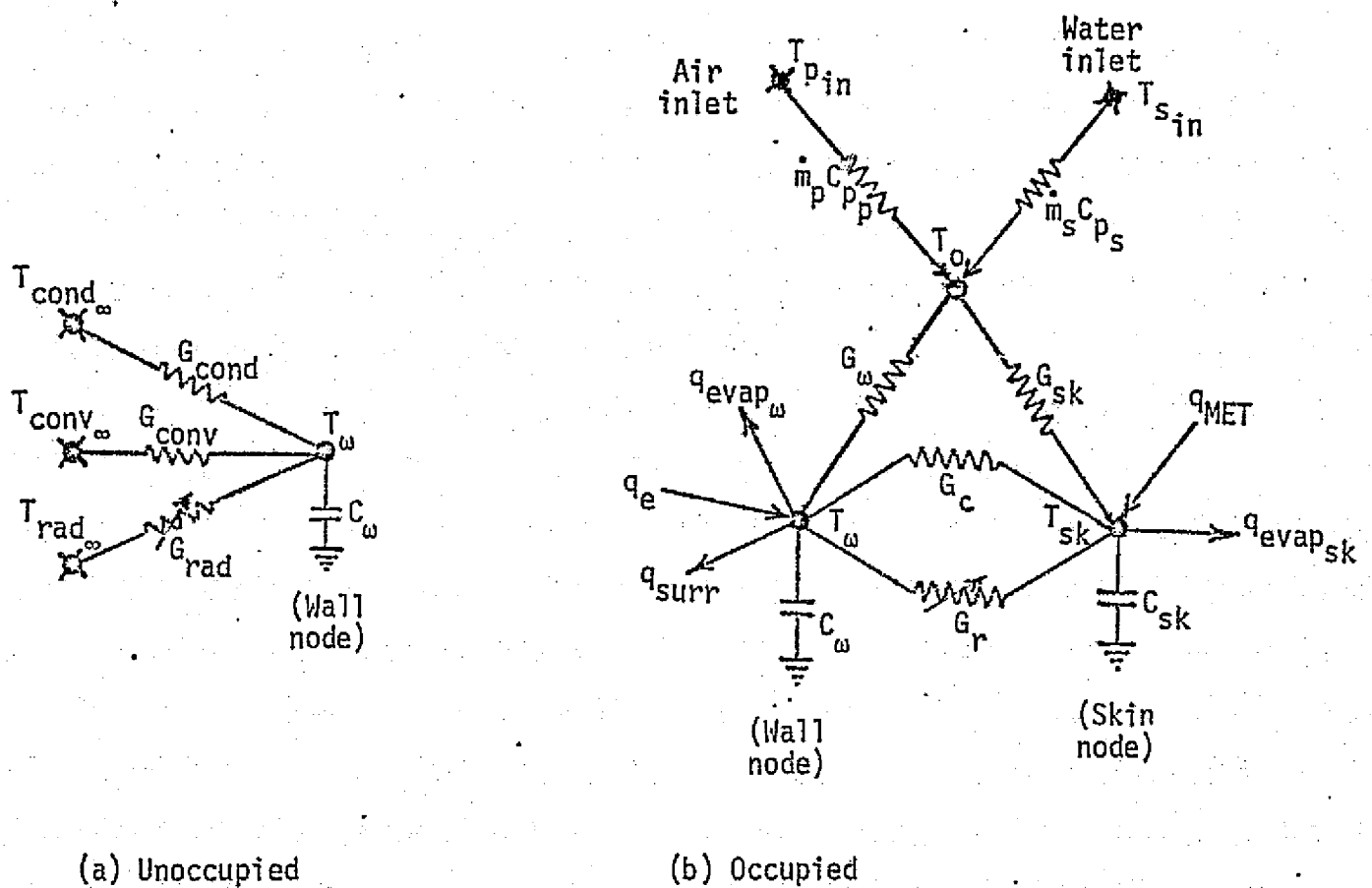


Figure 2.2-7. Thermal Model of Shower Stall Component

2.2.1.5 WASDRY Subroutine Description

The WASDRY subroutine, designated as G-189A No. 70, will simulate operation of the following appliances:

- o Clothes washer
- o Clothes dryer
- o Clothes washer/dryer combination
- o Dishwasher
- o Dish dryer

2.2.1.5 (Continued)

- o Dishwasher/dryer combination
- o Towel/cloth drying rack

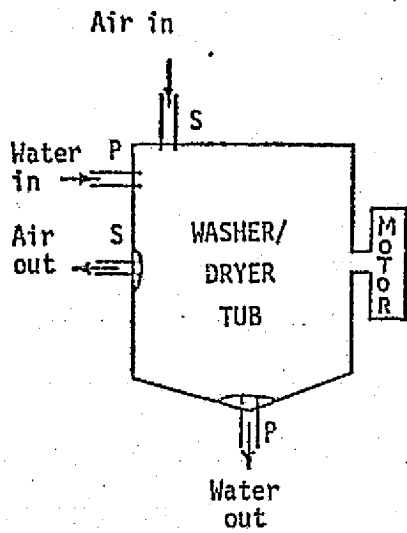
A flow schematic of the WASDRY component is shown in Figure 2.2-8. Seven operational usage phases may be simulated:

- Phase 0 - Unit off
- Phase 1 - Wash water fill
- Phase 2 - Wash (circulate)
- Phase 3 - Spin dry - wash water out
- Phase 4 - Rinse water fill
- Phase 5 - Rinse (circulate)
- Phase 6 - Spin dry - rinse water out
- Phase 7 - Dry

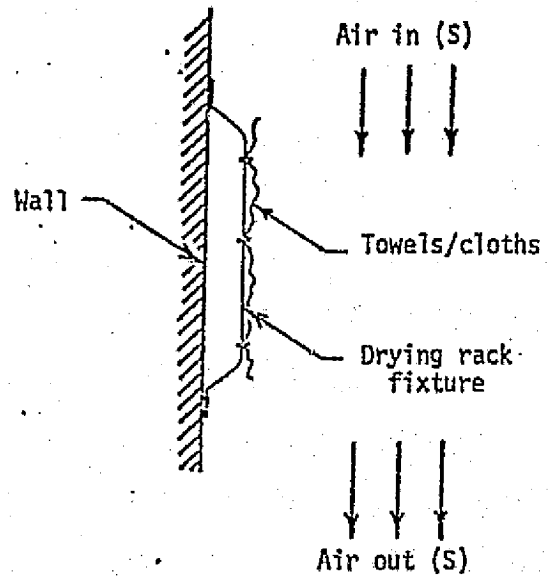
The routine will control the switching between phases based on input cycle schedules if requested by the user. Thermal exchange between the tub and frame and the ambient environment is modeled using the standard G-189A library routine QSURR. During the drying phase, the evaporation process is modeled in detail as a function of air inlet flow rate, humidity and properties, velocity within the tub, and water retention in the load. The thermal nodal network used to simulate the WASDRY component is shown in Figure 2.2-9. The subroutine models the thermal/mass exchange in the agitator or tub only, with the peripheral pumps, valves, accumulator, etc. to be simulated by standard G-189A component routines.

2.2.1.6 WASTE C Subroutine Description

The WASTE C subroutine, designated as G-189A No. 68, will simulate a urine/fecal waste collector applicable to space use, such as a urinal or dryjohn. A flow schematic of the WASTE C component is shown in Figure 2.2-10. Three

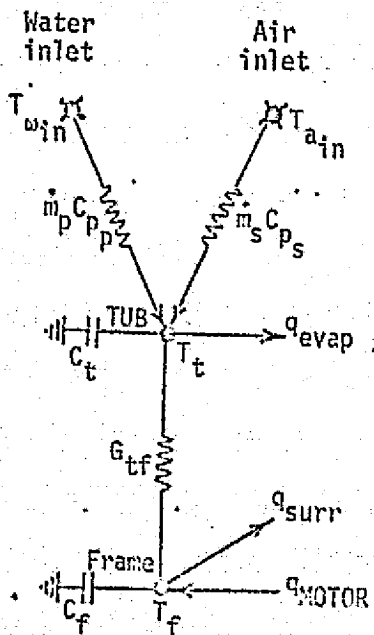


(a) Washer/dryer

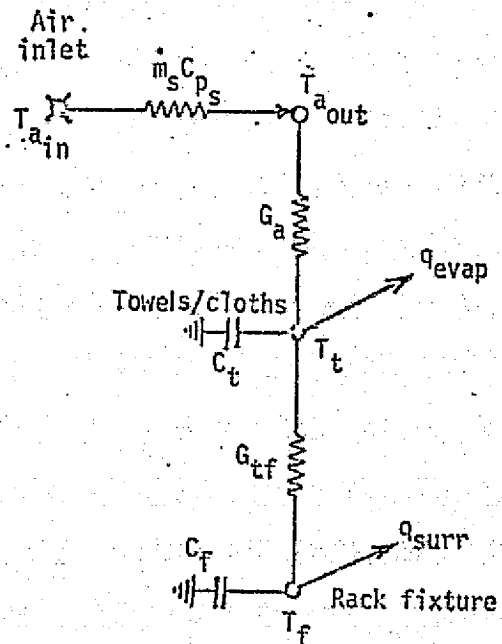


(b) Towel/cloth rack dryer

Figure 2.2-8. WASDRY Component Flow Schematic



(a) Washer/dryer



(b) Towel/cloth rack dryer

Figure 2.2-9. Thermal Model for WASDRY Component

2.2.1.6 (Continued)

operational usage phases may be simulated:

- Phase 0 - Unit off
- Phase 1 - Urine collection
- Phase 2 - Fecal collection
- Phase 3 - Combined urine/fecal collection

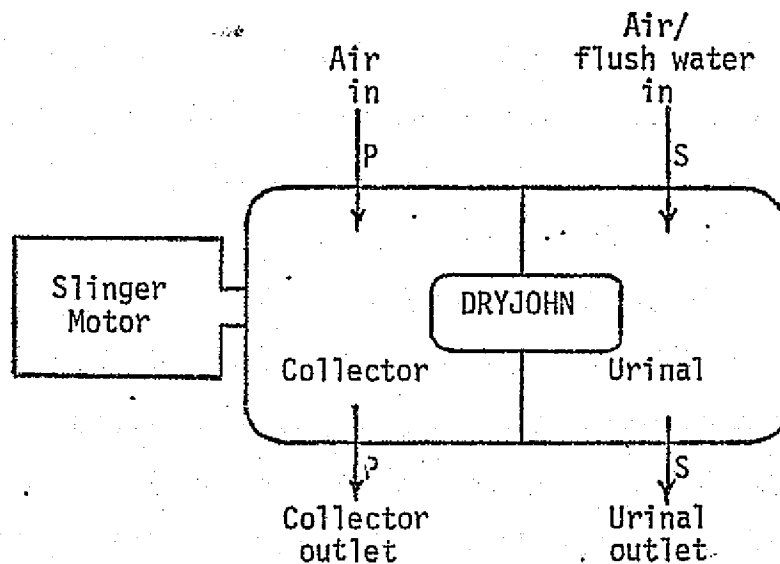


Figure 2.2-10. WASTEC Component Flow Schematic

Commode contents may be under vacuum, if requested, during phases 0 and 1. Each time vacuum is initiated following operation of a fecal collection phase (2 and 3), a pumpdown or blowdown is automatically performed. During vacuum drying, the latent heat of evaporation or sublimation is computed from standard vacuum drying equations.

Thermal exchange between the collector and ambient environment is modeled using the standard G-189A library routine QSURR. The thermal nodal network used to simulate the component is shown in Figure 2.2-11. The subroutine

2.2.1.6 (Continued)

models the thermal/mass exchange in the collector and urinal only, with the peripheral pumps, valves, etc. to be simulated by standard G-189A component routines.

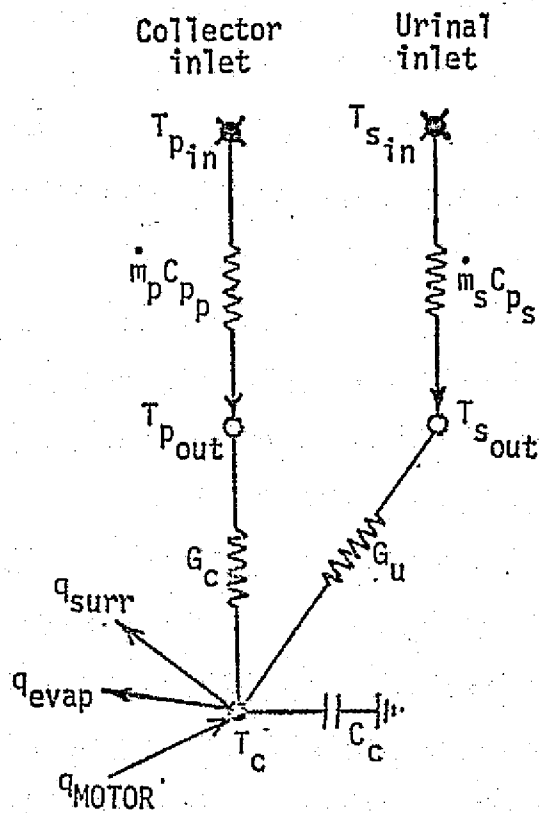


Figure 2.2-11. Thermal Model for WASTEC Component

2.2.2 Validation of Routines

2.2.2.1 Individual Appliance Subroutine Checkout

The new crew appliance subroutines have been run in the G-189A program to verify their accuracy and operational status. First, each component modeled was run separately (i.e., not connected in an all-up system model) with dummy ambient and inlet flow conditions. These conditions were held constant during a run and a steady state and transient solution obtained. The results of these checkout runs are described in the Crew Appliance Computer Program Manual, Chapter 4. Calculations are presented to verify conservation of mass and energy within the components, and the solutions compared with test data where available. The results were found to be reasonable and accurate, and excellent agreement with test data was achieved where available. Many of these appliances have not yet been built for spacecraft application, and the available test data required for correlation of the models was limited. For such cases, further testing and model correlation are recommended when the actual hardware is designed and built.

2.2.2.2 Shuttle Orbiter Appliances Simulation

To demonstrate that the appliance subroutines are operational in an all-up G-189A system simulation, they were run in a Space Shuttle Orbiter and Modular Space Station G-189A ECLSS model. The appliances included in the models were taken from the concept trade studies and represent the optimum set of appliances for each vehicle. The only Shuttle appliances selected which required the new G-189A appliance subroutines were a space radiator refrigerator, food heating/serving trays, and a dryjohn. Since a refrigerator is currently not included in the Shuttle design and since the Shuttle cabin coolant loop would be only marginally effective for the space radiator concept, the refrigerator was not included in the Shuttle model. (Both refrigerators and freezers were included in the Space Station model in Section 2.2.2.3).

2.2.2.2 (Continued)

An available steady-state G-189A model of the Shuttle Orbiter ECLSS developed by Mc Donnell Douglas Corporation (MDAC) was used for the basic Shuttle system model. This model obtains a single steady-state solution for up to 23 different mission phases. For the purpose of verifying the appliance subroutines, this model was run for mission phases 12, 13, 14, and 15 which represent four different days of normal orbital operations. Two cases were run. First, an unmodified case was run with all program inputs exactly as supplied by MDAC. No appliances or modifications were included

A dryjohn and food heating trays were then added to the basic Shuttle model, and the same case was rerun. A flow schematic of the G-189A components added to the basic Shuttle case is shown in Figure 2.2-12. The dryjohn air inlet and outlet were connected directly to the secondary side of component 2, which was the Orbiter cabin in the basic model. The food heating trays were not connected directly in any fluid flow loop; thus, no components are shown attached in Figure 2.2-12.

To exercise various appliance subroutine options, different conditions were assumed during each of the four mission phases, as shown in Table 2.2-1. Complete results from the Shuttle appliance system runs are presented and discussed in the Crew Appliance Computer Program Manual, Chapter 5. The results demonstrate that the new appliance subroutines are valid and work properly in an all-up G-189A system model.

2.2.2.3 Space Station Appliances Simulation

To demonstrate that the new appliance subroutines are operational in an all-up G-189A system simulation, they were run in a Space Shuttle Orbiter and Modular Space Station G-189A ECLSS model. Since no operational model of the complete Space Station ECLSS was available, a simplified model of the pertinent subsystems was developed in which to check the appliance subroutines.

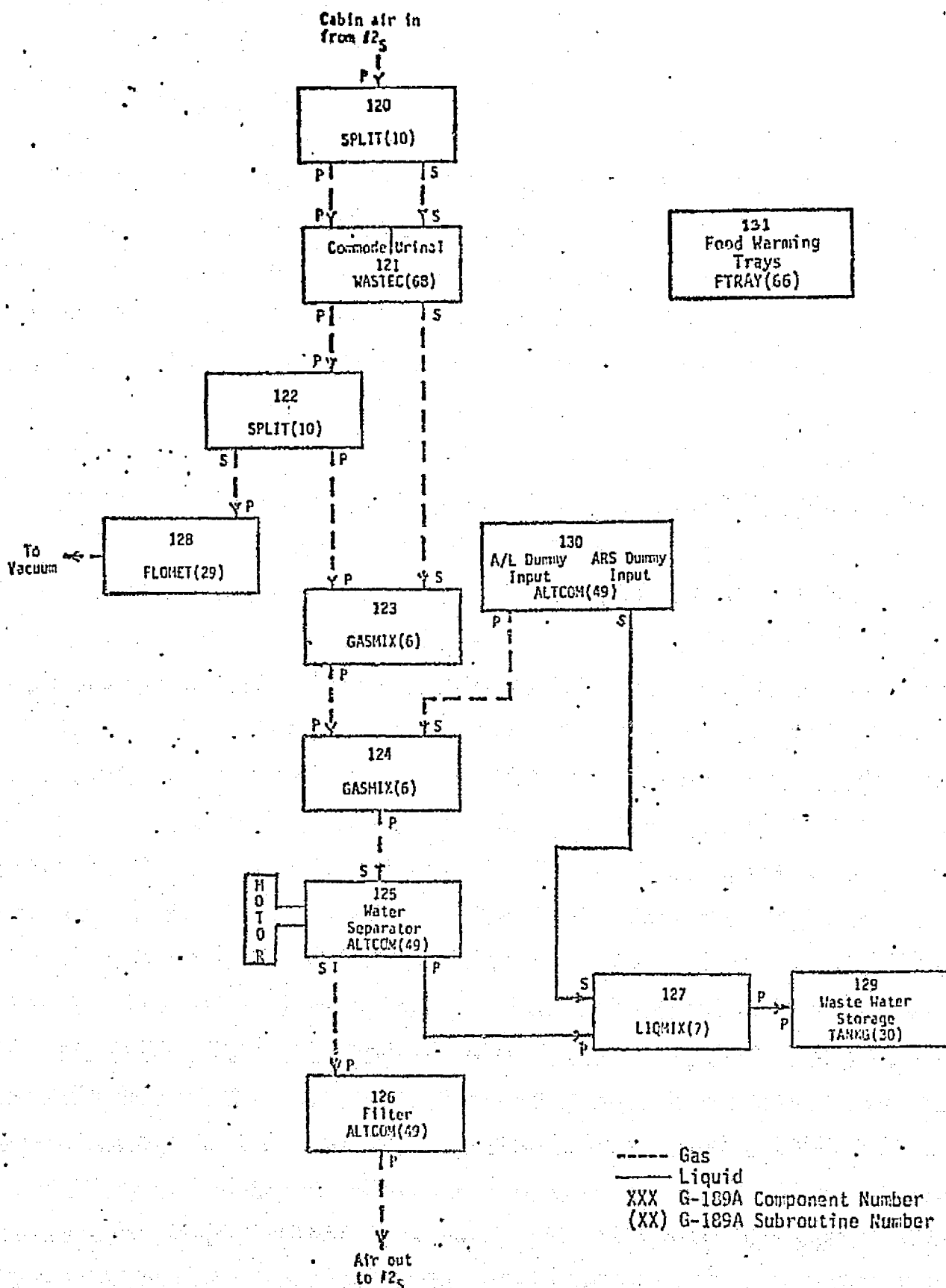


Figure 2.2-12. Flow Schematic of G-189A Appliance Components Added to Basic Shuttle Orbiter Model

TABLE 2.2-1

APPLIANCE COMPONENT OPTIONS ASSUMED
IN SHUTTLE ORBITER SIMULATION

MISSION PHASE	USAGE PHASE	DESCRIPTION	D R Y J O H N		FOOD TRAYS
			CABIN AIR FLOW, CFM		TOTAL NUMBER
			URINAL	COLLECTOR	BEING HEATED
12	0	Not in use Vacuum dry	0	0	0
13	1	Urine collection Vacuum dry	20	0	2
14	2	Fecal collection	20	15	3
15	3	Combined urine/ fecal collection	20	15	4

2.2.2.3 (Continued)

The Modular Space Station concept (Reference 11) involves eight separate compartments for crew habitability, work, experiments, etc. Only two of these compartments were included in the model. The first includes most of the personal hygiene equipment, and the other the crew eating and sleeping quarters. The G-189A flow schematic for these cabins and associated appliances is shown in Figure 2.2-13. The water loop used to supply these appliances is shown in Figure 2.2-14. Flow schematics for the other appliances not included in these two flow loops are shown in Figure 2.2-15. The appliances were run in a 10-hour transient simulation according to a typical daily schedule shown in Figure 2.2-16. The following appliances were included in the Space Station model:

- Refrigerators
- Freezers
- Food trays
- Reverse osmosis unit
- Shower
- Clothes washer/dryer
- Dishwasher/dryer
- Dryjohn
- Wet wipe wetting unit

The G-189A flow networks used to describe the shower, clothes washer, dishwasher and dryjohn are shown in Figures 2.2-17 through 2.2-20. For the other appliances, only the single new G-189A component described in Section 2.2.1 was required. The operation of the ECLSS system and each individual appliance is discussed in detail in the Crew Appliance Computer Program Manual, Chapter 6. Complete model input and output data are presented, with plots showing transient cabin temperatures, humidity, CO₂ levels, and the thermodynamic performance of each of the appliances. The results demonstrate that the new crew appliance subroutines are accurate and operational within the G-189A computer program environment.

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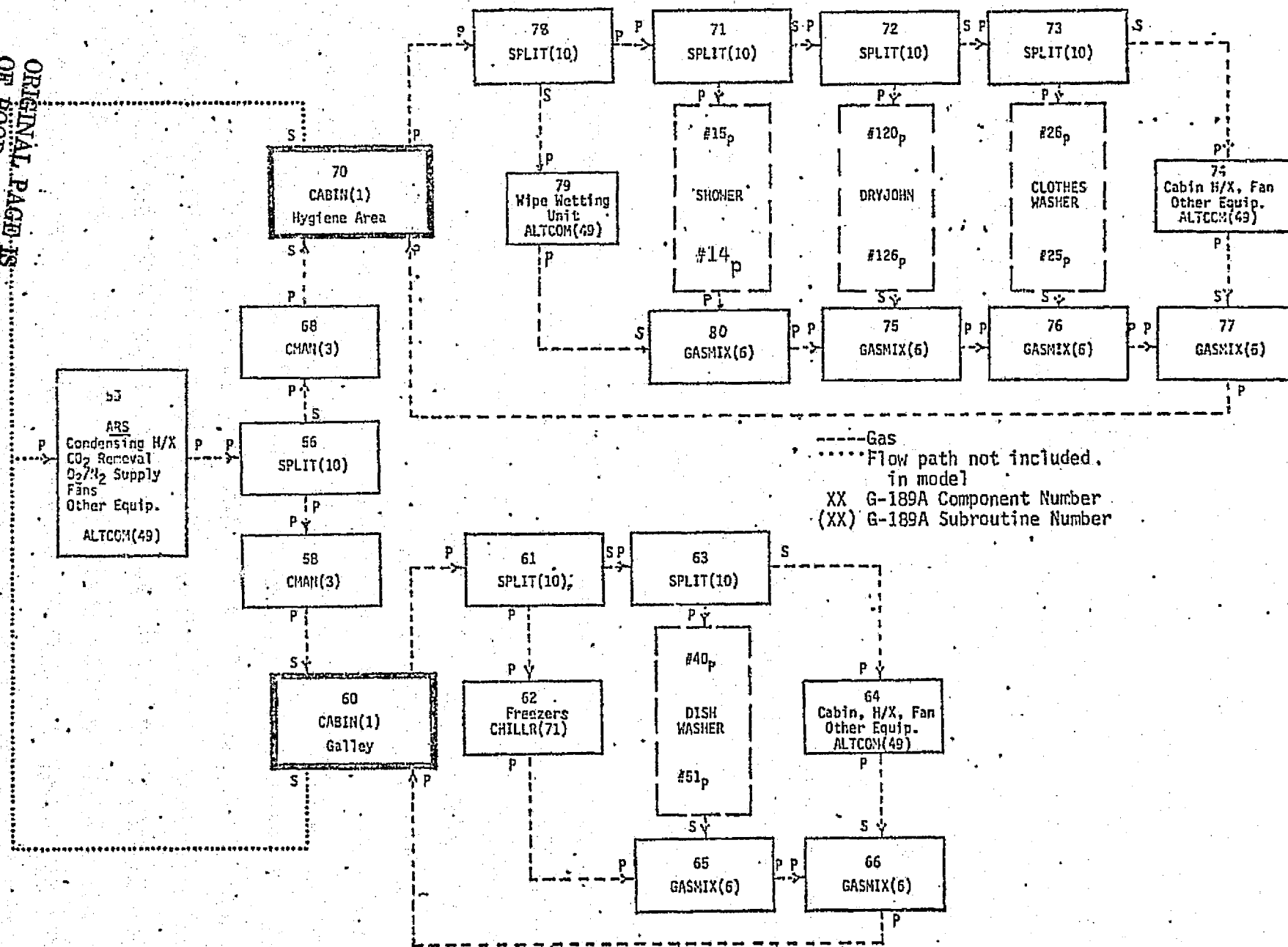
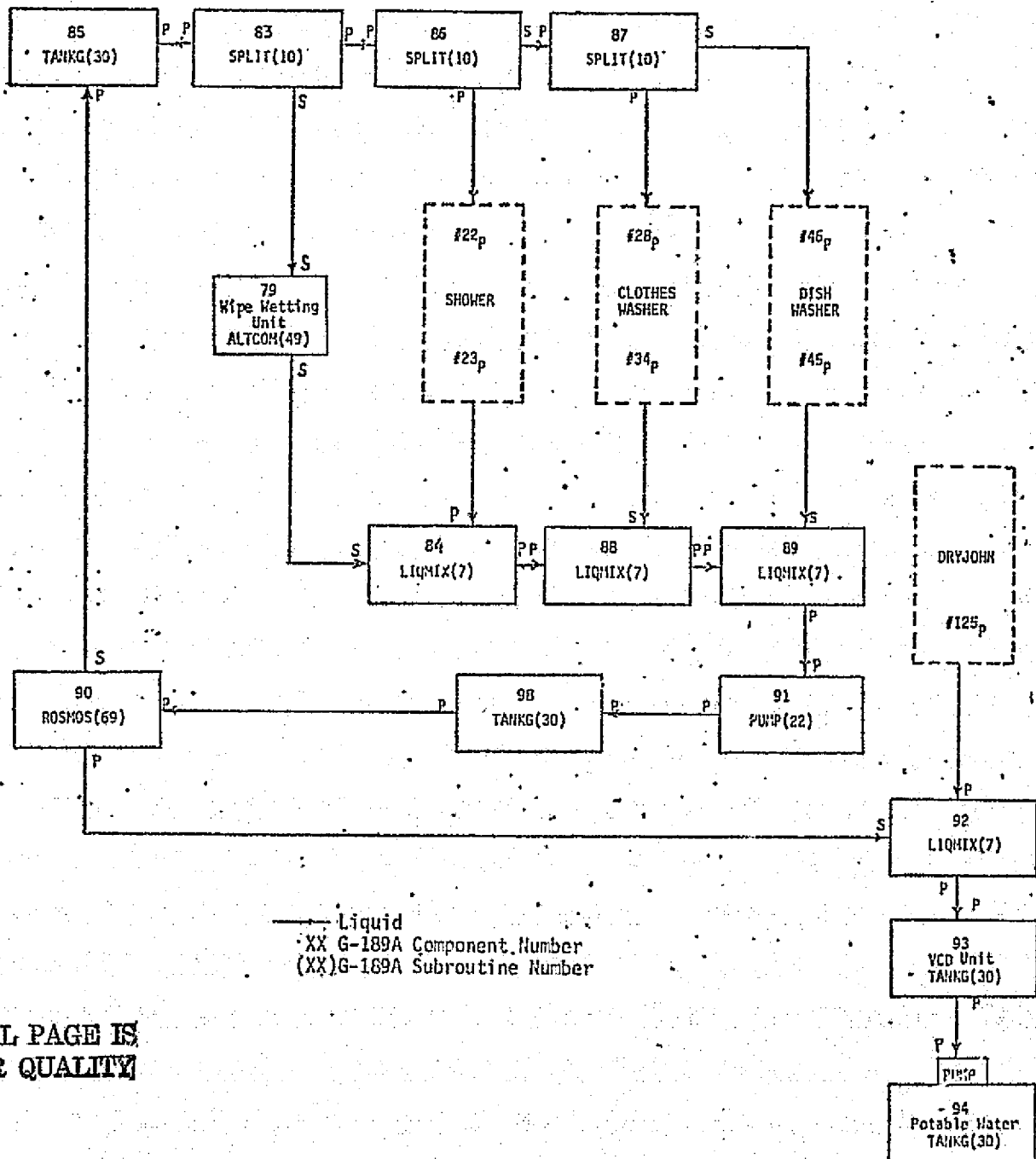
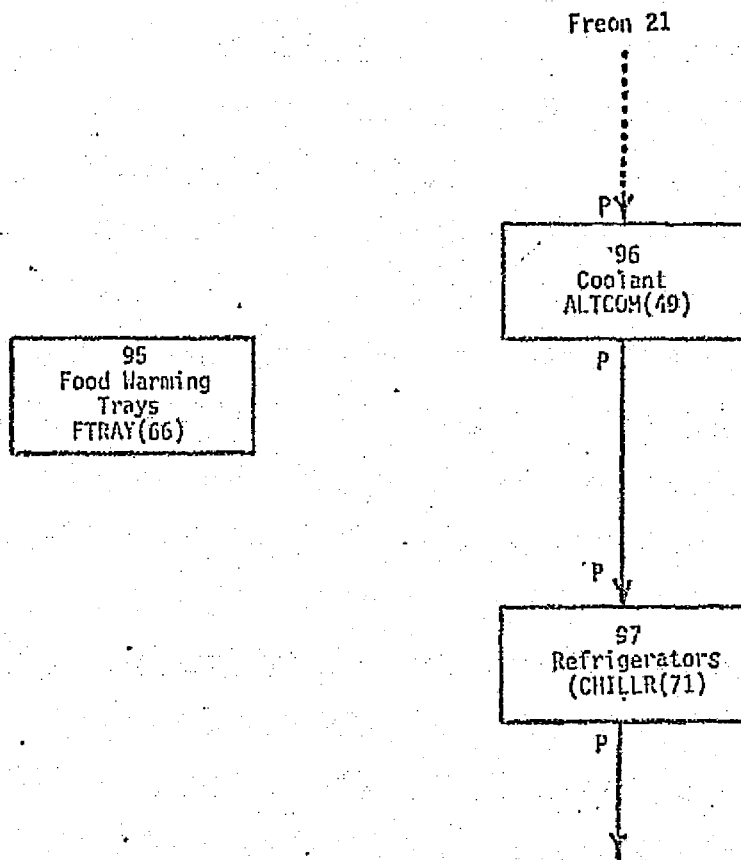


Figure 2.2-13. G-189A Flow Schematic of Space Station Cabin Gas Loop



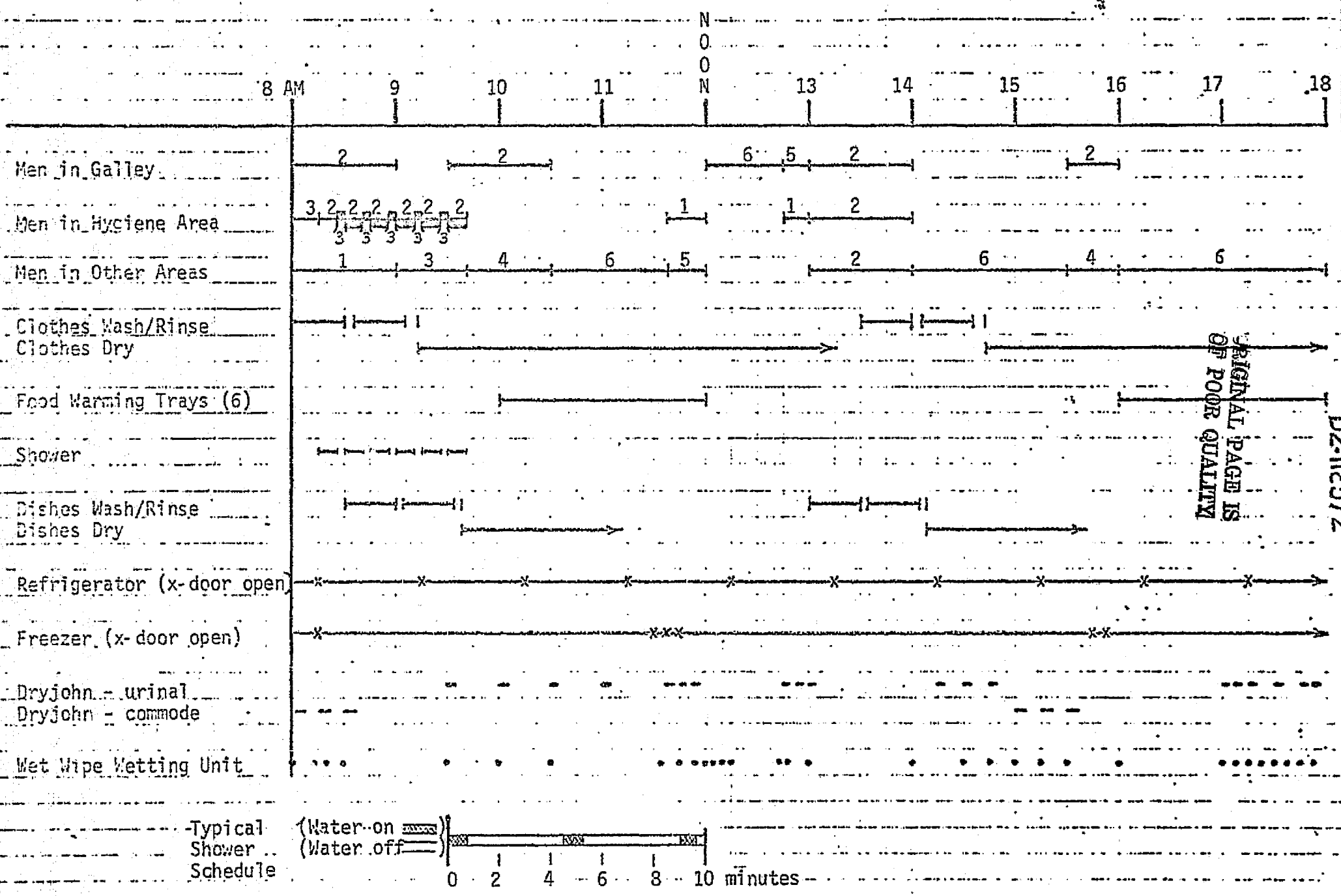
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Figure 2.2-14. G-189A Flow Schematic of Space Station Water Loop



—— Liquid
..... Flow path not included
in model
XX G-189A Component Number
(XX) G-189A Subroutine Number

Figure 2.2-15. Other G-189A Components Used in Space Station Model



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Figure 2.2-16. Appliance Usage Schedules in Space Station Transient Simulation

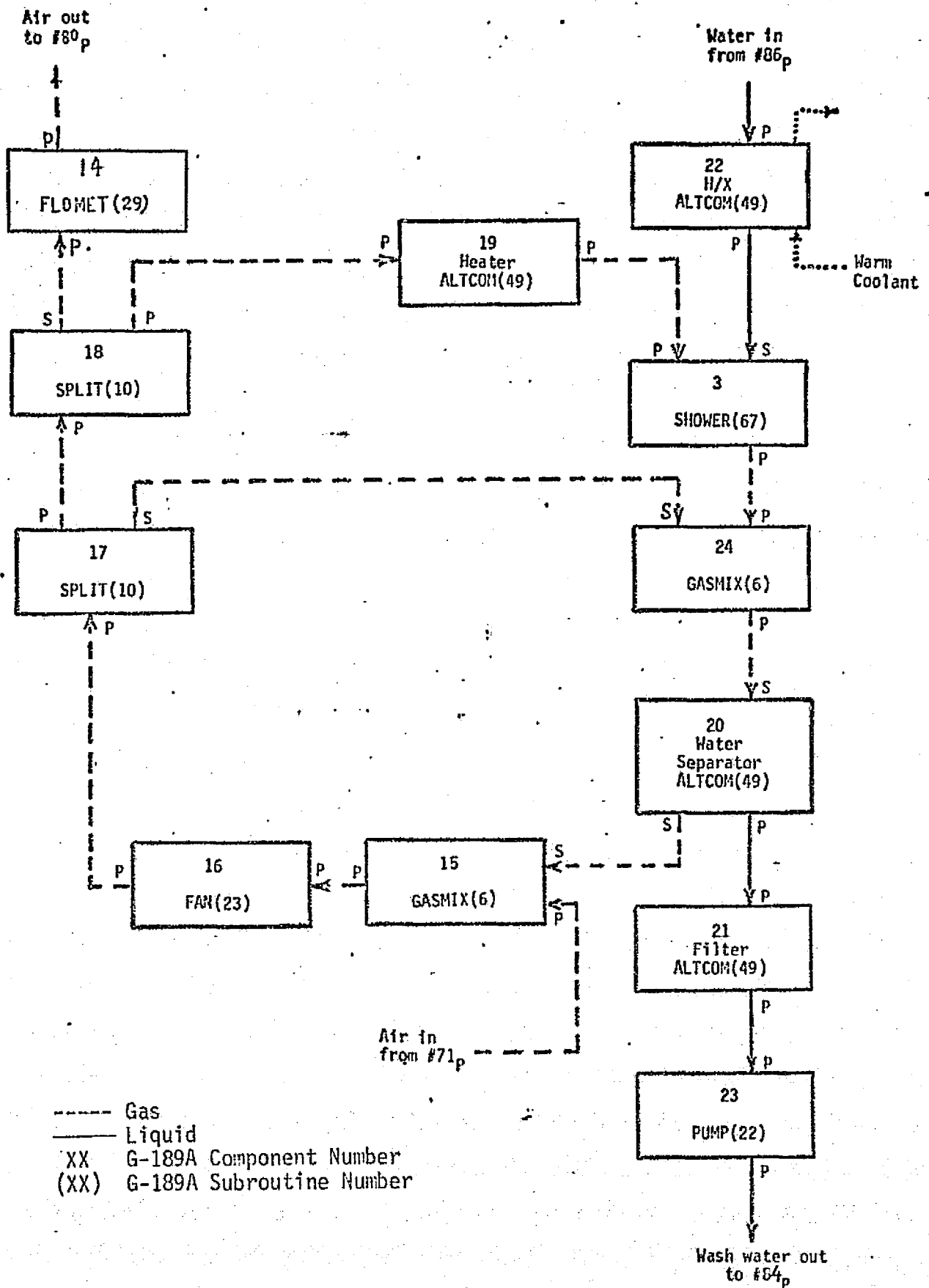


Figure 2.2-17. G-189A Flow Schematic of Space Station Shower Model

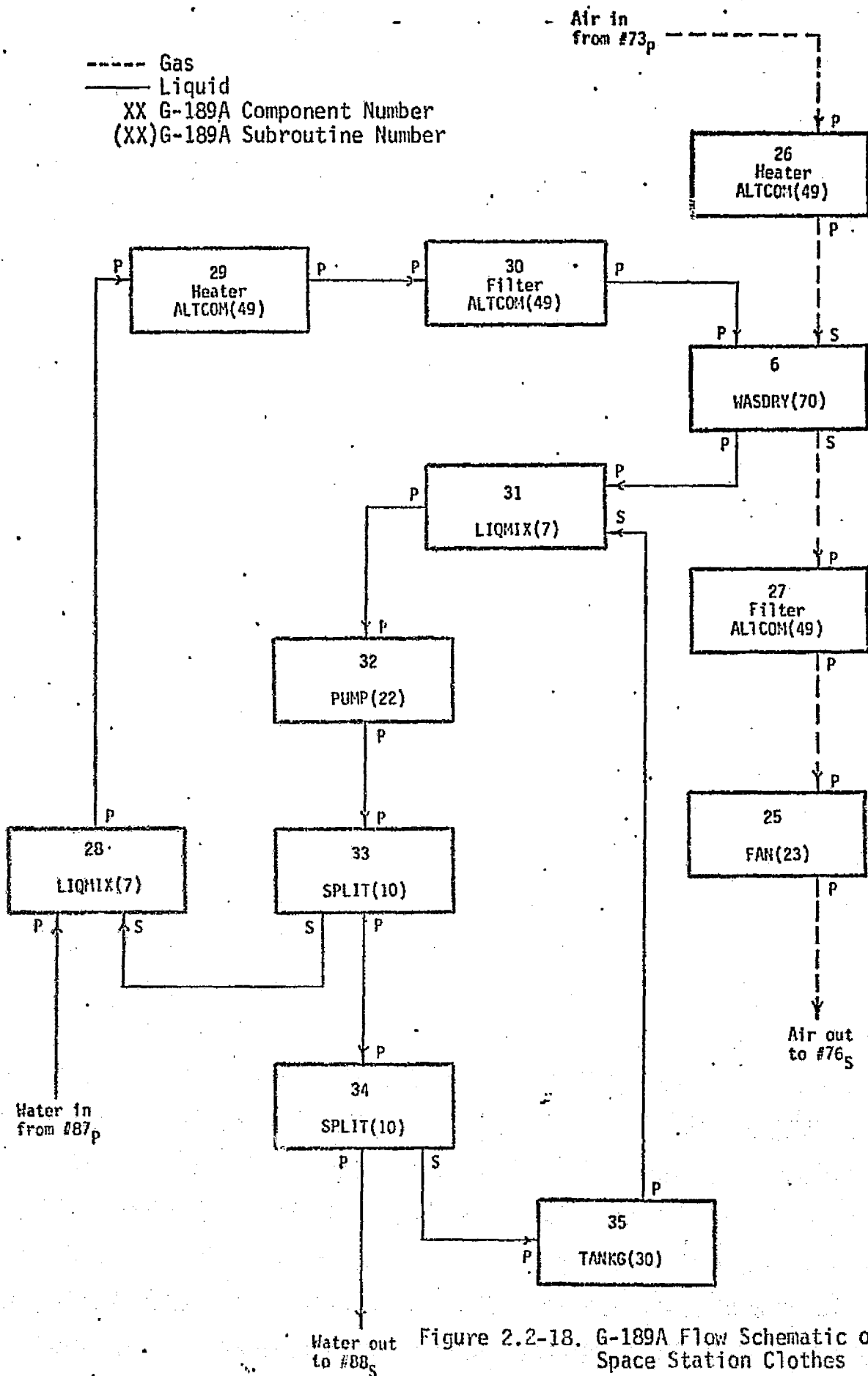


Figure 2.2-18. G-189A Flow Schematic of Space Station Clothes Washer/Dryer Model

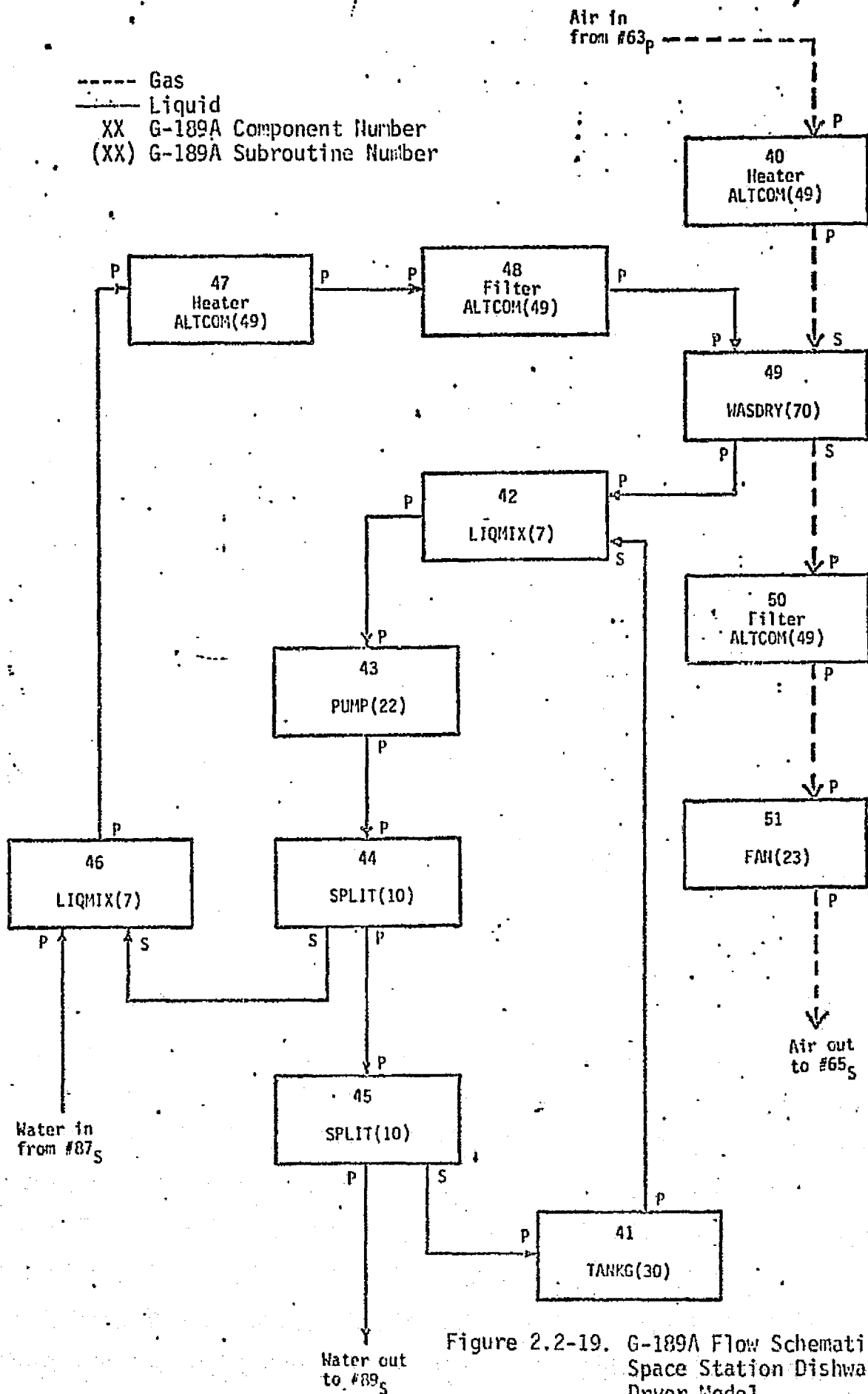


Figure 2.2-19. G-189A Flow Schematic of Space Station Dishwasher/Dryer Model

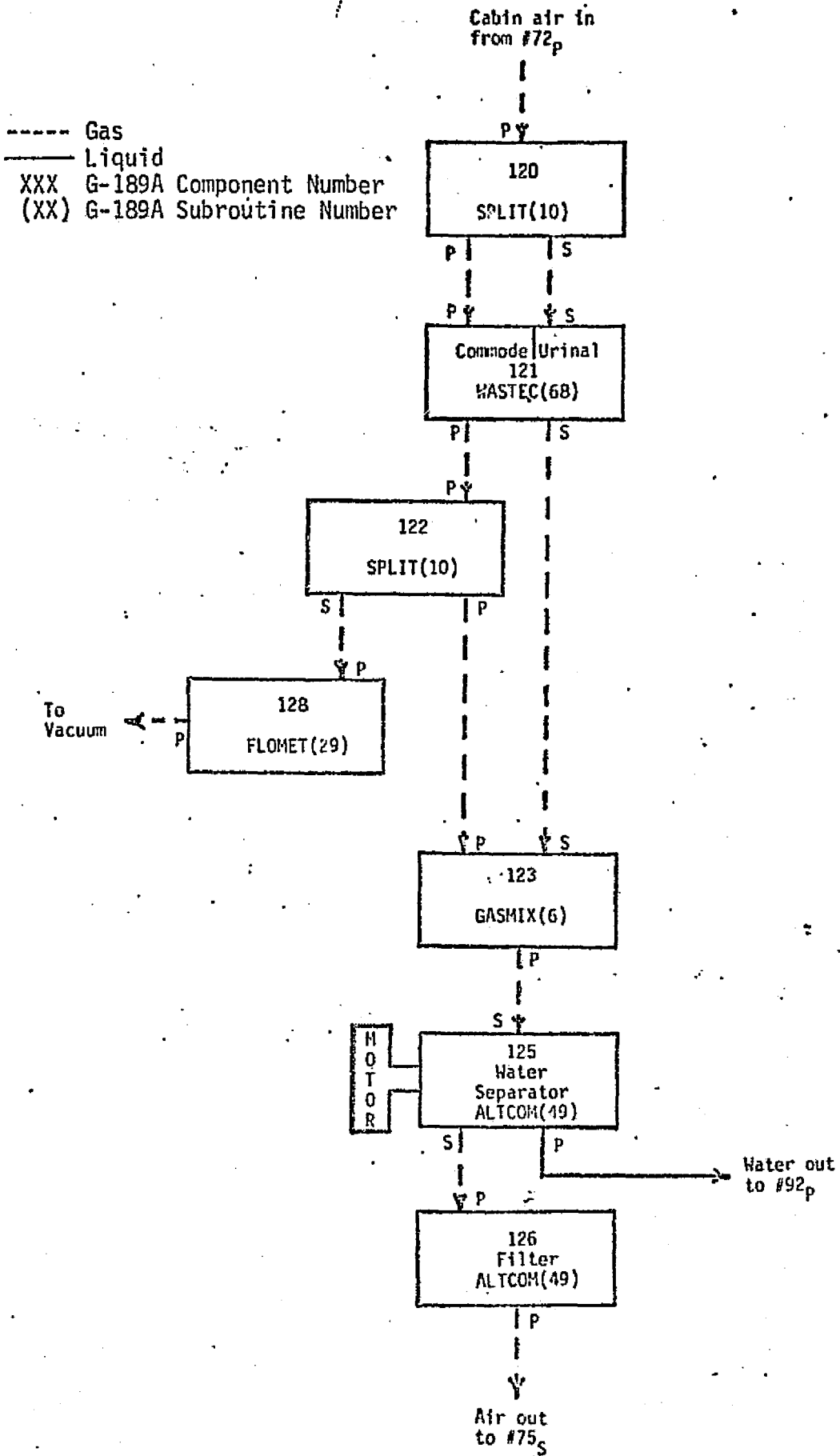


Figure 2.2-20. G-189A Flow Schematic of Space Station Dryjohn Model

2.3 TASK 3.0, GENERATION OF DEVELOPMENT PLANS

Development plans were generated for the selected optimized integrated crew appliance systems for the Space Orbiter and the Space Station. These development plans provide a cost-effective approach for appliance subsystems development. The approach is based on resolution of appliance weaknesses and deficiencies identified during the study.

The plans are structured to define the technical approach recommended for resolving the appliance subsystem weaknesses through further analysis, design and testing. A proposed schedule for phasing of the development effort was presented for selected appliance concepts. A summary of the plans presented are contained in Table 2.3-1.

2.3.1 Shuttle "Kit" Freezer Development

Discussion

The desirability for a varied food diet on long duration missions, which cannot be achieved with rehydrated foods, is recognized. To provide facilities for the frozen storage of whole food items, as well as medical samples, on board the Shuttle Orbiter a conceptual study has been conducted. Results from this study demonstrated the feasibility of a self-contained unit, requiring only an electrical power interface, which can be developed to satisfy the required storage volume and thermal environment and can be effectively mounted in the Orbiter crew compartment.

Technical Objective

The objective of this program is to develop a self contained freezer "kit" to provide storage for food and medical samples.

Approach

Primary elements of the "kit" freezer include the storage box and the refrigeration system. The storage box is a conventional freezer design of inner and outer box structure with polystyrene foam thermal insulation between.

Table 2.3-1 APPLIANCE DEVELOPMENT PLANS SUMMARY

HABITABILITY SUBSYSTEM	HABITABILITY FUNCTION	APPLIANCE FUNCTION	DEVELOPMENT PLAN STATUS
FOOD MANAGEMENT	FOOD STORAGE	REFRIGERATED FROZEN	PROPOSED DEVELOPMENT PLAN (PARAGRAPH 2.3.1)
	FOOD PREPARATION	WARMING	STATE OF THE ART
	GALLEY CLEANUP	DISH CLEANUP	PROPOSED DEVELOPMENT PLAN (PARAGRAPH 2.3.2)
PERSONAL HYGIENE	WASTE COLLECTION	FECAL COLLECTION URINE COLLECTION VOMITUS COLLECTION	GENERAL ELECTRIC DEVELOPING SYSTEM FOR SHUTTLE STATE OF THE ART
		BODY CLEANSING	SHOWER PARTIAL BODY WASHING PARTIAL BODY DRYING
	PERSONAL GROOMING	SHAVING HAIRCUTTING	STATE OF THE ART STATE OF THE ART
		HAIL CARE	STATE OF THE ART
		DENTAL CARE	STATE OF THE ART
HOUSEKEEPING	EQUIPMENT CLEANUP	SURFACE WIPING	CURRENTLY ON-GOING STUDY
	REFUSE MANAGEMENT	MANUAL COLLECTION	STATE OF THE ART
		VACUUM COLLECTION	STATE OF THE ART
		REFUSE PROCESSING REFUSE DISPOSAL	STATE OF THE ART STATE OF THE ART
GARMENT/LINEN MAINTENANCE	CLOTHES WASH/DRY	PROPOSED DEVELOPMENT PLAN (PARAGRAPH 2.3.2)	
OFF-DUTY ACTIVITIES	ENTERTAINMENT	MUSIC LIBRARY TELEVISION GAMES	STATE OF THE ART STATE OF THE ART STATE OF THE ART STATE OF THE ART
	PHYSICAL CONDITIONING	EXERCISES	STATE OF THE ART

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2.3.1 Continued

The refrigeration system consists of a circulating coolant used to transfer heat from the storage box to the refrigeration unit. The refrigeration unit employ a Stirling cycle principle cooler to pump heat from the coolant to the cabin atmosphere.

A preprototype of the freezer storage box (all freezer components except refrigeration unit (R/U)) will be fabricated and tested to define the freezer thermal characteristics. This box would be fabricated to the conceptual design with necessary refinements. Coolant temperature and flow-rates will be easily simulated without the necessity of a refrigeration unit. Thermal environment simulating the Orbiter crew compartment can be economically accomplished at sea level pressure. Using this test article, the validity of the thermal model calculations will be determined and the necessary refinements to the model made to provide a more accurate characterization of the freezer. These tests will determine if the volume allocated to the R/U is adequate or not. In the event it is not, the amount of insulation must be reduced (therefore an increase in thermal load to the R/U) and the R/U resized. Trades of amount of thermal insulation versus R/U volume requirements can be conducted with greater confidence using the results of the preprototype test and a refined thermal model.

The refrigeration unit preprototype would be an accurate representation of the conceptual design in all respects except the drive mechanism. The drive mechanism proposed has been utilized on other Stirling refrigeration systems, and it would not be necessary to demonstrate its feasibility at this point in the development. A bench test setup using an external drive system would be employed to investigate the major operating parameters of the Stirling system or head of the unit. Cycle efficiency, electrical power requirements, cyclic frequency effects, and cooling requirements will be established. These tests will also aid in determining the R/U volume and weight requirements. However, the R/U mechanism (except the drive) will be fabricated to the conceptual design specification for possible use in prototype testing in the event the preprototype tests demonstrate its performance is satisfactory. The head will be designed to adapt to the more sophisticated drive mechanism used on the prototype.

2.3.1 Continued

A prototype freezer will be tested to investigate the performance of the storage box and refrigeration unit combination. The prototype will utilize the preprototype storage box and refrigeration unit unless the preprototype testing and analysis indicates that these units must be radically resized. This is not anticipated with the storage box since some allowance for an oversized R/U can be accommodated in the box insulation in the area above the pallet.

Testing of the prototype freezer will be conducted to assess the performance of the complete refrigeration system. Items to be investigated are:

- o R/U component life
- o R/U cooling system efficiency
- o Nominal and off-nominal operation
- o Temperature control system
- o Storage box temperature profiles
- o Optimum cooling liquid flowrate
- o Ice build-up inside storage volume and on stored items

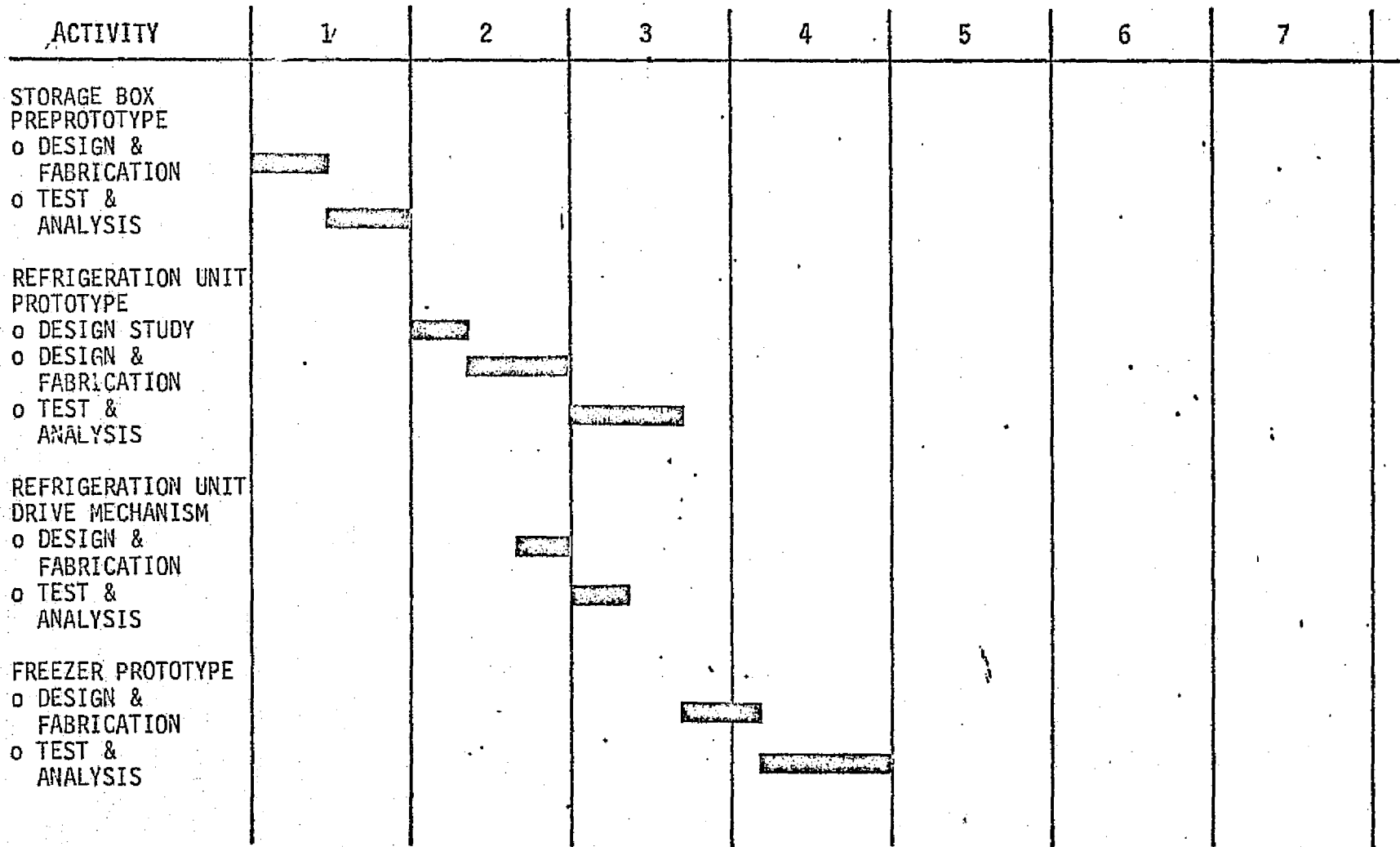
Since a considerable amount of zero "g" operating experience has been accumulated on the Stirling principled coolers, zero "g" testing will not be necessary. A flight article can be fabricated from the information gained from prototype testing. The proposed development schedule is shown in Figure 2.3-1.

2.3.2 Washer/Dryer Combination (Dishes and Clothes) Development

Discussion

Mechanical washer/dryer for dishes and clothes has potential application for long duration space missions (greater than 180 days). This appliance would eliminate the necessity for the launching with many disposable items such as crewmen's clothes, linens, cleaning and drying cloths, and dishes and eating utensils and provide a savings in weight and volume. Using a water spray agitation concept permits washing of both rigid and non-rigid items in the same enclosure; eliminating the need for two individual appliances and consequently providing a reduction in development effort.

YEARS FROM GO-AHEAD



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Figure 2.3-1. Freezer Development Schedule

2.3.2 Continued

Technical Objective

The objective of this effort is to develop an appliance for long duration space station application which will function as a washer and dryer for items normally identified as disposable.

Approach

A dual function washer/dryer combination to operate in a space station environment is feasible using water spray agitation as the cleaning mode and electrically heated circulating air as the method of drying. A rack to restrain the washer load when used as a dish washer is removed when the washer operates as a clothes washer. Pulsating, high velocity water jets are directed onto the load from all sides to provide effective agitation and to prevent clothes from trapping against the washer sides. Circulating air transports the water from the washer to the water separator. Verification of this washer concept by ground testing would be difficult, since accurate simulation of the zero "g" suspension of clothing is impractical. Feasibility of water to control the position of the clothes load in the washer should be investigated in zero "g" aircraft tests. However, demonstration of cleaning and rinsing effectiveness and the water transporting system must be conducted in orbital flights of sufficient duration.

No technological problems are foreseen in the operation of this concept in the drying mode. Air jets, designed to center the clothes in the dryer, will induce a tumbling action to the clothes as well as provide a drying medium.

Ground test data for commercial vendors' models and space oriented prototypes will provide some data which can be related to the flight test item. Effectiveness of water cleaning of dishes as well as convective air drying will be investigated from these data. Electrical power requirements for heating of wash water and drying air, plus optimum cycle times will be established. The proposed development schedule is shown in Figure 2.3-2.

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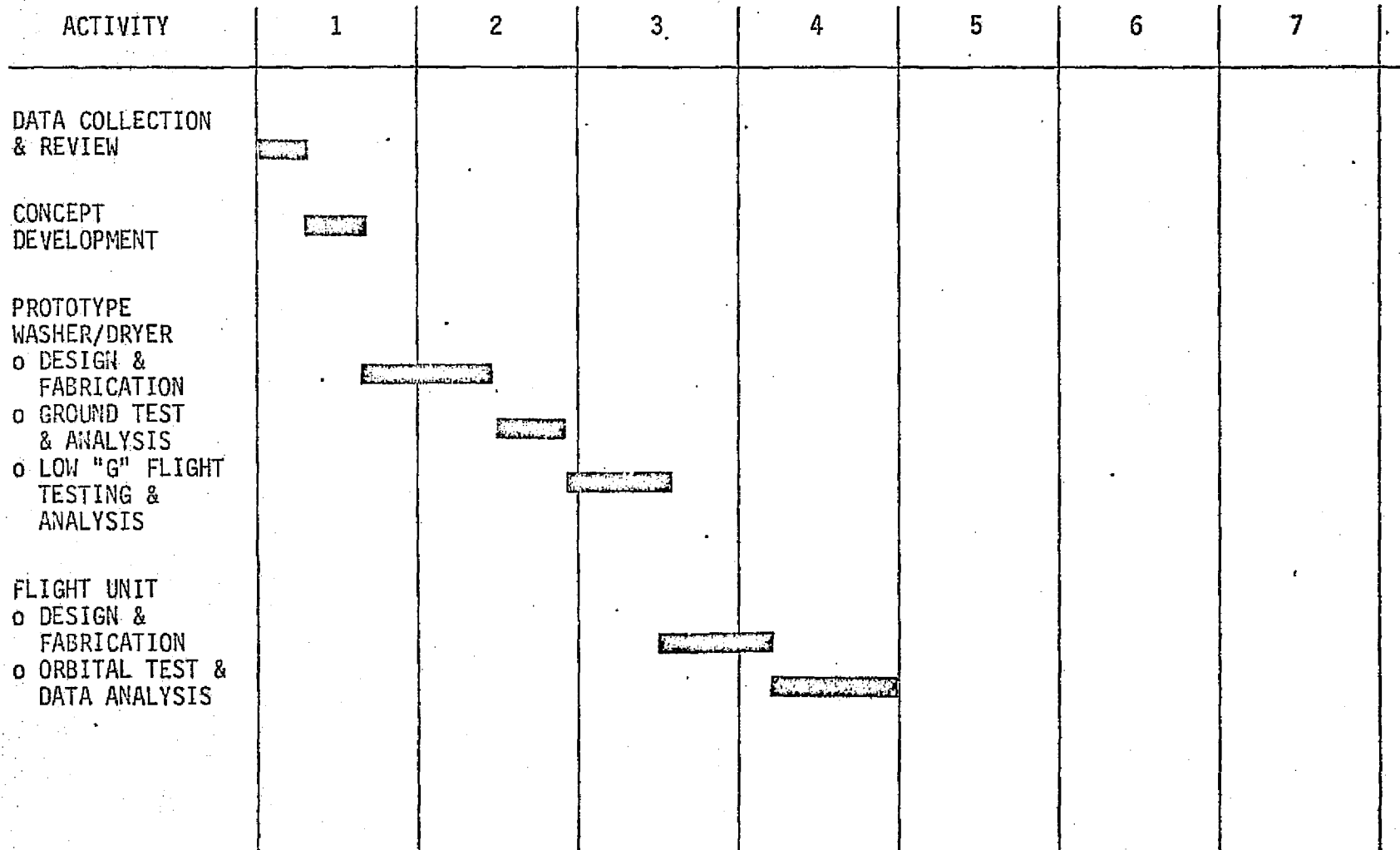


Figure 2.3-2. Washer/Dryer Development Schedule

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2.3.3 Shower Development

Discussion

Whole body cleaning becomes a mandatory requirement as mission durations extend. A whole body shower has been found to be the most reasonable approach for this bodily function. This appliance, using proper design, can greatly reduce the crew member washing time which has been for the most part accomplished by partial body washing techniques. The trade studies have indicated a collapsible shower, similar to the Skylab design, is the optimum approach for this appliance. The technical approach recommended is based principally on the literature surveys conducted during the study and experience gained during shower test support activities conducted at NASA-JSC.

Technical Objective

The objective of this effort is to develop an appliance for long duration space station application which will function as a whole body shower for crewmembers.

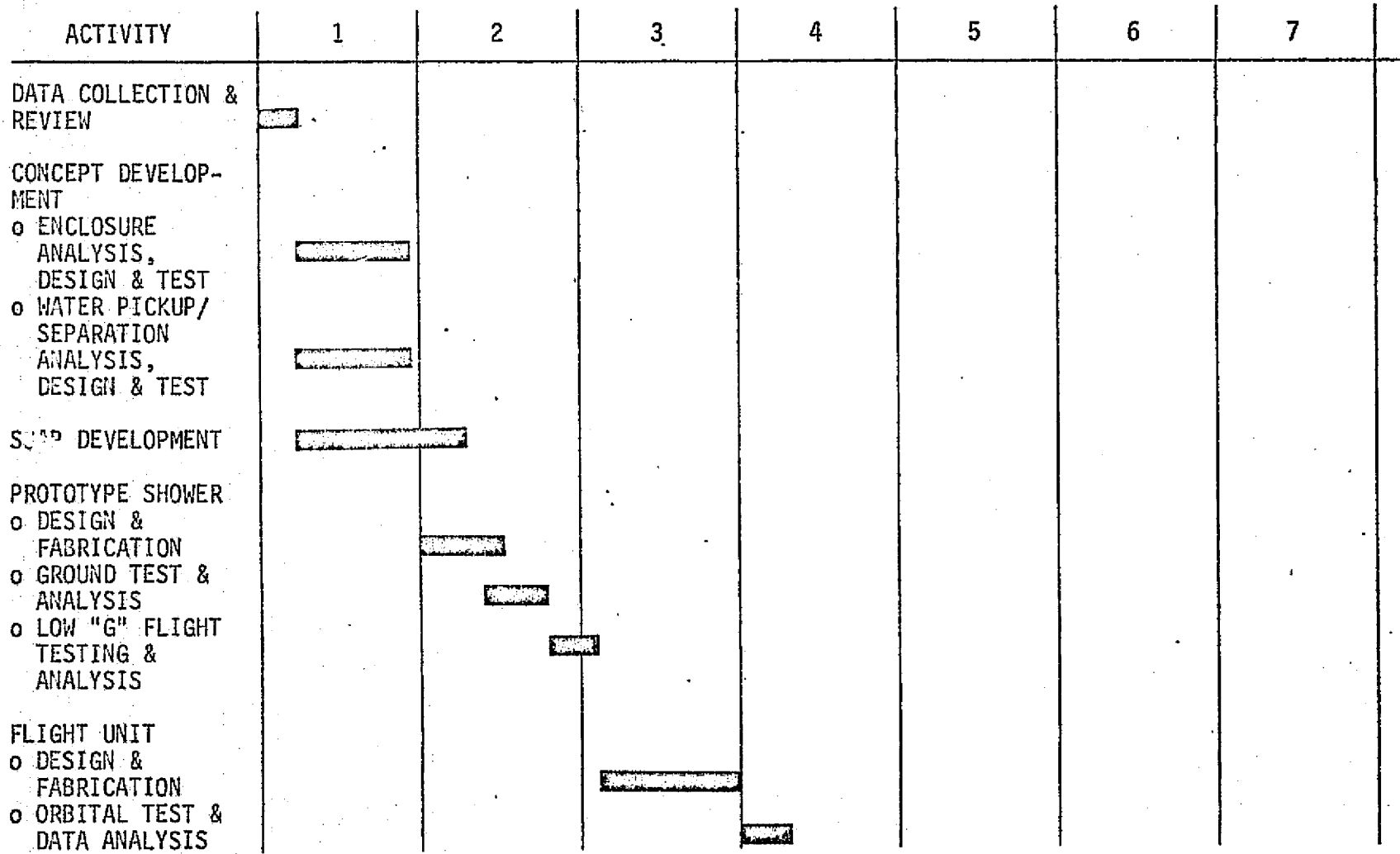
Approach

Several designs of whole body showers have been advanced, however all have a common problem of a good water pickup technique. The water pickup technique must be incorporated into the shower design in conjunction with the selection and design of the enclosure. The biggest crew complaint of the Skylab shower was the long laborious job of water pickup. A water pickup system must therefore be designed which will speed the process of loose water pickup. A collapsible semi-rigid enclosure should be considered to exploit its obvious advantages of lower weight and volume. Water/air separation must be improved to handle a greater latitude of cleaning soaps. Present designs do not allow for separation of high sudsing soaps which are normally more comfortable to the user. Concurrent with this study, a low sudsing soap should be investigated which does not leave an "oily feeling" like Miranol after usage. Water/air separator techniques should consider a dynamic technique for zero "g" usage in addition to consideration of baffles or screens for anti-foaming action.

2.3.3 Continued

The shower system should be ground tested for acceptance testing and personnel evaluation. Aircraft low gravity tests should be conducted to evaluate the water pickup and water separation systems. Finally, a flight configuration should be tested, for instance, in the Shuttle payload module to evaluate the system under long term zero gravity conditions. The proposed development schedule is shown in Figure 2.3-3.

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Figure 2.3-3. Shower Development Schedule

3.0 RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

The Shuttle Orbiter appliance system defined by this study is within the currently allocated thermodynamic, electrical power, weight, and volume vehicle requirements. Appliance concepts selected by the trade studies and optimization techniques applied during the study showed that disposable appliance concepts were the best compromise for the Shuttle Orbiter appliance system.

The appliance system described for the Space Station was one which offers the optimum in crew convenience with minimum impact on thermodynamic, electrical power, weight, and volume vehicle requirements. Establishment of a firm set of Space Station thermodynamic and electrical power requirements are needed for future appliance studies.

Crew performance/convenience requirements were found to drive the selection of the appliance concepts for the optimum system. Therefore, the selected appliance concepts based on the weighted trade study were, in many cases, not the concepts chosen as a result of the subsystem and system optimization. The weighted trade study did not account for crew preference/convenience due to the difficulty of developing an objective rating system without satisfactory reference data. Future studies should provide a survey of astronauts in order to derive statistical crew approval ratings of the various appliance concepts which could be factored into the computerized weighting trade program.

The computerized weighting trade program developed during this study proved to be an excellent method to objectively select the best appliance concepts in terms of weight, power, volume, thermodynamics, reliability, maintainability, safety, development cost, and resupply. Advantages of the trade program are rapid rerating of appliance concepts caused by trade parameter changes, a convenient, flexible, and quick method for comparing numerous appliance concepts, and easy manipulation of trade parameter weighting distribution. Future programs should consider this computerized trade program as a necessary tool for an objective selection of systems with numerous competitive concepts.

3.0 Continued

A Crew Appliance Bibliography of 682 references was compiled in a computerized format using a generalized data handling program, COMPOSIT'77, available on the Commander-II System of Com-Share timesharing computer located at Ann Arbor, Michigan. This bibliography can be easily accessed remotely and with periodic updating will provide a comprehensive listing of the current appliance reference data. These data can be retrieved by reference number, title, author(s), date, publishing organization, contract number, NASA-JSC library number, and/or subject matter.

Selected appliance concepts were modeled within the G-189A framework and were demonstrated to be compatible with the G-189A program. These subroutines provide a tool for future appliance analysis. The models are flexible, with generalized input, such that many different appliance concepts or designs can be handled by a single subroutine. Since many of these appliance concepts have not yet been designed or built for spacecraft applications, additional appliance testing is required before correlation of the subroutines to actual test data can be made.

Appliance trade studies for a space station having a resupply period of 180 days have shown that a clothes washer/dryer and dishwasher are not the optimum conceptual choice. These appliances were specified for this study to provide the maximum appliance utility and minimum consumables requirements. Further study is warranted to develop data necessary to perform a detailed trade study of the interrelationship of crew time with thermodynamic and electrical power requirements.

Test support activities have successfully demonstrated the long term operation of the Oxygen Generation Subsystem. This subsystem electrolyzes water into hydrogen and oxygen. Oxygen will be used for cabin leakage and metabolic leakage makeup and hydrogen will be provided to the CO₂ Collection Subsystem, thus allowing for CO₂ removal from cabin air. Shower testing (in excess of 60 showers) has attained high marks for personal acceptance with water usage per shower averaging .50 to .75 gallons. The method of water pickup after showering should be improved.

3.0 Continued

The Shuttle "kit" Freezer Study has demonstrated the conceptual feasibility of a portable "kit" freezer which will satisfy the stated food and medical sample storage requirements for Shuttle operation. The conceptual freezer can be passed through the Orbiter side hatch fully assembled and can be mounted on existing storage module supports, located in the Orbiter crew compartment, using standardized fasteners and tools. Total design launch weight of the freezer and contents of 285 pounds is within the maximum weight restraint capability of the storage module supports. Conventional construction techniques are employed in the conceptual freezer which will require short lead times and economy in fabrication.

The self-contained refrigeration unit requiring 206 watts peak electrical power will provide a safe and efficient cooling system with a coefficient of performance (C.O.P.) of 0.355. The steady state duty cycle is approximately 69% with an 80°F ambient cabin temperature.

Thermal analyses of the freezer have shown the cooling capacity of the refrigeration unit is sufficient to maintain the storage box structure and contents at 0.0°F or below after medical sample insertions and door openings. A warm medical sample can be cooled from 80°F to 30°F in approximately 3 hours. The steady state heat leakage rate of the storage box is 46.4 watts with an ambient temperature of 80°F and an average storage temperature of -10°F.

Limitation of volume allocated to the freezer results in a thermal insulation thickness which is less than optimum. This also impacts the sizing of the refrigeration unit since it must provide rejection of the additional thermal load at the expense of weight and electrical penalties. Because of the criticality of the freezer insulation properties, it is recommended that the thermal characteristics of the freezer box be carefully validated early in the freezer development program. If tests reveal the thermal load to the refrigeration system is greater than predicted, then two options are available:

3.0 Continued

1. Increase the insulation thickness at the expense of storage capacity.
2. Increase the cooling capacity of the refrigeration unit with the inherent penalty of weight and electrical power increases.

Design, fabrication, and testing of the freezer can be accomplished with a relatively small investment and will provide valuable information to firm up the freezer configuration. These tests will make a definite establishment of the volume which can be allocated to the refrigeration unit, and the R/U volume constraints must be defined with reasonable certainty before a cost-effective R/U development program can be initiated.

An integrated appliance/ECLSS E-189A computer model should be developed to (1) determine optimum hook-up between the appliance and spacecraft systems, and (2) establish system timeline characteristics. This model would provide the data necessary for the most efficient utilization of crew appliances.