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SHUTTLE FREEZER CONCEPTUAL DESIGN

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CREW APPLIANCE STUDY

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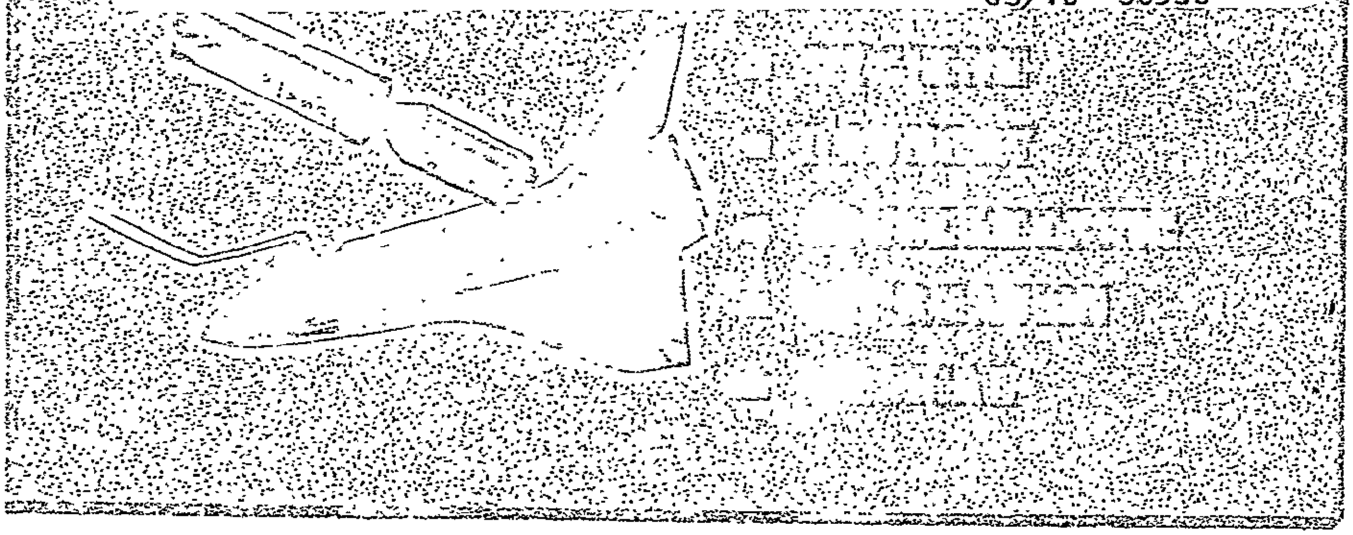

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ABSTRACT

A study was performed to develop a conceptual design for a "kit" freezer for operation onboard Shuttle missions. This study was performed for NASA-JSC, Crew Systems Division, under Contract NAS 9-13965 by the Boeing Aerospace Company in conjunction with the LTV Aerospace Corporation. The freezer under study features a self-contained unit which can be mounted in the Orbiter crew compartment and is capable of storing food at launch and returning with medical samples. Packaging schemes were investigated to provide the optimum storage capacity with a minimum weight and volume penalty. Several types of refrigeration systems were evaluated to select one which would offer the most efficient performance and lowest hazard of safety to the crew. Detailed performance data on the selected, Stirling cycle principled refrigeration unit were developed to validate the feasibility of its application to this freezer. Thermal analyses were performed to determine the adequacy of the thermal insulation to maintain the desired storage temperature with the design cooling capacity, and stress analyses were made to insure the design structure integrity could be maintained over the Shuttle flight regime. A proposed prototype freezer development plan is presented.

KEY WORDS

Food Storage
Heat Rejection
Medical Sample Storage
Orbiter Storage Module
Shuttle Orbiter
Stirling Cycle
Thermal Insulation
Thermal Modeling
Thermoelectric
Vapor-cycle

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1.0 SUMMARY

This report documents the results of a study conducted to develop a conceptual "kit" freezer to be used to store food and medical samples on long duration Shuttle missions. The design described 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.

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.

2.0 INTRODUCTION

The desirability for a varied food diet on long duration missions, which cannot be achieved by rehydrated meals, is recognized. To provide facilities for the frozen storage of whole food items as well as medical samples on board the Shuttle Orbiter, Crew Systems Division was requested by the Life Sciences Directorate to determine the feasibility of a freezer "kit" which would not be permanently mounted but which could be readily installed on board the vehicle for selected orbital missions. The task of developing a conceptual design for such a freezer was assigned to the Boeing Aerospace Company to be integrated into the Crew Appliance Study (Contract NAS 9-13965) in progress at the time. 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 volume is limited by the volume which can be passed through the Orbiter side hatch and by the crew equipment storage module dimensions. Because of this limitation, the design storage volume was minimized by utilizing the emptied food storage volume as medical sample storage space. Limitation of volume also curtailed the amount of thermal insulation which could be employed. Because the insulation thickness was less than optimum, a detailed thermal analysis was conducted to insure the design thickness was adequate to maintain the required storage temperature for expected heat leakage and thermal perturbations with the cooling capacity available.

Orbiter cabin air was used as the heat sink medium for the refrigeration unit because of the restriction of freezer location in the crew compartment demanded by liquid cooling. An optimization process was conducted to select the refrigeration concept which would provide the necessary cooling with minimum weight, volume, and electrical power requirements, and expose crew-members to the minimum hazard of safety.

3.0 FREEZER DESIGN REQUIREMENTS

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).

3.1 FOOD STORAGE REQUIREMENTS

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 dried 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 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^{0}F prelaunch and stowed in the freezer initially at this temperature. The freezer will maintain food items at an average temperature of from 0^{0}F to -20^{0}F.

3.2 MEDICAL SAMPLE STORAGE REQUIREMENTS

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. Urine is assumed produced at a rate of 120 milliliters (ml) per crewman per day or for the seven (7) man crew a daily urine pool of 840 ml will be generated. Packaged weight for this pool is 2.72 pounds.

Feces samples are to be taken from each crewman for each defecation (assumed to occur 1.5 times/day during the 30-day mission). Of an approximate feces weight of 150 grams per defecation per crewman, 25% will be frozen as a medical sample. Packaging weight for each sample is 100 grams. These samples will be placed into the freezer as they are collected and not pooled. Total daily packaged sample for seven (7) crewmembers will weigh 1.55 pounds.

Based upon the above descriptions the maximum expected medical sample weights and volumes collected during a 30-day mission are:

	Weight (lb.)	Volume (ft^3)
Urine	81.6	1.75
Feces	46.7	0.88
Total	128.3	2.63

Weights and volumes shown include amounts for packaging.

3.3 FREEZER OPERATING ENVIRONMENT

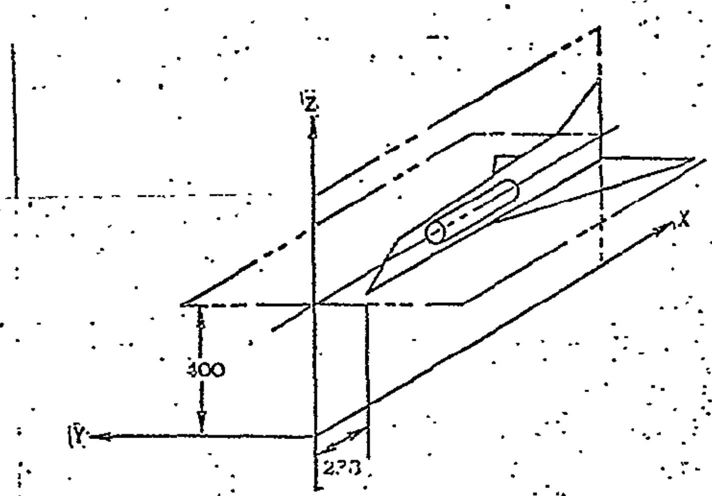
The freezer is to be designed for operation within the Orbiter crew compartment. Compartment atmospheric pressure is 14.7 psia at 80°F and with a dew point of 50°F.

Imposed steady and dynamic accelerations are summarized in Table 3-1 (from Reference 1).

Figure 3-1 illustrates the Orbiter coordinate axis system and defines the sign convention utilized.

TABLE 3-1 ORBITER STEADY AND DYNAMIC ACCELERATIONS

Mission Phase	Longitudinal (X)		Transverse (Y or Z)	
	Steady (g)	Dynamic (g)	Steady (g)	Dynamic (g)
Lift-Off	-1.70	±4.00	-0.10 (Z)	±1.00
Max. Q Region	-1.60	±0.25	-0.25 (Z) ±0.10 (Y)	±0.25
Booster Max. Acceleration	-3.00	±0.25	-0.30 (Z)	±0.25
SRB Staging	-1.00	±3.00	-0.28 (Z)	±1.00
Orbiter Max. Acceleration	-3.00	±0.25	-0.68 (Z)	+0.25
ET Separation	-	-	0.03 (Z)	-
Orbiter AOA Separation	-	-	0.03 (Z)	-
RTLS Abort Separation	TBD	TBD	TBD	TBD
Space Operations	+0.02 -0.08	-	±0.02 (Y) ±0.04 (Z)	-
Entry	1.60	-	2.50 (Z)	-
Flyback	TBD	TBD	TBD	TBD
Landing/Taxiing/ Braking	TBD	TBD	TBD	TBD



TYPE: Rotating, vehicle referenced

ORIGIN: 238 inches ahead of the nose and 400 inches below the centerline of the payload bay.

ORIENTATION AND LABELING:

The X axis is parallel to the centerline of the payload bay, positive rearward.

The Z axis is positive upward in landing attitude.

The Y completes the right-handed system.

The standard subscript is Vo.

Figure 3-1. Orbiter Coordinate System

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4.0 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.

4.1 STORAGE COMPARTMENT OPTIMIZATION

The requirement for separation of food and medical sample items necessitates a storage volume which is larger than that required to just provide food storage. With unlimited volume accommodations the freezer volume would be compartmented for separate food storage and medical sample storage volumes. This would require a total freezer storage volume of 6.63 cubic feet (4 ft^3 for food and 2.63 ft^3 for samples). However, by utilizing the food storage volumes being emptied during the course of the mission as medical storage space, the total freezer volume requirements are much less.

Assuming constant food consumption and medical sample generation rates, the storage volume requirements versus mission time are as plotted in Figure 4-1. Because of the required separation and because medical samples are to be generated and stored during the first day of the mission, the freezer must be launched with an empty volume. The objective of the optimization is to reduce this empty volume to the lowest practical value.

Using these characteristics, five compartmentation options (described in Table 4-1) were investigated. As indicated by the volume totals listed in the table, configuration option #5 requires the smallest storage volume of 4.6 ft^3 using four (4) different sized compartments. This volume can be reduced further by the use of even more compartments; however, the size of the empty compartment becomes impractical as does the number of compartments.

TABLE 4-1

OPTIMIZATION OF STORAGE VOLUME COMPARTMENTS

- NEED MINIMUM OF 4 FT^3 OF FOOD STORAGE PLUS MUST ACCOMMODATE 2.6 FT^3 OF MEDICAL SAMPLES
- SHOULD MINIMIZE STORAGE VOLUME FOR MORE EFFICIENT FREEZER THERMAL OPERATION AND LESS WEIGHT

	2 COMPARTMENTS	3 EQUAL SIZE COMPARTMENTS	4 EQUAL SIZE COMPARTMENTS	3 COMPARTMENTS WITH OPTIMIZED VOLUMES	4 COMPARTMENTS WITH OPTIMIZED VOLUMES
INITIALLY EMPTY MEDICAL SAMPLE COMPARTMENT VOLUME (FT^3)	2.6	2.0	1-1/3	1.1	0.6
FOOD COMPARTMENT VOLUMES (FT^3)	4.0	2.0	1-1/3	1.6	1.0
	-	2.0	1-1/3	2.4	1.4
	-	-	1-1/3	-	1.6
TOTAL FREEZER STORAGE VOLUME (FT^3)	6.6	6.0	5.33	5.1	4.6

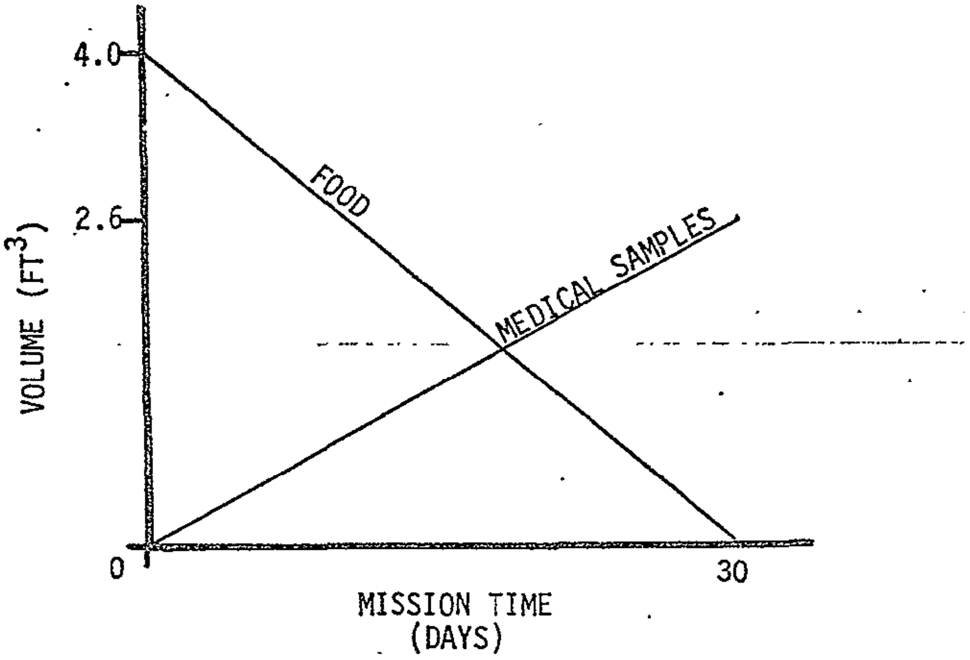
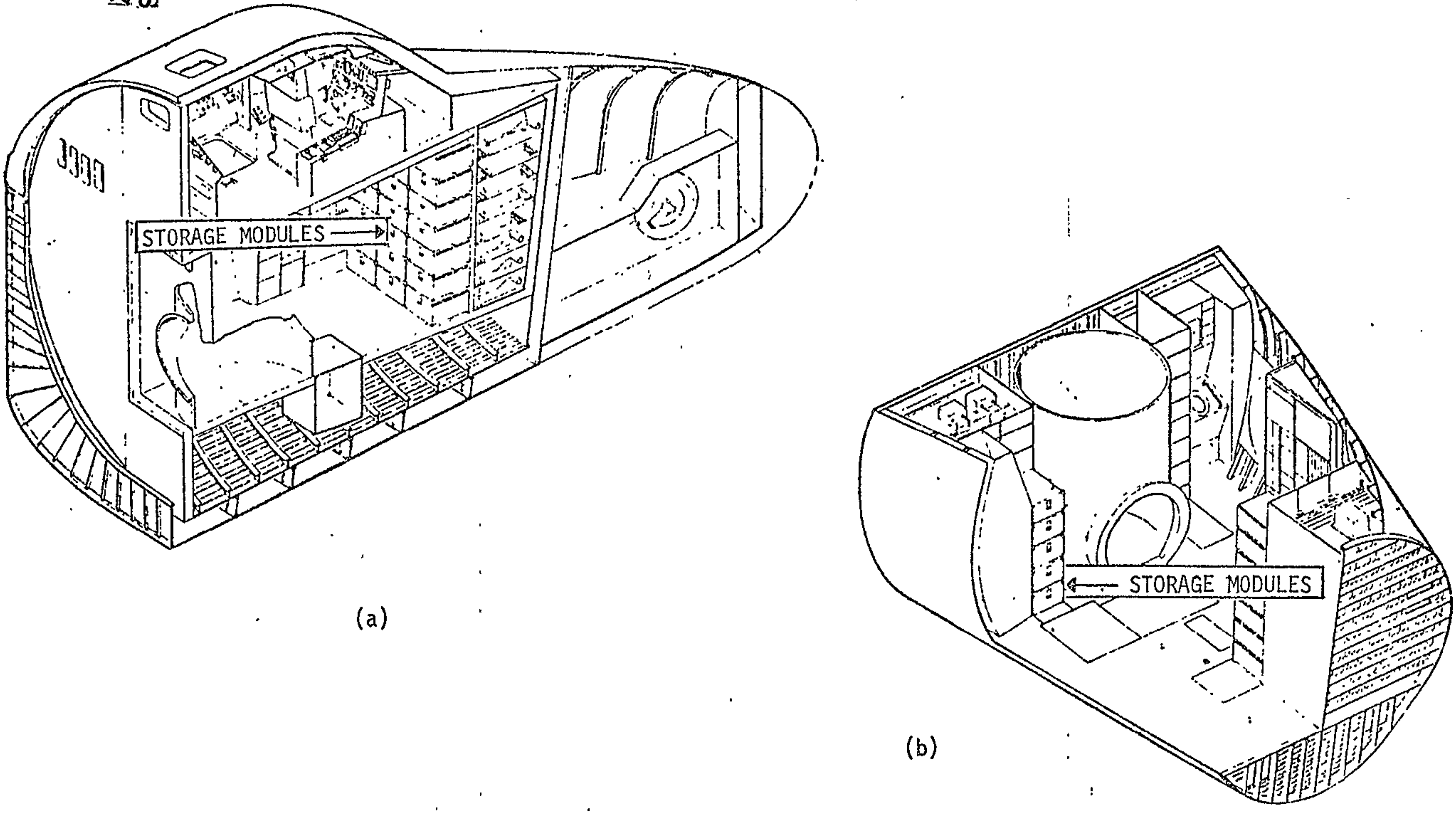


Figure 4-1. Food Usage and Medical Sample Production

The fill and empty sequence begins with the 0.6 ft^3 empty volume being filled with medical samples as the smallest food storage volume (1.0 ft^3) 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.

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 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 is illustrated in Figures 4-2a and 4-2b. The modules are



(a)

(b)

Figure 4-2. Crew Compartment Configuration mounted on posts, which extend from the Orbiter floor to ceiling, using fasteners located at each corner of each module. As seen in Figure 4-2a, 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 ajacent modules by 3/8 inch on all sides.

A drawing giving the dimensions of a single storage module is shown in Figure 4-3. The module is to be constructed of a fiberglass composite with an aluminum back plate and door. Mounting fasteners are permanently attached to the back plate and driven from the front of the module using an extension rod. The door is to be hinged in the longer frontal dimension and can be opened upward or downward depending upon the attitude in which the module is installed. The design weight of equipment which can be stored in the module is 70 lbs. and the expected module weight is five (5) pounds.

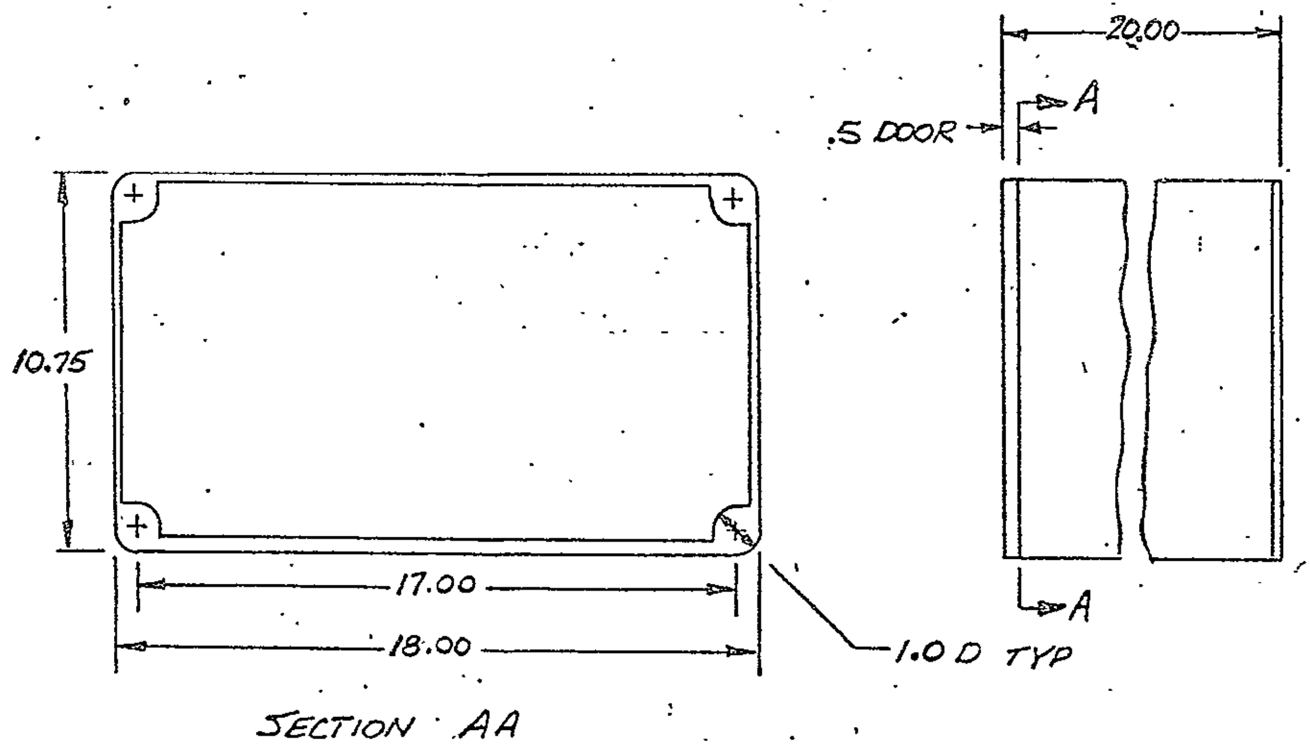


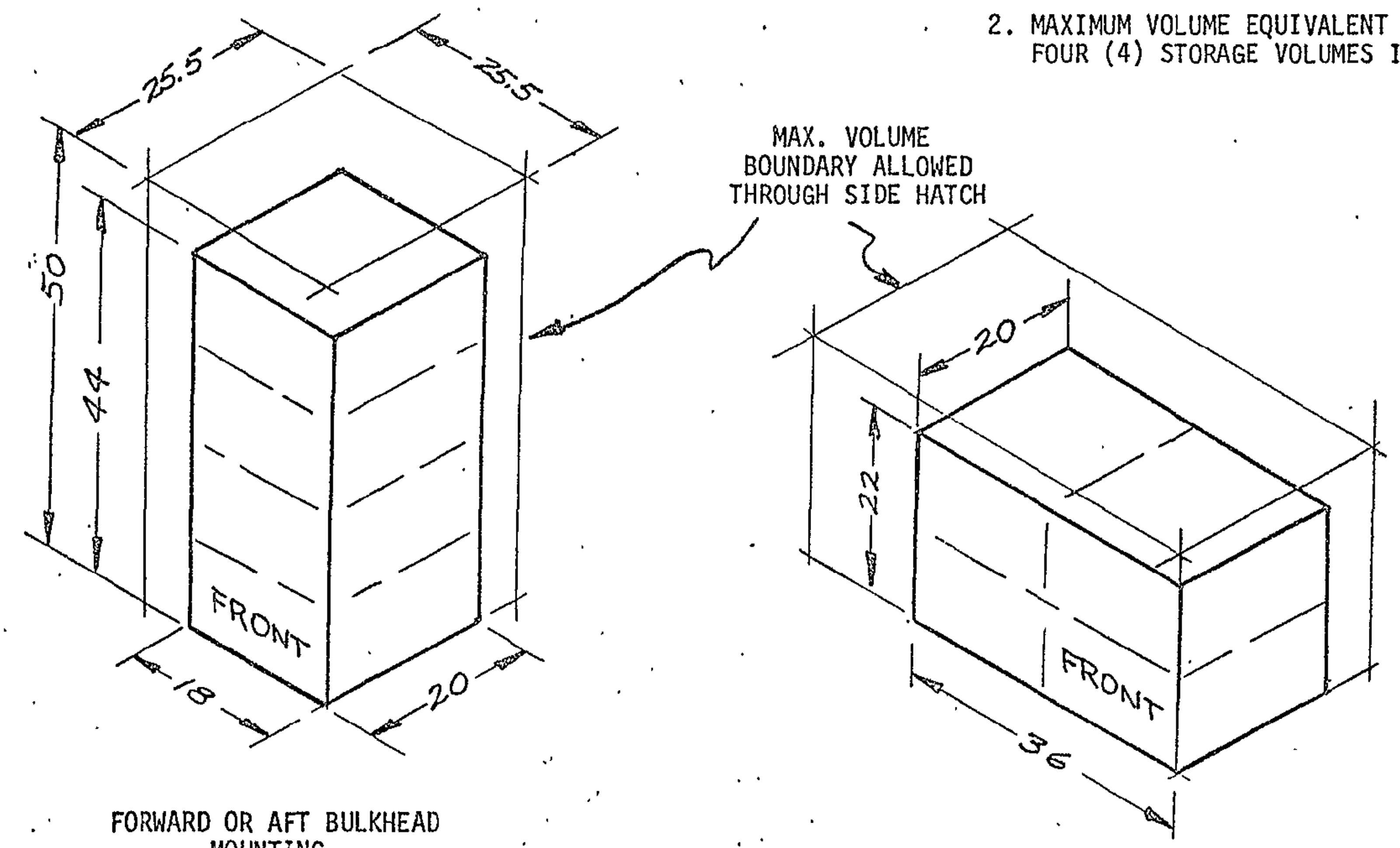
Figure 4-3. Orbiter Storage Module Configuration

The volume which can be passed through the Orbiter side hatch (with the airlock installed) is defined by the 25" x 25" x 50" rectangular volume. This maximum volume boundary is outlined in Figure 4-4 along with two possible equivalent module volume configurations which can fit within the boundary. In each configuration four (4) equivalent module volumes are within the 25" x 25" x 50" volume. One configuration is one module width stacked four (4) modules high - (4 x 1) and the other is two (2) widths stacked two (2) modules high - (2 x 2). Both orientations provide the same enclosed volume; however, the 4 x 1 arrangement has the larger surface area and is least efficient from the standpoint of thermal leakage. Also this configuration does not provide the flexibility in compartmentizing as does the 2 x 2 configuration. Because of these reasons, the 2 x 2 volume configuration was chosen.

This choice mandates that the freezer be mounted on the forward bulkhead since the aft bulkhead cannot accommodate side by side modules (see Figure 4-2a). Thus using the equivalent volume of four storage modules an enclosed volume of 9.2 ft^3 with external dimensions of 20 x 36.375 x 21.875 is available for the freezer.

NOTE: 1. ALL DIMENSIONS IN INCHES

2. MAXIMUM VOLUME EQUIVALENT OF FOUR (4) STORAGE VOLUMES IS 9.2 FT^3



FORWARD OR AFT BULKHEAD MOUNTING

FORWARD BULKHEAD MOUNTING ONLY

Figure 4-4. Available Freezer Volume Arrangements

5.0 FREEZER REFRIGERATION SYSTEM DESCRIPTION

The freezer refrigeration system includes the storage volume to 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. This section discusses the selection of the heat transmission and a trade study to determine the optimum refrigeration system.

5.1 STORAGE VOLUME TO REFRIGERATION HEAT TRANSMISSION

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 5-1 with two identified options (A and B) for each type. Type IA utilizes direct conduction (through tubing) between the cooling medium and the storage volume structure. For type IB heat is conducted from the storage volume by connection to the cold plates then to the circulating cooling medium.

The second type is essentially the same as type I except the function of the cooling medium is performed by the circulating refrigerant used in the vapor cycle type of refrigeration unit. This is the type of heat transmission used in most household freezers. The two options (IIA and IIB) used to transfer the heat to the refrigerant are the same as types IA and IB.

The third type of heat transmission available is direct connection of the R/U to the storage box with the storage volume heat transferred to the R/U coldplate by force convection. Of the two type III options considered, type IIIA would be restricted to the use of an R/U which is small and compact such as a thermoelectric cooler. Using this type each compartment is isolated. Type IIIB employs the same principle as type IIIA however with a single R/U and a common connective system for all storage volume compartments.

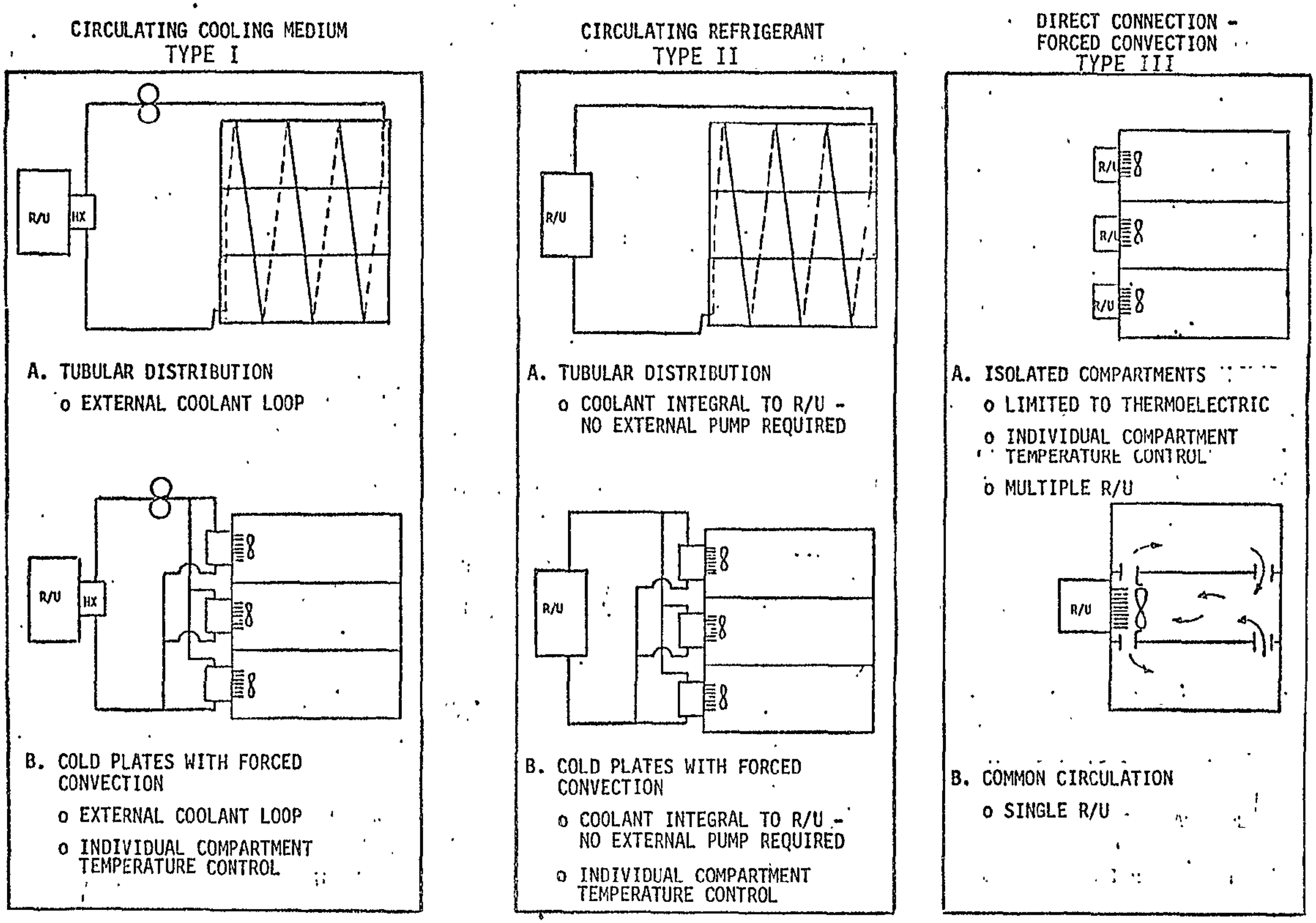


Figure 5-1. Storage to R/U Heat Transmission Options

Of the six types of heat transmission presented above, four can be initially eliminated for the various reasons summarized in Figure 5-2. 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 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.

5.2 REFRIGERATION SYSTEM TRADE STUDY

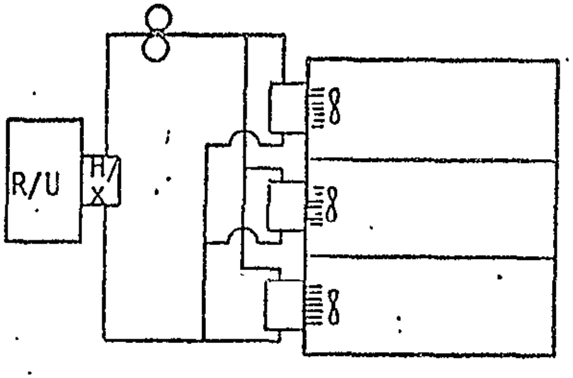
A screening of potential R/U concepts was conducted by LTV Aerospace to identify those concepts which were applicable to the requirements of the Shuttle freezer performance. Refrigeration concepts considered by LTV and a critique of each is tabulated in Table 5-1. Of these concepts, three were chosen for continued evaluation:

- Thermoelectric
- Stirling Cycle
- Vapor Cycle

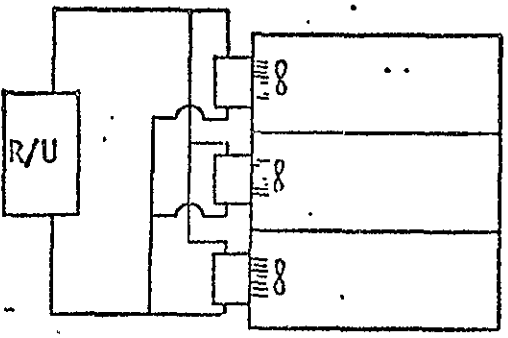
The working gases for the Stirling cycle and the vapor cycle are helium and ammonia, respectively.

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^{o}F, (2) water cooling at 80^{o}F, and (3) water cooling at 45^{o}F. The resulting weight, volume, and power requirements are plotted versus cooling rates in Figure 5-3 for each of the three concepts.

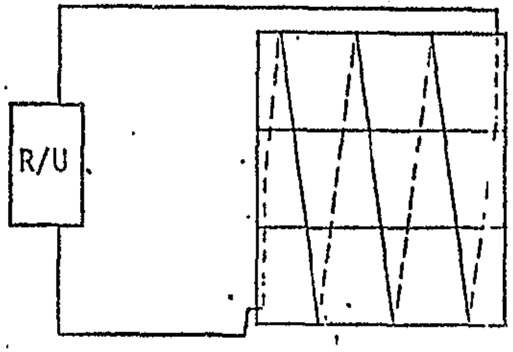
Preliminary estimates of the thermal leakage and thermal perturbation rates were made to determine the peak and average cooling rates to be developed by the R/U. Using these values the thermal loads weight and electrical



REASON:
- o HIGHER VOLUME REQUIREMENT
- o HIGHER ELECTRICAL POWER CONSUMPTION
- o HIGHER WEIGHT PENALTY



REASON:
- o HIGHER VOLUME REQUIREMENT
- o POTENTIAL SAFETY HAZARD (REFRIGERANT OUTSIDE SEALED HOUSING)



REASON:
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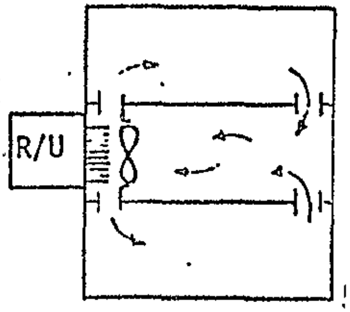

REASON:
- o CONTAMINATION OF FOOD BY MEDICAL SAMPLES

Figure 5-2. Eliminated Heat Transmission Options

TABLE 5-1. REFRIGERATION UNIT CANDIDATES

REFRIGERATOR		MISSION SUITABILITY	HARDWARE DEVELOPMENT STATUS	FIXED ELEMENTS		COP	SAFETY PROBLEMS	COSTS		COMMENTS
				WEIGHT	VOLUME			DEVELOPMENT	RECURRING	
GAS 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	• NO DEVELOPMENT OF APPROPRIATE SIZE EQUIPMENT FOR ZERO G • EXISTING HARDWARE MUCH TOO LARGE OR IS NOT SUITABLE	GOOD	GOOD	VERY GOOD	FLUIDS FOR CYCLE	MORE EXPENSIVE THAN STIRLING	MORE EXPENSIVE THAN T/E	• NEEDS DEVELOPMENT OF A ZERO G COMPRESSOR • MAY BE ABLE TO MODIFY A STIRLING MACHINE
ABSORPTION/ ADSORPTION 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 ON ORBIT MISSION PHASE ONLY	SPACE QUALIFIED	POOR	POOR	EXCELLENT	MINOR	FAIR	FAIR	• SYSTEM SUFFERS FROM HIGHLY COMPLEX INTERFACES • QUESTIONABLE FEASIBILITY WITHOUT ORIENTATION CONSTRAINTS

Prepared by LTV Aerospace

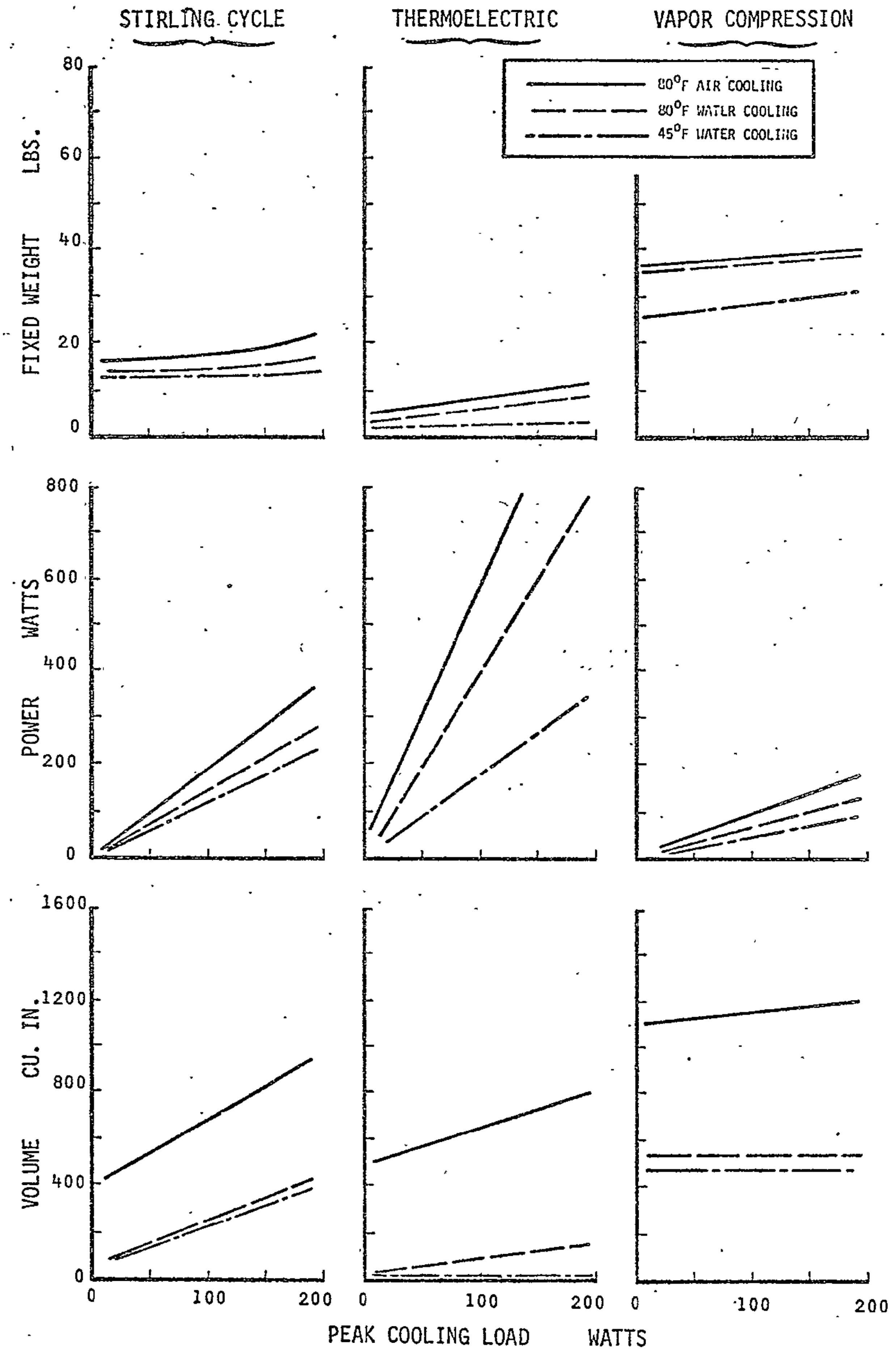

Figure 5-3. Refrigerations Unit Weight Volume and Electrical Power Requirements

power requirements of the three R/U types were derived for each mode of cooling. These values are listed in Table 5-2. The equivalent weight represents the weight of the R/U plus the fuel cell weight penalty.

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 maintenence factors were used as inputs to a computerized trade program. The program developed for a crew appliance optimization study is described in detail in Reference 2. A summary of values used as inputs to the trade program are presented in Table 5-3.

The results of freezer concept trade are tabulated in Table 5-4. 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. ft^3, 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. These values are plotted for each concept in Figure 5-4. As seen in this plot the Stirling cycle system utilizing $45^{O}F$ 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. As seen in Figure 5-4, 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 5-2. THERMOELECTRIC, VAPOR COMPRESSION, AND STIRLING CONCEPT CHARACTERISTICS

HEAT SINK MODE		FREEZER THERMAL LOAD, PEAK/AVG. (WATTS)	ELECTRIC POWER LOAD PEAK/AVG. (WATTS)	ELECTRICAL ENERGY (KW HR) (KG)	TOTAL EQUIV. WT. (KG)
CABIN AIR (26.7°C)	THERMO-ELECTRIC	62/28	363/167	120	68.3
	VAPOR COMPRESSION	75/42	70/39	28	44.7
	STIRLING CYCLE	65/32	121/59	43	42.2
WATER LOOP (26.7°C)	THERMO-ELECTRIC	60/27	240/108	78	51.5
	VAPOR COMPRESSION	75/42	52/29	21	41.5
	STIRLING CYCLE	65/32	95/47	34	31.1
WATER LOOP (7.2°C)	THERMO-ELECTRIC	60/27	108/48	35	34.4
	VAPOR COMPRESSION	75/42	38/21	15	35.1
	STIRLING CYCLE	65/32	80/39	28	35.5

NOTE:
1. NOMINAL FREEZER INSIDE TEMPERATURE = -23.5°C (-10°F) AND AMBIENT TEMPERATURE = 26.7°C (80°F)
2. CONDITIONED FOR 7 MAN-30 DAY MISSION

TABLE 5-3. APPLIANCE CONCEPT FUNCTION MATRIX

INDEX NO. 1.1.2. .... FREEZER (SHUTTLE)

CONCEPT NO.	USAGE TIME	CONSUMABLES AND FLOW REQUIREMENTS					THERMAL REQMTS		ELEC PWR REQMTS		WT/VOL REQMTS		DEVELOPMENT COST		RESUPPLY
	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)	AVAIL (**)	INDEX (***)	WEIGHT -KG- (LBS)
1	1.000	1	.0000	3.78	.0	26.7	0.	363.	.0	.0	68.5	.26	2	35	.0
	24.000		(.0000)	(8.00)	(.0)	(80.0)	(0.)	(1238.)	363.0	167.0	(151.0)	(9.20)			(.0)
2	1.000	1	.0000	3.78	.0	26.7	0.	70.	70.0	39.0	44.9	.26	4	80	.0
	24.000		(.0000)	(8.00)	(.0)	(80.0)	(0.)	(238.)	.0	.0	(99.0)	(9.20)			(.0)
3	1.000	1	.0000	3.78	.0	26.7	0.	121.	121.0	59.0	42.2	.26	3	65	.0
	24.000		(.0000)	(8.00)	(.0)	(80.0)	(0.)	(412.)	.0	.0	(93.0)	(9.20)			(.0)
4	1.000	4	.0000	226.80	.0	26.7	240.	0.	.0	.0	51.7	.26	2	35	.0
	24.000		(.0000)	(500.00)	(.0)	(80.0)	(820.)	(0.)	240.0	108.0	(114.0)	(9.20)			(.0)
5	1.000	4	.0000	226.80	.0	26.7	52.	0.	52.0	29.0	41.7	.26	4	80	.0
	24.000		(.0000)	(500.00)	(.0)	(80.0)	(177.)	(0.)	.0	.0	(92.0)	(9.20)			(.0)
6	1.000	4	.0000	226.80	.0	26.7	95.	0.	95.0	47.0	38.1	.26	3	65	.0
	24.000		(.0000)	(500.00)	(.0)	(80.0)	(324.)	(0.)	.0	.0	(84.0)	(9.20)			(.0)
7	1.000	4	.0000	226.80	.0	7.2	108.	0.	.0	.0	34.5	.26	2	35	.0
	24.000		(.0000)	(500.00)	(.0)	(45.0)	(368.)	(0.)	108.0	48.0	(76.0)	(9.20)			(.0)
8	1.000	4	.0000	226.80	.0	7.2	38.	0.	38.0	21.0	34.9	.26	4	80	.0
	24.000		(.0000)	(500.00)	(.0)	(45.0)	(130.)	(0.)	.0	.0	(77.0)	(9.20)			(.0)
9	1.000	4	.0000	226.80	.0	7.2	80.	0.	80.0	39.0	35.4	.26	3	65	.0
	24.000		(.0000)	(500.00)	(.0)	(45.0)	(273.)	(0.)	.0	.0	(78.0)	(9.20)			(.0)

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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.)

TABLE 5-4. CREW APPLIANCE SELECTION MATRIX FOR FREEZER

```
SELECTION MATRIX  .  .  .  .  .  FREEZER (SHUTTLE)

            MIN         MAX                                      C O N C E P T
FACTOR      VALUE       VALUE     PTS     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
RELIAB-Y    .97617      .99465      5    .00     .58    1.65    2.18    2.80    3.85    2.18    2.80    3.88
MAINTENC    .99998     1.00000      5    .00     .63    1.74    1.83    2.51    3.57    1.83    2.51    3.62
SAFETY      .00000     1.00000      5    .00     .00    5.00     .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   46.49   54.05


APPLIANCE
 CONCEPT
   NO.          C O N C E P T   N A M E

   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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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.)

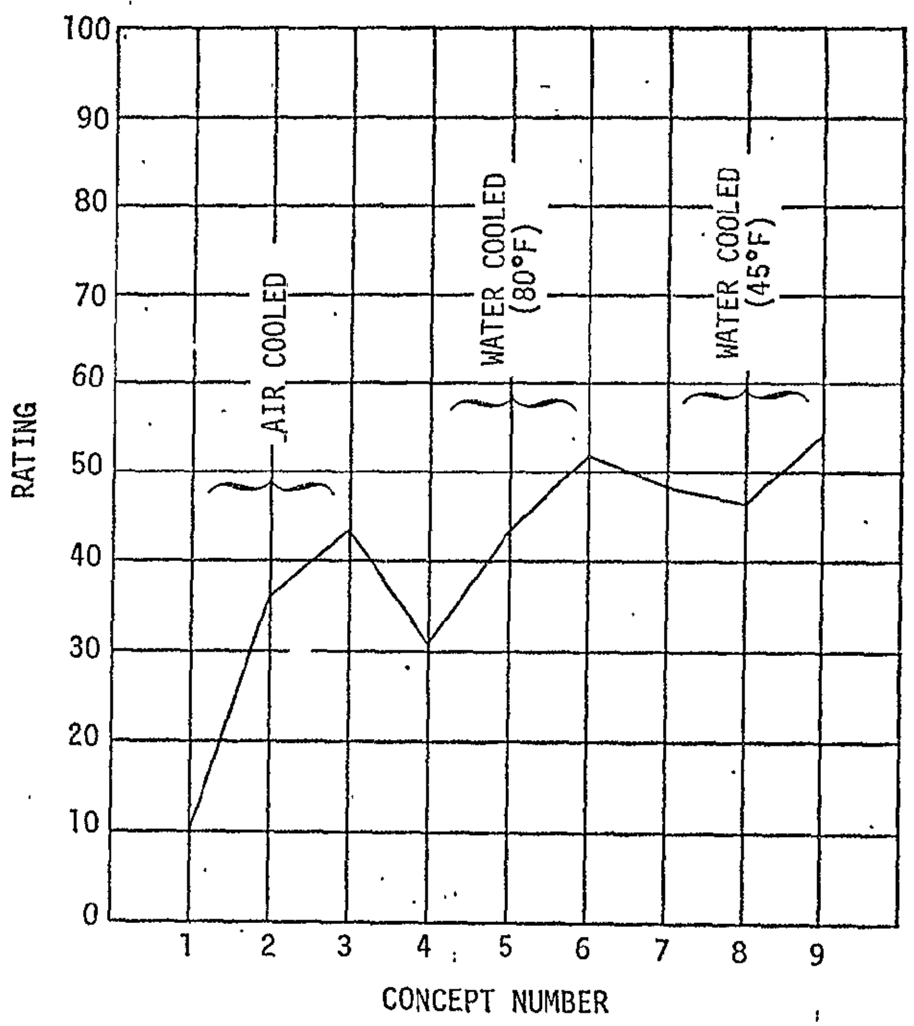


Figure 5-4. Freezer Trade Results

5.3 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. In this section, the refrigeration unit characteristics will be discussed briefly. A detailed description of the theory and design of the Stirling cycle unit can be found in Reference 3.

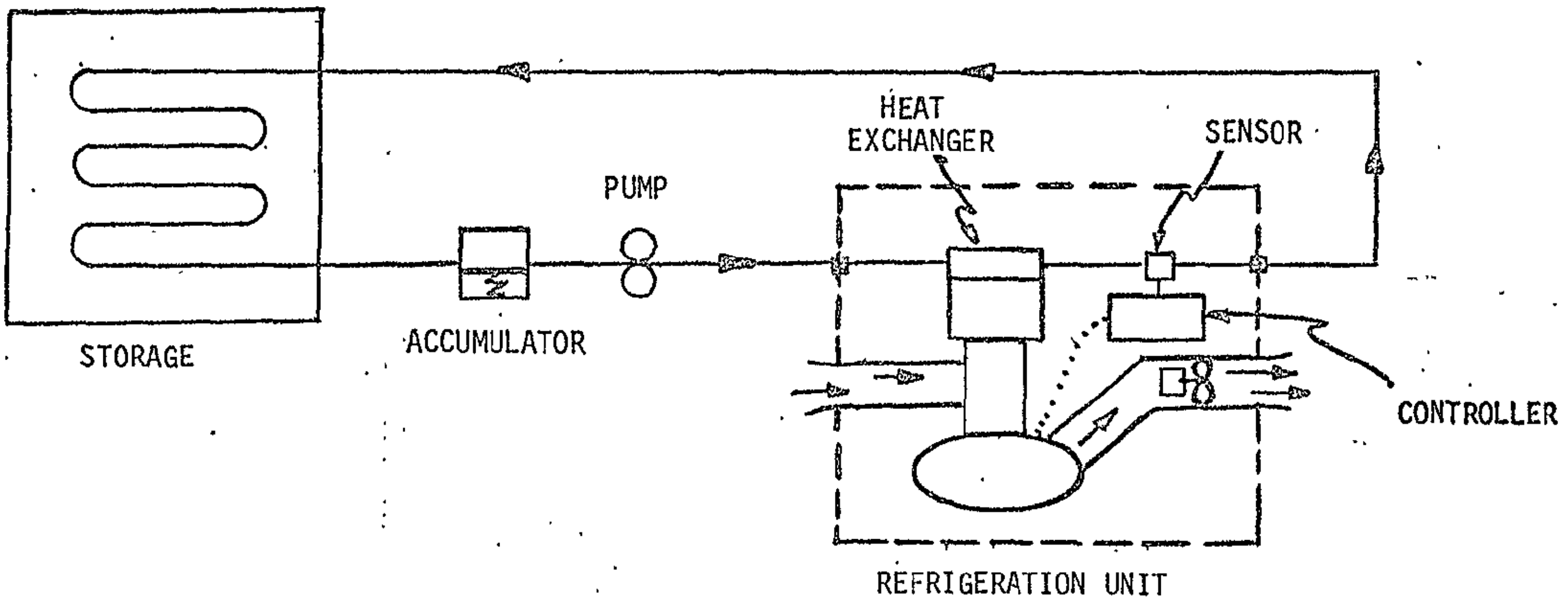
After sizing of the external freezer envelope and satisfying the storage volume requirements, the remaining volume was allocated to thermal insulation and the refrigeration unit. Calculations were made to determine the maximum insulation thickness possible with enough volume remaining to accommodate 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 design thermal load to the refrigeration unit was 75 watts, peak. 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 5-5.

A schematic showing the elements of the R/U and cooling loop is presented in Figure 5-5. The cooling liquid (Coolanol 15) is pumped continuously through the system once electric power is applied to the freezer. A temperature sensor downstream of the heat exchanger at the cold head senses the Coolanol 15 temperature which is conditioned by a controller. The controller provides "ON" and "OFF" electrical switching to the Stirling unit motor within specified temperature limits. Cooling air is drawn from the Orbiter cabin into the R/U enclosure, across the hot side of the Stirling unit, then over the drive motor and mechanism, and finally exhausted to the cabin. An accumulator is located in the cooling loop to cancel the pressure effects of cooling fluid expansion and contraction and minor leakage.

TABLE 5-5

REFRIGERATION UNIT PERFORMANCE

o Refrigeration Cycle	Stirling
o Cooling Rate	75 watts from Coolanol 15 ($\simeq$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 Ø Regulated AC	30 watts (Fan)
TOTAL	206 watts
o Coolanol 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



- COOLANT IS PUMPED CONTINUOUSLY
- REFRIGERATION UNIT (R/U) CYCLE CONTROLLED "ON - OFF" BY COOLANT TEMPERATURE LIMITS

Figure 5-5. Freezer Refrigeration System

6.0 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 stress analysis was made primarily to investigate those areas of the structure which by inspection are subjected to the most detrimental stress loads.

Figure 6-1 is a cutaway illustration identifying the basic mechanical design features of the freezer concept. Each of the components shown are discussed in the following paragraphs.

6.1 FREEZER MECHANICAL DESIGN FEATURES

The freezer design consists of a number of individual elements of which some serve functions other than structural. Details of the freezer design are illustrated in the two drawings shown in Figures 6-2 and 6-3. The structure is basically two boxes, one inside the other and thermally insulated from one another. 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-in-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. In the discussion of the basic freezer structural elements made in the following paragraphs certain dash numbers used to refer to parts of freezer correspond to those identified in the drawings of Figures 6-2 and 6-3.

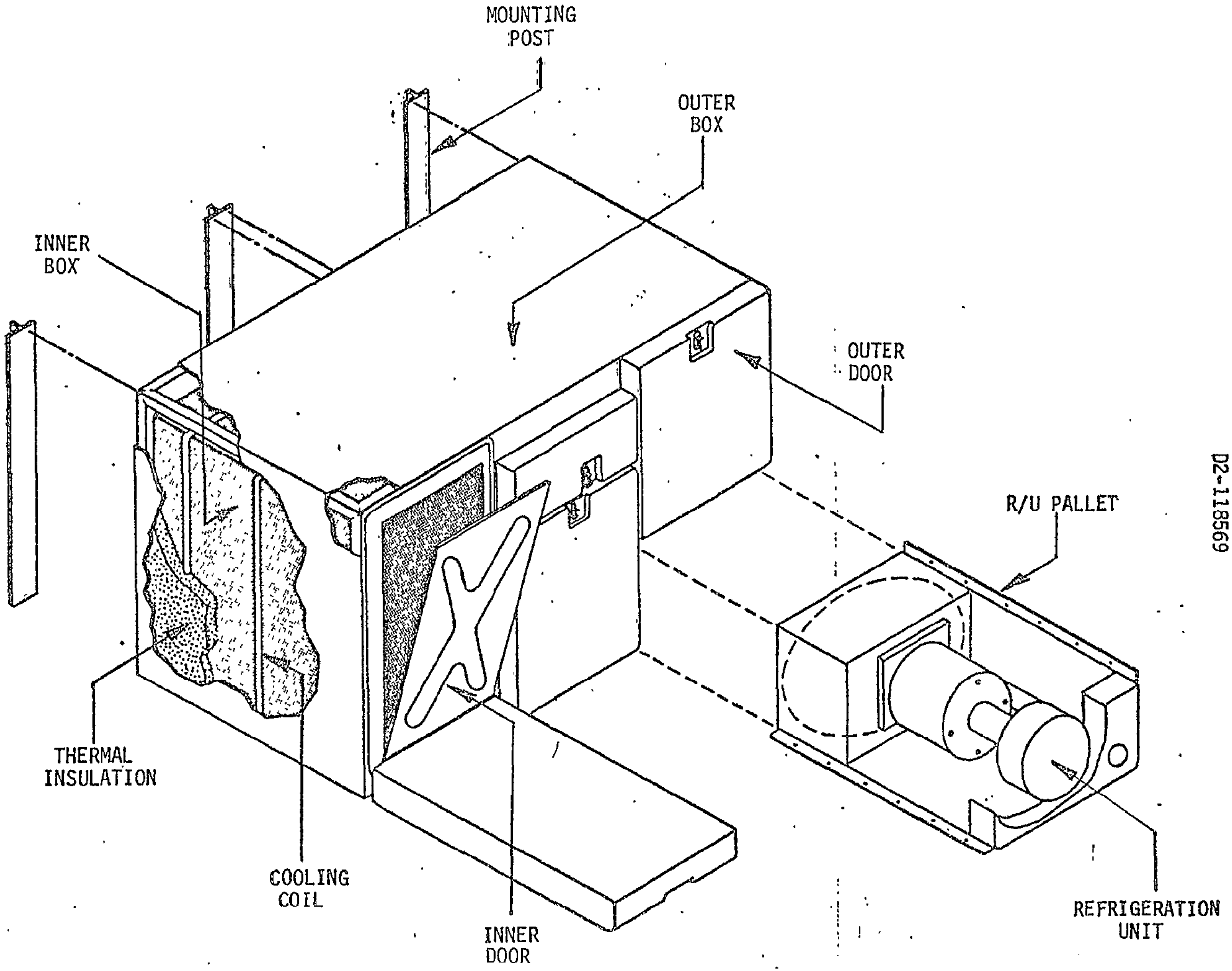


Figure 6-1. Shuttle Freezer Conceptual Design Features

6.1.3 (Continued)

and to provide a force to maintain both doors in the opened position once unlatched. Both doors have latching systems. The inner door latches will be designed with sufficient strength to restrain the stored contents against predicted acceleration loads.

6.1.4 Thermal Insulation

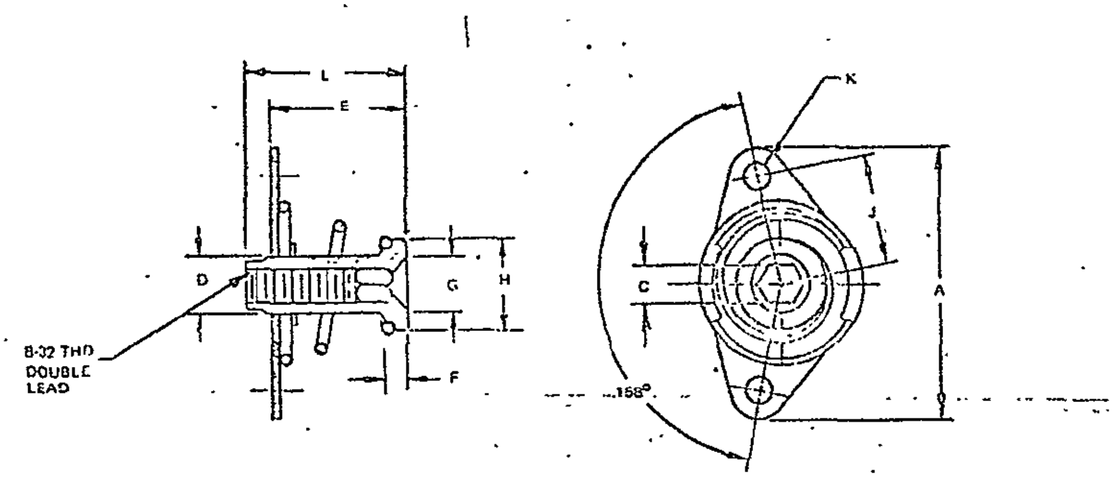
The thermal insulation (-15) provides a thermal barrier between the ambient environment and the storage volume and distributes structural loads from the inner to the outer box. Polystyrene foam is insulation material to be used and will be foamed in place between the inner and outer box at a thickness of approximately two (2) inches on all sides.

6.1.5 Mounting Fixtures

Fasteners used to attach the freezer to the mounting posts are identical to those used on the storage module. Since the freezer volume will be equivalent to four storage modules each using four mounting fasteners, 16 potential fasteners are available for use on the freezer. However, analysis of the load carrying capacity of the fastener versus the expected loads indicate that only 12 fasteners around the freezer perimeter provide adequate strength. A drawing of the proposed fasteners and fastener pattern is shown in Figure 6-4. Fasteners, mounted onto the back frame of the outer box, are sleevebolts which are retractable and self-retained. They are to be driven from the front of the freezer onto a recessed stud, permanently fixed to the storage module mounting post.

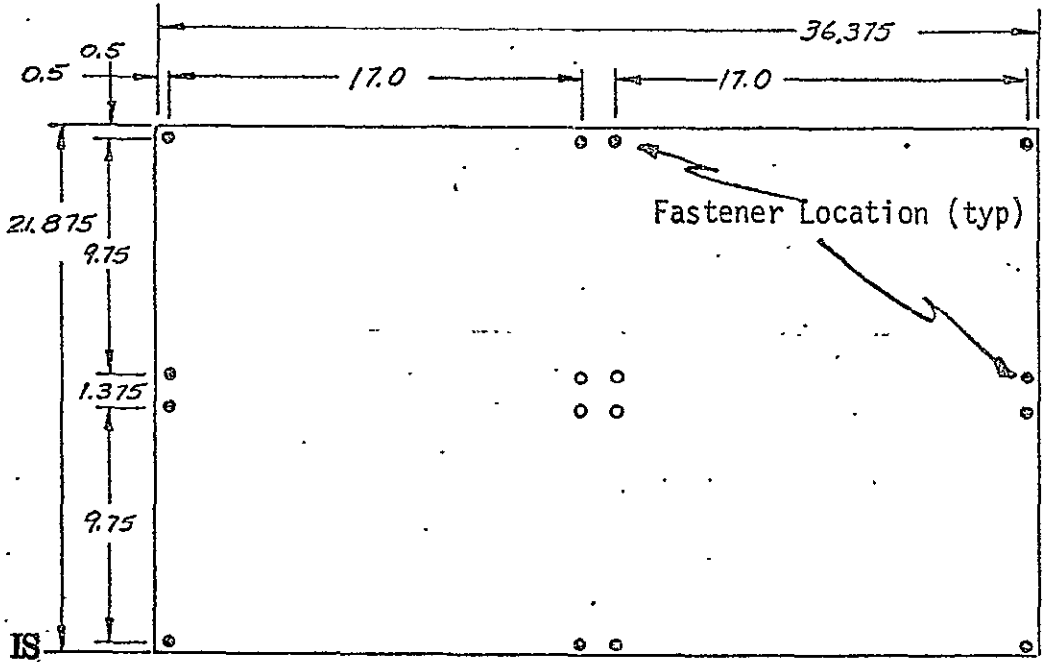
6.1.6 R/U Pallet

Freezer volume allocated to the R/U was determined from preliminary estimates of the R/U volume requirements. However, as the R/U design progressed, it became obvious that this allocated volume was marginal, and that if the volume was to be enclosed by the freezer structural framework installation of the R/U would be impossible. Therefore, the decision was made to mount the R/U to a pallet which would in turn be



A MAX.	B MAX.	C	D	E MAX.	F MAX.	H	G MIN.	J	K	L MAX.
1.115	.665	.158	.2495 .2435	.625	.120	.415 .405	.245	.461 .459	.103 .098	.750

(a) Fastener Design



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(b) Fastener Pattern

Figure 6-4. Proposed Freezer Fastener and Fastener Pattern

6.1.6 (Continued)

attached to the freezer structure. When in place, the pallet forms a part of the freezer bottom and side.

The pallet is attached to the freezer outer box by means of two rows of screws which are joined to nut plates mounted on the box. These rows are located along the side and bottom of the outer box.

Items mounted on the pallet are the Stirling cycle unit, interfacing heat exchanger between the Stirling cold head and circulating coolant, and the R/U cooling fan. Thermal insulation necessary to the cold areas of the R/U are attached to pallet. The front face of the pallet has an access panel to facilitate installation.

Coolant pump and reservoir are mounted onto the inner box, recessed into the thermal insulation. The R/U pallet with thermal insulation is attached over the pump and reservoir and coolant loop connections are made through the access panel.

6.2 STRUCTURAL STRESS ANALYSIS

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. The assumptions used in these analyses and calculations performed are included in Appendix A of this document. The accelerations assumed in all calculations are summarized in Table 6-1.

TABLE 6-1

MAXIMUM COMBINED ACCELERATIONS

	ACCELERATION					
CONDITION	$+g_x$	$-g_x$	$+g_y$	$-g_y$	$+g_z$	$-g_z$
1 ($+g_{x_{max}}$)	2.30	-----	1.00	-1.00	0.90	-1.10
2 ($-g_{x_{max}}$)	-----	-5.70	1.00	-1.00	0.90	-1.10
3 ($+g_{y_{max}}$)	2.30	-5.70	1.00	-----	0.90	-1.10
4 ($-g_{y_{max}}$)	2.30	-5.70	-----	-1.00	0.90	-1.10
5 ($+g_{z_{max}}$)	1.60	-----	-----	-----	2.50	-----
6 ($-g_{z_{max}}$)	2.00	-4.00	1.00	-1.00		-1.28

NOTE: Reverse signs of accelerations for inertia load factors acting on freezer structure.

Combination accelerations were utilized to define the six conditions (maximum acceleration for each directional possibility) shown.

6.2 (Continued)

Assumptions were that strength and number of all rivets, bolts, and screw fasteners used in the freezer construction would be adequate to provide the necessary structural integrity. All imposed loads were increased to provide a factor of safety of 1.5.

6.2.1 Mounting Fastener Loads

As discussed in Paragraph 6.1.5, the same mounting fasteners used to secure the crew equipment storage modules are used in the freezer design. Each fastener has the minimum load carrying capacity of 2500 lbs. tensile strength and 2800 lbs. single shear strength. Load computations were made using 12 of 16 possible fasteners for securing the freezer to the mounting posts. These fasteners are located around the perimeter of the freezer and receive tension loads from direct axial forces as well as those from resulting moments. Shear loads were computed from the resultant of two coincidental loads when necessary. The results of the fastener load analyses are summarized in the chart shown in Table 6-2.

TABLE 6-2

SUMMARY--MAXIMUM ULTIMATE BOLT LOADS

BOLT. NO.	$P_{S_{MAX}}$	P_T	$P_{T_{MAX}}$	P_S
1	87.5	125.75	274.45	52.03
2	↑	------	229.18	↑
3		------	229.18	
4		------	284.51	
5		125.75	244.77	
		------	------	
		------	------	
8		------	254.83	
9		125.75	244.77	
		------	------	
		------	------	
12		------	254.83	
13		125.75	279.45	
14		------	229.18	
15	↓	------	229.18	↓
16	87.5	------	284.51	52.03

The loads shown in the table pair the corresponding tension load (P_T) with maximum shear load ($P_{S_{MAX}}$) calculated and similarly the shear load (P_S) with the maximum tension load ($P_{T_{MAX}}$). The resulting fastener loads are well within the strength limits of the fasteners.

6.2.2 Thermal Insulation Deformation

Although the thermal insulation is designed to act as a load bearing part of the freezer structure, the support structure around the insulation must demonstrate sufficient strength to prevent excessive compression of the insulation. Compression of the insulation equal to one-tenth of the thickness will result in a permanent deformation causing degradation of the thermal properties.

Investigation of center compartment lower panel deflection (worst case) revealed that the insulation would be deformed beyond its yield point using the inner and outer box without stiffeners required to stiffen the inner box sufficiently. Assuming two "Z" stiffeners attached to the lower panel of the inner box in the Y-direction of the X-Y plane, the estimated maximum deflection is 0.05 inch, which is well within the 0.10 inch limit. The design "Z" stiffeners would be of 0.05 inch aluminum with 0.5 inch height and 0.625 inch flanges. These stiffeners are correspondingly attached to the inner box top panel and both side panels.

6.2.3 Inner and Outer Box Aft Attachment Fixtures

Initial design of the freezer structure employed only the front frame as the structural connection between the inner and outer boxes with the thermal insulation providing the major inner box support for ±Z, ±Y, and -X directional loads. This was done to provide maximum thermal isolation of the inner box from the outer box. However, analysis of this design indicated that torsional and bending loads would result in excessive deflections of the front frame. Therefore, design revisions were made to include attachment points for the inner box to the back frame.

6.2.3 (Continued)

For the purpose of analysis the attachment fixtures are assumed to be bands of 0.01 inch thick, 1.0 inch wide stainless steel which span between the back frame and inner box at each corner of the box and at the junction of the box partitions and top and bottom panels. Other materials could be used for these bands; however, stainless steel was chosen for its lower thermal conductance properties.

Analyses were made of the buckling and bending characteristics of the bands under -X, ±Y, and ±Z loads. These evaluations made under extremely conservative assumptions indicate the minimum margin of safety is approximately 3.

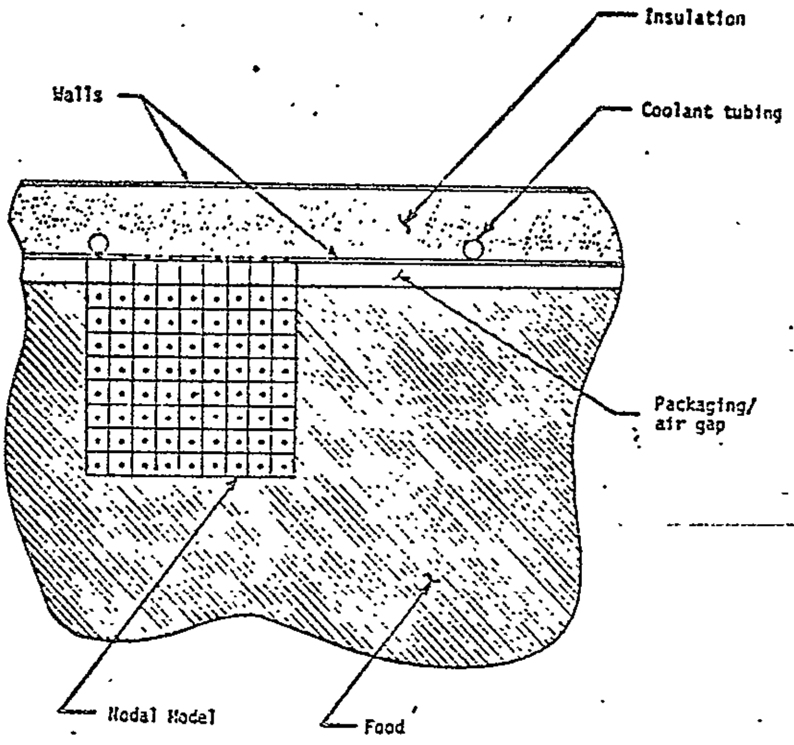
7.0 FREEZER THERMAL ANALYSIS AND EVALUATION

The SINDA (Systems Improved Numerical Differencing Analyzer) thermal analyzer computer program was used to select and to verify the thermal design of the freezer. SINDA (Reference 4) is a highly developed and flexible computer program designed basically for solving generalized lumped parameter systems governed by diffusion equations (e.g., thermal systems, electrical resistor-capacitor networks, gaseous diffusion problems, non-viscous fluid flow, etc.). The general application of the SINDA program has been oriented primarily toward nodal-network type thermal problems involving conduction, convection and radiation.

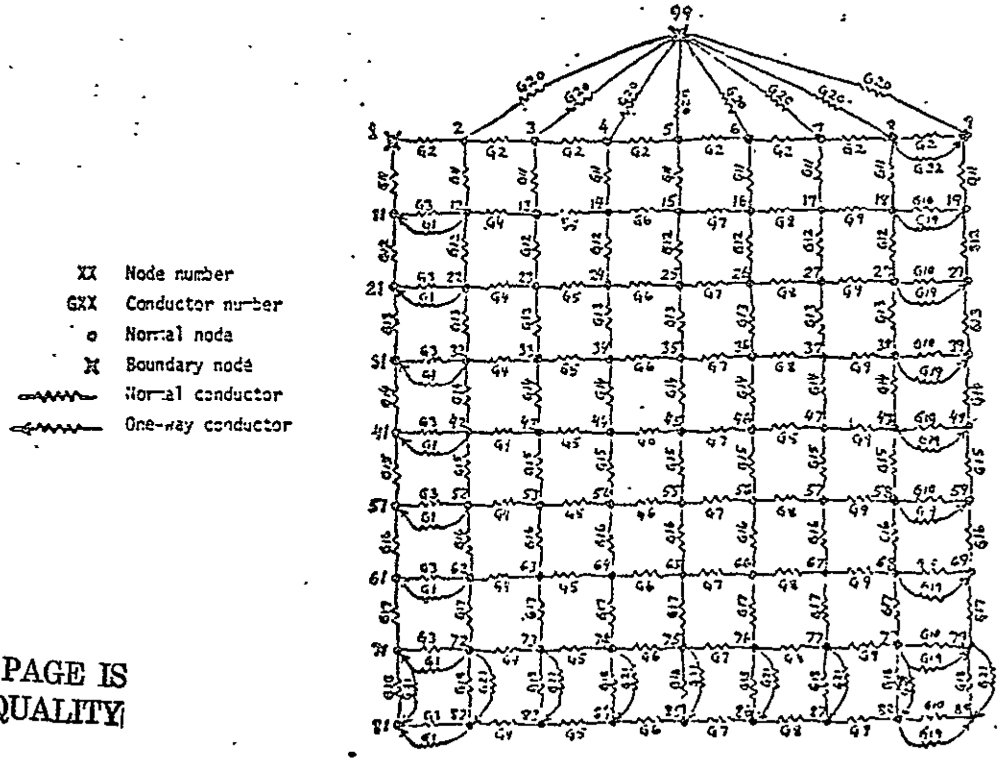
Two thermal models were constructed to analyze the freezer. The first was a simplified two-dimensional representation of a single slice through the freezer. Its purpose was to examine the effect of spacing between the coolant tubing. The second model was a detailed three-dimensional nodal network of 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. These models, with their results for the Shuttle freezer thermal performance, are presented in the following sections.

7.1 COOLANT DISTRIBUTION ANALYSIS

A two-dimensional model of a single slice through the freezer was made to examine the effect of spacing between the coolant tubing. This model, described in Figure 7-1, 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 two cooling tubes, as shown in Figure 7-1(a). A listing of the SINDA computer model input is given in Appendix B. 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.



(a) Model Cross-sectional Layout



(b) Node/conductor Network

Figure 7-1. Freezer Slice Model Description

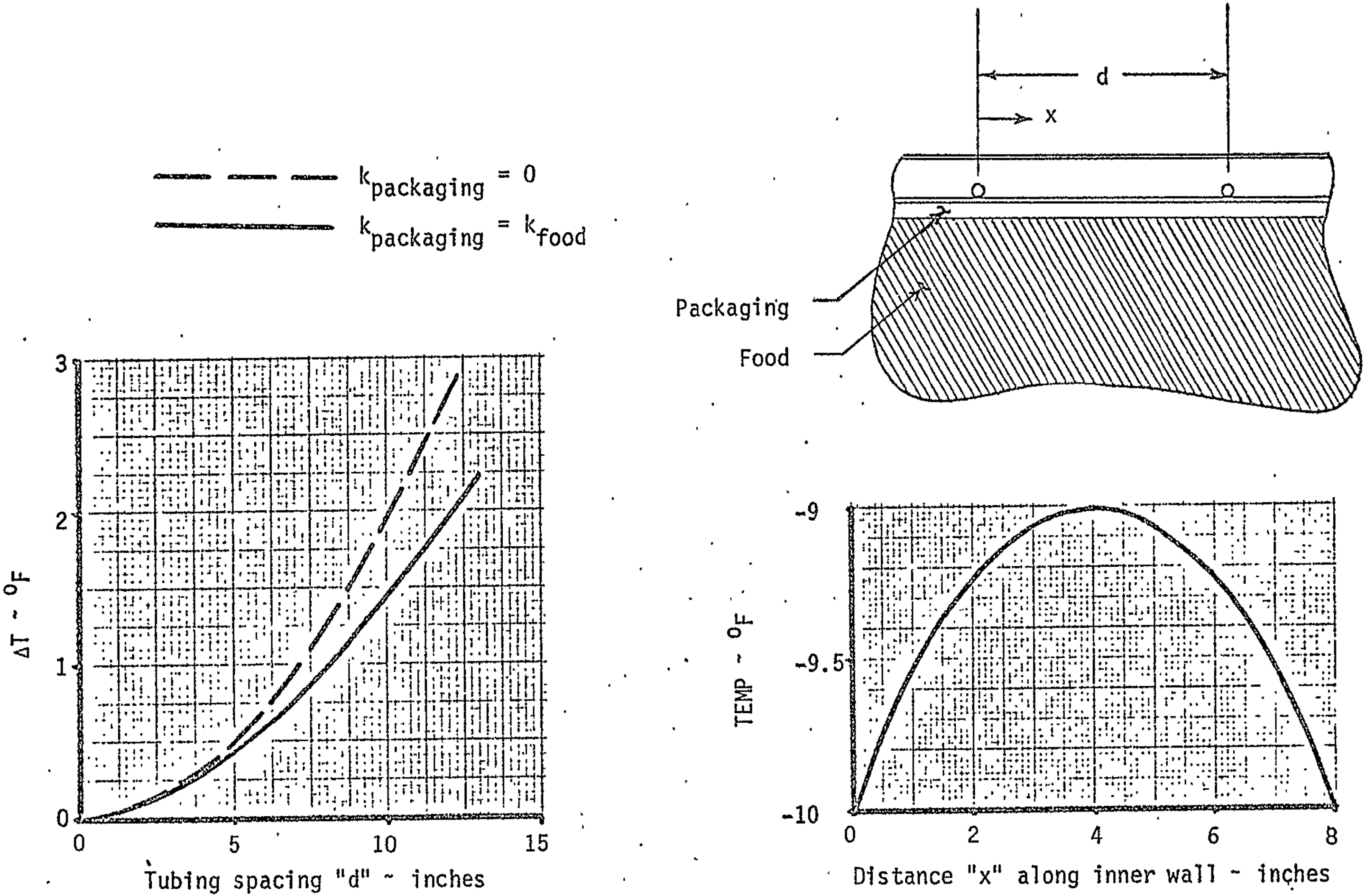
7.1 (Continued)

The effect of tubing spacing on the food temperatures is shown in Figure 7-2(a) for a food thermal conductivity of 1.0 Btu/hr-ft-^{0}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 effect of this variable. The results in Figure 7-2(b) show a maximum food temperature variation between coolant tubes of 1.0^{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. Note that this analysis isolates only the effect of coolant tubing spacing. Other important effects, some of which are mentioned above, will exert a significant effect on the results, and were accounted for in the more detailed analysis discussed in the following paragraph.

7.2 EFFECTS OF THERMAL LEAKAGE AND THERMAL PERTURBATIONS

A detailed three-dimensional model of the entire freezer was developed, as described in Figure 7-3, 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 node/conductor network is shown in Figures 7-3 and 7-4. The model accounts for all corner and edge effects, structural hard attach points, control scheme, and effects of door opening and medical sample insertion. A listing of this SINDA computer model input is given in Appendix B.

The steady state solution for a constant -10^{0}F coolant inlet temperature in an 80^{0}F ambient environment is shown in Figure 7-5. The relative positions of the output temperatures in the figure correspond to the frontal view of the nodal network shown in Figure 7-4. Thus, the temperature at any node may be readily located by visual inspection without



(a) Max Temperature Increase Along Inner Wall

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

Figure 7-2. Effect of Coolant Tubing Spacing on Food Temperature

FEATURES

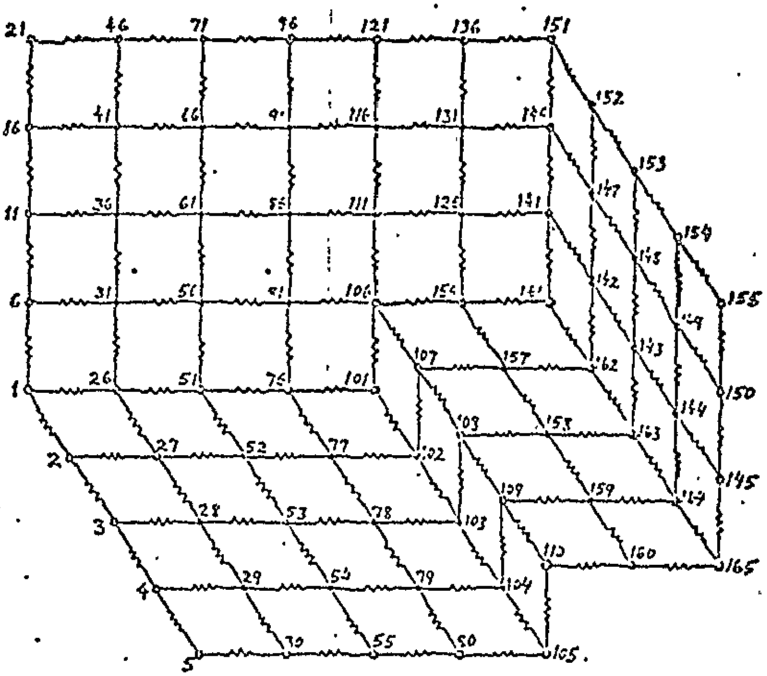
- * USES "SINDA" THERMAL ANALYZER PROGRAM
- * FULL THREE-DIMENSIONAL MODEL
- * 169 NODES; 656 CONDUCTORS
- * TRANSIENT AND STEADY STATE
- * GENERALIZED INPUTS TO ACCOMMODATE DESIGN CHANGES

INPUTS

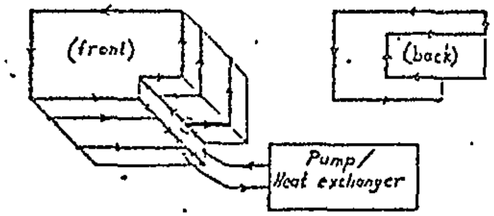
- * GEOMETRY
- * THERMOPHYSICAL PROPERTIES
- * BOUNDARY CONDITIONS
- * COOLANT TUBING ROUTING
- * DOOR OPENING SCHEDULE
- * MEDICAL SAMPLE INSERTION SCHEDULE
- * REFRIGERATION UNIT AND PUMP SIZE
- * CONTROL SCHEME

OUTPUTS

- * TEMPERATURE PROFILE AT ALL LOCATIONS THROUGHOUT FREEZER
- * REFRIGERATION UNIT DUTY CYCLE
- * MEDICAL SAMPLE COOL-DOWN PROFILE
- * STRUCTURAL HEAT LEAK

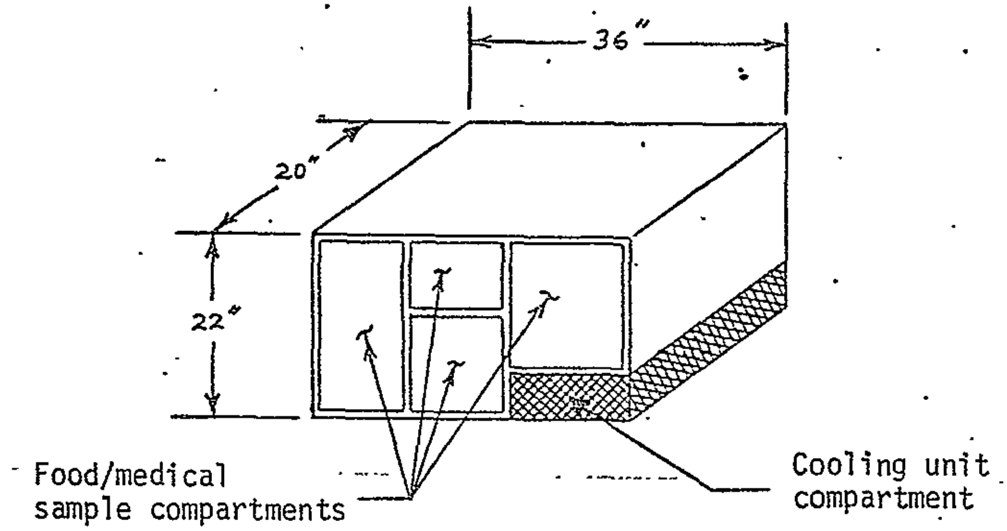


(a) Node numbers (boundary conductors to ambient and refrigeration unit not shown)

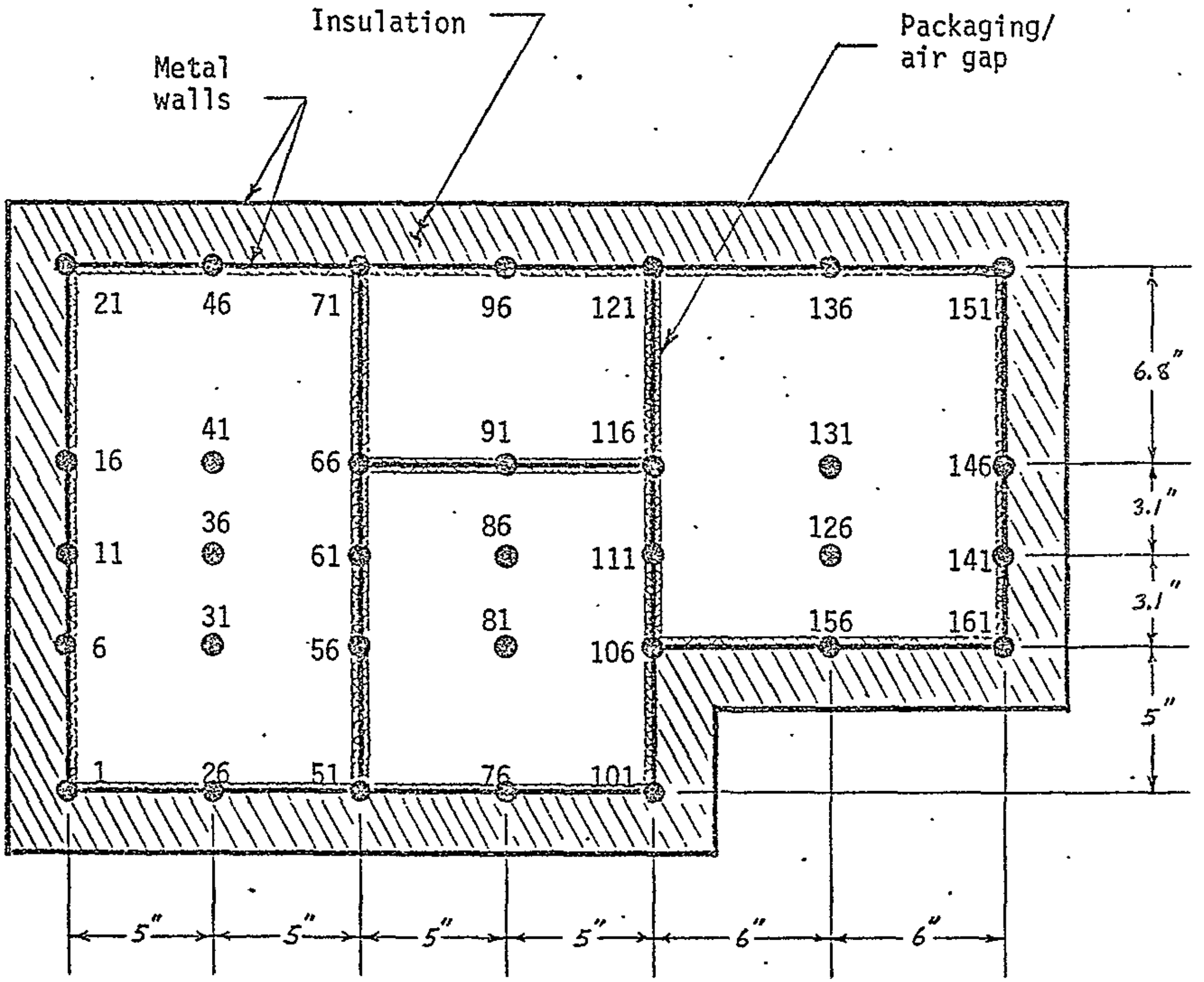


(b) Coolant tubing routing in model

Figure 7-3. Three-Dimensional Thermal Model Description



(a) Basic freezer layout



(b) Nodal breakdown of front slice through freezer (typical of five slices)

Figure 7-4. Basic Nodal Subdivision Used for Freezer Thermal Model

(All temperatures in degrees Fahrenheit.)

```
        TMIN=  -9.969           TMAX=  -6.555            TAVG=  -8.758


                    FRONT WALL

-8.5138   -8.6028   -8.7059   -8.8060   -8.9068   -9.0102   -9.1306
-8.4175   -7.4477   -7.7397   -7.8519   -8.3357   -8.2249   -9.2331
-8.3564   -7.3083   -7.5338   -7.6172   -8.7094   -8.5475   -9.3337
-8.2804   -7.3663   -7.5494   -7.7043   -9.6349   -9.4954   -9.3973
-8.2061   -8.1149   -8.0316   -7.9507   -7.8875


                    SECOND SLICE ( 3.875 INCHES BACK)

-8.8965   -8.9910   -9.0673   -9.1643   -9.2355   -9.3276   -9.4119
-8.8225   -8.2640   -8.3206   -8.4711   -8.8524   -8.9733   -9.5126
-8.7757   -8.1711   -8.1984   -8.4881   -9.2349   -9.1501   -9.5839
-8.7153   -8.1728   -8.1886   -8.5290   -9.8420   -9.7426   -9.6315
-8.6320   -8.5601   -8.4779   -8.4130   -8.1332


                    THIRD SLICE ( 7.750 INCHES BACK)

-8.0339   -8.4094   -8.6885   -8.6719   -8.8812   -8.7701   -8.5455
-8.1791   -8.3790   -8.6446   -8.7990   -9.0733   -9.0408   -8.8529
-8.1431   -8.3213   -8.5643   -8.8187   -9.4199   -9.0990   -8.8064
-8.0634   -8.2619   -8.4810   -8.7661   -9.9062   -9.0063   -8.4113
-7.7373   -7.9729   -8.1555   -8.0064   -8.1180


                    FOURTH SLICE (11.625 INCHES BACK)

-8.9083   -9.0023   -9.0760   -9.1581   -9.2258   -9.3105   -9.3947
-8.8378   -8.5117   -8.9834   -9.0730   -9.2255   -9.1934   -9.4991
-8.7936   -8.4462   -8.9430   -9.1016   -9.4891   -9.2179   -9.5718
-8.7367   -8.4244   -8.8754   -8.9757   -9.9690   -9.8179   -9.6443
-8.6548   -8.5877   -8.5299   -8.4715   -8.2011


                    BACK WALL (15.500 INCHES BACK)

-8.5547   -8.6526   -8.7234   -8.7623   -8.8538   -8.9032   -8.9704
-8.4928   -8.0347   -9.3925   -9.3330   -9.2659   -9.1669   -9.0737
-8.4537   -7.9832   -9.5067   -9.7210   -9.2563   -8.2959   -7.7752
-8.4040   -8.0036   -9.5735   -8.8892   -9.8062   -7.8941   -6.5546
-8.3151   -8.2572   -8.2457   -8.1661   -8.1281
```

Figure 7-5. Freezer Steady State Thermal Solution for -10°F Coolant Inlet Temperature

7.2 (Continued)

consulting a specific node number. The temperatures throughout the entire freezer are seen to vary between -6.6°F and -10.0°F.

Transient results from the model are shown in Figures 7-6 and 7-7 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 7-6. 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 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 7-7 (for a urine freezing temperature of 30°F), and the effect on adjacent samples and the freezer coolant return temperature is shown in Figure 7-6. A representative temperature "snapshot" throughout the freezer at a time of 7 hours is shown in Figure 7-8. These results verify the freezer to be of adequate thermal design to maintain satisfactory temperatures while providing acceptable medical sample cool-down.

In Figures 7-9 and 7-10 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.

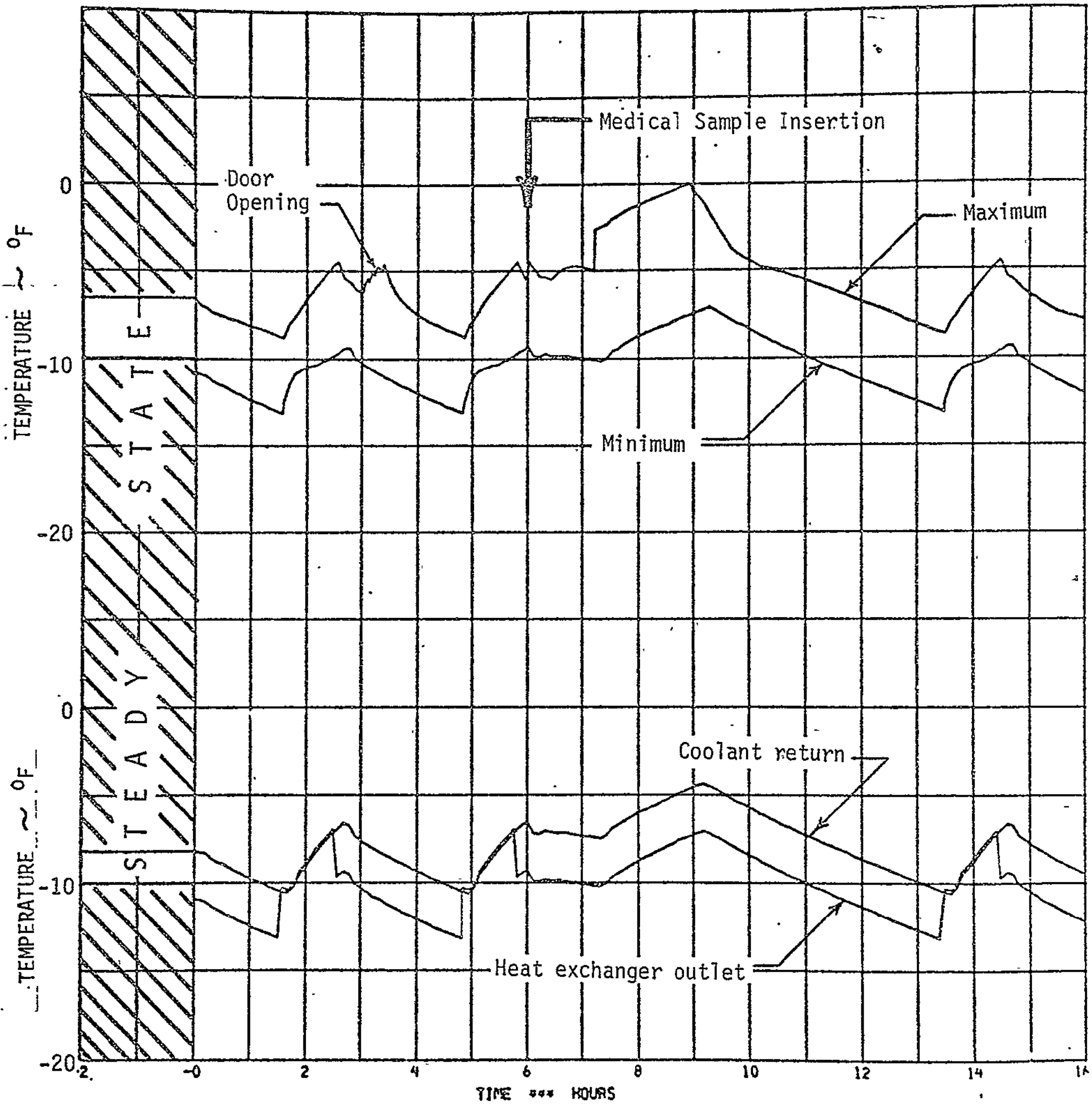


Figure 7-6. Transient Freezer Thermal Response Under "Worst-Case" Conditions

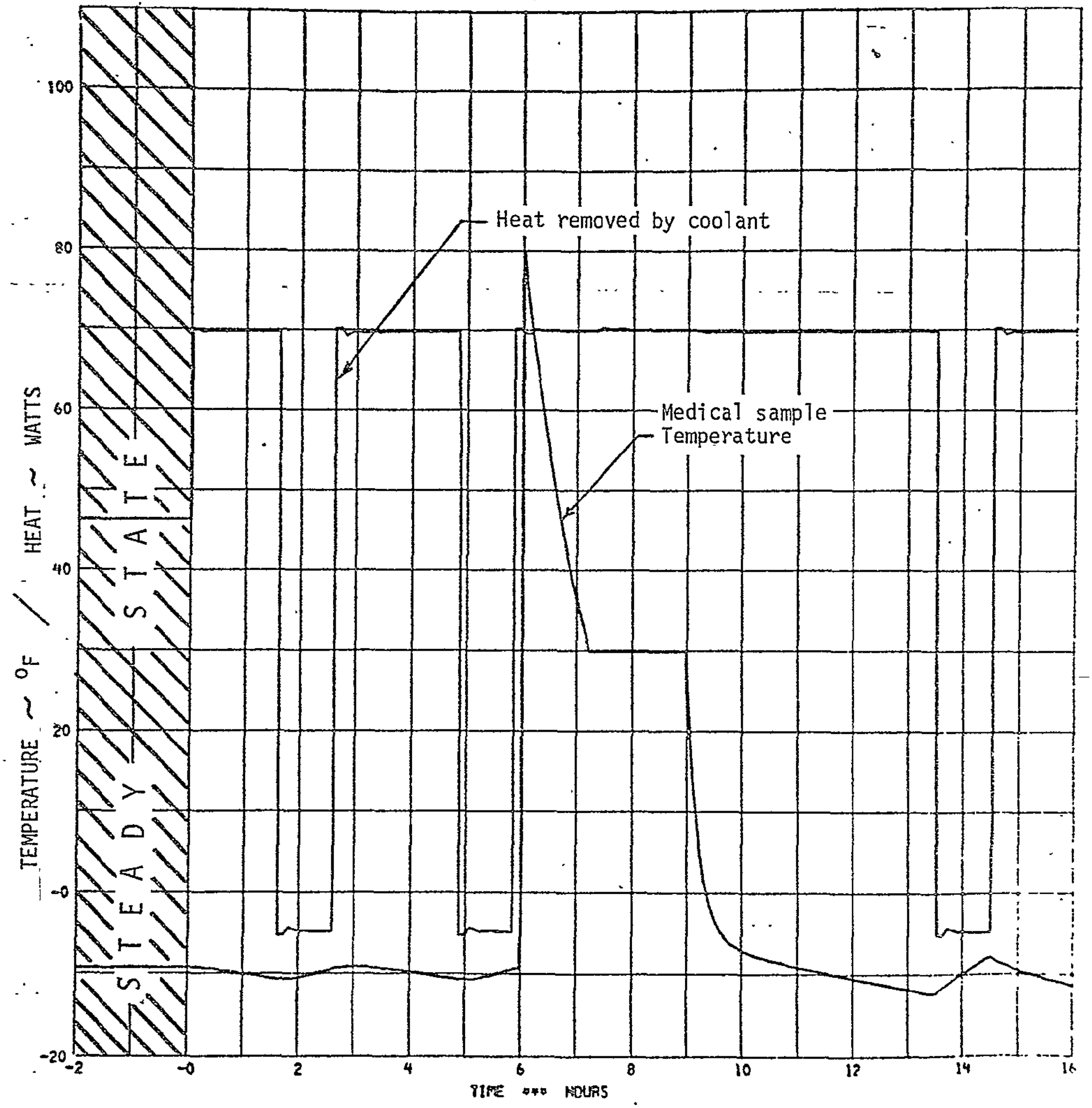


Figure 7-7. Transient Medical Sample Temperature and Coolant Heat Removal under "Worst-Case" Conditions

(All temperatures in degrees Fahrenheit.)

```
        TMIN=  -9.984             TMAX=  36.180            TAVG=  -6.400

                          FRONT WALL

   -8.3800    -8.4729    -8.5825    -8.6956    -8.8060    -8.9222    -9.0507
   -8.2780    -7.2592    -7.3566    -7.4368    -7.9816    -8.0157    -9.1565
   -8.2135    -7.1176    -7.1676    -7.2757    -8.4590    -8.3709    -9.2632
   -8.1331    -7.1748    -7.2241    -7.4381    -9.5770    -9.4304    -9.3305
   -8.0555    -7.9588    -7.8638    -7.7763    -7.7126

                  SECOND SLICE ( 3.875 INCHES BACK)

   -8.6768    -8.7810    -8.8708    -9.0009    -9.0933    -9.2198    -9.3239
   -8.5931    -8.1104    -7.7158    -7.7597    -8.3133    -8.7264    -9.4353
   -8.5403    -8.0224    -7.5988    -7.6907    -8.8667    -8.9286    -9.5203
   -8.4721    -7.9910    -7.6492    -7.9635    -9.8040    -9.6914    -9.5765
   -8.3810    -8.2987    -8.1898    -8.1114    -7.8958

                  THIRD SLICE ( 7.750 INCHES BACK)

   -7.5026    -7.8866    -8.1239    -8.1561    -8.4290    -8.4364    -8.2950
   -7.6513    -8.0165    -7.5109    -7.3715    -8.1115    -8.6057    -8.6284
   -7.6066    -7.9648    -7.3658    -6.0742    -8.7585    -8.7401    -8.6254
   -7.5098    -7.8615    -7.3991    -7.0462    -9.8872    -8.8677    -8.3026
   -7.1522    -7.3710    -7.4270    -7.2878    -7.8701

                  FOURTH SLICE (11.625 INCHES BACK)

   -8.1700    -8.3003    -8.4219    -8.6190    -8.7600    -8.9839    -9.1579
   -8.0635    -7.6434    -7.0916    -6.5876    -7.6056    -8.2591    -9.3331
   -7.9977    -7.5575    -6.8070    36.1803    -8.3507    -8.5283    -9.4844
   -7.9143    -7.5131    -6.9843    -4.7806    -9.9843    -9.7864    -9.5921
   -7.8083    -7.7107    -7.5794    -7.4657    -7.3361
                                                  Fresh Medical Sample
                  BACK WALL (15.500 INCHES BACK)

   -6.4336    -6.5013    -6.5441    -6.5284    -6.5907    -6.5652    -6.5852
   -6.3954    -5.9346    -6.7557    -6.6819    -6.7121    -6.6510    -6.6343
   -6.3707    -5.8874    -6.8320    -7.0052    -7.7827    -6.6258    -6.3716
   -6.3384    -5.9081    -6.8942    -6.3548    -9.6739    -7.0299    -5.7529
   -6.2717    -6.2327    -6.2376    -6.1659    -6.1761
```

Figure 7-8. Freezer Thermal Solution at Time 7 Hours
During "Worst-Case" Run

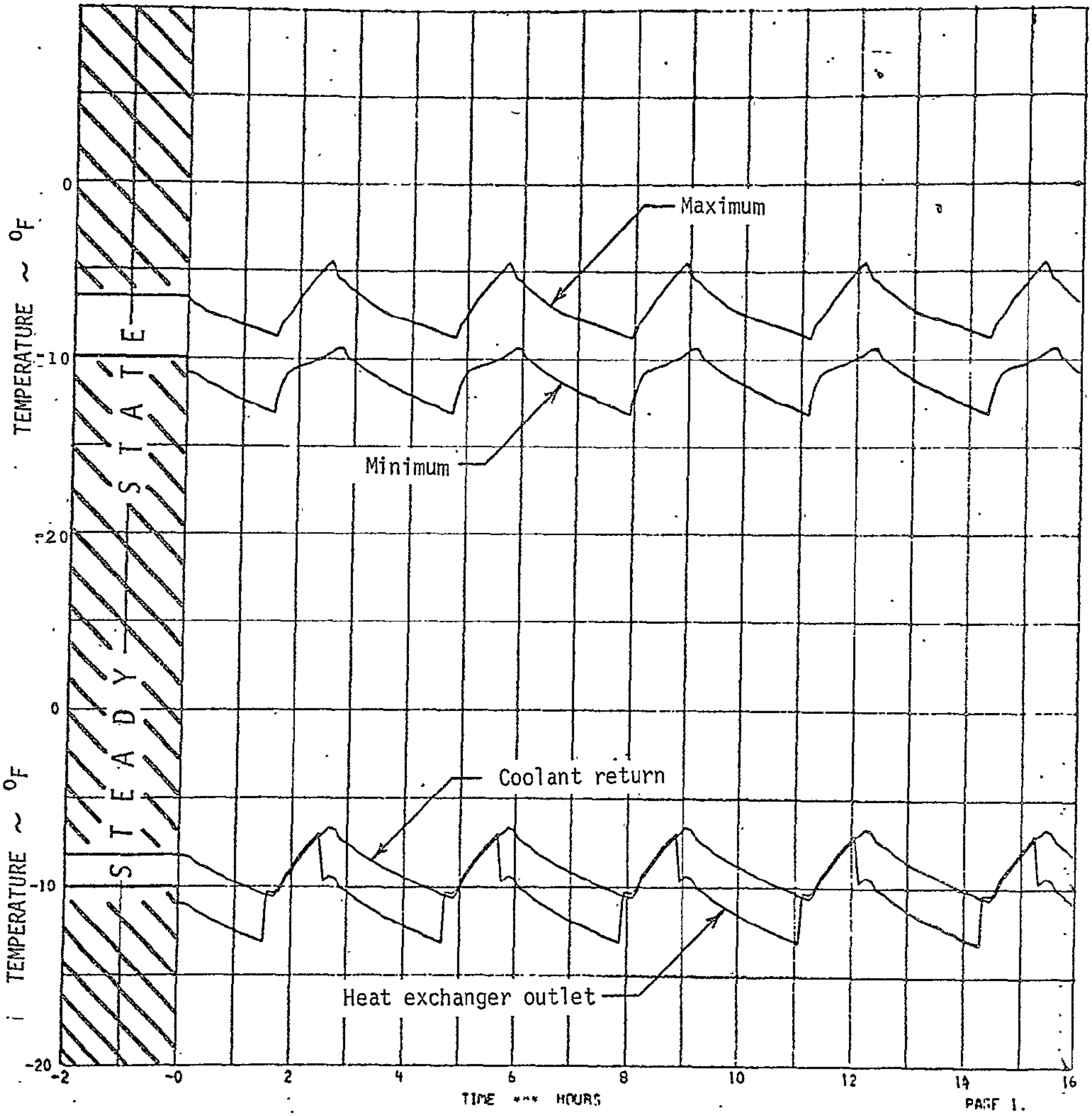


Figure 7-9. Transient Freezer Thermal Response With No Door Opening or Medical Sample Insertion

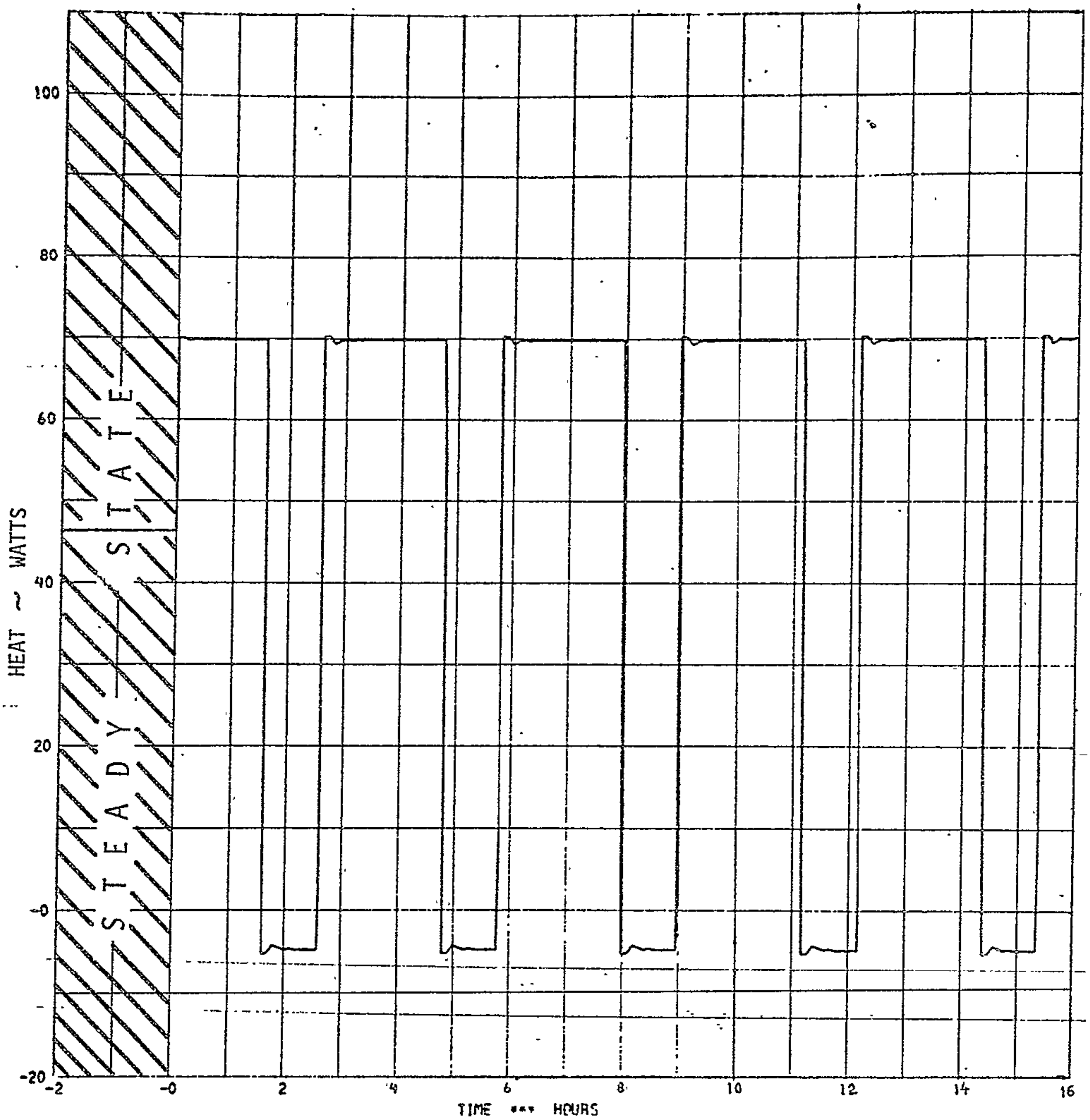


Figure 7-10. Freezer Transient Coolant Heat Removal With No Door Openings or Medical Sample Insertion

8.0 FREEZER DEVELOPMENT PLAN

Results of this study have demonstrated the conceptual feasibility of a portable or "kit" freezer for Shuttle operations. However, certain assumptions and computations used in determining the freezer thermal characteristics, structural design, refrigeration unit performance figures, and packaging schemes must be validated through a development and testing effort. A plan to provide the basis for the development of a freezer which will verify the acceptability of the proposed freezer design is outlined in this section. A schedule of Tasks related to the development of the freezer is shown in Figure 8-1.

8.1 PREPROTOTYPE FREEZER STORAGE BOX

The limited volume available for the freezer, due to the dimensional constraints of side hatch and storage module configuration, demand that the volumes allocated to storage, thermal insulation, and refrigeration system be validated in the initial stages of freezer development. Although the refrigeration unit has the highest level of technological development and will require the longest development lead time, it is recommended that the thermal characteristics of the storage box be investigated prior to the R/U development in order to determine the adequacy of the thermal insulation thickness. This phase of the freezer development will determine if the storage capacity requirements can be met and if the predicted R/U cooling capacity is sufficient. These tests can be accomplished with a full scale model of the storage box which accurately represents all components of the freezer except the refrigeration unit. An ambient sea level environment with elevated temperatures can be easily simulated. The refrigeration unit can be simulated by circulating the coolant through a dry ice bath with coolant inlet temperature to the storage box being varied using a bypassing system. Measurements of coolant temperature rise and flowrate will provide a direct calculation of the overall heat load to the cooling system. Coolant loop pressure drop measurements will be made to aid in sizing the coolant pump. Results from these tests will also be used to validate the accuracy of the existing mathematical thermal model. This model will be a valuable tool for investigating revised freezer configurations should they become necessary.

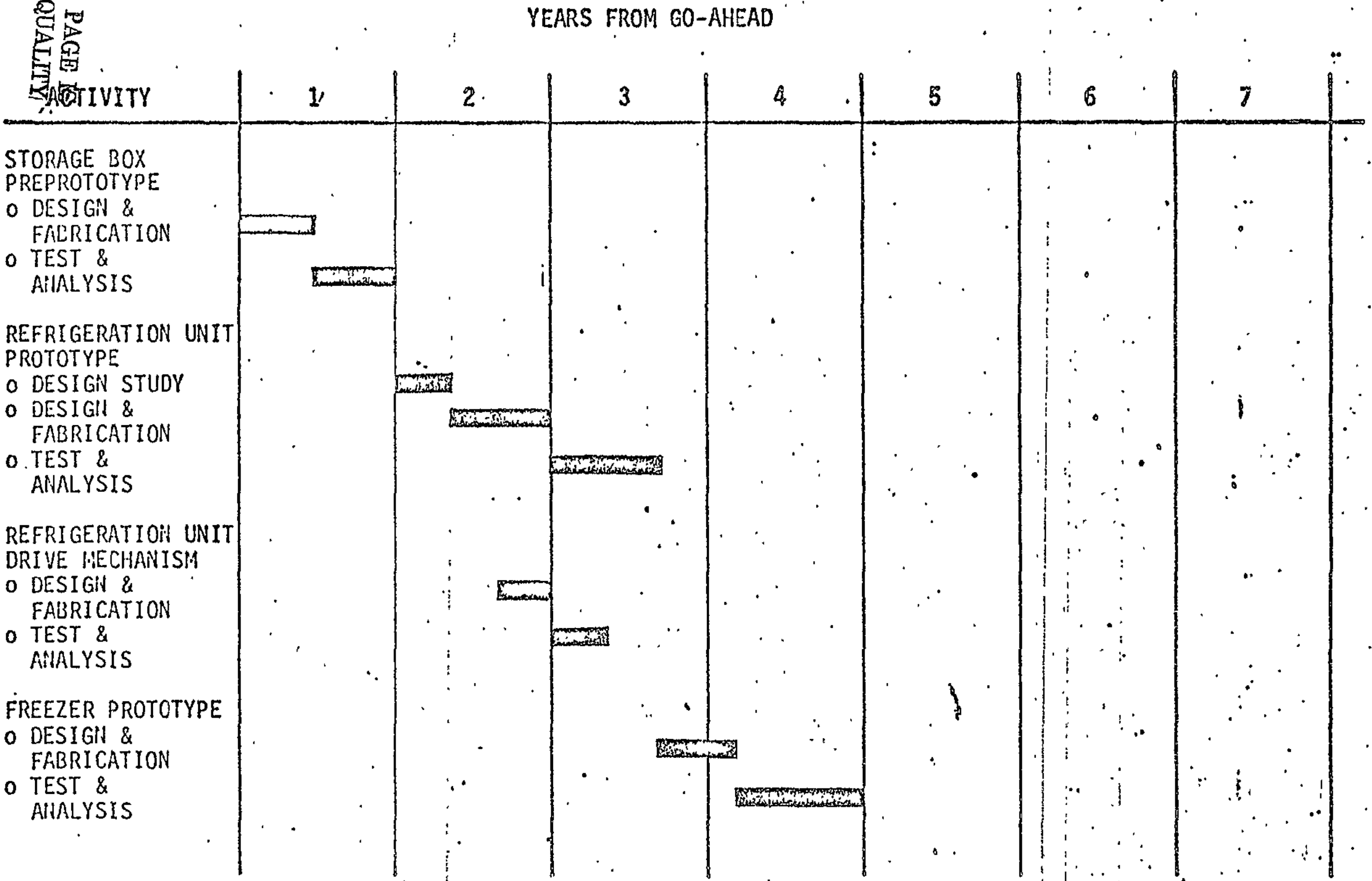


Figure 8-1. Proposed Freezer Prototype Development Schedule

8.1 (Continued)

Assuming the thermal load to the refrigeration unit is less than predicted, then the possibility of a R/U with a smaller cooling capacity (and consequently smaller volume requirements) can be utilized. This surplus volume can be devoted to additional storage or thermal insulation. However, if the thermal load is greater than predicted, then more thermal insulation must be added, at the expense of storage volume, or the refrigeration unit must be sized upward. This may require a reduction in insulation or storage space to accommodate the larger R/U. Once the peak cooling requirements have been established, then the refrigeration unit preprototype design can commence.

8.2 PREPROTOTYPE REFRIGERATION UNIT

The refrigeration unit preprototype will 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 to be used on the prototype.

8.3 REFRIGERATION UNIT DRIVE MECHANISM

The R/U drive mechanism includes the electric motor and a gear mechanism which imparts a linear driving force to the piston rod. This concept allows the use of dry lubricants between the piston and cylinders and has had

8.3 (Continued)

previous space hardware application on Stirling cooler systems. Once the refrigeration unit has been sized, the design of the drive mechanism can be initiated. After the drive is fabricated it will be mated with the R/U head, and the total unit bench tested to insure compatibility.

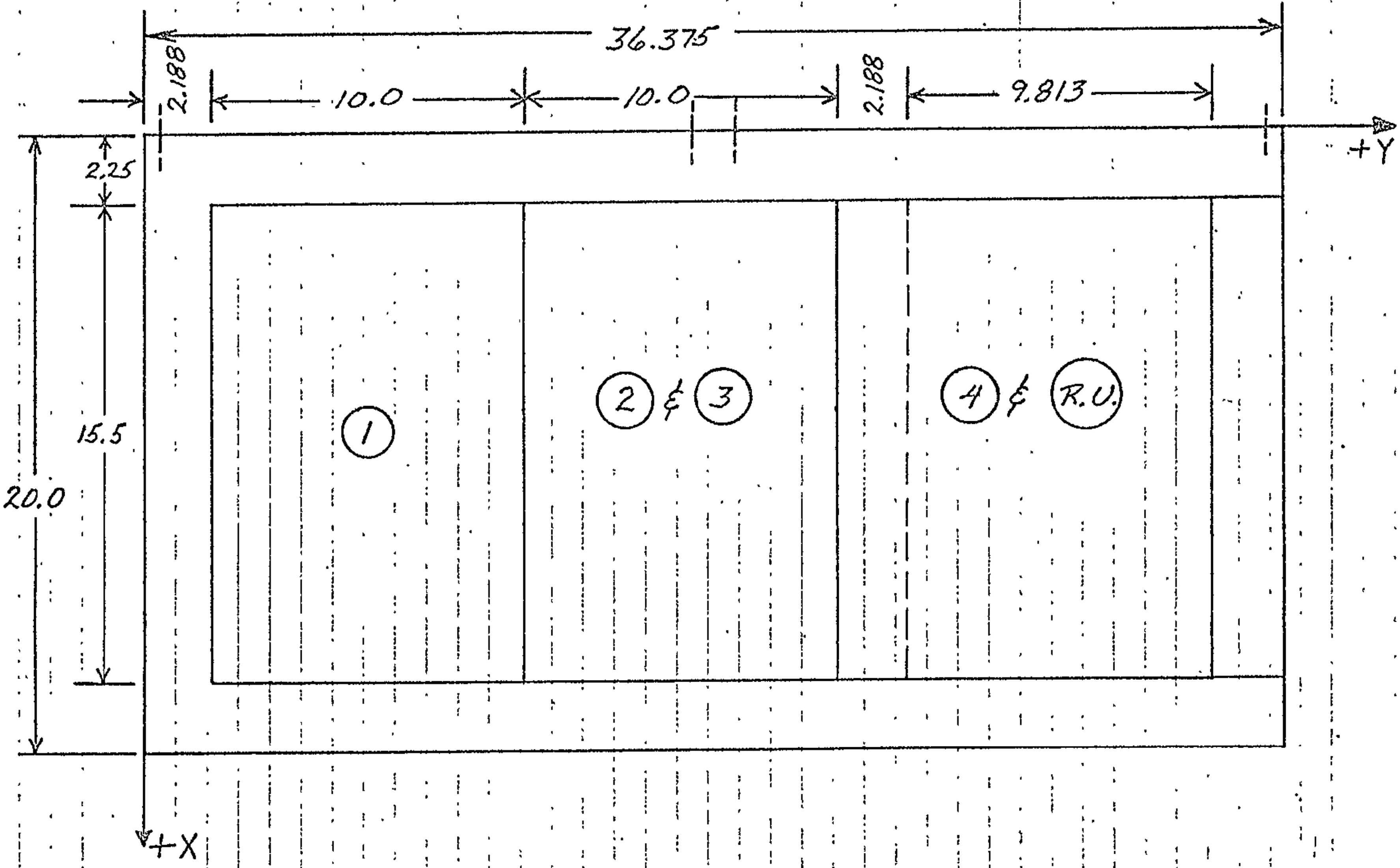
8.4 PROTOTYPE FREEZER

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:

- R/U component life
- R/U cooling system efficiency
- Nominal and off-nominal operation
- Temperature control system
- Storage box temperature profiles
- Optimum cooling liquid flowrate
- 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.



FREEZER KIT TOP VIEW

9.0 CONCLUSIONS AND RECOMMENDATIONS

This 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 $80^{\circ}F$ 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 $0.0^{\circ}F$ or below (Figure 7-6) after medical sample insertions and door openings. As shown in Figure 7-7, a warm medical sample can be cooled from $80^{\circ}F$ to $30^{\circ}F$ in approximately 3 hours. The steady state heat leakage rate of the storage box is 46.4 watts with an ambient temperature of $80^{\circ}F$ and an average storage temperature of $-10^{\circ}F$.

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:

9.0 (Continued)

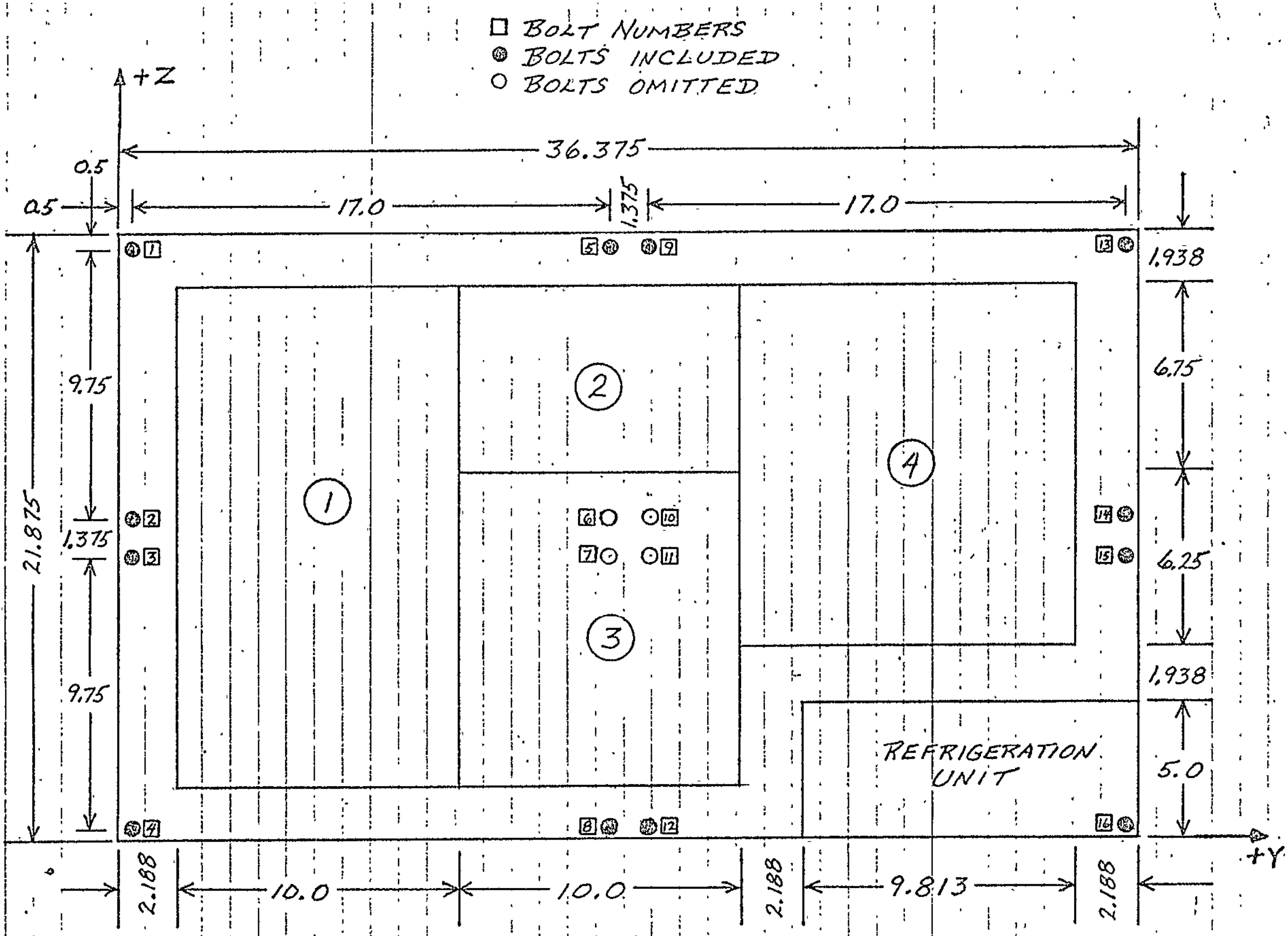
(1) Increase the insulation thickness at the expense of storage capacity.

(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.

APPENDIX A

STRUCTURAL STRESS ANALYSES



FREEZER KIT FRONT VIEW

BOLT LOCATIONS & FREEZER DIMENSIONS

PAGE 1.

DESIGN WEIGHTS & C.G.'s

UNIT	WT. (LB.)	C.G.'s (IN.) X	Y	Z
①	86.0	10.0	7.188	10.938
②	0	10.0	17.188	16.563
③	53.75	10.0	17.188	7.563
④	75.25	10.0	28.188	15.375
R.U.	20.0	10.0	30.375	2.5
STRUCTURE	45.0	10.0	18.188	10.938
TOTAL	280	10.0	18.17	10.35

THE FOLLOWING ACCELERATIONS WERE USED FOR ANALYSIS OF THE FREEZER. REFERENCE

MISSION PHASE	LONGITUDINAL (X)		TRANSVERSE (Y OR Z)	
	STEADY	DYNAMIC	STEADY	DYNAMIC
LIFT-OFF	−1.70	±4.00	−0.10 (Z)	±1.00
MAX Q REGION	−1.60	±0.25	−0.25 (Z) ±0.10 (Y)	±0.25
BOOSTER MAX g	−3.00	±0.25	−0.30 (Z)	±0.25
SRB STAGING	−1.00	±3.00	−0.28 (Z)	±1.00
ORBITER MAX g	−3.00	±0.25	−0.68 (Z)	0.25
ET SEP	—	—	0.03 (Z)	—
ORBITER AOA SEP	—	—	0.03 (Z)	—
ENTRY	1.60	—	2.50 (Z)	—

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COMPOSITE WEIGHT C.G.

X_{REF} @ CONTAINER/BULKHEAD INTERFACE

TOTAL WEIGHT = 235 # + CONTAINER WT. = 235 + 45 = 280 #

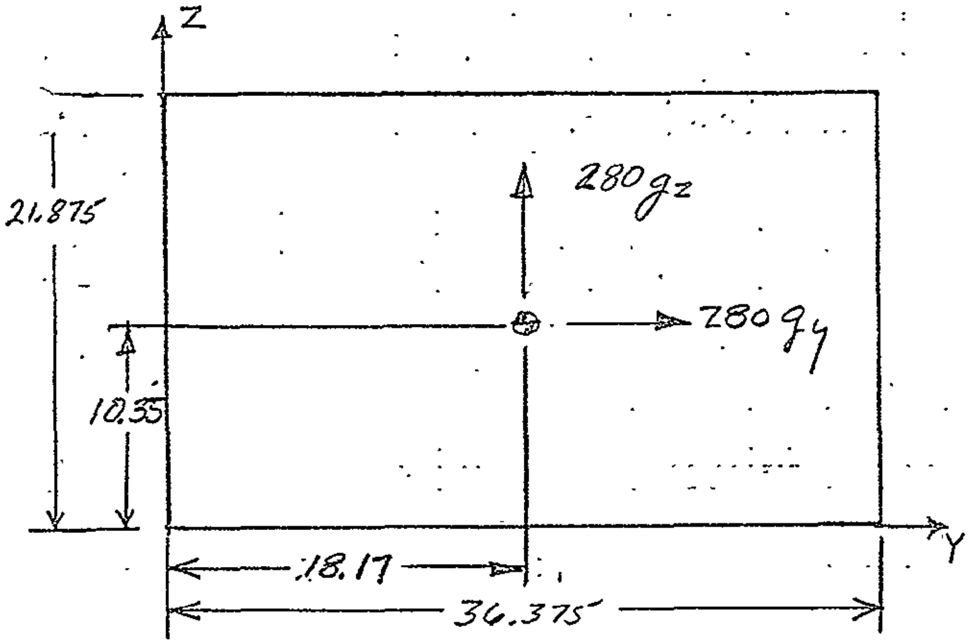
$$\overline{X} = \frac{15.5}{2} + \frac{20.0 - 15.5}{2} = 10.0 \text{ IN.}$$

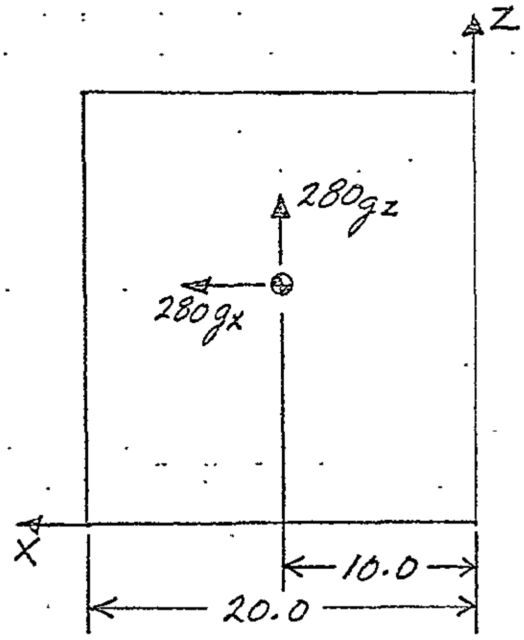
$$\overline{Y} = \frac{\overset{1}{86 \times 7.19} + \overset{2}{54 \times 17.19} + \overset{3}{45 \times 18.19} + \overset{4}{75 \times 28.18} + \overset{5}{20 \times 30.38}}{280}$$

$$\boxed{\overline{Y} = 18.17 \text{ IN.}}$$

$$\overline{Z} = \frac{86 \times 10.94 + 54 \times 7.56 + 45 \times 10.94 + 75 \times 13.44 + 20 \times 2.5}{280}$$

$$\boxed{\overline{Z} = 10.35 \text{ IN}}$$





BOLT LOADS

$+P_X$

LOADS ARE TRANSFERRED FROM INNER CONTAINER TO FRONT FRAME OF OUTER CONTAINER TO OUTER

BOLT LOADS, CONT'D.

CONTAINER SIDES, TOP, & BOTTOM. THE LOAD PATH TO BOLTS 6, 7, 10, & 11 IS VERY LONG COMPARED TO THE OTHERS, HENCE, IT IS ASSUMED THAT THESE BOLTS PICK UP NO $+P_X$ LOAD.

P_X (FOR EACH BOLT OTHER THAN THOSE ABOVE) $= \boxed{\frac{280 \times 1.5 \times g_X}{12} = 35\ g_X}$

$-P_X$ LOAD PATH IS THE SAME AS FOR $+P_X$ EXCEPT THAT THE EFFECTIVE BOLT LOADS ARE COMPRESSION. THEREFORE THE BOLTS ARE NOT LOADED

$\pm P_Y$ THE STIFFEST LOAD PATH IS THROUGH THE OUTER CONTAINER TOP & BOTTOM. THEREFORE, ASSUME THAT ONLY THE TOP & BOTTOM BOLTS REACT THE SHEAR LOAD.

SHEAR LOAD IN TOP BOLTS $= \left(\frac{10.35}{21.875}\right) \times 280\overset{\times 1.5}{g_Y} = 198.8\ g_Y$

SHEAR LOAD/BOLT FOR BOLTS 1, 5, 9 & 13 $= \frac{198.8\ g_Y}{4} = 49.69\ g_Y$

4,

$M_Z = 10.0 \times 280\ g_Y = 2800\ g_Y$

SIDE BOLTS REACT TENSION LOAD DUE TO $\pm M_Z$

TENSION LOAD/BOLT FOR BOLTS 1, 2, 3, & 4 $= \frac{2800\overset{\times 1.5}{g_Y}}{4 \times 35.375} = \boxed{29.68\ g_Y}$ ✓
13, 14, 15, & 16

eec. 5/21/75

BOLT LOADS, CONT'D

$\pm P_Z$ THE STIFFEST LOAD PATH IS THROUGH THE OUTER CONTAINER SIDES. THEREFORE, ASSUME THAT ONLY THE SIDE BOLTS REACT THE SHEAR LOAD

SHEAR LOAD/BOLT FOR BOLTS 1, 2, 3, & 4 $= \left(\frac{18.205}{36.375}\right) \times \frac{280 \overset{\times 1.5}{g_z}}{4} = 52.55 g_z$

SHEAR LOAD/BOLT FOR BOLTS 13, 14, 15, & 16 $= \left(\frac{18.17}{36.375}\right) \times \frac{280 \times g_z^{1.5}}{4} = 34.97 g_z$

$M_Y = 10.0 \times 280 g_z = 2800 g_z$

SIDE BOLTS REACT TENSION LOAD DUE TO $\pm M_Y$

TENSION LOAD/BOLT FOR BOLTS 1, 5, 9, & 13
4, 8, 12, & 16 $= \frac{2800 \times 1.5 \times g_z}{4 \times 20.875} = \boxed{50.3 g_z}$ ✓

MAXIMUM ACCELERATIONS (REF. PAGE 5)

CONDITION	$+g_x$	$-g_x$	$+g_Y$	$-g_Y$	$+g_z$	$-g_z$
1. $+g_{x\,MAX}$	2.3	——	1.0	1.1	0.9	1.1
2. $-g_{x\,MAX}$	——	5.7	1.0	1.1	0.9	1.1
3. $+g_{Y\,MAX}$	2.3	5.7	1.0	——	0.9	1.1
4. $-g_{Y\,MAX}$	2.3	5.7	——	1.0	0.9	1.1
5. $+g_{Z\,MAX}$	1.6	——	——	——	2.5	——
6. $-g_{Z\,MAX}$	2.0	4.0	1.0	1.0	——	1.28

eec 5/21/75

MAXIMUM COMBINED ACCELERATIONS

(REFERENCE PAGE 4)

CONDITION	ACCELERATION					
	$+g_X$	$-g_X$	$+g_Y$	$-g_Y$	$+g_Z$	$-g_Z$
1 ($+g_{X\,MAX}$)	2.30	——	1.00	-1.00	0.90	-1.10
2 ($-g_{X\,MAX}$)	——	-5.70	1.00	-1.00	0.90	-1.10
3 ($+g_{Y\,MAX}$)	2.30	-5.70	1.00	——	0.90	-1.10
4 ($-g_{Y\,MAX}$)	2.30	-5.70	——	-1.00	0.90	-1.10
5 ($+g_{Z\,MAX}$)	1.60	——	——	——	2.50	——
6 ($-g_{Z\,MAX}$)	2.00	-4.00	1.00	-1.00		-1.28

NOTE: REVERSE SIGNS OF ACCELERATIONS FOR INERTIA LOAD FACTORS ACTING ON FREEZER STRUCTURE.

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ATTACHMENT BOLT LOADS

THE FOLLOWING ASSUMPTIONS WERE USED IN DETERMINING LOADS ON THE SUPPORT BOLTS.

1. ULTIMATE FACTOR OF SAFETY = 1.50

2. FREEZER STRUCTURE ACTS AS RIGID BODY

3. +X LOAD IS REACTED BY ALL BOLTS EQUALLY IN TENSION

4. −X LOAD INDUCES NO LOAD IN BOLTS

5. +Y LOAD IS REACTED BY ALL BOLTS EQUALLY IN SHEAR. MOMENT INDUCES TENSION IN BOLTS 1, 2, 3, 4

6. −Y LOAD IS REACTED BY ALL BOLTS EQUALLY IN SHEAR. MOMENT INDUCES TENSION IN BOLTS 13, 14, 15, 16

7. +Z LOAD IS REACTED BY ALL BOLTS EQUALLY IN SHEAR. MOMENT INDUCES TENSION IN BOLTS 4, 8, 12, 16

8. −Z LOAD IS REACTED BY ALL BOLTS EQUALLY IN SHEAR. MOMENT INDUCES TENSION IN BOLTS 1, 5, 9, 13

SUMMARY - MAXIMUM ULTIMATE BOLT LOADS

BOLT NO.	$P_{S_{MAX}}$	P_T	$P_{T_{MAX}}$	P_S
1	87.5	125.75	274.45	52.03
2	↑	——	229.18	↑
3		——	229.18	
4		——	284.51	↓
5		125.75	244.77	52.03
		——	——	——
		——	——	——
8		——	254.83	52.03
9		125.75	244.77	52.03
		——	——	——
		——	——	——
12		——	254.83	52.03
13		125.75	274.45	↑
14		——	229.18	
15	↓	——	229.18	↓
16	87.5	——	284.51	52.03

CONDITION 1:

SHEAR (EACH BOLT) $P_S = \left[(35)^2 + (38.5)^2\right]^{1/2} = 52.03\#$

TENSION - BOLT 1 $P_T = 29.68 + 45.27 = 74.95\#$

- BOLT 2 $P_T = 29.68\#$

- BOLT 3 $P_T = 29.68\#$

- BOLT 4 $P_T = 29.68 + 55.33 = 85.01\#$

- BOLT 5 $P_T = 45.27\#$

- BOLT 8 $P_T = 55.33\#$

- BOLT 9 $P_T = 45.27\#$

- BOLT 12 $P_T = 55.33\#$

- BOLT 13 $P_T = 29.68 + 45.27 = 74.95\#$

- BOLT 14 $P_T = 29.68\#$

- BOLT 15 $P_T = 29.68\#$

- BOLT 16 $P_T = 29.68 + 55.33 = 85.01\#$

CONDITION 2:

SHEAR (EACH BOLT) $P_S = 52.03\#$

TENSION - BOLT 1 $P_T = 199.5 + 74.95 = 274.45\#$

- BOLT 2 $P_T = 199.5 + 29.68 = 229.18\#$

- BOLT 3 $P_T = 199.5 + 29.68 = 229.18\#$

- BOLT 4 $P_T = 199.5 + 85.01 = 284.51\#$

- BOLT 5 $P_T = 199.5 + 45.27 = 244.77\#$

- BOLT 8 $P_T = 199.5 + 55.33 = 254.83\#$

- BOLT 9 $P_T = 199.5 + 45.27 = 244.77\#$

- BOLT 12 $P_T = 199.5 + 55.33 = 254.83\#$

CONDITION 2, CONT'D:

-BOLT 13 $P_T = 199.5 + 74.95 = 274.45$ #

-BOLT 14 $P_T = 199.5 + 29.68 = 229.18$ #

-BOLT 15 $P_T = 199.5 + 29.68 = 229.18$ #

-BOLT 16 $P_T = 199.5 + 85.01 = 284.51$ #

CONDITION 3:

SAME AS CONDITION 2

CONDITION 4:

SAME AS CONDITION 2 & 3

CONDITION 5:

SHEAR (EACH BOLT) $P_S = 87.5$ #

TENSION -BOLT 1 $P_T = 125.75$ #

-BOLT 5 $P_T = 125.75$ #

-BOLT 9 $P_T = 125.75$ #

-BOLT 13 $P_T = 125.75$ #

BOLTS 3, 4, 6, 7, 8,
10, 11, 12, 14, 15, 16
HAVE NO TENSION

CONDITION 6:

SHEAR (EACH BOLT) $P_S = \left[(35)^2 + (44.8)^2\right]^{1/2} = 56.85$ #

TENSION -BOLT 1 $P_T = 140 + 29.68 = 169.68$ #

-BOLT 2 $P_T = 140 + 29.68 = 169.68$ #

-BOLT 3 $P_T = 140 + 29.68 = 169.68$ #

-BOLT 4 $P_T = 140 + 29.68 + 64.38 = 234.06$ #

-BOLT 5 $P_T = 140$ #

CONDITION 6, CONT'D:

- BOLT 8 $P_T = 140 + 64.38 = 204.38$ #
- BOLT 9 $P_T = 140$ #
- BOLT 12 $P_T = 140 + 64.38 = 204.38$ #
- BOLT 13 $P_T = 140 + 29.68 = 169.68$ #
- BOLT 14 $P_T = 140 + 29.68 = 169.68$ #
- BOLT 15 $P_T = 140 + 29.68 = 169.68$ #
- BOLT 16 $P_T = 140 + 29.68 + 64.38 = 234.06$ #

MATERIAL PROPERTIES

URETHANE FOAM INSULATION

REFERENCE: MATERIALS SELECTOR 73

PAGE 272, DENSITY = 2-3 pcf

COMPRESSION STRENGTH (@ 10% DEFLECTION)	20-50 psi
COMPRESSION MODULUS OF ELASTICITY	300-600 psi
TENSILE STRENGTH	20-70 psi
BENDING STRENGTH	60-100 psi
BENDING MODULUS OF ELASTICITY	800-900 psi
SHEAR STRENGTH	20-30 psi
SHEAR MODULUS OF ELASTICITY	170-210 psi

MATERIAL PROPERTIES

6061-T6 ALUMINUM ALLOY

SHEET AND PLATE (0.010-2.000 IN. THICK)

"A VALUES (REF. MIL-HDBK-5A, TABLE 3.2.6.0(b))

F_{TU} ~ psi	42,000
F_{TY}	36,000
F_{CY}	35,000
F_{SU}	27,000
F_{BRU}	67,000 (e/D = 1.5)
F_{BRU}	88,000 (e/D = 2.0)
F_{BRY}	50,000 (e/D = 1.5)
F_{BRY}	58,000 (e/D = 2.0)
E	9.9×10^6
E_c	10.1×10^6
G	3.8×10^6

INNER CONTAINER ANALYSIS

DETERMINE MOST CRITICAL WALL PANEL :

TO PREVENT FUNCTIONAL DAMAGE TO URETHANE INSULATION, PANEL DEFLECTION MUST NOT EXCEED 10% OF INSULATION THICKNESS.

$$\delta_{ALLOWABLE} = 0.10 \times 1.93 = 0.193 \text{ IN.}$$

REF. ROARK'S FORMULAS FOR STRESS AND STRAIN, TABLE X, CASE 36 FOR METHOD OF ANALYSIS.

COMPARTMENT		SIDE	BACK	BOTTOM
1	$P_{ULT.}$ =	129#	296.7#	322.5#
2	" =	80.63#	185.45#	201.58#
3	" =	112.88#	259.62#	282.2#
1	$b \times a$ =	15.5 x 18	10 x 18	10 x 15.5
2	" =	11.25 x 15.5	10 x 11.25	10 x 15.5
3	" =	13 x 18	12 x 13	12 x 15.5
1	α =	0.861	0.556	0.645
2	" =	0.726	0.889	0.645
3	" =	0.722	0.923	0.774
1	ω =	0.462	1.648	2.081
2	" =	0.462	1.648	1.301
3	" =	0.482	1.664	1.517
1	C =	11,062	11,943	13,063
2	" =	4,010	6,456	8,167
3	" =	7,515	12,603	15,536

$$C = \frac{\omega b^4}{1 + 2.21\alpha^3}$$

INNER CONTAINER ANALYSIS, CONT'D

THE "C" PARAMETER ON PAGE 9 IS A DIRECT INDICATOR OF PANEL CRITICALITY. BY INSPECTION, THE BOTTOM PANEL OF COMPARTMENT 3 IS THE MOST CRITICAL.

CALCULATE REQUIRED MONOCOQUE THICKNESS TO LIMIT DEFLECTION TO 0.190 IN.:

$$t = \left[\frac{0.1422\, w \ell^4}{\delta E (1+2.21\alpha^3)}\right]^{1/3}$$

$$= \left[\frac{0.1422 \times 1.517 \times (12.0)^4}{0.190 \times 9.9 \times 10^6 \times (1+2.21 \times \overline{0.774}^3)}\right]$$

$$= 0.106 \text{ IN.}$$

IF ALL EDGES ARE ASSUMED FIXED:

$$t = \left[\frac{0.0284\, w \ell^4}{\delta E (1+1.056\alpha^5}\right]^{1/3}$$

$$= \left[\frac{0.0284 \times 1.517 \times (12.0)^4}{0.190 \times 9.9 \times 10^6 \times (1+1.056 \times \overline{0.774}^5)}\right]^{1/3}$$

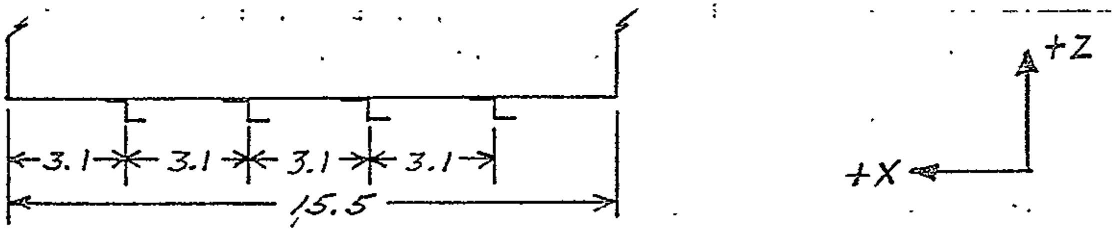
$$= 0.072 \text{ IN.}$$

THE INNER CONTAINER SKIN IS ASSUMED TO BE 0.03 IN. THICK & THE OUTER CONTAINER SKIN IS 0.02 IN. THICK. THE TWO SKINS COMBINED ARE LESS THAN THE THICKNESS REQUIRED TO LIMIT THE DEFLECTION TO 0.19 IN. HOWEVER, THE INSULATION PROPERTIES WILL NOT BE DEGRADED SINCE A COMPRESSIVE LOAD OF AT LEAST 20 #/IN^2 WOULD BE REQUIRED TO EXCEED ITS YIELD STRENGTH. THE MAXIMUM IMPOSED LOAD IS 2.081 #/IN^2.

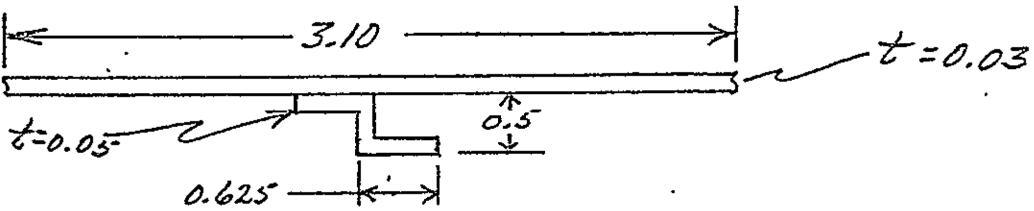
INNER CONTAINER ANALYSIS, CONT'D

AN ARBITRARY CRITERION OF 0.10 IN. MAXIMUM DEFLECTION WILL BE ASSUMED FOR PANEL DESIGN. IN ORDER TO LIMIT THE DEFLECTION TO THIS VALUE, OR LESS, IT WILL BE NECESSARY TO ADD STIFFENERS IN THE Y-Z PLANE ALL THE WAY AROUND THE INNER COMPARTMENT.

CONSIDER THE FOLLOWING CONFIGURATION:



BOTTOM PANEL - COMPARTMENT 3



CHECK PANEL DEFLECTION:

$$\delta = \frac{0.1422 \times 1.517 \times (3.1)^4}{9.9 \times 10^6 \times (0.03)^3 \times (1+2.21\times\overline{0.258}^3)}$$

$$= 0.072 \text{ IN} < 0.10 \text{ IN,} \qquad \underline{\underline{\text{O.K.}}}$$

(SEE PAGE 12 FOR LARGE DEFLECTION ANALYSIS)

INNER CONTAINER ANALYSIS, CONT'D

REF. ROARK'S FORMULAS FOR STRESS AND STRAIN, PAGE 222, FOR ANALYSIS PROCEDURE.

$$\frac{wb^4}{Et^4} = \frac{1.517 \times (3.1)^4}{9.9 \times 10^6 \times (0.03)^4} = 17.47$$

$$a/b = 12.0/3.1 = 3.87$$

	COEFF.
y/t	0.795

$$y = 0.795 \times 0.03 = 0.024 \text{ IN.}$$

∴ PANEL DEFLECTION IS MUCH LESS THAN THAT PREDICTED BY SMALL DEFLECTION THEORY. TRY USING ONLY 2 STIFFENERS WITH 5.167 IN. SPACING.

$$\frac{wb^4}{Et^4} = \frac{1.517 \times (5.167)^4}{9.9 \times 10^6 \times (0.03)^4} = 134.84$$

$$a/b = 12.0/5.167 = 2.32$$

$y/t = 1.78$ $\quad$ $y = 1.78 \times 0.03 = 0.05 \text{ IN.}$

$S_d b^2/Et^2 = 8.54$ $\quad$ $S_d = \dfrac{8.54 \times 9.9 \times 10^6 \times (0.03)^2}{(5.167)^2} = 2850 \text{ PSI}$

$Sb^2/Et^2 = 17.01$ $\quad$ $S = \dfrac{17.01 \times 9.9 \times 10^6 \times (0.03)^2}{(5.167)^2} = 5680 \text{ PSI}$

$$S_{TOTAL} = 2850 + 5680 = 8530 \text{ PSI}$$

$$M.S._{ULT.} = \frac{42000}{8530} - 1 = \underline{\underline{3.92}}$$

INNER CONTAINER ANALYSIS, CONT'D

CHECK STIFFENER FOR BEAM BENDING:

REF. PAGE 11 FOR CROSS-SECTION & PAGE 12 FOR REVISION.

$A_{STIFF} = 0.0852 \text{ IN}^2$

$I_{STIFF} = 0.0035 \text{ IN}^4$

A	Y	AY	AY^2	I_o
0.0852	0.250	0.0213	0.0053	0.0035
0.1550	0.515	0.0798	0.0411	———
0.2402		0.1011	0.0464	0.0035

$\bar{Y} = 0.1011/0.2402 = 0.4209$

$I = 0.0035 + 0.0464 - (0.1011 \times 0.4209) = 0.0073 \text{ IN}^4$

$\omega = 1.517 \times 5.167 = 7.838\ \#/\text{IN}$

$M_{MAX} = \omega l^2/8 = 7.838 \times (12)^2/8 = 141.08 \text{ IN-}\#$

$$\delta = \frac{5\omega l^4}{384EI} = \frac{5 \times 7.838 \times (12)^4}{384 \times 9.9 \times 10^6 \times 0.0073} = 0.029 \text{ IN.} \quad \underline{\underline{\text{O.K.}}}$$

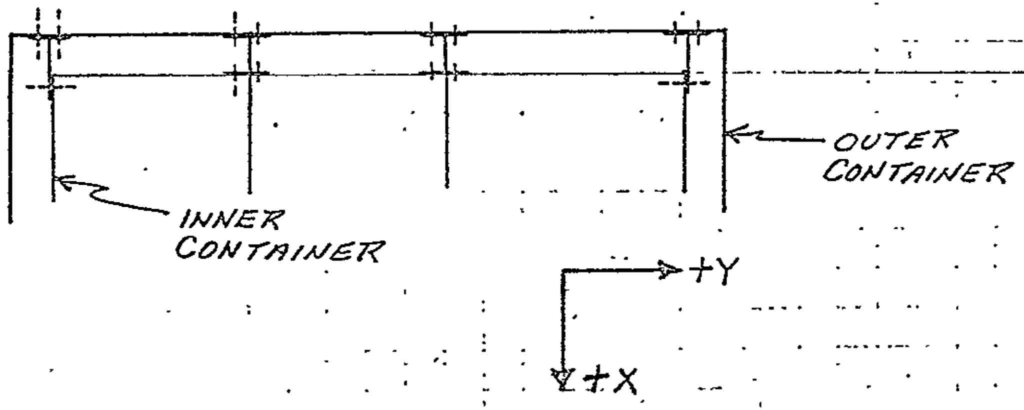
$$f_b = \frac{141.08 \times 0.4209}{0.0073} = 8130 \text{ psi}$$

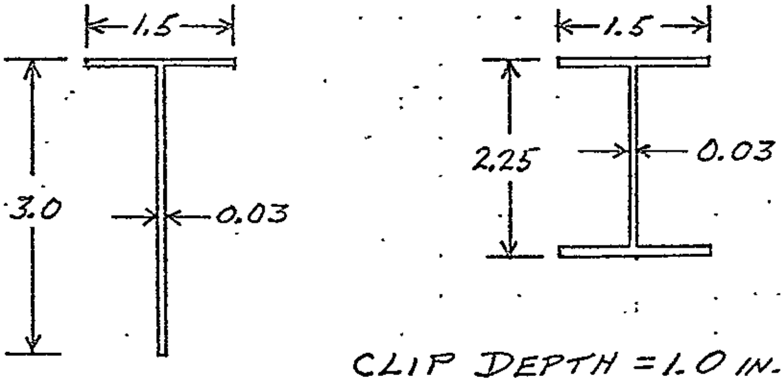
$$M.S._{ULT} = \frac{42000}{8130} - 1 = \underline{\underline{4.17}}$$

INNER/OUTER CONTAINER ATTACHMENTS

BACK WALL (-X) ATTACHMENT

THE BACK WALL OF THE INNER CONTAINER WILL BE ATTACHED TO THE BACK WALL OF THE OUTER CONTAINER WITH CLIPS. THE FOLLOWING CLIP CONFIGURATIONS ARE RECOMMENDED.





CLIP DEPTH = 1.0 IN.

THESE CLIPS ARE REQUIRED AT BOTH TOP AND BOTTOM OF THE INNER CONTAINER.

```
        BCD 3THERMAL LPCS
        BCD 3 CASE 1
        BCD 8 SHUTTLE FREEZER  -  SINGLE SLICE MODEL
        END
        BCD 3NODE DATA
            -1,-10., 1. $
        GEN 2,8,1,-10., 1. $
        GEN 11,9,1,-10.,1. $
        GEN 21,9,1,-10.,1. $
        GEN 31,9,1,-10.,1. $
        GEN 41,9,1,-10.,1. $
        GEN 51,9,1,-10.,1. $
        GEN 61,9,1,-10.,1. $
        GEN 71,9,1,-10.,1. $
        GEN 81,9,1,-10.,1. $
            -99,80., 1. $
        END
        BCD 3CONDUCTOR DATA
        GEN 1,8,0,-12,10,11,10, 0. $
        GEN 2,8,0,1,1,2,1, 0. $
        GEN 3,8,0,11,10,12,10, 0. $
        GEN 4,8,0,12,10,13,10, 0. $
        GEN 5,8,0,13,10,14,10, 0. $
        GEN 6,8,0,14,10,15,10, 0. $
        GEN 7,8,0,15,10,16,10, 0. $
        GEN 8,8,0,16,10,17,10, 0. $
        GEN 9,8,0,17,10,18,10, 0. $
        GEN 10,8,0,18,10,19,10, 0. $
        GEN 11,9,0,1,1,11,1, 0. $
        GEN 12,9,0,11,1,21,1, 0. $
        GEN 13,9,0,21,1,31,1, 0. $
        GEN 14,9,0,31,1,41,1, 0. $
        GEN 15,9,0,41,1,51,1, 0. $
        GEN 16,9,0,51,1,61,1, 0. $
        GEN 17,9,0,61,1,71,1, 0. $
        GEN 18,9,0,71,1,81,1, 0. $
        GEN 19,8,0,-18,10,19,10, 0. $
        GEN 20,8,0,2,1,99,0, 0. $
        GEN 21,9,0,-71,1,81,1, 0. $
            22,-8,9, 0. $
        END
```

INNER/OUTER CONTAINER ATTACHMENTS

BACK WALL (-X) ATTACHMENT

CHECK TEE CLIP: (REF. PAGE 14)

ASSUME CLIP MATERIAL IS 301 SS 1/4 H

F_{TU} = 125,000 psi

F_{TY} = 75,000 psi $\qquad$ $E = 27 \times 10^6$ psi

F_{CY} = 43,000 psi

F_S = 67,500 psi

$P_{C_{MAX}} = 260 \times 1.5 \times 2.30 = 897$ # ULT.

$P_{S_{MAX}} = 260 \times 1.5 \times 2.50 = 975$ # ULT.

$P_{B_{MAX}} = 260 \times 1.5 \times 1.00 = 390$ # ULT.

COMPRESSION BUCKLING: (ASSUME TOTAL LOAD ON 1 CLIP)

$$F_{CCR} = KE(t/b)^2 = 6.5 \times 27 \times 10^6 \times \left(\frac{0.03}{1.0}\right)^2 = 157{,}950 \text{ psi}$$

$$f_c = 897/1.0 \times 0.03 = 29{,}900$$

$$M.S. = \frac{157{,}950}{29{,}900} - 1 = \underline{4.28}$$

SHEAR BUCKLING: (ASSUME TOTAL LOAD ON 1 CLIP)

$$F_{SCR} = KE(t/b)^2 = 5.5 \times 27 \times 10^6 \times \left(\frac{0.03}{1.0}\right)^2 = 133{,}650 \text{ psi}$$

$$f_s = 975/1.0 \times 0.03 = 32{,}500 \text{ psi}$$

$$M.S. = \frac{133650}{32{,}500} - 1 = \underline{3.11}$$

INNER/OUTER CONTAINER ATTACHMENTS

BACK WALL (-X) ATTACHMENT

CLIP BENDING:

ASSUME TOTAL "Y" LOAD ACTS ON 1.0 x 13.0 STRIP OF THERMAL INSULATION TO CALCULATE BENDING DEFLECTION OF CLIP.

$$\delta = \frac{390 \times 2.188}{1.0 \times 13.0 \times 600} = 0.109 \text{ IN}$$

$$P_{CLIP} = \frac{0.109 \times 3 \times 27 \times 10^6 \times I}{(2.25)^3} = 775{,}111\ I\ \#$$

$$f_b = \frac{2.25 \times 775{,}111 \times I \times 0.0015}{I} = 2620 \text{ PSI}$$

$$M.S. = \frac{125{,}000}{2{,}620} - 1 = \underline{47}$$

FRONT FRAME IS 0.06 IN. THICK. THEREFORE, THE ATTACHMENT TO THE FRONT FRAME IS STRONGER THAN THE CLIP ATTACHMENT.

THE INNER DOOR IS AT LEAST AS STRONG AS THE INNER COMPARTMENT WALLS & THEREFORE HAS ADEQUATE STRENGTH. THE HINGES & LATCHES MUST BE SELECTED TO ADEQUATELY SUPPORT THE LOADS PREVIOUSLY SHOWN.

THE OUTER DOOR IS ONLY REQUIRED TO SUPPORT ITS OWN WEIGHT TIMES THE ACCELERATION & IS THEREFORE STRUCTURALLY ADEQUATE BY INSPECTION.

APPENDIX B

LISTING OF SINDA TWO-DIMENSIONAL FREEZER SLICE MODEL

LISTING OF SINDA TWO-DIMENSIONAL FREEZER SLICE MODEL

This appendix contains a complete listing of the SINDA two-dimensional freezer "slice" model described in Section 7.1. This report is not intended to serve as a users manual for the model. However, the listing, with attached brief description and the nodal network identification in Figure 7-1, should allow one proficient with the SINDA program to modify and use the model to perform further freezer thermal analyses.

The primary Fortran symbols used in the model listing are defined in Table B-1. The SINDA long pseudo-compute sequence is used to obtain steady state solutions only. Various model parameters are input and defined in the CONSTANTS data block. The actual values for the thermal conductors are all computed in the EXECUTION block. These values are computed in terms of variable geometry and material thermophysical properties to allow easy accommodation for varying freezer designs. The VARIABLES I and OUTPUT CALLS blocks are used only for periodic output of selected parameters, and the VARIABLES II block is not used.

TABLE B-1

SYMBOLS USED IN SINDA TWO-DIMENSIONAL FREEZER SLICE MODEL

DELT	Maximum temperature change along inner wall between cooling tubes (°F)
DX,DY,DZ	Dimensions of nodes in slice model (ft)
G	SINDA array of conductor values (Btu/hr °F)
GPACK	Thermal conductor through packaging layer, from food to wall (Btu/hr °F)
LOOPCT	System iteration counter
NCASE	Number of the current case being simulated
QCIN	Heat conducted into wall through insulation (Btu/hr)
QCL	Heat conducted into coolant tube per foot (Btu/hr/ft)
T	SINDA array of nodal temperatures (°F)

c-2

```
           BCD 3CONSTANTS DATA
               DRLXCA=.0005
               ARLXCA=.0005
               NLOOP=700
               DAMPD=1.0
               DAMPA=1.0
               2=12.     $ INCHES BETWEEN TUBES
               3=9.      $ INCHES HEIGHT OF FOOD SLICE
               4=1.      $ INCHES THICKNESS OF SLICE
               5=2.      $ INSULATION THICKNESS (IN.)
               6=.013    $ INSULATION CONDUCTIVITY (BTU/HR-FT-F)
               7=.032    $ METAL WALL THICKNESS (IN.)
               8=116.    $ METAL WALL CONDUCTIVITY (BTU/HR-FT-F)
               9=-10.    $ COOLANT BOUNDARY TEMP (F)
               11=1.     $ FOOD THERMAL COND. (BTU/HR-FT-F)
               12=1.     $ PACKING THERMAL CONDUCTIVITY (BTU/HR-FT-F)
           END
           BCD 3ARRAY DATA
           END
           BCD 3EXECUTION
F         DIMENSION X(8000)
F         NDIM=8000
F         NTH=0
F         DATA NCASE /0/
F     10  NCASE=NCASE+1
M         DX=XK(2)/8./12. /2.
M         DY=(XK(3)-.2)/8./12.
M         DZ=XK(4)/12.
M         T(1)=XK(9)
M         G(1)=XK(11)*DY*DZ/DX
M         DUM=XK(8)*XK(7)*DZ/DX/12.
M         DUM2=XK(6)*.2/12.*DZ/DX
M         G(2)=DUM+DUM2+ XK(12)*.2/12. *DZ/DX
F         DO 20 N=3,10
F     20  G(N)=G(1)
M         G(12)=XK(11)*DX*DZ/DY
M         GPACK=XK(12)*DX*DZ/ (.2/12.)
F         G(11)=GPACK*2.*G(12)/ (GPACK+2.*G(12))
F         DO 30 N=13,18
F     30  G(N)=G(12)
F         G(19)=G(10)
M         G(20)=XK(6)*DX*DZ/XK(5)*12.
F         G(21)=G(18)
F         G(22)=G(2)
```

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```
          CALL GPRINT
          IF (NCASE.EQ.1) CALL PCTDMP
F         WRITE (6,5) (XK(N),N=1,10)
F       5 FORMAT (///1X, 5G12.5///)
F         WRITE (6,45)
F      45 FORMAT ( 1H1,'  N       QCOOL     DTMAX    DRLXCC      QCIN      T(2)      T(5)
F        *     T(8)      T(9)      T(31)     T(39)     T(61)     T(69)     T(81)     T(85)
F        *  T(89)'//)
F         CALL CINDSL
F         GO TO (62,63,64,99), NCASE
M      62 XK(2)=9.
F         GO TO 10
M      63 XK(2)=6.
F         GO TO 10
M      64 XK(2)=3.
F         GO TO 10
F      99 CONTINUE
M         IF (XK(12) .LT. .2) GO TO 199
M         XK(12)=0.
M         XK(2)=12.
F         NCASE=0
F         GO TO 10
F     199 CONTINUE
           END
           BCD 3VARIABLES 1
F         N=LOOPCT/5
F         IF (N*5 .NE. LOOPCT) GO TO 999
M         QCL=(2.*G(2)*(T(2)-T(1))+G(11)*(T(11)-T(1)) +G(20)*(T(99)-T(1)))
M        * /XK(4)*12.
M         DELT=T(9)-T(1)
F         QCIN=0.
F         DO 5 N=1,8
F       5 QCIN=QCIN+T(N)
M         QCIN=G(20) * (9.*T(99)-QCIN-T(1))
M         WRITE (6,10) LOOPCT,QCL,DELT,DRLXCC,QCIN, T(2), T(5),T(8),T(9),
M        * T(31),T(39),T(61),T(69), T(81),T(85),T(89)
F      10 FORMAT ( 1X, I3, F8.3, F8.4, F9.6, F8.3, 11F8.3)
F     999 CONTINUE
           END
           BCD 3VARIABLES 2
           END
           BCD 3OUTPUT CALLS
F         WRITE (6,40)
F         WRITE (6,30) T(81), (T(N),N=1,80), T(82)
F      30 FORMAT (1X, 9F12.3)
F      40 FORMAT (/// )
           END
```

APPENDIX C

LISTING OF SINDA THREE-DIMENSIONAL FREEZER MODEL

LISTING OF SINDA THREE-DIMENSIONAL FREEZER MODEL

This appendix contains a complete numbered listing of the SINDA three-dimensional freezer model. This report is not intended to serve as a users manual for the model. However, the listing, with attached brief description and the nodal network identification in Figures 7-3 and 7-4, should allow one proficient with the SINDA program to modify and use the model to perform further freezer thermal analyses.

The primary Fortran symbols used in the model listing are defined in Table C-1. The SINDA long pseudo-compute sequence is used to obtain steady state and transient solutions for the freezer. Freezer nodes are defined in statement numbers 7 through 14, and conductors in numbers 15 through 95. Various model parameters are input and described in the CONSTANTS data block, statement numbers 107 through 131. The actual values for the thermal capacitors and conductors are all computed in the EXECUTION block, statement numbers 137 through 781, using standard Fortran V language. These values are all computed in terms of variable freezer geometry and material thermo-physical properties to allow easy accommodation for varying freezer designs. Comment cards are included to allow easy identification of the specific variables being computed in each section of the program. The EXECUTION program is divided logically into major functional blocks to facilitate changes of portions of the model. These blocks are identified as follows:

Line Numbers	Function
146-170	Define overall freezer size and internal dimensions
175-228	Evaluate thermal conductors through food and medical samples only
232-260	Thermal resistance added to conductors for packaging at internal spacer walls
265-321	Thermal resistance added to conductors for packaging at inner structural walls
325-462	Thermal conductors modified for conduction through insulation, packaging and walls
467-582	Thermal conductors through insulation to boundary walls evaluated
584-590	Thermal conductors through hard-attach points added

Appendix C (Continued)

Line Numbers	Function
594-600	Coolant flow conductors evaluated
606-625	Food/medical sample thermal capacitance evaluated
628-757	Thermal capacitance of walls, packaging and insulation added
761-780	Parametric conditions for sequenced runs set up

The VARIABLES I block is used only to print out various parameters of interest at selected intervals during a run. In VARIABLES II the following functions are performed:

- o Include effect of fresh medical sample insertion
- o Include door opening effect
- o Operate cooling unit thermostat control
- o Store selected data for final plotting, and make plots

The logic used for performing these functions is labeled by comment cards for easy identification. The OUTPUT CALLS block is used only to print out a "thermal snapshot" of the temperatures throughout the freezer at selected intervals during a run.

TABLE C-1

SYMBOLS USED IN SINDA THREE-DIMENSIONAL MODEL

A	SINDA array used to input arbitrary door opening time schedule.
C	SINDA array of capacitance values (Btu/^{o}F)
CAP	Thermal capacitance (Btu/^{o}F)
CDLINS	Thermal conductivity of insulation divided by its thickness (Btu/hr sq ft ^{o}F)
CTL	Effective thermal conductivity of front angle connecting inner and outer shells, divided by insulation thickness (Btu/hr sq ft ^{o}F)
CTOT	Total thermal specific heat of all freezer internal nodes (Btu/^{o}F)
CTWALL	Combined thermal conductivity of the walls/insulation/packaging layer divided by its thickness (Btu/hr sq ft ^{o}F)
CWATTS	Total heat removed by refrigeration unit when on (Btu/hr)
DX,DY,DZ	Arrays of nodal thicknesses in the X (horizontal), Y (vertical), and Z (axial) directions (feet)
DXL,DYL,DZL	Arrays of distances between nodal centers in X (horizontal), Y (vertical), and Z (axial) directions (feet)
G	SINDA array of conductor values (Btu/hr ^{o}F)
GDLPAK	Thermal conductivity of packaging layer divided by its thickness (Btu/hr ft^{2} ^{o}F)
GXP,GXL,GYP,GYL,GZP,GZL	Conductor values from fresh medical sample node to adjacent nodes. X, Y, Z refers to horizontal, vertical and axial directions. P and L refer to plus and minus directions along axes.
J	Typically used as counter for numbering nodes in the X (horizontal) direction
L	Typically used as counter for numbering nodes in the Z (axial) direction
LOOPCT	System iteration counter
LPLOT	Flag to request storing of plot data when positive

TABLE C-1 (Continued)

M	Typically used as counter for numbering nodes in the Y (vertical) direction
NCASE	Number of the current case being simulated
NLINE	Selected data will be identified and defined after it is printed every NLINE lines
NPR	Selected data will be output every NPR lines
NPTS	Number of data points to be plotted
NSAMP	Node number used for fresh medical sample
NXP,NXL,NYP,NYL,NZP,NZL	Conductor numbers from fresh medical sample node to adjacent nodes. X, Y, Z refers to horizontal, vertical and axial directions. P and L refer to plus and minus directions along axes.
OPEN	Used to store door opening flag from previous iteration. Door is assumed to open whenever this flag changes sign.
PWATTS	Coolant pump electrical power (watts)
QCOOL	Heat removed from locker by coolant (Btu/hr)
QDOOR	Heat input to locker from a single door opening (Btu)
QLAT	Latent heat of fusion in fresh medical sample water (Btu)
QREM	Net heat removed from coolant by refrigeration unit (Btu/hr)
QWALL	Net heat leak into locker through freezer walls (Btu/hr)
RCPT	Wall/insulation/packaging layer density--specific heat product divided by its thickness (Btu/lb sq ft ^{O}F)
TAVG	Bulk average temperature of all freezer internal nodes (^{O}F)
TCOUT	Coolant outlet temperature from locker (^{O}F)
TCNTRL	Temperature used for thermostat control of refrigeration unit
TFR	Medical sample liquid freezing temperature (^{O}F)
TITLX,TITLY	Hollerith titles used for axes of output plots
TMAX,TMIN	Maximum and minimum temperature of all freezer internal nodes (^{O}F)
TOFF	Low temperature limit at which refrigeration unit turns off (^{O}F)

TABLE C-1 (Concluded)

TON	High temperature limit at which refrigeration unit turns on (°F)
TPLOT	Next time for storing data to be plotted
X2	Array of X-values to be plotted (time - hours)
XKS	Initial thermal conductivity of material in medical sample location (Btu/hr ft °F)
Y2,Y3,Y4,Y5,Y6,Y7	Arrays of Y-values to be plotted

```
@ELT,UL  29.MODEL
ELTDT7 RLIB70 07/11-22:17:58-(0,1)
000001        000            BCD 3THERMAL LPCS
000002        000            BCD 6 SHUTTLE FREEZER THERMAL MODEL
000003        001            REM   PREPARED BY  ...  D J PUSSELL
000004        001            REM             JULY 1975
000005        001            REM
000006        000            END
000007        000            BCD 3NODE DATA
000008        000            GEN 1,155,1,-10.,1. S
000009        000            GEN 156,10,1, -10., 1. S
000010        000                -200,-20., 1. S INTERFACE HEAT EXCHANGER
000011        000                -500,80.,1. S  AMBIENT BOUNDARY TEMP
000012        000                -501,100.,1. S BOUNDARY TEMP BETWEEN FOOD AND COOLING UNIT
000013        000                -502,90.,1. S CORNER BOUNDARY TEMP AROUND COOLING UNIT
000014        000            END
000015        000            BCD 3SOURCE DATA
000016        000            END
000017        000            BCD 3CONDUCTOR DATA
000018        000            REM              WITHIN FOOD
000019        000            REM    VERTICAL (Y)
000020        000            GEN 1,20,1,1,1,6,1, 0.      S
000021        000            GEN 21,20,1,26,1,31,1, 0.   S
000022        000            GEN 41,20,1,51,1,56,1, 0.   S
000023        000            GEN 61,20,1,76,1,81,1, 0.   S
000024        000            GEN 81, 20,1,101,1,106,1, 0. S
000025        000            GEN 101,10,1,126,1,131,1, 0. S
000026        000            GEN 111,10,1,141,1,146,1, 0. S
000027        000            REM    HORIZONTAL (X)
000028        000            GEN 121,100,1,1,1,26,1, 0.  S
000029        000            GEN 221,30,1,111,1,126,1, 0. S
000030        000            REM    AXIAL (Z)
000031        000            GEN 251,31,1,1,5,2,5, 0.    S
000032        000            GEN 282,31,1,2,5,3,5, 0.    S
000033        000            GEN 313,31,1,3,5,4,5, 0.    S
000034        000            GEN 344,31,1,4,5,5,5, 0.    S
000035        000            REM          (EXTRA FOOD)
000036        000            GEN 375,5,1, 156,1, 126,1, 0. S
000037        000            GEN 380,5,1, 161,1, 141,1, 0. S
000038        000            GEN 385,5,1, 106,1, 156,1, 0. S
000039        000            GEN 390,5,1, 156,1, 161,1, 0. S
000040        000            GEN 395,4,1, 156,1, 157,1, 0. S
000041        000            GEN 399,4,1, 161,1, 162,1, 0. S
000042        000            REM             INNER WALLS-TO-OUTER BOUNDARY
000043        000            GEN 1001,100,1,1,1,500,0, 0. S
000044        000            GEN 1101,6,1,101,1,502,0, 0. S
000045        000            GEN 1107,3,1,107,1,501,0, 0. S
000046        000                1110,110,502, 0. S
000047        000            GEN 1111,45,1,111,1,500,0, 0.S
000048        000                1156,156,502, 0. S
000049        000            GEN 1157,3,1, 157,1, 501,0, 0. S
000050        000            GEN 1160,6,1, 160,1, 502,0, 0. S
000051        000            REM             COOLANT FLOW IN TUBES
000052        000                2109,-200,109, 1. S
000053        000                2108,-109,108, .5 S
000054        000                2107,-108,107, .5 S
000055        000                2106,-107,106, .25 S
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 000056      000              2156,-106,156, .25 $
 000057      000              2157,-107,157, .25 $
 000058      000              2159,-109,159, .25 $
 000059      000              2161,-156,161, .25 $
 000060      000              2162,-157,162, .25 $
 000061      000              2164,-159,164, .25 $
 000062      000              2141,-161,141, .25 $
 000063      000              2142,-162,142, .25 $
 000064      000              2144,-164,144, .25 $
 000065      000          GEN 2146,2,5,-141,5,146,5, .25 $
 000066      000          GEN 2147,2,5,-142,5,147,5, .25 $
 000067      000          GEN 2149,2,5,-144,5,149,5, .25 $
 000068      000          GEN 2136,2,-15,-151,-15,136,-15, .25 $
 000069      000          GEN 2137,2,-15,-152,-15,137,-15, .25 $
 000070      000          GEN 2139,2,-15,-154,-15,139,-15, .25 $
 000071      000          GEN 2096,4,-25, -121,-25,96,-25, .25 $
 000072      000          GEN 2097,4,-25, -122,-25,97,-25, .25 $
 000073      000          GEN 2099,4,-25, -124,-25,99,-25, .25 $
 000074      000          GEN 2016,4,-5, -21,-5,16,-5, .25 $
 000075      000          GEN 2017,4;-5, -22,-5,17,-5, .25 $
 000076      000          GEN 2019,4;-5, -24,-5,19,-5, .25 $
 000077      000          GEN 2026,4,25, -1,25, 26,25, .25 $
 000078      000          GEN 2027,4,25, -2,25, 27,25, .25 $
 000079      000          GEN 2029,4,25, -4,25, 29,25, .25 $
 000080      000              3102,-101,102, .25 $
 000081      000              2103,-102,103, .5 $
 000082      000              3104,-103,104, .5 $
 000083      000              2110,-109,110, .25 $
 000084      000              2090,-110,90, .25  $
 000085      000              2060,-90,60, .25  $
 000086      000          GEN 2065,2,5, -60,5,65,5, .25 $
 000087      000          GEN 2095,2,25, -70,25,95,25, .25 $
 000088      000          GEN 2135,2,15, -120,15,135,15, .25 $
 000089      000              2155,-150,155, .25 $
 000090      000          GEN 2140,2,-15, -155,-15,140,-15, .25 $
 000091      000          GEN 2100,4,-25, -125,-25,100,-25, .25 $
 000092      000          GEN 2020,4,-5, -25,-5,20,-5, .25 $
 000093      000          GEN 2030,4,25, -5,25,30,25, .25 $
 000094      000              4104,-105,104, .25 $
 000095      000          END
 000096      000          BCD 3CONSTANTS DATA
 000097      000              NLOOP=300
 000098      000              DRLXCA=.00002
 000099      000              ARLXCA=.00002
 000100      000              DAMPD=1.0
 000101      000              DAMPA=1.0
 000102      000              CSGFAC=1.1
 000103      000              DTIMEH=.1
 000104      000              DTIMEL=.0001
 000105      000              DTMPCA=2.
 000106      000              ATMPCA=2.
 000107      000              1=0      $  CASE NUMBER
 000108      000              2=1.969  $  INSULATION THICKNESS (IN.)
 000109      000              3=.03125 $ METAL WALL THICKNESS (IN)                    - STRUCTURE
 000110      000              4=116.   $  METAL WALL CONDUCTIVITY (BTU/HR-FT-F)        - STRUCTURE
 000111      000              5=.208   $  METAL WALL SPECIFIC HT. (BTU/LB-F)           - STRUCTURE
 000112      000              6=169.   $  METAL WALL DENSITY (LB/CU FT)                - STRUCTURE
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000113     000                 7=.01167 S INSULATION CONDUCTIVITY (BTU/HR-FT-F)
000114     000                 8=.2     S INSULATION SPECIFIC HT. (BTU/LB-F)
000115     000                 9=2.     S INSULATION DENSITY      (LB/CU FT)
000116     000                 10=.1    S PACKING LAYER THICKNESS (IN.)
000117     000                 11=.05   S PACKING LAYER CONDUCTIVITY (BTU/HR-FT-F)
000118     000                 12=.2    S PACKING LAYER SPECIFIC HT  (BTU/LB-F)
000119     000                 13=1.5   S PACKING LAYER DENSITY       (LB/CU FT)
000120     000                 14=116.  S WALL SPACER CONDUCTIVITY (BTU/HR-FT-F)
000121     000                 15=.0625 S WALL SPACER THICKNESS (IN.)
000122     000                 16=.208  S WALL SPACER SPECIFIC HT. (BTU/LB-F)
000123     000                 17=169.  S WALL SPACER DENSITY  (LB/CU FT)
000124     000                 18=1.    S FOOD CONDUCTIVITY (BTU/HR-FT-F)
000125     000                 19=.4    S FOOD SPECIFIC HT.
000126     000                 20=30.   S FOOD DENSITY
000127     000                 21=200.  S COOLANT FLOWRATE (LB/HR)
000128     000                 22=.44   S COOLANT SPECIFIC HT. (BTU/LB-F)
000129     000                 23=9     S COOLING UNIT ON(+)/OFF(-) SWITCH
000130     001                 24=6.    S TIME FOR FIRST MEDICAL SAMPLE INSERTION (HRS)
000131     000                 25=3.    S TIME FOR FIRST DOOR OPENING (HRS)
000132     000             END
000133     000             BCD 3ARRAY DATA
000134     000                 3 S  DOOR OPENING SCHEDULE
000135     000                   0.,1., .1,-1., .2,1., .3,-1., .4,99., END
000136     000             END
000137     000             BCD 3EXECUTION
000138     000     F      COMMON /FREZR/ DX(7),DY(5),DZ(5), DXL(6),DYL(4),DZL(4),QCOOL
000139     000     F     *,NSAMP,QLAT,XKS,OPEN
000140     000     F      COMMON /UPLOTX/ NPTS,TPLOT,X2(300),Y2(300),Y3(300),Y4(300),Y5(300)
000141     000     F     *, Y6(300),Y7(300)
000142     000     F      DIMENSION X(8000)
000143     000     F      GSER(G1,G2)=G1*G2/(G1+G2)
000144     000     F      NDIM=8000
000145     000     F      NTH=0
000146     000     F      DATA DXL/ 4*5., 2*6./
000147     000     F      DATA DYL/ 5., 2*3.1, 6.8/
000148     000     F      DATA DZL/ 4*3.875/
000149     000     F      IF (K(1).GT.0) GO TO 10
000150     000     F      DO 5 N=1,6
000151     000     F      DXL(N)=DXL(N)/12.
000152     000     F      IF (N.GT.4) GO TO 5
000153     000     F      DYL(N)=DYL(N)/12.
000154     000     F      DZL(N)=DZL(N)/12.
000155     000     F    5 CONTINUE
000156     000     F   10 CONTINUE
000157     000     F      DATA NCASE /0/
000158     000     F   15 NCASE=NCASE+1
000159     000     F      DX(1)=.5*DXL(1)
000160     000     F      DY(1)=.5*DYL(1)
000161     000     F      DZ(1)=.5*DZL(1)
000162     000     F      DO 20 N=2,6
000163     000     F      DX(N)=.5*(DXL(N-1)+DXL(N))
000164     000     F      IF (N.GT.4) GO TO 20
000165     000     F      DY(N)=.5*(DYL(N-1)+DYL(N))
000166     000     F      DZ(N)=.5*(DZL(N-1)+DZL(N))
000167     000     F   20 CONTINUE
000168     000     F      DX(7)=.5*DXL(6)
000169     000     F      DY(5)=.5*DYL(4)
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000170      000    F       DZ(5)=.5*DZL(4)
000171      000    C
000172      000    C       -- COMPUTE ALL FOOD CONDUCTORS
000173      000    C
000174      000    C                       VERTICAL (Y)
000175      000    F       DO 40 M=0,3
000176      000    F       DUM=1.
000177      000    F       IF (M.LT.1) DUM=.5
000178      000    F       DO 40 L=1,5
000179      000    F       N=5*M+L-1
000180      000    F       G(1+N)= XK(18)*DX(1)*DZ(L)/DYL(M+1)
000181      000    F       G(21+N)=XK(18)*DX(2)*DZ(L)/DYL(M+1)
000182      000    F       G(41+M)=XK(18)*DX(3)*DZ(L)/DYL(M+1)
000183      000    F       G(61+N)=XK(18)*DX(4)*DZ(L)/DYL(M+1)
000184      000    F       G(81+N)=XK(18)*DX(5)*DZ(L)/DYL(M+1)*DUM
000185      000    F       IF (M.GT.1) GO TO 40
000186      000    F       G(101+N)=XK(18)*DX(6)*DZ(L)/DYL(M+3)
000187      000    F       G(111+N)=XK(18)*DX(7)*DZ(L)/DYL(M+3)
000188      000    F       IF (M.GT.0) GO TO 40
000189      000    F       G(375+N)=XK(16)*DX(6)*DZ(L)/DYL(2)
000190      000    F       G(380+N)=XK(18)*DX(7)*DZ(L)/DYL(2)
000191      000    F    40 CONTINUE
000192      000    C                       HORIZONTAL (X)
000193      000    F       DO 50 M=0,4
000194      000    F       DUM=1.
000195      000    F       DO 50 L=1,5
000196      000    F       N=5*M+L-1
000197      000    F       G(121+N)=XK(18)*DY(M+1)*DZ(L)/DXL(1)
000198      000    F       G(146+N)=XK(18)*DY(M+1)*DZ(L)/DXL(2)
000199      000    F       G(171+N)=XK(18)*DY(M+1)*DZ(L)/DXL(3)
000200      000    F       G(196+N)=XK(18)*DY(M+1)*DZ(L)/DXL(4)
000201      000    F       IF (M.GT.2) GO TO 50
000202      000    F       G(221+N)=XK(18)*DY(M+3)*DZ(L)/DXL(5)*DUM
000203      000    F       G(236+N)=XK(18)*DY(M+3)*DZ(L)/DXL(6)*DUM
000204      000    F       IF (M.GT.0) GO TO 50
000205      000    F       G(385+N)=XK(18)*DY(2)*DZ(L) /DXL(5)*.5
000206      000    F       G(390+N)=XK(18)*DY(2)*DZ(L) /DXL(6)*.5
000207      000    F    50 CONTINUE
000208      000    C                       AXIAL (Z)
000209      000    F       DO 60 J=1,7
000210      000    F       ML=0
000211      000    F       IF (J.GT.5) ML=1
000212      000    F       DO 60 M=ML,4
000213      000    F       DUM=1.
000214      000    F       IF (M.LT.2 .AND. J.GT.4) DUM=.5
000215      000    F       IF (M.EQ.1 .AND. J.EQ.5) DUM=.75
000216      000    F       DO 60 L=1,4
000217      000    F       IF (J.GT.5) GO TO 55
000218      000    F       N=M+31*(L-1) + 5*(J-1)
000219      000    F       G(251+N)=XK(18)*DX(J)*DY(M+1)/DZL(L)*DUM
000220      000    F       GO TO 60
000221      000    F    55 N=M-2 + 31*(L-1) + 3*(J-6)
000222      000    F       IF (M.GE.2) GO TO 57
000223      000    F       N=4*(J-6) + L-1
000224      000    F       G(395+N)=XK(18)*DX(J)*DY(2)/DZL(L)*.5
000225      000    F       GO TO 60
000226      000    F    57 CONTINUE
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000227     000  F       G(276+N)=XK(18)*DX(J)*DY(M+1)/DZL(L)*DUM
000228     000  F    60 CONTINUE
000229     000  C
000230     000  C         ADD RESISTANCE THRU PACKAGING AT SPACER WALLS (SERIES)
000231     000  C
000232     000  F       GDLPAK=XK(11)/XK(10)*12.
000233     000  C                           VERTICAL WALLS
000234     000  F       DO 62 M=0,4
000235     000  F       DUM=1.
000236     000  F       IF (M.EQ.1) DUM=.5
000237     000  F       DO 62 L=1,5
000238     000  F       GP=GDLPAK*DY(M+1)*DZ(L)
000239     000  F       N=5*M + L-1
000240     000  F       G(146+N)=GSER( G(146+N), GP)
000241     000  F       G(171+N)=GSER( G(171+N), GP)
000242     000  F       IF (M.EQ.0) GO TO 62
000243     000  F       IF (M.GT.1) GO TO 61
000244     000  F       N=L-1
000245     000  F       G(201+N)=GSER( G(201+N), GP)
000246     000  F       G(385+N)=GSER( G(385+N), GP*DUM)
000247     000  F       GO TO 62
000248     000  F    61 CONTINUE
000249     000  F       N=5*(M-2) + L-1
000250     000  F       G(206+N)=GSER( G(206+N), GP)
000251     000  F       G(221+N)=GSER( G(221+N), GP*DUM)
000252     000  F    62 CONTINUE
000253     000  C                           HORIZONTAL WALL
000254     000  F       DO 63 M=0,1
000255     000  F       DO 63 L=1,5
000256     000  F       GP=GDLPAK*DZ(L)
000257     000  F       N=5*M + L-1
000258     000  F       G(51+N)=.5*G(51+N) + GSER( .5*G(51+N), GP*DX(3)*.5)
000259     000  F       G(71+N)=GSER( G(71+N), GP*DX(4))
000260     000  F    63 G(91+N)=.5*G(91+N) + GSER( .5*G(91+N), GP*DX(5)*.5)
000261     000  C
000262     000  C         ADD RESISTANCE THRU PACKAGING AT STRUCTURAL WALLS (SERIES)
000263     000  C
000264     000  C                           TOP-BOTTOM SIDES
000265     000  F       DO 69 J=1,7
000266     000  F       DUM=1.
000267     000  F       IF (J.EQ.5) DUM=.5
000268     000  F       DO 69 L=1,5
000269     000  F       GP=GDLPAK*DX(J)*DZ(L)
000270     000  F       IF (J.GT.5) GO TO 67
000271     000  F       N=L-1 + 20*(J-1)
000272     000  F       G(1+N)=GSER(G(1+N), GP*DUM)
000273     000  F       G(16+N)=GSER(G(16+N),GP)
000274     000  F       GO TO 69
000275     000  F    67 N=L-1 + 10*(J-5)
000276     000  F    68 G(96+N)=GSER( G(96+N), GP)
000277     000  F       N=L-1 + 5*(J-6)
000278     000  F       G(375+N)=GSER( G(375+N), GP)
000279     000  F    69 CONTINUE
000280     000  C                           LEFT-RIGHT SIDES
000281     000  F       DO 74 M=0,4
000282     000  F       DUM=1.
000283     000  F       IF (M.EQ.1) DUM=.5
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000284     000   F        DO 74 L=1,5
000285     000   F        GP=GDLPAK*DY(M+1)*DZ(L)
000286     000   F        N=5*M + L-1
000287     000   F        G(121+N)=GSER(G(121+N), GP)
000288     000   F        IF (M.EQ.0) GO TO 70
000289     000   F        IF (M.GT.1) GO TO 72
000290     000   F        N=L-1
000291     000   F        G(390+N)=GSER( G(390+N), GP*DUM)
000292     000   F        GO TO 74
000293     000   F     70 G(196+N)=GSER(G(196+N), GP)
000294     000   F        GO TO 74
000295     000   F     72 N=5*(M-2) + L-1
000296     000   F     73 G(236+N)=GSER( G(236+N), GP*DUM)
000297     000   F     74 CONTINUE
000298     000   C                          FRONT-BACK SIDES
000299     000   F        DO 76 J=1,7
000300     000   F        ML=0
000301     000   F        IF (J.GT.5) ML=1
000302     000   F        DO 76 M=ML,4
000303     000   F        GP=GDLPAK*DX(J) * DY(M+1)
000304     000   F        DUM=1.
000305     000   F        IF (J.GT.4 .AND. M.LT.2) DUM=.5
000306     000   F        IF (J.EQ.5 .AND. M.EQ. 1) DUM=.75
000307     000   F        IF (J.GT.5) GO TO 75
000308     000   F        N=M + 5*(J-1)
000309     000   F        G(251+N)=GSER( G(251+N), GP*DUM)
000310     000   F        G(344+N)=GSER( G(344+N), GP*DUM)
000311     000   F        GO TO 76
000312     000   F     75 N=M-2 + 3*(J-6)
000313     000   F        IF (M.GT.1) GO TO 77
000314     000   F        N=4*(J-6)
000315     000   F        G(395+N)=GSER( G(395+N), GP*DUM)
000316     000   F        G(398+N)=GSER( G(398+N), GP*DUM)
000317     000   F        GO TO 76
000318     000   F     77 CONTINUE
000319     000   F        G(276+N)=GSER( G(276+N), GP*DUM)
000320     000   F        G(369+N)=GSER( G(369+N), GP*DUM)
000321     000   F     76 CONTINUE
000322     000   C
000323     000   C          ADD WALL/INSULATION/PACKING CONDUCTION (PARALLEL)
000324     000   C
000325     000   F        CTWALL=XK(7)*.5*XK(2)/12. + XK(4)*XK(3)/12. + XK(11)*XK(10)/12.
000326     000   C                          VERTICAL (Y)
000327     000   F        DO 85 M=0,3
000328     000   C                                     (LEFT-RIGHT WALLS)
000329     000   F        DO 80 L=1,5
000330     000   F        N=5*M+L-1
000331     000   F        G(1+N)=G(1+N)+CTWALL*DZ(L)/DYL(M+1)
000332     000   F        IF (M.GT.1) GO TO 79
000333     000   F        IF (M.EQ.0) GO TO 78
000334     000   F        N=L-1
000335     000   F        G(380+N)=G(380+N)+CTWALL*DZ(L)/DYL(2)
000336     000   F        GO TO 80
000337     000   F     78 CONTINUE
000338     000   F        G(81+N) =G(81+N) +CTWALL*DZ(L)/DYL(M+1)
000339     000   F        GO TO 80
000340     000   F     79 N=5*(M-2) + L-1
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000341     000    F       G(111+N)=G(111+N)+CTWALL*DZ(L)/DYL(M+1)
000342     000    F    80 CONTINUE
000343     000    C                                 (FRONT-BACK WALLS)
000344     000    F       DO 83 L=0,4,4
000345     000    F       DUM=1.
000346     000    F       IF (M.LT.1) DUM=.5
000347     000    F       N=5*M+L
000348     000    F       G(1+N)=G(1+N)+CTWALL*DX(1)/DYL(M+1)
000349     000    F       G(21+N) =G(21+N) +CTWALL*DX(2)/DYL(M+1)
000350     000    F       G(41+N) =G(41+N) +CTWALL*DX(3)/DYL(M+1)
000351     000    F       G(61+N) =G(61+N) +CTWALL*DX(4)/DYC(M+1)
000352     000    F       G(81+N) =G(81+N) +CTWALL*DX(5)/DYL(M+1)*DUM
000353     000    F       IF (M.GT.1) GO TO 83
000354     000    F       G(101+N)=G(101+N)+CTWALL*DX(6)/DYL(M+3)
000355     000    F       G(111+N)=G(111+N)+CTWALL*DX(7)/DYL(M+3)
000356     000    F       IF (M.EQ.1) GO TO 83
000357     000    F       G(375+N)=G(375+N)+CTWALL*DX(6)/DYL(2)
000358     000    F       G(380+N)=G(380+N)+CTWALL*DX(7)/DYL(2)
000359     000    F    83 CONTINUE
000360     000    F    85 CONTINUE
000361     000    C                      HORIZONTAL (X)
000362     000    F       DO 100 M=0,4
000363     000    F       DO 100 J=1,6
000364     000    F       IF (M.GT.0) GO TO 95
000365     000    C                                 (TOP-BOTTOM WALLS)
000366     000    F       DO 90 L=1,5
000367     000    F       IF (J.GT.4) GO TO 88
000368     000    F       N=L-1+25*(J-1)
000369     000    F       G(121+N)=G(121+N)+CTWALL*DZ(L)/DXL(J)
000370     000    F       G(141+N)=G(141+N)+CTWALL*DZ(L)/DXL(J)
000371     000    F       GO TO 90
000372     000    F    88 N=L-1+15*(J-5)
000373     000    F       G(231+N)=G(231+N)+CTWALL*DZ(L)/DXL(J)
000374     000    F       N=L-1 + 5*(J-5)
000375     000    F       G(385+N)=G(385+N)+CTWALL*DZ(L)/DXL(J)
000376     000    F    90 CONTINUE
000377     000    C                                 (FRONT-BACK WALLS)
000378     000    F    95 IF (J.GT.4) GO TO 97
000379     000    F       N=5*M+25*(J-1)
000380     000    F       G(121+N)=G(121+N)+CTWALL*DY(M+1)/DXL(J)
000381     000    F       G(125+N)=G(125+N)+CTWALL*DY(M+1)/DXL(J)
000382     000    F       GO TO 100
000383     000    F    97 IF (M.GT.2) GO TO 100
000384     000    F       N=5*M+15*(J-5)
000385     000    F       DUM=1.
000386     000    F       G(221+N)=G(221+N)+DUM*CTWALL*DY(M+3)/DXL(J)
000387     000    F       G(225+N)=G(225+N)+DUM*CTWALL*DY(M+3)/DXL(J)
000388     000    F       IF (M.GT.0) GO TO 100
000389     000    F       N=5*(J-5)
000390     000    F       G(385+N)=G(385+N)+.5*CTWALL*DY(2)/DXL(J)
000391     000    F       G(389+N)=G(389+N)+.5*CTWALL*DY(2)/DXL(J)
000392     000    F   100 CONTINUE
000393     000    C                      AXIAL (Z)
000394     000    C                                 (LEFT-RIGHT WALLS)
000395     000    F       DO 110 M=0,4
000396     000    F       DUM=1.
000397     000    F       IF (M.EQ.1) DUM=.5
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000398     000   F      DO 110 L=1,4
000399     000   F      N=M+31*(L-1)
000400     000   F      G(251+N)=G(251+N)+CTWALL*DY(M+1)/DZL(L)
000401     000   F      IF (M.GT.1) GO TO 105
000402     000   F      G(271+N)=G(271+N)+DUM*CTWALL*DY(M+1)/DZL(L)
000403     000   F      IF (M.EQ.0) GO TO 110
000404     000   F      N=L-1
000405     000   F      G(399+N)=G(399+N)+DUM*CTWALL*DY(2)/DZL(L)
000406     000   F      GO TO 110
000407     000   F  105 N=M-2+31*(L-1)
000408     000   F      G(279+N)=G(279+N)+DUM*CTWALL*DY(M+1)/DZL(L)
000409     000   F  110 CONTINUE
000410     000   C                              (TOP-BOTTOM WALLS)
000411     000   F      DO 120 J=1,7
000412     000   F      DUM=1.
000413     000   F      IF (J.EQ.5) DUM=.5
000414     000   F      DO 120 L=1,4
000415     000   F      IF (J.GT.5) GO TO 115
000416     000   F      N=5*(J-1)+31*(L-1)
000417     000   F      G(251+N)=G(251+N)+DUM*CTWALL*DX(J)/DZL(L)
000418     000   F      G(255+N)=G(255+N)+    CTWALL*DX(J)/DZL(L)
000419     000   F      IF (J.LT.5) GO TO 120
000420     000   F      N=31*(L-1)
000421     000   F      G(272+N)=G(272+N)+DUM*CTWALL*DX(J)/DZL(L)
000422     000   F      GO TO 120
000423     000   F  115 N=3*(J-5)+31*(L-1)
000424     000   F      G(275+N)=G(275+N)+    CTWALL*DX(J)/DZL(L)
000425     000   F      N=L-1 + 4*(J-6)
000426     000   F      G(395+N)=G(395+N)+CTWALL*DX(J)/DZL(L)
000427     000   F  120 CONTINUE
000428     000   C
000429     000   C       ADD CONDUCTION THROUGH SPACER WALLS (PARALLEL)
000430     000   C
000431     000   F      CTWALL=XK(14)*XK(15)/12. + 2.*XK(11)*XK(10)/12.
000432     000   C                        VERTICAL WALLS
000433     000   C                              (VERTICAL - Y)
000434     000   F      DO 140 M=0,3
000435     000   F      DO 140 L=1,5
000436     000   F      N=5*M+L-1
000437     000   F      G(41+N)=G(41+N)+CTWALL*DZ(L)/DYL(M+1)
000438     000   F      IF (M.LT.1) GO TO 140
000439     000   F      G(81+N)=G(81+N)+CTWALL*DZ(L)/DYL(M+1)
000440     000   F  140 CONTINUE
000441     000   C                              (AXIAL - Z)
000442     000   F      DO 150 M=0,4
000443     000   F      DUM=1.
000444     000   F      IF (M.EQ.1) DUM=.5
000445     000   F      DO 150 L=1,4
000446     000   F      N=M+31*(L-1)
000447     000   F      G(261+N)=G(261+N)+CTWALL*DY(M+1)/DZL(L)
000448     000   F      IF (M.LT.1) GO TO 150
000449     000   F      G(271+N)=G(271+N)+DUM*CTWALL*DY(M+1)/DZL(L)
000450     000   F  150 CONTINUE
000451     000   C                        HORIZONTAL WALL
000452     000   F      DUM=.5
000453     000   F      DO 160 L=1,5
000454     000   F      N=L-1 *5
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000455    000   F        G(181+N)=G(181+N)+CTWALL*DZ(L)/DXL(3)
000456    000   F        G(206+N)=G(206+N)+CTWALL*DZ(L)/DXL(4)
000457    000   F        IF (L.EQ.5) GO TO 160
000458    000   F        N=31*(L-1) +1
000459    000   F        G(263+N)=G(263+N)+DUM*CTWALL*DX(3)/DZL(L)
000460    000   F        G(268+N)=G(268+N)+     CTWALL*DX(4)/DZL(L)
000461    000   F        G(273+N)=G(273+N)+DUM*CTWALL*DX(5)/DZL(L)
000462    000   F 160 CONTINUE
000463    000   C
000464    000   C           CONDUCTORS TO BOUNDARY WALLS
000465    000   C           (NEGLECTING CORNER-EDGE EFFECTS)
000466    000   C
000467    000   F        CDLINS=XK(7)/XK(2)*12.
000468    000   F        DO 162 N=0,164
000469    000   M 162 G(1001+N)=0.
000470    000   C                     FRONT ANGLE CONNECTING INNER/OUTER SHELLS
000471    000   F        CTL=8.3*.03/XK(2)
000472    000   F        CTL=CTL/8.
000473    000   F        DO 163 J=0,4
000474    000   F        DUM=1.
000475    000   F        IF (J.EQ.4) DUM=.5
000476    000   M        G(1001+25*J)=CTL*DX(J+1)*DUM
000477    000   M        G(1021+25*J)=CTL*DX(J+1)
000478    000   M 163 G(1001+5*J)=G(1001+5*J) + CTL*DY(J+1)
000479    000   F        DO 164 J=0,1
000480    000   M        G(1136+15*J)=CTL*DX(J+6)
000481    000   M        G(1156+5*J) =CTL*DX(J+6)
000482    000   M 164 G(1141+5*J) =CTL*DY(J+3)
000483    000   M        G(1101)=G(1101) + CTL*DY(1)
000484    000   M        G(1106) = CTL*.5* (DX(5)+DY(2))
000485    000   M        G(1161)=G(1161) + CTL*DY(2)*.5
000486    000   M        G(1151)=G(1151) + CTL*DY(5)
000487    000   C                          LEFT-RIGHT SIDES
000488    000   F        DO 170 M=0,4
000489    000   F        DUM=1.
000490    000   F        IF (M.EQ.1) DUM=.5
000491    000   F        DO 170 L=1,5
000492    000   F        N=5*M+L-1
000493    000   M        G(1001+N)=G(1001+N)+CDLINS*DY(M+1)*DZ(L)
000494    000   F        IF (M.GT.1) GO TO 165
000495    000   M        G(1101+N)=G(1101+N)+DUM*CDLINS*DY(M+1)*DZ(L)
000496    000   F        IF (M.EQ.1) GO TO 170
000497    000   M        G(1161+N)=G(1161+N)+DUM*CDLINS*DY(2)*DZ(L)
000498    000   F        GO TO 170
000499    000   F 165 N=5*(M-2)+L-1
000500    000   M        G(1141+N)=G(1141+N)+DUM*CDLINS*DY(M+1)*DZ(L)
000501    000   F 170 CONTINUE
000502    000   C                          TOP-BOTTOM SIDES
000503    000   F        DO 180 J=1,7
000504    000   F        DUM=1.
000505    000   F        IF (J.EQ.5) DUM=.5
000506    000   F        DO 180 L=1,5
000507    000   F        IF (J.GT.5) GO TO 175
000508    000   F        N=L-1+25*(J-1)
000509    000   M        G(1021+N)=G(1021+N)+CDLINS*DX(J)*DZ(L)
000510    000   M        G(1001+N)=G(1001+N)+CDLINS*DX(J)*DZ(L)*DUM
000511    000   F        IF (J.LT.5) GO TO 180
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000512     000   F        N=L-1
000513     000   M        G(1106+N)=G(1106+N)+DUM*CDLINS*DX(J)*DZ(L)
000514     000   F        GO TO 180
000515     000   F  175   N=L-1+15*(J-5).
000516     000   M        G(1121+N)=G(1121+N)+     CDLINS*DX(J)*DZ(L)
000517     000   F        N=L-1 + 5*(J-6)
000518     000   M        G(1156+N)=G(1156+N)+CDLINS*DX(J)*DZ(L)
000519     000   F  180   CONTINUE
000520     000   C                         FRONT-BACK SIDES
000521     000   F        DO 190 J=1,7
000522     000   F        ML=0
000523     000   F        IF (J.GT.5) ML=1
000524     000   F        DO 190 M=ML,4
000525     000   F        DUM=1.
000526     000   F        IF (J.GT.4 .AND. M.LT.2) DUM=.5
000527     000   F        IF (J.EQ.5 .AND. M.EQ.1) DUM=.75
000528     000   F        IF (J.GT.5) GO TO 185
000529     000   F        N=5*M+25*(J-1)
000530     000   M        G(1001+N)=G(1001+N)+DUM*CDLINS*DX(J)*DY(M+1)
000531     000   M        G(1005+N)=G(1005+N)+DUM*CDLINS*DX(J)*DY(M+1)
000532     000   F        GO TO 190
000533     000   F  185   IF (M.GT.1) GO TO 187
000534     000   F        N=5*(J-6)
000535     000   M        G(1156+N)=G(1156+N) + CDLINS*DX(J)*DY(2)*DUM
000536     000   M        G(1160+N)=G(1160+N) + CDLINS*DX(J)*DY(2)*DUM
000537     000   F        GO TO 190
000538     000   F  187   N=5*(M-2)+15*(J-6)
000539     000   M        G(1126+N)=G(1126+N)+DUM*CDLINS*DX(J)*DY(M+1)
000540     000   M        G(1130+N)=G(1130+N)+DUM*CDLINS*DX(J)*DY(M+1)
000541     000   F  190   CONTINUE
000542     000   C           (CORNER EDGES)
000543     000   C
000544     000   F        CTLINS=XK(7)* 2.*(XK(10)+XK(3)+.5*XK(2))/12. /(1.20.*XK(2)/12.)
000545     000   C                   HORIZONTAL - X
000546     000   F        DO 210 L=0,4,4
000547     000   M        G(1106+L)=G(1106+L)+CTLINS*DX(5)*.5
000548     000   F        DO 210 J=1,7
000549     000   F        DUM=1.
000550     000   F        IF (J.EQ.5) DUM=.5
000551     000   F        IF (J.GT.5) GO TO 205
000552     000   F        N=25*(J-1)+L
000553     000   M        G(1001+N)=G(1001+N)+DUM*CTLINS*DX(J)
000554     000   M        G(1021+N)=G(1021+N)+     CTLINS*DX(J)
000555     000   F        GO TO 210
000556     000   F  205   N=15*(J-5)+L
000557     000   M        G(1121+N)=G(1121+N)+     CTLINS*DX(J)
000558     000   F        N=5*(J-6) + L
000559     000   M        G(1156+N)=G(1156+N)+CTLINS*DX(J)
000560     000   F  210   CONTINUE
000561     000   C                   AXIAL - Z
000562     000   F        DO 220 L=0,4
000563     000   M        G(1001+L)=G(1001+L)+     CTLINS*DZ(L+1)
000564     000   M        G(1021+L)=G(1021+L)+     CTLINS*DZ(L+1)
000565     000   M        G(1101+L)=G(1101+L)+     CTLINS*DZ(L+1)
000566     000   M        G(1161+L)=G(1161+L)+     CTLINS*DZ(L+1)
000567     000   M  220   G(1151+L)=G(1151+L)+     CTLINS*DZ(L+1)
000568     000   C                   VERTICAL - Y
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000569        000   F        DO 230 M=0,4
000570        000   F        DUM=1.
000571        000   F        IF (M.EQ.1) DUM=.5
000572        000   F        DO 230 L=0,4,4
000573        000   F        N=5*M+L
000574        000   M        G(1001+N)=G(1001+N)+CTLINS*DY(M+1)
000575        000   F        IF (M.GT.1) GO TO 225
000576        000   M        G(1101+N)=G(1101+N)+DUM*CTLINS*DY(M+1)
000577        000   F        IF (M.LT.1) GO TO 230
000578        000   M        G(1161+L)=G(1161+L)+DUM*CTLINS*DY(2)
000579        000   F        GO TO 230
000580        000   F 225 N=5*(M-2)+L
000581        000   M        G(1141+N)=G(1141+N)+DUM*CTLINS*DY(M+1)
000582        000   F 230 CONTINUE
000583        001   C                       ATTACH POINTS AT BACK (INNER-TO-OUTER SHELL)
000584        001   F        POINT=7.8*.03/XK(2)/12.
000585        000   M        G(1005) = G(1005) + POINT
000586        000   M        G(1025) = G(1025) + POINT
000587        000   M        G(1080) = G(1080) + POINT
000588        000   M        G(1100) = G(1100) + POINT
000589        000   M        G(1165) = G(1165) + POINT
000590        000   M        G(1155) = G(1155) + POINT
000591        000   C
000592        000   C          INPUT COOLANT FLOW CONDUCTORS
000593        000   C
000594        000   F        IF (NCASE.EQ.2) GO TO 260
000595        000   F        DUM=XK(21)*XK(22)
000596        000   F        IF (NCASE.GT.1) DUM=DUM/DUMST
000597        000   F        DUMST=XK(21)*XK(22)
000598        000   F        DO 250 N=0,88
000599        000   M 250 G(2109+N) = G(2109+N) * DUM
000600        000   F 260 CONTINUE
000601        000   C
000602        000   C          COMPUTE NODAL THERMAL CAPACITANCE
000603        000   C
000604        000   C                       FOOD
000605        000   C
000606        000   F        DO 420 J=1,7
000607        000   F        ML=0
000608        000   F        IF (J.GT.5) ML=1
000609        000   F        DO 420 M=ML,4
000610        000   F        DUM=1.
000611        000   F        IF (J.GT.4 .AND. M.LT.2) DUM=.5
000612        000   F        IF (J.EQ.5 .AND. M.EQ.1) DUM=.75
000613        000   F        DO 420 L=1,5
000614        000   F        CAP=XK(20)*XK(19) * DX(J)*DY(M+1)*DZ(L)*DUM
000615        000   F        IF (J.GT.5) GO TO 405
000616        000   F        N=5*M + 25*(J-1) + L-1
000617        000   F        C(1+N)=CAP
000618        000   F        GO TO 420
000619        000   F 405 IF (M.GT.1) GO TO 410
000620        000   F        N=L-1 + 5*(J-6)
000621        000   F        C(156+N)=CAP
000622        000   F        GO TO 420
000623        000   F 410 N=5*(M-2) + 15*(J-6) + L-1
000624        000   F        C(126+N)=CAP
000625        000   F 420 CONTINUE
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000626      000   C                      OUTER WALLS/PACKING/INSULATION
000627      000   C
000628      000   F       RCPT=XK(6)*XK(5)*XK(3)/12. + XK(13)*XK(12)*XK(10)/12.
000629      000   F      *  +XK(9)*XK(8)*XK(2)/12.
000630      000   C                                       (LEFT-RIGHT SIDES)
000631      000   F       DO 440 M=0,4
000632      000   F       DUM=1.
000633      000   F       IF (M.EQ.1) DUM=.5
000634      000   F       DO 440 L=1,5
000635      000   F       CAP=RCPT*DY(M+1)*DZ(L)
000636      000   F       N=5*M + L-1
000637      000   F       C(1+N)=C(1+N)+CAP
000638      000   F       IF (M.GT.1) GO TO 430
000639      000   F       C(101+N)=C(101+N)+CAP*DUM
000640      000   F       IF (M.LT.1) GO TO 440
000641      000   F       N=L-1
000642      000   F       C(161+N)=CAP*DUM
000643      000   F       GO TO 440
000644      000   F 430   N=5*(M-2) + L-1
000645      000   F       C(141+N)=C(141+N)+CAP*DUM
000646      000   F 440   CONTINUE
000647      000   C                                       (TOP-BOTTOM SIDES
000648      000   F       DO 460 J=1,7
000649      000   F       DUM=1.
000650      000   F       IF (J.EQ.5) DUM=.5
000651      000   F       DO 460 L=1,5
000652      000   F       CAP=RCPT*DX(J)*DZ(L)
000653      000   F       IF (J.GT.5) GO TO 450
000654      000   F       N=25*(J-1) + L-1
000655      000   F       C(21+N)=C(21+N)+CAP
000656      000   F       C(1+N) =C(1+N) +CAP*DUM
000657      000   F       IF (J.LT.5) GO TO 460
000658      000   F       N=L-1
000659      000   F       C(106+N)=C(106+N)+CAP*DUM
000660      000   F       GO TO 460
000661      000   F 450   N=15*(J-5) + L-1
000662      000   F       C(121+N)=C(121+N)+CAP
000663      000   F       N=L-1 + 5*(J-6)
000664      000   F       C(156+N)=C(156+N)+CAP*DUM
000665      000   F 460   CONTINUE
000666      000   C                                       (FRONT-BACK SIDES)
000667      000   F       DO 480 J=1,7
000668      000   F       ML=0
000669      000   F       IF (J.GT.5) ML=1
000670      000   F       DO 480 M=ML,4
000671      000   F       DUM=1.
000672      000   F       IF (J.GT.4 .AND. M.LT.2) DUM=.5
000673      000   F       IF (J.EQ.5 .AND. M.EQ.1) DUM=.75
000674      000   F       CAP=RCPT*DX(J)*DY(M+1)
000675      000   F       IF (J.GT.5) GO TO 467
000676      000   F       N=5*M + 25*(J-1)
000677      000   F       C(1+N)=C(1+N)+CAP*DUM
000678      000   F       C(5+N)=C(5+N)+CAP*DUM
000679      000   F       GO TO 480
000680      000   F 467   IF (M.GT.1) GO TO 470
000681      000   F       N=5*(J-6)
000682      000   F       C(156+N)=C(156+N) + CAP*DUM
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000    F        C(160+N)=C(160+N) + CAP*DUM
000    F        GO TO 480
000    F  470 N=5*(M-2) + 15*(J-6)
000    F        C(126+N)=C(126+N)+CAP*DUM
000    F        C(130+N)=C(130+N)+CAP*DUM
000    F  480 CONTINUE
000    C                          SPACER WALLS/PACKING
000    C
000    F        RCPT=XK(17)*XK(16)*XK(15)/12. + 2.*XK(13)*XK(12)*XK,10)/12.
000    C                                    (VERTICAL)
000    F        DO 500 M=0,4
000    F        DUM=1.
000    F        IF (M.EQ.1) DUM=.5
000    F        DO 500 L=1,5
000    F        N=5*M + L-1
000    F        C(51+N)=C(51+N)+RCPT*DY(M+1)*DZ(L)
000    F        IF (M.LT.1) GO TO 500
000    F        C(101+N)=C(101+N)+RCPT*DY(M+1)*DZ(L)*DUM
000    F  500 CONTINUE
000    C                                    (HORIZONTAL)
000    F        DO 510 J=3,5
000    F        DUM=.5
000    F        IF (J.EQ.4) DUM=1.
000    F        DO 510 L=1,5
000    F        N=25*(J-3) + L-1 +5
000    F  510 C(61+N)=C(61+N)+RCPT*DX(J)*DZ(L)*DUM
000    C                          CORNER-EDGES - PACKING/WALL/INSULATION
000    C
000    F        RCPA=(XK(13)*XK(12)*XK(10)*XK(10) + XK(6)*XK(5)*XK(3)*(2.*XK(10)+
000    F       * XK(3)) + XK(9)*XK(8)*((XK(2)+XK(10))**2-XK(10)**2)) /144.
000    C                                    (HORIZONTAL - X)
000    F        DO 520 J=1,7
000    F        DUM=1.
000    F        IF (J.EQ.5) DUM=.5
000    F        DO 520 L=0,4,4
000    F        IF (J.GT.5) GO TO 515
000    F        N=25*(J-1) + L
000    F        C(21+N)=C(21+N)+RCPA*DX(J)
000    F        C(1+N) =C(1+N)+RCPA*DX(J)*DUM
000    F        IF (J.LT.5) GO TO 520
000    F        C(106+L)=C(106+L)+RCPA*DX(J)*DUM
000    F        GO TO 520
000    F  515 N=15*(J-5) + L
000    F        C(121+N)=C(121+N)+RCPA*DX(J)
000    F        N=5*(J-6) + L
000    F        C(156+N)=C(156+N)+RCPA*DX(J)
000    F  520 CONTINUE
000    C                                    (VERTICAL - Y)
000    F        DO 540 M=0,4
000    F        DUM=1.
000    F        IF (M.EQ.1) DUM=.5
000    F        DO 540 L=0,4,4
000    F        N=5*M + L
000    F        C(1+N)=C(1+N)+RCPA*DY(M+1)
000    F        IF (M.GT.1) GO TO 530
000    F        C(101+N)=C(101+N)+RCPA*DY(M+1)*DUM
000    F        IF (M.LT.1) GO TO 540
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000740     000   F       C(161+L)=C(161+L)+RCPA*DY(2)*DUM
000741     000   F       GO TO 540
000742     000   F  530  N=5*(M-2) + L
000743     000   F       C(141+N)=C(141+N)+RCPA*DY(M+1)*DUM
000744     000   F  540  CONTINUE
000745     000   C                              (AXIAL - Z)
000746     000   F       DO 550 L=0,4
000747     000   F       CAP=RCPA*DZ(L+1)
000748     000   F       C(1+L)=C(1+L)+CAP
000749     000   F       C(21+L)=C(21+L)+CAP
000750     000   F       C(101+L)=C(101+L)+CAP
000751     000   F       C(161+L)=C(161+L)+CAP
000752     000   F  550  C(151+L)=C(151+L)+CAP
000753     000   C
000754     000   F       C(104) = C(104) * .8/XK(19)
000755     000   F       C(161)= C(161)*1.66/XK(19)
000756     000   F       C(162)= C(162)*1.66/XK(19)
000757     000   F       C(164)= C(164)*1.66/XK(19)
000758     000   C
000759     000   F       IF (NCASE.EQ.1) CALL PCTDMP
000760     000   C
000761     000   F       K(1)=0
000762     000   F       K(23)=9
000763     000   H       T(200)=-10.
000764     000   F       NPTS=0
000765     000   F       TPLOT=.02
000766     000   F       CALL CINDSL
000767     000   F       LOOPCT=0
000768     000   F       K(1)=NCASE
000769     000   F       TIMEO=0.
000770     000   F       TIMEND=16.
000771     000   F       OUTFUT=3.5
000772     000   F       XKS=.33
000773     000   F       QLAT=309.6
000774     000   F       NSAMP=-99
000775     000   F       OPEN=-1.
000776     000   F       CALL CNFRDL
000777     000   F       XK(24)=99999.
000778     000   F       XK(25)=99999.<- F  IF (NCASE.LT.2) GO TO 15
000779     000   F  999  CONTINUE
000780     000   F       CALL GPRINT
000781     000            END
000782     000            BCD 3VARIABLES 1
000783     000   F       COMMON /FREZR/ DX(7),DY(5),DZ(5), DXL(6),DYL(4),DZL(9),QCOOL
000784     000   F      *,NSAMP,QLAT,XKS,OPEN
000785     000   F       DATA NPR,NLINE/ 16, 7/
000786     000   F       N=LOOPCT/NPR
000787     000   F       IF (N*NPR .NE.LOOPCT) GO TO 999
000788     000   F       NLINE=NLINE+1
000789     000   F       IF (NLINE.LT.23) GO TO 40
000790     000   F       NLINE=0
000791     000   F       WRITE (6,800)
000792     000   F  800  FORMAT (        / '   L    TIME     DRLXCC          DTMPCC           QCOOL
000793     000   F      *     QWALL    T(H/X)      TCOUT      T(36)     T(88)      T(89)       T(
000794     000   F      *90)         QREM'/)
000795     000   F   40  CONTINUE
000796     000   M       QREM = G(2109) * (T(104)-T(200))
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000       F        QWALL=0.
000       F        DO 55 N=0,99
000       M   55 QWALL=QWALL + G(1001+N) * (T(500)-T(1+N))
000       F        DO 60 L=0,44
000       M   60 QWALL = QWALL + G(1111+L) * (T(500)-T(111+L))
000       F        DO 65 L=0,4
000       M        QWALL = QWALL + G(1101+L) * (T(502)-T(101+L))
000       M   65 QWALL = QWALL + G(1161+L) * (T(502)-T(161+L))
000       F        DO 68 L=0,4,4
000       M        QWALL = QWALL + G(1106+L) * (T(502)-T(106+L))
000       M   68 QWALL = QWALL + G(1156+L) * (T(502)-T(156+L))
000       F        DO 70 L=1,3
000       M        QWALL = QWALL + G(1106+L) * (T(501)-T(106+L))
000       M   70 QWALL = QWALL + G(1156+L) * (T(501)-T(156+L))
000       M        WRITE (6,100) LOOPCT,TIMEO,DRLXCC,DTHPCC,QCOOL,QWALL,T(200),T(104)
000       F       *, T(36),T(68),T(89),T(90),QREM
000       F  100 FORMAT ( 1X, I4, F9.4, 2(1X,G12.5), 9F10.3)
000       F  999 CONTINUE
000              END
000             -BCD 3VARIABLES 2
000       F        COMMON /FREZR/ DX(7),DY(5),DZ(5), DXL(6),DYL(4),DZL(4),QCOOL
000       F       *,NSAMP,CLAT,XKS,OPEN
000       F        COMMON /UPLOTX/ NPTS,TPLOT,X2(300),Y2(300),Y3(300),Y4(300),Y5(300)
000       F       *, Y6(300),Y7(300)
000       F        DIMENSION TITLX(12),TITLY(12)
000       F        LOOPCT=LOOPCT+1
000       M        QCOOL= G(2109) * (T(104)-T(200))
000       F        IF (K(1).EQ.0) GO TO 300
000       F        LPLOT=-8
000       C
000       C                          HOT MEDICAL SAMPLE INSERTION
000       C
000       F        IF (TIMEO .LT. XK(24)) GO TO 80
000       F        DATA NM,NXP,NXL,NYP,NYL,NZP,NZL/
000       F       * 89,239,184,74,69,361,330/
000       F        DATA TFR/ 30./
000       F        IF (NSAMP.GT.0) GO TO 60
000       F        NSAMP=99
000       F        GXP=G(NXP)
000       F        GXL=G(NXL)
000       F        GYP=G(NYP)
000       F        GYL=G(NYL)
000       F        GZP=G(NZP)
000       F        GZL=G(NZL)
000       F        T(NM)=80.
000       F   50 C(NM)=2.15
000       F   55 CONTINUE
000       F        DUM=2./ (1.+XK(18)/XKS)
000       F        G(NXP)=GXP*DUM
000       F        G(NXL)=GXL*DUM
000       F        G(NYP)=GYP*DUM
000       F        G(NYL)=GYL*DUM
000       F        G(NZP)=GZP*DUM
000       F        G(NZL)=GZL*DUM
000       F        G(NZP)=.8533
000       F        IF (NSAMP.LT.150) G(NZP)=.22
001       F        DUM=6.0
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000854     001    F        DUM2=DUM*.05
000855     000    F        G(NXP) = G(NXP) * DUM2
000856     000    F        G(NXL) = G(NXL) * DUM2
000857     000    F        G(NYP) = G(NYP) * DUM2
000858     000    F        G(NYL) = G(NYL) * DUM2
000859     000    F        G(NZP) = G(NZP) * DUM
000860     000    F        G(NZL) = G(NZL) * DUM2
000861     000    F        LPLOT=8
000862     000    F    60  CONTINUE
000863     000    F        IF (T(NM) .GT. TFR) GO TO 80
000864     000    F        IF (NSAMP.GT.150) GO TO 70
000865     000    F        NSAMP=300
000866     000    F        XKS=1.76
000867     000    F        C(NM)=2.15*.73
000868     000    F        GO TO 55
000869     000    F    70  CONTINUE
000870     000    F        QOUT=C(NM) * (TFR-T(NM))
000871     000    F        QLAT=QLAT-QOUT
000872     000    F        T(NM)=TFR
000873     000    F        IF (QLAT.GT. 0.) GO TO 80
000874     000    F        C(NM)=2.15*.46
000875     000    F        T(NM)=TFR+QLAT/C(NM)
000876     000    F        LPLOT=6
000877     000    F        XK(24)=99999.
000878     000    F    80  CONTINUE
000879     000    C
000880     000    C                        INCLUDE DOOR OPENING EFFECT
000881     000    C
000882     000    F        IF (TIMEO .LT. XK(25)) GO TO 100
000883     000    M        CALL STPIAS( TIMEO-XK(25), A(3), DUM)
000884     000    F        DUM2=DUM*OPEN
000885     000    F        OPEN=DUM
000886     000    F        IF (ABS(DUM) .GT. 50.) XK(25)=99999.
000887     000    F        IF (DUM2 .GT. 0.) GO TO 100
000888     000    F        QDOOR=.075*.5* (.24*90. + .011*1220.)
000889     000    F        DUM=QDOOR/ (C(6) +C(11)+ C(16) +C(31) +C(36) +C(41))
000890     000    F        DO 90 N=6,16,5
000891     000    F        T(N)= T(N) +DUM
000892     000    F    90  T(N+25) =T(N+25) +DUM
000893     000    F        LPLOT=8
000894     000    F   100  CONTINUE
000895     000    C
000896     000    C                        COOLING UNIT THERMOSTAT CONTROL
000897     000    C
000898     000    F        DATA TON,TOFF,CWATTS,PWATTS/ -7., -10.5, 75., 5./
000899     000    F        TCNTRL=T(104)
000900     000    F        IF (K(23).LT.0 .AND. TCNTRL.LT. TON) GO TO 210
000901     000    F        IF (K(23).GT.0 .AND. TCNTRL.GT.TOFF) GO TO 220
000902     000    F        LPLOT=8
000903     000    F        IF (K(23) .LT. 0) GO TO 220
000904     000    M   210  T(200)=T(104) + PWATTS*3.412/G(2109)
000905     000    F        K(23)=-9
000906     000    F        GO TO 240
000907     000    M   220  T(200)=T(104) - (CWATTS-PWATTS)*3.412/G(2109)
000908     000    F        K(23)=9
000909     000    F   240  CONTINUE
000910     000    C
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000   C                        STORE PLOT DATA  AND  MAKE PLOTS
000   C
000   F       DATA TITLX/ 72H      TIME ... HOURS
000   F      .                                    /
000   F       DATA TITLY/ 72H           TEMPERATURES
000   F      .                                    /
000   F       IF (LPLOT.LT.0) GO TO 310
000   F       X2(NPTS+1)=TIMEO
000   F       TPLOT=TIMEO+.03
000   F       GO TO 311
000   F 300   IF (LOOPCT.LT.5) GO TO 999
000   F 308   IF (NPTS.GE.2) GO TO 999
000   F       Y2(1)=-2.
000   F       X2(2)=0.
000   F       GO TO 312
000   F 310   IF (TIMEN.LT.TPLOT) GO TO 340
000   F       X2(NPTS+1)=TIMEO
000   F       TPLOT=TPLOT+.1
000   F 311   IF (TPLOT.GT.TIMEND-.001 ) TPLOT=TIMEND-.001
000   F 312   NPTS=NPTS+1
000   F       TMAX=T(36)
000   F       TMIN=T(109)
000   F       DO 320 N=1,165
000   F       Y=T(N)
000   F       IF (Y.LT.TMIN) TMIN=Y
000   F 320   IF (Y.GT.TMAX.AND. N.NE.NM) TMAX=Y
000   F       Y2(NPTS)=TMAX+30.
000   F       Y3(NPTS)=TMIN+30.
000   F       Y4(NPTS)=T(104)
000   M       Y5(NPTS)=T(200)
000   F       Y6(NPTS)=T(NM)
000   F       Y7(NPTS)=QCOOL/3.412
000   F       IF (K(1).EQ.0) GO TO 308
000   F       IF (TIMEN.LT.TIMEND-.001) .AND. NPTS.LT.299) GO TO 340
000   F       TPLOT=99999.
000   F       WRITE (6,325)
000   F 325   FORMAT (1H1, 'PLOTS CREATED'// 6X,'X', 10X,'Y2', 10X,'Y3',
000   F      . 10X,'Y4', 10X,'Y5', 10X,'Y6', 10X,'Y7'//)
000   F       WRITE(6,327) (X2(N),Y2(N),Y3(N),Y4(N),Y5(N),Y6(N),Y7(N),N=1,NPTS)
000   F 327   FORMAT (1X, F10.4, 6F11.4)
000   F       CALL QUIKML(-1,-2.,TIMEO,-20., 40., 1H ,TITLX,TITLY,NPTS,X2,Y2)
000   F       CALL QUIKML( 0,-2.,TIMEO,-20., 40., 1H ,TITLX,TITLY,NPTS,X2,Y3)
000   F       CALL QUIKML( 0,-2.,TIMEO,-20., 40., 1H ,TITLX,TITLY,NPTS,X2,Y4)
000   F       CALL QUIKML( 0,-2.,TIMEO,-20., 40., 1H ,TITLX,TITLY,NPTS,X2,Y5)
000   F       CALL QUIKML(-1, -2.,TIMEO,-20., 100.,1H ,TITLX,TITLY,NPTS,X2,Y6)
000   F       CALL QUIKML( 0, -2.,TIMEO,-20., 100.,1H ,TITLX,TITLY,NPTS,X2,Y7)
000   F       IF (K(1).EQ.1) REWIND 2
000   F       WRITE TAPE 2,NPTS
000   F       WRITE TAPE 2,(X2(N),N=1,NPTS)
000   F       WRITE TAPE 2,(Y2(N),N=1,NPTS)
000   F       WRITE TAPE 2,(Y3(N),N=1,NPTS)
000   F       WRITE TAPE 2,(Y4(N),N=1,NPTS)
000   F       WRITE TAPE 2,(Y5(N),N=1,NPTS)
000   F       WRITE TAPE 2,(Y6(N),N=1,NPTS)
000   F       WRITE TAPE 2,(Y7(N),N=1,NPTS)
000   F 340   CONTINUE
000   F 999   CONTINUE
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000            END
000            BCD 3OUTPUT CALLS
000    F      COMMON /FREZR/ DX(7),DY(5),DZ(5), DXL(6),DYL(4),DZL(4),QCOOL
000    F     *,NSAMP,QLAT,XKS,OPEN
000    F      WRITE (6,10)
000    F   10 FORMAT (1H1)
000    F      CALL STNDRD
000    F      CTOT=0.
000    F      TAVG=0.
000    F      TMAX=T(36)
000    F      TMIN=T(109)
000    F      DO 13 N=1,165
000    F      Y=T(N)
000    F      IF (Y.GT.TMAX) TMAX=Y
000    F      IF (Y.LT.TMIN) TMIN=Y
000    F      CTOT=CTOT+C(N)
000    F   13 TAVG=TAVG+C(N)*Y
000    F      TAVG=TAVG/CTOT
000    F      WRITE (6,15) TMIN,TMAX,TAVG
000    F   15 FORMAT (// 20X, 'TMIN=',F8.3,8X, 'TMAX=',F8.3,8X, 'TAVG=',F8.3)
000    F      DO 40 L=0,4
000    F      DUM=DZL(1)*12.
000    F      DUM2=DZL(2)*12. + DUM
000    F      IF (L.EQ. 0) WRITE (6,41)
000    F      IF (L.EQ. 1) WRITE (6,42) DUM
000    F      IF (L.EQ. 2) WRITE (6,43) DUM2
000    F      DUM=DZL(3)*12. + DUM2
000    F      DUM2=DUM + DZL(4)*12.
000    F      IF (L.EQ.3) WRITE (6,44) DUM
000    F      IF (L.EQ.4) WRITE (6,45) DUM2
000    F      M=0
000    F   20 N2=21+L-M
000    F      N3=N2+100
000    F      N4=136+L-M
000    F      N5=151+L-M
000    F      IF (M.GT.12) N4=156+L
000    F      IF (M.GT.12) N5=161+L
000    F      WRITE (6,25) (T(N),N=N2,N3,25), T(N4), T(N5)
000    F   25 FORMAT (10X, 8F10.4)
000    F      M=M+5
000    F      IF (M.LT.17) GO TO 20
000    F      N2=1+L
000    F      N3=N2+100
000    F      WRITE (6,25) (T(N),N=N2,N3,25)
000    F   40 CONTINUE
000    F   41 FORMAT(//28X, 'FRONT WALL'/)
000    F   42 FORMAT(//28X, 'SECOND SLICE (', F6.3, ' INCHES BACK)'/)
000    F   43 FORMAT(//28X, 'THIRD SLICE (', F6.3, ' INCHES BACK)'/)
000    F   44 FORMAT(//28X, 'FOURTH SLICE (', F6.3, ' INCHES BACK)'/)
000    F   45 FORMAT(//28X, 'BACK WALL (', F6.3, ' INCHES BACK)'/)
000    F      WRITE (6,10)
000            END
000            BCD 3END OF DATA

END ELT.
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