NASA CR-134375

FINAL REPORT
SPACE SHUTTLE/ FOOD SYSTEM STUDY
VOLUME II

APPENDIX A
ACTIVE HEATING SYSTEM - SCREENING ANALYSIS

APPENDIX B
RECONSTITUTED FOOD HEATING TECHNIQUES ANALYSIS

prepared for

NATIONAL AERONAUTICS and SPACE ADMINISTRATION
Johnson Spacecraft Center
Houston, Texas 77058

Contract NAS9-13138

Prepared by

Pillsbury

THE PILLSBURY CO.

(NASA-CR-134375) SPACE SHUTTLE/FOOD SYSTEM STUDY. VOLUME 2, APPENDIX A: ACTIVE HEATING SYSTEM-SCREENING ANALYSIS. APPENDIX B: RECONSTITUTED (Pillsbury Mills, Inc.) ~~170~~ p HC ~~$11.50~~ CSCL 06H G3/05

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FINAL REPORT
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1.0 INTRODUCTION

The active heating system approach is based on the use of an external heating method other than hot water to maintain the food temperature within the palatable range. After reconstitution, no attempt is made to insulate the food packages. The food is positioned in a heating device (such as an oven or Skylab type tray) and the temperature is elevated to the required degree for serving. The meal is then assembled and distributed to the crew.

Various techniques to accomplish active heating are available and must be considered for Shuttle use. The screening analysis evaluated these methods and resulted in the selection of a hot air oven, electrically heated food tray and microwave oven, for further consideration and analysis.

2.0 APPROACH

The approach used to develop technical data for the active system of applying additional heat by means of an external device, such as an oven, was as follows:

- Review engineering data generated in previous food system study for potential applicability to Shuttle study.
- Generate a list of options of techniques to be assessed for preliminary screening for Shuttle use.
- Apply a selection rationale that quantitatively evaluates the options and results in final selection of candidates for detail application.

2.0 Cont'd

- Perform calculations for the selected candidates in terms of Shuttle vehicle impact penalties of weight, volume and power.

3.0 Technical Analysis

3.1 General

A summary of the various equipment heating techniques is shown in Table 1. Each of the techniques are described and a Shuttle feasibility decision indicated. The rationale for the decision is also given in a brief explanation. Where Shuttle feasibility is indicated as limited, the screening process resulted in a marginal analysis due to either a significant advantage or disadvantage outweighing the balance of items. The resistance oven by itself is inefficient in zero gravity and produces high temperatures with potential burn hazards. However, if combined with a hot air convection oven, a more efficient combination is produced than either by itself. Similarly, the self heating food packages are desirable from a systems viewpoint but are costly in development and per flight use. With development, however, they may become acceptable.

TABLE 1. SHUTTLE FEASIBILITY EQUIPMENT HEATING TECHNIQUES

Technique	Description	Shuttle Feasibility			Rationale
		Yes	No	Limited	
Hot Air Convection Oven	Heating by impingement of hot air on food. Air circulated by fan or blower in insulated compartment.	X			Heating effectiveness is independent of gravity. Utilizes on board power. Proven concept requiring minimum development for 0-g use.
Microwave Oven	Heating by directing microwave energy to an insulated food cavity.	X			Immediate warmup and cooking time. No emission of heat from oven surfaces. Minimum development required. Utilizes on board power.
Resistance Oven	Heating by radiation from electrically heated elements within a closed chamber.			X	No convection coefficients hence radiation is in all directions with loss of efficiency. Packaging interface with plastic could be problem. High temperatures may create burn hazard.
Dielectric Heating	Heating by rapid molecular agitation as a high frequency potential applied to electrode plates of a special container.		X		Temperature control difficult. Dielectric constant varies with food type, requiring power converter that is complex and bulky.
Wrap-on Heating Jacket	Heating by an external jacket containing flexible resistance elements wrapped around food container.		X		Jacket contact with container critical to heating efficiency. Type of packaging therefore limited to rigid containers rather than soft, flexible packages.

TABLE 1. SHUTTLE FEASIBILITY EQUIPMENT HEATING TECHNIQUES

Technique	Description	Shuttle Feasibility			Rationale
		Yes	No	Limited	
Self Heating Food Package	An electrical resistance circuit is made by slotting a sheet of aluminum foil so that remaining foil forms a continuous electrical path. When integrated into a package, electrical power applied to create uniform heat.			X	Compatible with all container sizes and shapes. Very light, low volume and low power concept. Applicable to individual packaging. Major development required.
Induction Heating	The food container is placed within a wound helical conduction coil which develops a multidirectional magnetic field when AC applied to coil. Heating occurs without contact.		X		Concept requires auxiliary power converter, metallic containers and produces large weight and power penalties. Cold spots can occur in larger food containers requiring food stirring.
Conduction Heating Oven	The oven consists of separate compartments independently lined with resistance heating elements to permit contact of package so as to establish conductive coupling.		X		The compartments provide a large mass that is heated concurrently with the food. Volume penalties inherent in design. Packaging limited due to size and material compatibility.
Probe-Type Resistance Heating	A resistance heated probe is inserted directly into food mass and heating is by conduction between solid and liquid. Penetration is through package.		X		Excess package ullage required to prevent spillage on probe insertion. Volume penalties result throughout system. Constant cleansing required of probe. Time factor may be excessive.

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 1. SHUTTLE FEASIBILITY EQUIPMENT HEATING TECHNIQUES

Technique	Description	Shuttle Feasibility			Rationale
		Yes	No	Limited	
Pressure Cooker Heating	Heating by boiling/condensing within a pressure cooker (pressurized chamber)		X		Zero gravity boiling problems severe, possibly requiring centrifugally created gravity field. Safety, operability and crew acceptance low. Packaging must prevent water penetration and food seepage.
Flash Steam Heating	200°F water is introduced into a low pressure food chamber where it flashes into a vapor phase. Heating occurs when high velocity stream impinges on food packages.		X		Steam chamber requires venting to space or pumping to maintain internal pressure. Water must be provided to the power source circuit. Design requires large weight, development and operability penalties.
Solar Energy Exposure	Food heating accomplished by direct exposure to solar energy collected and concentrated into high intensity ray.		X		Requires extensive development. Potential safety problem and low crew acceptability.
Electrically Heated Food Tray	Heating of food cans is accomplished in food trays with suitable cavities that are heated by resistance elements lining the cavity and provide zero gravity retention.	X			Current Skylab concept that will be flight qualified prior to Shuttle usage. Penalties involve time to heat and weight and complexity of each tray.

3.2 Selection Rationale Process

The selection of the equipment heating candidates for Shuttle use was based on the preliminary screening performed by the selection rationale process. A description of this process follows:

A quantitative rationale was established in order to document the selection for further study of various concepts. The rationale considers the following parameters, all or part of which affect the stated concepts to some extent:

- On-Orbit Performance

  1) Gravitational Effect -- This parameter is employed to consider the gravitational effect on a particular concept for a range of operability between zero-g to one-g.

  2) Safety -- A measure of the condition (of the particular item or concept) of being safe from causing hurt, injury, loss, or inactivity. The rating ranges from excellent, to good, fair, and poor or hazardous.

  3) Operability -- This parameter pertains to the product of two factors related to the reliability maintainability of the particular concept. Reliability is scaled from a low to high ranking, and maintainability is assumed to range from complex to simple maintenance task requirements.

4) <u>System Compatibility</u> -- This parameter pertains to the product of three prime systems considerations; namely, the weight, volume, and power requirements for each concept under consideration. The effect of weight is considered over that of volume since the launch weight of the Shuttle is considered to govern, rather than the volumetric constraints. Since power requirements are more closely related to weight than are volume requirements, this sub-parameter of the system compatibility factor has been assumed of greater importance than volume.

- <u>Ground Operations</u>

5) <u>Serviceability</u> -- This parameter considers the turnaround times or ground servicing required by a particular concept and relates to ease of servicing, cleaning, and checking out an item during normal turnaround procedures. The ratings range from minimal time, to low, normal or lengthy.

- <u>Crew Interface</u>

6) <u>Crew Acceptability</u> -- This is a measure of the anticipated crew acceptability for a concept; the rating ranges from excellent, to good, fair, poor, and not acceptable. As applicable, crew acceptability criteria is considered for such elements as: sensory input (sight, smell, etc.); familiarity; task complexity, meniality, or boredom; aesthetics; and confidence.

7) Crew Time -- A measure of crew time requirements for a particular concept, ranging from maximum to minimum. The scale ranges from minimal time requirements through low, medium, and high usage of crew time to accomplish a functional task.

- Cost

8) Development Risk -- This parameter considers the status of a particular concept and ranges from what is available or current state-of-the-art, to various magnitudes of effort required to fully develop the concept for space shuttle usage.

9) Operating Cost -- This measures an estimate of per launch cost by rating number of expendables required or spares to support the particular concept in flight, and ranges from minimal through expensive.

In order to normalize the nine parameters, the following multipliers (or effective weights) have been established. The list, for example, shows that "System Compatibility" is considered to have twice the impact on selection as "Crew Time".

Parameter	Multiplier
1) Gravitational Effect	1
2) Safety	2
3) Operability	3
4) System Compatibility	4
5) Serviceability	3

3.2 Cont'd

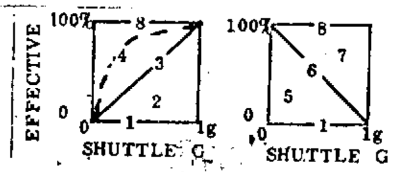
	Parameter	Multiplier
6)	Crew Acceptability	2
7)	Crew Time	2
8)	Development Risk	3
9)	Operating Cost	3

Graphs, presenting the particular criteria for each parameter, have been produced to establish a set of factors which are employed in the concept selection process. The factors for each parameter range, in general, from zero to a value of eight. For the parameters in which products are used (Operability and System Compatibility), the use of more readily scaled numbers produces maximum values in excess of eight. The summation of the product of all factors and their appropriate multipliers gives an overall sum, which when divided by the number of parameters utilized in the process, yields the "final selection factor". This factor is then compared to a preselected value; a final selection factor below this value means that the concept is discarded, a factor equal to or above the selected value implies that the concept has been selected for further study.

The format for the concept selection rationale is shown in the attached figure. It is to be noted that three basic types of graphs are employed: their use is clarified in the following paragraphs, taking an example of each type:

3.2 Cont'd

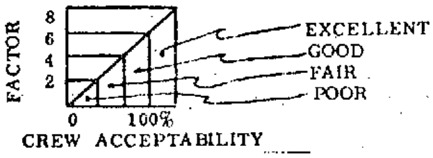
GRAVITATIONAL FACTOR



Example: Consider the effectiveness of a resistance type oven under the effects of gravity

From an examination of the charts at point g =), it is determined that the left hand graph is applicable since for zero gravity there would be no convection coefficients, hence radiation is in all directions with loss of effectiveness. Then mentally construct the shape of a curve (see dotted line) which best represents the anticipated effectivity of the concept as g-forces increase. Since the curve falls within area (4), a factor of 4 is recorded in the appropriate column of the chart.

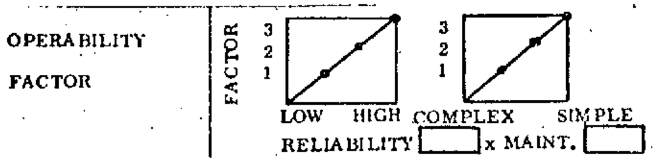
CREW ACCEPTABILITY FACTOR



Example: Consider crew acceptability of a resistance type oven

3.2 Cont'd

The graph shows a linear relationship between crew acceptability and rating factor, and gives the investigator a choice of two ways to obtain the factor. In the first case, if one anticipates that 3 out of 6 crewmembers (50%) could find the concept acceptable (as opposed to unacceptable), then a factor of 4 is obtained. The more standard way would be to consider how the average crewmember would view the concept, a ranking of "poor" would at its highest range also yield a factor of 4. The poor rating for this concept is based on the high temperatures encountered in a resistance type oven which has radiated this heat to all surfaces.



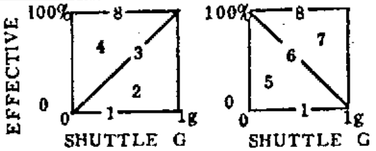
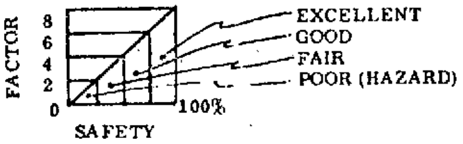
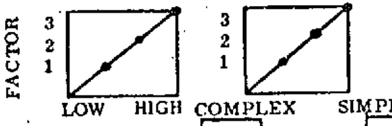
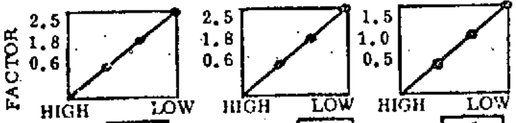
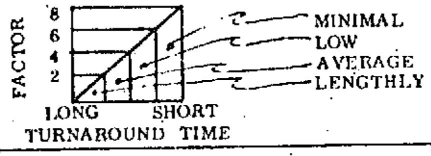
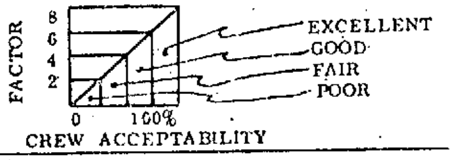
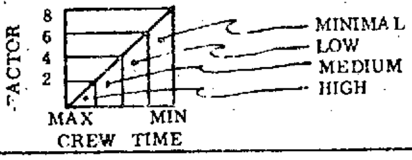
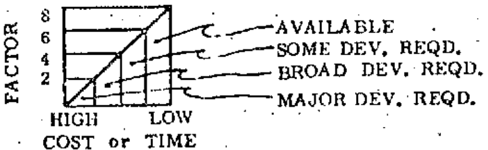
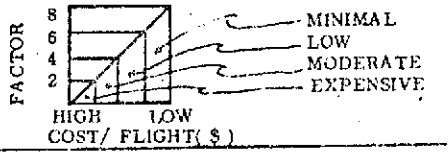
This graph shows a linear relationship between reliability and the rating factor. Since this and other graphs of this type are employed where the product of two or more chart factors are taken, discrete points are established between (in this case) low and high ratings, in order to simplify the procedure. A low rating gives a factor of either 0 or 1; a high rating 2 or 3; and an intermediate reliability rating of either 1 or 2.

The actual selections and ratings are given in the following sheets for the six candidate techniques. A summary of the selection rationale factors is shown in Table 2.

TABLE 2. SUMMARY EQUIPMENT HEATING TECHNIQUES SELECTION RATIONALE FACTORS

Rationale Parameters	Hot Air Convection	Microwave Oven	Resistance Oven	Wrap-On Heating Jacket	Self-Heating Food Package	Electrically Heated Food Tray
Gravitational Factor	8	8	2	8	7	4
Safety Factor	5	5	4	4	4	4
Operability Factor	7	6	6	4	6	6
System Compatibility Factor	5	2	5	4	6	4
Serviceability Factor	6	6	5	4	4	6
Crew Acceptability Factor	6	5	4	4	4	4
Crew Time Factor	6	7	5	2	3	4
Development Risk Factors	6	6	5	4	3	8
Operating Cost Factor	5	4	3	3	3	4

CONCEPT:
Hot Air
Convection
Oven

		SELECTION RATIONALE Select appropriate curve representation, then use corresponding factor. Chart use: If chart is used, put 1 in this column; if not used, put in 0.	MULTIPLIER	FACTOR	MULT x FACTOR	CHART USE
ON- ORBIT PERFORMANCE	1. GRAVITATIONAL FACTOR	 ○ FACTOR	1	8	8	1
	2. SAFETY FACTOR		2	5	10	1
	3. OPERABILITY FACTOR	 RELIABILITY ☐ x MAINT. ☐	3	7	21	1
	4. SYSTEM COMPATIBILITY FACTOR	 WT. 2.2 xPOWER 2.2 xVOL 1	4	5	20	1
GROUND OPERATION	5. SERVICEABILITY FACTOR		3	6	18	1
CREW INTERFACE	6. CREW ACCEPTABILITY FACTOR		2	6	12	1
	7. CREW TIME FACTOR		2	6	12	1
COST	8. DEVELOPMENT RISK FACTOR		3	6	18	1
	9. OPERATING COST FACTOR		3	5	15	1
					134	9

STUDY SELECTION

DISCARD ≤ 12 ☐

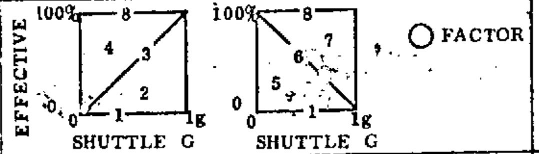
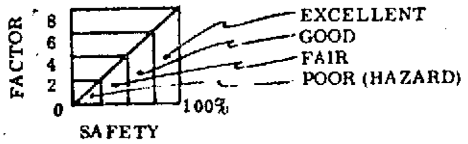
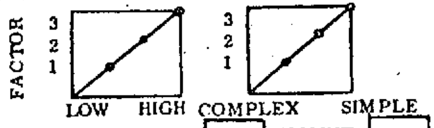
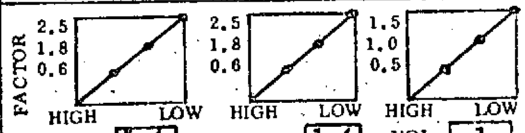
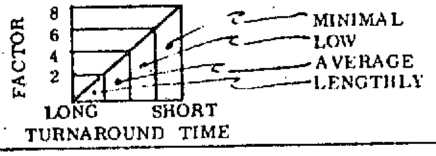
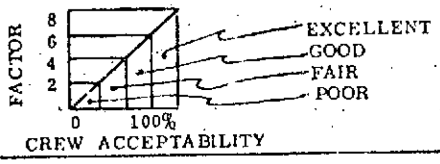
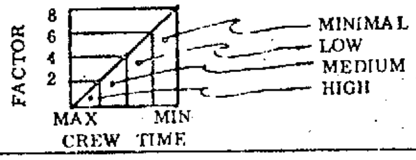
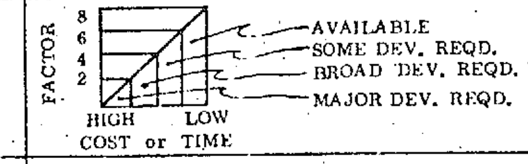
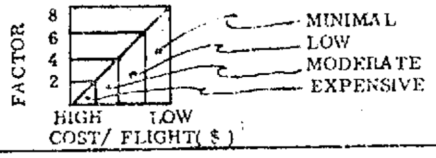
STUDY >12 ☑

$\frac{134}{9} = 14.9$

CONCEPT:
Microwave Oven

SELECTION RATIONALE

Select appropriate curve representation, then use corresponding factor.
Chart use: If chart is used, put 1 in this column; if not used, put in 0.

			MULTIPLIER	FACTOR	MULT x FACTOR	CHART USE
ON-ORBIT PERFORMANCE	1. GRAVITATIONAL FACTOR		1	8	8	1
	2. SAFETY FACTOR		2	5	10	1
	3. OPERABILITY FACTOR	 RELIABILITY ☐ x MAINT. ☐	1 3	6	18	1
	4. SYSTEM COMPATIBILITY FACTOR	 WT. 1.4 xPOWER 1.4 xVOL 1	4	2	8	1
GROUND OPERATION	5. SERVICEABILITY FACTOR		3	6	18	1
CREW INTERFACE	6. CREW ACCEPTABILITY FACTOR		2	5	10	1
	7. CREW TIME FACTOR		2	7	14	1
COST	8. DEVELOPMENT RISK FACTOR		3	6	18	1
	9. OPERATING COST FACTOR		3	4	12	1
					116	9

STUDY SELECTION

DISCARD ≤ 12 ☐

STUDY >12 ☑

$\frac{116}{9} = 12.9$

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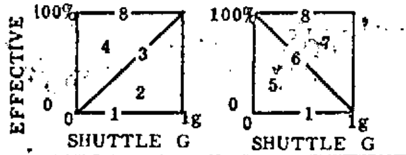
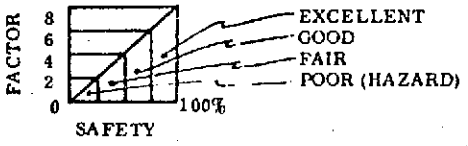
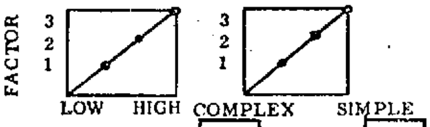
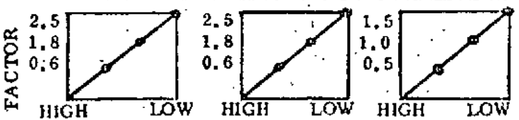
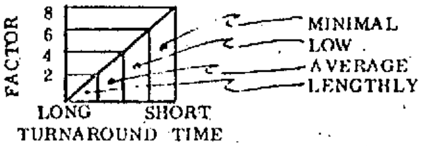
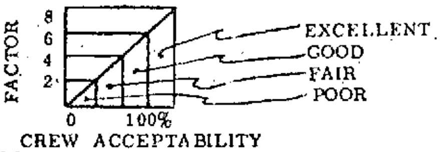
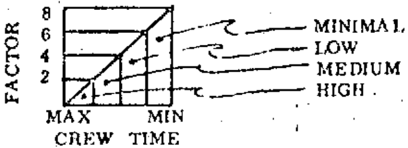
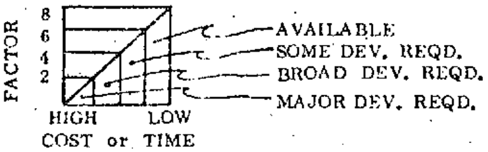
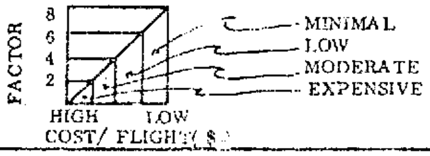
CONCEPT: Resistance Oven		SELECTION RATIONALE Select appropriate curve representation, then use corresponding factor. Chart use: If chart is used, put 1 in this column; if not used, put in 0.	MULTIPLIER	FACTOR	MULT x FACTOR	CHART USE
ON- ORBIT PERFORMANCE	1. GRAVITATIONAL FACTOR	 ○ FACTOR	1	2	2	1
	2. SAFETY FACTOR		2	4	8	1
	3. OPERABILITY FACTOR	 RELIABILITY ☐ x MAINT. ☐	3	6	18	1
	4. SYSTEM COMPATIBILITY FACTOR	 WT. 2.2 xPOWER 2.2 xVOL 1	4	5	20	1
GROUND OPERATION	5. SERVICEABILITY FACTOR		3	5	15	1
CREW INTERFACE	6. CREW ACCEPTABILITY FACTOR		2	4	8	1
	7. CREW TIME FACTOR		2	5	10	1
COST	8. DEVELOPMENT RISK FACTOR		3	5	15	1
	9. OPERATING COST FACTOR		3	3	9	1
					105	9

STUDY SELECTION

DISCARD ≤ 12 ☑

STUDY > 12 ☐

105/9 = 11.7

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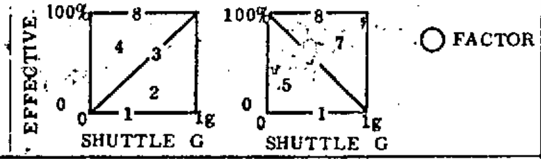
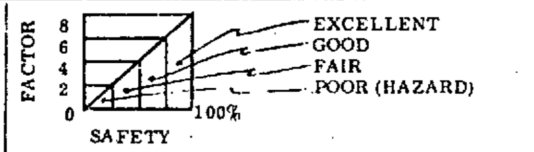
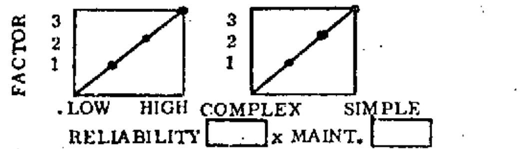
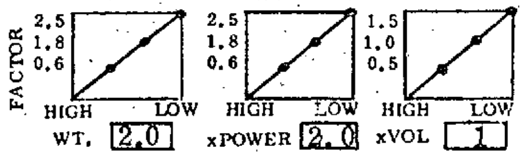
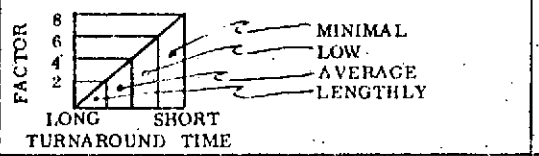
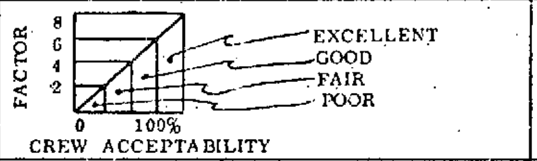
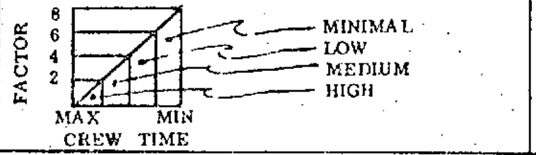
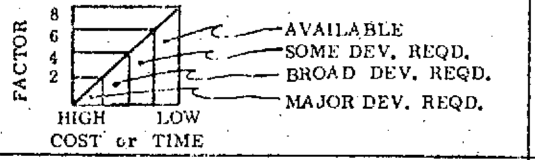
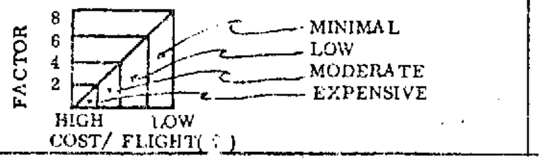
CONCEPT:
Wrap-On Heating Jacket

SELECTION RATIONALE

Select appropriate curve representation, then use corresponding factor.
Chart use: If chart is used, put 1 in this column; if not used, put in 0.

		SELECTION RATIONALE	MULTIPLIER	FACTOR	MULT x FACTOR	CHART USE
ON- ORBIT PERFORMANCE	1. GRAVITATIONAL FACTOR		1	8	8	1
	2. SAFETY FACTOR		2	4	8	1
	3. OPERABILITY FACTOR		3	4	12	1
	4. SYSTEM COMPATIBILITY FACTOR		4	4	16	1
GROUND OPERATION	5. SERVICEABILITY FACTOR		3	4	12	1
CREW INTERFACE	6. CREW ACCEPTABILITY FACTOR		2	4	8	1
	7. CREW TIME FACTOR		2	2	4	1
COST	8. DEVELOPMENT RISK FACTOR		3	4	12	1
	9. OPERATING COST FACTOR		3	3	9	1
					89	9

STUDY SELECTION

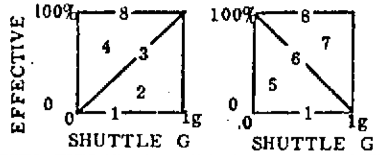
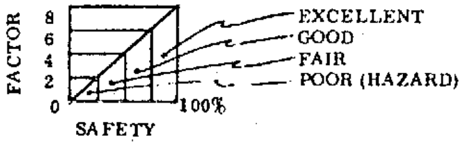
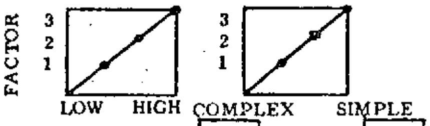
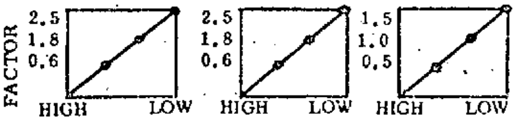
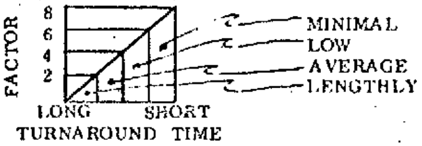
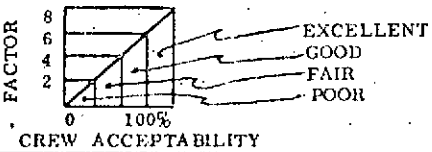
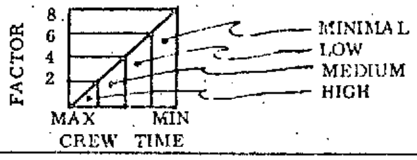
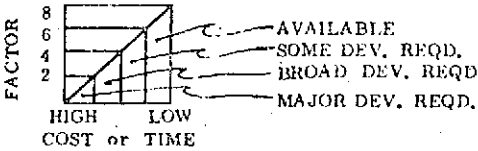
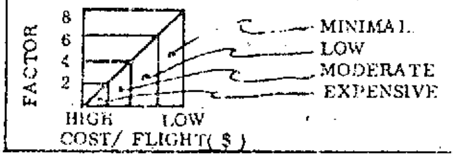
DISCARD ≤ 12 ☑ STUDY >12 ☐

$$\frac{89}{9} = 9.9$$

CONCEPT: Self-Heating Food Package

SELECTION RATIONALE

Select appropriate curve representation, then use corresponding factor.
Chart use: If chart is used, put 1 in this column; if not used, put in 0.

			MULTIPLIER	FACTOR	MULT x FACTOR	CHART USE
ON- ORBIT PERFORMANCE	1. GRAVITATIONAL FACTOR	 ○ FACTOR	1	7	7	1
	2. SAFETY FACTOR		2	4	8	1
	3. OPERABILITY FACTOR	 RELIABILITY ☐ x MAINT. ☐	3	6	18	1
	4. SYSTEM COMPATIBILITY FACTOR	 WT. 2.4 xPOWER 2.2 xVOL 1.2	4	6	24	1
GROUND OPERATION	5. SERVICEABILITY FACTOR		3	4	12	1
CREW INTERFACE	6. CREW ACCEPTABILITY FACTOR		2	4	8	1
	7. CREW TIME FACTOR		2	3	6	1
COST	8. DEVELOPMENT RISK FACTOR		3	3	9	1
	9. OPERATING COST FACTOR		3	3	9	1
					101	9

STUDY SELECTION

DISCARD ≤ 12 ☑

STUDY >12 ☐

$\frac{101}{9} = 11.2$

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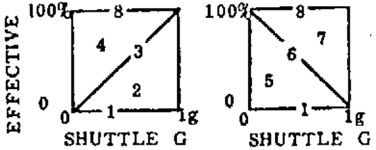
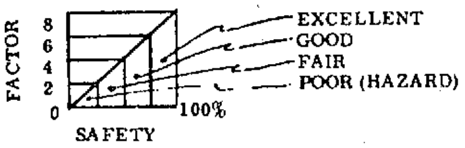
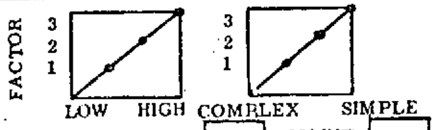
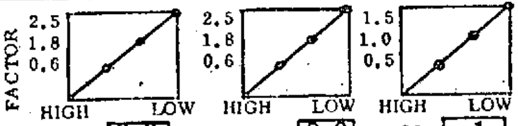
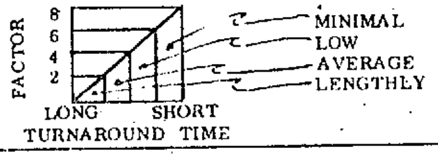
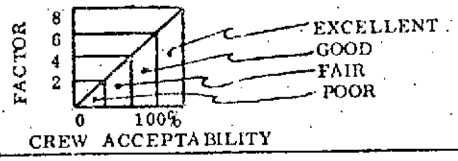
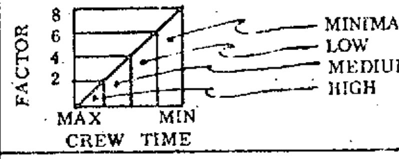
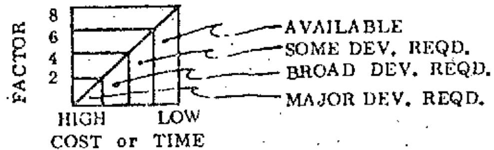
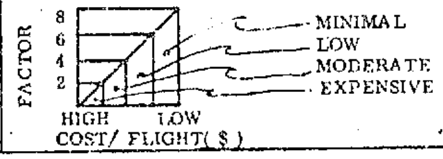
CONCEPT:
Electrically Heated Food Tray

SELECTION RATIONALE

Select appropriate curve representation, then use corresponding factor.
Chart use: If chart is used, put 1 in this column; if not used, put in 0.

			MULTIPLIER	FACTOR	MULT x FACTOR	CHART USE
ON- ORBIT PERFORMANCE	1. GRAVITATIONAL FACTOR	 ○ FACTOR	1	4	4	1
	2. SAFETY FACTOR		2	4	8	1
	3. OPERABILITY FACTOR	 RELIABILITY ☐ x MAINT. ☐	3	6	18	1
	4. SYSTEM COMPATIBILITY FACTOR	 WT. 2.0 xPOWER 2.0 xVOL 1	4	4	16	1
GROUND OPERATION	5. SERVICEABILITY FACTOR		3	6	18	1
CREW INTERFACE	6. CREW ACCEPTABILITY FACTOR		2	4	8	1
	7. CREW TIME FACTOR		2	4	8	1
COST	8. DEVELOPMENT RISK FACTOR		3	8	24	1
	9. OPERATING COST FACTOR		3	4	12	1
					116	9

STUDY SELECTION

DISCARD ≤ 12 ☐

STUDY >12 ☑

$\frac{116}{9} = 12.9$

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FINAL REPORT
SPACE SHUTTLE/FOOD SYSTEM STUDY
VOLUME II

APPENDIX B
RECONSTITUTED FOOD HEATING TECHNIQUES ANALYSIS

prepared for

NATIONAL AERONAUTICS and SPACE ADMINISTRATION
Johnson Spacecraft Center
Houston, Texas 77058

Contract NAS9-13138

Prepared by

THE PILLSBURY CO.

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ILLUSTRATIONS

ILLUSTRATIONS Cont'd

ILLUSTRATIONS Cont'd

1.0 INTRODUCTION

This study is concerned with the relative merits and penalties associated with various approaches to the heating of rehydrated food during a mission of the Space Shuttle. The techniques investigated are indicated in the accompanying "study approach", Figure 1. The three techniques represent an increasing order of potential complexity and cost, ranging from a passive storage system where food would be held at palatable temperatures, to a completely active system where additional heat is required to achieve necessary temperatures. Each of the techniques were studied to assess feasibility in terms of vehicle impact penalties.

In the studies presented the following assumptions are implicit in the analyses:

1) The mission is of seven day duration with a six man crew.
2) The design meal consists of an entree, two side dishes, soup, and a dessert. The entree and side dishes are contained in 401 cans and the soup in a 211 can. These dishes, after rehydration, are to be served in a temperature range of 135 - 145°F.
3) Forced convection heat transfer is obtained between the cabin air and the food heating and storage gear with an average effective coefficient of $h=1.45$ BTU/hr-ft^2-°F.
4) Total time for food preparation, eating and clean-up should preferably not exceed one hour.

1.0 Cont'd

5) The system penalties include considerations of weight, heat loss to cabin (calculated as 0.133 lbs per average $\frac{BTU}{hr}$ over a 24-hour period) and electrical energy consumed (1.514 lbs per Kw hr).

6) Water available for rehydration in temperature range 35 - 190°F.

7) Supplementary information pertaining to food data are shown in Table 1.

8) Heating calculations based on 401 and 211 cans being filled with an equivalent weight of water.

The food preparation approaches treated in this report are:

Passive:	a)	Insulated Jacket System
	b)	Insulated Tray System
Semi-Active	a)	Storage Oven
Active:	a)	Hot Air Convective Oven
	b)	Microwave Oven
	c)	Individually Heated Serving Trays
	d)	Chemical Heating System
	e)	Hot Water Source

A summary matrix of the study results is presented in Table 2, and cost estimates for each of the considered systems are shown in Table 3.

TECHNIQUE	OBJECTIVE	APPROACH
Passive	Maintain reconstituted food temperature at 135°-145°F using hot water with no external or added energy	Use insulated storage cavity and best stacking arrangement
Semi-Active	Create equivalent hot environment for reconstituted food	Use storage cavity that is maintained at 135°-145°F • Electric blanket • Hot water jacket
Active	Add heat as required to elevate reconstituted food temperatures to 135°-145°F	• Oven (forced hot air convection; microwave) • Heated tray (Skylab) • Chemical (Exothermal Reaction)

Figure 1. Study Approach

TABLE 1. CURRENT DATA AND ASSUMPTIONS

Temperature range to begin a meal	135 - 145°F	
Water content of foods	Entree's	75%
	Side dishes	80%
	Beverages	90 - 95%
Large main meal for purpose of heating analysis	Entree	6 oz
	Side dishes	15 oz
	Beverages	8 oz
	Dessert	3 oz
	Soup	4 oz
Specific heat	$1.00\left(\frac{\text{Btu/lb}}{\text{ft}}\right)$ reconstituted	
	0.50 dry	
Thermal conductivity	$0.28\left(\frac{\text{Btu/lb ft}^2\ {}^\circ\text{F}}{\text{ft}}\right)$ thawed food	
	0.75 frozen	
Rate of temperature decay	Kneading	2.7 °F/minutes
	Still air	1.2 °F/minutes
	Insulated	0.34°F/minute

Initial food temperature as function of water temperature

Entree	3:1 ratio (75% water)	$T_m = 0.86\ T_W + 10$	
Side dish	4:1 ratio (80% water)	$T_m = 0.89\ T_W + 8$	Assumed storage at 70°F
	$2\frac{1}{2}$:1 ratio (71% water)	$T_m = 0.83\ T_W + 12$	
Beverage	19:1 ratio (95% water)	$T_m = 0.97\ T_W + 6$	
Soup	(85% water)	$T_m = 0.92\ T_W + 6$	

Volume 401 x 105 can 17.01 in.^{3} = 9.43 fl oz

Volume 211 x 105 can 7.45 in.^{3} = 4.13 fl oz

Volume water .976 fl oz/oz at 145°F

Rehydration times	Entree	20 minutes
	Vegetables	15 minutes
	Soup	10 minutes
	Beverage	0 minute

TABLE 2. SUMMARY MATRIX - FOOD HEATING SYSTEM ANALYSIS

Technique	Option	Weight (lbs)	Power (Kw)	Electrical Energy Kw-hr	Heat to Cabin Btu/hr Aver. for 24 hrs	Volume (ft^3)	*Combined System Penalty Equivalent (lbs)
Passive	Insulated Jacket $\dot{W}$ = 60 lb/hr One man prep. Prep. time 54.1 min	10.93	.248	.375	6.37	1.85	12.36
	Insulated Jacket $\dot{W}$ = 60 lb/hr Two man prep. Prep. time 34.0 min	10.57	.248	.375	6.37	1.54	12.0
	Insulated Tray $\dot{W}$ = 60 lb/hr One man prep. Prep. time 55.2 min	9.13	.256	.388	6.55	1.19	10.6
	Insulated Tray $\dot{W}$ - 60 lb/hr Two man prep. Prep. time 35.0 min	9.20	.252	.380	6.41	1.08	10.6
Semi-Active	Oven $\dot{W}$ = 30 One man prep. Prep. time 50.6 min	11.66	.259	.426	21.1	1.92	15.2
	Oven $\dot{W}$ = 60 One man prep. Prep. time 40.4 min	11.53	.246	.405	20.3	1.86	14.9
	Oven $\dot{W}$ = 30 Two man prep. Prep. time 27.9 min	11.98	.246	.402	19.1	1.84	15.1
	Oven $\dot{W}$ = 60 Two man prep. Prep. time 24.9 min	11.98	.246	.402	19.1	1.84	15.1
Active	Hot Air Convective Oven	14.3	1.63	11	60	1.0	35.29
	Microwave	82.5	3.6	18.9	220	3.0	140.5
	Heated Trays*** (6 trays)	14.4 with covers 11.0 w/o covers	1.57	12.1	83	1.0 with covers 0.71 w/o covers	43.0 with covers 39.9 w/o covers
	** Hot 150°F Water 170°F Source 190°F	.516 .545 .577	.236 .277 .318	.348 .408 .468	6.44 7.42 8.23	.103 .119 .136	1.90 2.15 2.38

* 0.133 lbs per average Btu/hr heat loss to cabin over 24 hour period
1.514 lbs per Kw-hr

** Penalties included in passive and semi-passive systems

*** Performance based on contact efficiency of food and heating source. This may be a high risk system.

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TABLE 3. COST ESTIMATE

	Hours			R&D Cost			Production Cost
	Design Engineering	Test Engineering	Dev/Qual Manufacturing	Engineering (@ $25/hr)	Manufacturing (@ $20/hr)	Other (Mat, Test)	Per Unit (5 Systems)
Insulated Jacket (Incl. serving tray + hot water tank)	2400	960	1280	84K	25.6K	18K	5K
Insulated Tray (Incl. hot water tank)	1920	640	720	64K	14.4K	10K	3K
Semi-Active Oven (Incl. serving tray + hot water tank	3480	1440	2080	123K	41.6K	25K	8K
Hot Air Oven (Incl. serving tray)	5040	1680	2280	168K	45.6K	30K	15K
Microwave Oven (Incl. serving tray)	4320	2160	3000	162K	60K	40K	18K
Electric Heat Tray (See Note)	960	480	640	36K	12.8K	5K	5K

NOTE: Estimate based on adapting existing Skylab tray to Shuttle requirements for menu sizing, type of food packages, decreased weight and volume study, and electrical simplification. Qualification by similarity.

2.0 DISCUSSION

2.1 Passive Systems

Two passive systems were studied: the insulated jacket system and the insulated tray system, both of which require a source of hot water to heat as well as reconstitute dry food. The insulated jacket system utilizes cylindrical, covered jackets to prevent excessive cooling of dishes during preparation, and requires trays insulated only sufficiently to prevent food from cooling below 105°F by the end of the 20 minute dining period. The insulated tray system utilizes covered trays insulated sufficiently to prevent excessive cooling during meal preparation as well as to prevent food from cooling below 105°F during the dining period.

Touch temperature of surfaces was not considered as a criteria in the analysis of these systems. However, the results in the analysis sections wherever surface temperature are calculated tend to show that these will be less than 105°F. Other assumptions made in the analyses are as follows:

1) Heat transfer to the cabin from FMS surfaces and food was calculated on the basis of natural convection at sea level. The values of h_B and h_C used in the analyses were extracted from cooling tests conducted at The Pillsbury Company. The value of h_B was obtained from Figure 3 of WADC TR55-254, "Engineering Study of Air Conditioning Load Requirements of Aircraft Compartments." The heat transfer coefficient, h_r, is that due to radiation, and is a function of source and sink temperature.

2.1 Cont'd

2) Cabin temperature, t_f, was 75°F.

3) Thermal contact resistance between can and contents, between can and insulated jacket, or between can and tray was not accounted for. The results, therefore, are somewhat conservative.

4) The time lines developed in the analyses were governed by the water requirements given by The Pillsbury Company in Table 1 for the various dishes and the following time increments for preparation steps:

0.25 min. to open a can and unpack the water valve,
0.50 min. to knead the contents of a can,
0.25 min. to replace the contents of a can and repack the water valve.

5) Rehydration times for the various dishes were the values given in Table 1.

6) Only the temperature of the entree was followed in the analyses since this dish will have the lowest temperature at reconstitution and is, therefore, the most critical.

2.1.1 Insulated Jacket System

Three cases were studied for the insulated jacket system:

1) Meals Served Individually -- All hot dishes for a meal are prepared and stored one by one in a jacket until rehydration is completed. At this point, the dishes are placed in a tray and the meal served. Then preparation of the next meal is begun. The sequence continues in this manner until all six meals have been served.

2.1.1 Cont'd

2) Meals Served in Groups of Three -- All hot dishes for a meal are prepared and stored one by one in a jacket. At this point, the preparation and storage of dishes for the next meal are begun. When the third meal is fully rehydrated, all dishes are placed in trays and the meals served. The same sequence is followed for the next group of three meals.

3) Meals Served in a Group of Six -- The same sequence of preparation and storage of individual meals described in the previous case is followed. When the sixth meal is fully rehydrated, all dishes are placed in trays and the meals served.

Table 4 shows that only the last case, with a heated water flow rate of 60 lb/hr, can provide a total preparation time under one hour. Total preparation time is defined as the time elapsed to the point when the last meal is fully rehydrated. To this time must be added dining and clean-up times to determine total elapsed time.

2.1.2 Insulated Tray Analysis

Three cases were studied for the insulated tray system:

1) Meals Served Individually -- All cans for a meal are first placed in a tray, and all preparation steps (except kneading) take place with the cans in an uncovered tray. When all preparation steps are completed, the tray is covered until rehydration is completed, and then served. At this point, preparation of the next meal is begun. The sequence continues in this manner until all six meals have been served.

TABLE 4. MEAL PREPARATION TIME SUMMARY

(1) Meals stored in insulated jacket and served individually:

$\dot{W}$	Total Preparation Time (minutes)
7	156.5
15	128.2
30	124.9
60	123.2

(2) Meals stored in insulated jacket - prepared and served in groups of three:

$\dot{W}$	Total Preparation Time (minutes)
7	131.0
15	90.2
30	75.3
60	67.9

(3) Meals stored in insulated jacket - prepared and served in groups of six:

$\dot{W}$	Total Preparation Time (minutes)
7	124.7
15	80.7
30	63.0
60	54.1

2.1.2 Cont'd

2) Meals Served in Groups of Three -- All cans for a meal are first placed in a tray, and all preparation steps (except kneading) take place with the cans in an uncovered tray. When all preparation steps are completed, the tray is covered and set aside. At this point, preparation of the next meal is begun. When the preparation steps are completed, the tray is covered and stacked on the previous tray. The sequence continues in this manner, and when the third meal is fully rehydrated, all three meals are served. The same sequence is followed for the next group of three meals.

3) Meals served in a Group of Six -- The same sequence described in the previous case is followed. When the sixth meal is fully rehydrated, all six meals are served.

Table 5 shows that only the last case, with a heated water flow rate of 60lb/hr, can provide a total preparation time under one hour. Total preparation time is defined as the time elapsed to the point when the last meal is fully rehydrated. Dining and cleanup times must be added for total elapsed time.

2.1.3 Alternate Preparation Analysis

In order to assess an optimum preparation technique and establish a total meal timeline, the most efficient preparation cycle was analyzed for one-man preparation (Figure 2) and then 2-man preparation (Figure 3) for both 6-man and 4-man crews. The preparation technique entails reconstitution of the entrees first, followed by the 2 side dishes, soup and beverage. Assuming serving times, dining, and clean-up times, total meal cycles were generated. The thermal analysis indicates the feasibility of the passive system within the estimated times established.

An additional analysis was made utilizing an individual preparation cycle where complete meals were reconstituted in predetermined sequences. Whereas all other techniques enable crewmen to dine simultaneously, the individual method shown in Figure 4, is based on three overlapping shifts. The total time, however, is competitive with the other techniques.

A summary of these data is shown in Table 6.

TABLE 5. MEAL PREPARATION TIME SUMMARY

(1) Meals prepared in insulated trays and served individually:

$\dot{W}$	Total Preparation Time (minutes)
7	150.5
15	134.2
30	131.2
60	129.2

(2) Meals prepared in insulated trays and served in groups of three:

$\dot{W}$	Total Preparation Time (minutes)
7	129.0
15	92.2
30	77.4
60	70.0

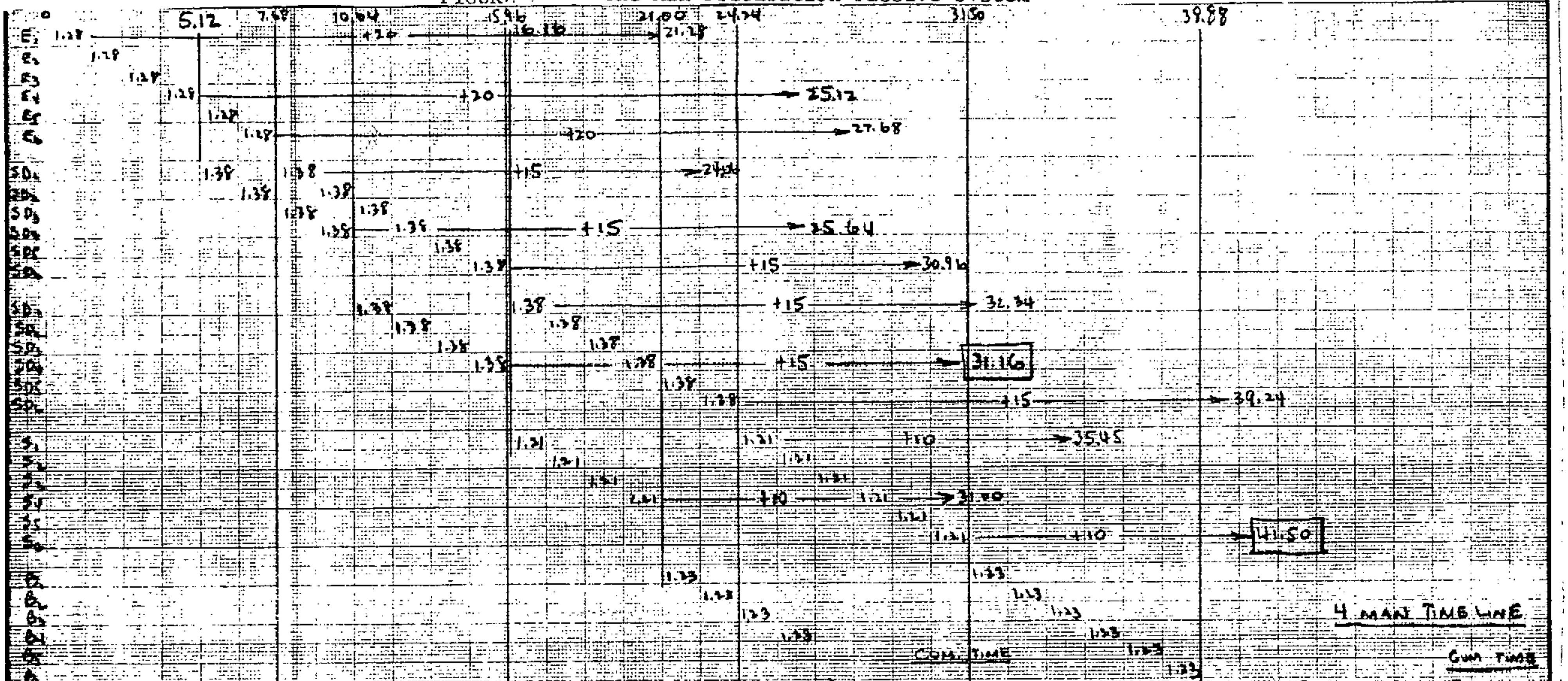
(3) Meals prepared in insulated trays and served in groups of six:

$\dot{W}$	Total Preparation Time (minutes)
7	123.7
15	81.7
30	64.0
60	55.2

TABLE 6. SUMMARY-ALTERNATE PREPARATION TECHNIQUES

Method	Preparation Time (Minutes)	Total Time (Minutes)
1-Man Preparation	41.50	88
2-Man Preparation	27.12	66
Individual Preparation	-	80

FIGURE 2 - One Man Preparation Passive System



COM. TIME

1. PREPARE, RECONSTITUTE, REHYDRATE (IN TRAYS) — 41.50 MIN
2. SERVE 6 TRAYS (.50 MIN EA) 3.00 MIN — 44.50 MIN
3. DINE 20.00 MIN — 64.50 MIN
4. CLEAN-UP & RESTOW EQUIP. 15.00 MIN — 79.50 MIN

CONTINGENCY 10% - 8M 87.50 MIN

ASSUME - 88 MIN/6 MEN

4 MAN TIME LINE

CUM TIME

- 31.16 M

(4 TRAYS) 2.00 MIN - 33.16 M

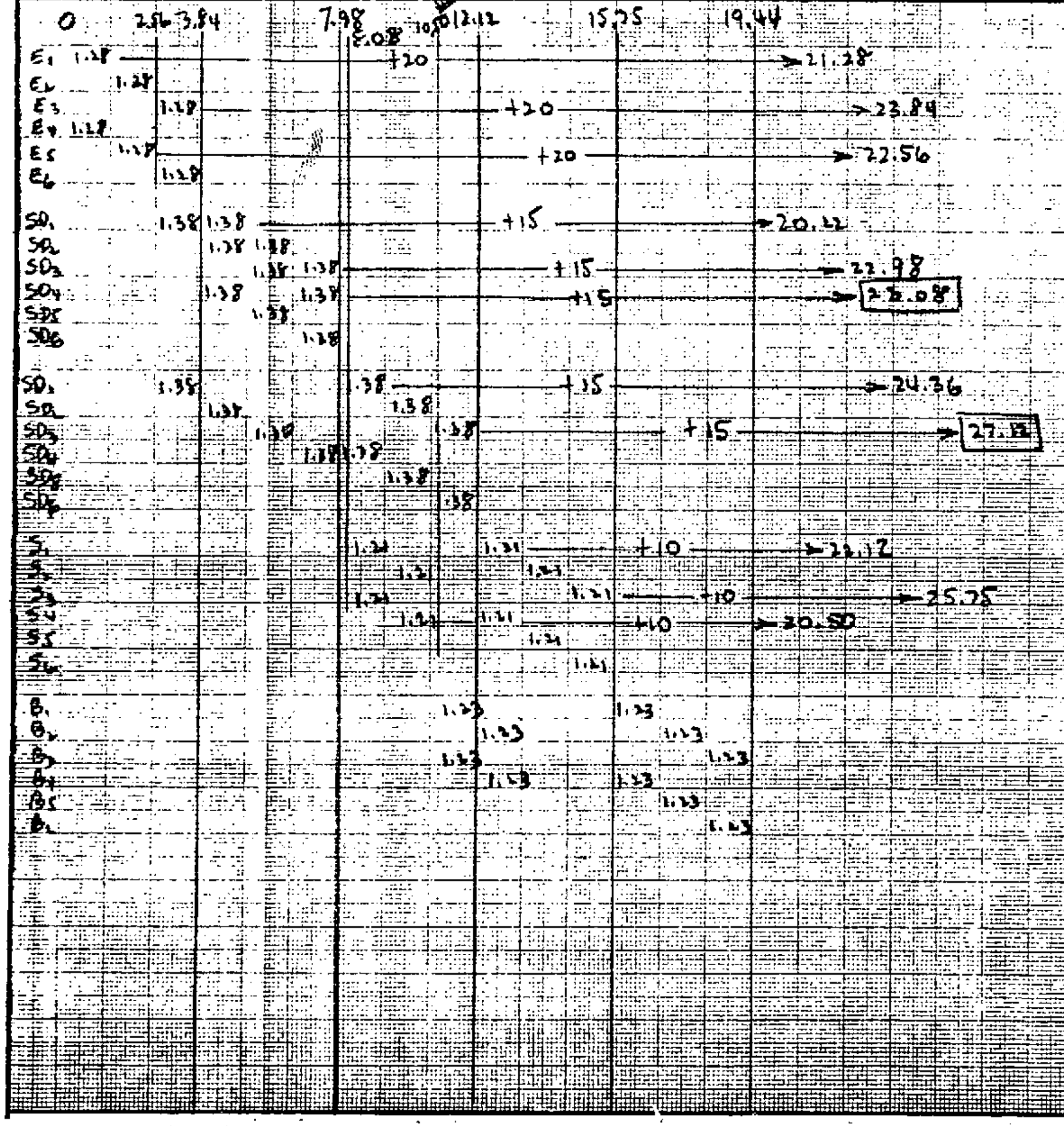
20.00 MIN - 53.16 M

10.00 MIN - 63.16 M

10% 6 MIN - 69.16 M

ASSUME 70 MIN/4 MEN

FIGURE 3 - Two Man Preparation Passive System



CUM TIME

1. PREPARE, RECONSTITUTE, REHYDRATE (IN TRAYS) — 27.12 M

2. SERVE 6 TRAYS (.50 MIN EA) 3.00 MIN — 30.12 M

3. DINE 20.00 MIN — 50.12 M

4. CLEAN UP & RESTOW EQUIP. 10.00 MIN — 60.12 M

CONTINGENCY 10% - 6 MIN - 66.12 M

ASSUME 66 MIN / 6 MEN

4 MAN TIME LINE

1. — 23.08 M

2. 4 TRAYS 2.00 MIN — 25.08 M

3. 20.00 MIN - 45.08 M

4 5.00 MIN - 50.08 M

10% - 5 MIN - 55.08 M

ASSUME 55 MIN / 4 MEN

FIGURE 4-a Individual Meal Preparation Passive System

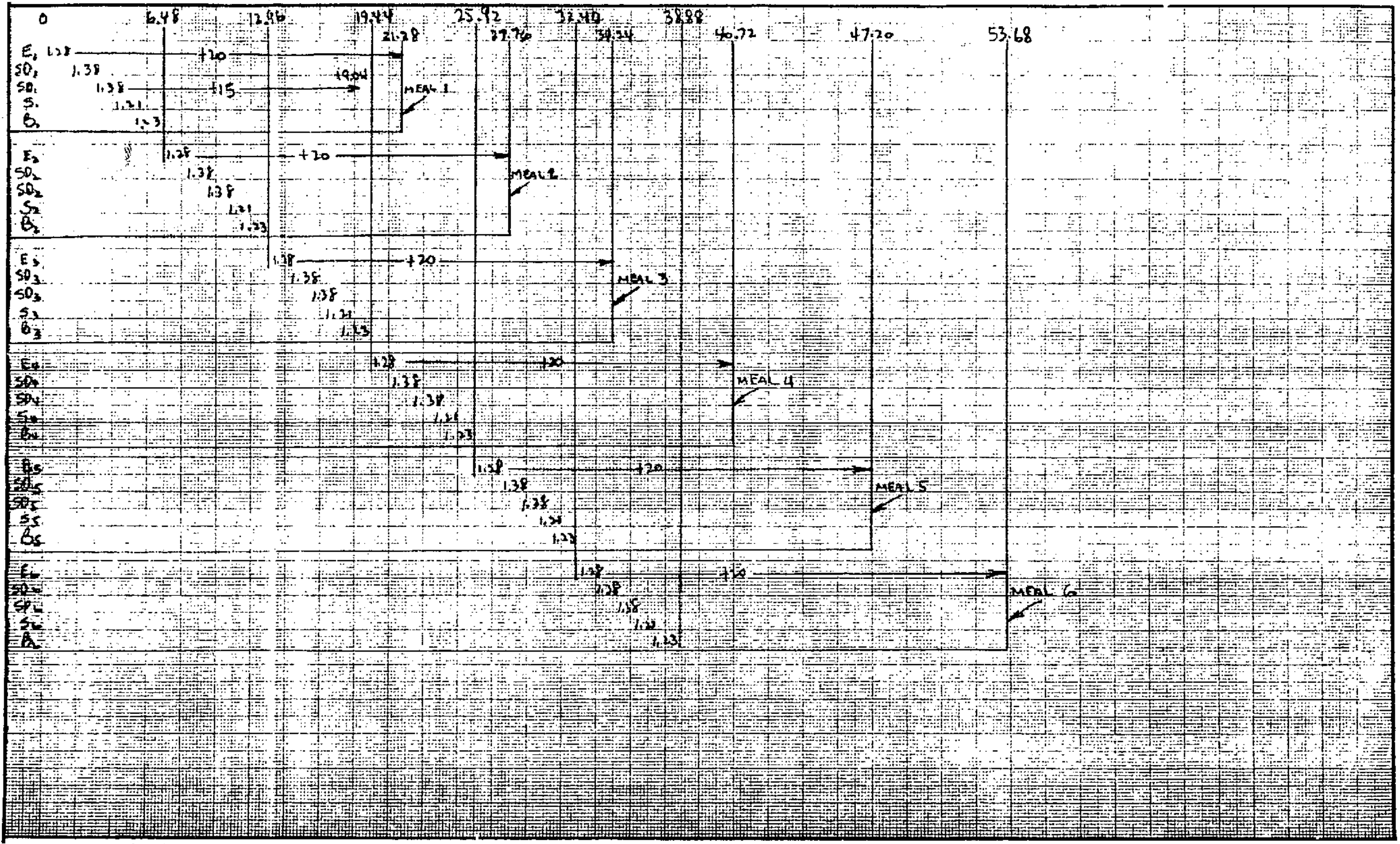
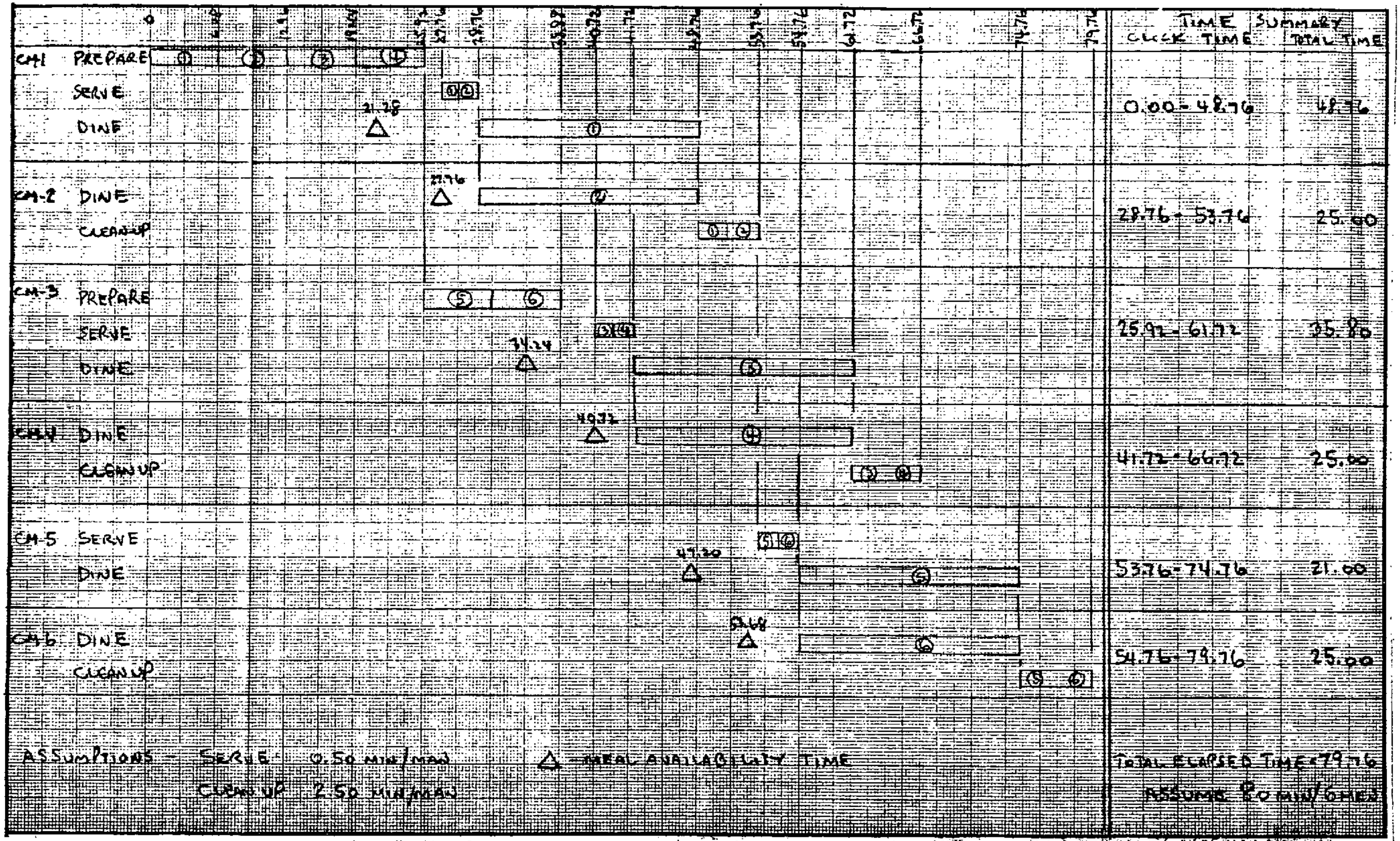


FIGURE 4-b Individual Meal Preparation Passive System



2.2 Semi-Active Oven System

The purpose of the semi-active oven is to prevent further cooling of dishes once they have been heated by hot water and prepared. This system requires a source of hot water and an insulated oven whose inner wall is maintained at a selected serving temperature by means of resistance heaters. Also required are trays insulated only sufficiently to prevent food from cooling below 105°F by the end of the 20 minute dining period. The analysis of this system was based on preparing and storing all hot dishes (except beverages) required to serve six crewmembers at one sitting.

Table 7 shows that this system, with heated water flow rates of 30 and 60 lb/hr, can provide total preparation times under one hour. Total preparation time is defined as the time elapsed to the point when all dishes are prepared or rehydrated, whichever is longer.

2.3 Active Systems

2.3.1 Hot Air Convective Oven

The oven is designed to simultaneously heat the full complement of cans required for six meals, i.e., eighteen No. 401 cans plus six No. 211 cans. The oven is a closed, insulated box containing electrical air heating elements, flow baffles, plenum chambers, and retainers for the cans. An external blower ducted to the internal plenum chambers serves to circulate heated air over the cans.

TABLE 7. PREPARATION SUMMARY-SEMI-ACTIVE OVEN

$\dot{W}$		τ_2	τ_E, τ_{D1}, τ_{D2}, τ_S, τ_B	T_R (minutes)
7	Entree'	2.41	35.96	118.32
	Side Dish	3.21	56.22	
	Side Dish	3.21	81.48	
	Soup	1.82	93.40	
	Beverage	4.07	118.32	
15	Entree'	1.12	28.22	71.22
	Side Dish	1.5	38.22	
	Side Dish	1.5	53.22	
	Soup	.85	59.32	
	Beverage	1.90	71.22	
30	Entree'	.56	24.86	50.58
	Side Dish	.75	30.36	
	Side Dish	.75	40.86	
	Soup	.42	44.38	
	Beverage	.95	50.58	
60	Entree'	.28	23.18	40.35
	Side Dish	.38	26.46	
	Side Dish	.38	34.74	
	Soup	.21	37.00	
	Beverage	.475	40.35	

Assuming a rehydration water flow rate of 60 lbs/hr, approximately 10 minutes will be required to fill all the bags for a given meal. During this period the oven will be "on" for an initial preheat during which time the oven will come up to operating temperature. At the end of the preheat, the cans which now contain bags of rehydrated food, are inserted into the oven. The four cans of each meal are contained in an integral retainer.

The blower delivers recirculated air to a plenum chamber which contains electrical heating elements. The latter are controlled so that the air is not heated above 270°F which is the maximum tolerable to the food bag material. The heated gas flows over the cans in a two-pass heat transfer arrangement ultimately returning to the blower for reintroduction into the plenum containing the heaters. To be compatible with the time constraint on meal duration, the heating time is limited to 15 minutes assuming the most conservative case of 35°F rehydration water available.

It was established that with an average effective gas temperature of 250°F, the blower must induce sufficient flow to generate a heat transfer coefficient of $h=5.5$ Btu/hr-ft^2-°F over the surface of the cans. This can be done with a small blower having low power requirements. The required insulation thickness for the oven was determined on two bases. The first was the maximum allowable external "touch" temperature chosen as 105°F to be consistent with Skylab practice. The second basis was determination of the optimum thickness to minimize overall system penalty. It was found that the "touch" temperature requirement dictated the insulation thickness.

2.3.1 Cont'd

A schematic sketch of the convective oven and details of the analysis are contained in the appended calculations. System penalty values are presented in the summary matrix (Table 2-Ref.).

2.3.2 Microwave Oven

Though microwave ovens are heat conservative in the sense that the heating is accomplished inside the food while the oven structure remains cool, it is, as yet, a highly inefficient, heavy device. The assembly includes a magnetron microwave generating tube, a power supply to transform line voltage to 3500 volts, a waveguide to convey microwave energy to the oven and associated electronic devices and controls, all aside from the metal oven enclosure. The efficiency of conversion of supply line electrical energy to microwave energy is 50%, and of the microwave energy generated, only 85% is effective in heating the food. Therefore, the overall efficiency is 0.5 x 0.85 = 0.425. The line power required to heat 6 meals simultaneously from 40°F to 145°F in 15 minutes amounts to 3.6 Kw (1.8 Kw microwave energy produced).

Microwave ovens are currently employed in certain of the operational 747 aircraft. The weight of these units which deliver 2.4 Kw microwave energy is 110 lb each. A weight estimate for our required capacity construed from this value amounts to 82.5 lbs.

2.3.2 Cont'd

The microwave oven will not heat the contents of metal cans, since the latter reflect the microwave energy. Accordingly, the rehydrated food bags would have to be introduced into the oven directly rather than the original can containers.

2.3.3 Heated Tray

This approach provides individual trays for each meal. The unit tray contains full depth recesses for three 401 cans and one 211 can. The recesses are lined with electrical heater elements which contact the sides and possibly the bottom of each can. The recesses are surrounded with insulation and the tray may include an insulated cover. To heat the cans, they are pressed into the recesses which fit snugly around the cans to provide good thermal contact between the cans and the heater elements. The latter are limited to a maximum of 270°F to avoid damage to the food bags.

The ability to heat the food from 40°F to 145°F in 15 minutes depends upon the thermal contact conductance between the heaters and the can walls. This conductance does not lend itself to analytical prediction. It is necessary to establish achievable values through test. The Skylab food heating system is similar to this configuration and existing performance data would be extremely valuable in assessing the merit of this approach. It was determined that with heating sides and bottom, a conductance value of 7 to 8 Btu/hr-ft^2-°F would be required while if only the sides are heated, a conductance level ~14 would be required. The system analysis assumes these conductances can be obtained pending affirmation from experimental data.

2.3.4 Hot Water Source

The hot water source, which is activated only prior to and during meal preparation, consists of an insulated spherical tank of sufficient volume to contain the water required to reconstitute six main meals, an electrical water inlet heater and an electrical internal heater to make up the heat leak through the insulation. The water inlet heater receives 35°F water from the fuel cells at a constant flow rate of 7 lb/hr.

2.3.5 Chemical Heating System

To date no exothermic reactions of possible interest to the present application have been determined in the light of the following considerations:

1. Safety factors-explosion, fire, health hazards
2. Zero-g environment
3. Controlled chemical reaction
4. Container and heat transfer requirements

Generally, exothermic reactions involving direct combination of chemical elements appear to be unsatisfactory on the basis of the above. Also liquid reactions such as mixing of salt solutions and neutralization of acides and bases have been discarded, to date, due to thermoneutrality, low heat production, and safety hazards.

2.3.5 Cont'd

Further consideration will be given to systems utilizing precipitation reactions from solution and the release of heat due to hydration and solution of various salts.

2.3.6 Preparation Summary

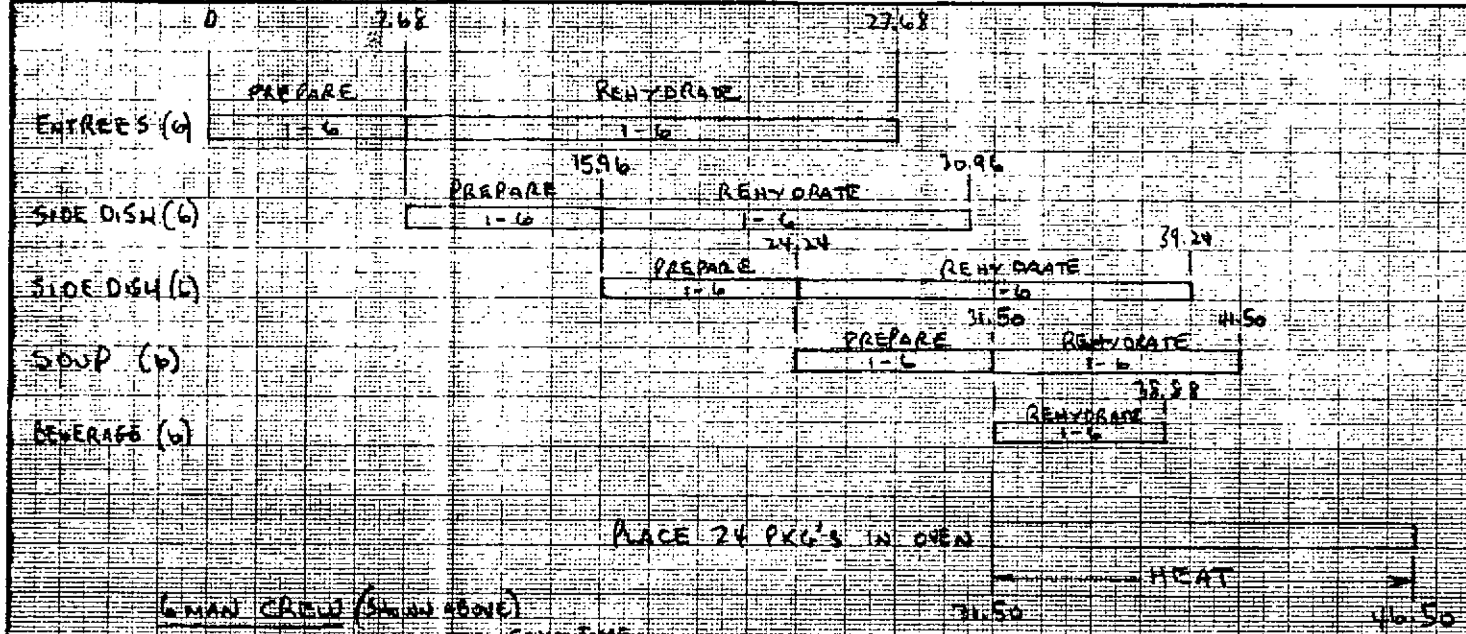
A timeline for 1-man preparation based on the previously determined optimum technique, is presented in Figure 5. The time is competitive with the other methods and calculated penalties for power and weight are also reasonable.

2.3.7 Hydraulic Warming Concept

This concept provides for the utilization of hot water to replace heating coils in the Skylab type tray . The design is based upon hot water available from either a heat waste loop or hot water heater.

The concept is not applicable to shuttle by reason of excessive time to bring food to temperature.

FIGURE 5 1 Man Preparation Hot Air Oven



6 MAN CREW (SHOWN ABOVE)

CUM. TIME

1. PREPARE, RECONSTITUTE FOOD PKGS - 31.50 MIN.

2. INSERT 24 PKGS IN OVEN & HEAT - 46.50 MIN
FOR 15 MIN.

3 REMOVE FROM OVEN & SET UP - 49.50 MIN
6 TRAYS (.50 MIN EA) 3.00 M

4. SERVE 6 TRAYS (.50 MIN EA) 3.00 M - 52.50 MIN

5 DINE 20.00 MIN - 72.50 MIN

6. CLEANUP & RESTOW EQUIP 15.00 M - 87.50 MIN

CONTINGENCY 10% - 9 M - 96.50 MIN

ASSUME 97 MIN / 6 MEN

4 MAN CREW

CUM. TIME

1. - 21.00 M

2. 16 PKGS - 15 MIN HEAT - 36.00 M

3. 4 TRAYS (.50 M EA) - 2.00 M - 38.00 M

4. 4 TRAYS (.50 M EA) - 2.00 M - 40.00 M

5. 20.00 M - 60.00 M

6. 10.00 M - 70.00 M

10% 7.00 M - 77.00 M

ASSUME 77 MIN / 4 MEN

3.0 DETAILED ANALYSIS

3.1 Passive Heating Systems

3.1.1 Insulated Jacket Analysis

3.1.1.1

Preparation Sequences for Individual Meals Stored in an Insulated Jacket.

1) Can is opened and valve is unpacked.

2) Water is added to contents.

3) Contents are removed from can and kneaded.

4) Contents are replaced in can, valve is repacked and can is stored in jacket.

Dishes are prepared in the order of rehydration times: entree', side dishes, soup, beverage.

Entree' is most critical because it has the lowest initial temperature.

During water addition entree' cools to cabin

$$h'_g A(t_1 - t) = \rho V_{cp} \frac{dt}{d\tau}$$

$h_g = 1.80$ BTU/hr·Ft²·°F , from test

A is can total surface area

V is can volume

$$\frac{t_1 - t_T}{t_i - t_f} = \text{Exp}\left\{ \frac{-h'_g}{\rho C_p} \frac{A}{V} \tau_1 \right.$$

$$\frac{A}{V} = \frac{2}{R} + \frac{2}{L}$$

where r and L can radius and depth,reflectively.

$$\frac{t_1 - t_f}{t_i - t_f} = \text{Exp}\left\{ \frac{-h'_g}{\rho c_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \tau_1 \right\}$$

Entree' cools to cabin environment during kneading

$$h_c A(t_1 - t) = V\rho C_p \frac{dt}{d\tau}, \quad h_c = 5.06 \frac{\text{BTU}}{\text{Hr}\cdot\text{Ft}^2\cdot{}^\circ\text{F}}$$ from test

$$\frac{t_2 - t_f}{t_1 - t_f} = \text{Exp}\left\{ \frac{-h_c}{\rho c_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \tau_2 \right\}$$

Entree' cools to cabin environment during repacking and storing.

$$h'_g A(t_f - t) = V\rho C_p \frac{dT}{d\tau}$$

$$\frac{t_3 - t_f}{t_2 - t_f} = \text{Exp}\left\{ \frac{-h'_g}{\rho C_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \tau_3 \right\}$$

Entree' cools in insulated jacket while first side dish is prepared.

$$h A_T \left(t_f - t \right) + h_A A_{BS} \left(t_f - t \right) = V_\rho c_p \frac{dt}{d\tau}$$

$$\frac{A_T}{V} = \frac{1}{L}$$

$$\frac{A_{BS}}{V} = \frac{2}{r_1} + \frac{1}{L}$$

$$\frac{t_4 - t_T}{t_s - t_T} = \exp\left[- \left\{ \frac{h}{\rho c_p} \frac{1}{L} + \frac{h_A}{\rho c_p} \left(\frac{1}{L} + \frac{2}{r_1} \right) \right\} \theta_1 \right]$$ where $\theta_1 = \tau_1 + \tau_2 + \tau_3 + \tau_4$ for first side dish

Entree' cools in insulated jacket while subsequent dishes are prepared and stacked on entree'.

Heat transfer between stored can is negligible due to small temperature differences.

$$h_A A_{BS} \left(t_f - t \right) = V \rho c_p \frac{dt}{d\tau}$$

$$\frac{t - t_T}{t_4 - t_T} = \exp\left\{ \frac{-h_A}{\rho c_p} \left(\frac{1}{L} + \frac{2}{r_1} \right) \tau \right\}$$

COMBINING EQUATIONS:

$$\frac{t - t_T}{t_i - t_T} = \exp\left[\frac{-h'_T}{\rho c_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \left(\tau_1 + \tau_2 \right) \frac{-h_c}{\rho c_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \tau_3 - \left\{ \frac{h}{\rho c_p} \frac{1}{L} + \frac{h_A}{\rho c_p} \left(\frac{1}{L} + \frac{2}{r_1} \right) \right\} \theta \frac{-h_A}{\rho c_p} \left(\frac{1}{L} + \frac{2}{r_1} \right) \tau \right]$$

$t_i = .86\,T_w + 10$ where T is water temperature. This relationship assumes dry food storage at 70° F, and applies to entree'. This relationship was provided by the Pillsbury Co.

In the time lines which follow, τ is defined for the first entree' prepared. The dish will be the coldest of all dishes by the end of the preparation period.

Preparation of Individual Meals - meal stored in insulated jacket during rehydration.

Rehydration Times:	Entree'	20 minutes	provided by the Pillsbury Co.
	Vegetables	15 "	
	Soup	10 "	
	Beverage	0 "	

Preparation Times: Assume τ_1 = .25 minutes to open a can and unpack valve.

τ_3 = .50 minutes to knead contents

τ_4 = .25 minutes to replace contents, repack valve and store in jacket

τ_2 = W/W, where is the time required to add water, W is the water requirement for the dish, and W is the water flow rate.

Water requirements:	Entree'	W_E = 4.5 oz.
	2 Side dishes	W_D = 12.0 oz.
	Soup	W_S = 3.4 oz.
	Beverage	W_B = 7.6 oz.

All dishes are contained in 401 x 105 cans, except for soup, which is contained in a 211 x 105 can.

Time Lines W = 7LB/HR 1.867 oz./min.

		Cumulative Time	Cum. + Rehydration time.
Entree'	τ_1 = .25 min	.25	
	τ_2 = 2.41	2.66	22.66
	τ_3 = .5	3.16	
	τ_4 = .25	3.41	
Side Dish	τ_1 = .25	3.66	
	τ_2 = 3.21	6.87	21.87
	τ_3 = .5	7.37	
	τ_4 = .25	7.62	
Side Dish	τ_1 = .25	7.87	
	τ_2 = 3.21	11.08	26.08
	τ_3 = .5	11.58	
	τ_4 = .25	11.83	
Soup	τ_1 = .25	12.08	
	τ_2 = 1.82	13.09	23.90
	τ_3 = .5	14.10	
	τ_4 = .25	14.65	
Beverage	τ_1 = .25	14.90	
	τ_2 = 4.07	18.97	
	τ_3 = .5	19.47	
	τ_4 = .25	19.72	

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Meal is fully reconstituted 26.08 minutes after preparation begins.

$\tau_2 + \tau_4 = 2.66$ minutes

$\tau_3 = .5$

$\theta_1 = 4.21$

$\tau = 26.08 - .25 - 2.66 - .5 - 4.21 = 18.46$

W = 15 lb/HR = 4 oz./min.

	Cumulative time	Cum + Rehydration Time	
Entree'	$\tau_1 = .25$ min.	.25	
	$\tau_2 = 1.12$	1.37	21.37
	$\tau_3 = .5$	1.87	
	$\tau_4 = .25$	2.12	
Side Dish	$\tau_1 = .25$	2.37	
	$\tau_2 = 1.5$	3.87	18.87
	$\tau_3 = .5$	4.37	
	$\tau_4 = .25$	4.62	
Side Dish	$\tau_1 = .25$	4.87	
	$\tau_2 = 5$	6.37	21.37
	$\tau_3 = .5$	6.87	
	$\tau_4 = .25$	7.12	
Soup	$\tau_1 = .25$	7.37	
	$\tau_2 = .85$	8.22	18.22
	$\tau_3 = .5$	8.72	
	$\tau_4 = .25$	8.97	
Beverage	$\tau_1 = .25$	9.22	
	$\tau_2 = 1.90$	11.12	
	$\tau_3 = .5$	11.62	
	$\tau_4 = .25$	11.87	

Meal is fully reconstituted 21.37 minutes after preparation begins.

$\tau_2 + \tau_4 = 1.87$ minutes

$\tau_3 = .5$

$\theta_1 = 2.5$

$\tau = 21.87 - .25 - 1.37 - .5 - 2.5 = 16.75$

$W = 30$ LB/HR ≈ 8 oz./min.

	Cumulative time		Cum. + Rehydration time
Entree'	τ_1 = .25 minutes	.25	20.81
	τ_2 = .56	.81	
	τ_3 = .5	1.31	
	τ_4 = .25	1.36	
Side Dish	τ_1 = .25	1.81	
	τ_2 = .75	2.56	17.56
	τ_3 = .5	3.06	
	τ_4 = .25	3.31	
Side Dish	τ_1 = .25	3.56	
	τ_2 = .75	4.31	19.31
	τ_3 = .5	4.81	
	τ_4 = .25	5.06	
Soup	τ_1 = .25	5.31	
	τ_2 = .42	5.73	15.73
	τ_3 = .5	6.23	
	τ_4 = .25	6.48	
Beverage	τ_1 = .25	6.73	
	τ_2 = .95	7.68	
	τ_3 = .5	8.18	
	τ_4 = .25	8.43	

Meal is fully reconstituted 20.81 minutes after preparation begins.

$\tau_2 + \tau_4 = .81$

$\tau_3 = .5$

$\theta_1 = 1.75$

$\tau = 20.81 - .25 - .81 - .5 - 1.75 = 17.50$

W = 60 + /HR 16 oz./min.

		Cumulative Time	Cum. + Rehydration Time
Entree'	τ_1 =.25 minutes	.25	20.53
	τ_2 =.28	.53	
	τ_3 =.5	1.03	
	τ_4 =.25	1.28	
Side Dish	τ_1 =.25	1.53	
	τ_2 =.38	1.91	16.91
	τ_3 =.5	2.41	
	τ_4 =.25	2.66	
Side Dish	τ_1 =.25	2.91	
	τ_2 =.38	3.29	18.29
	τ_3 =.5	3.79	
	τ_4 =.25	4.04	
Soup	τ_1 =.25	4.29	
	τ_2 =.21	4.50	14.50
	τ_3 =.5	5.00	
	τ_4 =.25	5.25	
Beverage	τ_1 =.25	5.50	
	τ_2 =.475	5.975	
	τ_3 =.5	6.475	
	τ_4 =.25	6.725	

Meal is fully reconstituted 20.53 minutes after preparation begins.

$\tau_2 + \tau_4 = .53$

$\tau_3 = .5$

$\Theta = 1.38$

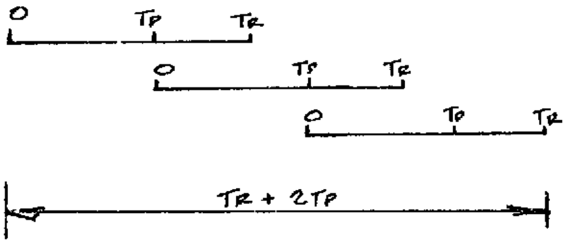
$\tau = 20.53 - .25 - .53 - .5 - 1.38 = 17.87$

3.1.1.2

Preparation and Storage in Insulated Jacket of Three Meals at a time.

Define T_R as the time in which a meal is fully rehydrated T_P as the time to prepare a meal, beginning with opening of first can.

Meals would be prepared and stored in sequence given below:



The three meals would be served after $T_R + 2T_P$ minutes. During the time internal 0 to T_P minutes, the five cans comprising a meal and prepared and stored in the insulated jacket. The relationship characterizing the cooking of the entreés is the same as that already given, except that for the first entree' prepared must include the additional time required for preparing and rehydrating the subsequent meals.

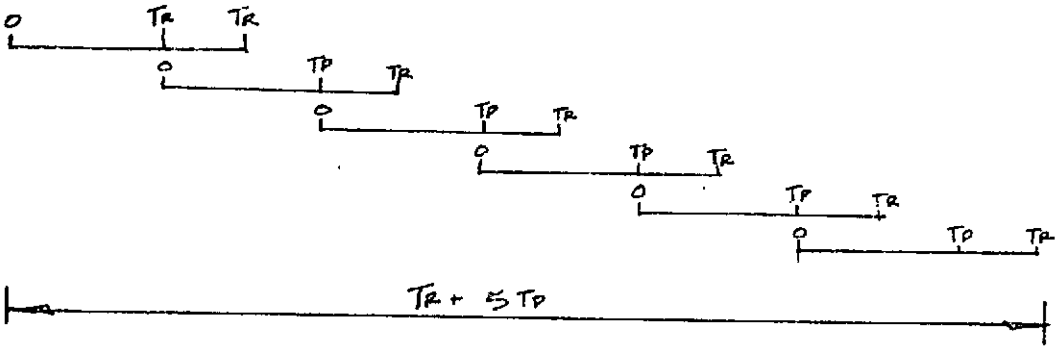
$$\tau = T_R + 2T_P - .25 - (T_2 + T_4) - T_3 - \theta_1$$

W	T_R	T_P	$T_2 + T_4$	T_3	θ_1	τ	$T_R + 2T_P$
7	26.08	19.72	2.66	.5	4.21	57.90	65.52
15	21.37	11.87	1.37	.5	2.50	40.49	45.11
30	20.81	8.43	.81	.5	1.75	34.36	37.67
60	20.53	6.72	.53	.5	1.38	31.31	33.97

3.1.1.3

Preparation and Storage in Insulated Jacket of Six Meals at a Time.

Meals would be prepared and stored in sequence given below:



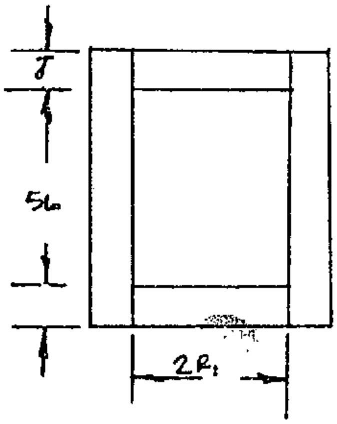
The six meals would be served after $T_R + 5\ T_P$ minutes

$$\tau = T_R + 5T_P - .25 \cdot (\tau_2 + \tau_4) - \tau_3 - \theta_1$$

W	T_R	T_P	$\tau_2 + \tau_4$	τ_3	θ_1	τ	$T_R + 5T_P$
7	26.08	19.72	2.66	.5	4.21	117.06	124.68
15	21.37	11.87	1.37	.5	2.5	76.10	80.72
30	20.81	8.43	.81	.5	1.75	59.65	62.96
60	20.53	6.72	.53	.5	1.38	51.47	54.13

3.1.1.4

Insulated Jacket Weight



$L = 1.312''$

$R_1 = 2.031''$

SHEATHED, ALL FACES WITH .020 GAGE ALUMINUM

INSULATION DENSITY .6 LB/FT^3

ALUMINUM DENSITY 173 LB/FT^3

Figure 6

δ	INSULATION VOL.	WEIGHT	FACES AREA	WEIGHT	TOTAL WT	JACKET VOLUME
.5	67.13	.022368	270.1 IN^2	.540868	.56468	152.1 IN^3
1.0	162.0	.0563	330.4	.6615	.718	247.1
2.0	454.0	.1577	479.2	.9594	1.12	539.1

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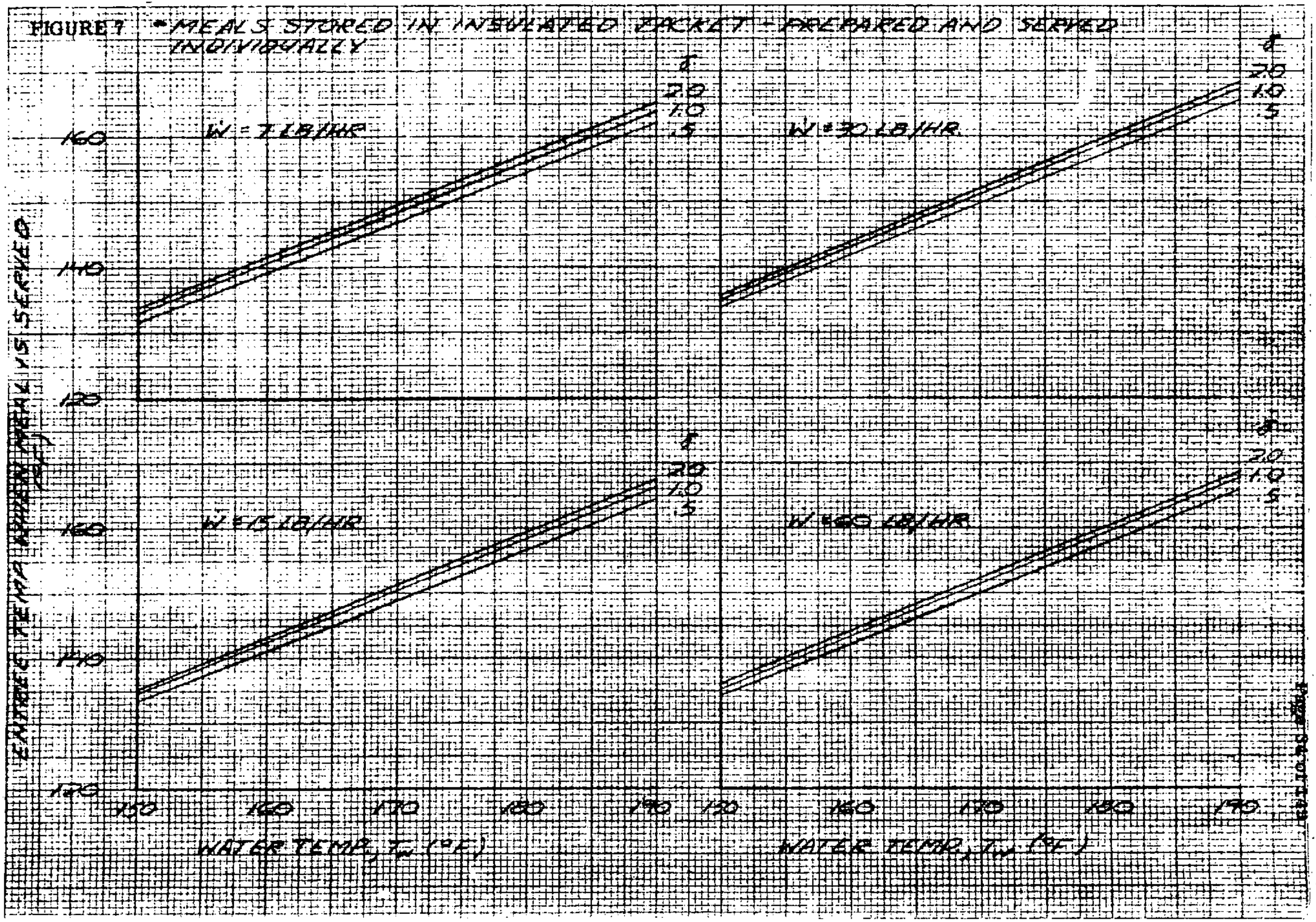
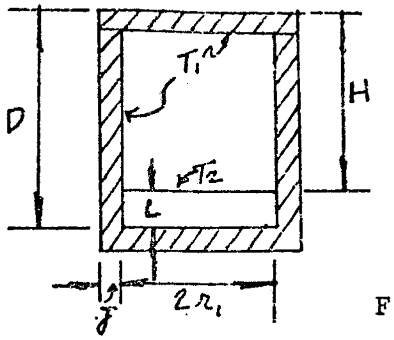


FIGURE 7 *MEALS STORED IN INSULATED PACKET - PREPARED AND SERVED INDIVIDUALLY

3.1.1.5

Heat Loss From Covered Insulated Jacket - 5 Can Storage



First four cans stored are 401 x 105 Cans: r = 2031 in., L = 1.312 in.

$$F_1^{\,2} = 1.0$$

$$F_1^{\,1} = 1 - F_2^{\,1} = 1 - \frac{A_2}{A_1}$$

$$\left(A_1 - A_2 - \frac{A_1}{1-E_1}\right) R_1^{\,2} + A_2 R_2^{\,2} = -E_2 A_2$$

$$A_2 R_1^{\,2} - \frac{A_2}{1-E_2} R_2^{\,3} = 0$$

$$R_2^{\,2} = (1-E_2) R_1^{\,2}$$

$$\left(A_1 \frac{E_1}{1-E_1} + A_2\right) R_1^{\,2} - (1-E_2) A_2 R_1^{\,2} = E_2 A_2$$

$$R_1^{\,2} = \frac{E_2}{\frac{A_1}{A_2}\frac{E_1}{1-E_1} + 1 - (1-E_2)} = \frac{E_2}{\frac{A_1}{A_2}\frac{E_1}{1-E_1} + E_2}$$

$$A_2 \mathcal{F}_1^{\,2} = R_1^{\,2} A_1 \frac{E_1}{1-E_1}$$

$$A_2 \mathcal{F}_1^{\,2} h_{r_{12}} (t_2 - t_1) + UA_1 (t_f - t_1) = 0$$

$$\frac{1}{UA} = \frac{\delta}{K} \frac{\ln\left(1+\frac{\delta}{R_1}\right)}{2\pi\delta D} + \frac{1}{2\pi(R_1+\delta)(0)(h_3 + E_2 h_{Rff})}$$

U DETERMINED FROM THIS EQUATION WILL BE USED FOR THE TOP & BOTTOM SURFACES ALSO, AS AN ALLOWANCE FOR CORNER HEAT LOSS.

ASSUME $E_1 = .2$ (ALUMINUM), $E_2 = .9$ (OPEN CAN), $K = 0.25 \frac{BTU}{HR\ FT^2\ °F}$

$h_B = \frac{1.45\ BTU}{HR.FT.^2\ °F}$ (CABIN SIDE CONNECTIVE HEAT TRANSFER COEFFICIENT.)

$t_f = 70°F$ (MINIMUM CABIN TEMPERATURE), THEN $H_{F t_f} = 1.020$ BTU/HR FT² °F

ONE CAN STORED(D=46)	TWO CANS STORED D=36	THREE CANS STORED (D=26)
$A_1 = .55506\ FT^2$	$A_1 = .43890\ FT^2$	$A_1 = .32253\ FT^2$
$A_2 = .08999\ FT^2$	$A_2 = .08999\ FT^2$	$A_2 = .08999\ FT^2$
$A_2 \mathcal{F}_1^{\,2} = .05114\ FT^2$	$A_2 F_1^{\,2} = .04639\ FT^2$	$A_2 \mathcal{F}_1^{\,2} = .04041\ FT^2$

$$\dot{Q} = A_2 \mathcal{F}_1^{\,2} h_{r_{12}} (t_2 - t_1)$$

$h_T = \dot{Q} / \{A_2 (t_2 - t_f)\}$ OVERALL CONDUCTANCE TOP OF CAN TO CABIN ENVIRONMENT.

LET $t_2 = 150$ °F
$t_3 \cdot 150$ °F

ONE CAN STARTED

$\delta = .50$ IN
$k \cdot (1 + \delta/\lambda_1) = .2201$

$U = .4399$ BTU/HR FT^2 °F $= h_a$
$.05114 h_{r12} (150 - t_i) + .2442 (70 - t_f) = 0$

SOLUTION IS $t_1 = 87.5$°F
$\Phi = 4.258$ BTU/HR
$h = .5914$ BTU/HR FT^2 °F

$\delta = 1.0$ IN
$k : \left(1 + \frac{\delta}{\lambda_1}\right) = .4009$
$U = .2739$ BTU/HR. FT^2 °F $= h_A$
$.05114 \; h_{r_{13}} (150 - t_1) + .1518 (70 - t_1) = 0$

SOLUTION IS $t_1 = 95.1$ °F
$\Phi = 3.812$ BTU/HR. FT^2 °F
$h = .5295$ BTU/HR. FT^2 °F

$\delta = 2.0$ IN
$k \left(1 + \frac{\delta}{\lambda_1}\right) = .6855$

$U = .1705$ BTU/HR FT^2 °F $= h_a$
$.05114 \; h_{r_{12}} (150 - \tau_1) + .0945 (70 - \tau_1) = 0$

SOLUTION IS $t_1 = 104.3$°F
$\Phi = 3.247$ BTU/HR.
$h = .4510$ BTU/ HR FT^2 °F

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FIGURE 8. MEALS STORED IN INSULATED JACKET - PREPARED AND SERVED IN GROUPS OF THREE

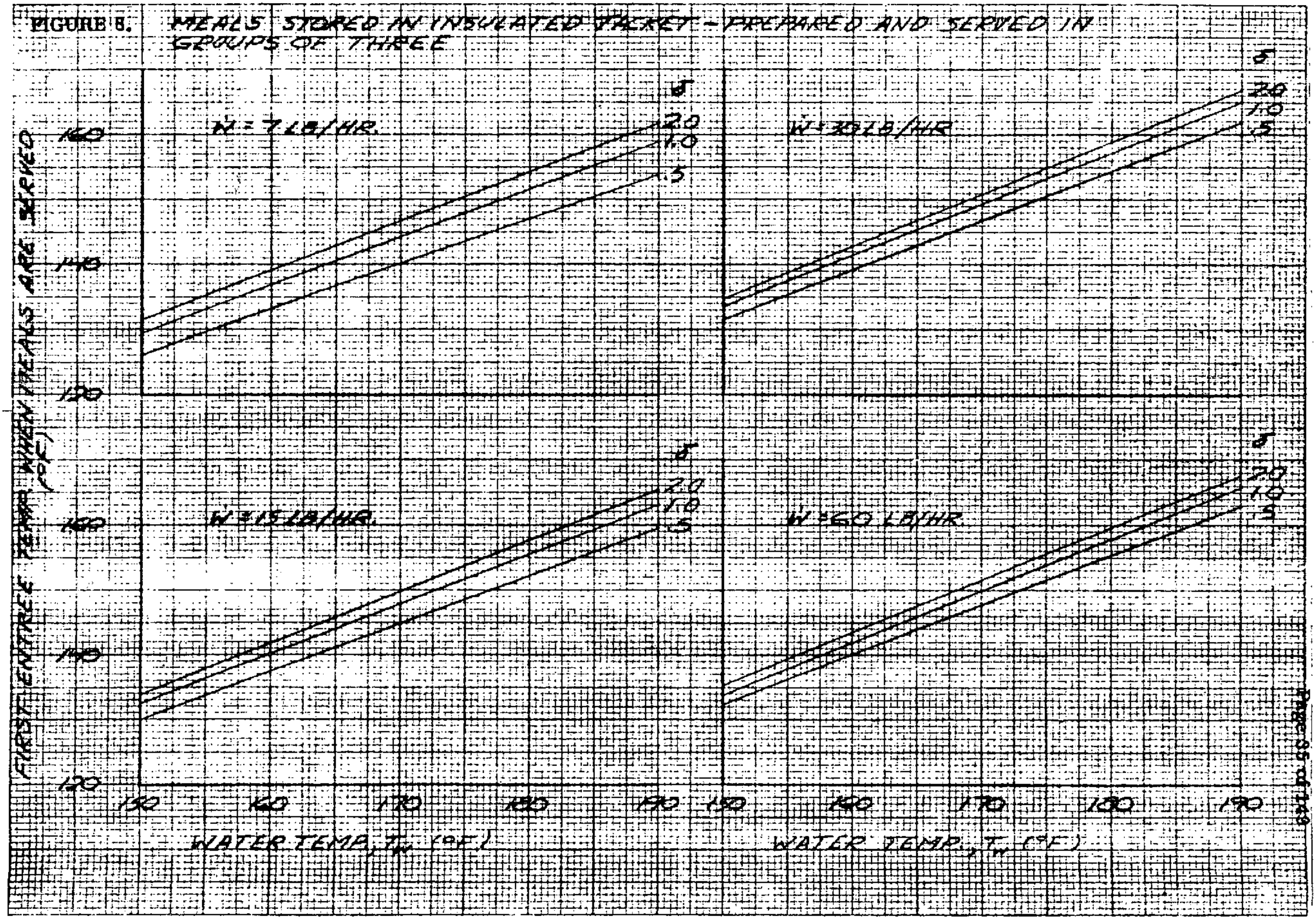
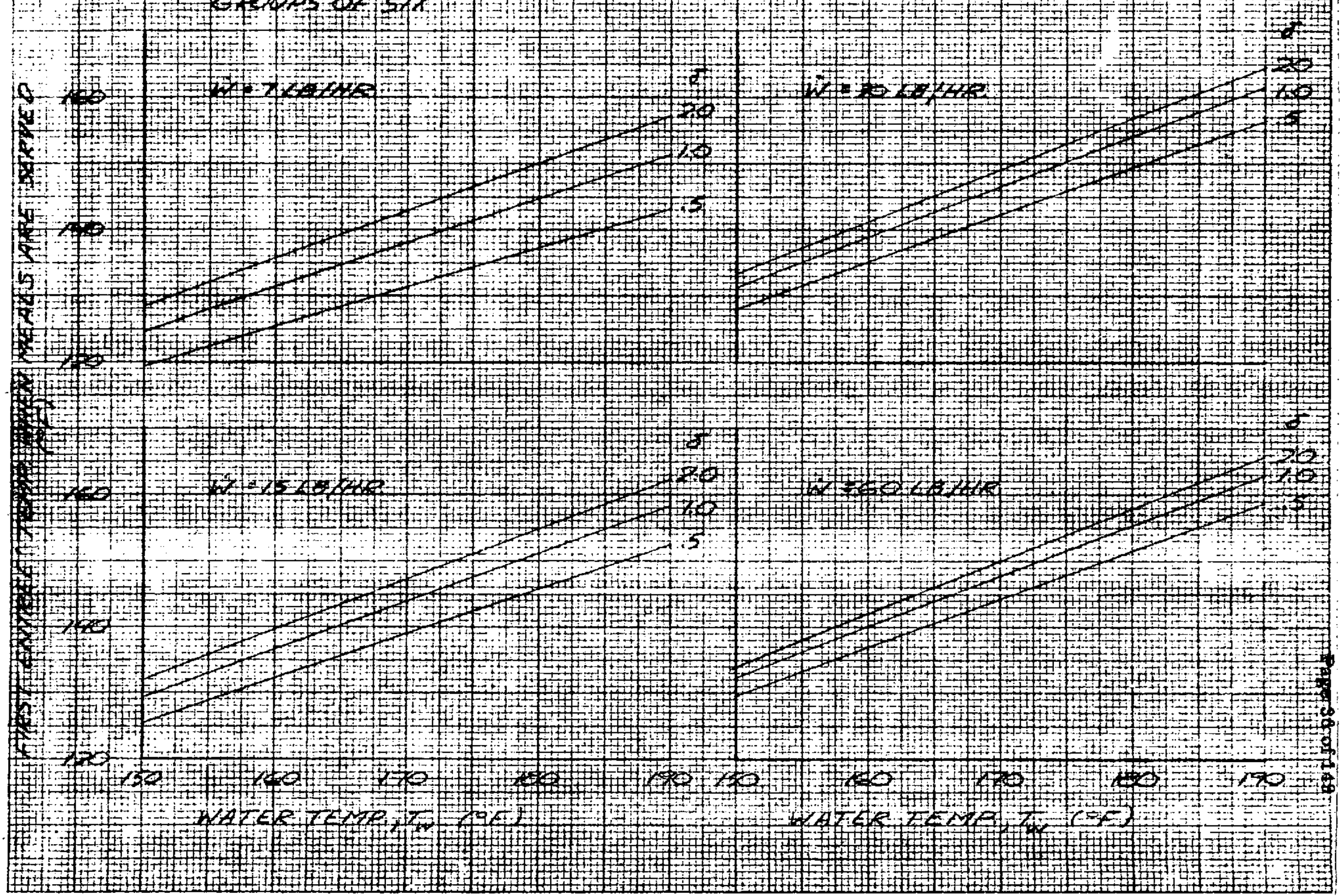


FIGURE 9. MEALS STORED IN INSULATED JACKET - PREPARED AND SERVED IN GROUPS OF SIX



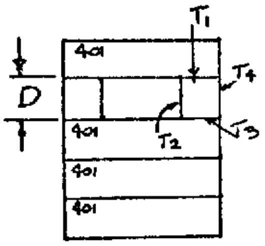
3.1.1.6

Heat Loss Analysis - 5 Can Storage

In order to complete the analysis, the temperatures of the hottest dishes as well as the coldest must be ascertained in order to determinethat all are within the 135 - 145°F serving temperature band when meals are served. The hottest dishes when meals are served would be the beverage and soup of the last meal prepared. Attention will be restricted to the care characterized by a water flow rate of 50 LB/HR, and preparation and serving of meals in groups of six (one man preparation) since Table 4 shows that this care results in a total meal preparation time under one hour. For comparison purposes, results are furnished for a case characterized by a water flow rate of 60 LB/HR, and preparation and serving of meals in two groups of three (two man preparation). For this case, it was assumed that each man prepares three complete meals. The total preparation time would be half the value given in Table 4 for meals prepared and served in groups of three with a water flow rate of 60 LB/HR, or 34.0 minutes.

For both the case of one man preparation and two man preparation results we presented for water temperature yielding 135°F and 140° F coldest entree' temperatures. This dish would be the first one prepared.

Heat Loss From Covered Insulated Jacket - 5 can Storage Analysis



Next to last and last cans stored are a 211 x 105 and a 401 x 105 can, respectively.

Configuration Factor, F_j^i
SUPERSCRIPT DENOTES , SUBSCRIPT DENOTES

$F_2^H = .430$
$F_H^H = .129$
$F_4^2 = .430\ (2.031/1.344 = .64980$
$F_1^2 = F_3^2 = (1-.64980)/2 = .17510$
$F_1^4 = F_3^4 = (1-.430-.109)/2 = .22050$

$F_1' = 0$
$F_2^2 = 0$
$F_3^3 = 0$

$A_2 = 0.07694\ FT^2$
$A_1 = A_3 = .0508\ FT^2$
$A_4 = .11627\ FT^2$
$F_2' = .17510(.07694/.05058) = .26635$ $F_3' = F_1^3 = 1 - F_2' - F_4' \doteq .22678$
$F_4' = .22050(.11627/.05058) = .50687$

$$\left(A_1F_1' - \frac{A_1}{1-E_1}\right) R_1^4 + A_2 F_1^2 - \frac{A_2}{1-E_3} R_2^4 + A_3 F_2^3 R_3^4 + A_4 F_2^4 R_4^4 = -E_4 A_4 F_2^4 \quad (1)$$

$$A_1 F_2' R^4 + \left(A_2 F_2^2 - \frac{A_2}{1-E_2}\right) R_2^4 + A_3 F_2^3 R_3^4 + A_4 F_2^4 R_4^4 = -E_4 A_4 F_2^4 \quad (2)$$

$$A' F_3' R_1^4 + A_2 F_3^2 R_2^4 + \left(A^3 F_2^3 - \frac{A_4}{1-E_3}\right) R_3^4 + A_4 F_3^4 R_4^4 = -E_4 A_4 F_3^4 \quad (3)$$

$$A_1 F_4' R_1^4 + A_2 F_4^2 R_2^4 + A_3 F_4^3 R_3^4 + \left(A_4 F_4^4 - \frac{A_4}{1-E_4}\right) R_4^4 = -E_4 A_4 F_4^4 \quad (4)$$

$E_1 = .22$
$E_3 = .9$
$E_2 = E_4 = .2$

$$-.06223 R_1^4 + .01347 R_2^4 + .01147 R_3^4 + .02564 R_4^4 = -.00513 \quad (1)$$

$$.01347 R_1^4 - .09618 R_2^4 + .01347 R_3^4 + .05020 R_4^4 = -.0100 \quad (2)$$

$$.01147 R_1^4 + .01347 R_2^4 - .50580 R_3^4 + .02564 R_4^4 = -.00513 \quad (3)$$

$$.02564 R_1^4 + .05000 R_2^4 + .02564 R_3^4 - .13034 R_4^4 = -.00300 \quad (4)$$

$$R_4^H = .08112 + .21316\, R_2^H + .18143\, R_3^H + .44057\, R_H^H$$

SUBSTITUTING INTO EQUATIONS (2), (3), (4,)

$$-.09331\, R_2^H + .01591\, R_3^H + .05546\, R_H^H = -.01109$$

$$.01591\, R_2^H - .50372\, R_3^4 + .03029\, R_4^H = -.00606$$

$$.05546\, R_2^H + .03029\, R_4^H - .1194\, R_4^H = -.00508$$

$$R_2^H = \frac{\begin{vmatrix} -.01109 & .01591 & .05546 \\ -.00606 & -.50372 & .03029 \\ -.00508 & .03029 & -.11994 \end{vmatrix}}{\begin{vmatrix} -.09331 & .01591 & .05546 \\ .01591 & .50372 & .03029 \\ .05546 & .03029 & -.11994 \end{vmatrix}} = \frac{.00082595}{.0039187} = .21077$$

$$.01591\, R_3^H + .05546\, R_H^H = .00858$$

$$-.50372\, R_3^H + .03029\, R_H^H = -.00491$$

$$R_4^H = \frac{\begin{matrix} .00858 & .05546 \\ -.00941 & .03029 \end{matrix}}{\begin{matrix} .01591 & .05546 \\ -.50372 & .03029 \end{matrix}} = .02751$$

$$R_H^H = .14676 \qquad R_1^4 = .19057$$

$$A_i\, \mathcal{F}_j^{\,i} = R_j^i\, A_j \frac{E_i}{1-E_j}$$

$$A_4\, \mathcal{F}_2^4 = .21077\,(.07694)(.2/.8) = .00405$$

$$A_4\, \mathcal{F}_3^4 = .02751\,(.05058)(.9/.1) = .01252$$

$$A_4\, \mathcal{F}_4^4 = .14676\,(.11672)(.2/.8) = .00426$$

$$A_4\, \mathcal{F}_1^4 = .19057\,(.05058)(.2/.8) = .00241$$

HEAT BALANCE.

$t_1 = t_2 = t_3$

$$1/VA = \frac{\delta}{k}\,\frac{\ln(1+\delta/r_1}{2\pi\,\delta D} + \frac{1}{2\pi(r_1+\delta)(D)(h_B+\epsilon_1)}$$

BEVERAGE CAN

$\Phi = A_4\ \mathcal{F}_1^4\ h_{R\,14}(t_1 - t_4$

$h_L = \Phi/\epsilon A_T(t_1 - t_f)$, $A_T = \pi R_1{}^3 = .08999\ FT^3$

$h_A \cdot UA/A_4$

$h_U = U_A/A_4$

SOUP CAN

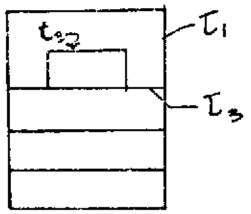
$\Phi = A_4\ \mathcal{F}_2^4\ h_{r\,24}(t - t_f)$

$h_A = \Phi/\epsilon A_2(t_2 - t_f)$

$h = 0$

	BEVERAGE	SOUP
$\delta = .5''$ $UA = .055146$ $.01898\,h_{r\,14}(150 - t_4) + .051146(70 - t_H) = 0$ SOLUTION $t_H = 96.9$ °F	$\Phi = .1746$ $h_L = .0242$ $h_A \cdot .4399$ $h_U = .4399$	$\Phi = .2933$ $h_A = .0477$
$\delta = 1.0''$ $V_A \cdot .03178$ $.01898\,h_{r\,14}(150 - t_H) + .01378(70 - t_H) = 0$ SOLUTION $t_H = 116.3$ °F	$\Phi = .1467$ $h_L = .02037$ $h_A = .2734$ $h_U = .2734$	$\Phi \cdot .2465$ $h_A \cdot .04005$
$\delta = 2.0$ IN. UA .01999 $.01898\,h_{r\,14}(150 - t_w) + .01979(70 - T_H) = 0$ SOLUTION $t_H = 110.3$°F	$\Phi \cdot .1162$ $h_L \cdot .01614$ $h_A = .1704$ $h_U \cdot .1704$	$\Phi \cdot .1953$ $h_A \cdot .03173$

NEXT TO LAST CAN STARTED IS A 211 x 105 CAN



$r_1 = 1.344$
$L = 1.312$

$F_3^2 = .17512$
AREA OF SIDE OF CAN $.07694\ FT^2 = A_{35}$
TOTAL EXPOSED SURFACE AREA OF CAN $A_3 = .11635\ FT^2$
$A_2 F_1^3 = A_2 - A_3 F_3^2 = .01388$
$F_3^3 = .26635$
$F_1^3 = 1 - .26635 = .73365$
$A_3 F_1^3 = .05058\,(.73365) = .03711$
$A_1 = .32253$
$A_1' F_1' = A_1 - A_1 F_2' - A_1 F_3' = .18254$

$$\left(A_1 F_1' - \frac{A_1}{1-E_1}\right) R_1' + A_3 F_1^2 R_2' + A_3 F_1^3 R_3' = -E A_1 F_1'$$

$$A_1 F_2' R' + \left(A_2 F_2^2 - \frac{A_{35}}{1-A_{35}} - \frac{A_3 - A_{35}}{1-E_{ST}}\right) R_3' + A^3 F_2^3 R_3' = -E_1 A_1 F_3'$$

$$A_1 F_3' R_1' + A_2 F_2' R_2' + \left(A_3 F_3^3 - \frac{A_3}{1-E_3}\right) R_3' = -E_1 A_1 F_3'$$

$E_1 = .2$
$E_{35} = .2$
$E_{2c} = .9$
$E_3 = .2$

$$-.22062\, R_1' + .10288\, R_2' + .03711\, R_3' = -.03651$$

$$.10288\, R_1' - .49028\, R_2' + .01847\, R_3' = -.02058$$

$$.03711\, R_1' + .01347\, R_2' - .06322\, R_3' = -.00742$$

$$R_1' = \frac{\begin{matrix} -.03651 & .10288 & .03711 \\ -.02058 & -49028 & .01347 \\ -.00742 & .01347 & .06322 \end{matrix}}{\begin{matrix} -.22062 & .10288 & .03711 \\ .10288 & -.49028 & .01347 \\ .00711 & .01347 & .06322 \end{matrix}} = \frac{-.0011444}{-.0053510} = .21387$$

$$.10288 R_2' + .03711 R_3' = .01067$$

$$-.49028 R_2' + .01347 R_3' = -.04258$$

$$R_2' = \frac{\begin{matrix} .01067 & .03711 \\ .04258 & .01347 \end{matrix}}{\begin{matrix} .10288 & .03711 \\ -.49028 & .01347 \end{matrix}} = .08804$$

$$R_3' = .26167$$

$$A_1 \mathcal{F}_1' = .21387(.32253)(.2/.8) = .01723$$

$$A_1 F_1' = .26167(.05058)(.2/.8) = .00331$$

$$A_1 \mathcal{F}_2' = .08804\{.07694\,(.2)/(.8) + .03941(.9)/(.1)\} = .03292$$

HEAT BALANCE

$$A_1 \mathcal{F}_2' h_{r_{12}}(t_2 - t_1) + A_1 \mathcal{F}_3' h_{r_{13}}(t_3 - t_1) + UA_1(t_f - t_1) = 0$$

$$t_2 = t_3$$

$$(A_1 \mathcal{F}_2' + A_1 \mathcal{F}_3') h_{r,12}(t_2 - t_1) + UA_1(t_f - t_1) = 0$$

$$1/UA = \delta/k \; \frac{\ln(1+\delta/r_1)}{2\pi \delta D} + \frac{1}{2\pi(r_1+\delta)(D)(h_B + \epsilon_1 h_{r\#\#}}$$

SOUP CAN.

$$\phi = A_1 \mathcal{F}_2' h_{r_{12}}(t_2 - t_1)$$

$$h = \phi/\{A_2(t_2 - t_1)\}$$

$\delta = .50$ IN.
$U = .4399$
$.03623\, h_{r,12}(150 - t_1) + .14188(70 - t_1) = 0$
$t_1 = 90.4$ °F

$\phi = 2.633$
$h = .2828$

$\delta = 1.0$
$U = .2733$
$.03623\, h_{r,12}(150 - t_1) + .08816(70 - t_1) = 0$
$t_1 = 98.8$ °F

$\phi = 2.310$
$h = .2482$

$\delta = 2.0$
$U = .1702$
$03623\, h_{r,12}(150 - t_1) + .05490(70 - t_1) = 0$
$t_1 = 108.5$ °F

ϕ 1.971
$h = .2060$

In preparation of last meal:

Beverage cools dining water addition for τ_2 minutes

$$\frac{\tau_1 - \tau_f}{\tau_1 - \tau_f} = EXP\left\{\frac{-h_r'}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_3\right\}$$

Beverage cools during kneading for τ_3 minutes

$$\frac{\tau_2 - \tau_f}{\tau_1 - \tau_f} = EXP\left\{-\frac{h'_r}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_3\right\}$$

Beverage cools during repacking and storing for τ_4 minutes

$$\frac{\tau_3 - t_f}{t_2 - \tau_f} = EXP\left\{\frac{-h'_B}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_4\right\}$$

Beverage cools in insulated jacket until rehydration is complete.

$$h_v A_T(\tau_f - t) + h_n A_s(t_f - t) + h A_T(T_f - t) = \rho V C_p \frac{dt}{d\tau}$$

$$\frac{t - t_f}{\tau_3 - t_f} = EXP\left[\left\{\frac{-h_v + h_L}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1}\right\}\tau\right], \quad \tau = T_R - T_P$$

Combining Equation

$$\frac{t - t_f}{t_i - t_f} = EXP\left[\frac{-h'_b}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)(\tau_2 + \tau_4) - \frac{h_c}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_3 - \left(\frac{h_v + h_L}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\right.\right.$$

$$\left.\left.\frac{2}{r_1}\right)\tau\right]$$

$\tau_i = .97\ T_W + 2$

FOR W = 60 LB/HR, $T_R = 20.53$ MIN

$T_P = 6.72$ MIN

$T_2 + T_4 = .725$

$\tau = 13.81$

$\tau_3 = .5$

$h'_b = 1.80$

$h_c = 5.06$

δ	h_v	h_L	h_A
.5	.4399	.0242	.4399
1.0	.4734	.0204	.2734
2.0	.1704	.0161	.1704

$\rho = 61.7$ PCF

$C_p = 1.0$ BTU/68°F

L = 1.312 IN

$R_1 = 2.031$ IN

In preparation of last meal:

Soup cools during water addition for τ_2 minutes

$$\frac{\tau_1 - \tau_f}{t_i - t_f} = EXP\left\{\frac{-h_b'}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_2\right\}$$

Soup cools during kneading for τ_3 minutes.

$$\frac{\tau_2 - \tau_f}{\tau_1 - \tau_f} = EXP\left\{\frac{-h_c}{\rho C_p}\left(\frac{2}{R_1} + \frac{2}{L}\ \tau_3\right\}$$

Soup cools during repacking and stowing for τ_4 minutes.

$$\frac{t_3 - \tau_f}{\tau_2 - t_f} = EXP\left\{\frac{-h_b'}{\rho C_p}\left(\frac{2}{R_1} + \frac{2}{L}\right)\tau_4\right\}$$

Soup cools in insulated jacket while beverage is prepared.

$$h_{A B s}(\tau_f - t) = U\rho_{c_p}\frac{d\tau}{d\tau}$$

$$\frac{t_w - t_f}{t_3 - t_f} = EXP\left\{\frac{-h}{\rho C_p}\left(\frac{2}{R_1} + \tau\right)\tau_1 + \tau_2 + \tau_3 + \tau_4)_B\right\}$$

Soup cools in insulated jacket until rehydration is complete.

$$h_A A_s\ (t_f - t) = \rho V C_\rho\ \frac{d\tau}{d\tau}$$

$$\frac{t_4 - t_f}{t_1 - t_f} = EXP\left\{\frac{-h_A}{\rho C_p}\ \frac{2}{r_1}\ \tau\right\},\quad \tau = T_R - T_P$$

Combining Equations

$$\frac{\tau - t_f}{t_i - t_f} = EXP\left\{\frac{-h'_A}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\left(\tau_3 + \tau_4\right) - \frac{h_c}{\rho C_p}\left(\frac{2}{R_1} + \frac{2}{L}\right)\left(\tau_3 - \frac{h}{\rho C_p}\right)\left(\frac{2}{R_1} + \frac{1}{L}\right)\left(\tau_1 + \tau_2 + \tau_3 + \tau_4\right) -\right.$$

$$\left.\frac{h_A}{\rho C_p}\ \frac{2}{R_1}\ \tau\right\}$$

$t_1 = .92\ TW + 6$

FOR W = 60 LB/HR

$T_R = 20.53$
$T_P = 6.72$
$\tau_2 + \tau_4 = .46$
$(\tau_1 + \tau_2 + \tau_3 + \tau_4) = 1.475$
$\tau = 13.81$

$\tau_3 = .5$
$h'_B = 1.80$
$h_c = 5.06$

$\rho = 61.7$ PCF
$C_p = 1.0$ BTU/LB°F
$R_1 = 1.344$
$L = 1.312$

δ	h	h_A
.5	.2828	.0477
1.0	.2482	.04005
2.0	.2060	.03173

Meals prepared in insulated jackets and served in groups of six, $W = 60$ LBS/HR, $t_f = 75°F$

Total preparation time 54.1 minutes

First entree'

At the point in time where meals are served

					LAST ENTREE' τ		LAST BEVERAGE τ		LAST SOUP τ	
JACKETS	$\frac{\tau_i-\tau_f}{\tau_i-\tau_f}$	τ	t_i	REQUIRED T_w	$\frac{\tau-\tau_f}{\tau_i-\tau_f}$	τ	$\frac{\tau-\tau_f}{\tau_i-\tau_f}$	τ	$\frac{\tau-\tau_f}{\tau_i-\tau_f}$	τ
.5	.85044	140	154.4	164.5	.931467	145.7	.93574	156	.96173	154.2
1.0	.89408		147.7	160.1	.94182	143.5	.94812	153	.96258	150.4
2.0	.92234		145.5	157.5	.95271	142.1	.95594	151.3	.96355	148.1
.5	85044	135	145.6	157.6	.92469	141.2	.93574	149.7	.96173	148.1
1.0	.89048		142.0	153.6	.94182	138.2	.94812	147.0	.96258	144.6
2.0	.92234		140.1	151.2	.95271	137.0	.95954	145.4	.96355	142.5

Results for this case are plotted in Figure 10

Entree $t_i = PC\ T_w + 10$

Beverage $t_i = .97\ T_w + 2$

Soup $\tau_i = .92 T_w + 6$

Meals prepared in insulated jacket and served in two groups of three, $W = 60$ LBS/HR $t_f = 75°F$

Total preparation time 34.0 minutes

Fruit entree' τ

At the point in time when meals are served

					LAST ENTREES		LAST BEVERAGE		LAST SOUP	
JACKETS	$\frac{\tau-\tau_f}{\tau_i-\tau_f}$	τ	τ_i	T_w REQ'D	$\frac{t-t_f}{t_i-t_f}$	τ	$\frac{\tau-\tau_f}{\tau_i-\tau_f}$	τ		
.5	.89424	140	147.7	160.1	.92469	143.2	.93974	152.0	.96173	150.3
1.0	.92242		145.5	157.5	.94182	141.4	.94812	150.6	.96258	148.1
2.0	.94045		144.1	155.9	.95271	140.8	.95594	149.8	.96355	146.7
.5	.89424	135	143.1	153.6	.92469	137.0	.93574	146.1	.96173	144.5
1.0	.92242		140.0	151.2	.94182	136.2	.94812	144.8	.96258	142.5
2.0	.94045		138.8	149.8	.955184	135.8	.95594	144.1	.96355	141.3

Results for this case are plotted in Figure 11

ONE MAN PREPARATION

Figure 10 shows that water temperatures required to furnish a first entree' temperature of 1 0°F yield last soup and beverage temperatures above 145° F for the range of jacket insulation thicknesses studied. The figure also shows that water temperatures required to furnish a first entree' temperature of 135° F can yield last soup temperature within the serving temperature band, but that last beverage temperatures would be above 145° F. Assuming that soup temperature is the parameter, all dish temperatures (except beverage) will be within the serving temperature band for a choice of jacket insulation thickness and water temperature of 0.925 in. and 154.0° F, respectively

W	Jacket	T	Hot Water	Source Penalty	Tray Penalty	Jacket Penalty	Total Penalty*
60	.925	1540	1.95LB	183 IN^3	5.76LB 1627 IN^3	4.15LB 1380 IN^3	12.36LB. 3190 IN^3

	(Jacket)		(Tray)		(Water Source)	(Water Gun)	
Hardware Weight =	4.15	+	5.76	+	.52	.5	= 10.93 lb.

Hot Water source requirement .24 PKW

Hot water resource electrical .375 KW/HR

Hot water source heat to cabin 6.37 BTU

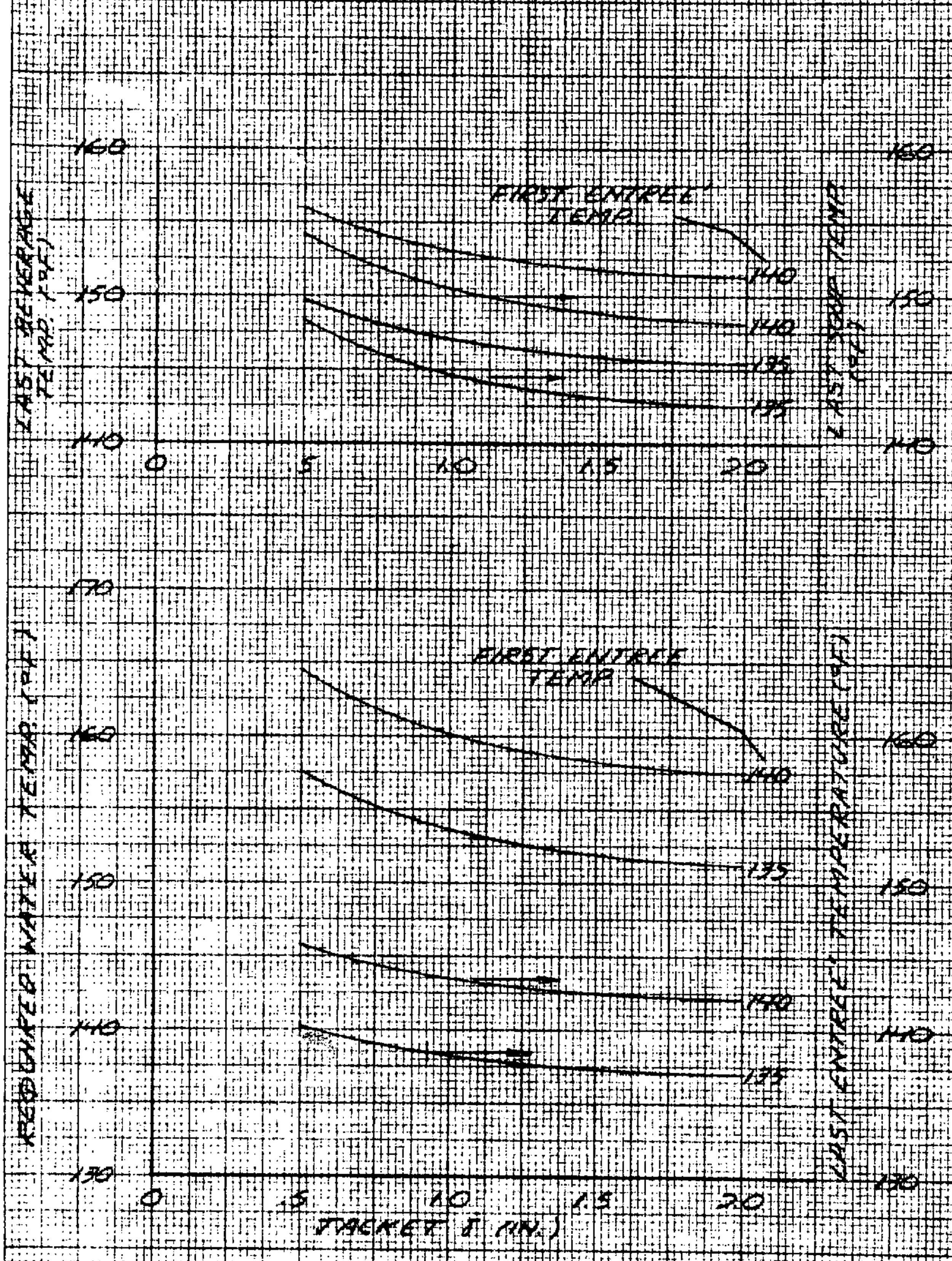
Note: Tray configuration is that of an uninsulated tray(See Insulated Tray Analysis)
Figure 19 (Ref) that an uninsulated 135° F entree' will not cool below 105° F by the end of a 20 minute dining period.

* Total penalty includes a 0.5 LB allowance for a water

FIGURE 10

MEALS PREPARED IN INSULATED JACKETS AND SERVED IN A GROUP OF SIX

W = 60 LB/HR



TWO MAN PREPARATION

Figure 11 shows that water temperatures required to furnish a first entree' temperature of 140° F yield last soup and last beverage temperatures above 145° F for the range of jacket insulation thickness studied. The figure also shows that water temperatures required to furnish a first entree' temperature of 135° F can yield last soup temperatures within the serving temperature band, but that last beverage temperatures would be above 145° F. Assuming that soup temperature is the governing parameter, all dish temperatures (except beverage) will be within the serving temperature band for a choice of jacket insulation thickness and water temperature of 0.425 in. and 154.2° F, respectively.

W	Jacket	T	Hot Water Source Penalty	Tray Penalty	Jacket Penalty	Total Penalty*
60	.425	154.2	1.95LB 183 in.	5.76LB 1627in.	3.29LB F52 in.	12.00LB 266.2 in.

	(Jacket)		(Tray)		(Water Source)		(Water Gun)		
Hardware Weight =	3.29	+	5.76	+	.52	+	1.0	=	10.57 lb.

Hot water source former requirement .248 KW

Hot water source electrical energy requirement .375 KW-HR

Hot water source heat to cabin 6.38 BTU

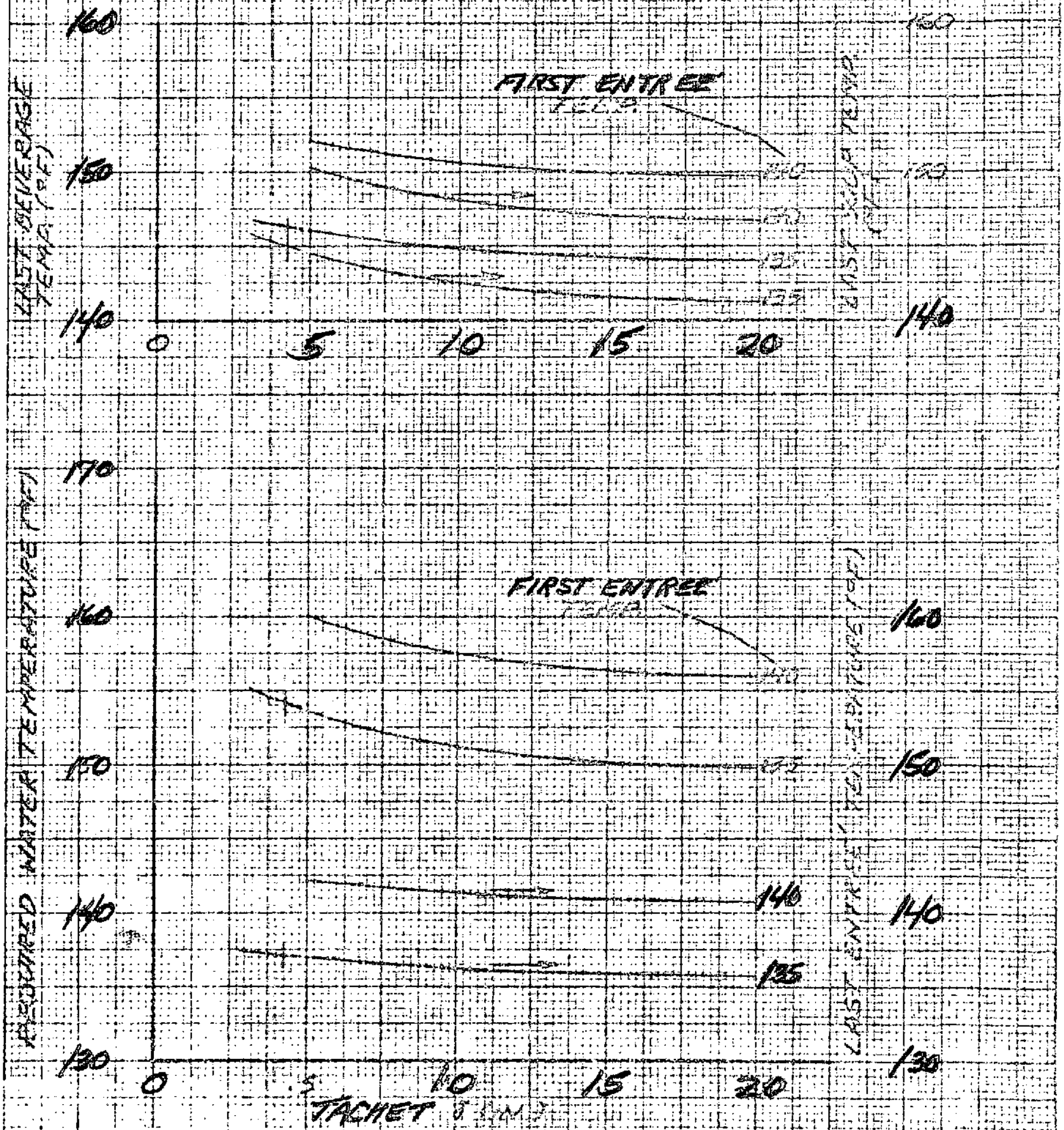
Note: Tray configuration is that of an uninsulated tray (see Insulated Tray Analysis) Figure 18 (Ref) shows that an uninsulated 135° F entree' will not cool below 105° F by the end of a 20 minute dining period.

* Total Penalty includes a 1.0 LB allowance for two water guns.

FIGURE 11.

MEALS PREPARED IN INSULATED JACKETS AND SERVED IN TWO GROUPS OF THREE

W = 60 LB/HR



3.1.2 Insulated Tray Analysis

Preparation Sequence for Individual Meals in Trays

1) All cans for a meal are placed in a tray.

2) Cans are opened and valves are unpacked

3) Water is added to entree', side dishes, soup and beverage

4) Beginning with entree', contents of a can are kneaded, replaced in can, and the valve repacked.

5) After all dishes are prepared, insulated cover is placed over tray.

Entree' is most critical because it has the lowest initial temperature. During water addition, entree' cools to cabin through open top and insulated sides and bottom of tray.

$$(h_B' A_T + h_A A_S + h A_T)(t_f - t) = V \rho c_p \frac{dt}{d\tau} \quad , \; h_B' = 1.80 \text{ BTU/HR FT}^2 \; {}^\circ\text{F, FROM TEST}$$

$$\frac{A_T}{V} = \frac{1}{L}$$

$$\frac{A_S}{V} = \frac{2}{r_1}$$

$$\frac{t_1 - t_f}{t_i - t_f} = \text{EXP}\left\{-\left(\frac{h_B'}{\rho C_p} \frac{1}{L} + \frac{h_A}{\rho C_p} \frac{2}{r_1} + \frac{h}{\rho C_p} \frac{1}{L}\right) \Theta_3\right\} \quad ,$$

Θ is sum of τ's for all dishes,

$t_i = .86 T_W + 10$ where T_W is water temperature. This relationship assumes dry food storage 70° F and applies to entree'.

Entree' cools during kneading

$$h_c A(t_f - t) = V \rho c_p \frac{dt}{d\tau} \quad , \quad h_c = 5.06 \text{ BTU/HR FT}^2 \; {}^\circ\text{F, FROM TEST}$$

$$\frac{A}{V} = \frac{2}{r_1} + \frac{2}{L}$$

$$\frac{t_2 - t_f}{t_1 - t_f} = \text{EXP}\left\{\frac{-h_c}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right) \tau_3\right\}$$

Entree' cools to cabin through open top and insulated sides and bottom tray while entree' valve is repacked and while other cans are kneaded and repacked.

$$\frac{t_3 - t_f}{t_2 - t_f} = \text{EXP}\left\{-\left(\frac{h_B'}{\rho C_p} \frac{1}{L} + \frac{h_A}{\rho C_p} \frac{2}{r_1} + \frac{h}{\rho C_p} \frac{1}{L}\right) \Theta_4\right\}$$

Prep. for Ind. Meals in Trays Cont'd

Θ_4 IS SUM OF $\tilde{\tau}_4$ FOR ENTREE' AND $\tau^{3's}$ AND τ_4's FOR ALL OTHER DISHES

Entree' cools through insulated cover and insulated sides and bottom of tray.

$$(2h\,A_T + h_A A_S)(t_f - t) = V\rho c_p \frac{dt}{d\tau}$$

$$\frac{t-t_f}{t_3-t_f} = EXP\left\{-\left(\frac{h}{\rho c_p}\,\frac{2}{L} + \frac{h_A}{\rho c_p}\,\frac{2}{r_1}\right)\tau\right\} \quad , \quad \tau = \Theta_3 + \tilde{\tau}_3 + \Theta_4$$

$$\Theta_3 = W_T/W$$

$$\Theta_4 = 5\tilde{\tau}_4 + 4\tilde{\tau}_3$$

Combining equations

$$\frac{t-t_f}{t_1-t_f} = EXP\left\{-\left(\frac{h_\beta'}{\rho c_p}\,\frac{1}{L} + \frac{h_A}{\rho c_p}\,\frac{2}{r_1} + \frac{h}{\rho c_p}\,\frac{1}{L}\right)\left(\frac{W_c}{W} + 5\tau_4 + 4\tilde{\tau}_3\right) - \frac{h_c}{\rho c_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_3 - \left(\frac{h}{\rho c_p}\,\frac{2}{L} + \frac{h_A}{\rho c_p}\,\frac{2}{r_1}\right)\tilde{\tau}\right.$$

In the time lines which follow, is defined for the first entree' prepared. This dish will be the coldest of all dishes by the end of the preparation period.

3.1.2.1

Preparation of Individual Meals in Trays

Rehydration Times:	Entree'	20 minutes
	Vegetables	15
	Soup	10
	Beverage	0

Preparation Times: assume τ_1 = .25 minutes to open a can and unpack valve.

τ_3 = .50 minutes to knead contents

τ_4 = .25 minutes to replace contents, repack valve.

τ_2 = W/W, time to add water, where W is the water requirement for the dish and W is the water flow rate.

Water requirements:	Entree'	W_E= 4.5 oz.	
	Side Dishes	W_D= 12.0	Total, W_T = 27.5 oz. per meal
	Soup	W_S= 3.4	
	Beverage	W_B= 7.6	

All dishes are contained in 401 x 105 cans, except soup, which is contained in a 211 x 105 can.

Time Lines W = 7LB/HR 1.867 oz/min.

	Cumulative Time	Cum. + Rehydration Time	
Open all cans and unpack valves:			
	1.25min.	1.25min.	
Add water to:			
Entree'	2.41	3.66	23.66 min.
Side Dish	3.21	6.87	21.87
Side Dish	3.21	10.08	25.08
Soup	1.82	11.90	21.90
Beverage	4.07	15.97	
Knead contents and repack valve	3.75	19.72	

Meal is fully reconstituted 25.08 min. after cans are placed in tray.

3.1.2.1 Cont'd

$\Theta_3 + \Theta_4 = 17.98 \text{ min}$
$\tau_3 = .5$
$\tau = 25.08 - 1.25 - 17.98 - .5 = 5.35$

W = 15 LB/HR   4 oz. 1 min.

		Cumulative Time	Cum. + Rehydration Tome	
Open all cans and unpack valves:		1.25 min.	1.25	
Add water to:	Entree	1.12	2.37	22.37
	Side Dish	1.50	3.87	18.87
	Side Dish	1.50	5.37	20.37
	Beverage	1.90	8.12	
Knead contents and repack valves		3.75	11.87	

Meal is fully reconstituted 22.37 minutes after cans are placed in tray.

$\Theta_3 + \Theta_4 = 10.12 \text{ MIN}$
$\tau_3 = .5$
$\tau = 22.37 - 1.25 - 10.12 - .5 = 10.50 \text{ MIN}$

W = 30 LB/Hr   8 oz./min.

		Cumulative Time.	Cum. + Rehydration Time	
Open all cans and un-pack valves		1.25 min.	1.25	
	Entree'	.56	1.81	21.81
	Side Dish	.75	2.56	17.56
	Side Dish	.75	3.31	18.31
	Soup	.42	3.73	13.73
	Beverage	.95	4.68	
Knead contents and repack valve		3.75	8.43	

Meal is fully reconstituted 21.86 min. after cans are placed in tray.

$\Theta_3 + \Theta_4 = 6.69$
$\tau_3 = .5$
$\tau = 21.81 - 1.25 - 6.69 - .5 = 13.42$

3.1.2.1 Cont'd

W = 60 LB/HR 16 oz./min.

	Cumulative Time	Cum. + Rehydration Time	
Open all cans and unpack valves	1.25 min.	1.25	
Add water to:			
Entree'	.28	1.53	21.53
Side Dish	.38	1.91	16.91
Side Dish	.38	2.29	17.29
Soup	.21	2.50	12.50
Beverage	.475	2.975	
Knead contents and repack valves	3.75	6.725	

Meal is fully reconstituted 21.53 minutes after cans are placed in trays.

$\Theta_3 + \Theta_4 = 4.97$ min

$\tau_3 = .5$

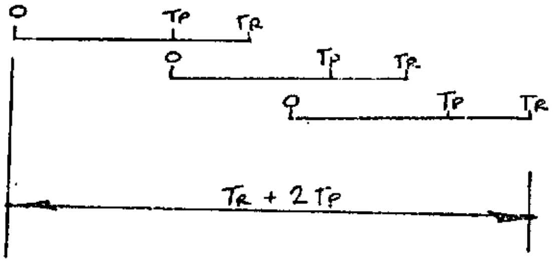
$\tau = 21.53 - 1.25 - 4.97 - .5 = 14.81$

3.1.2.2

Preparation of Meals in Trays-Three Meals at a Time

Define T_R as the time in which a meal is fully rehydrated

T_P as the time to prepare a meal, beginning with opening cans. Trays would be prepared in the sequence given below:



The three trays would be served after T_R + Tp minutes

First entree cools: During water addition for Θ_3
During kneading for τ_3
During kneading and repacking other Θ_4 } $T_P - 1.25$
cans for T_P covered for T_P while second tray is prepared stacked under second tray for T_P while third is prepared stacked under second and third trays for T_R - T_P + 1.25 while rehydration of third tray is completed.

Third entree'cools: During water addition for Θ_3
During kneading for τ_3
During kneading and repacking of other Θ_4 } $T_P - 1.25$
cans for $T_R - T_P + 1.25$ stacked on top of second and first trays for T_R - T_P + 1.25 while rehydration is completed.

Heat transfer between stacked, covered trays is negligible due to small temperature differences. Therefore for first and last trays:

$$(hA_T + h_A A_S)(t_f - t) = V\rho c_p \frac{dt}{d\tau}$$

$$\frac{t - t_E}{t_0 - t_f} = EXP\left\{-\left(\frac{h}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1}\right)\tau\right\}$$ WHERE t_0 IS THE INITIAL TEMPERATURE FOR THIS STEP.

, where t is the initial temperature for this step.

Combining equations as before:

FIRST ENTREE'

$$\frac{t - t_f}{t_i - t_f} = EXP\left\{-\left(\frac{h_\beta'}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1} + \frac{h}{\rho C_p}\frac{1}{L}\right)(\theta_3 + \theta_4) - \frac{h_c}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_5 - \left(\frac{h}{\rho C_p}\cdot\frac{2}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1}\right)T_P - \left(\frac{h}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1}(T_R + 1.25)\right\}$$

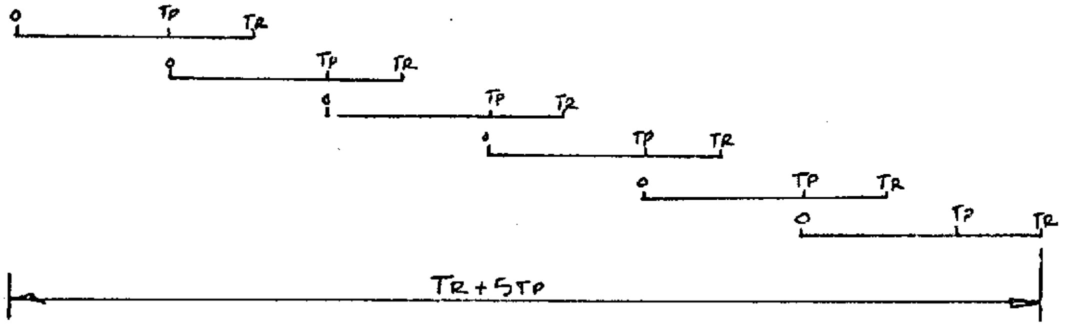
LAST ENTREE'

$$\frac{t - t_f}{t_i - t_f} = EXP\left\{-\left(\frac{h_\beta'}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1} + \frac{h}{\rho C_p}\frac{1}{L}\right)(\theta_3 + \theta_4) - \frac{H_c}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau\ 3\frac{h}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1}\right)(T_R - T_P + 1.25)\right\}$$

3.1.2.3

Preparation of Meals in Trays - Six Meals at a Time

Trays would be prepared in the sequence given below:



The six trays would be served after T_R + S T_P minutes

First entree' cools: During Water addition for θ_3

During kneading for τ_3

During kneading and repacking of other θ_4

$\Big\}$ Tp - 1.25

cans for covered for T_P while second tray is prepared stacked under subsequent trays for $4T_P$ while they are prepared, stacked under all trays for T_R - Tp + 1.25 while rehydration of last tray is completed.

Last entree' cools: During water addition for θ_3

During kneading for τ_3

During kneading and repacking of other θ_4 cans for stacked on top of fifth tray for T_R - T_P + 1.25 while rehydration is completed.

Combining equations as before:
First Entree'

$$\frac{t_c - t_f}{t_i - t_f} = EXP\left\{-\left(\frac{h_a'}{\rho C_p}\frac{1}{L} + \frac{h_a}{\rho C_p}\frac{2}{r_1} + \frac{h}{\rho C_p}\frac{1}{L}\right)(\theta_3 + \theta_4) - \frac{h_c}{\rho C_p}\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau_3 - \left(\frac{h}{\rho C_p}\frac{2}{L} + \frac{h_a}{\rho C_p}\frac{2}{r_1}\right)T_p - \left(\frac{h}{\rho C_p}\frac{1}{L} + \frac{h_a}{\rho C_p}\frac{2}{r_1}\right)\right.$$

$$\left. TR + 3T_p + 1.25)\right\}$$

3.1.2.4 Tray Weights

3.1.2.4.1 Insulated Tray

The insulated tray consists of a cover if insulation thickness τ , and a tray section having the cutouts in insulation shown in the half scale drawing in Figure 12. The cutouts are of can height, and the insulation thickness of the bottom of the tray section is also . All surfaces, including the can recesses are sheathed with .020 gage aluminum.

Tray weight is first calculated on the basis of the plan view area and perimeter shown in Figure 12, varying only the insulation thickness of the cover and the tray section bottom. Corrections are then made for the change in plan view area as at the sides of the tray is reduced . 5 inches for the δ = .5 case and increased 1.0 inches for the = 2.0 case.

Insulation density .6 LB/FT^3

Aluminum density 173 LB/FT^3

Perimeter for = 1.0 inch case: P = 44.6 in.
Plan view area for = 1.0 inch case: A = 149.6 in.^{2} } case depicted in Figure 12

Can height 1.3.12 in.

Top area of all cans 63.2 in.^{2}

Plan view surface area of cut-out insulation 149.6-63.2 = 86.4 in.^{2} Volume of cutout insulation 86.4 (1.312)=113.4 in.^{3}

	Vol. of Top Cover	Vol. of Tray Bottom	Total Volume	Ins. Weight
.5	74.8 in.^{3}	74.8 in.^{3}	263.0 in.^{3}	.0913 LB
1.0	149.6	149.6	412.6	.1433
2.0	299.2	299.2	711.8	..2472

Surface area of cover upper and lower surface and tray bottom 3(149.6) - 448.8

Edge surface area of cut out insulation 58.5 in.^{2}

Surface area of can recess 152.3 in.^{2}

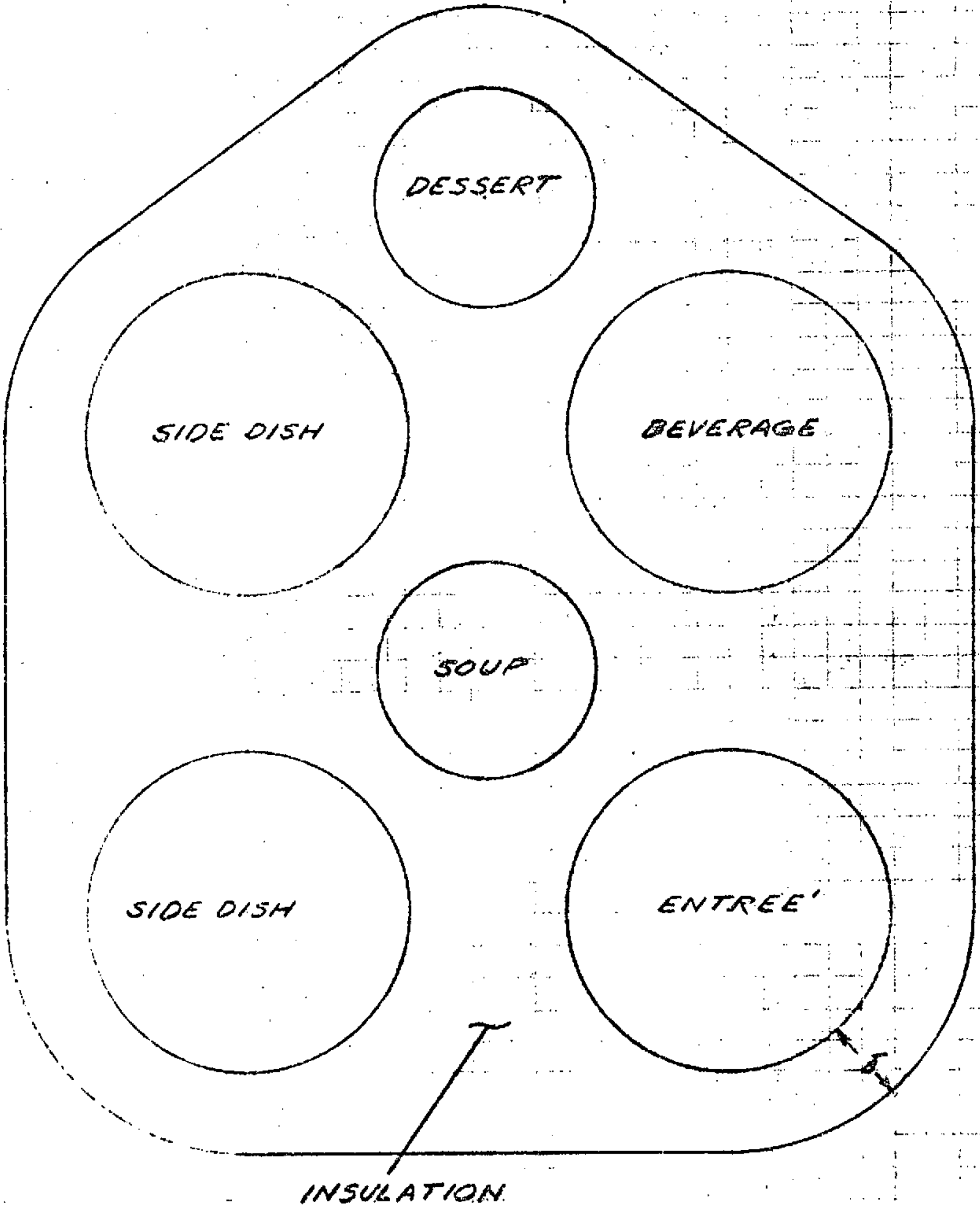
Surface area of cut-out insulation 86.4 in.^{2}

	Edge Surface Area of Cover	Edge Surface Area of Bottom	Total Surface Area
.5	22.3 in.^{2}	22.3	790.6 in.^{2}
1.0	44.6	44.6	835.2
2.0	89.2	89.2	924.4

	Sheath Weight	Tray Weight (constant plan area)
.5	1.583 LB	1.674 LB
1.0	1.672	1.816
2.0	1.851	2.098

FIGURE 12.

TRAY CONFIGURATION



δ IS INSULATION THICKNESS OF TRAY COVER AND TRAY BOTTOM

$\Delta A = HP\Delta\gamma$

Δ VOL. = $P\Delta\gamma (H)$, H IS OVERALL HEIGHT OF COVERED TRAY INSULATION

γ	$\Delta\gamma$	ΔA	Δ WEIGHT AL	H	ΔV	Δ WEIGHT INSUL
.5	-.5	- 892 IN^2	-.17968	2.312	-51.6	-.0179 LB
1.0	0	0	0	3.312	0	0
2.0	1.0	+178.4	+.35768	5.312	236.9	+.0823

γ	CORRECTED TRAY WT.	OVERALL HEIGHT	OVERALL VOLUME
.5	1.477 LBS	2.472	369.8 IN^3
1.0	1.816	3.472	519.4
2.0	2.537	5.472	818.6

3.1.2.4.2 Uninsulated Tray

The uninsulated tray consists of a sheet metal tray section having the can recesses shown in Figure 12 and of the same plan area. The height of the tray section is .5 inches greater than can height. The tray section has no bottom surface and is fabricated of .030 aluminum to impart rigidity.

Uninsulated Tray Weight .960 LB

Overall Volume 27.1. in.^{3}

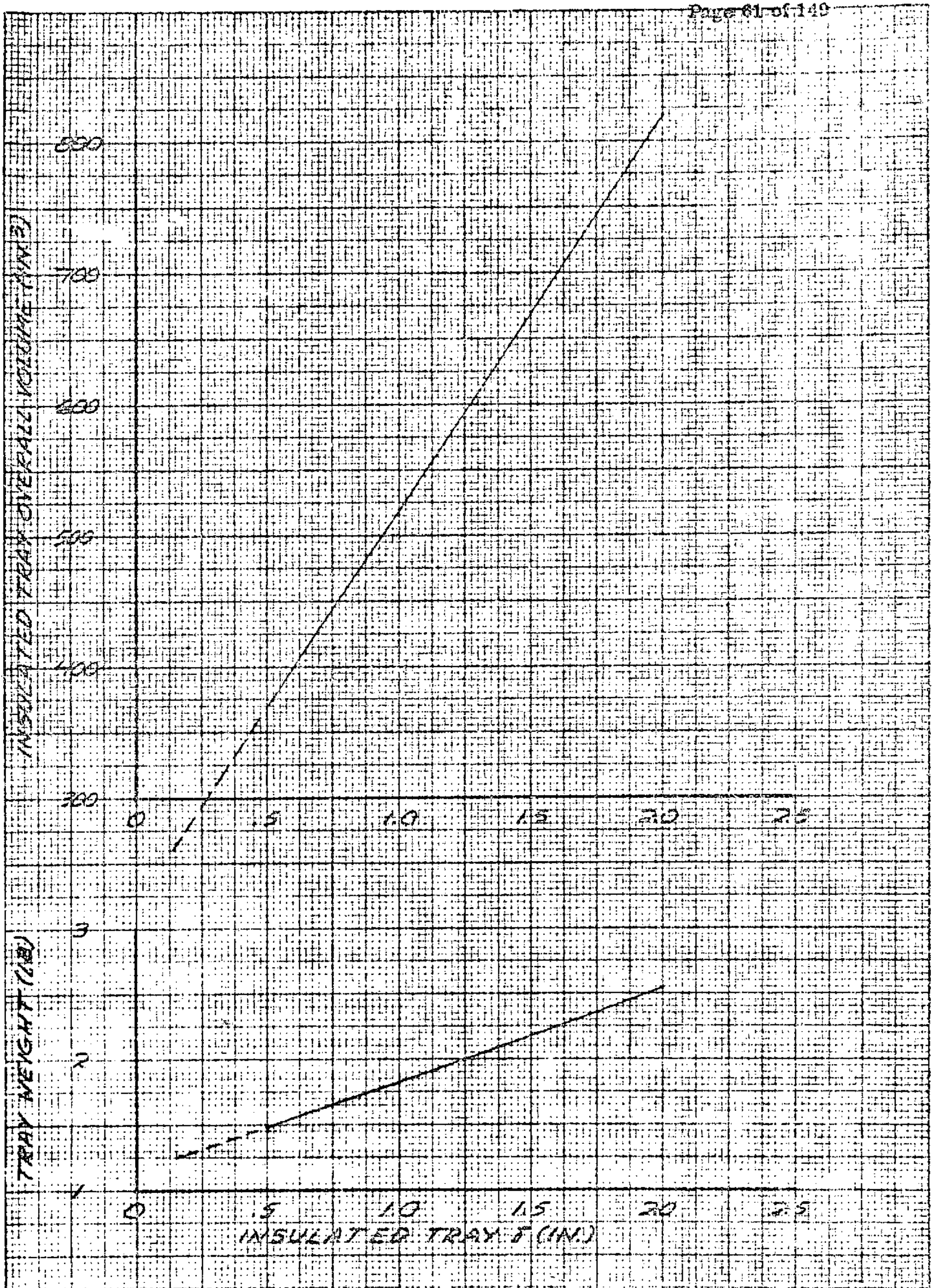
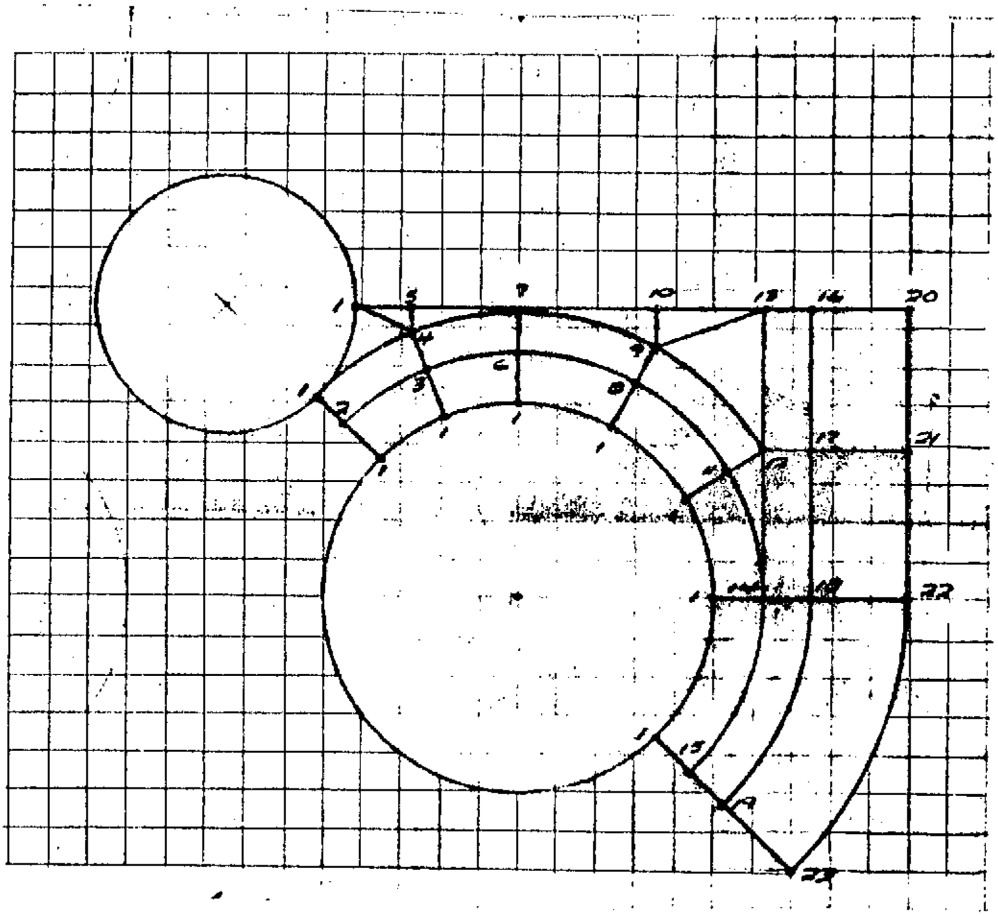


Figure 13. Insulated Tray — Weight and Volume

3.1.2.5 Thermal Network for Heat Loss Through Sides of Tray



Emissivity for heat loss from side of tray 0.2

Cabin side connective heat transfer coefficient 1.45 BTU/NR. FT.^{2} ^{o}F

Cabin temperature 70 ^{o} F.

Insulation thermal conductively 0.25 BTU-in./HR.Ft.^{2o}F

Overall Heat Transfer Coefficient for Heat Loss Through Sides of Tray.

Overall Heat Transfer Coefficient for Heat Loss Through Sides of Tray Cont'd.

$\delta = 0.5$ IN.
$h_A = 1.654 \{1.530(81-70) + .750(75-70) + 1.774(87-70) + (.994)(87-70)\} / \{2.031(\pi)(150-70)\}$
$h_A = .222$ BTU'S/HR FT^2 °F
FOLLOWING EQUATIONS ON BOTTOM OF SHEET.)

Overall Heat Transfer Coefficient for Heat Loss Through Bottom of Tray and Insulated Cover.

$\delta = .05''$
$h = .384$ BTU'S/HR FT^2 °F

$\delta = 1.0$ IN
$h = .217$

$\delta = 2.0$
$h = .116$

$\delta = 1.0''$
$h_A = 1.654 \{.750(75-70) + 1.530(77-70) + 1.970(79-70) + 1.190(78.5-70)\} / \{2.031(\pi)(80)\}$
$h_A = .137$

$\delta = 2.0$
$h_A = 1.654 \{.750(75-70) + 1.530(77-70) + 2.363(75-70) + 2.363(75.0-70)\} / \{2.031(\pi)(80)$
$h_A = .101$

3.1.2.6

Tray Design to Keep Food Hot for 20 Minutes after Removal from Oven.

$$(h_B' A_T + h_A A_S + h A_T)(t_f - t) = V \rho C_p \frac{dt}{d\tau}$$

$h_B' = 1.80$ BTU/HR FT^2 °F FROM TEST

$$\frac{A_T}{V} = \frac{1}{L}$$

$$\frac{A_S}{V} = \frac{2}{R_1}$$

$$\frac{t - t_f}{t_i - t_f} = EXP\left\{-\left(\frac{h_B'}{\rho C_p}\frac{1}{L} + \frac{h_B}{\rho C_p}\frac{2}{R_1} + \frac{h}{\rho C_p}\frac{1}{L}\right)\tau\right\}$$

t_1 IS OVEN TEMPERATURE

$t_f = 75°F$

$L = 1.312$ IN

$r_1 = 2.031$ IN

} 401x105 CAN

$\rho = 61.7$ PCF

$C_p = 1.0$ BTU/LB °F

$\tau = 20$ MINUTES

δ	h_A	h	$\left(\frac{H_B'}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{r_1} + \frac{h}{\rho C_p}\frac{1}{L}\right)\tau$	$\frac{t - t_f}{t_i - t_f}$
.5IN	.222	.384	.12209	.88507
1.0	.137	.217	.10841	.89726
2.0	.101	.116	.10112	.90392

δ	t_1	t
.5	135	128.1
1.0		128.8
2.0		129.2
.5	140	132.5
1.0		133.3
2.0		133.7
.5	145	137.0
1.0		137.8
2.0		138.3

UNINSULATED ENTREES' CAN, $h_A = h - h_B'$

$$\frac{t - t_f}{t_1 - t_f} = EXP\left\{-\left(\frac{h_B'}{\rho C_p}\right)\left(\frac{2}{r_1} + \frac{2}{L}\right)\tau\right\}$$

$$\frac{t - t_f}{t_i - t_f} = .74617$$

t_1	t
135	120 °F
140	123.5
145	127.2

L-2

FIGURE 14. ENTREE' TEMPERATURE AFTER COOLING 20 MINUTES IN AN UNCOVERED, INSULATED TRAY

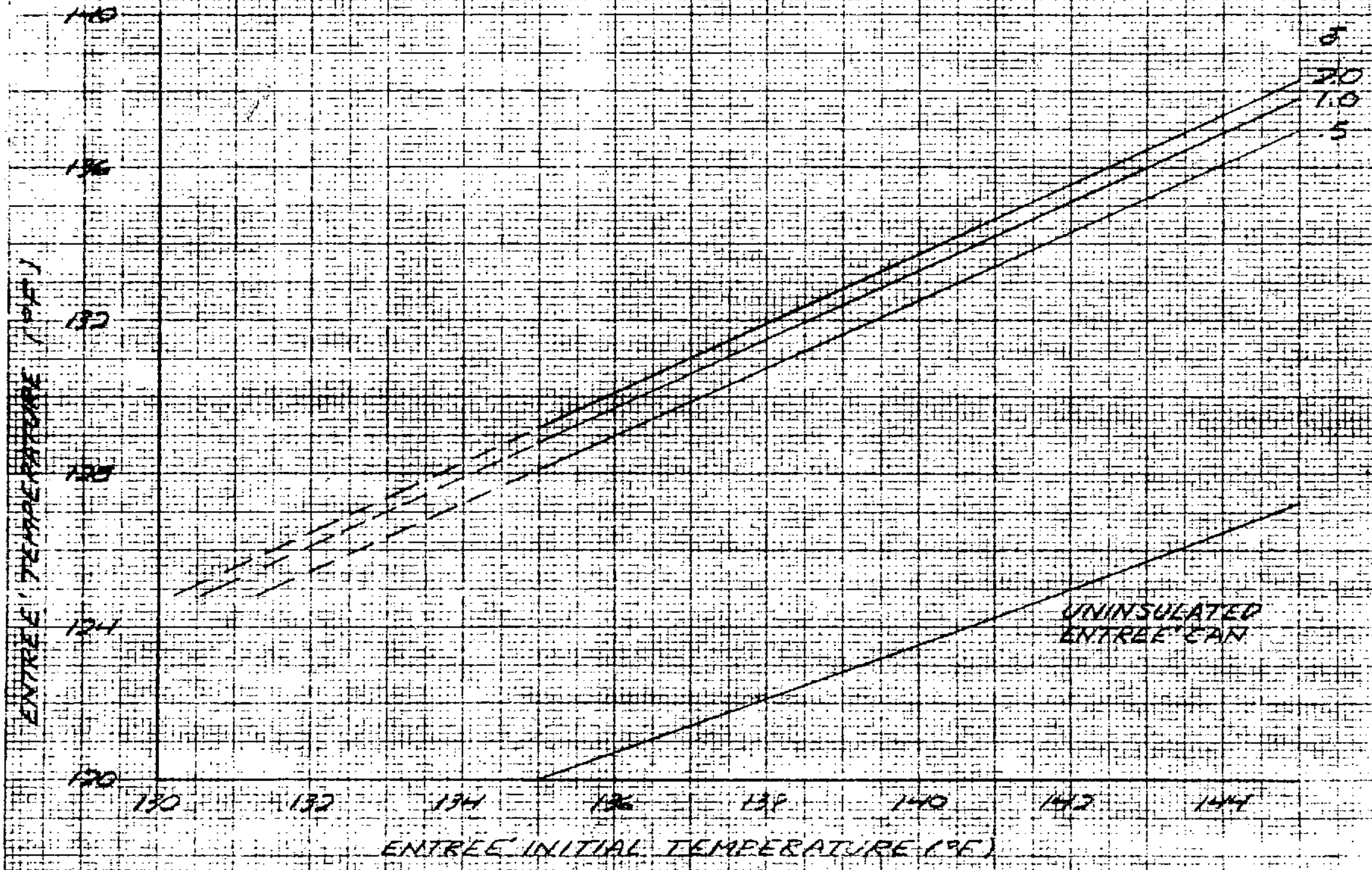


FIGURE 21.2-8

FIGURE 15.

ENTREE' TEMPERATURE AFTER COOLING 20 MINUTES IN AN UNCOVERED, INSULATED TRAY

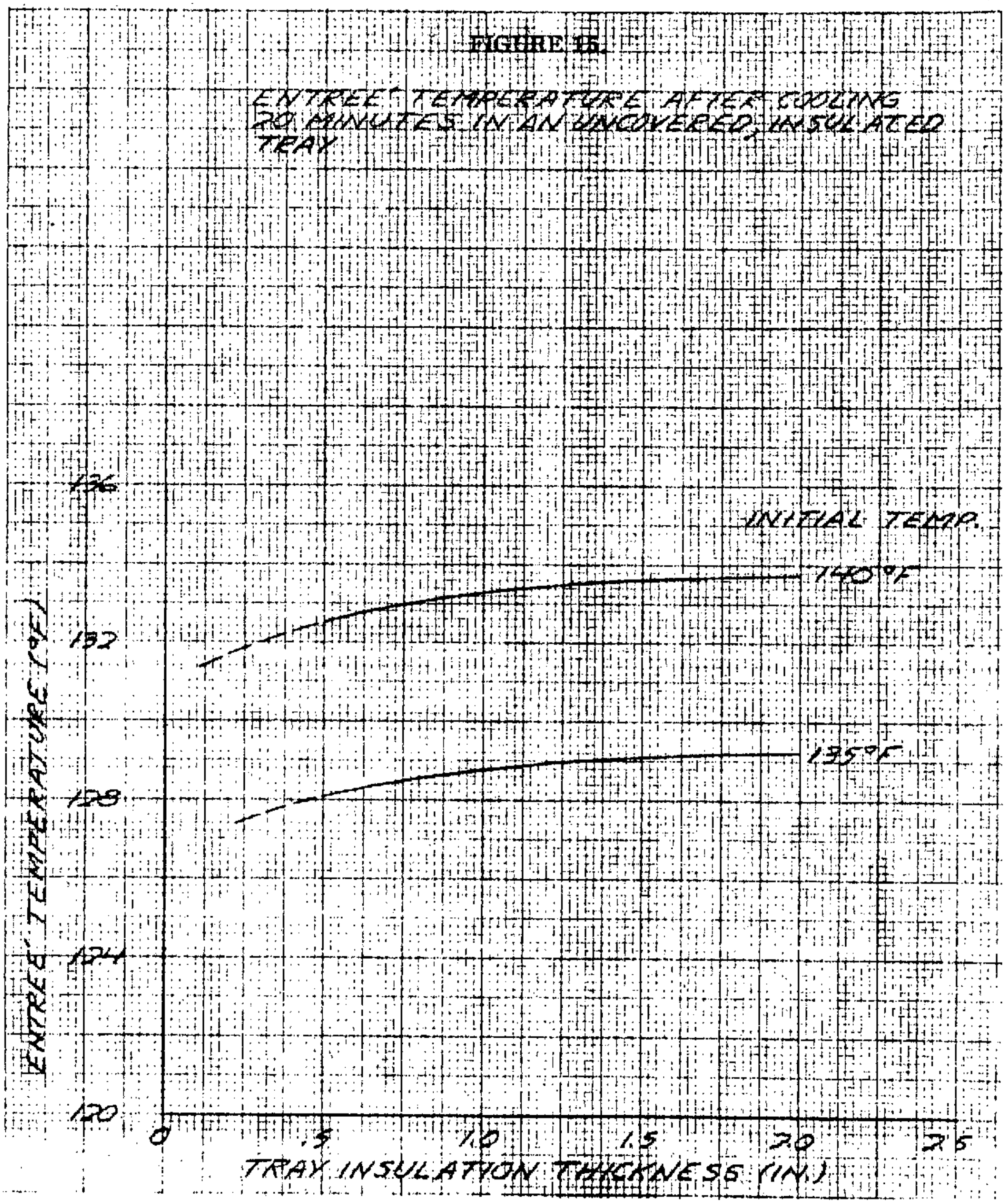


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Figure 16. MEALS PREPARED IN INSULATED TRAYS AND SERVED INDIVIDUALLY

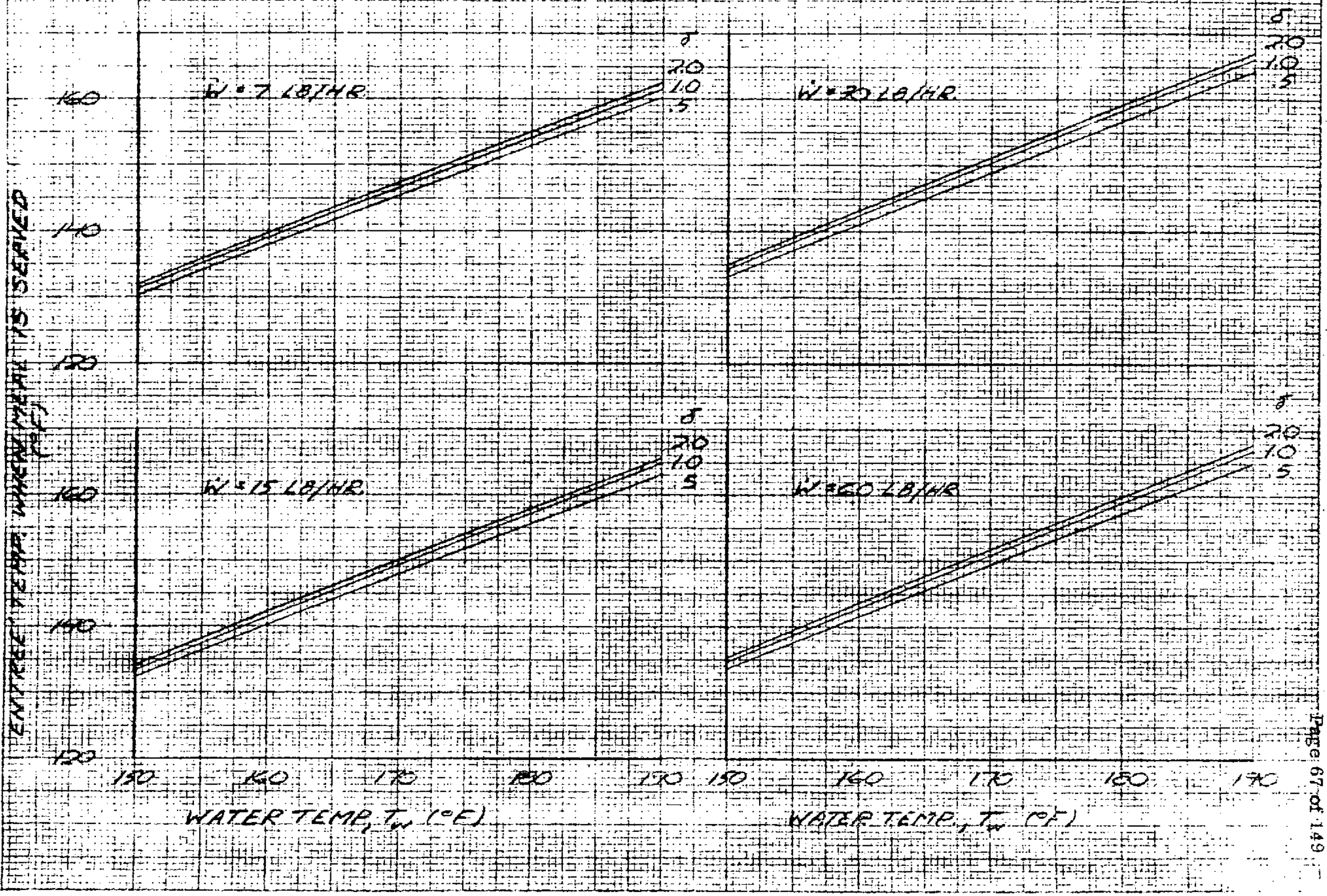


FIGURE 17. MEALS PREPARED IN INSULATED TRAYS AND SERVED IN GROUPS OF THREE

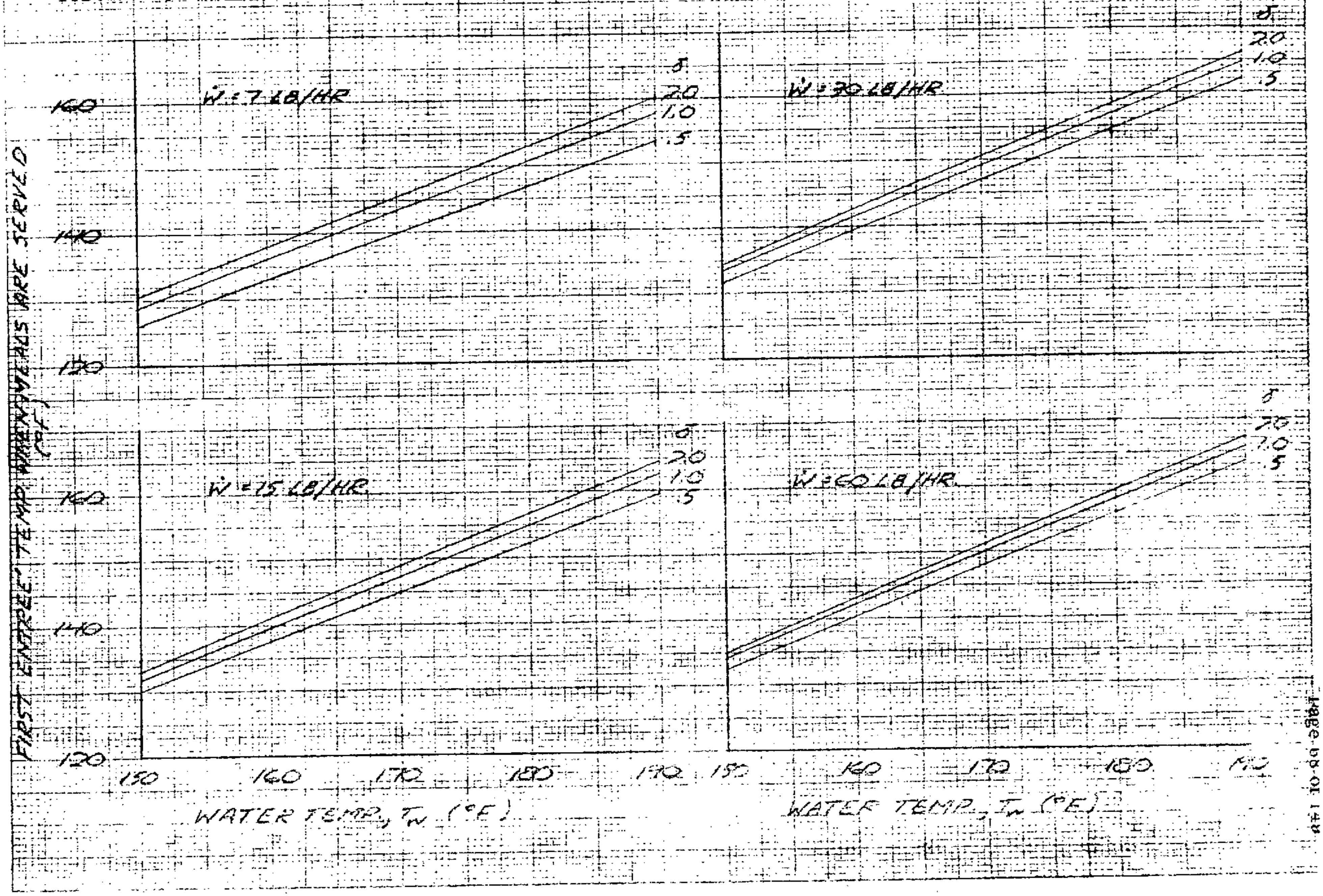


FIGURE 16. MEALS PREPARED IN INSULATED TRAYS AND SERVED IN GROUPS OF SIX

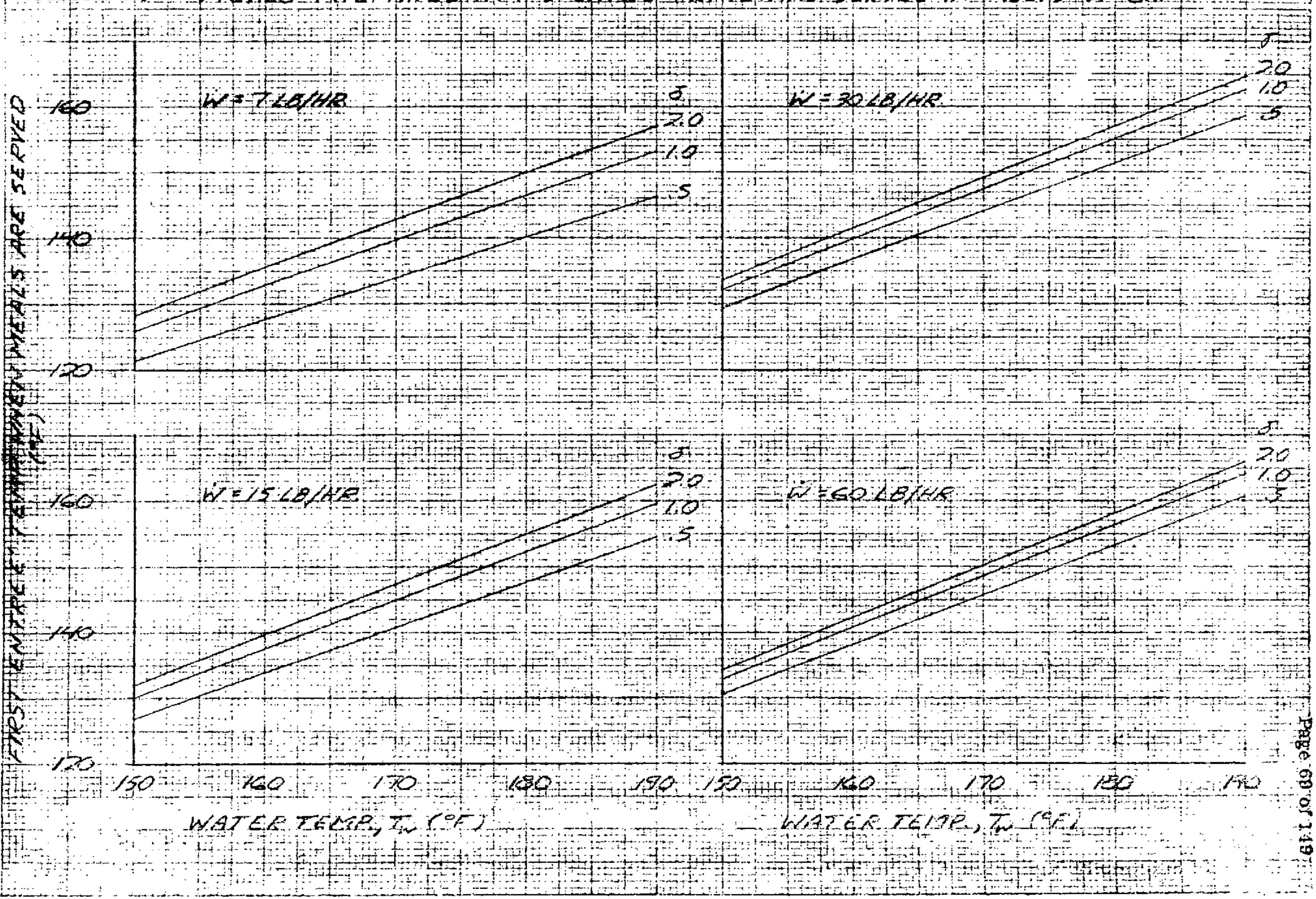
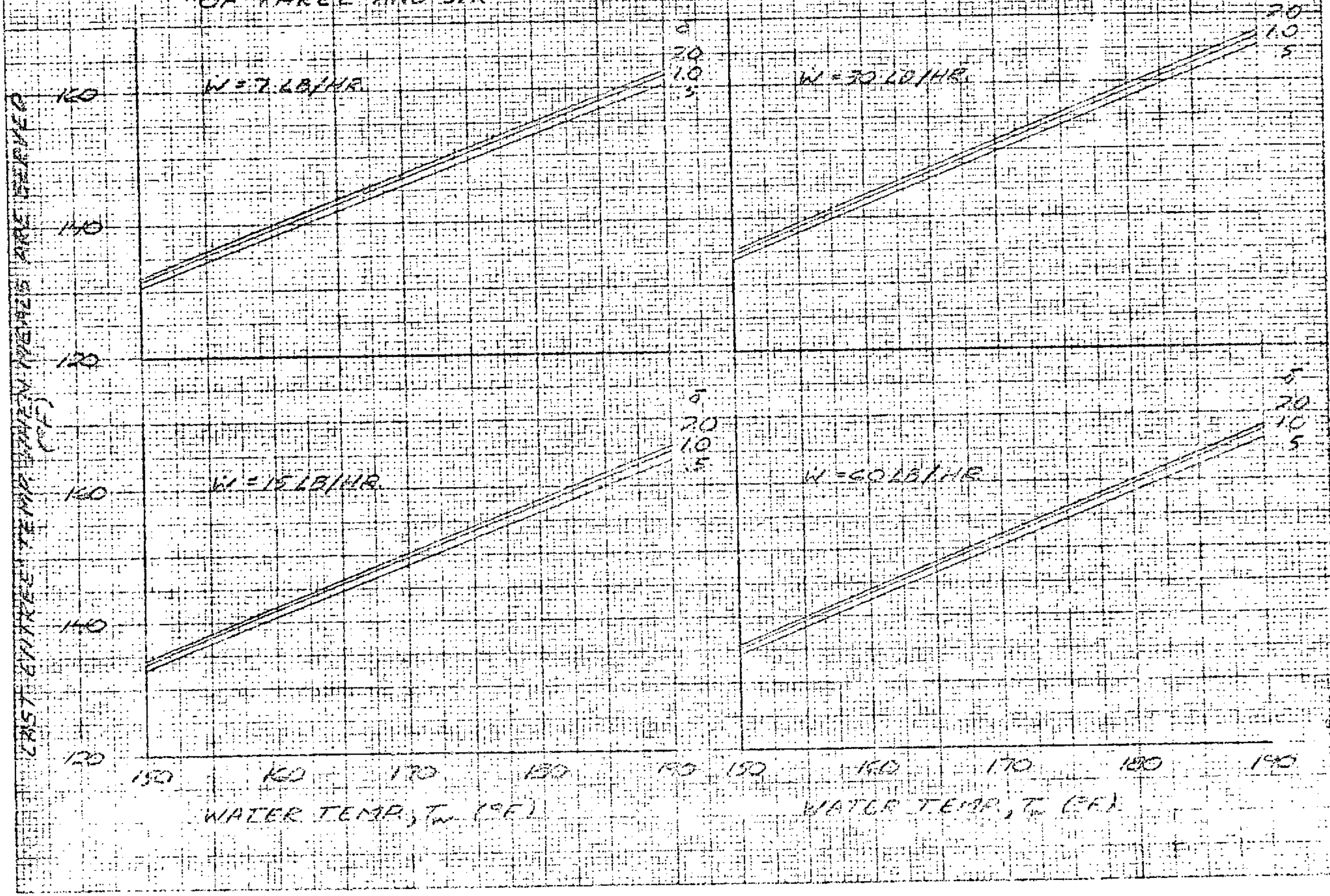


FIGURE 19. MEALS PREPARED IN INSULATED TRAYS AND SERVED IN GROUPS OF THREE AND SIX



3.1.2.7

Temperature Analysis - Insulated Tray

In order to complete the analysis, the temperatures of the hottest dishes as well as the coldest must be ascertained in order to determine that all are within the 135-145° F serving temperature band when meals are served. The hottest dishes when meals are served would be the beverage and soup of the last meal prepared. Attention will be restricted to the case characterized by a water flow rate of 60 LB/HR, and preparation and serving of meals in a group of six (one man preparation) since Table 5 shows that this case results in a total meal preparation time under one hour. For comparison purposes, results are furnished for a case characterized by a water flow rate of 60 LB/HR, and preparation and serving of meals in two groups of three (two man preparation). For this case, it was assumed that each man prepares three complete meals. The total preparation time would be half the value given in Table 5 for meals prepared and served in groups of three with a water flow rate of 60 LB/HR., or 35.0 minutes.

For both the case of one man preparation and two man preparation, results are furnished for water temperatures yielding 135° F and 145° F coldest entree' temperatures. This dish would be the first one prepared.

In preparation of last tray:

Beverage cools during water addition through open top and insulated sides and bottom of tray for τ_2 minutes.

$$\frac{t_2 - t_f}{t_1 - t_f} = EXP\left\{-\left(\frac{h_B'}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{R_1} + \frac{h}{\rho C_p}\frac{1}{L}\right)\tau_2\right\}$$

Beverage cools during kneading and repacking of entree', two side dishes, and soup through open top and insulated sides and bottom of tray for $\tau_3 + \tau_4$ minutes.

$$\frac{t_1 - t_f}{t_i - t_f} = EXP \{ -\frac{h'_B}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{R_1} + \frac{h}{\rho C_p}\frac{1}{L})(H)\tau_3 + \tau_4) \}$$

Beverage cools during kneading for τ_3 minutes.

$$\frac{T_3 - t_f}{t_2 - t_f} = EXP \{ -\frac{h_c}{\rho C_p}(\frac{2}{R_1} + \frac{2}{L})\tau_3 \}$$

Beverage cools during repacking through open top and insulated sides and bottom of tray for τ_4 minutes.

$$\frac{t_4 - t_f}{t_3 - t_f} = EXP \{ (\frac{h'_B}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_p}\frac{2}{R_1} + \frac{h}{\rho C_p}\frac{1}{L})\ \tau_4) \}$$

Beverage cools through insulated cover and insulated sides and bottom of tray until rehydration is complete

$$\frac{t - t_f}{t_4 - t_f} = EXP \{ -(\frac{h}{\rho C_p}\frac{2}{L} + \frac{h_A}{\rho C_p}\frac{2}{R_1})\tau \}$$

$\tau = T_R - T_P$

Combining equations

$$\frac{-t_f}{t_i - t_f} = EXP[-\frac{h'_B}{\rho C_p}\frac{1}{L} + \frac{h_A}{\rho C_1}\frac{2}{R_1} + \frac{h}{\rho C_p}\frac{1}{L}) \{ \tau_3 + h(\tau_3 + \tau_4) + \tau_4 \} \frac{-h_c}{\rho C_p}(\frac{2}{R_1} + \frac{2}{L})\tau_3 - (\frac{h}{\rho C_p}\frac{2}{R_1})\ \tau]$$

$t_1 = 2031$, $L = 1.312$

$t_i = .97 T_W + 2$

FOR $W = 60$ LB/HR

$T_P = 6.72$ MINUTES

$T_R = 21.53$ "

$\tau_2 = .475$

$\tau_3 = .5$ MINUTES

$\tau_4 = .25$ "

In preparation of last tray:

Soup cools during water addition through open top and insulated sides and bottom of tray for τ_2 minutes. From this point on, the soup cools according to the equation characterizing cooling of the beverage.

For the soup, $h_A = o$

$$\frac{t-t_f}{t_i-t_f} = EXP\left[-\left(\frac{h_B'}{\rho C_p}\frac{1}{L}+\frac{h}{\rho C_p}+\frac{1}{L}\right)\left\{(\tau_2)_5+(\tau_2)_8+H(\tau_3+\tau_4)+\tau_4\right\}-\frac{h_6}{\rho C_p}\left(\frac{2}{r_1}+\frac{2}{L}\right)\tau_3-\frac{h}{\rho C_p}\,\frac{2}{L}\,\tau\right],\ \tau = T_R - T_P$$

$r_1 = 1.344,\ L = 1.312$

$t_i = .92\,T_W + 6$

FOR W = 60 LB/HR, →

T_P = 6.72 MINUTES

T_R 21.53

$(\tau_2)_8$ .475

$(\tau_2)_5$ .21

τ_3 .5

τ_4 .25

Tray Surface Temperature in Vicinity of Beverage Container.

$$\frac{k}{\delta}\left(t_8 - t\right)+\left(h_B + E\ h_R\right)\left(t_f - t\right) = 0$$

$k = .25$ BTU-IN/HR. FT^2 °F

$h_B = 1.45$ BTU/HR FT^2 °F

$E = .20$

h_R RADIATION HEAT TRANSFER COEFFICENT, A FUNCTION OF t_f AND t.

$t_f = 75$ °F

LET $t = 105$°F

$h_R = 1.141$

$T_B = 105 + 50.345\ \delta/k$

δ	T_B
.1	125.1
.15	135.2
.2	145.3
.25	155.3
.3	165.4

Meals prepared in insulated trays and served in groups of six, w = 60 lb/HR, t_f = 75°F

First entree' t At the point in time when meals are served					Last entree' t		Last beverage t		Last soup t	
Tray t	$\frac{t-t_f}{t_i-t_f}$	t	t_i	Required T_w	$\frac{t-t_f}{t_i-t_f}$	t	$\frac{t-t_f}{t_i-t_f}$	t	$\frac{t-t_f}{t_i-t_f}$	t
.5	.86927	140	149.7	162.5	.92540	144.1	.92135	153.0	.92863	149.8
1.0	.90531		146.8	159.1	.93880	142.4	.93882	151.4	.94159	147.8
2.0	.92507	135	145.3	157.3	.94602	141.5	.94869	150.5	.94949	146.8
.5	.86927		144.0	155.8	.92540	138.8	.92135	147.0	.92863	143.8
1.0	.90531		141.3	152.6	.93880	137.7	.93882	145.4	.94159	142.1
2.0	.92507		139.9	151.0	.94602	136.4	.94869	144.7	.94949	141.4

Results for this case are plotted in Figure 20

Entree' t_i = .86 T_w + 10
Beverage t_i = .97 T_w + 2
Soup t_i = .92 T_w + 6

Meals prepared in insulated trays and served in two groups of three, w = 60 lb/HR, t_f = 75°F

First entree' t At point in time when meals are served					Last entree' t		Last beverage t		Last soup t	
Tray t	$\frac{t-t_f}{t_i-t_f}$	t	t_i	Required T_w	$\frac{t-t_f}{t_i-t_f}$	t	$\frac{t-t_f}{t_i-t_f}$	t	$\frac{t-t_f}{t_i-t_f}$	t
.5	.89924	140	147.3	159.6	.92540	141.9	.92135	150.0	.92863	147.3
1.0	.92326		145.4	157.4	.93880	141.1	.93882	149.8	.94159	146.4
2.0	.93651		144.4	156.3	.94602	140.7	.94869	149.6	.94948	146.0
.5	.89924	135	141.7	153.2	.92540	136.8	.92135	144.7	.92863	141.8
1.0	.92326		140.0	151.1	.93880	136.0	.93882	144.1	.94159	140.7
2.0	.93651		139.1	150.1	.94602	135.6	.94869	143.9	.94949	140.6

Results for this case are plotted in Figure 21

FIGURE 20.

MEALS PREPARED IN INSULATED TRAYS AND SERVED IN A GROUP OF SIX

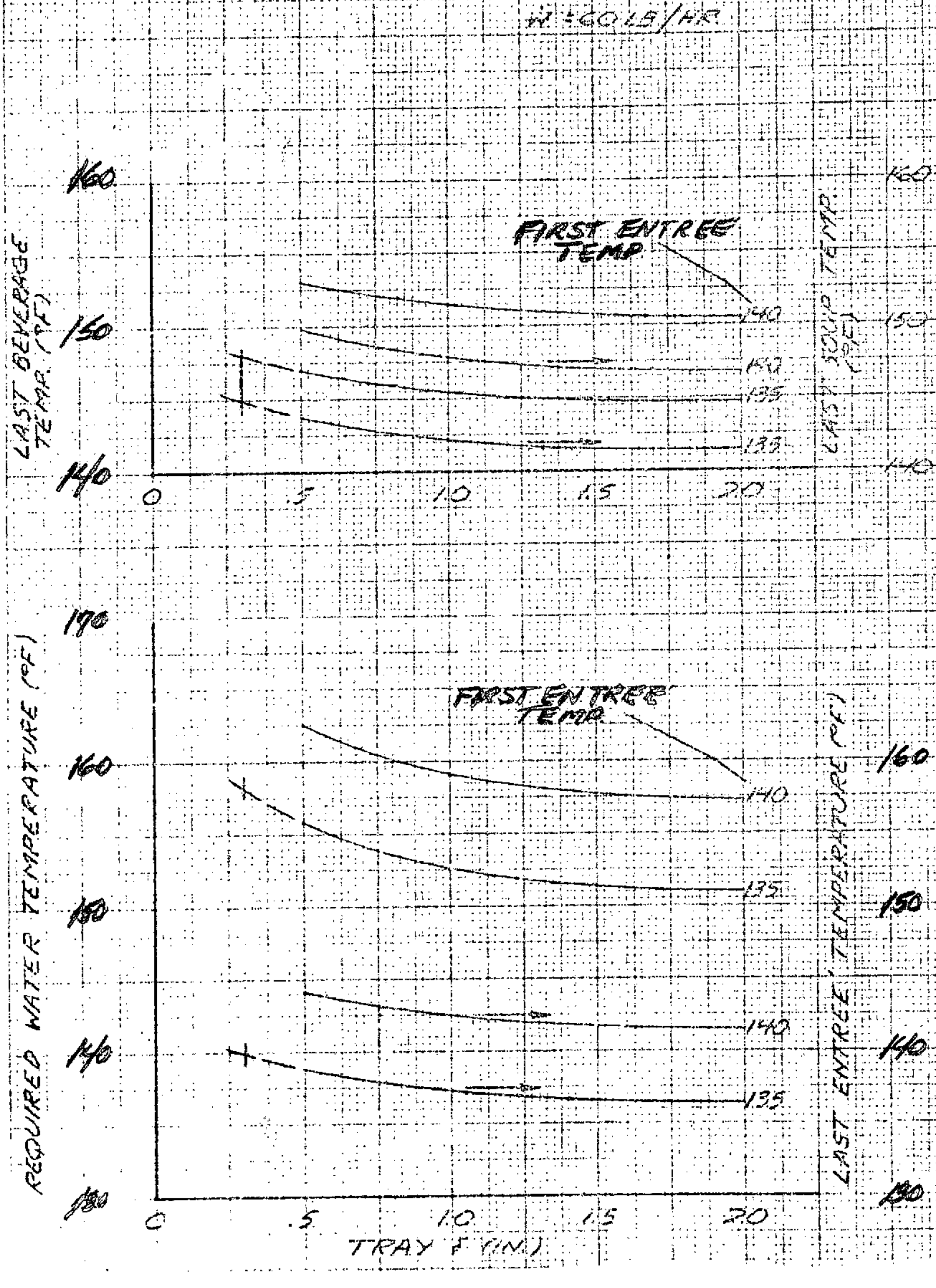
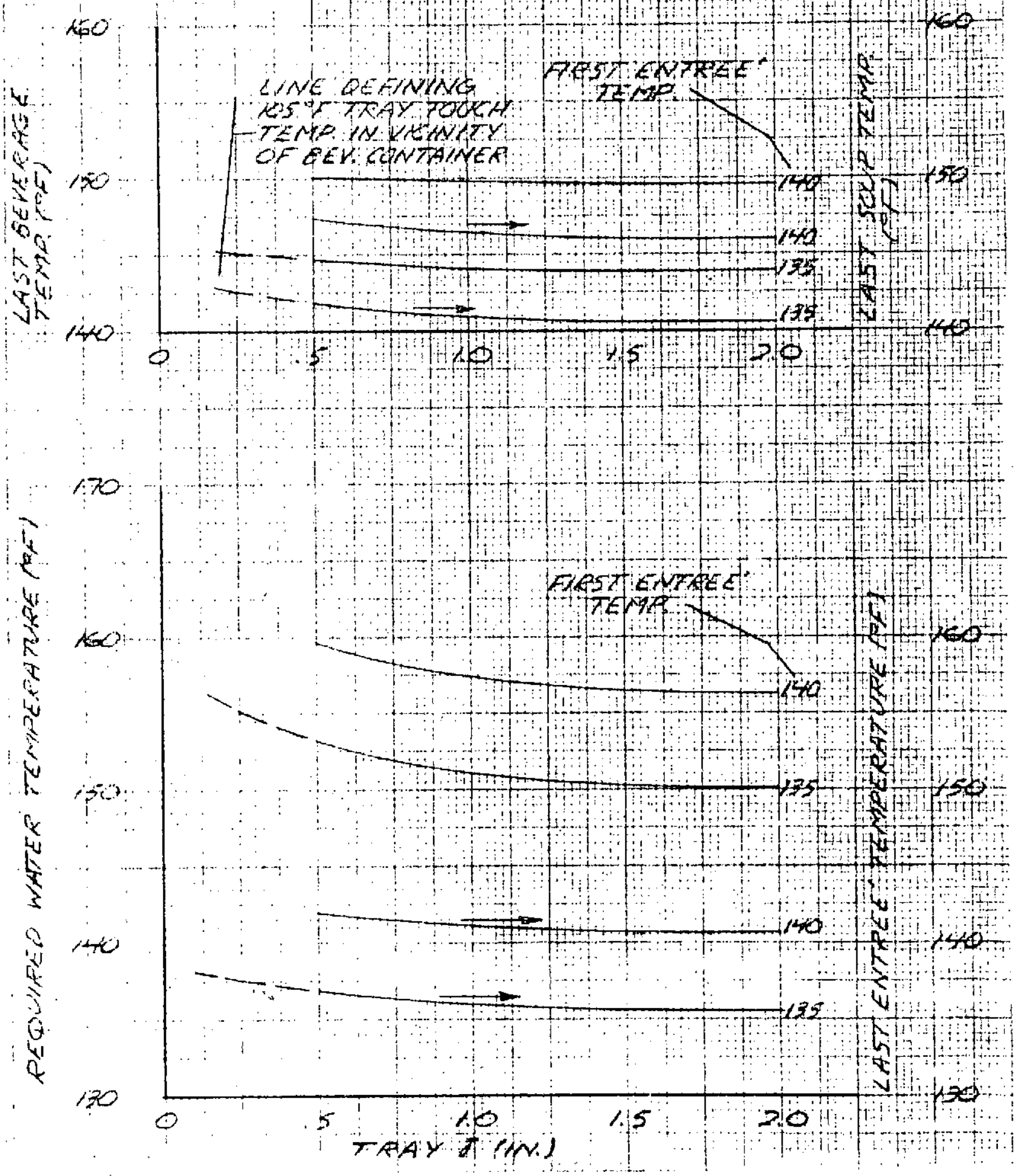


FIGURE 21.

MEALS PREPARED IN INSULATED TRAYS AND SERVED IN TWO GROUPS OF THREE

W = 60 LB/HR



3.1.2.8 Summary

ONE MAN PREPARATION

Figure 20 shows that water temperatures required to furnish a first entree' temperature of 140° F yield last soup and last beverage temperatures above 145 ° F for the range of tray insulation thicknesses studied. The figure shows also that water temperatures required to furnish a first entree' temperature of 135° F can yield last soup temperatures and last beverage temperatures within the serving temperature band. Assuming that soup temperature is the governing parameter, all dish temperatures (except beverage) will be within the serving temperature band for a choice of tray insulation thickness and water temperature of 0.30 in. and 158.2° F, respectively.

W	Tray	T_W	Hot Water Source Penalty		Tray Penalty		Total Penalty*	
60	0.30	158.2	2.00 LB.	188 in.^{3}	8.10 LB	1860 in^3	10.60 LB	2048 in^3

	(Tray)		(Water Source)		(Water Gun)		
Hardware Weight	8.10	+	.53	+	.5	=	9.13 LB

Hot water source power requirement .256 KW

Hot water source electrical energy requirement .388 KW - HR.

Hot water source heat to cabin 6.55 BTU

Note: Figure 15 shows that a 135° F entree' will not cool below 105°F by the end of the 20 minute dining period.

* Total penalty includes a 0.5 LB allowance for a water gun.

TWO MAN PREPARATION

Figure 21 shows that water temperatures required to furnish a first entree' temperature of 140° F yield last soup and last beverage temperatures above 145° F for the range of tray insulation thicknesses studied. Even though soup temperature can be made to approach within 1° F of 145° F, the latter figure will be considered to be an absolute limit in order to furnish a uniform criteria for evaluating food preparation systems. Figure 21 shows also that water temperatures required to furnish a first entree' temperature of 135° F can yield last soup temperatures and last beverage temperatures within the serving temperature band. Assume that soup temperature is the governing parameter. The figure shows that soup temperature would be within the band for small tray insulation thicknesses but that considerations of touch temperature in the vicinity of the hottest container place a lower bound of 0.20 in. an insulation thickness. Therefore, this insulation thickness and associated water temperature (155.7° F) will be selected as the governing parameters for the case of two man preparation

W	Tray	T_W	Hot Water Source Penalty		Tray Penalty		Total Penalty*	
60	0.20	155.7	1.97LB	185 in.^{3}	7.68 LB	1680 in^3	10.65LB	1865 in^3

(Tray) (Water Source) (Water Gun)

Hardware Weight 7.68 + .525 + 1.0 = 9.20 LB.

Hot water source power requirement .252 KW

Hot water source electrical energy requirement .380 KW -HR.

Hot water source heat to cabin 6.44 BTU

Note: Figure 15 shows that a 135° F entree' will not cool below 105°F by the end of a 20 min. dining period.

* Total penalty includes a 1.0 LB allowance for a water gun.

3.2 Semi-Active Heating System

3.2.1 Heated Cavity (Oven)

3.2.1.1

Preparation Sequence for Semi-Active Oven Analysis

Dishes are prepared in the following order: all entreés, all side dishes, all soups, all beverages.

When each group of six dishes is prepared it is placed in the semi-active oven to prevent cooking.

1) All cans in a group are opened and valves are unpacked.

2) Water is added to each can.

3) Contents of each can are kneaded, replaced in can, and the valve repacked.

Entreés are most critical because they have the lowest initial temperature.

Equations below are valid for all can groups:

During water addition entree' cools to cabin

$$h_B' A(t_1 - t_f) = PVC_p \frac{d\tau}{d\tau}, \quad h_B' = 1.80 \text{ BTU/HR FT °F}$$ FROM TEST

A IS CAN TOTAL SURFACE AREA.

V IS CAN VOLUME

$$\frac{t_1 - t_f}{t_i \quad t_f} = EXP\left\{ -\frac{h_B'}{\rho C_p} \frac{A}{V} \tau_W \right\}$$

$$\frac{A}{V} = \frac{2}{R_1} + \frac{2}{L},$$ WHERE r_1 AND L ARE CAN RADIUS AND HEIGHT RESPECTIVELY

$$\frac{T_1 - t_f}{t_i - t_f} = EXP\left\{ \frac{-h'_B}{\rho C_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \tau_W \right\}$$ DEFINITION OF τ_W CHARACTERIZES CAN WITHIN GROUP, i.e. FIRST, THIRD, LAST.

Entree' cools to cabin environment during kneading

$$h_c A(t_f - t) = V\rho C_p \frac{dt}{d\tau}, \quad h_c = 5.06 \text{ BTU/HRFT}^2 \text{°F}$$ FROM TEST

$$\frac{t_2 - t_1}{t_1 - t_f} = EXP\left\{ \frac{-h_c}{\rho C_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \tau_3 \right\}$$

Entree' cools to cabin environment during repacking, and kneading and repacking of subsequent cans.

$$h'_B A(t_f - t) = V\rho C_p \frac{dt}{d\tau}$$

$$\frac{t - t_f}{t_2 - t_f} = EXP\left\{ \frac{-h'_B}{\rho C_p} \left(\frac{2}{r_1} + \frac{2}{L} \right) \tau_P \right\}$$

3.2 Cont'd

3.2.1.1 Cont'd.

Combining equations

$$\frac{t - t_f}{t_i - t_f} = EXP\left[-\left\{\frac{h'_B}{\rho C_p}(\tau_W + \tau_P) + \frac{h_c}{\rho C_p}\tau_3\right\}\left(\frac{2}{r_1} + \frac{2}{L}\right)\right]$$

t_i = .86 T_W + 10, where T_W is water temperature. This relationship assumes dry food storage at 70° F, and applies to entree'.

For entree', r_1 = 2.031 in. and L - 1.312 in.

soup, r_1 = 1.344 in. and L = 1.312 in.

3.2.1.2 Preparation Times

Rehydration Times:	Entree'	20 minutes
	Vegetables	15
	Soup	10
	Beverage	0

Preparation Time: assume τ_1 = .25 minutes to open a can and unpack valve.

τ_3 = .50 minutes to knead contents

τ_4 = .25 minutes to replace contents and repack valve

τ_2 = W/W, where is the time required to add water, W is the water requirement for the dish, and W is the water flow rate.

Water requirements:	Entree	W_E = 4.5 oz.
	2Side Dishes	W_D = 12.0 oz.
	Soup	W_S = 3.4 oz.
	Beverage	W_B = 7.6 oz.

All dishes are contained in 401 x 105 cans, except for soup, which is contained in a 211 x 105 can.

Time Lines - Preparation by one man.

3.2 Cont'd

3.2.1.2 Cont'd

Define T_R as the time from the beginning of preparation to the point at which all dishes are prepared and fully rehydrated. T_R is the greatest of the following:

For Entree'

$$\tilde{T}_E = 6(\tilde{T}_1 - \tilde{T}_2) + 20$$

For Side dish

$$\tilde{T}_{D1} = 6(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4) + 6(\tilde{T}_1 + \tilde{T}_2)_{D1} + 15$$

For Side dish

$$\tilde{T}_{D2} = 6(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4)_E + 6(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4)_{D_1} + 6(\tilde{T}_1 + \tilde{T}_2)_{D_1} + 15$$

For Soup

$$\tilde{T}_S = 6(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4)_E + 12(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4)_{D1} + 6(\tilde{T}_1 + \tilde{T}_2)_S + 10$$

For Beverage

$$\tilde{T}_B = 6(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4)_E + 12(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4)_{D1} + 6(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}_4)_S + 6(\tilde{T}_1 + \tilde{T}_2 + \tilde{T}_3 + \tilde{T}$$

3.2.1.2 Cont'd

TABLE 7 (REF).

W		τ_2	$\tau_E, \tau_{D1}, \tau_{D2}, \tau_S, \tau_B$	τ_R
7	Entree'	2.41	35.96	118.32 min.
	Side Dish	3.21	36.22	
	Side Dish	3.21	81.48	
	Soup	1.83	93.40	
	Beverage	4.07	118.32	
15	Entree'	1.12	28.22	71.22
	Side Dish	1.5	38.22	
	Side Dish	1.5	53.22	
	Soup	.85	59.32	
	Beverage	1.90	71.22	
30	Entree'	.56	24.86	50.58
	Side Dish	.75	30.36	
	Side Dish	.75	40.86	
	Soup	.42	44.38	
	Beverage	.95	50.58	
60	Entree'	.28	23.18	40.35
	Side Dish	.38	26.46	
	Side Dish	.38	34.74	
	Soup	.21	37.00	
	Beverage	.475	40.35	

The first group of six cans (entreés) would be placed in the oven $6(\tau_1+\tau_2+\tau_3+\tau_4)_E$ minutes after the beginning of the preparation sequence.

Assume beverages are placed directly into trays after preparation.

3.2 Cont'd

3.2.1.2 Cont'd

Therefore, the oven operating time is

$$T_o = T_R - 6(\tau_1 + \tau_2 + \tau_3 + \tau_4)_E - 6(\tau_1 + \tau_2 + \tau_3 + \tau_4)_\Delta + 10$$

where 10 minutes are allowed for warmup.

W	T
7	77.44 minutes
15	51.10
30	39.52
60	33.82

The temperature at which entreés are served are selected as 135 and 140° F. Since the function of the semi-active oven is to prevent further cooling, the coldest entree in the group of six must not be at a temperature less than serving temperature. The coldest entree prepared would be the first and its cooling times as a function of water flow rate are:

$\tau_W = 6\tau_2$ (This definition of τ_w characterizes the first
$\tau_3 = .5$ can prepared in each group of six cans)
$\tau_P = \tau_4 + 5(\tau_3 + \tau_4)$

W	τ_W	τ_3	τ_P
7	14.46	.5	4.00
15	6.72	"	"
30	3.36	"	"
60	1.68		

From the equation characterizing cooling, and for a cabin temperature, t_f = 75° F, the initial temperature necessary to furnish a 135 or 140°F entree' temperature at the end of the preparation period can be determined. Once t_i is known, the water temperature required can be determined.

		140° F entree'		135°F entree'	
W	$\frac{t-t_f}{t_i-t_f}$	t_i	T_W	t_i	T_W
7	.74764	161.9	176.7	155.3	168.9
15	.83735	152.6	165.8	146.7	158.9
30	.87957	148.9	161.5	143.2	154.9
60	.90147	147.1	159.4	141.6	153.0

The weight P_W and V_W penalties associated with water usage are given in Figure 34 in the Water Tank Analysis as a function of T_W:

	140° F Entree'		135° F Entree'	
W	P_W	V_W	P_W	V_W
7	2.23LB	215 In^3	2.13	203
15	2.10	199	2.01	190
30	2.05	193	1.95	184
60	2.01	190	1.93	182

Cooling times and temperatures for the last entree' prepared are: (This definition of τ_w characterizes the last can prepared in each group of six cans).

$\tau_w = \tau_2$ (THIS DEFINITION OF TW CHARACTERIZES THE LAST CAN PREPARED IN OPENING OF SIX CANS.)

$\tau_3 = .5$

$\tau_p = \tau_4 + 5(\tau_3 + \tau_4)$

					140° ENTREE'		135° ENTREE'	
W	τ_w	τ_3	τ_p	$\frac{t-t_f}{t_i-t_f}$	t_i	t	t_i	t
7	2.41	.5	400	.09188	161.9	152.5	155.3	146.6
15	1.12			.90888	152.6	145.5	146.7	140.3
30	.56			.91637	148.9	142.7	143.7	137.5
60	.28			.92013	147.1	141.3	141.6	136.3

The cooking times and temperatures for the first and last cans prepared in the other groups of six and given in Table 8 for water flow rates of 30 and 60 LB/HR. Table 7 shows that the slower water flow rates extend preparation times beyond the realm of feasibility.

TABLE 8 - COOLING TIMES & TEMP. FOR FIRST & LAST CANS

DISH	$\dot{w}$	T_w	T_3	T_D	$\frac{t-t_f}{t_i-t_f}$	140°F entree'		135°F entree'	
						T_w	t	T_w	t
First entree'	30	3.16	.5	4.0	.87957	161.5	140.0	154.9	135.0
	60	1.68	↓	↓	.90147	159.4	143.0	153.0	135.0
Last entree'	30	.56			.91637	161.5	142.7	154.9	137.5
	60	.28			.92013	159.4	141.7	153.0	136.3
First side dish	30	4.50			.88500	161.5	141.3	154.9	136.3
	60	2.25			.89997	159.4	142.0	153.0	136.9
Last side dish	30	.75			.91382	161.5	145.1	154.9	139.8
	60	.375			.91885	159.4	143.8	153.0	138.6
First side dish	30	4.50			.88500	161.5	141.3	154.9	136.3
	60	2.25			.89397	159.4	142.0	153.0	136.9
Last side dish	30	.75			.91382	161.5	145.1	154.9	139.8
	60	.375			.91885	159.4	143.8	153.0	138.6
First soup	30	2.52			.86976	161.5	144.2	154.9	138.9
	60	1.26			.88744	159.4	144.0	153.0	138.9
Last soup	31	.42			.90227	161.5	146.9*	154.9	141.3
	60	.21			.90601	159.4	145.3	153.0	140.1
First beverage	30	5.70			.79721	161.5	141.7	154.9	136.6
	60	2.85			.88616	159.4	147.3	153.0	141.8
Last beverage	30	.95			.91115	161.5	151.3	154.9	145.4
	60	.475			.91751	159.4	149.9	153.0	144.2

* It is assumed that the temperature of this dish decreases in the oven to within the serving temperature band during the 10 minutes required to prepare six beverages. It is also assumed that beverage temperatures are not governing parameters. Under these assumptions, all cases are admissible.

3.2 Cont'd

3.2.1.3 Oven Weight & Volume

The oven inner dimensions are the same as those used in the active oven analysis: 17.4 x 14.2 x 3.87. The oven inner surface is assumed to be .040 gage fiberglass having the following properties:

ρ = 110LB/FT.^{3}

C_p = .25 BTU/LB$^{\circ}$ F

The oven outer surface is assumed to be .030 gage aluminum having the following properties

ρ = 173 LB/FT^3

C_p = .22 BTU/LB$^{\circ}$ F

The oven insulation has the following properties:

ρ = .6 LB/FT^3

C_p = .21 BTU/LB$^{\circ}$ F

K = .25 BTU - IN./HR. FT^2 $^{\circ}$F

Inner surface area 5.130 FT^2

Fiberglass weight 1.881 LB

δ	Outer Dimensions	Insulation Vol.	Outer Surf. Area
.25	17.9 x 14.7 x 4.37	193.7 In.^{3}	3.633 FT.^{2}
.5	18.4 x 15.2 x 4.87	405.8	6.157
1.0	19.4 x 16.2 x 5.87	888.6	7.267
2.0	21.4 x 18.2 x 7.87	2109.0	9.738

Ins. Wt.	Al. Wt.
.0673 LB.	2.436 LB.
.1409	2.663
.3085	3.143
.7323	4.212

3.2.1.3 Cont'd

Oven Weight and Overall Volume

γ	Weight, ρ_4	Volume
.25	4.384 LB	1149.9 In.^{3}
.5	4.685	1362.0
1.0	5.332	1844.8
2.0	6.825	3065.2

3.2.1.4 Weight Penalties Associated With Fuel Cell & ECS Interfaces

1) A power consumption penalty (1.514 LB/KW-HR) is incurred in heating the oven to equilibrium temperature from cabin temperature. This penalty is a function of insulation thickness and oven temperature. Cabin temperature is taken as 75° F and oven temperature as 135 and 140° F.

2) A power consumption penalty (1.514 LB/KW.=HR.) and an ECS penalty (.133 LB/BTU) are incurred in making up and absorbing the heat leak through the oven insulation. This penalty is a function of oven temperature, insulation thickness, and oven operating time (which is a function of heated water flow rate). Oven temperature is 135 and 140° F.

3) An ECS penalty (.133LB/BTU) is incurred as the heated oven cools from equilibrium temperature to cabin temperature after meal preparation. This penalty is a function of insulation thickness and oven temperature.

Penalty (1): 140° F oven temperature

Equilibrium Temperature, t, and energy consumption,

KW.-HR.

$$\frac{k}{\delta}\left(\tau_f - t\right) + \left(h_B + E h_R\right)\left(t_F - \tau\right) = 0$$

$h_B = 1.45$ BTU/HRFT^2 °F
$E = .20$ EMMISIVITY OF OUTER OVEN SURFACE
$t_f = 75$°F
$\tau_o = 140$°F

δ	k/δ	τ	CAPACITANCE AL	$\bar{t}$	CAP INS	CAP FIB.
.25	1.0	99.3°F	.5360	119.6	.0141	.4702
.5	.5	90.0	.5858	115.6	.0296	
1.0	.25	83.5	.6915	111.8	.0648	
2.0	.125	79.5	.9266	109.8	.1537	

Penalty, P_1

δ	E	P_1
.25	.01295 KW -HR	.01961 LB.
.5	.01187	.01797
1.0	.01122	.01721
2.0	.01175	.01779

$t = \frac{1}{2}(t \quad + t)$

Insulation is taken to heat from t_f to $\bar{t}$

Fiberglass heats from t_f to t_o

Aluminum heats from t_f to t

$$E = \left\{ (1\,\text{CAP. AL})\left(\bar{t} - t_f\right)\left(\text{CAP. FIBERGLASS}\right)\left(\tau_o - t_f\right) \right\} / 3413$$

Penalty (3): 140° F oven temperature

3.2 Cont'd

3.2.1.4 Cont'd

The same energy that heats the oven to equilibrium temperature is dissipated to the cabin during cooling. It is assumed that this energy is dissipated to the cabin at a uniform rate over an eight hour period.

From the analysis for Penalty (1)

γ	E/8	P_3
.25	5.525 BTU	.7348 LB
.5	5.062	.6733
1.0	4.850	.6450
2.0	5.012	.6667

Penalty 2: 140° F oven temperature

The heat leak ratio from the oven is given by where A is the outer surface area and t is the equilibrium temperature of the insulation outer surface tabulated in the analysis for Penalty (1).

W	γ	t	T_o	k/γ	A	E	E/8	P_2
7	.25	99.3°F	77.44 min.	1.0	5.633	.OPE7 KW-HR	36.99BTU	5.051 LB
	.5	90.0	"	.5	6.157	.0582	24.83	3.391
	1.0	83.5	"	.25	7.267	.0388	16.56	2.261
	2.0	79.5	"	.125	9.738	.0278	11.88	1.622
15	.25	99.3	51.10	1.0	5.633	.0572	24.41	3.333
	.5	90.0	"	.5	6.157	.0384	16.38	2.237
	1.0	83.5	"	.25	7.267	.0256	10.93	1.492
	2.0	79.5	"	.125	9.738	.0183	7.839	1.070
30	.25	99.3	39.52	1.0	5.633	.0442	18.88	2.578
	.5	90.0	"	.5	6.157	.0297	12.67	1.730
	1.0	83.5	"	.25	7.267	.0198	8.451	1.154
	2.0	79.5	"	.125	9.738	.0142	6.063	.8279

3.2 Cont'd

3.2.1.4 Cont'd

W	τ	t	T	k/τ	A	E	E/8	P_2
60	.25	99.3	33.82	1.0	5.633	.0379	16.15	2.205
	.5	90.0	"	.5	6.157	.0254	10.84	1.480
	1.0	83.5	"	.25	7.267	.0169	7.232	.9874
	2.0	79.5	"	.125	9.738	.0121	5.188	.7083

In evaluating the ECS penalty, it was assumed that energy dissipated to the cabin would be dissipated at a uniform rate over an eight hour period.

3.2.1.4.1 Summary - Weight & Power Penalty

W	τ	P_1	P_2	P_3	P_4	Total Wt. Penalty
7	.25	.01961	5.051	.7348	4.384	10.19 LB
	.5	.01797	3.391	.6733	4.685	8.767
	1.0	.01721	2.261	.6450	5.332	8.255
	2.0	.01779	1.622	.6667	6.825	9.131
15	.25	.01961	3.333	.7348	4.384	8.471
	.5	.01797	2.237	.6733	4.685	7.613
	1.0	.01721	1.492	.6450	5.332	7.486
	2.0	.01779	1.070	.6667	6.825	8.579
30	.25	.01961	2.578	.7348	4.384	7.716
	.5	.01797	1.730	.6733	4.685	7.106
	1.0	.01721	1.154	.6450	5.332	7.148
	2.0	.01779	.8279	.6667	6.825	8.337
60	.25	.01961	2.205	.7348	4.384	7.343
	.5	.01797	1.480	.6733	4.685	6.856
	1.0	.01721	.9874	.6450	5.332	6.982
	2.0	.01779	.7083	.6667	6.825	8.218

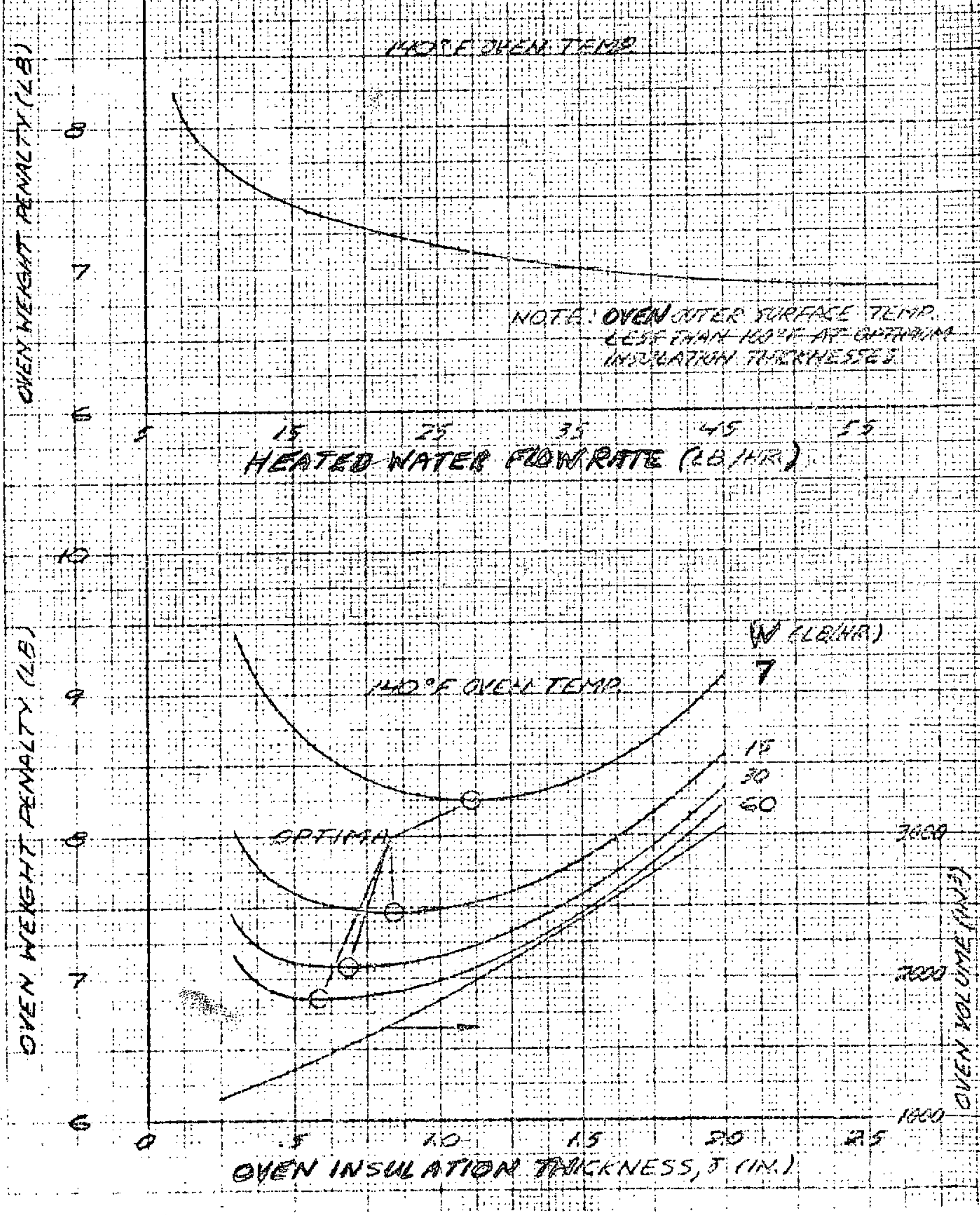
3.2.1.4.1 Cont'd

The total penalty is plotted in Fig. 22 as a function of insulation thickness and heated water flow rate. The optimum insulation thicknesses are determined from this figure, and the oven weight penalties associated with these optimum are given in Figure 22 as a function of heated water flow rate.

Power requirements are shown in Figure 23.

FIGURE 22.

OPTIMUM OVEN WEIGHT PENALTY



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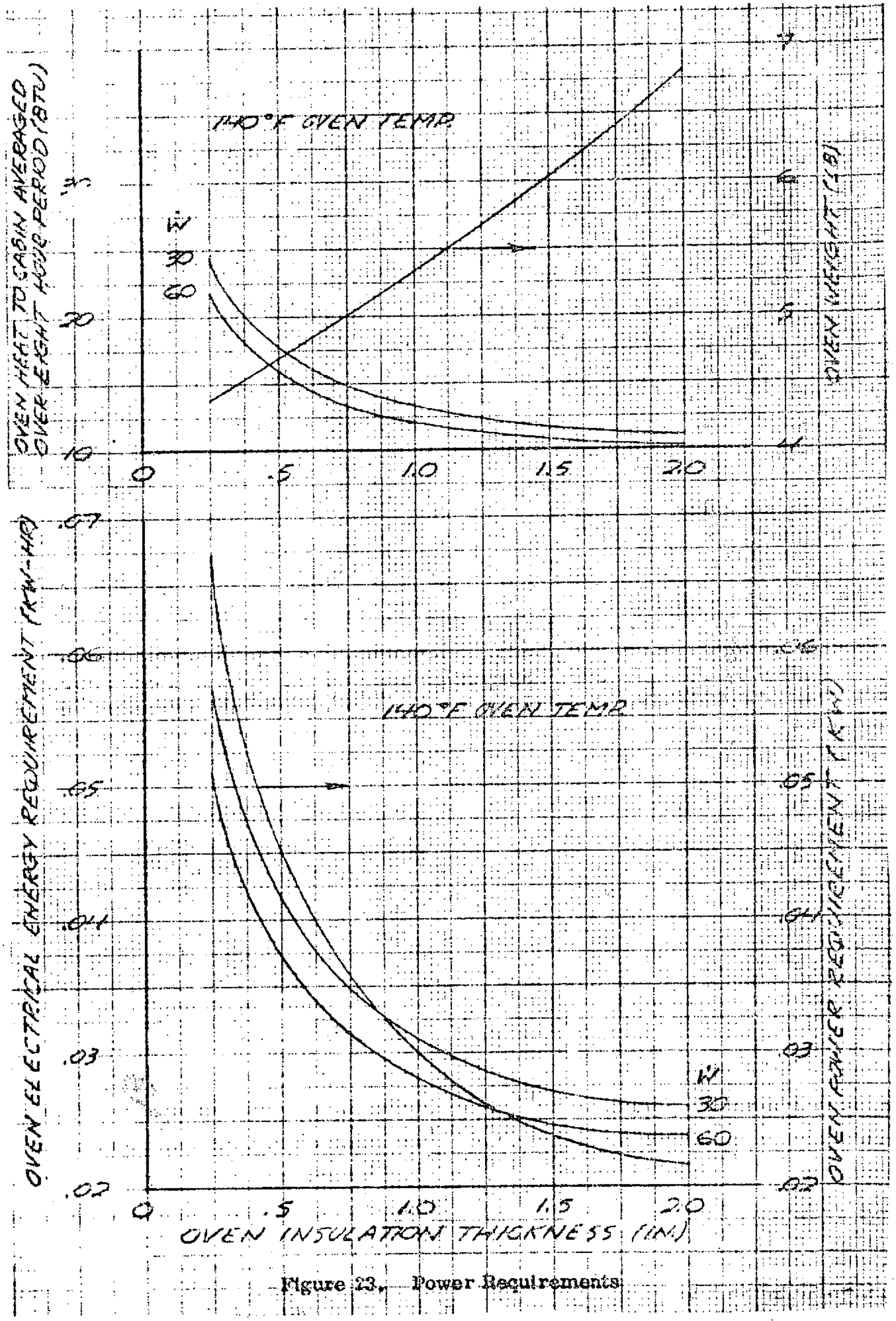


Figure 23. Power Requirements

3.2.1.5

ONE MAN PREPARATION (140° F Entree)

140°F First Entree' Temperature

W	T_w	Hot Water	Source Penalty	Tray Penalty		Optimum Oven	Oven Penalty		Total Penalty*	
30	161.5	2.05LB	193 In.^{3}	5.76LB	1627in^3	.688 in.	7.07LB	1520in^3	15.38LB	3340 in^3
60	159.4	2.01	190	5.76	1627	.588	6.85	1430	15.12LB	3247 in^3

W = 30

	(oven)		(trays)		(water source)		(water gun)	
Hardware weight	4.93	+	5.76	+	.53	+	.5	= 11.72 LB

Hot water source power requirement .263 KW

Electrical energy requirement .398 KW-HR

Heat to cabin 6.70 BTU

Oven power requirement .0378 KW

Electrical energy requirement .0362 KW-HR

Heat to cabin 15.5 BTU

W = 60

	(oven)		(trays)		(Water source)		(water gun)	
Hardware weight	4.80	+	5.76	+	.53	+	.5	= 11.59 LB

Hot water source power requirement .259 KW

Electrical energy requirement .392 KW-HR

Heat to cabin 6.60 BTU

Oven power requirement .0415 KW

Electrical energy requirement .0350 KW=HR

Heat to cabin 15.0 BTU

NOTE: Tray configuration is that of an uninsulated tray. Figure 14 shows that an uninsulated 135 or 140°F entree' will not cool below 105°F by the end of a 20 minute dining period.

* Total penalty includes a 0.5 LB allowance for a water gun.

3.2 Cont'd

3.2.1.5 Cont'd

Penalty (1) : 135° F oven temperature

Equilibrium temperature, t and energy consumption, E KW - HR

$$\frac{k}{\gamma}(t_o - t) + (h_\beta + \epsilon h_R)(t_f - t) = 0$$

h_β = 1.45 BTU/HR.FT. °F

ϵ = .20 (emissivity of oven outer surface)

t_f = 75° F

t_o = 135° F

γ	k/γ	t	CAPACITANCE AL	$\bar{t}$	CAPACITANCE INS.	CAP. FIBER.
.25	1.0	97.4	.5360	116.2	.0141	.4702
.5	.5	88.8	.5858	111.9	.0296	
1.0	.25	82.8	.6915	108.9	.0648	
2.0	.125	79.2	.9266	107.1	.1537	

Penalty, P_1

γ	E	P_1
.25	.01195 KW-HR	.01810 LB.
.5	.01095	.01659
1.0	.01049	.01588
2.0	.01085	.01643

$t = \frac{1}{2}(t_o + t)$

Insulation is considered to heat from t_f to $\bar{t}$

Fiberglass heats from t_f to t_o

Aluminum heats from t_f to t

$$E = \left\{(\text{CAP. AL})(t - t_f) + (\text{CAP INS.})(\bar{t} - t_f) + (\text{CAP. FIBERGLASS})(t_o - t_f)\right\}/3413$$

Penalty (3) : 135°F oven

3.2 Cont'd

3.2.1.5 Cont'd

The same energy that heats the oven to equilibrium temperature is dissipated to the cabin at a uniform rate over an eight hour period.

From the analysis for Penalty (1)

τ	E/8	P_3
.25	5.100 BTU	.6783 LB
.5	4.674	.6216
1.0	4.475	.5952
2.0	4.630	.6157

Penalty 2: 135° F oven temperature

The heat leak rate from the oven is given by where A is the oven outer surface area and t the equilibrium temperature of the insulation outer surface tabulated in the analysis for Penalty (1).

W	τ	t	T_o	k/τ	A	E	E/8	P_3
30	.25	97.4	39.52	1.0	5.633	.04087KW-HR	17.44BTU	2.381 LB
	.50	88.8	"	.5	6.157	.02745	11.71	1.599
	1.0	82.8	"	.25	7.267	.01830	7.808	1.066
	2.0	79.2	"	.125	9.738	.01311	5.592	.7636
60	.25	97.4	33.82	1.0	5.633	.03498	14.92	2.038
	.50	88.8	"	.5	6.157	.02349	10.02	1.368
	1.0	82.8	"	.25	7.267	.01566	6.682	.9124
	2.0	79.2	"	.125	9.738	.01122	4.786	.6535

In evaluating the ECS penalty, it was assumed that energy is dissipated to the cabin at a uniform rate over an eight hour period.

3.2.1.5.1 Summary - Total Weight & Power Penalty

W	τ	P_1	P_2	P_3	P_4	Total Wt. Penalty
30	.25	.01810	2.381	.6783	4.384	7.461 LB
	.5	.01659	1.599	.6216	4.685	6.922
	1.0	.01688	1.066	.5952	5.332	7.009
	2.0	.01643	.7636	.6157	6.825	8.221
60	.25	.01810	2.038	.6783	4.384	7.118
	.5	.01659	1.368	.6216	4.685	6.691
	1.0	.01588	.9124	.5952	5.332	6.855
	2.0	.01643	.6535	.6157	6.825	8.11

The total weight penalty is plotted in Figure 24 as a function of oven insulation thickness and heated water flow rate. The optimum insulation thicknesses are determined from this figure.

Power requirements are shown in Figure 25.

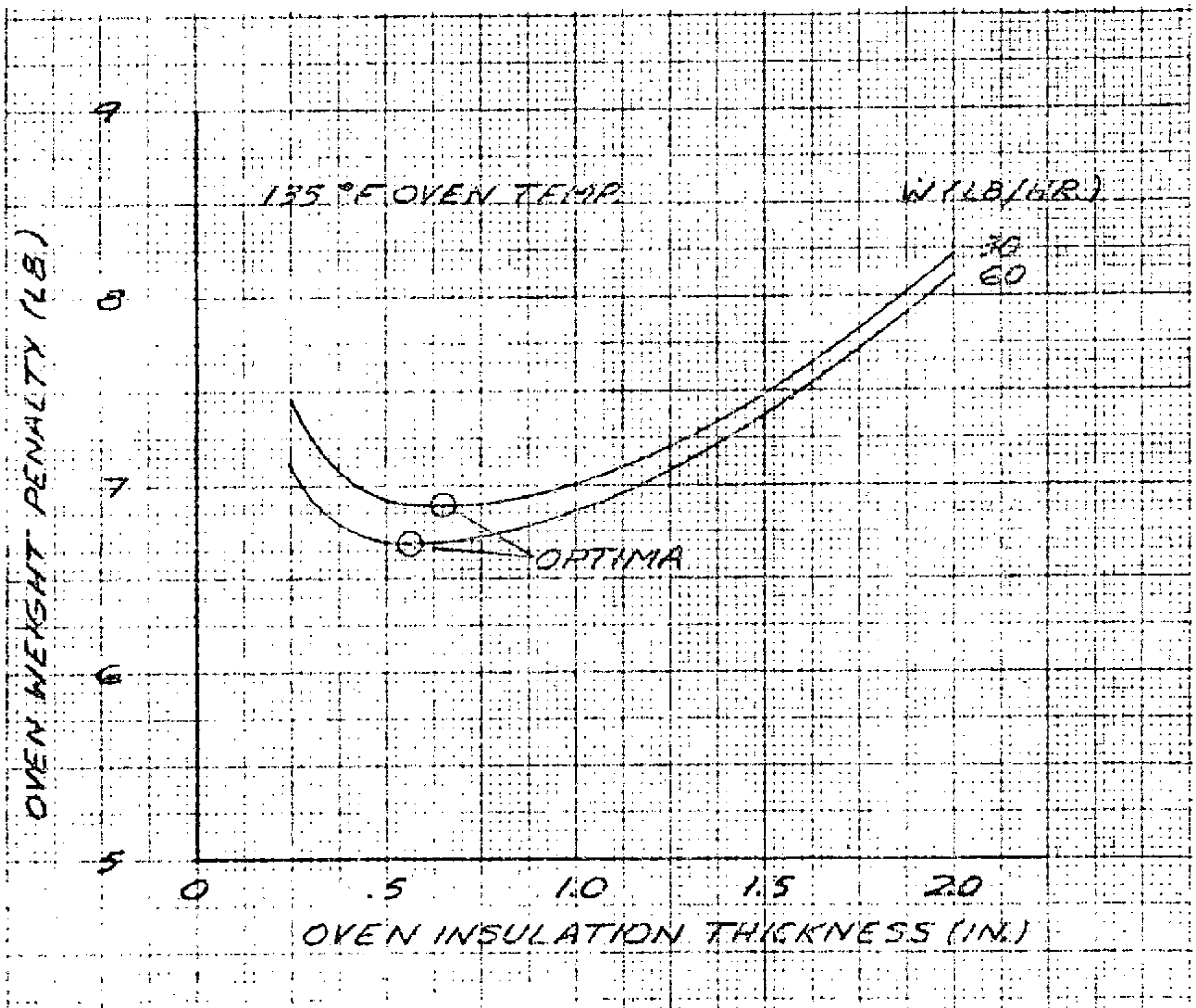


Figure 24. Total Oven Weight Penalty

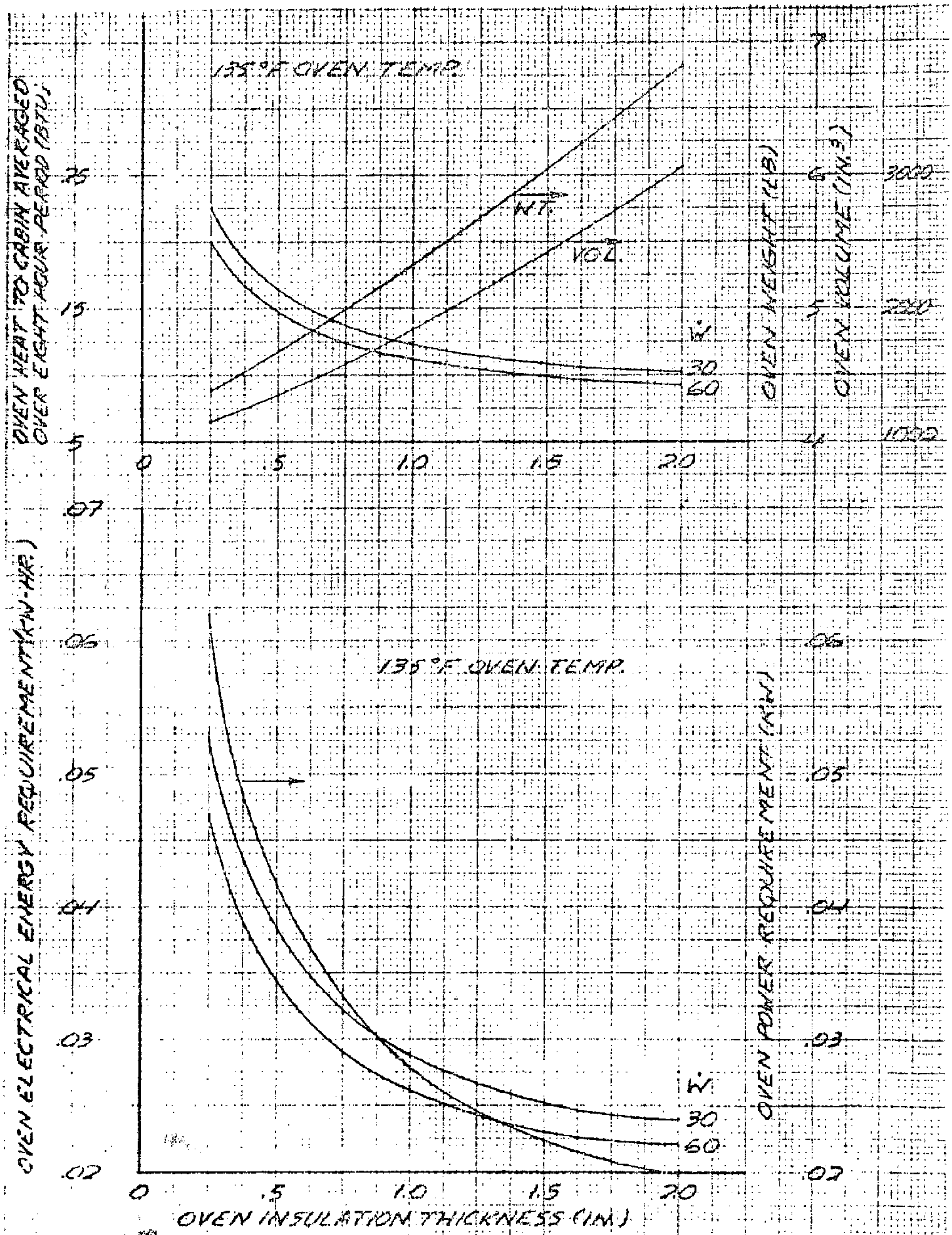


Figure 25. Power Requirements

ONE MAN PREPARATION

135°F First Entree Temperature

W	T_W	Hot Water	Source Penalty	Tray	Penalty	Optimum Oven	Oven	Penalty	Total	Penalty*
30	159.4	2.01LB	190 In^3	5.76LB.	1627 In^3	.650 IN.	6.90 LB.	1500 In.^{3}	15.17LB	3317 In.^{3}
60	153.0	1.93	182	5.76	1627	.562	6.69	1400	14.88	3209

W = 30

	(oven)		(trays)		(water source)		(water gun)	
Hardware weight	4.87	+	5.76	+	.53	+	.5	= 11.66 LB.

Hot water source power requirement .259 KW

Electrical energy requirement .392 KW-HR
Heat to cabin 6.60 BTU

Oven power requirement .0362 KW

Electrical energy requirement .0342 KW-HR
Heat to cabin 14.5 BTU

W = 60

	(oven)		(trays)		(water source)		(water gun)	
Hardware weight	4.75	+	5.76	+	.52	+	.5	=11.53 LB

Hot water source power requirement .246 KW

Electrical energy requirement .372 KW-HR
Heat to cabin 6.33 BTU

Oven power requirement .0392 KW

Electrical energy requirement .0327 KW-HR.
Heat to cabin 14.0 BTU

Note: Tray configuration is that of an uninsulated tray. Figure 14 shows that an uninsulated 135 or 140°F entree' will not cool below 105° F by the end of a 20 minute dining period.

* Total penalty includes a 0.5 LB allowance for a water gun.

3.2.1.7 Time Lines - Preparation by Two Men

Assume each man prepares three meals.

Define T_R as the time from the beginning of preparation to the point at which all dishes are prepared and fully rehydrated. T_R is the greatest of the following:

For entree'

$$\tau_E = 3(\tau_1 + \tau_2)_E + 20$$

FOR SIDE DISH.

$$\tau_{D1} = 3(\tau_1 + \tau_2 + \tau_3 + \tau_4)_E + 3(\tau_1 + \tau_2)_{D1} + 15$$

FOR SIDE DISH

$$\tau_{D2} = 3(\tau_1 + \tau_2 + \tau_3 + \tau_4)_E + 3(\tau_1 + \tau_2 + \tau_3 + \tau_4)_{D_1} + 3(\tau_1 + \tau_2)_S + 10$$

FOR BEVERAGE.

$$\tau_B = 3(\tau_1 + \tau_2 + \tau_3 + \tau_4)_E + 6(\tau_1 + \tau_2 + \tau_3 + \tau_4)_{D1} + 3(\tau_1 + \tau_2 + \tau_3 + \tau_4)_S + 3(\tau_1 + \tau_2 + \tau_3 + \tau_4)_B$$

Table 9 - 2 Man Preparation Times

7	Entree'	2.41	27.98	59.16 min.
	Side dish	3.21	35.61	
	Side dish	3.21	48.24	
	Soup	1.82	51.70	
	Beverage	4.07	59.16	
15	Entree	1.12	24.11	35.61
	Side Dish	1.50	26.61	
	Side Dish	1.50	34.11	
	Soup	.85	34.66	
	Beverage	1.90	35.61	
30	Entree'	.56	22.43	27.93
	Side Dish	.75	22.68	
	Side Dish	.75	27.93	
	Soup	.42	27.19	
	Beverage	.95	25.29	
60	Entree'	.29	21.59	24.87
	Side Dish	.38	20.73	
	Side Dish	.38	24.87	
	Soup	.21	23.50	
	Beverage	.475	20.18	

3.2.1.7 Cont'd

The first two groups of three cans (entrees) would be placed in the oven $3\left(\tau_1+\tau_2+\tau_3+\tau_4\right)_E$ minutes after the beginning of the preparation sequence.

Assume beverages are placed directly into trays after preparation.

Therefore, the oven operating time is

$$T_0 = T_R - 3\left(\tau_1+\tau_2+\tau_3+\tau_4\right)_E - 3\left(\tau_1+\tau_2+\tau_3+\tau_4\right)_B + 10$$

where 10 minutes are allowed for warmup.

W	T_o
7	43.72 minutes
15	30.55
30	27.40
60	26.60

The cooling times during preparation of the first and last cans of a group of three are:

First Can	Last Can
$\tau_w = 3\tau_3$	$\tau_w = \tau_2$
$\tau_3 = .5$	$\tau_3 = .5$
$\tau_p = \tau_4 + 5(\tau_3 + \tau_4) = 4.0$	$\tau_p = \tau_4 + 5(\tau_3 + \tau_4) = 4.0$

From the equation characterizing cooling, and for a cabin temperature, $t_f = 75^\circ$ F, the initial temperature necessary to furnish a 135 or 140°F entree' temperature at the end of the preparation period can be determined. Once t_i is know, the water temperature required can also be determined.

		140° ENTREE		135° ENTREE	
W	$\frac{t-t_f}{t_i-t_f}$	t_i	T_w	t_i	T_w
30	.09147	147.1	159.4	141.6	153.0
60	.91262	146.2	158.4	140.7	152.0

3.2.1.7 Cont'd

The weight, P_W, and volume V_W, penalties associated with water usage are given in Figure 34 in the Water Tank Analysis as a function of T_W:

140°F Entree'

W	P_W	V_W	P_W	V_W
30	2.01	190	1.93	182
60	2.00	189	1.92	180

The cooling times and temperatures for the first and last cans prepared in each group of three are given in Table 10 for water flow rates of 30 and 60 LB/HR.

3.2.1.7.1

Weight Penalties Associated with Fuel All and ECS Interfaces

The variation of penalties P_1 and P_3 with oven insulation thickness and temperature is identical to that determined for the care of meal preparation by one man. Penalty P_2, however, is dependent on oven operating time, which is much shorter for the case of meal preparation by two men:

TABLE 10 - COOLING TIMES & TEMP. FOR FIRST & LAST CANS

DISH	$\dot{w}$	τ_w	τ_3	τ_D	$\frac{t-t_f}{t_i-t_f}$	140°F entree'		135°F entree'	
						T_w	t	T_w	t
First entree'	30	1.68	.50	4.0	.90147	159.4	140.0	153.0	135.0
	60	.84	↓	↓	.91262	158.4	140.0	152.0	135.0
Last entree'	30	.56			.91637	159.4	141.1	153.0	136.0
	60	.28			.92013	158.4	140.5	152.0	135.5
First side dish	30	2.25			.89397	159.4	142.0	153.0	136.9
	60	1.125			.90882	158.4	142.3	152.0	137.1
Last side dish	30	.75			.91382	159.4	143.4	153.0	138.2
	60	.375			.91885	158.4	143.0	152.0	137.7
First side dish	30	2.25			.89397	159.4	142.0	153.0	136.9
	60	1.125			.90882	158.4	142.3	152.0	137.1
Last side dish	30	.75			.91382	159.4	143.4	153.0	138.2
	60	.375			.91885	158.4	143.0	152.0	137.7
First soup	30	1.26			.88944	159.4	144.0	153.0	138.9
	60	.63			.89934	158.4	144.0	152.0	138.7
Last soup	30	.42			.90267	159.4	145.1	153.0	139.8
	60	.21			.90601	158.4	144.5	152.0	159.2
First beverage	30	2.85			.88616	159.4	147.3	153.0	141.8
	60	1.425			.90484	158.4	147.9	152.0	142.3
Last beverage	30	.95			.91115	159.4	149.4	153.0	143.7
	60	.475			.91751	158.4	149.0	152.0	143.3

It is assumed that beverage temperatures are not governing parameters. Under this assumption, all cases are admissible.

Penalty (2) : <u>140°F oven temperature</u>

W	δ	t	T_o	b/B	A	E	E/B	P_2
30	.25	99.3	27.40	1.0	5.633	.0306 KW-HR	13.09 BTU	1.787 LB
	.5	90.0		..5	6.157	.0206	8.784	1.199
	1.0	83.5		.25	7.267	.0137	5.859	.8000
	2.0	79.5		.125	9.738	.00985	4.204	.5740
60	.25	99.3	26.60	1.0	5.633	.0298	12.70	1.734
	.5	90.0		.5	6.157	.0200	8.526	1.164
	1.0	83.5		.25	7.267	.0133	5.689	.7766
	2.0	79.5		.125	9.738	.00952	4.080	.5571

Summarizing penalties for this case - See Figure 26.

W	δ	P_1	P_2	P_3	P_4	TOTAL WEIGHT PENALTY
30	.25	.01961	1.787	.7348	4.384	6.925 LB
	.5	.01797	1.199	.6733	4.685	6.575
	1.0	.01721	.8000	.6450	5.332	6.794
	2.0	.01779	.5740	.6667	6.825	8.083
60	.25	.01961	1.734	.7348	4.384	6.872
	.5	.01797	1.164	.6733	4.685	6.540
	1.0	.01721	.7766	.6450	5.332	6.771
	2.0	.01779	.5571	.6667	6.825	8.067

A summary of power requirements is shown in Figure 27.

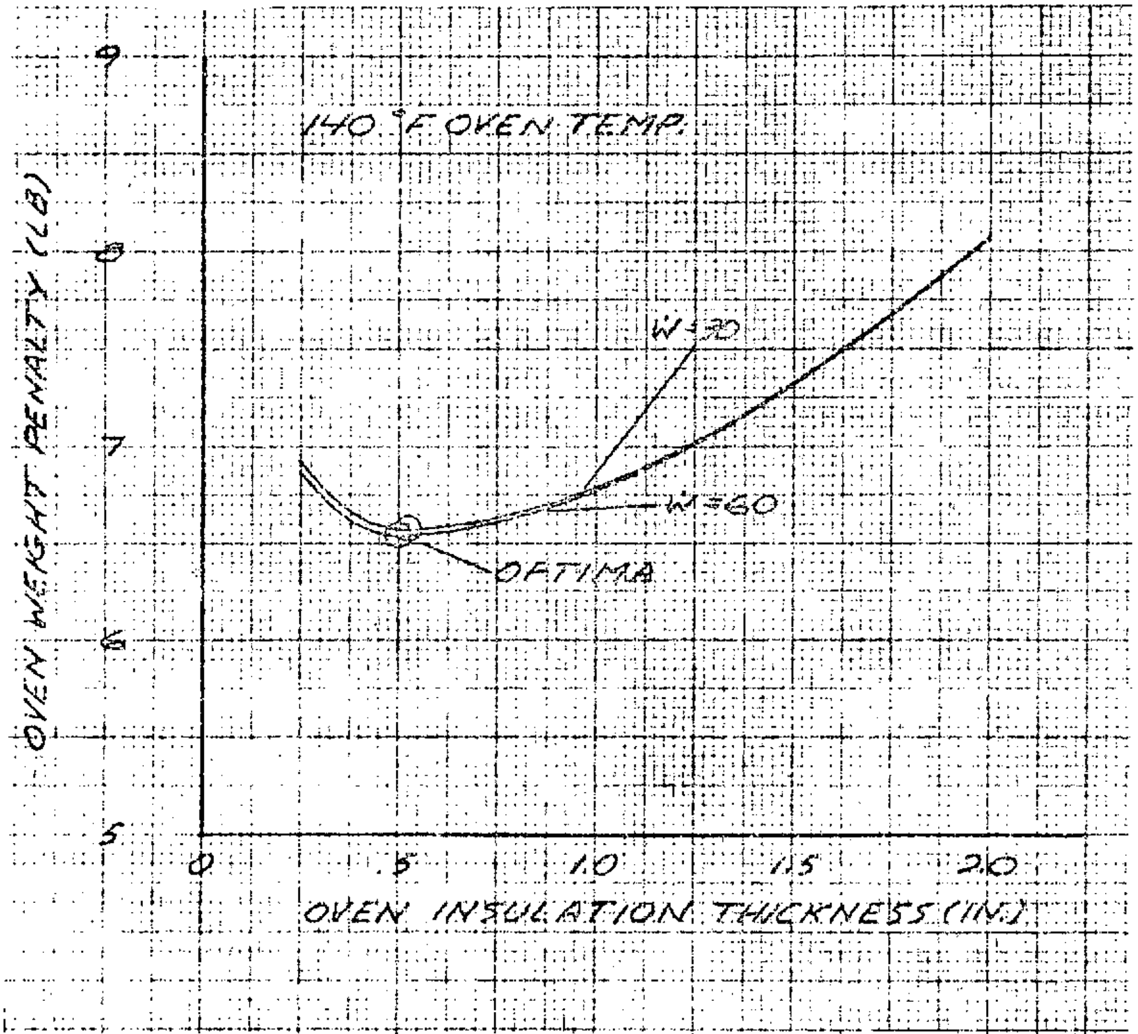


Figure 26. Oven Weight Penalty

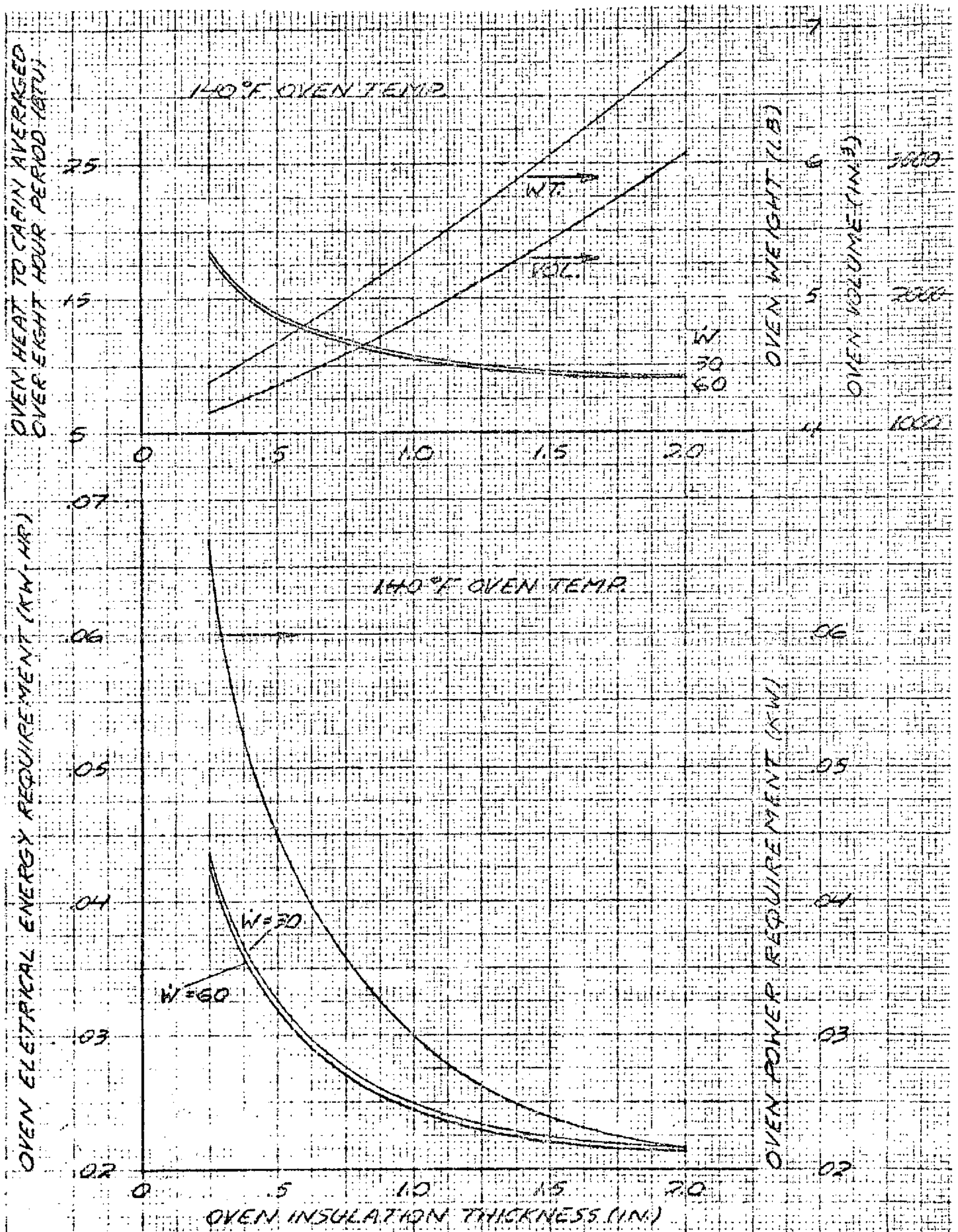


Figure 27. Power Requirements

3.2.1.7.2 Weight Penalty (P_2) - 135°F Oven Temperature

W	δ	t	To	k/δ	A	E	E/δ	P2
30	.25	97.4	27.40	1.0	5.633	.02834KW-HR	12.09BTU	1.651 LB
	.5	88.8		.5	6.157	.01903	8.119	1.109
	1.0	82.8		.25	7.267	.01269	5.413	.7391
	2.0	79.2		.125	9.738	.00909	3.877	.5294
60	.25	97.4	26.60	1.0	5.633	.02751	11.73	1.603
	.5	88.8		.5	6.157	.01848	7.881	1.076
	1.0	82.8		.25	7.267	.01232	5.256	.7176
	2.0	79.2		.125	9.738	.00882	3.764	.5140

Summarizing penalties for this case - See Figure 28

W	δ	P1	P2	P3	P4	TOTAL WEIGHT PENALTY
30	.25	.01810	1.651	.6783	4.384	6.731
	.5	.01659	1.109	.6216	4.684	6.432
	1.0	.01588	.7391	.5952	5.332	6.682
	2.0	.01643	.5294	.6157	6.825	7.987
60	.25	.01810	1.603	.6783	4.384	6.683
	.5	.01659	1.076	.6216	4.685	6.399
	1.0	.01588	.7176	.5952	5.332	6.661
	2.0	.01643	.5140	.6157	6.825	7.971

A summary of power requirements is shown in Figure 29.

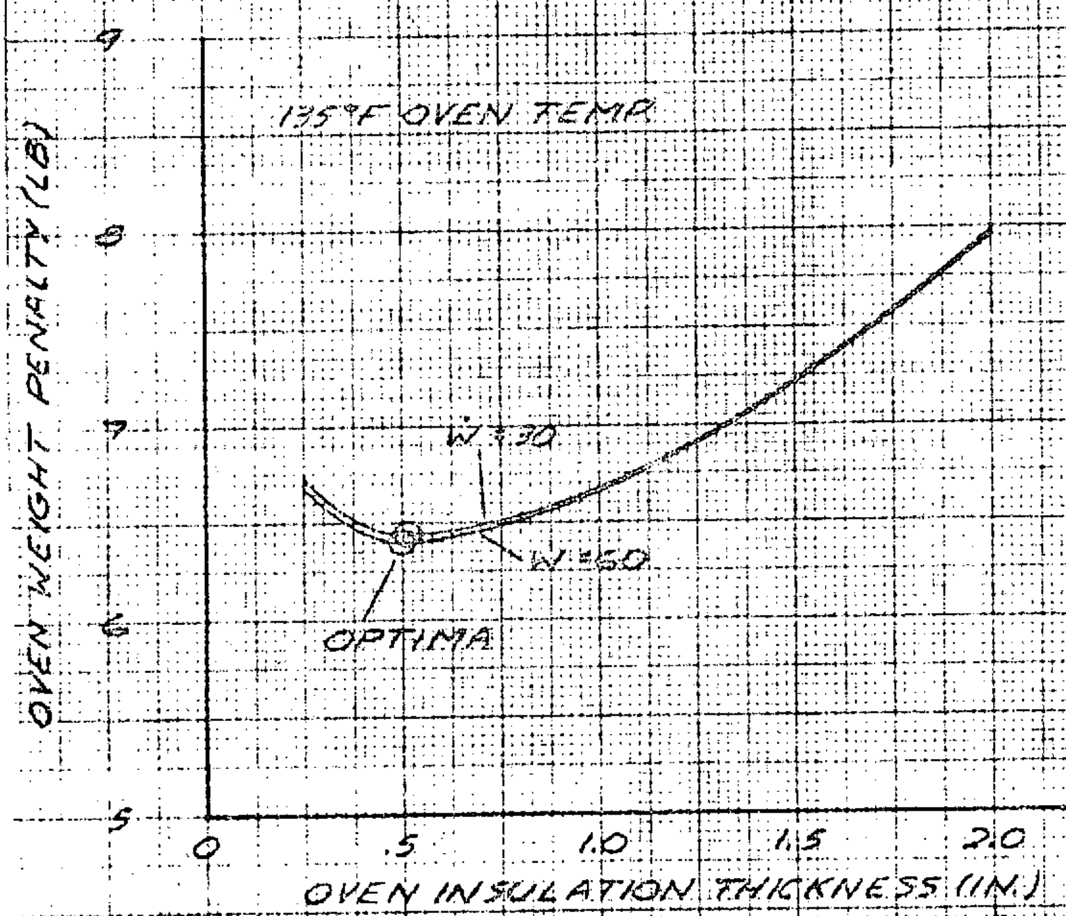


Figure 28. Oven Weight Penalty

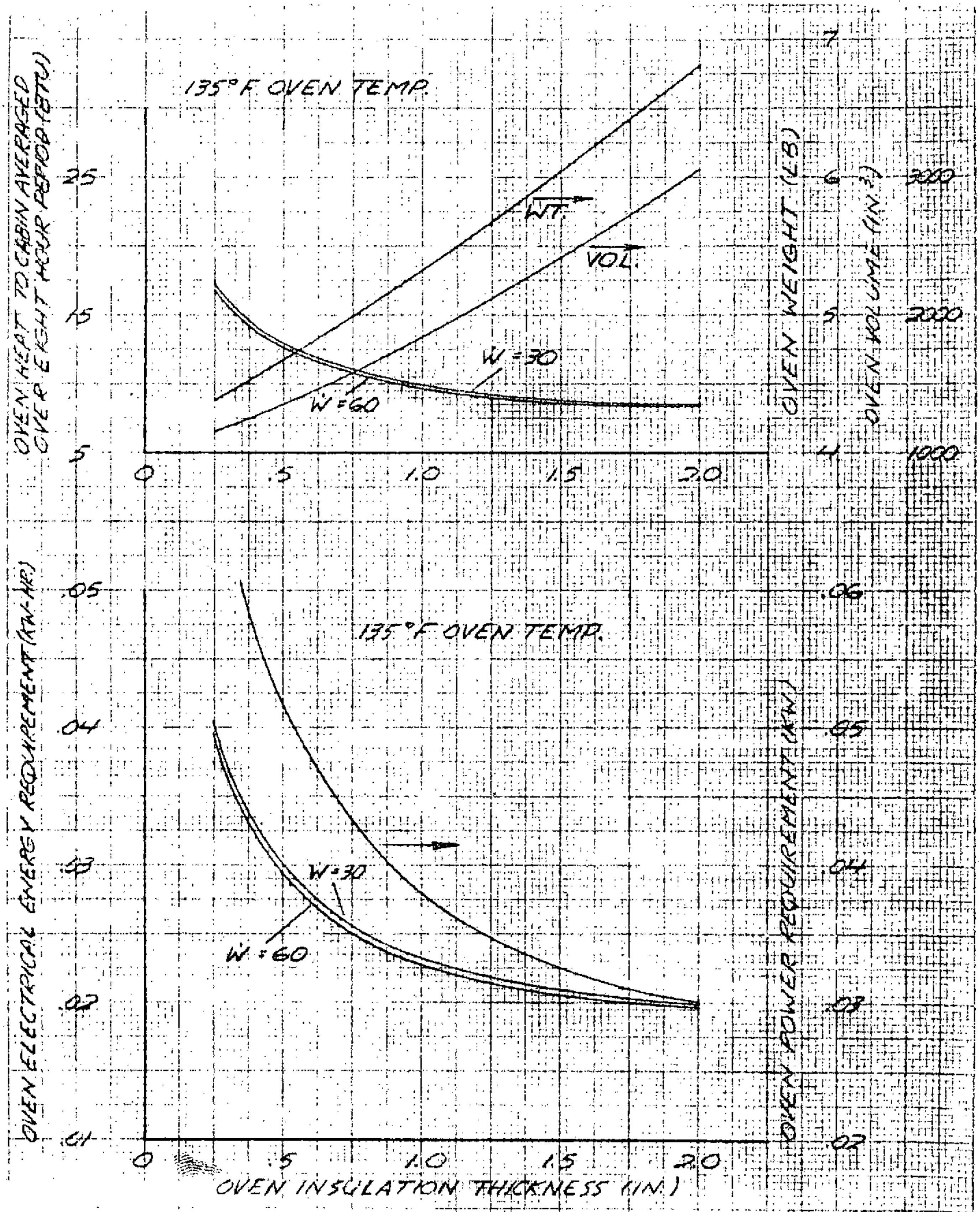


Figure 29. Power Requirements

TWO MAN PREPARATION

For the case of two man preparation, requirements for 30 and 60 lb/hr water flow rates are so close that only those for a 30 lb/hr rate will be detailed.

140°F First Entree' Temperature

W	T_W	Hot Water Source Penalty		Tray Penalty		Optimum Oven T	Oven Penalty		Total Penalty*	
30	159.4	2.01 LB	190 IN.^{3}	5.76LB	1627In^3	.525 IN.	6.58 LB	1380In^3	15.35LB	3197 In^3

	(oven)		(trays)	(water source)		(water gun)	
Hardware weight	4.71	+	5.76	+.53	+	1.0	=12.00 LB

Hot water source power requirement .259 KW

Electrical energy requirement .392 KW-HR
Heat to cabin 6.60 BTU

Oven power requirement .0438 KW

Electrical energy requirement .0320 KW-HR.
Heat to cabin 13.7 BTU

135°F First Entree' Temperature

W	T_W	Hot Water Source Penalty		Tray Penalty		Optimum Oven T	Oven Penalty		Total Penalty *	
30	153.0	1.93 LB	182 In.^{3}	5.76 LB	1627 In^3	.512 In.	6.45 LB.	1370 In^3	1514LB.	3179 In^3

	(oven)		(trays)		(water source)		(water gun)	
Hardware weight	4.70	+	5.76	+	.52	+	1.0	= 11.98 Lb.

Hot water source power requirement .246 KW

Electrical energy requirement .372 KW-HR
Heat to cabin 6.33 BTU

Oven power requirement .0610 KW

Electrical energy requirement .0298 KW=HR.
Heat to cabin 12.8 BTU

NOTE: Tray configuration is that of an uninsulated tray, Figure 14 shows that an uninsulated 135 or 140°F entree' will not cool below 105°F by the end of a 20 min. dining period.

* Total penalty includes a 1.0 LB allowance for a water gun.

3.3 Active Heating Systems

3.3.1 Convective Hot Air Oven

3.3.1.1 Hot Air Convective Heating Oven-Heating Time

Determine time to heat 401 and 211 cans from initial to final temperatures. Variables are:

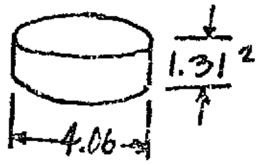
T = Contemperature °F

T_g = Gas temperature °F

h = Convective heat transfer coefficient - $\frac{ATn}{hv\text{-}ft^2\text{-}{}^\circ F}$

θ = time - hrs.

For 401 Can:



TOTAL SURFACE AREA =

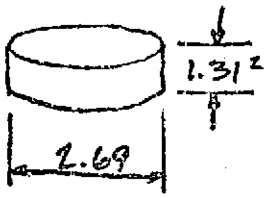
$A = 2 \times \frac{\pi}{4}(4.06)^2 + \pi \times 4.06 \times 1.31^2$

$= 42.7 \text{ IN}^2 = 0.296 \text{ ft}^2$

VOLUME = $\frac{\pi}{4}(4.06)^2 \times 1.31^2 = 17 \text{ IN}^3$

W = Contents weight assuming water = 0.6#

For 211 Can:



TOTAL SURFACE AREA =

$A = 2 \times \frac{\pi}{4}(2.69)^2 + \pi(2.69)(1.3125)$

$= 22.42 \text{ in}^2 = 0.156 \text{ ft}^2$

VOLUME = 7.5 in^3

W = Contents weight assuming water = 0.27#

C = Specific heat of can contents = 1.0 $\frac{AT^n}{\# - F}$

Assuming internal contents of can heats uniformly,

$$hA(T_g - T) = WC\frac{dT}{d\theta} \tag{1}$$

$$\int_{T_i}^{4} \frac{-dT}{T_g - T} = -\int_0^{\theta} \frac{hA\,d\theta}{WC}$$

WHERE :

T_i = INITIAL CAN TEMP.

T_F = FINAL CAN TEMP.

3.3 Cont'd

3.3.1.1 Cont'd

INTEGRATING AND REARRANGING GIVES:

(2) $T_f = T_g - (T_g - T\ ) \exp ($

T_i : T_i can be cabin temperature, say 70° F or if water is available at 35°, the mixed temperature resultant with the dehydrated food.

The latter is determined as follows from given equations:

For entree' $T_m = 0.86 \times 35 + 10 = 40°F$

Side Dish $T_m = 0.89 \times 35 + 8 = 40°F$

$0.83 \times 35 + 12 = 41°F$

∴ Assume lowest initial temp. = 40°F

T_f: Prepared food temp. stipulated to be $135 \leqslant T_f \leqslant 145°F$

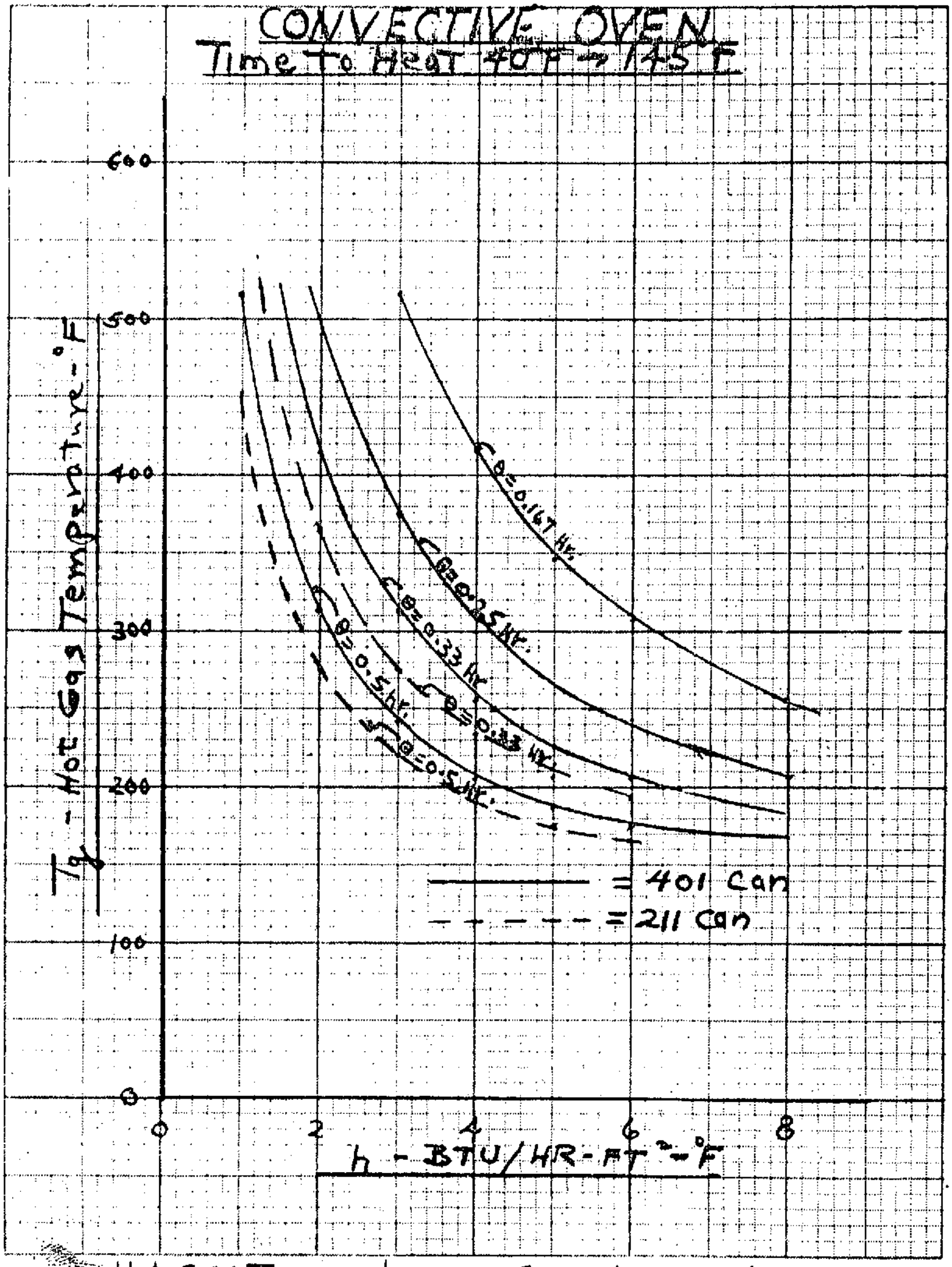
T_g: The heated gas temperature is limited by the nature of the plastic food bag inside the cans. Allowing a maximum spot temperature occuring in the bag to be 270°F, a lower maximum average effective temperature will be taken for the heated gas flowing over the cans, say 250°F.

Using equation (2) on Page , determine the relationship between T_g, h, and Θ in increasing can temp. from T_i to T_f. Results are plotted in Fig. 30 for heating from 40°F to 145°F and Fig. 31 for heating from 70°F to 145°F.

3.3 Cont'd

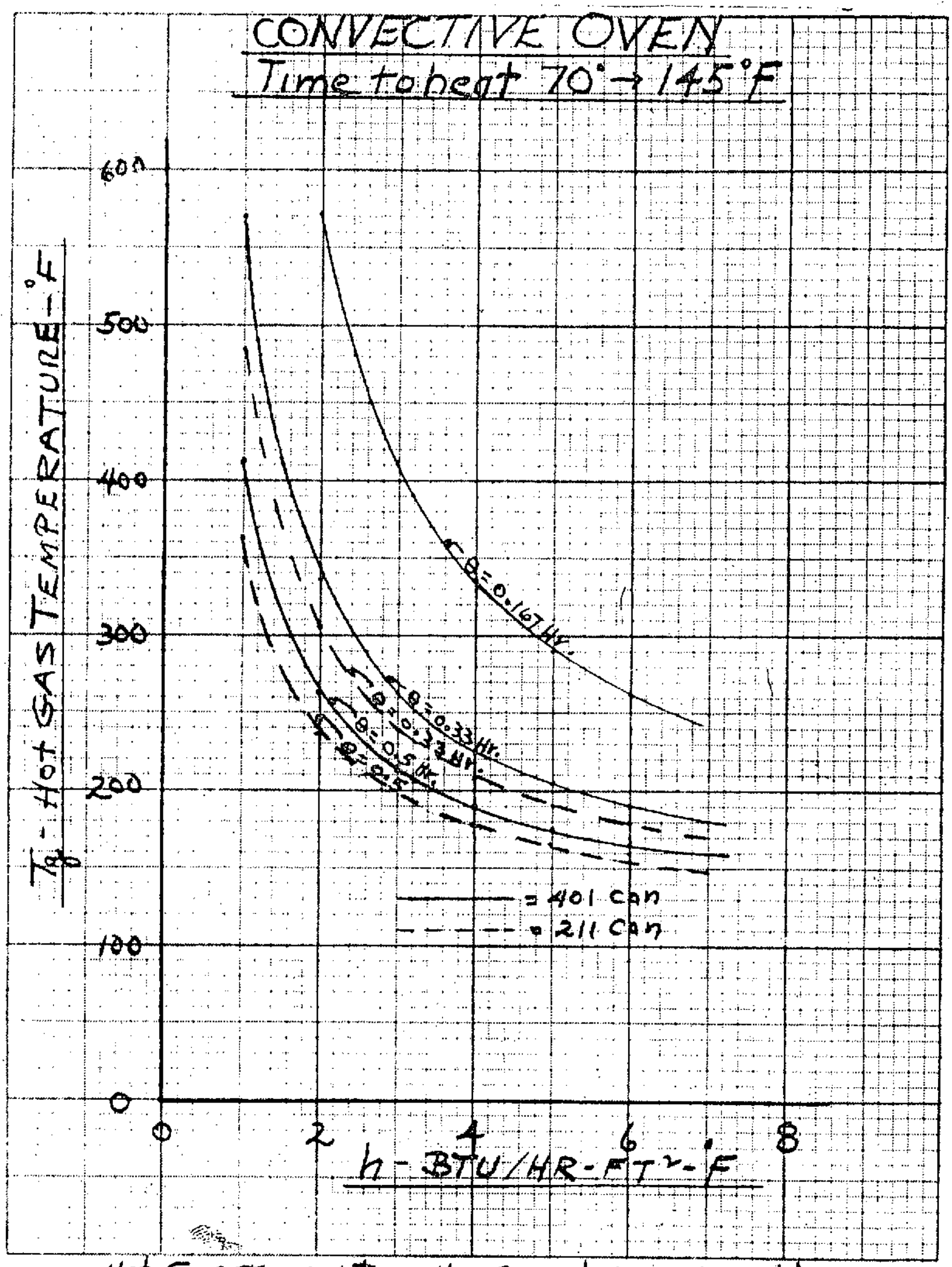
3.3.1.2 Oven Arrangement

Fig. 32 is a schematic arrangement of a convective oven which will heat six meals simultaneously, each meal consisting of three 401 size cans and one 211 can (one entree', 2 side dishes, and a soup). The four cans of each meal are arranged in an in-line configuration retainer in an individual meal serving tray which can be slipped into guide channels in the oven. Closed loop hot air recirculation is induced by means of a radial blower driven by an electric motor which is external to the hot air circuit, thereby obviating high temperature operating problems. The blower discharges into a plenum chamber provided with electrical heating elements. The heated air then flows over the cans in the upper cavity of the oven to the opposite end of the oven. A slot at the end of the baffle permits the air to flow downward into the bottom cavity and over the bottom cans in the reverse direction to enter the bottom plenum which feeds the suction side of the blower. A temperature sensor in the airstream immediately downstream of the heater elements at the entrance to the upper cavity controls the heater power dissipation to limit the maximum air temperature to $T \leq 270^{\circ}F$.



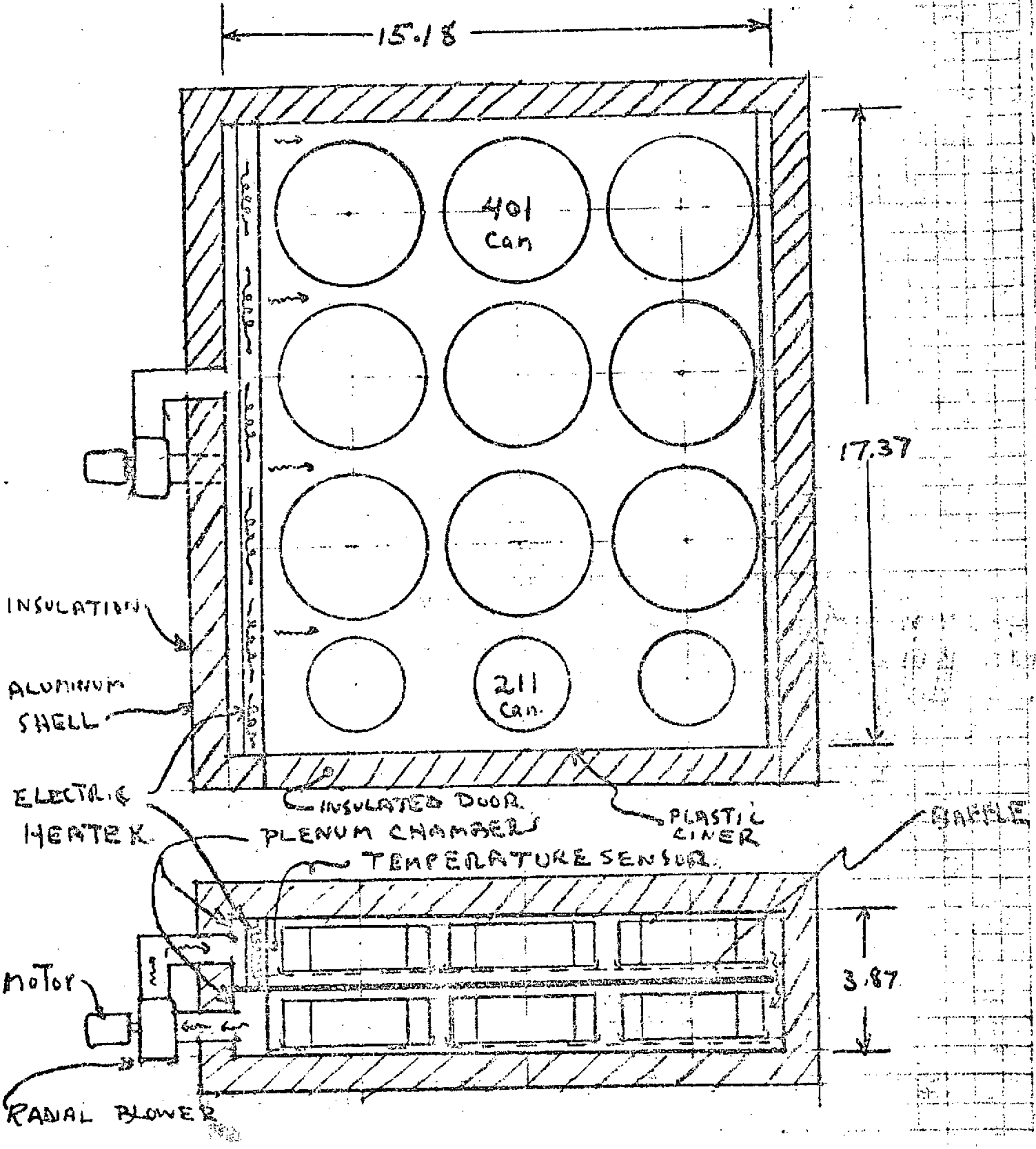
Hot Gas Temperature VS. Convective Coefficient To Heat from 40F to 145F with Time to Heat as Parameter - 401 & 211 Size Cans.

FIG. 30



Hot Gas Temperature Vs. Convective Coefficient To Heat from 70F to 145F with Time to heat as parameter - 401 & 211 Size Cans.

FIG 31



'Hot Air Convective Heating Oven Schematic Arrangement

FIG. 32

3.3.1.3 Convective Coefficient Calculation

Determination of "h".

Assuming that a total time of one hour is allowed for meal preparation, eating, and cleanup, a reasonable heating time should not be longer than about 15 minutes (0.25 hrs.). Referring to Fig. 30 and taking an average effective gas temperature to be 250°F, it is seen that a 401 can (which heats more slowly than the smaller 211 can) requires an "h" of 5.5 to be heated from 40°F to 145°F in 15 min. Fig. 31 shows that a 401 can initially at 70°F will reach 145°F in approximately 12 min. for the same conditions.

$\therefore$ Design for "h" = 5.5 ATn/ hr.-ft^2-F

Ref. Kreith - Principles of Heat Transfer -1958 p. 388.

$$\frac{\bar{h}_c D_o}{K_f} = 0.33 C_H \left(\frac{G_{MAX} D_o}{M_f} \right)^{0.6} Pr_f^{0.3} \tag{3}$$

For transverse flow over in line tubes provided a correction is applied for less than 10 transverse rows. The correction factor for three transverse rows = 0.87. For preliminary design the factor C_A may be taken as unity.

$\bar{h}_c$ = average "h"

D_o = cylinder = 4.06" for 401 can = 0.338 ft.

K_f, M_f, Pr_f = fluid properties at film temperature.

G max. = mass flow per UNIT area at minimum section.

3.3 Cont'd

3.3.1.3 Cont'd

Minimum Section:

Flow area between cans: 1.312 x 5 x 0.5 =3.28 in^2

Area above and below cans for 0.25"clearance:

2 x (0.25 x 17.37) = $\underline{8.68\ in^2}$

Flow area at minimum section = Σ = 11.96 in^2
= 0.0825 ft^2

3.3.1.4 Blower Sizing

Can average surface Temp:

If 40 → 145 F, then $\frac{40 + 145}{2}$ = 93°F

If 70 → 145 F, then $\frac{70 + 145}{2}$ = 108°F

Take average SURFACE temp = ~ 100°F

T gas average = 250°F

$\therefore$ T film = $\frac{250 + 100}{2}$ = 175°F average

than for air at 175°F.

K_f = 0.0169 BTU/hr-ft-F

Pr_f = 0.72

M_f = 0.043 $\frac{\#}{hr\text{-}ft}$

for air ρ 250°F = $\frac{14.7 \times 144}{53.5 \times 710}$ = 0.0558 #/ft^3

Then rearranging and substituting in equation (3)

$$\overset{h}{5.5} = \overset{k}{\frac{0.0169}{\underset{D_o}{0.338}}} \times \overset{C_n}{0.33 \times 1} \times \overset{CORRECTION}{0.87} \left[\frac{G_{MAX.} \times 0.338}{0.043}\right]^{0.6} (0.72)^{0.3}$$

ft

0.91

$$\therefore \left(\frac{G_{MAX} \times 0.338}{0.043}\right)^{0.6} = \frac{5.5 \times 0.338}{.0169 \times 0.33 \times 0.87 \times 0.91} = 420$$

$$G_{MAX} = \frac{(420)^{1.67} \times 0.043}{0.338}$$

$$\rho V_{MAX} = G_{MAX}$$

$$V_{MAX} = \frac{24030 \times 0.043}{0.0558 \times 0.338} \frac{ft}{hr} \times \frac{1\,hr}{3600\,sec} = 15.3\ ft/sec.$$

3.3.1.4.1 Required blower volume flow = $Q = A_{MIN} V_{MAX}$

$$Q_{\text{BLOWER}} = 0.0825\ ft^{\sim} \times 15.3 \frac{ft}{SEC} \times \frac{60\ SEC}{MIN} = 76\ cfm.$$

Find required pressure rise across blower.

$$\Delta P \sim \frac{k' \rho V^2}{2g} = \frac{k' \times 0.0558 \times 15.3 \times 15.3}{64.4 \times 144 \times 0.036} = K' 0.039'' H_2O$$

WHERE $K' = \Sigma$ HEAT LOSS

$K' = NF' + \Sigma$ DYNAMIC LOSSES, WHERE f' " FRICTIONAL

loss given (ref Kreith P.390) and N number of transverse rows.

$$(4)\quad f' = \left[0.044 + \frac{0.08\ S_L/D_o}{\left(\frac{S_T - 1}{D_o}\right)^{0.43 + 1.13\ D_o/S_L}}\right] \left[\frac{G_{MAX} D_o}{M_b}\right]^{-0.15}$$

Where S_L & S_T are longitudinal and transverse pitches respectively. For 401 cans $S_L = S_T = 4.56''$

$$f' = \left[\frac{0.044 + .08 \frac{4.56}{4.06}}{\left(\frac{3.56}{4.06}\right)^{0.43 + 1.13 \times \frac{4.06}{4.56}}}\right] \left[15,660\right]^{-0.18} = 0.0356$$

Say 0.04

For 6 transverse rows = 6 x 0.04 = 0.24

Estimated dynamic losses:

Heater Entrance	0.5
Heater	1.0
Heater Discharge	1.0
Turn Contractive	0.5
Turn Exit	1.0
Plenum Entrance	1.0
Blower Entrance	1.0
Blower Duct bands	0.5
Discharge into heater plenum	1.0

$K^1 = \Sigma = 7.74$

∴ System pressure drop = 7.74 x 0.039" H_2O = 0.302" H_2O for H = 5.5

3.3 Cont'd

3.3.1.4.2 Determine Blower Power = function of "h"

Substituting in equation (3).

$$h = \left[\frac{0.0169}{0.338} \times 0.33 \times 0.87 \times 0.91\right] Re^{0.6}$$

$$\therefore Re = [\beta h]^{1.67} = \frac{\rho V D}{M} \qquad \frac{\overset{''}{G_n D_o}}{M_f}$$

$$V = \frac{.043(\beta h)^{1.67}}{.0558 \times 0.338 \times 3600} = \gamma(\beta h)^{1.67}$$

$$g = \frac{\rho V^2}{2g \times 144 \times .06} \qquad \text{in. } H_2O = \frac{.0558\ \gamma^2(\beta h)^{3.34}}{64.4 \times 144 \times .036}$$

$$\therefore \Delta P = K' \times \delta \gamma^2 h^{3.34}$$

Air Power:

$$Q = \frac{ft^3}{min} \times \Delta P \frac{\#}{ft^2} \times \frac{1}{33000 \frac{ft\text{-}\#}{min\text{-}HP}} \times 746 \frac{watts}{HP}$$

$$Q = A_{min} V = A_{min}(ft^2) \times \gamma(\beta h)^{1.67} \times 60 = ft^3/min.$$

$$\text{Power} = A_{min}\ \gamma^3 \delta \beta^{5.0} \times 60 \times K' \times \delta \gamma^2 (\beta h)^{3.34} \times .036 \frac{psi}{''H_2O} \times \frac{144\ in^2}{ft^2} \times \frac{746\ watts}{33000 \frac{ft\text{-}\#}{min\text{-}HP}}$$

$$\text{Power} = A_{min}\ \gamma^3 \delta \beta^{5.0} (54.42) h^{5.0}$$

SUBSTITUTING FOR A, γ, δ, & β GIVES

Air Power= $5.0 \times 10^{-4}\ h^{5.0}$ watts

where h is BTU/ ft^2-hr-°F

h $\frac{BTU}{hr.\text{-}ft^2\text{-}F}$	Air Power Watts	(theoretical blower power)
4	0.5	
4.25	0.69	
5.	1.56	
5.5	2.52	
6.0	3.88	
6.5	5.8	
7.0	8.4	
7.5	11.67	
8.0	16.38	

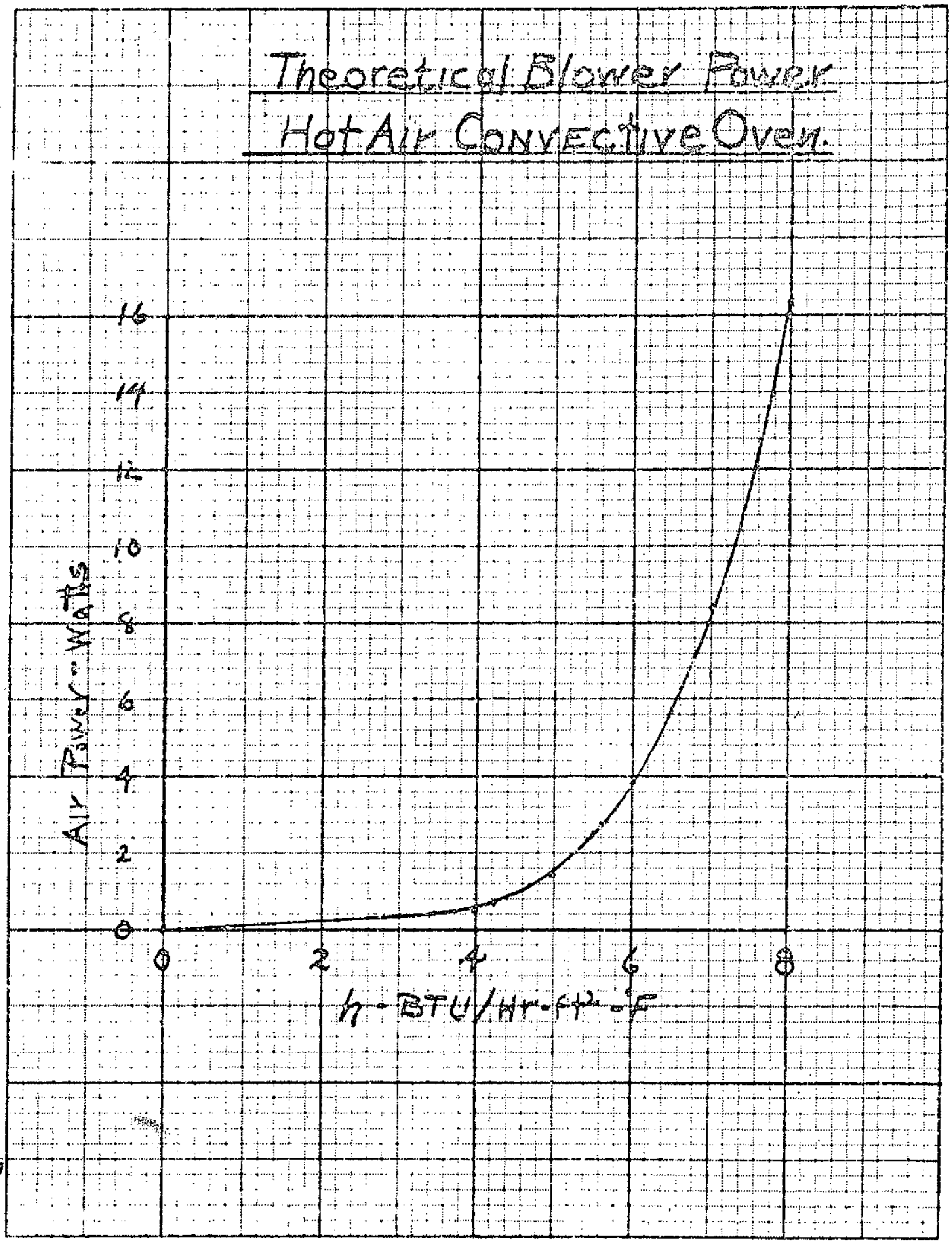

Theoretical Blower Power
Hot Air Convective Oven.
Air Power -- Watts
16
14
12
10
8
6
4
2
0
0
2
4
6
8
h - BTU/Hr-ft² -°F

FIG. 33

3.3 Cont'd

3.3.1.4.2 Cont'd

These values represent the theoretical blower power to flow air at a sufficient rate to provide the "h" values indicated. The values are plotted on Fig. 33.

3.3.1.5 Concurrant Heating

If oven is designed to heat 401 can from 40°F ⟶ 145°F in 15 minutes $T_g = 250^\circ F$, it was determined that h - 5.5 is required.

Question: Suppose a 211 can initially at 70°F is placed into the given conditions for 15 min.?

For 211 can $W = 0.265\#$, $A = 0.156\ ft^2$

Than $$\underset{\text{211 can}}{T_f} = \underset{T_g}{250} - (\underset{T_g}{250}-\underset{T}{7}) \exp\left(\frac{-5.5 \times 0.156 \times 0.25}{0.265 \times 1}\right)$$

$T_f = 170^\circ$ which is too hot.

Similar analysis shows that if oven is designed to heat 401 can from 40°F ⟶ 135°F (instead of 145°) in 15 minutes (accomplished with : 4.88 instead of 5.5), a 70°F 211 can would reach 162°F also for hot.

This can be remedied by baffling the heating air flowing over the line of 211 cans to diminish the heat transfer rate to the 211 cans (only) so that they reach design temp. at the same time as the 401 cans.

3.3.1.6 Insulation Study

Determine oven insulation to optimize heat loss penalty and produce allowable touch temperature.

From Skylab experience limit allowable order surface touch temperature to 105°F.

Let insulation have $K = 0.25\ \frac{BTU-in}{hr-ft^2-F}$

$\rho = 0.6\ \#/ft^3$ LIKE MICROLITE

3.3 Cont'd

3.3.1.6 Cont'd

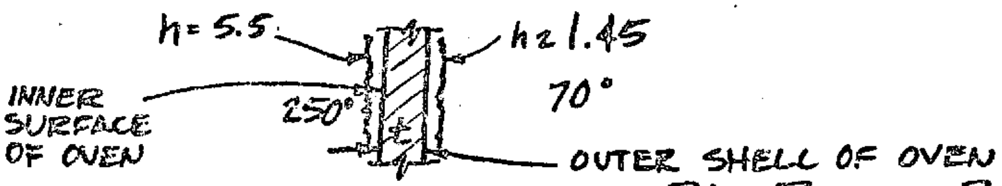
Cabin temperature = 70°F

Internal box temp. = 250°F

Internal h = 5.5 BTU/hr-ft^2-F

Cabinside h = 1.45 " " " "

3.3.1.6.1 Touch Temperature Requirement



$$\overset{R_i + R_{INSUL} + R_o}{}$$

$$\text{Thermal } R_{TOT} = \frac{1}{5.5} + \frac{t}{0.25} + \frac{1}{1.45} = \frac{1}{h_i} + \frac{x}{k} + \frac{1}{h_o} = 0.182 + 4t + 0.69 = 0.872 + 4t$$

$$\frac{\overset{105}{T_{OUTER\ SHELL}} - \overset{70}{T_{CABIN}}}{250 - 70} = \frac{R_o}{R_{TOTAL}} = \frac{0.69}{0.872 + 4t}$$

t = 0.67" = minimum allowable insulation

Thickness to limit outer surface to 105°F max.

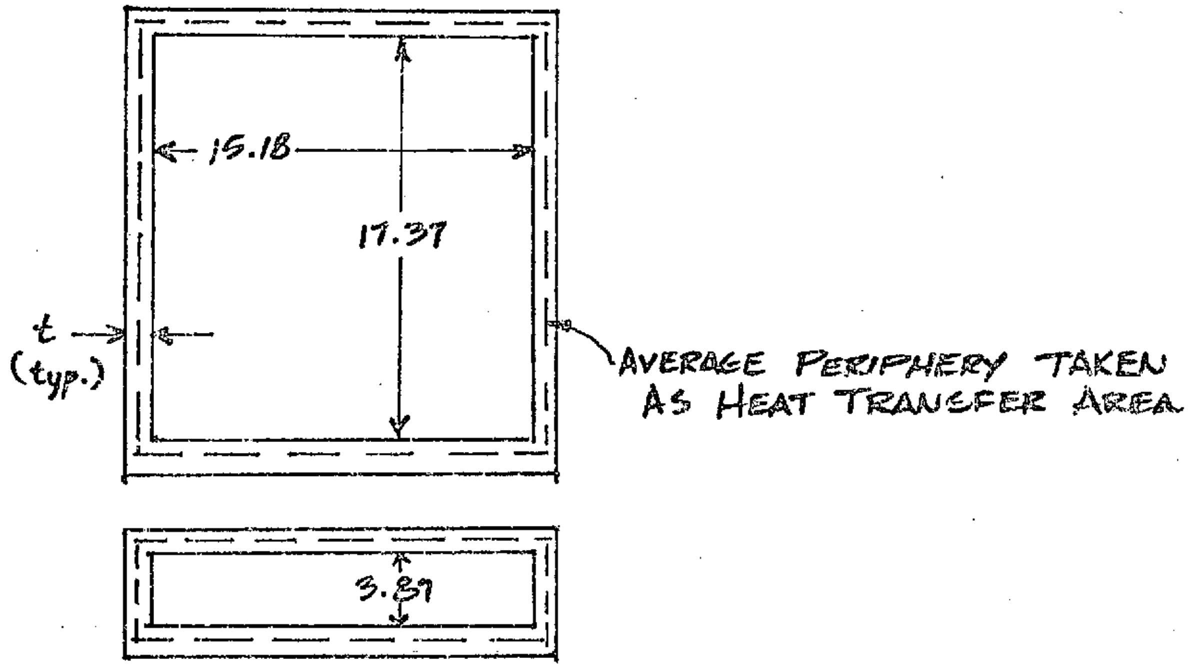
3.3.1.6.2 Determine Insulation Thickness Resulting in Minimum Vehicle Penalty:

Penalties: 1.514#/KW-HR electrical energy consumed.

(ref O T Stol of N.A.R.) 0.133 # per day average $\frac{BTU}{hr}$ dissipated into cabin.

3.3.1.6.2 Cont'd

Express heat transfer area and system weight penalties in terms of insulation thickness "t".



Heat Transfer Area:

Top Area $= (17.37 + t)(15.18 + t) = 263.68 + 32.55t + t^2$

Side "A" $= (17.37 + t)(3.87 + t) = 67.29 + 21.24t + t^2$

Side "B" $- (15.18 + t)(3.87 + t) = \underline{58.81 + 19.05t + t^2}$

$\frac{1}{2}$ Total Heat transfer Area $\Sigma = 389.78 + 72.84t = 3t^2$

Total Heat Transfer Area $= 2 \times \Sigma = 779.56 + 145.68t + 6t^2 \text{ in}^2$

$= 5.41 + 1.01t + 0.0417t^2 \text{ ft}^2$

3.3.1.6.3 Weight

Insulation Volume $= (17.37 + 2t)(15.18 + 2t)(3.87 + 2t) - 17.37 \times 15.18 \times 3.87 =$

$779.55t + 145.7t^2 + 8t^3 \text{ in}^3 =$

$0.45t + 0.0843t^2 + 0.00462t^3 \text{ ft}^3$

3.3.1.6.3 Cont'd

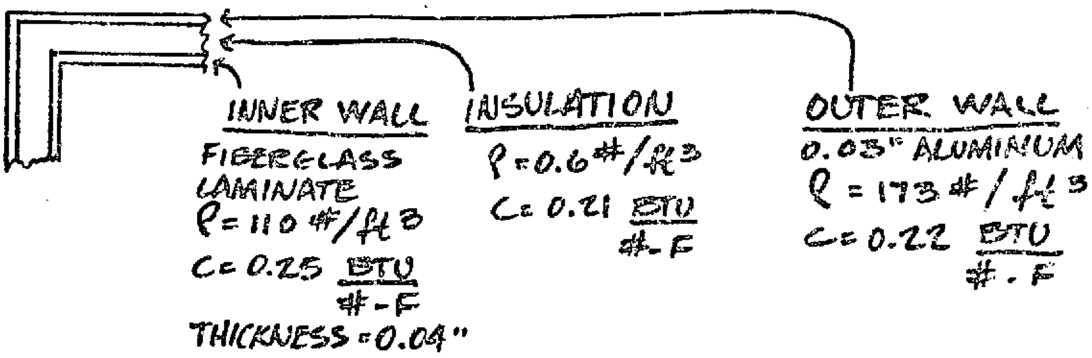
With ρ insulation = $0.6\#/\text{ft}^3$

$$\text{Weight of insulation} = 0.6(0.45t + 0.0843t^2 + 0.00462t^3) =$$

$$0.27t + .05058t^2 + 0.0028t^3 = \#$$

$$0.27t + 0.051t^2 + 0.0028t^3$$

Weight of Box



Weight of fiberglass inner wall: excludes plenus ext.

$$\text{Area} = 2 \times 17.37 \times 14.18 = 492.6$$

$$2 \times 14.18 \times 3.87 = 109.9$$

$$2 \times 17.37 \times 3.87 = \underline{134.6}$$

$$= 737\ \text{in}^2$$

Inner wall Mat'l vo. = $.04 \times 737 - 29.4\ \text{in.}^3$

Inner wall weight = $110 \times \frac{29.4}{1728} = 1.88\#$

Outer Aluminum Wall

$$\text{Area} = 2\left[(17.37 + 2t)(15.18 + 2t)\right] = 527.35 + 130.2t + 8t^2$$

$$2\left[(17.37 + 2t)(3.87 + 2t)\right] = 134.44 + 84.96t + 8t^2$$

$$2\left[(15.18 + 2t)(3.87 + 2t)\right] = \underline{117.49 + 76.2t + 8t^2}$$

$$\Sigma A = 779.28 + 291.36 + 24t^2$$

Volume: $.03 \times \Sigma A = 23.38 + 8.74t + 0.72t^2\ \text{in}^3$

$$\text{Wt. Outer Alum. Wall} = \frac{173}{1728}(23.38 + 8.74t + 0.72t^2) =$$

$$2.3 + 0.874t + 0.072t^2$$

3.3 Cont'd

3.3.1.6.3 Cont'd

Alum: 2 alum. shelves $2 \times 17.37 \times 14.18 = 492.6$

1 splitter $17.37 \times 15.18 = 264.$

1 plenum separater $17.37 \times 1 = \underline{17.37}$

$\Sigma = 773.97$ in.^{2}

Volume = 0.03" x 773.97 = 23.22 in^3

Wgt. inner shelves and splitter - 23.22in^3 x 0.1# alum.=2.32#

Wgt. Blower and ducting = 1.5#

6 trays @.03" THICK alum (merely a holder for 5 cans of food)

= 3.5#

Controls, mounts, handles etc. = 2#

Total wgt. reduces to:

$13.5 + 1.144t + 0.123t^2 + 0.00283t^3$#

3.3.1.7 Heat Loss (Penalty=0.133# per average $\frac{BTU}{hr}$)

Transferred to cabin over 24 hour period.

$$Q_{CABIN} = \underset{10\ min}{Q_{AREA}} + \underset{15\ min}{Q_{S.S}} + Q_{COOL\ DOWN} + Q_{BLOWER}$$

$Q_{PREHEAT}$ = $\frac{1}{2}$ STEADY STATE HEAT LOSS FOR 10 MINUTES

$$Q_{PREH} = \left(\frac{\overset{AREA}{5.41 + 1.01t + 0.0417t^2}}{\underbrace{0.872 + 4t}_{RESISTANCE}}\right)\left(\overset{\Delta T}{250-70}\right) \times \frac{1}{2} \times \frac{10}{60} \text{ BTU}$$

$$Q_{STEADY\ STATE} = \left(\frac{5.41 + 1.01t + 0.0417t^2}{0.872 + 4t}\right)(250-70) \times \frac{15}{60} \text{ BTU}$$

$$Q_{COOLDOWN} = 0.23 \frac{BTU}{\#-°F}\left[\underset{wgt.}{8.04 + 1.14t + 0.123t^2 + 0.0028t^3}\right]\left[\underset{\text{AVERAGE OVEN TEMP}}{178-70}\right] \text{ BTU}$$

$$Q_{BLOWER} = 16 \text{ WATTS} \times 3.41 \times \frac{25}{60} = 22.73 \text{ BTU}$$

TOTAL INPUT OVEN F

$$\frac{16-625}{16} \times 22.73 = 13.73 \text{ BTU}$$

3.3 Cont'd

3.3.1.7 Cont'd

Multiplying by $\frac{3}{24}$ to set average $\frac{BTU}{hr}$ for 3 meals over 24 hour period and 0.133# penalty per average $\frac{BTU}{hr}$ reducing and simplying gives:

$$P = \frac{5.396 + 1.01t + 0.041t^2}{0.872 + 4t} + 3.55 + 0.474t + 0.051t^2 + 0.0011t^3$$

3.3.1.8 Electrical Energy: (Penalty = 1.514#/KW-HR.)

$$\text{Elec. Energy} - E_{PREHEAT} + \underbrace{E_{SS}}_{Q_{SS} \quad Q_{FOOD}} + E_{BLOWER}$$

$$\underset{(BTU)}{E_{PREHEAT}} = \frac{1}{2} Q_{SS} \times \frac{10}{60} + Q_{STORED\ IN\ OVEN}$$

$$= \frac{1}{2} \frac{(5.41 + 1.01t + 0.0417t^2)(250-70)}{0.872 + 4t} \frac{10}{60} + 0.23\left[8.04 + 1.144t + 0.123t^2 + 0.0028t^3\right] \times [178 - 70]$$

$$= \frac{250 + 105}{2}$$

$$\underset{(BTU)}{E_{STEADY\ ST.}} = Q_{SS} + Q_{FOOD}$$

$$= \frac{(5.41 + 1.01t + 0.0417t^2)(250-70)}{0.872 + 4t} \times \frac{15}{60} + \overset{FOOD}{12.42\#_{FOOD}} \times \overset{SPEC.\ HT}{1} \times \overset{=\text{ MEAN OVEN TEMP.}}{(145 - 40)}$$

$$\underset{(BTU)}{E_{BLOWER}} = 16\ \text{WATTS} \times 3.41 \frac{BTU}{WATT\ HR.} \times \frac{25}{60}\ hr$$

Combining the above and multiplying by 3 meals/day x 7 days with 1.514# penalty for the above in KW-Hr units gives:

$$P_E = \frac{3.02 + 0.565t + 0.0233t^2}{0.872 + 4t} + 14.22 + 0.266t + 0.029t^2 + 0.00652t^3\#$$

Combining the above, Penalty = $P_{weight} + P_{heat\ loss} + P_{elec.energy}$ and simplifying gives

$$\Sigma P = \frac{8.42 + 1.58t + 0.064t^2}{0.872 + 4t} + 31.27 + 1.884t + 0.203t^2 + 0.004582t^3$$

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3.3 Cont'd

3.3.1.7 Cont'd

TAKING $\frac{dEP}{dt}$ = 0 GIVES:

$0.22t^4 + 6.6t^3 + 33.22t^2 + 13.57t - 30.87 = 0$

which gives a minimum penalty for $t \sim 0.78$"

However, there is negligible penalty difference between

t = 0.75" and t = 0.67", the touch temperature requirement

$\therefore$ h|e 0.67 to save a little volume.

Penalties for t = 0.67"

Penalty in Pounds (t=0.67")

Total Weight	Heat Loss	Electrical Energy	Total Penalty
14.32	5.6	15.37	35.29

3.3.1.8.1 Peak Electrical Power

$$\text{PEAK LOAD} = \left(\mathring{Q}_{SS} + \mathring{Q}_{FOOD} + \mathring{Q}_{BLOWER}\right) \frac{BTU}{hr}$$

$$= \left[\overset{\mathring{Q}_{SS}}{\frac{(5.41 + 1.01t + 0.0417t^2)}{0.872 + 4t}(180)} + \overset{\mathring{Q}_{FOOD}}{\frac{1304\ BTU}{0.25\ hr}} + \overset{\mathring{Q}_{BLOWER}}{16 \times 3.41} \right] \times \frac{1}{3413}$$

$$= (\text{FOR } t = 0.67) \quad \underline{1.63\ KW.}$$

3.3.2

Microwave Oven

Efficiency of microwave production = 50%

Efficiency of microwave heating capacity = 85%

∴ Overall electrical efficiency = 0.5 x 0.85 = 0.425

Heat power required in food for 40° → 145°F in 15 min.

$$= 12.42\# \times 1 \frac{BTU}{\# F} \times \frac{60}{15} \times \overset{\Delta T}{(105)} = 5216 \frac{BTU}{hr.}$$

3.3.2.1 Electrical Power Required $= \frac{5216}{0.425} = 12,300 \frac{BTU}{hr.} =$

$$= 12,300 \frac{BTU}{hr.} \times \underset{Kw\ hr}{\frac{1}{3413}} = \underline{\underline{3.6KW}}$$

Heat Loss to cabin per meal

$$= \frac{12,300 - 5216}{4} = \frac{7084}{4} = 1770\ BTU/MEAL$$

\# PENALTY/BTU

3.3.2.2 Heat Loss Penalty $= 0.133 \times \frac{1770 \times 3}{24\ Hr.} = \underline{\underline{29.5\#}}$

3.3.2.3 Electrical Energy Penalty

$$\overset{\#KW/hr}{1.514} \times \overset{Kw}{3.600} \times \overset{hr}{0.25} \times \overset{DAYS}{7} \times \overset{✓\ MEALS/DAY}{3} = 28.5\#$$

Weight estimated from existing equipment ref. Litton Atlerton Div. - on 747 airplanes 2400 watt microwave power oven weight 110#. Our required microwave power

$$= \frac{5216}{0.85} \times \frac{1}{3413} = 1.8KW$$

$$(?) = \frac{1.8}{1.4} \times 110 = 82.5\#$$

3.3.2.3 Cont'd

Total System Penalty =

Wgt. + Cabin Heat Loss penalty + Electric Energy Penalty

825 + 29.5 + 28.5 = 140.5#

Notes:

a) microwave oven cannot use metal cans

plastic bags should be heated directly.

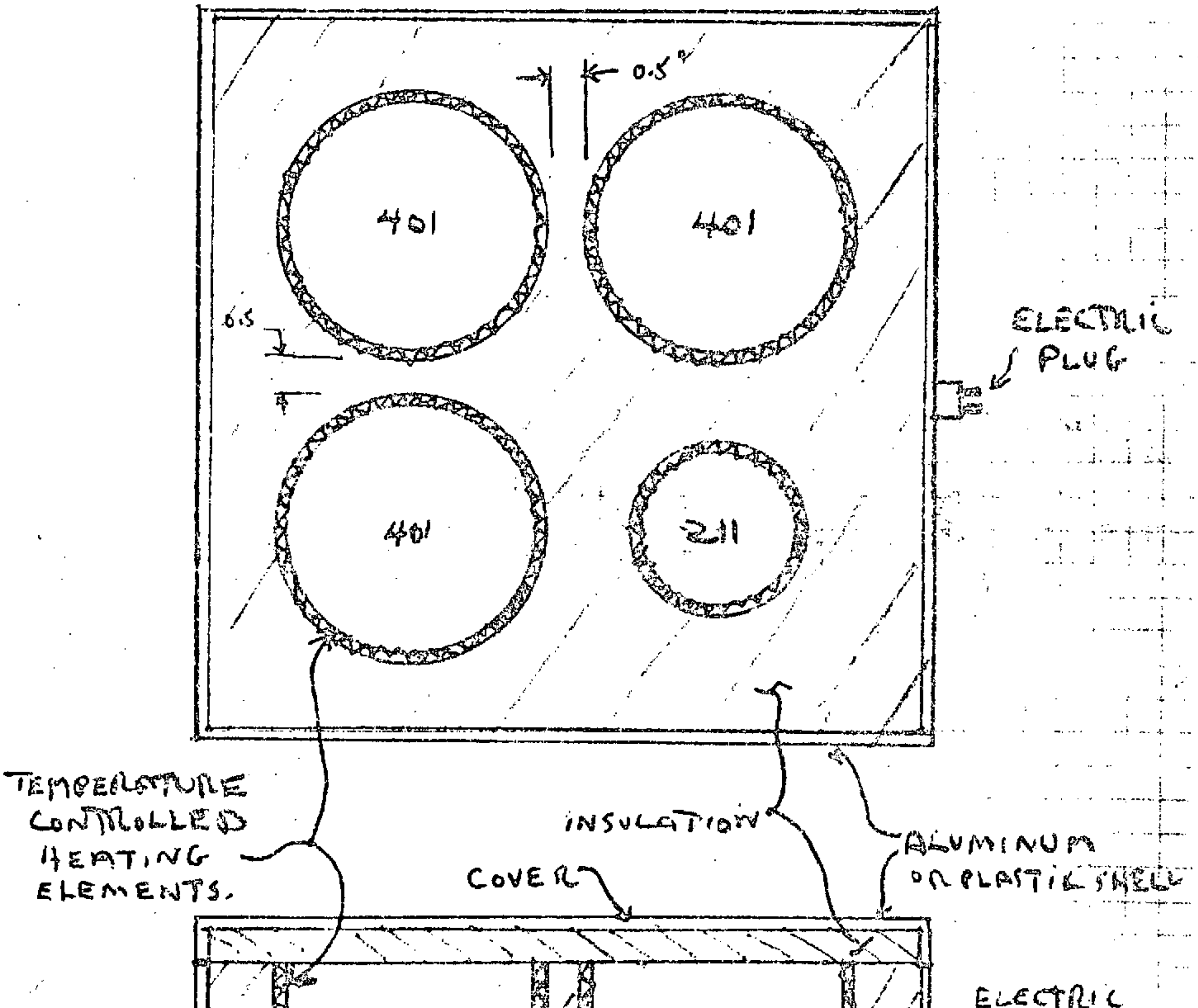
b) case insulation hot required due to internal heating

in Food. Case remains hot ambient temperature.

ASSEMBLY CONTAINS POWER SUPPLY 5 MIN MAGNETRO
OPERATES ON 3500V., MAGNETRON, WAVE CYCLE
CONTROLS.
THOUGH COMMERCIAL UNIT CASES ARE 0.04
ST. STEEL, CAN USE ALUMINUM

3.3.3 Heated Tray

Assume each meal contained in individual self heated tray, configuration as follows:



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Assume: Heaters on can sides and bottom

Ten minute proheat while water is added to the food.

Insulated cover provided for tray.

Check pure radiation coupling between heater and can and pure contact heating.

3.3.3.1 Radiation Heating

If heating is due to radiation between heater surfaces and can,

$$\sigma A \mathcal{F}(T_1^4 - T_2^4) = mc\frac{dT_2}{d\theta}$$

σ = CONSTANT

A = radiation area

$\mathcal{F}$ = combines configuration - emissivity factor

m = wgt of can

c = specific heat

θ = time

Let $\sigma A \mathcal{F}(T_1^4 - T_2^4) = h_r A(T_1 - T_2)$

where hr is a fictitious convective coefficient

$$\therefore hr = \sigma \mathcal{F}(T_1 + T_2)(T_1^2 + T_2^2)$$

$$\left.\begin{array}{lll} \text{Condition (1)} & T_1 = 250° & = 710°\text{ R} \\ & T_{2i} = 40°\text{F} & = 500°\text{ R} \\ & T_{2f} = 145°\text{F} & = 605°\text{R} \\ \text{Condition (2)} & T_1 = 250°\text{F} & = 710°\text{R} \\ & T_{2i} = 70°\text{F} & = 530°\text{R} \\ & T_{2f} = 145°\text{F} & = 605°\text{R} \end{array}\right\} \text{AVERAGE } \frac{hr}{\sigma} = 1.79$$

3.3 Cont'd

3.3.3.1 Radiation Heating

Assume that can surfaces are treated to give = 0.8 with similar value for heated surface.

Then: $\mathcal{F} = \frac{1}{\frac{1}{\varepsilon} + \frac{1}{\varepsilon_2} - 1} = \frac{1}{\frac{1}{.8} + \frac{1}{.8}} = 0.67$

$$hr_{AVERAGE} = 1.79 \times 0.67 = 1.2$$

$$T_{2f} = T_1 - (T_1 - T_{2i}) \exp\left(\frac{-hrA\theta}{mc}\right)$$

F For 401 Can   Area(side & bottom)=0.206 ft^2

M = 0.6#

Solve for time to heat from 40°F → 145°F

$$145 = 250-(250-40) \exp\left(\frac{-1.2 \times 0.206}{0.6 \times 1}\right)$$

θ = 1.67 hours.

$\therefore$ Pure radiation coupling for 250° heater surface takes much too long to heat.

Determine heater temperature to give 15 minutes time to rise from 40° to 135°   Smaller valve to shorten time.

$$135 = T_1 - (T_1 - 40) \exp.\left(\frac{-1.2 \times 0.206 \times 0.25}{0.6 \times 1}\right)$$

T_1 = 1040F obviously much too high.

Eliminate radiation coupling from consideration.

3.3.3.2 Conduction Heating

Assume pressure contact between heater elements and can surface.

Determine contact conductance, h_c, required between heater and can surfaces to provide 40° → 145° heating in 15 minutes, with heater at 250°F.

$$145 = 250 -(250-40) \exp\left(\frac{-h \times 0.206 \times 0.25}{0.6 \times 1}\right)$$

$\bar{h} = 8.1 \frac{BTU}{hr\text{-}ft^2\text{-}°F}$

3.3 Cont'd

3.3.3.2 Cont'd

What benefit in lowering h if heater temperature = 270°F?

Solving gives $h_{c\,210F}=7.1$ (moderate improvement)

Values of h_c actually achievable must be determined by test. Skylab heater trays data would be a valuable input.

Supper can is heater on side surface only (eliminating bottom) as in Skylab tray, then for 250° heater.

401 can side surface area = $\frac{\pi \times 4.06 \times 1.312}{144} = 0.116\ \text{ft}^2$

then $145 - 250 - (250-4\ )\ \exp\left(\frac{-h_c \times 0.116 \times 0.25}{0.6 \times 1}\right)$

$$\exp(-0.04833\ h_c\ )$$

$$e^{+0.04833h_c} = \frac{210}{105} = 2.$$

$$.04833h_c = 0.6931$$

$$h_c = 14.4 \qquad \frac{BTU}{hr\text{-}ft^2\text{-}°F}$$

3.3 Cont'd

3.3.3.3 Touch Temperature

To limit touch temperature to 105°F with cabin side

$$h = 1.45 \; \frac{BTU}{hr \cdot ft^2 \cdot {}^\circ F}$$

$$R = \frac{1}{1.45} + \frac{t}{\underset{\underset{\frac{K-BTU \cdot in}{hr \cdot ft^2 \cdot {}^\circ F}}{''}}{0.25}} = 0.69 + 4t$$

$$\frac{0.69}{0.69 + 4t} = \frac{105-70}{250-70}, \quad t = 0.72''$$

Assuming cover in place:

Top surface heat transfer area $= 3 \times \frac{\pi}{4} (4.06)^2 + \frac{\pi}{4} (2.69)^2$

$= 0.31 \text{ ft}^2$

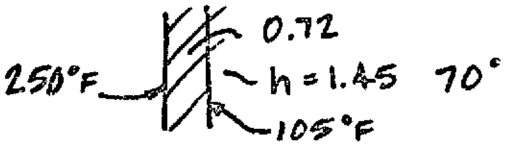
Bottom Surface same as top $= 0.31 \text{ ft}^2$

Through Sides (approx.)

$6 \times 4.06 \times 1.312 + 2 \times 2.09 \times 1.312$

Total approx. heat transfer area $= \Sigma = 0.89 \text{ ft}^2$

3.3.3.4 Tray Steady State Heat Loss



Top=Food Ave. temp.$=\frac{145 + 40}{2}$ .93

$R = \frac{1}{1.45} + \frac{0.72}{0.25} = 2.84 + 0.69 = 3.53$

Q top$= \frac{0.31(93-70)}{3.53} = 2$

Area Sides + bottom = 0.89 - 0.31 = 0.58

Sides + bottom $= \frac{0.58\ (250-70)}{3.53}$

= 29.6 BTU/hr

Loss for 6 trays=6(29.6 +2)= 192 BTU/hr. = six trays

Assume average tray temp.$=\frac{250 + 105}{2} = 178$°F

3.3 Cont'd

3.3.3.5 Tray Weight

Volume of tray including cover=

$(2 \times 4.06 + 0.5 + 2 \times 0.72)^2 \ (1.3.2 + 2 \times 0.72) -$

$-[3 \times \frac{\pi}{4}(4.06)^2 \times 1.312 + \frac{\pi}{4}(2.69)^2 \times 1.312]$

$= 220.13 \text{ in}^3 = 0.13 \text{ ft}^3$

Assume aluminum sheet on all surfaces including cover

(neglect can receptacle holes)

4 Surfaces $\times (2 \times 4.06 + 0.5 + 2 \times 0.72)^2 = 404.8 \text{ in}^2$

4 Surfaces x (2 x 4.06 + 0.5 + 2 x 0.72)(1.312 +7 x .72)=110.7

$\Sigma = 515.5 \text{ in}^2$

Aluminum Volume by sheet is 0.03" thick

Alum. Vol. - $515.5 \times 0.03 - 15.5 \text{ in}^3$

Wgt. Alum. Sheet - $15.5 \text{ in}^3 \times 0.1\# = 1.65\#$

Add 1 % for attachment wgt. Alum = 1.8#

Wgt. Six Trays - 6 x 1.8 = 10.8#/6 trays

3.3.3.5.1 Insulation Weight:

$\text{Vol.} = 0.13 \text{ ft}^3$ (ref. p.)

Weight $= 0.13 \text{ ft}^3 \times 0.6\# = 0.078$ 0.1#/tray

Heater Elements:

Assume heater elements weigh (4 per tray)

plus accessories = 4 x 2 oz. = 1 0.5#/tray

Total weight for 6 trays = 10.8 x 6[.1 + .5] =

Total weight 6 trays = 14.4#

3.3.3.6 Heat Loss Penalty

Preheat (assume $\frac{1}{2} Q_s$)

$\frac{19.2}{2} \frac{BTU}{hr} \times \frac{10}{60}$ hr = 16 BTU / 6 trays

Heating 192 x $\frac{15}{60}$ h = 48 BTU/ 6 trays

Cool Down:

Assume average temp. of tray = $\frac{105 + 250}{2}$ = 178

$14.4 \times \underset{\text{"cover}}{0.23} \times 178 - 590$ BTU for 6 trays

Total heat to cabin = 16 + 48 + 590 = 654 BTU

Penalty = 0.133 x $\frac{3 \text{ meals}}{24}$ x 654 = 11.0 # / 6 trays

3.3.3.7 Electrical Energy Penalty

Preheat: 1/2 Q_s x $P\theta$ + Stored Energy (6 trays)

= 192 $\frac{BTU}{hr}$ x 10 hr + 570 BTU = 622 BTU/6 trays

Heat = $\underset{\text{Heat to cabin}}{192 \times \frac{15}{60}} + \underset{\text{Food heating}}{12.42 \times 1 \times 105}$ = 1348 BTU

Total electrical = 1970

Elec. Energy Penalty = 1.514 x $\frac{1970}{34.3}$ x 3 x 7 = 18.4#/6 trays

Total System penalty (6 trays) =

Wgt + Heat Loss Penalty + Electrical Energy Penalty

13.6 + 11.0 + 18.4 $\underline{= 43.0\#}$

3.3.3.7.1 EEectrical Power Requires:

Steady State: 192 $\frac{BTU}{hr}$ + $\frac{1300}{0.25}$ $\frac{BTU}{hr}$

= 5392 $\frac{BTU}{hr}$ x $\frac{1}{3413}$ = 1.57 KW

3.3 Cont'd

3.3.3.8 Uncovered Trays

Suppose trays are not covered with insulated cover.

3.3.3.8.1 Weight Saving

Wgt. Saved is weight of cover

$= 2 \times (2 \times 4.06 + 0.5 + 2 \times 0.72)^2 \times .03 \times 0.1\#/\text{in}^3 = 0.57\#$

S 0.6#

Wgt saved for 6 trays - 6 x 0.6# = -3.6#

3.3.3.8.2 Heat Loss

Top uninsulated heat transfer area (with h = 1.45)

$$3 \times \frac{\pi}{4} (4.06)^2 + \frac{\pi}{4} (2.69)^2 = \sim 0.31 \text{ ft}^2$$

Insulated heat transfer area: (ref. p.)

Bottom	0.31 ft^2
Sides	0.271 ft^2
	0.58 ft^2

(ref. p.) Q top = 1.45 x 0.31 (93-70) = 10.3 BTU/hr

Q Sides & Bottom = 29.6

3.99 40

For 6 trays = 6 x 40 = 240 BTU/hr.

(ref.p.)

$$\text{Heat Loss Penalty} = \frac{240}{192} \times 16 = 20 \text{ BTU}/6 \text{ trays}$$

$$\text{Heat} = \frac{240}{192} \times 43 = 60 \quad /6\text{trays}$$

Cool Down = 555 BTU

Total heat to cabin = 636 BTU

$$\frac{635}{619} \times 10.3 = 10.6\#$$

Increase = +0.3#

3.3 Cont'd

3.3.3.8.3 Electrical Energy Penalty:

Preheat 240 x 10 + 555 = 595 BTU/6trays

Heat period = $240 \times \frac{15}{60} + 1300 = 1360$ BTU

$\Sigma = 1955$

$\frac{1955}{1935} \times 18 = 18.2$#

Increment = 0.2#

Change in Penalty

= Δ weight + Δ Heat Loss Penalty + Δ Electrical Energy =

-3.6# + 0.3 + 0.2 = -3.1# for 6 trays

∴ Cover can be eliminated or made much thinner.

Total system penalty w/thinner covers

= 41.9 -3.1 = 38.8# for 6 trays.

3.3.4 Water Tank Analysis

3.3.4.1 Hot Water Source Analysis

3.3.4.1.1 Water requirements:

Entree	4.5 oz.
2 Side Dishes	12.0
Soup	3.4
Beverages	7.6
	27.5 per meal

Total water requirement for six meals is 165 oz.

At an inlet flow from the fuel cells of 7 LB/HR, 1.473 hours would be required to fill the tank with the water required for six meals.

3.3.4.1.2 Tank Volume $[(\frac{163}{16})/61.7]$ (1728) = 288.8 cu. in.

Assume Tank is spherical

Tank radius 4.10 in.

Tank surface area 211.2 in.^{2}

Assume tank fabricated of .020 gage aluminum

Tank weighs .423 LB.

δ	Insulation Volume	Insulation Weight (ρ =.6 LB/FT^3)
.25 IN.	55.97 In.^{3}	.0194 LB.
.5	118.90	.0413
1.0	266.83	.0926
2.0	661.96	.2298

δ	Tank + Insul. Weight, P_c		Tank + Insul. Overall Vol.
.25 in.	.442 LB	The weight of the water expulsion mechanism is common to all cases and is not considered for a relative comparison of systems.	109.8 In^3
.5	.464		129.8
1.0	.516		176.9
2.0	.653		302.6

3.3.4.1.3

Weight Penalties (Assoc. with Fuel Cell & ECS Interfaces)

1) A power consumption penalty (1.514 LB/KW-HR) is incurred in heating the tank and insulation to their equilibrium temperatures from cabin temperature. This penalty is a function of insulation thickness and water temperature. Cabin temperature is taken as 75°F.

2) A power consumption penalty (1.514LB/KW-HR) is incurred in heating the water entering the tank. This penalty is a function of water flow rate, water temperature and water temperature at the tank inlet. Inlet water temperature is taken as 35°F.

3) A power consumption penalty (1.514 LB/KW-HR) and an ECS penalty(.133LB/BTU)are incurred in making up and absorbing the heat leak through the tank insulation. This penalty is a function of water temperature, insulation thickness, heated water flow rate, and mode of food preparation.

4)An ECS penalty (.133LB/BTU) is incurred as heated water cools to cabin temperature. This penalty is a function of water temperature.

5) An ECS penalty (.133LB/BTU) is incurred as the heated tank and insulation cool to cabin temperature during and after meal preparation. This penalty is a function of insulation thickness and water temperature.

3.3.4.1.3 Cont'd

Penalty (1)

Equilibrium Temperatures, t°F, and energy consumption, E KW-HR

$$\frac{k}{\delta}\left(\frac{R_1}{R_1+\delta}\right)(T_w - t) + h_g + E h_r)(t_f - t) = 0$$

k = .25 BTU-IN/Hr.Ft.^{2}°F

h = 1.45BTU/HR.FT.^{2}°F

E = .20 (assume outer surface of insulation is sheathed in aluminum foil)

t_f = 75°F

r_1 = 4.10 In.

T_w	δ	$\frac{k}{\delta}\left(\frac{R_1}{R_1+\delta}\right)$	t	ALUM.	$\bar{t}$	INSUL.	E
150°F	.25IN.	.94253	102.0°F	.1489BTU/°F	126.0°F	.00408 BTU/°F	.00333 KW-HR
	.5	.44563	90.8		120.4	.00867	.00339
	1.0	.20098	83.1		116.6	.01946	.00351
	2.0	.08402	78.6		114.3	.04827	.00383
170	.25	.94253	109.1		139.6	.00408	.00419
	.5	.44565	95.0		132.5	.00867	.00429
	1.0	.20098	85.2		127.6	.01946	.00444
	2.0	.08042	79.6		124.8	.04827	.00485
190	.25	.94253	116.2		153.1	.00408	.00511
	.5	.44565	99.2		144.6	.00867	.005.9
	1.0	.20098	87.4		138.7	.01946	.00581
	2.0	.08042	80.5		135.2	.04827	.00587

3.3.4.1.3 Cont'd

Penalty, P

T_w	δ	P,
150	.25	.00505 LB.
	.5	.00513
	1.0	.00531
	2.0	.00579
170	.25	.00635
	.5	.00649
	1.0	.00673
	2.0	.00734
190	.25	.00774
	.5	.00786
	1.0	.00879
	2.0	.00889

$\bar{t} = 1/2(T_W + t)$

Insulation is taken to heat from t_f TO $\bar{t}$
ALUMINUM TANK HEATS FROM
t_f to T_W

$$E = \left\{(\text{CAP. AL})(T_W - t_f) + (\text{CAP. INSUL.})(\bar{t} - t_f)\right\} / 3413$$

Insulation density $= .6 \text{LB/FT}^3$

$C_p = .21$ BTU/LB°F

Aluminum density $= 173 \text{ LB/FT}^3$

$C_p = .22$ BTU/LB°F

Penalty (5), P_5

The same energy that heats the tank and insulation to their equilibrium values during filling is dissipated to the cabin during cooling. It is assumed that this energy is dissipated to the cabin at a uniform rate over an eight hour period.

3.3.4 Cont'd

3.3.4.1.3 Cont'd

Penalty (5) Cont'd

From Penalty (1)

T_W	δ	E/8	P_5
150°F	.25	1.422BTU	.1892 LB
	.5	1.445	.1922
	1.0	1.498	.1992
	2.0	1.632	.2171
170	.25	1.789	.2379
	.5	1.830	.2434
	1.0	1.896	.2522
	2.0	2.069	.2751
190	.25	2.180	.2899
	.5	2.216	.2948
	1.0	2.478	.3295
	2.0	2.504	.3330

Penalty (2), P_2

$E = WC\ (T_W - T_{in})\ /3413$ $\quad T_{in} = 35°F$

$C = 1.0$ BTU/LB°F $\quad = 1.473$ HR

$W = 7$ LB/HR

T_W	E	P_2
150°F	.3474KW-HR	.5260LB
170	.4078	.6175
190	.4683	.7089

3.3.4.1.3 Cont'd

Penalty (3), P_3

The heat leak rate from a full tank is given by

where t is the equilibrium temperature of the insulation outer surface tabulated in the analyses for Penalty (1). Approximate the integrated average surface area during filling and emptying by half the surface area. The fill time is 1.473 hours. The emptying time is a function of the water flow rate to the galley and the mode of food preparation, but since the allowable cases require a total food preparation time of approximately one hour for six meals, the emptying time will be taken as one hour.

$$E = 2\pi \left(R_1 + \delta \right)^2 \frac{k}{\delta} \left(\frac{R_1}{R_1 - \delta} \right) \left(T_w - t \right) (2.473) / 3413$$

T_W	δ	E		E/8	P_3
150	.25	.02707KW-HR	92.38	11.55 BTU	1.577 LB
	.5	.01765	60.24	7.530	1.028
	1.0	.01106	37.74	4.718	.6442
	2.0	.00706	24.09	3.011	.4112
170	.25	.03434	117.2	14.65	2.000
	.5	.02236	76.32	9.540	1.303
	1.0	.01401	47.83	5.979	.8164
	2.0	.00893	30.49	3.811	.5204
190	.25	.04163	142.1	17.76	2.425
	.5	.02707	92.39	11.55	1.577
	1.0	.01695	5787	7.234	.9878
	2.0	.01082	36.93	4.616	.6303

3.3.4.1.3 Cont'd

Penalty Cont'd

In evaluating the ECS penalty, it was assumed that energy dissipated to the cabin would be dissipated at a uniform rate over an eight hour period.

Penalty (4), P_4

This penalty is based on 165 oz. of water cooling from T_W to t_f. In evaluating the penalty, it is assumed that this energy is dissipated to the cabin at a uniform rate over an eight hr. period.

$$Q = (165/16)(1.0)(T_W - t_f)/8$$

T_W	Q	P_4
150	96.68 BTU	12.86LB
170	122.5	16.29
190	148.2	19.72

Since this penalty was not considered in the active oven analysis, it will be neglected here in order to obtain comparative penalties for all systems.

3.3.4.2

Summary Penalty

T_W	δ	P	P_1	P_2	P_3	P_5	Total Weight Penalty
150°F	.25	.442	.00505	.5260	1.577	.1892	2.739
	.5	.464	.00513		1.028	.1922	2.215
	1.0	.516	.00531		.6442	.1992	1.891
	2.0	.653	.00579		.4112	.2171	1.813
170	.25	.442	.00635	.6175	2.000	.2379	3.304
	.5	.464	.00649		1.303	.2434	2.634
	1.0	.516	.00673		.8164	.2522	2.209
	2.0	.653	.00734		.5204	.2751	2.073
190	.25	.442	.00774	.7089	2.425	.2899	3.874
	.5	.464	.00786		1.577	.2948	3.053
	1.0	.516	.00879		.9878	.3295	2.551
	2.0	.653	.00889		.6303	.3330	2.334

The total weight penalty is plotted in Figure 34 as a function of insulation thickness and water temperature. It can be seen from the figure that optimum insulation thickness is somewhat greater than two inches, and that the weight penalty varies little over a wide range of insulation thickness around the optimum value. For this reason, practical optima were selected at the points where the weight penalty begins to vary markedly with change in insulation thickness. The weight penalties associated with the practical optimum insulation thicknesses are given in Figure 34 a function of water temperature.

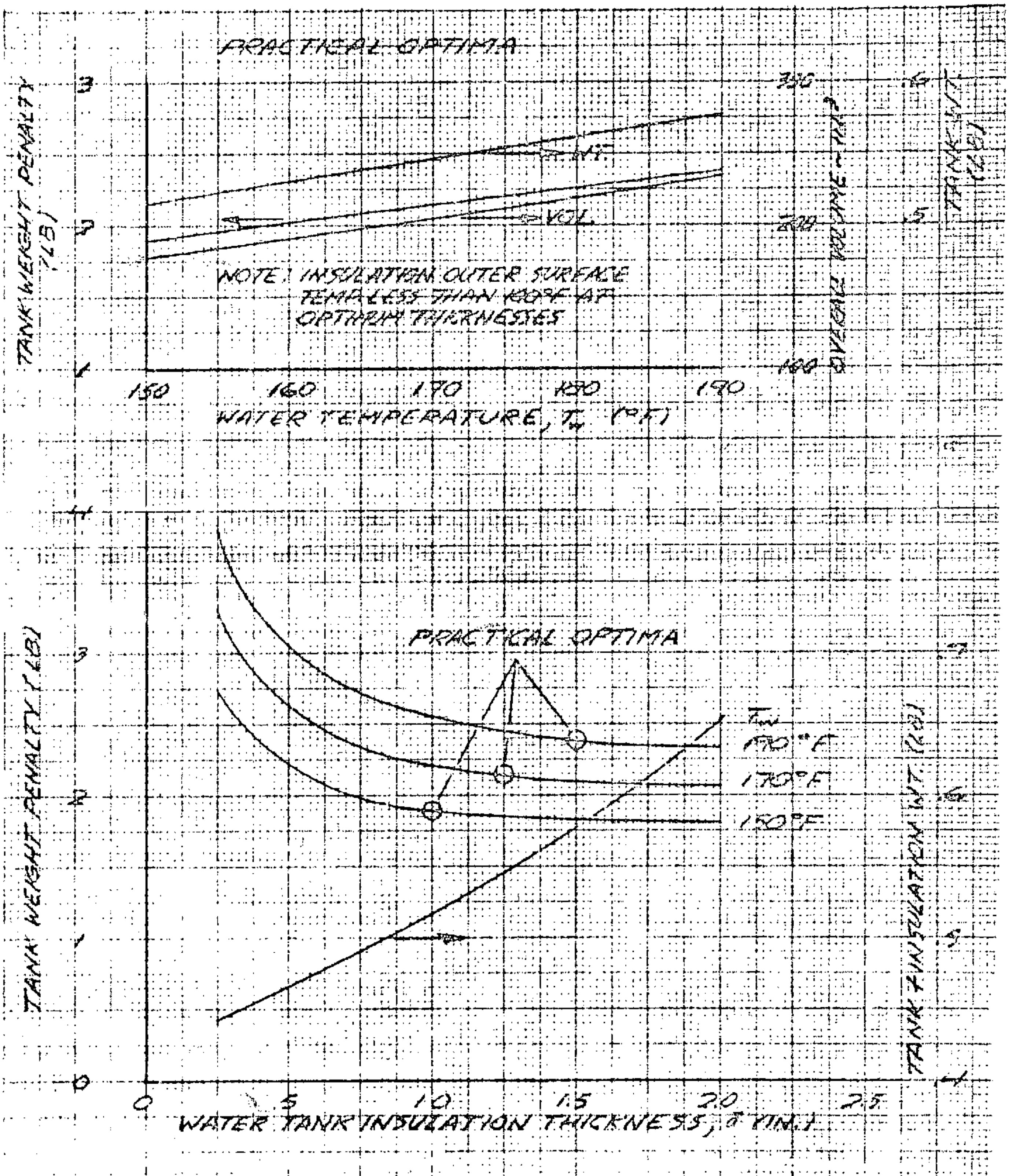


Figure 34. Total Weight Penalty

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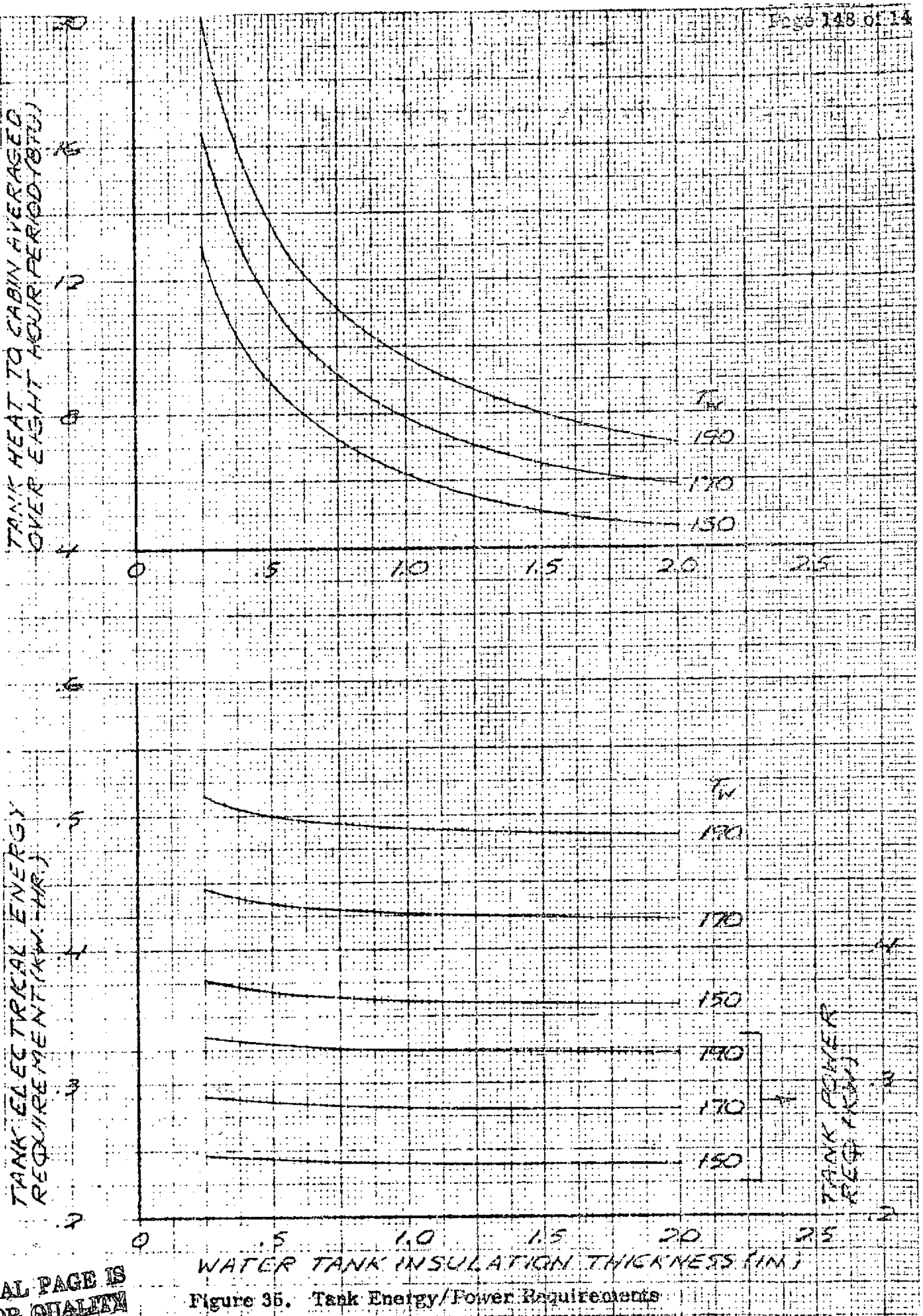
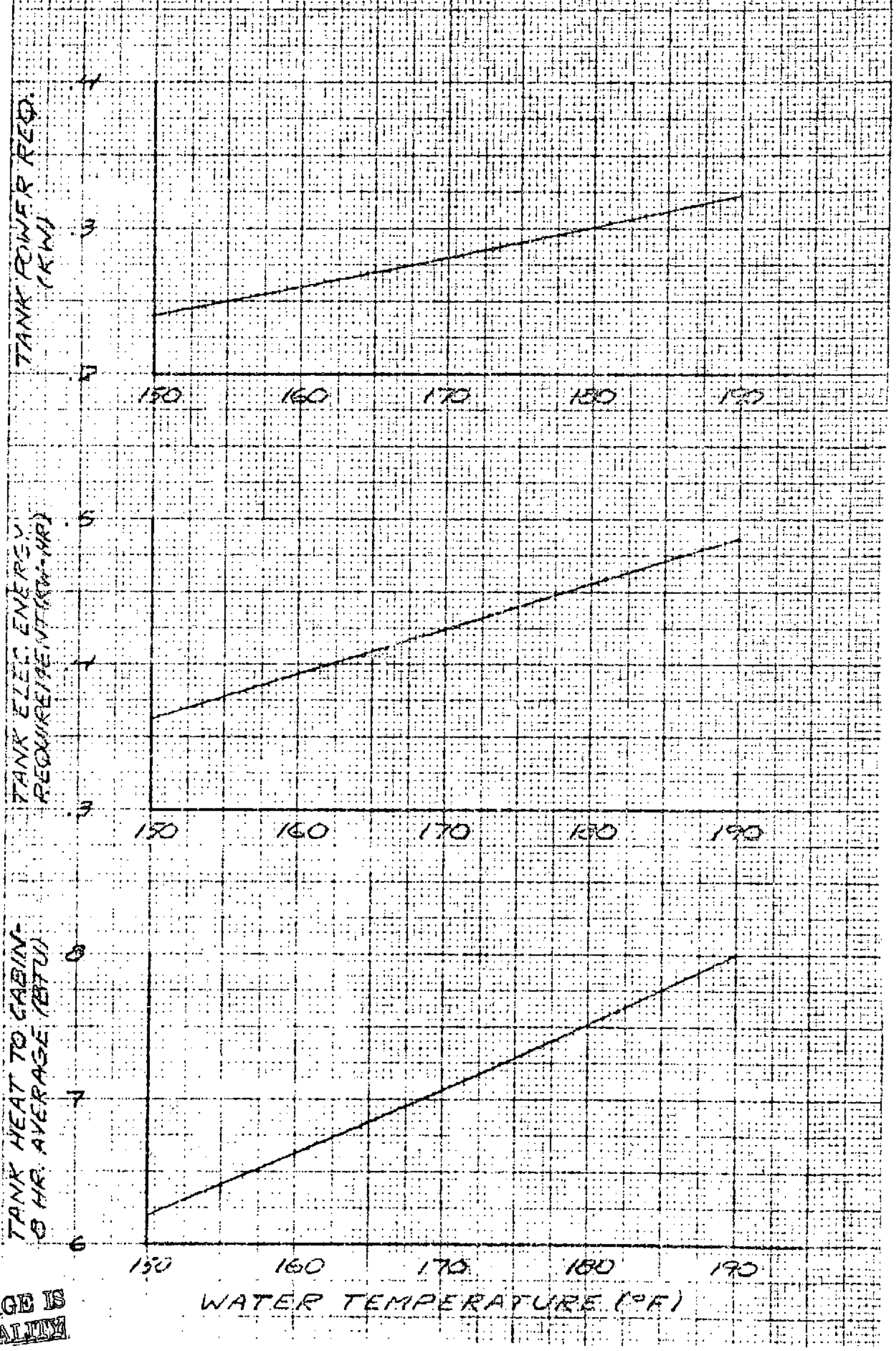


Figure 35. Tank Energy/Power Requirements

FIGURE 30. WATER TANK INTERFACE REQUIREMENTS AT OPTIMUM INSULATION THICKNESSES



3.3 Cont'd

3.3.5 Hydraulic Warming Concept

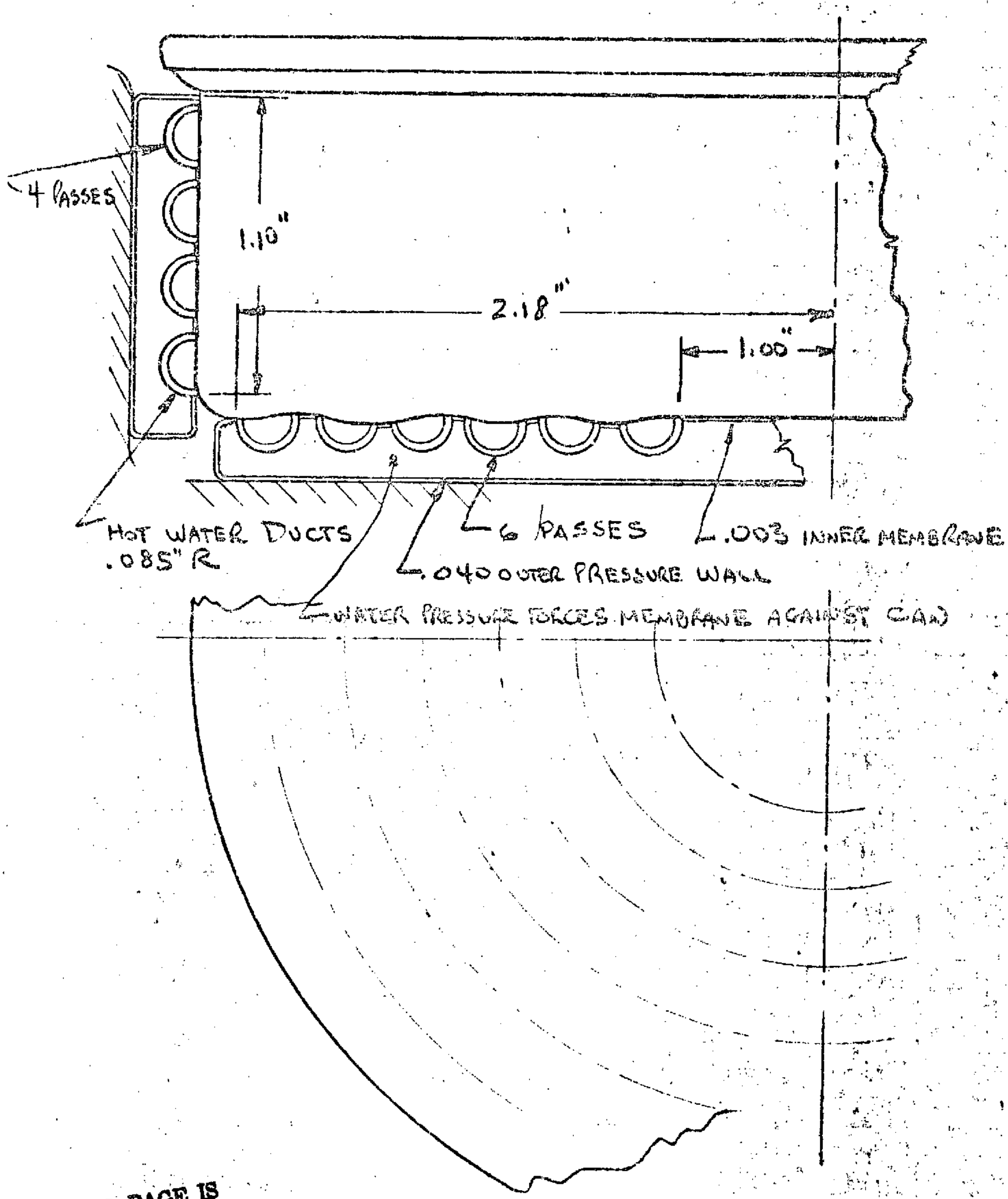
3.3.5.1 Description

The concept is based on the utilization of hot water to replace the electrical heating coils in the Skylab type tray. The food can cavities are encircled by conduits on the sides and bottoms, where hot water is directed from the vehicle supply through an inlet fitting and returned to the vehicle loop at an outlet fitting. The tray would contain disconnects at each fitting to permit plug-in when required.

The design is based on the use of hot water availability from the vehicle coolant loop as the primary source of heat energy. By plugging in the trays, a 'free' water supply at the proper temperatures enable warming of the food cans. A sketch of the hot water ducts arrangement is shown in Figure 1.

3.3.5.2 Assumptions

- Initial Ambient at 70°F
- Can size to be heated = 401 x 105
- Heat applied to bottom and sides
- Vehicle supplied temperature = 155°F



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WARMING CONCEPT

3.3.5.3 Calculations

Determine the coefficient of heat transfer through film between inside surface of cool tubing and warm liquid - low viscosity, streamline flow.

(1) $h= 1.62\frac{k}{d} [(\frac{M}{M_f})^{1/3}(1 +0.015\ Z^{1/3})]\ [\frac{4\ wc_p}{\pi\ kL}]^{1/3}$

where $Z = (d^3 p^2 \beta \Delta \tau \quad /u^2)\ g = 0$ (assume zero grav.)

M: Viscosity at 155°F = .00292 lb/hr.ft.

M_f: Viscosity at 80°F = .00578 lb/hr.ft

K: Thermal Conductivity = .384 BTU/hr.ft.°F

Cp: Specific Heat = 1.0 BTU/lb.°F

t: Liquid-Surface = 155°F -80°F

d: Hydraulic Diameter = $(\pi/2 + \pi)$D= .00865 Ft.

L: Tube Length =(TBD) ft.

W: Coolant Flow Rate =(TBD) lb/hr.

(2) $\therefore\ h = 1.62 \left(\frac{.384}{.00865}\right)\left(\frac{.292}{.578}\right)^{1/3}\left(\frac{4\times 1}{.384\pi}\right)^{1/3}\left[\frac{W}{L}\right]^{1/3}$

Where a value for the warming flow rate W is 20.1 lb/hr, as solved in equation (3).

Laminar Flow

The value of W = 20.1 lb/hr is the limit for flow in the laminar or streamline region based upon the following: Re = 2100

Re ~ dvp/u where

D: Hydraulic Diameter = .00865 ft.

V: Fluid Velocity = (TBD) ft/hr

ρ : Fluid Density = 61.2 lb/ft^3 @ 155°F

U: Fluid Viscosity = 1.05 lb/ft. hr.

Di: Geometric Diameter = .0142 ft.

3.3 Cont'd

3.3.5.3 Cont'd

(3) $W = VA_{TUBE}\rho = Re\,\frac{u}{D}\left(\pi/8\right)(Di)^2$

$W = 2100\ (1.05)/.00365\ \left(\frac{\pi}{8}\right)\ (.0142)^2$

$W = 20.1$ lb/hr. Max. flow for laminar regime

Thus in the equation (2), the coefficient of heat transfer becomes

(4) $H = 234\ L^{-1/3}$

where L is the length of heating lines.

Can Heating

For sides of Can -

$h_s = 234\ (4.81)^{-1/3}$ (from solution (4))

$\bar{h}_{side} = 146.5$ BTU/hr.ft^2°F

$\frac{1}{U} = \frac{\Delta x}{K} + \frac{1}{h_{side}}$ (assume perfect conductance at food surface)

Where U is overall surface conductance

X is thickness of teflon membrane between can and water film (from Fig. 1 = .003 in.)

K for teflon membrane = 0.14 BTU/hr.ft°F

$U^{-1} = \frac{.003}{12.14} + 1/146.5$

$U_{side} = 116$ BTU/hr-ft^2°F

For Bottom of can -

$h = 234\ (4.13)^{-1/3}$

$h_{bottom} = 139.0$ BTU/hr.ft^2°F

and

$U^{-1} = \frac{.003}{12}.14 + 1/139$

$U_{bottom} = 111.3$ BTU/hr.ft^2-°F

3.3 Cont'd

3.3.5.3 Cont'd

Effective Conduction Correction

Due to the fact that the unit surface conductance may act on only a portion of the actual available heat transfer area, the effective conductance acting on the sides and bottom of the food can will be adjusted for subsequent calculations with the following expression:

$$U_{\text{effective}} = U_{\text{actual}} \times \frac{A_{\text{effective}}}{A_{\text{actual}}} \quad (5)$$

Adjusting the previous values therefore

$$U_{\text{side (eff)}} = 116 \times \frac{.0552}{.0580}$$

$$U_{\text{side (eff)}} = 110.2 \text{ BTU/hr.ft}^2\text{-°F}$$

and

$$U_{\text{bottom (eff)}} = 111.3 \times \frac{.025}{.0387}$$

$$U_{\text{bottom (eff)}} = 72.0 \text{ BTU/hr.ft}^2\text{°F}$$

Physical Properties Used For Food
(Based on 70% water; 30% solid food)

$K = 0.20$ BTU/hr-ft^2-°F

$C = 0.82$ BTU/ °F

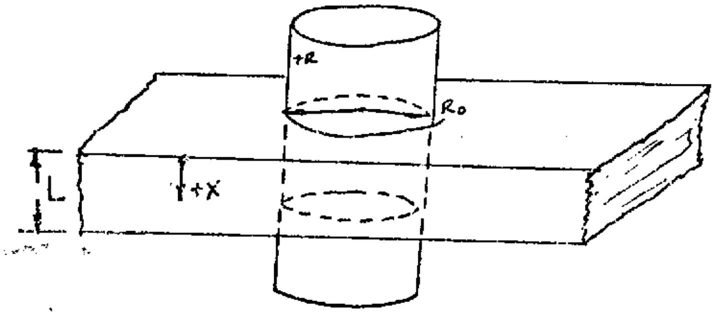
$\rho = 50.0$ lb/ft^3

$\alpha = .00488$ ft^2/hr

3.3.5.3 Cont'd

Physical Prop. used for Food Cont'd

Assume that the sides and bottom of the food can are heated from the vehicle water source at 155°F, at the respective conductance values. For the graphical solution presented below, the curved walls of the food can are considered as a long cylinder, while the end effects are considered as parallel surfaces of a wall; one surface of the wall is heated (can bottom) while the other wall surface is assumed perfectly insulated (can lid).



$R_o = 2.28$
$L = 1.10$

Defined point of interest at (X=0),r= 0)

Determine temperature transient of point x = 0, r = 0 versus time for an initial ambient condition of 70°F (Flow rate of 155°F fluid is 20.1 lb/hr).

Solution: Calculate two intermediate transient temperatures for x = 0, r = 0 using 130°F and 150°F

From Kreith (1), it can be determined for the Heisler tables:

$$(6)\ \left(\frac{T - T_\infty}{T_0 - T_\infty}\right) = \frac{130°F - 155°F}{70°F - 155°F} = .294$$

for the surface of the wall' (can bottom)

$$\frac{K}{\tau_h r_o} = \frac{.20 \times 12}{72 \times 2.28} = .01465$$

using $U_{bottom(eff)} = \bar{h}$

3.3.5.3 Cont'd

(1) Principles of Heat Transfer, Frank Freith

For the surface of the 'cylinder' (curved sides of can)-

$$\frac{K}{\bar{h}L} = \frac{.20 \times 12}{110.2 \times 1.10} = .0198$$

using $U_{side\ (eff)} = \bar{h}$

For a finite cylinder, the product solution of the temperature ratios must agree according to -

$$\underbrace{\frac{T - T_\infty}{T - T_\infty}}_{\text{Finite Cylinder}} = \underbrace{\frac{T - T_\infty}{T - T_\infty}}_{\text{infinite cylinder}} \times \underbrace{\frac{T - T_\infty}{T - T_\infty}}_{\text{Finite plate}}$$

using equation (6)

$$(7) \quad \underbrace{\frac{T - T_\infty}{T - T_\infty}}_{\text{Finite cylinder}} = \frac{130°F - 155°F}{70°F - 155°F} = .294$$

The trial and error solution using figures in Kreith at $x/L = 0$ and $r/r_o = 0$ are shown below.

Trial and Error Solution (130°)

(HRS)	Flat Plate (Fig. 4-8)		Long Cylinder (Fig. 4 -10)		Product of Temperature Ratio	Comments on Size of Ratio (***)
Time	AT $\frac{\alpha\theta}{L^2}$	READ $\frac{T-T_\infty}{T_0-T_\infty}$	AT $\frac{\alpha\theta}{r_0^2}$	READ $\frac{T-T_\infty}{T_0-T_\infty}$		
2.0	1.164	.074	.270	.36	.0266	too small
1.0	.582	.37	.135	.69	.255	
0.8	.466	.40	.108	.80	.320	too large
0.9	.524	.36	.121	.78	.281	
0.88	.512	.367	.119	.79	.290	ok

*** NOTE: Comparison is with results of equation (7)

Temperature ratio = .294

The point at x = o, r = o reaches a temperature of 130°F in about .88 hours. (or 53 min.)

3.3 Cont'd

For the case of food at 150°F

$$\frac{T - T_\infty}{T_o - T_\infty} = \frac{150°F - 155°F}{70° - 155°F} = .0589$$

The trial and error solution using figures in Kreith'

at $x/L = o$ and $r/r_o = 0$, are shown below,

Trial & Error Solution (150°)

(HRS) Time	Flat Plate (Fig. 4-8)		Long Cylinder (Fig. 4-10)		Product of Temperature Ratio	Comments on Size of Ratio (***)
	At $\frac{d\theta}{L^2}$	Read $\frac{T-T_\infty}{T_o-T_\infty}$	At $\frac{d\theta}{r_o^2}$	Read $\frac{T-T_\infty}{T_o-T_\infty}$		
2.0	1.164	.074	.270	.36	.0266	Too small
1.9	1.105	.082	.256	.35	.0287	
1.5	.872	.148	.203	.46	.068	Too Large
1.6	.930	.13	.216	.45	.0585	OK

The point at x = o, r = o reaches a temperature of 150°F in about 1.6 hours. (or 96 min.)

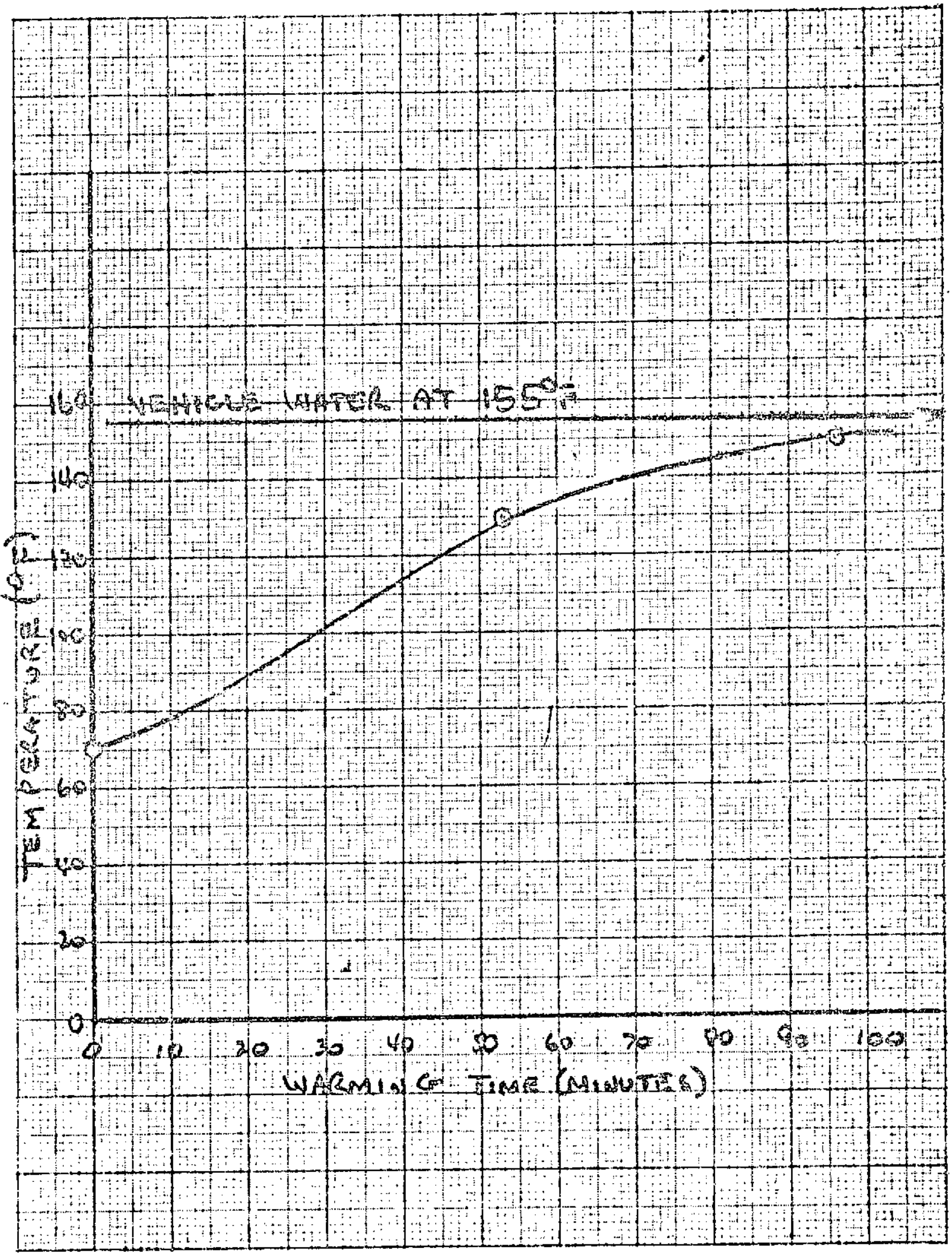


Figure 37

FOOD TEMPERATURE VS. WARMING TIMES

C-3

Figure 38 HYDRAULIC CONCEPT - COOLING TIMES