STUDY OF THERMAL CONTROL SYSTEMS FOR ORBITING POWER SYSTEMS

MATERIALS EXPERIMENT CARRIER

THERMAL CONTROL SYSTEM STUDY

Contract NAS8-33560

Report No. 2-53020/1R-52637

November 1980

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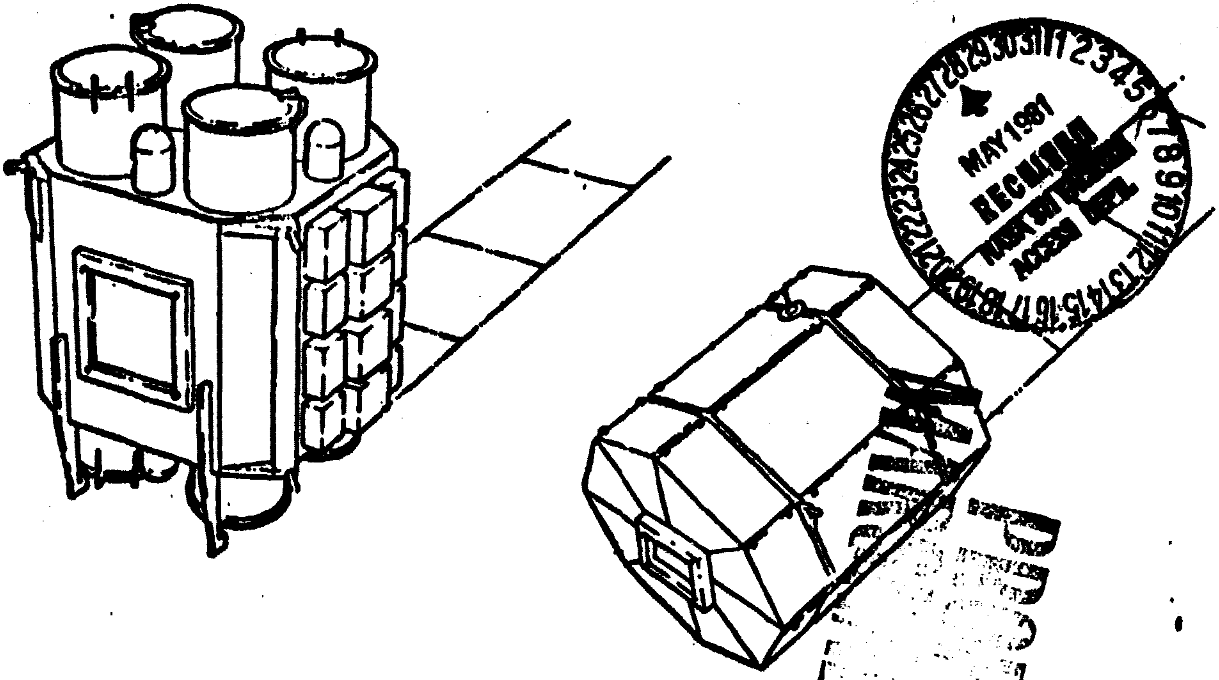

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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by

VOUGHT CORPORATION

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1.0 INTRODUCTION AND SUMMARY

The Materials Experiment Carrier (MEC) Thermal Control System Study was conducted by Vought as an add-on to the Study of Thermal Control Systems for Orbiting Power Systems (PS), Contract NAS8-33560. The study was conducted for NASA Marshall Space Flight Center. Jim Owen was the Technical Monitor and Ken Taylor acted as overseer of the MEC work.

A previous study (Reference 1) of MEC thermal control had been conducted under subcontract to TRW, Inc. This limited study concentrated on the MEC radiator design and conducted additional evaluations of centralized vs decentralized radiator location. The issue of decentralized MEC radiators vs centralized Power System radiators was addressed in that study with the conclusion that total weight to orbit could be minized by centralizing the radiators on the Power System even though the PS radiators operate at lower temperature than is possible for typical MEC heat loads. The type of MEC radiators, i.e. pumped liquid, all heat pipe, hybrid heat pipe, was also addressed with the conclusion that pumped liquid, bumpered tube radiators were the lightest weight.

As a result of that study, further MEC thermal control system work was defined under the current add-on effort to concentrate on systems trade studies comparing various methods of obtaining MEC thermal control. In addition to these trade studies, a fluid selection study for the MEC transport loop was conducted, and a study of the MEC thermal control loop interface with the experiments was performed. Methods of obtaining low temperature cooling for some of the MEC payloads were also considered. In addition, a review of available thermal control coatings for the MEC vehicle and potential high temperature MEC radiators was conducted. The results of all the work were then reviewed and items which would require further technology development were identified.

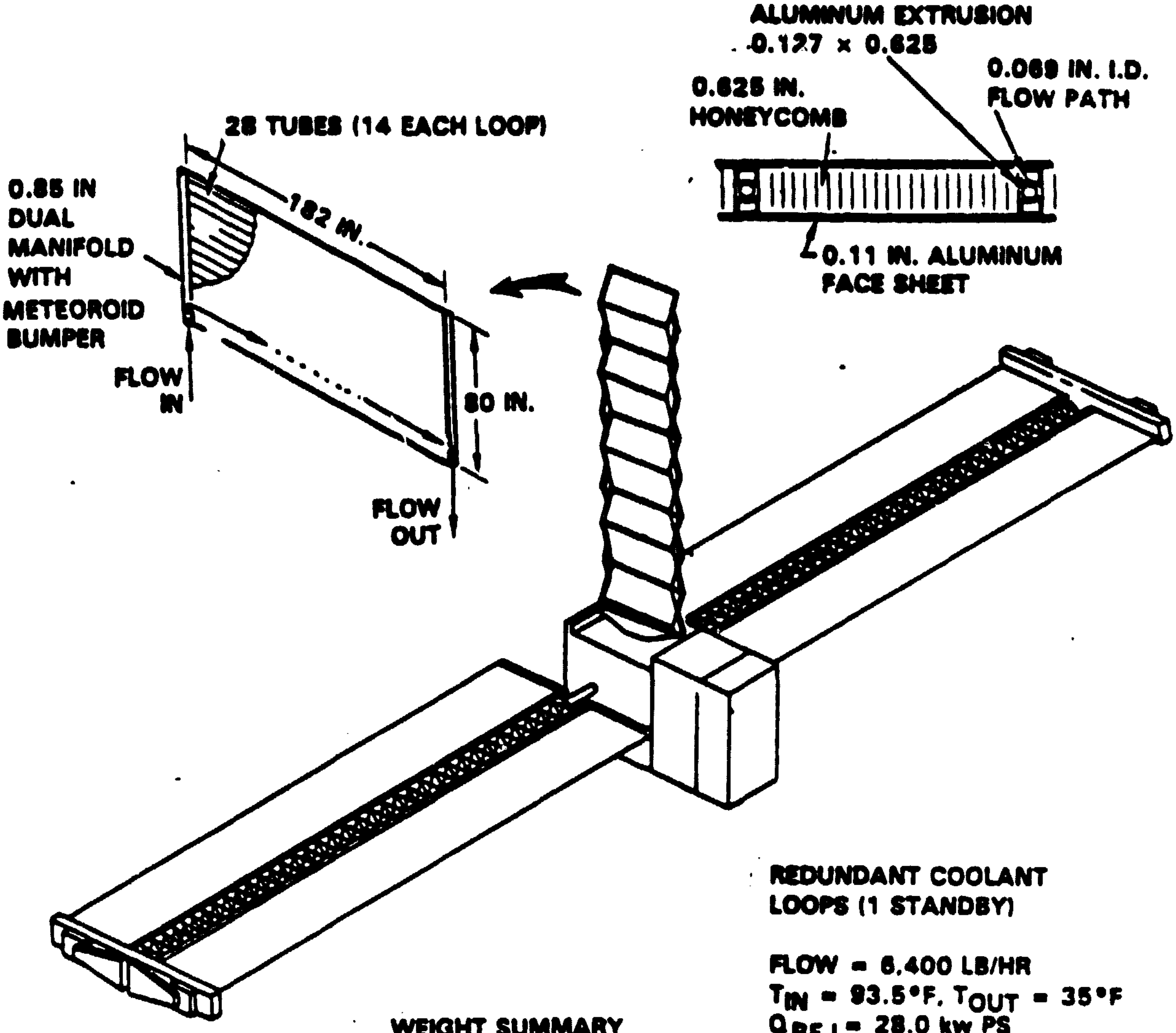
Four possible arrangements of the MEC and PS thermal control loops were defined which would provide symmetric heat rejection (i.e. one kW of heat rejection for each kW of power) to the MEC payload. These arrangements were then compared to the baseline reference concept which provides only 16 kW heat rejection. The comparisons were intended to show the cost of obtaining symmetry in terms of dollars, weight, complexity, growth potential, ease of integration, technology and total launch weight. The results of these comparisons was that the concept which splits the PS thermal control loop into two systems, one to reject PS waste heat and one payload waste heat, appeared favorable. The low temperature payloads are best accommodated with a separate PS/MEC low temperature heat exchanger if a low temperature PS thermal control loop is available. If a high temperature split loop is used further study is required to determine the best method to meet this requirement.

The fluid selection study resulted in recommendation of FC72 as the MEC heat transport fluid based on the thermal and physical characteristics. FC75 and FC77 are attractive alternates.

The coatings review indicated anodized and alodine treated aluminum surfaces or silver teflon are the best choices for the MEC vehicle where durability is an important factor. For high temperature radiators silver teflon or Zinc Orthotitanate are recommended choices.

2.0 MATERIALS EXPERIMENT CARRIER/POWER SYSTEM THERMAL CONTROL SYSTEM TRADE STUDIES

The Thermal Control System (TCS) trade studies were conducted using the results of the previous study discussed in Section 1.0 and the 25 kW Power System Reference Concept defined in earlier efforts of this contract and documented in Reference 2. The reference concept which was used as a basis for these studies is illustrated in Figures 1 through 3. Figure 1 illustrates the radiator configuration. Nine panels are deployed by a scissors type mechanism along the PS axis. The heat transport fluid (assumed to be R21) flows through 14 tubes manifolded at each end of the 182 x 80 inch panels. Each panel contains two identical flow passages. The nine panels are flow connected in parallel with flex hoses providing fluid transfer across the folding joints. The reference concept TCS loop is shown schematically in Figure 2. Completely redundant loops are provided with one loop operating at a time. Two pumps operating simultaneously are required to provide the required 6400 lbm/hr flow rate with a standby pump in each loop to provide component redundancy. The remaining components in the loop besides the radiators are a temperature control valve, GSE heat exchanger coldplates, three payload heat exchangers and three payload heat exchanger control valves. The payload heat exchanger temperature control valves are present to insure return temperature from the payloads does not exceed the 100°F limit of the design requirements. The stowed radiator configuration for the reference concept is shown in Figure 3 illustrating the proximity of the



REDUNDANT COOLANT LOOPS (1 STANDBY)

FLOW = 6,400 LB/HR
T_{IN} = 93.5°F, T_{OUT} = 35°F
Q_{REJ} = 28.0 kw PS
9 kw PAYLOAD
DEPLOYED NATURAL FREQUENCY = 0.11 HZ

WEIGHT SUMMARY

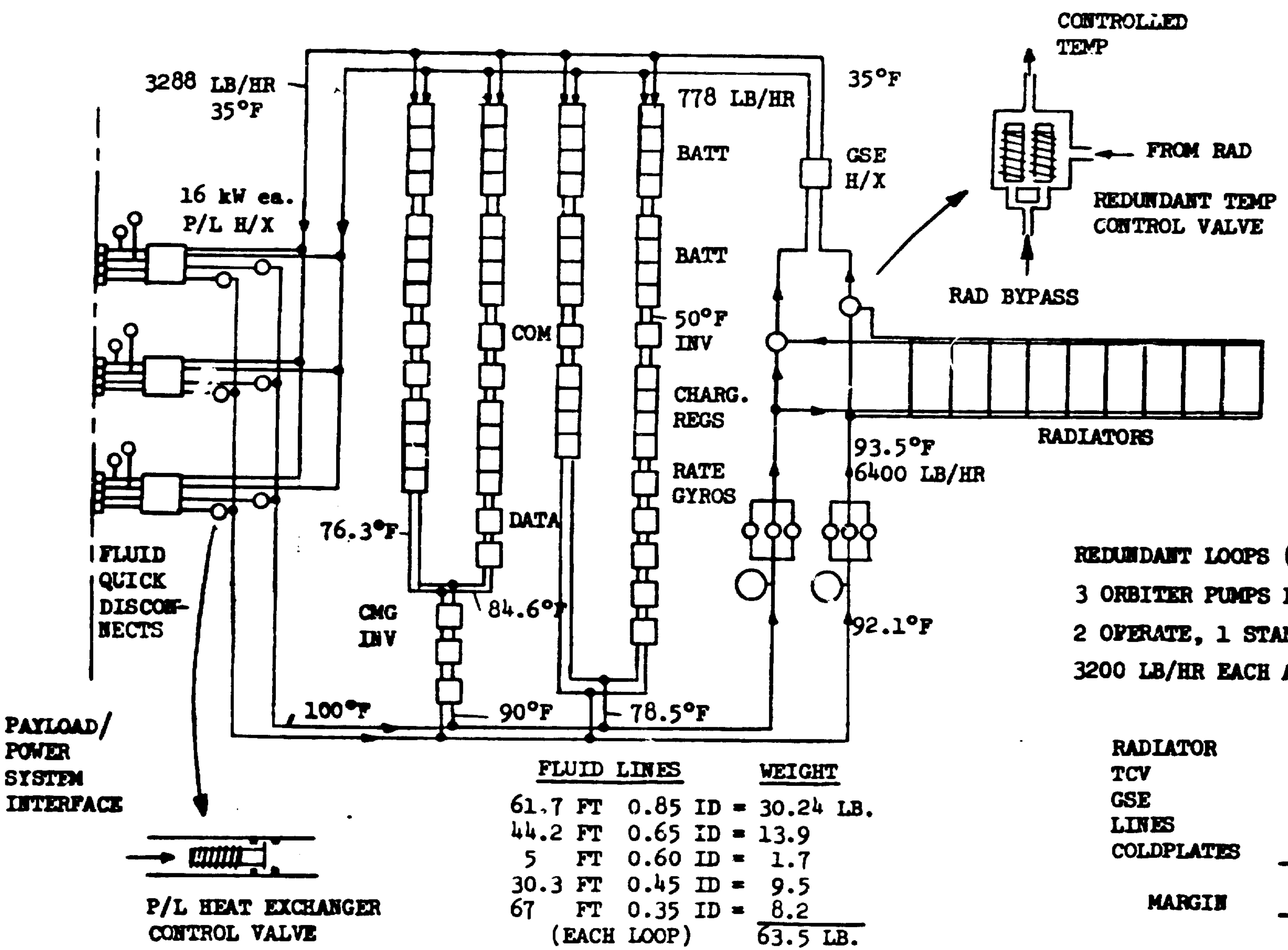
RADIATOR PANELS (9)	1,322 LB
INTER PANEL FLEX HOSES (40)	80 LB
SCISSORS ARMS (2 × 0.3 IN. WEB I BEAM)	234 LB
DEPLOYMENT BASE - (SOLAR AVOIDANCE) (GEARS, MOTOR, LATCHES, ETC)	247 LB
	1,883 LB

25kW POWER SYSTEM REFERENCE CONCEPT

FIGURE 1

VOUGHT

POWER SYSTEM TCS SCHEMATIC



FLUID LINES			WEIGHT
61.7	FT	0.85 ID =	30.24 LB.
44.2	FT	0.65 ID =	13.9
5	FT	0.60 ID =	1.7
30.3	FT	0.45 ID =	9.5
67	FT	0.35 ID =	8.2
(EACH LOOP)			63.5 LB.

REDUNDANT LOOPS (ONE STANDBY)

3 ORBITER PUMPS EACH LOOP

2 OPERATE, 1 STANDBY

3200 LB/HR EACH AT 64 PSI

	ΔP
RADIATOR	30.0
TCV	6.0
GSE	3.0
LINES	8.8
COLDPLATES	3.0
	50.8 PSI
MARGIN	13.2
	64

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FIGURE 2 25 kW POWER SYSTEM REFERENCE CONCEPT FLOW SCHEMATIC

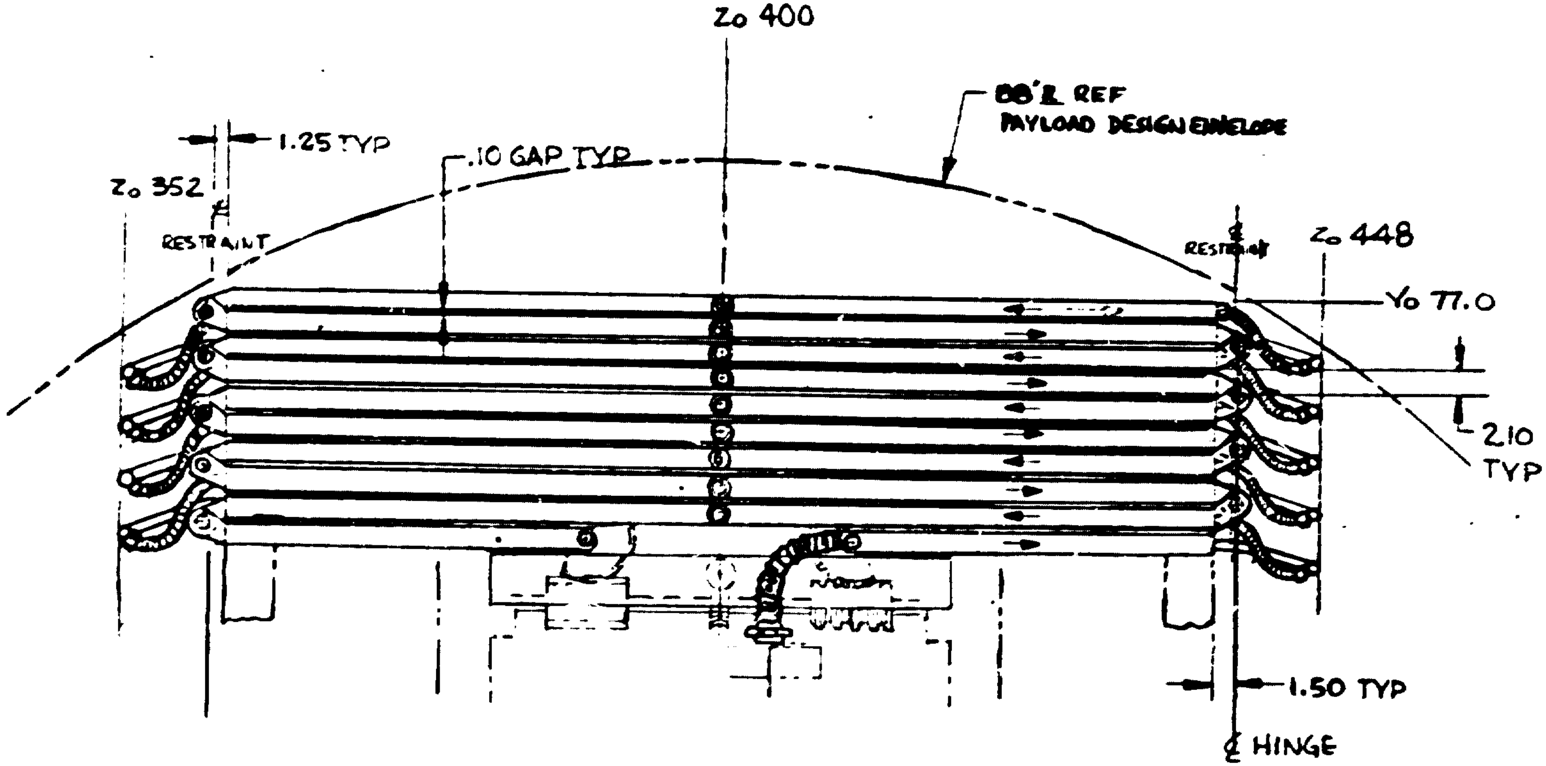


FIGURE 3

REFERENCE CONCEPT STOWED RADIATOR ENVELOPE stowed radiators to the reference concept payload design envelope. The equipment considered in the assumed MEC coolant loop is shown schematically in Figure 4. Four experiment containers with 6 kW power requirements each are assumed. This is representative of the "nominal" MEC vehicle from the TRW MEC Vehicle Studies described in Reference 3. The MEC electronic equipment requires 1 kW of power and heat rejection for a total of 25 kW. Redundant pumps are provided for reliability but a single loop used since the Reference 1 studies indicated the required reliability of 0.99 could be achieved with a redundant component approach. A temperature control valve is provided to accommodate the large temperature difference between the MEC and PS loop. This valve will provide a constant return temperature to, and heat transfer from, the MEC loop through a payload heat exchanger designed to transfer 16 to 25 kW at a much lower temperature difference for other payloads.

The objective of the system trades was to define alternate methods of obtaining 25 kW heat rejection for a MEC vehicle and compare them with the baseline system which provides 16 kW heat rejection. This comparison, along with comparisons of the alternatives were conducted to define the best methods of meeting the MEC requirements. Figure 5 contains the MEC requirements developed in this study for use as groundrules and guidelines in the concept definition and comparisons. Using these requirements four system concepts were defined and evaluated.

2.1 DESCRIPTION OF CANDIDATE SYSTEM CONCEPTS

Figure 6 shows a simplified schematic of the comparison baseline system. This system represents a combination of the reference concept TCS of Figure 2 and the MEC coolant loop of Figure 4. The payload heat rejection is that of the reference concept (16 kW) as is the total heat rejection (28 kW). Only 15 kW is available for MEC experiment heat rejection rather than the 24 kW indicated in the design requirements. The remainder of the concepts are configured to provide 25 kW payload heat rejection, a total of 37 kW total heat rejection. The desciption of the concepts will be given in terms of differences from the comparison baseline.

Concept A

A simplified schematic of Concept A is shown in Figure 7. This concept achieves the additional heat rejection by adding four additional

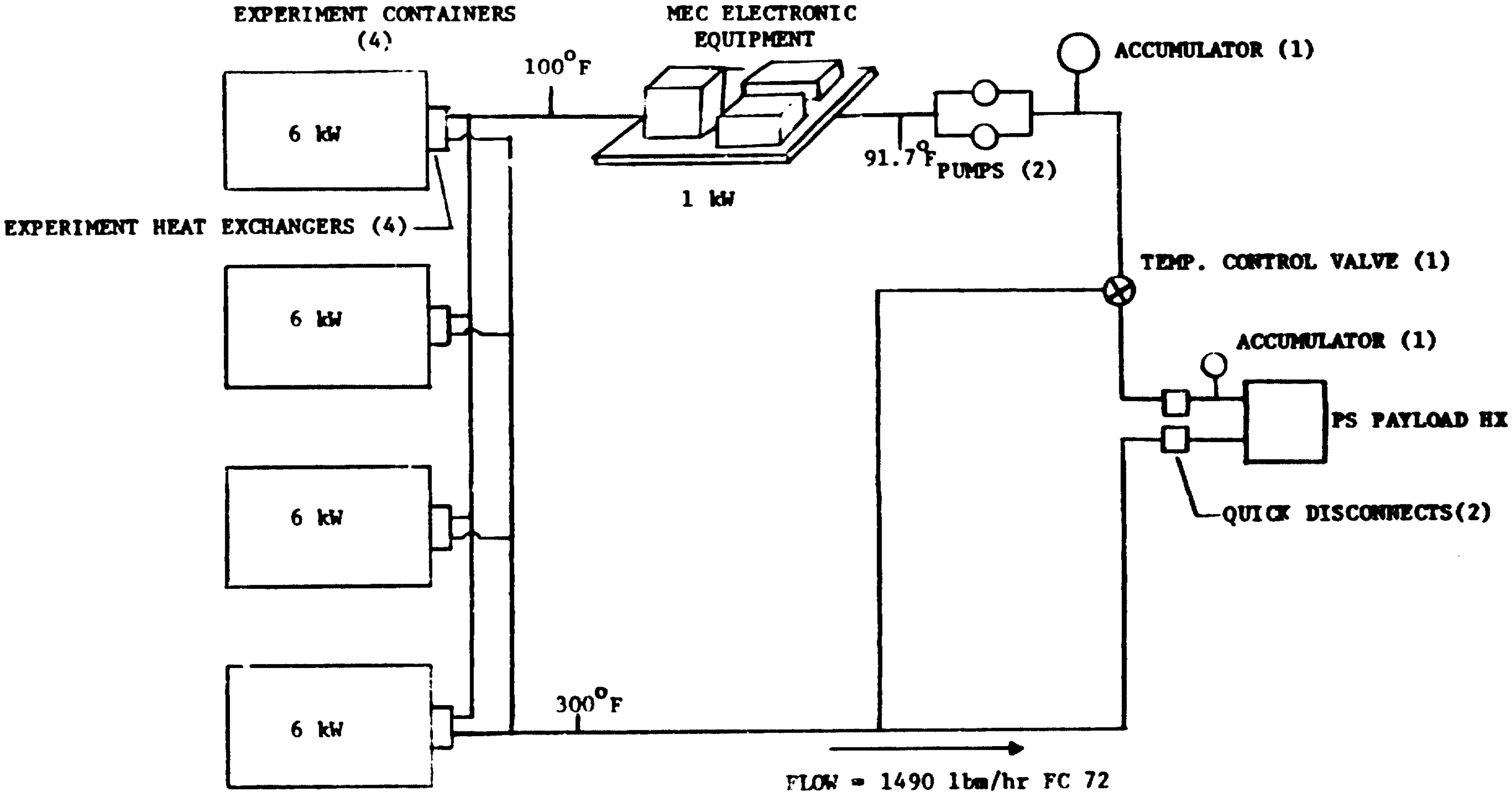


FIGURE 4

MEC COOLANT LOOP SCHEMATIC

FIGURE 5 DESIGN REQUIREMENTS

HEAT LOADS:

Electronics	1 kW	
Total Payload	24 kW	(Full Sun Orbit - 65 kW?)
Each Payload	6 kW	

TEMPERATURES:

Electronics Coldplate Outlet = 100°F (38°C)
Processing Equipment Outlet = 300°F (150°C)

POWER SYSTEM INTERFACE:

Upper (+Z) or Left (+X) PS Berthing Port
Liquid-to-Liquid 16 kW Heat Exchanger
Power System Supply Temperature = 35°F (2°C)
Max Return Temperature = 100°F (38°C)

MEC/PAYLOAD THERMAL INTERFACE

Payload Changeout On-Orbit at 90 Day Intervals
TMS or Orbiter RMS
Payload TCS - Coolant Loop or Heat Pipes

POWER SYSTEM/MEC ORBIT (RADIATOR SINK TEMP):

235 N.M. Solar Inertial, X-axis Perpendicular to Orbit Plane, Z-axis Parallel to Sun Line, Beta Angle 0°-90°

RELIABILITY:

No single Point Failure Will Result in Loss of Mission.
Fail-Safe
Probability of Survival = 0.99

LIFE:

MEC - 30 days to 1 year
Payloads - 90 days maximum

IOC:

First Quarter 1986

GUIDELINES:

Design to low cost - utilize Orbiter technology.

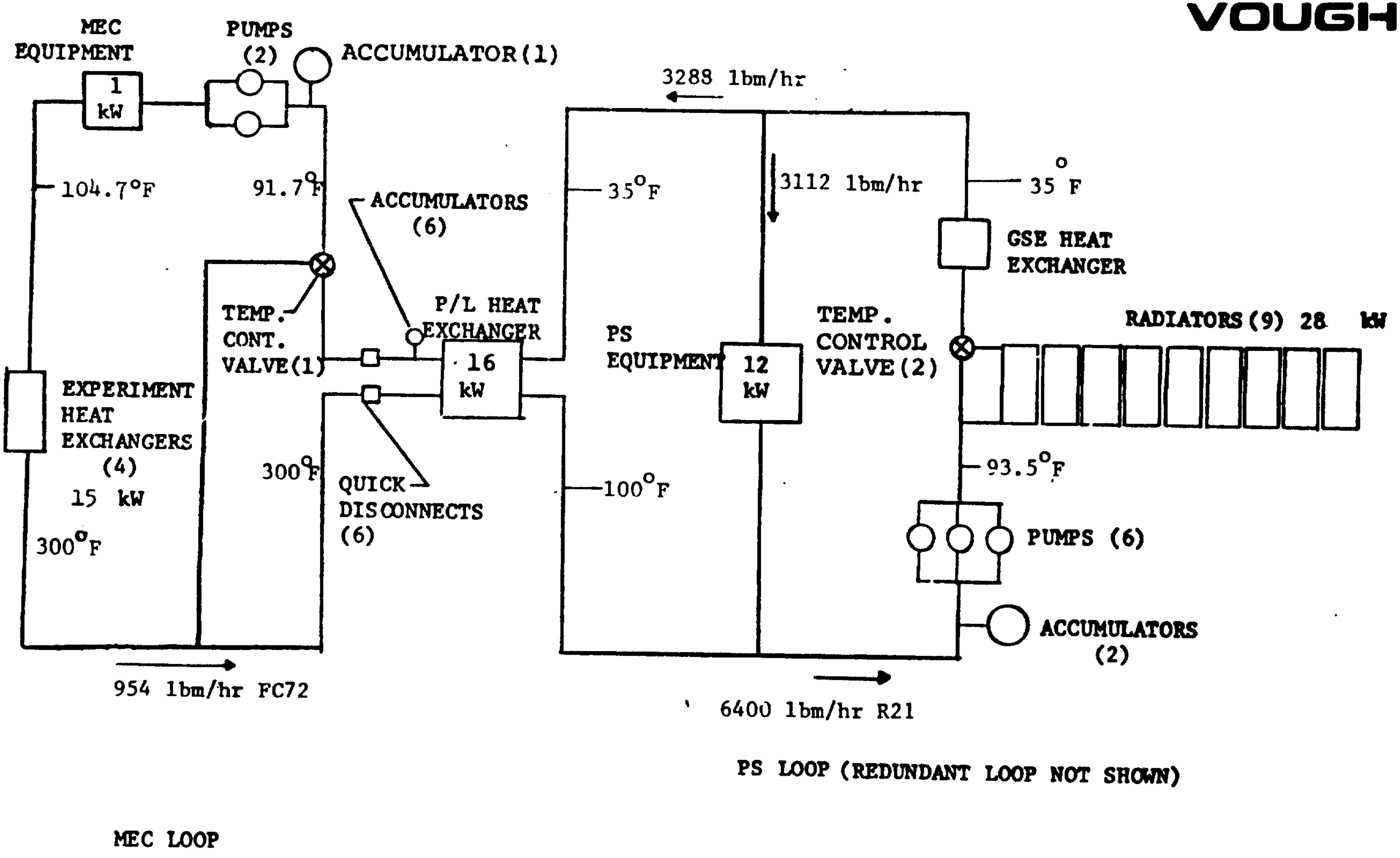


FIGURE 6 COMPARISON BASELINE SYSTEM SIMPLIFIED SCHEMATIC

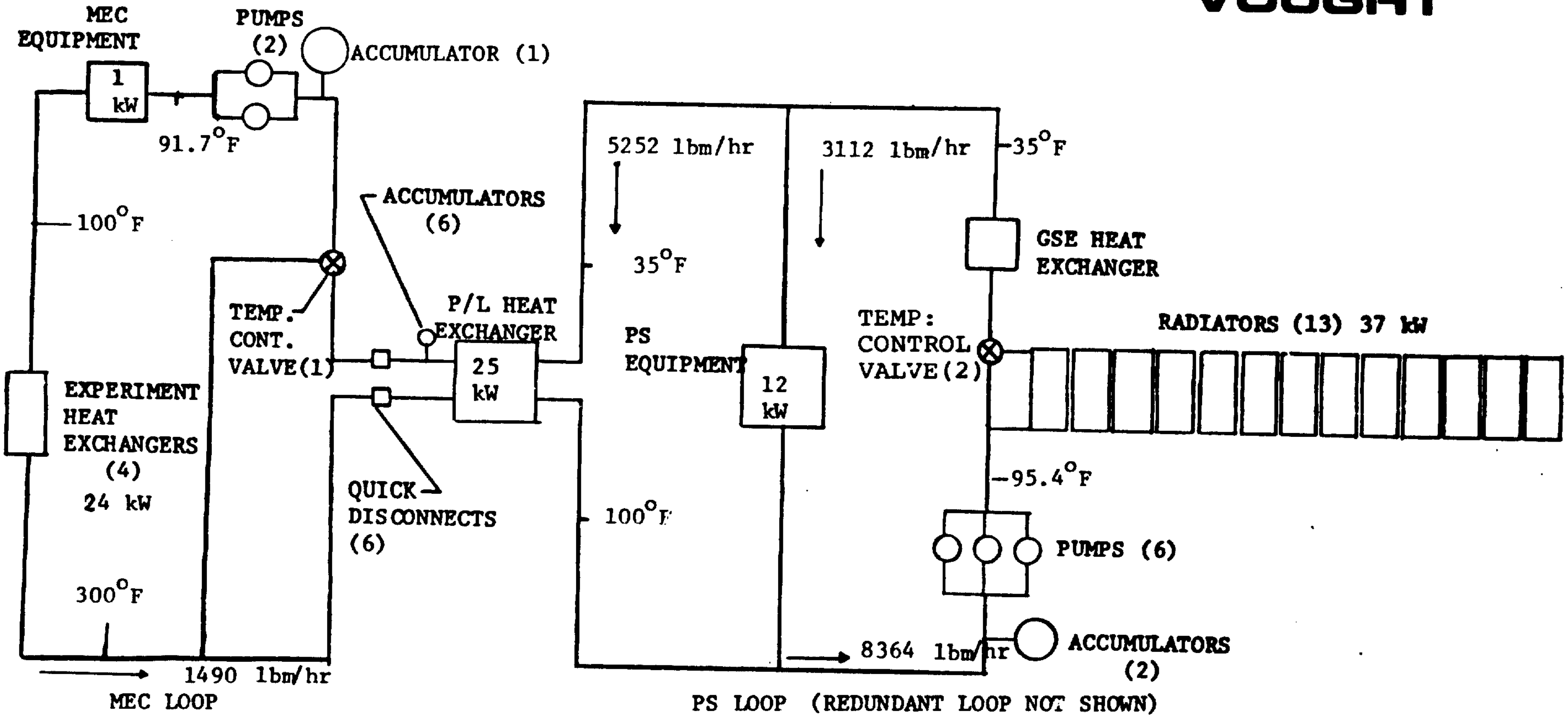


FIGURE 7
CONCEPT A - 37 kW PS HEAT REJECTION SIMPLIFIED SCHEMATIC

radiator panels on the reference concept configuration. The radiators are assumed to be of the same design as the reference concept radiators. A higher flow rate will be required to support the increased heat rejection while maintaining the same loop temperatures. Pump performance curves of the pumps originally considered for the reference concept, indicate the increased flow can be obtained by two pumps operating in parallel as was the case for the comparison baseline. No changes were made to the MEC Thermal Control System loop from the comparison baseline other than to increase the flow rate to accommodate the increased heat load.

Concept B

A simplified schematic of Concept B is shown in Figure 8. This concept increases the payload heat rejection in the Power System by spliting the loop into separate payload and PS thermal control systems. The PS loop uses four of the nine radiators to reject the 12 kW of PS waste heat and provide the required 35°F return from the radiators. The payload loop temperatures are not limited and are allowed to increase to the maximum possible (approximately 81.7°F payload heat exchanger inlet and 290°F outlet). This configuration will provide more than 25 kW payload heat rejection from the remaining five radiators since they are operating at a much higher temperature than in the comparison baseline case. Low temperature heat loads at the reference concept levels of 16 kW can be accommodated by operating the payload loop at lower temperatures. A variable set point temperature control valve is provided which can be adjusted to the desired payload heat rejection temperature for either high temperature MEC payloads or low temperature payloads. The maximum operating temperature of the radiators is approximately 290°F which is above the 250°F limit of the orbiter panel type design being considered for the reference concrpt panels. A new, high temperature radiator design would therefore be required for Concept B. Since the heat loads are lowered for each system the flow rate requirements are reduced from the comparison baseline. The Concept B flow rates can be achieved with one "Orbiter" type pump. Dismissing the requirement for two simultaneously operating pumps enhances the reliability and makes it possible to achieve the 0.99 level with redundant systems without a standby pump in each. The MEC loop differs from the comparison baseline in that the

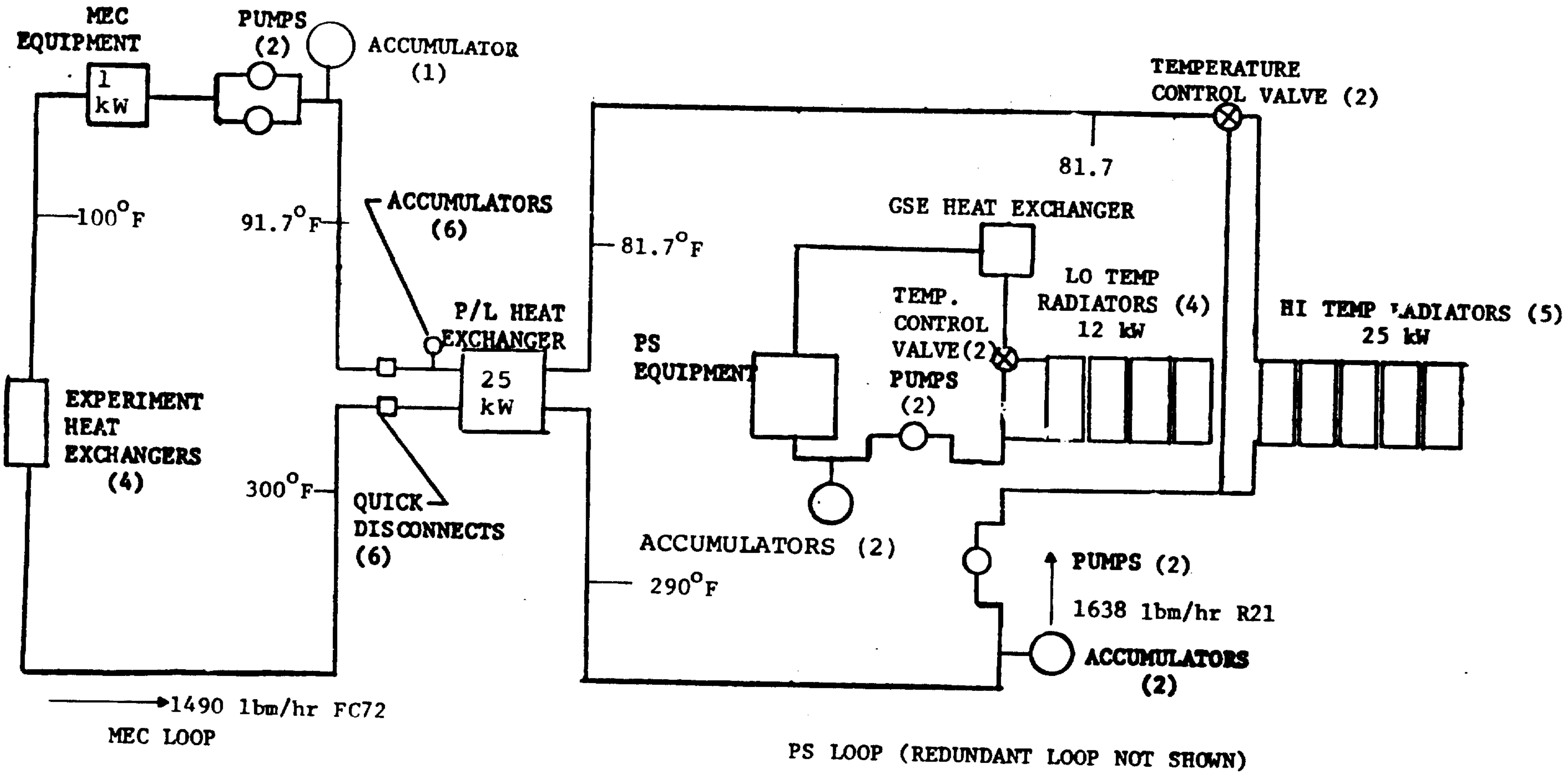


FIGURE 8

CONCEPT B - SPLIT PS LOOP SIMPLIFIED SCHEMATIC requirement for a temperature control valve is removed since this function is performed by the variable set point temperature control valve in the PS payload thermal control loop.

Concept B1

Since Concept B required design of a new radiator panel, Concept B1 shown in Figure 9 was conceived which is identical to Concept B except that the maximum temperature is limited to 250°F so all radiators can be of the same design. The PS part of the split loop is identical to Concept B. The payload loop differs from Concept B only in removal of the requirement for the high temperature radiators lower operating temperatures. Payload heat rejections greater then 25 kW are still possible with the lower 250°F payload heat exchanger outlet. The MEC coolant loop is the same as for Concept B except limiting the radiator inlet temperature results in lower MEC operating temperature. The MEC loop operates over a 260 to 52°F range for Concept B1.compared to 300 to 92°F range for the other concepts.

Concept C

Concept C is illustrated in the schematic of Figure 10. This approach utilizes an additional, high temperature radiator in the MEC coolant loop to achieve the additional 9 kW heat rejection necessary to provide MEC the required 25 kW. As shown in Figure 10, a 74 ft^2 radiator is located in the MEC coolant loop directly downstream of the experiment heat exchangers reduces the payload heat exchanger inlet temperature to 225°F from 300°F. The only other difference between Concept C and the comparison baseline is the addition of a diverter valve to bypass the MEC radiator when additional heat rejection is not necessary.

2.2 SYSTEM CONCEPT EVALUATION AND COMPARISON

The five configurations described in 2.1 were analyzed to provide data for evaluations and comparisons. Weight and cost evaluations were conducted then the concepts evaluated for complexity, ease of integration, potential growth, technology requirements and total launch weight.

Weight Evaluations

The component and total weight of the Thermal Control System are given in Figures 11 through 14 for the Comparison Baseline, Concept A, Concepts B and B1 and Concept C respectively. The weights were obtained,

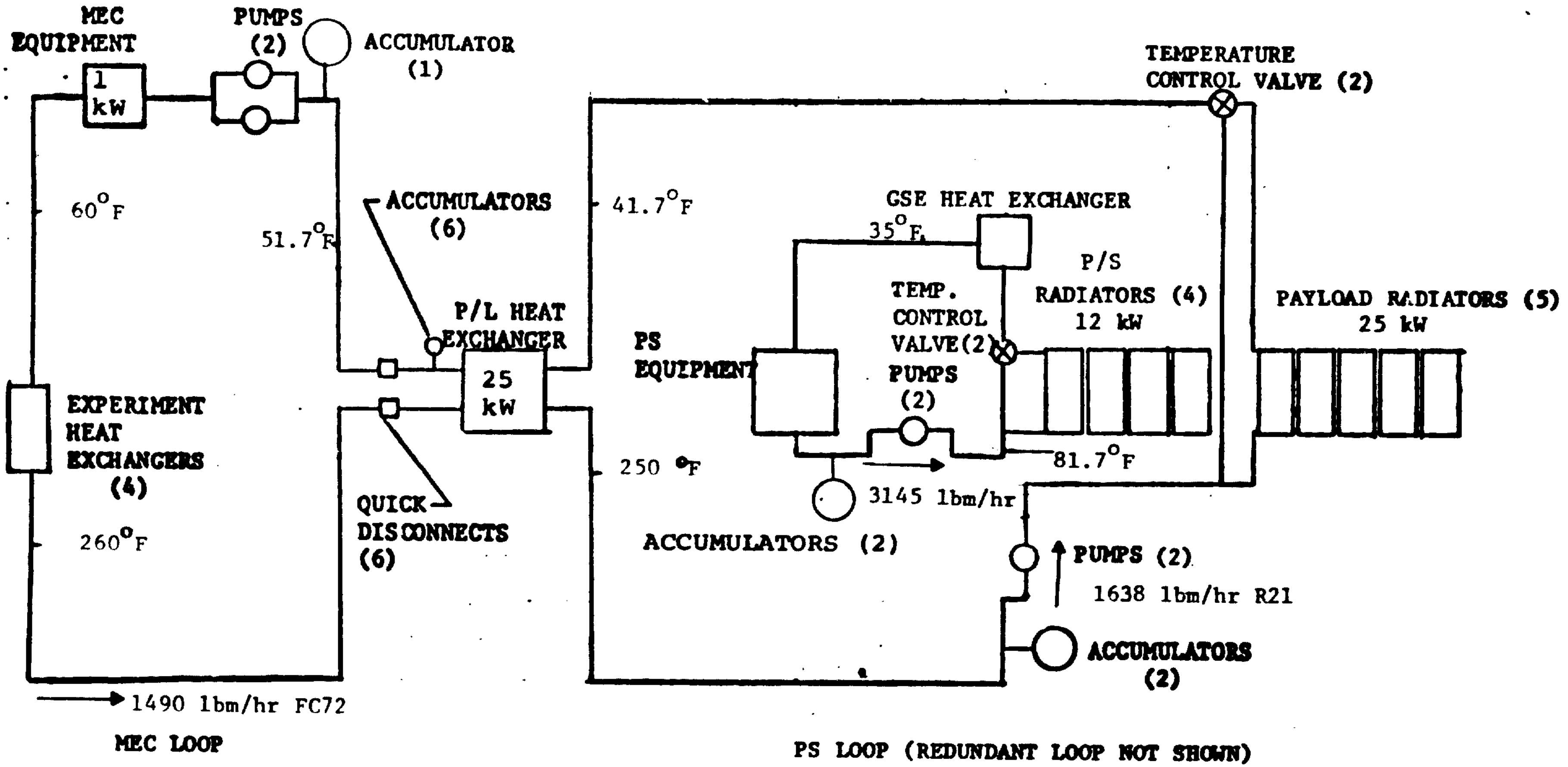


FIGURE 9
CONCEPT B1- SPLIT PS LOOP SIMPLIFIED SCHEMATIC

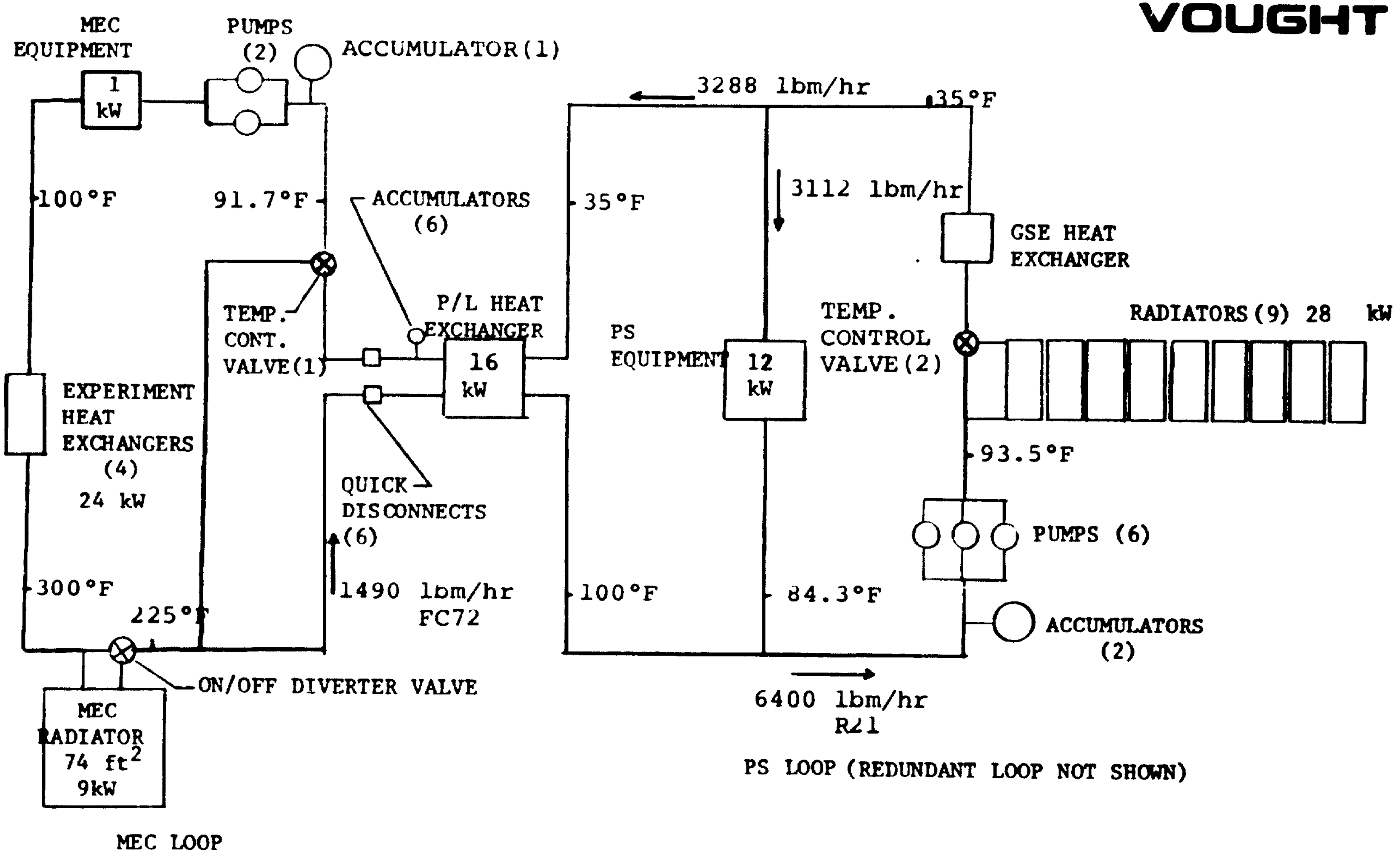


FIGURE 10

CONCEPT C - 9kW MEC RADIATOR SIMPLIFIED SCHEMATIC

FIGURE 11

TCS WEIGHT SUMMARY
COMPARISON BASELINE TCS

POWER SYSTEM	
. RADIATORS (WITH DEPLOYMENT FIXTURES AND HOSES)	1883.0 LBm
. TEMPERATURE CONTROL VALVES (2)	8.0
. GSE HEAT EXCHANGER	17.0
. PAYLOAD HEAT EXCHANGERS (3)	96.0
. PUMPS (6)	32.4
. ACCUMULATORS (2)	37.8
. LINES (2 LOOPS)	127.0
. QUICK DISCONNECTS (12)	24.0
. QUICK DISCONNECT ACCUMULATORS (6)	30.0
. COLDPLATES (50 ORBITER TYPE)	425.0
	2680.2
MEC	
. PUMPS (2)	10.8
. ACCUMULATOR (1 REDUNDANT DESIGN DRY)	9.5
. COLDPLATES (3 ORBITER TYPES)	25.5
. EXPERIMENT HEAT EXCHANGERS (4 SHUTTLE PAYLOAD HX)	131.2
. TEMPERATURE CONTROL VALVES (2)	8.0
. LINES	31.8
	216.8

TOTAL - 2897.0 LBm

FIGURE 12

TCS WEIGHT SUMMARY
CONCEPT A

POWER SYSTEM	
. RADIATORS (WITH DEPLOYMENT FIXTURES AND HOSES)	2608.0 LBm
. TEMPERATURE CONTROL VALVES (2)	8.0
. GSE HEAT EXCHANGER	17.0
. PAYLOAD HEAT EXCHANGERS (3)	96.0
. PUMPS (6)	32.4
. ACCUMULATORS (2)	37.8
. LINES (2 LOOPS)	127.0
. QUICK DISCONNECTS (12)	30.0
. QUICK DISCONNECT ACCUMULATORS (6)	30.0
. COLDPLATES (50 ORBITER TYPE)	425.0
	3411.2
MEC	
. PUMPS (2)	10.8
. ACCUMULATOR (1 REDUNDANT DESIGN)	9.5
. COLDPLATES	25.5
. EXPERIMENT HEAT EXCHANGERS (4)	131.2
. TEMPERATURE CONTROL VALVES (2)	8.0
. LINES	31.8
	216.8

TOTAL - 3628.0 LBm

FIGURE 13
TCS WEIGHT SUMMARY
CONCEPT B & B1

POWER SYSTEM

. RADIATORS (WITH DEPLOYMENT FIXTURES AND HOSES)	1964.0 LBm
. TEMPERATURE CONTROL VALVES (2)	8.0
. VARIABLE SETTING TEMP CONTROL VALVES (2)	50.0
. GSE HEAT EXCHANGER	17.0
. PAYLOAD HEAT EXCHANGERS (3)	96.0
. PUMPS (6)	21.6
. ACCUMULATORS (2)	37.8
. LINES (2 LOOPS)	139.7
. QUICK DISCONNECTS (12)	24.0
. QUICK DISCONNECT ACCUMULATORS (6)	30.0
. COLDPLATES (50 ORBITER TYPE)	425.0
	2813.1

MEC

. PUMPS (2)	10.8
. ACCUMULATOR (1 REDUNDANT DESIGN)	9.5
. COLDPLATES	25.5
. EXPERIMENT HEAT EXCHANGERS (4)	131.2
. TEMPERATURE CONTROL VALVES (2)	8.0
. LINES	31.8
	216.8

TOTAL - 3029.9 LBm

FIGURE 14
TCS WEIGHT SUMMARY
CONCEPT C

POWER SYSTEM

. RADIATORS (WITH DEPLOYMENT FIXTURES AND HOSES)	1883.0 LBm
. TEMPERATURE CONTROL VALVES (2)	8.0
. GSE HEAT EXCHANGER	17.0
. PAYLOAD HEAT EXCHANGER (3)	96.0
. PUMPS (6)	32.4
. ACCUMULATORS (2)	37.8
. LINES (2 LOOPS)	127.0
. QUICK DISCONNECTS (12)	24.0
. QUICK DISCONNECT ACCUMULATORS (6)	30.0
. COLDPLATES (50 ORBITER TYPE)	425.0
	2680.2

MEC

. RADIATOR	74.0
. DEPLOYMENT SYSTEM	40.0
. PUMPS (2)	10.8
. ACCUMULATOR (1 REDUNDANT DESIGN)	9.5
. COLDPLATES	25.5
. EXPERIMENT HEAT EXCHANGERS (4)	131.2
. TEMPERATURE CONTROL VALVES (2)	8.0
. ON/OFF DIVERTER VALVE (2)	8.0
. LINES	31.8
. FLEX HOSES (2)	4.0
	342.8

TOTAL - 3023.0 LBm

where applicable, from the Reference 2 study. Other weights were generated from actual hardware where available or from similar hardware. Except for the radiators, mounting and structural attachment hardware were not considered in the weight evaluations.

Cost Evaluations

Comparative cost evaluations were performed for the five concepts. The objective of these evaluations was to obtain data to compare the relative costs rather than a determination of the total dollar costs of the systems. As a result, all of the components of the systems were not considered in these cost evaluations. Notable exemptions from the cost comparison were heat exchangers, coldplates and flow lines except for the flex hoses associated with the radiator system. These items are the same in all of the concepts in both number and design and therefore their omission will not affect the cost comparisons of the concepts. Figure 15 contains a list of the hardware which was considered in these cost evaluations.

The cost evaluations were performed using the RCA PRICE routine. This routine computes cost of individual components based on a set of inputs illustrated by the sample Input Data Worksheet shown in Figure 16. Given the number, weight and type of component the key input to the PRICE Routine is the Manufacturing Complexity. Where possible, this input was used from the Reference 2 analysis. In that study many of the complexities were generated using a feature of the PRICE Routine (called ECRIP) allowing input of actual costs for hardware and giving complexity as an output. These complexity figures can then be used for similar hardware.

In addition to the components, costs are calculated for the integration and testing of system. The final results include development and production costs of the components and costs of the system integration and test.

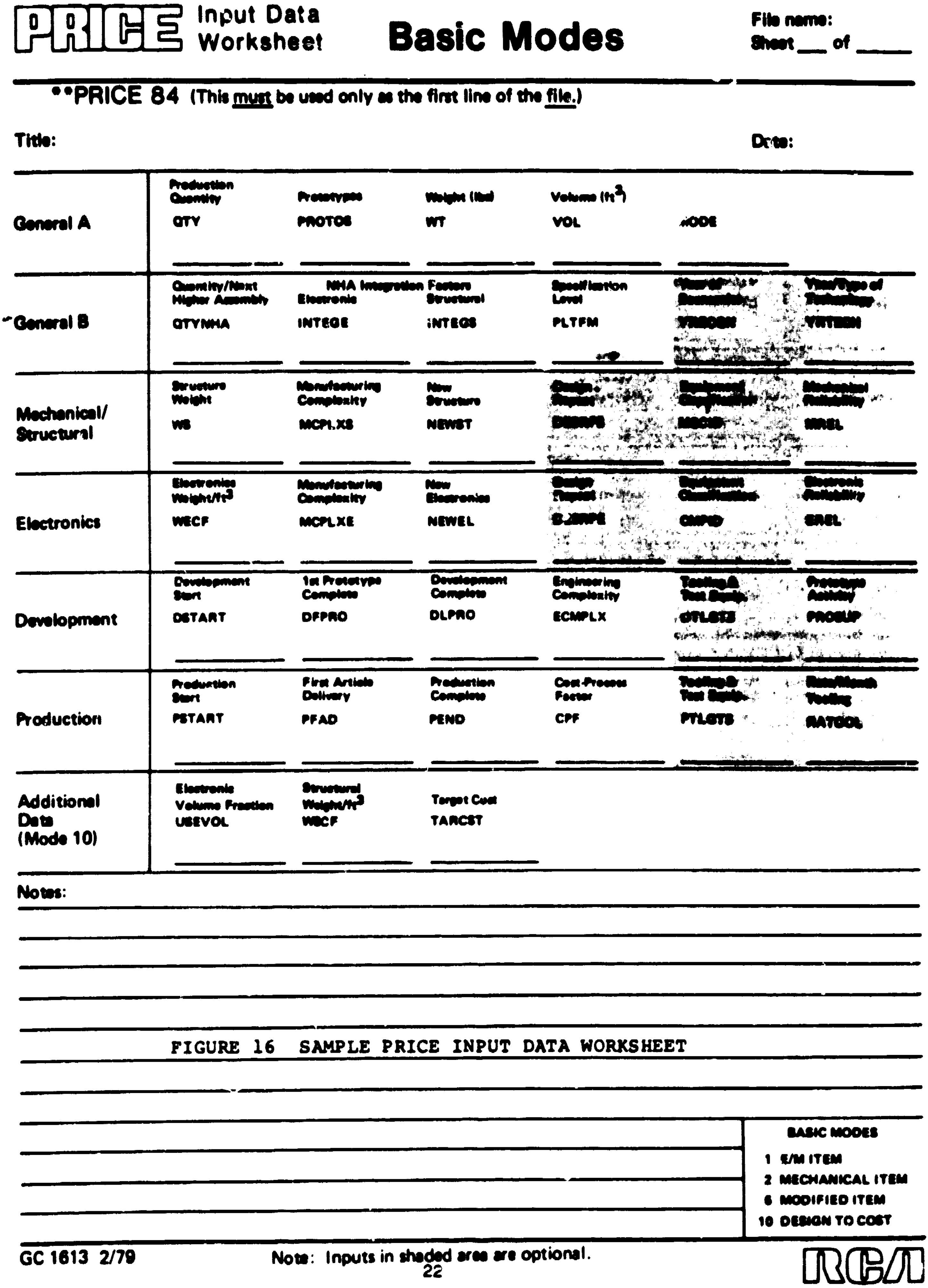
Results of the cost comparisons are shown in Figure 17 for the five concepts evaluated.

Concept Comparisons

A summary of the comparisons of the five concepts is given in Figure 18. The Comparison Baseline weight was 2897 lbm. The highest weight concept of the four 25 kW Payload Heat Rejection systems was the 13 Radiator

FIGURE 15
HARDWARE CONSIDERED IN COST COMPARISONS

HARDWARE ITEM	BASELINE PS + MEC TCS	SYSTEM CONCEPT A	SYSTEM CONCEPT B	SYSTEM CONCEPT C
RADIATOR PANEL - REGULAR PS	9	13	4	9
RADIATOR PANEL - HI TEMP			5	1
PUMP/MOTOR	8	8	6	8
ACCUMULATORS	3	3	5	3
TEMPERATURE CONTROL VALVES	3	3	2	3
TEMPERATURE CONTROL VALVES - VARIABLE SETTING			2	
ON/OFF DIVERTER VALVE				2
FLEX HOSES	40	56	56	42
DEPLOYMENT MECHANISM - MULTIPLE PANEL	1	1	1	1
DEPLOYMENT MECHANISM - SINGLE PANEL				1



PRICE Input Data Worksheet

Basic Modes

File name:
Sheet ___ of ___

**PRICE 84 (This must be used only as the first line of the file.)

Title:

Date:

General A	Production Quantity QTY	Prototypes PROTOS	Weight (lbs) WT	Volume (ft^3) VOL	MODE	
General B	Quantity/Next Higher Assembly QTYNHA	NHA Integration Factors Electronic INTEGE	Structural INTEGS	Specification Level PLTFM	Year of Economics YRECON	Year/Type of Technology YRTECH
Mechanical/ Structural	Structure Weight WS	Manufacturing Complexity MCPLXS	New Structure NEWST	Design Repeat DESRPS	Equipment Classification MECID	Mechanical Reliability MREL
Electronics	Electronics Weight/ft^3 WECF	Manufacturing Complexity MCPLXE	New Electronics NEWEL	Design Repeat DESRPE	Equipment Classification CMPID	Electronic Reliability EREL
Development	Development Start DSTART	1st Prototype Complete DFPRO	Development Complete DLPRO	Engineering Complexity ECMPLX	Tooling & Test Equip. DTLGTS	Prototype Activity PROSUP
Production	Production Start PSTART	First Article Delivery PFAD	Production Complete PEND	Cost-Process Factor CPF	Tooling & Test Equip. PTLGTS	Rate/Month Tooling RATOOL
Additional Data (Mode 10)	Electronic Volume Fraction USEVOL	Structural Weight/ft^3 WSCF	Target Cost TARCST			

Notes:

FIGURE 16 SAMPLE PRICE INPUT DATA WORKSHEET

BASIC MODES
1 E/M ITEM
2 MECHANICAL ITEM
6 MODIFIED ITEM
10 DESIGN TO COST

GC 1613 2/79

Note: Inputs in shaded area are optional.

RCA

FIGURE 17
MEC/PS TCS COST COMPARISONS
(USING RCA PRICE ROUTINE)

	COMPARISON BASELINE	CONCEPT A (MORE LO TEMP RADIATORS)	CONCEPT B (SPLIT LOOP WITH HI TEMP RADIATORS	CONCEPT B1 (SPLIT LOOP CURRENT RADIATOR DESIGN	CONCEPT C (MEC RADIATOR)
POWER SYSTEM					
RADIATOR PANELS-REGULAR	4.430	5.200	3.409	4.430	4.430
RADIATOR PANELS-HI TEMP			3.941		
PUMP/MOTORS	.526	.526	.440	.440	.526
ACCUMULATORS	.350	.350	.355	.355	.350
TEMP CONTROL VALVE	.418	.418	.418	.418	.418
VARIABLE TEMP CONTROL			2.451	2.451	
FLEX HOSES	.113	.141	.152	.152	.113
DEPLOYMENT MECHANISM	1.779	2.049	1.779	1.779	1.779
MEC					
ACCUMULATORS	.109	.109	.109	.109	.109
PUMP/MOTORS	.364	.364	.364	.364	.364
TEMP CONTROL VALVE	.286	.286			.286
DIVERTER VALVE					.286
RADIATOR PANEL-HI TEMP					.992
DEPLOYMENT MECHANISM					.565
INTEGRATION AND TEST	1.165	1.467	1.163	1.165	1.233
TOTAL	9.540	10.910	14.581	11.663	11.451

	COMPARISON BASELINE	CONCEPT A (ADD MORE LO TEMP POWER SYSTEM RADIATORS)	CONCEPT B (SPLIT LOOP-HI TEMP RADIATORS REQUIRED)	CONCEPT BI (SPLIT LOOP-ONE RADIATOR DESIGN)	CONCEPT C (MEC RADIATORS)
WEIGHT - PS - MEC TOTAL	2680.2 LBm 216.8 2897.0	3411.2 LBm 216.8 3628.0	2813.1 LBm 216.8 3029.9	2813.1 LBm 216.8 3029.9	2680.2 LBm 342.8 3023.0
COMPLEXITY	16 COMPONENTS 3 SYSTEMS	16 COMPONENTS 3 SYSTEMS	17 COMPONENTS 5 SYSTEMS	17 COMPONENTS 5 SYSTEMS	20 COMPONENTS 3 SYSTEMS
EASE OF INTEGRATION	BASELINE	REQUIRES VIOLATION OF BASELINE ENVELOPE.	MUST TRANSFER 4 FLUID SYS ACROSS 1ST 4 PANEL FOLDS.	MUST TRANSFER 4 FLUID SYS ACROSS 1ST 4 PNL FOLDS.	NO IMPACT ON PS 1 PANEL DEPLOY FROM MEC SURFACE.
POTENTIAL GROWTH	RESTRICTS MEC TO 16 kW	LITTLE WITH CURRENT PS DESIGN	WILL ACCOMMODATE UP TO 43 kW AT HI TEMPERATURES	WILL ACCOMMODATE UP TO 37 kW AT MAX 250°F TEMP.	DEPLOY OF ADDITIONAL PANELS FROM MEC
TECHNOLOGY	CURRENT PS	CURRENT PS	NEED HIGH TEMP RAD PANELS	CURRENT PS	NEED HIGH TEMP RAD PANELS
COMPARATIVE COST $M (PS + MEC TCS)	9.539	10.911	14.580	11.663	11.450
TOTAL LAUNCH WEIGHT	2680 + 210.8/MEC LOWEST	3411 + 216.8/MEC LOWER THAN C AFTER 5 LAUNCHES	2813.1 + 216.8/MEC LOWER THAN C AFTER 1 MEC LAUNCH	2813.1 + 216.8/MEC LOWER THAN C AFTER 1 MEC LAUNCH	2680 + 342.8/MEC 126 LBm MORE PER LAUNCH

FIGURE 18
PS/MEC TCS CONCEPT COMPARISON

Panel Concept (Concept A) which was 731 lbm heavier than the Baseline. The other four concepts were equivalent in weight from 126 to 133 lbm heavier than the baseline.

An indication of the system complexity is indicated by the number of components and independent systems in each concept. The MEC Loop Radiator Concept (Concept C) requires the most components (20 compared to 16 for the baseline), however, the Split Loop Concepts (Concepts B and B1) have two more systems than the other concepts. The 13 Radiator Panel Concept (Concept A) is equivalent to the baseline.

Consideration of the ease of integration of the concept into the PS/MEC combination indicates significant integration problems for the 13 Panel Concept (Concept A) since it requires addition of four radiator panels. Figure 3 illustrated the lack of room for additional panels while remaining within the reference concept envelope. Unless the envelope can be relaxed by allowing the panels to be wider than the reference concept 182 in. (see Figure 1) or the vehicle will allow more stack height, the addition of more radiator area will pose a significant integration problem. The Split Loop Concepts (Concepts B and B1) require the transfer of 4 fluid systems across the 1st four folding joints in order to flow both primary and redundant systems to the five independent payload heat rejection panels. The MEC Radiator Concept (Concept C) has no impact on Power System integration but a space for a radiator in the MEC loop must be provided along with a deployment mechanism. It would seem that the Split Loop Concepts and the MEC Radiator Concept (Concepts B, B1 and C) are roughly equivalent in ease of integration with the 13 Panel Concept (Concept A) posing potentially significant problems.

There is little growth potential for the comparison baseline or the 13 Panel Concept (Concept A) if higher power levels are achieved by orbital or operational maneuvers. The Split Loop, High Temperature Concept (Concept B) will accommodate up to 43 kW of high temperature payload heat load and the Split Loop 250°F Limit Concept (Concept B1) up to 37 kW without modification. The MEC Radiator Concept (Concept C) could accommodate higher payload heat rejections with the addition of more MEC radiator panels.

Comparative costs were roughly equivalent for the 13 Panel Concept, the Split Loop 250°F Limit Concept, and the MEC Radiator Concept

(Concepts A, B1 and C) indicating a cost of from \$1.37 to \$2.12M to upgrade the payload heat rejection to 25 kW from the 16 kW of the reference concept. The Split Loop High Temperature Concept (Concept B) indicated a \$5 million increased cost.

Total launch weight (weight of the vehicles times the number of times the vehicle will be launched) is less after five missions for the 13 Panel Concept (Concept A) which launches raditors only once over the MEC Radiator Concept (Concept C) which launches the radiators each time the MEC is launched. The Split Loop Concepts (Concepts B and B1) are lower than the MEC Radiator Concept (Concept C) in total launch weight if the MEC is ever launched again after the initial launch.

The results of these systems trades indicate a 250°F limit, split loop arrangement such as Concept B1 is an attractive method to accommodate 25 kW MEC heat loads while providing full 16 kW to low temperature payloads. Significant growth potential and flexibility to accommodate payloads other than MEC are also positive features of this type of system. If total launch weight is not an important consideration, putting radiators in the MEC loop appears to be approximately equivalent in these trades to the split loop. The financial burden for providing the additional heat rejection is placed on the Power System program for the Split Loop Concept (Concept B1) while the MEC Radiator Concept (Concept C) puts the burden on the MEC project.

2.3 TCS Installation and Instrumentation

A typical TCS installation on one of the MEC vehicle configurations from the Reference Study is shown in Figure 19. This layout was used in the weight comparisons in determing line lengths for the MEC TCS. Three coldplates were assumed for the MEC electronics and a nominal size flow equipment package from existing Shuttle hardware also assumed. Figure 19 shows the location of this equipment on the outside of the MEC vehicle in the approximate scale of the assumed sizes.

The instrumentation for the MEC TCS that is recommended to provide experiment information and monitor system health and operational status is illustrated in Figures 20 and 21. Temperature measurements are located at the outlet of each experiment heat exchanger in order to determine waste heat production of the experiments. The three temperature measurements at the

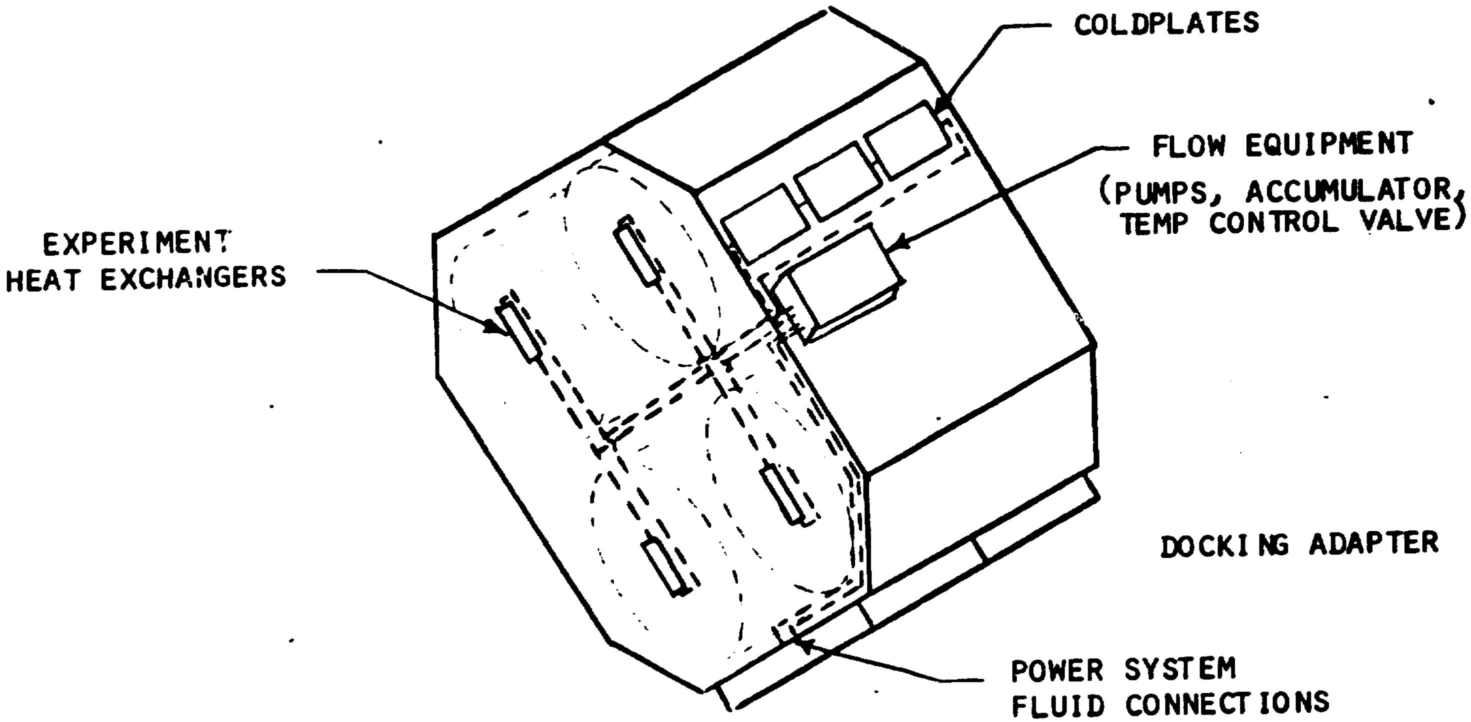


FIGURE 19
MEC TCS INSTALLATION

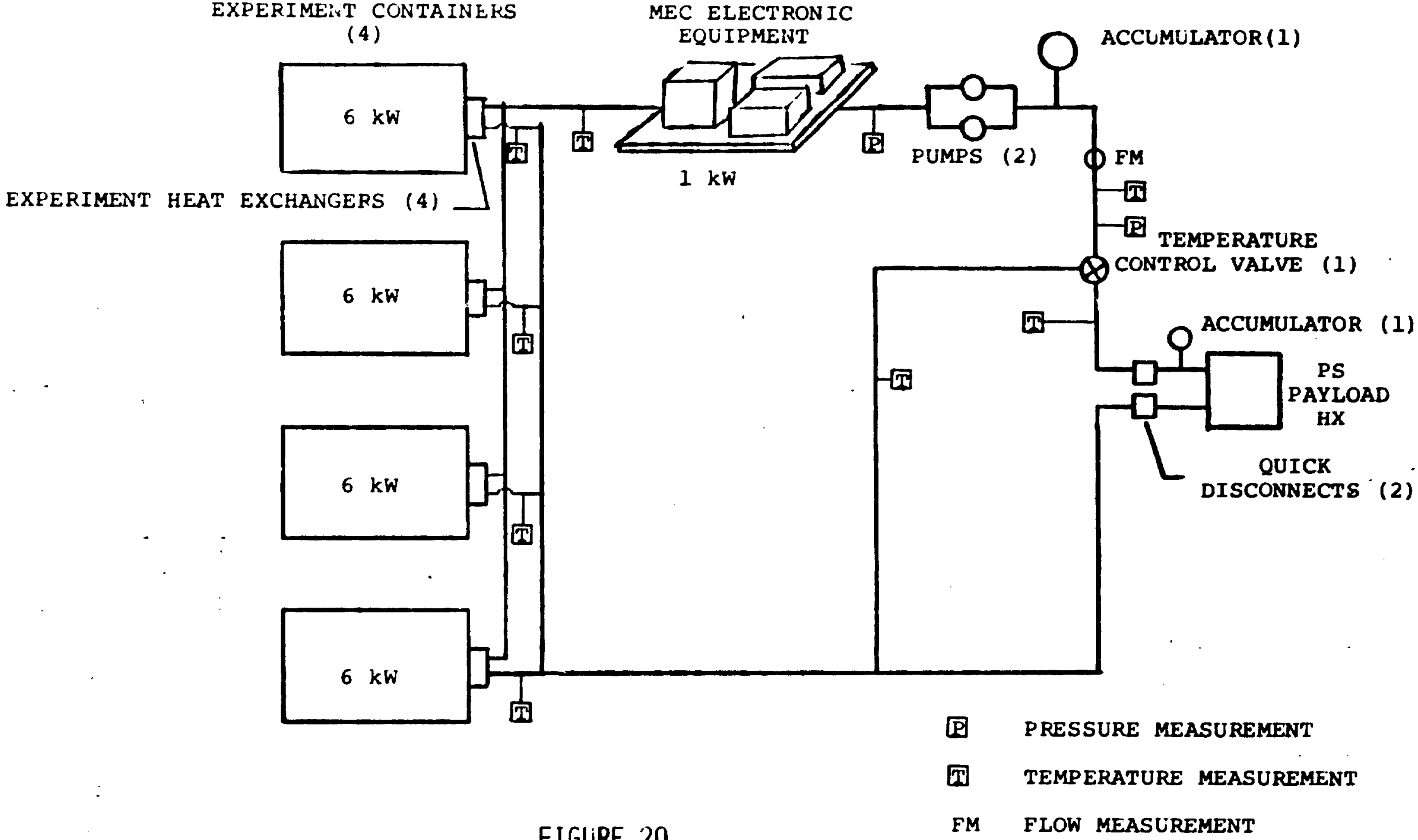


FIGURE 20

MEC COOLANT LOOP INSTRUMENTATION

FIGURE 21
MEC TCS INSTRUMENTATION

MEASUREMENT	NO.	DEVICE	SAMPLE RATE	VOLTS @ SENSOR	RESOLUTION 8 BITS
CONTAINERS INLET TEMPERATURE	1	KEYSTONE 'LINISTOR' MODEL 104/20	1 scm/sec	2.78 to 7.18	0.43 deg/bit
OUTLET TEMPERATURE EACH CONTAINER	4	"	"	"	"
CONTROL VALVE INLET TEMPERATURES	2	"	"	"	"
CONTROL VALVE OUTLET TEMPERATURE	1	"	"	"	"
PUMP INLET & OUTLET PRESSURE	2	CONRAC 451315/200	"	0 to 10	0.78 psi/bit
FLUID FLOW	1	CONRAC 4716/5	"	0 to 4.46	26 lbm/hr/bit
STATUS SIGNALS-PUMP 1 ON	1	RELAY SWITCH	"	5	N/A
PUMP 2 ON	1	" "	"	5	N/A
LO FLOW	1	" "	"	5	N/A
FAULT	1	" "	"	5	N/A

inlet and outlet of the PS Payload heat exchanger monitor the operation of the temperature control valve and verify PS payload heat exchanger heat transfer. Pump inlet and outlet pressures and system flowrate provide pump operation data and can signal a pump failure to initiate switch to redundant pump. Status signals indicating which pump is operating and if a fault signal has been activated provide data on the TCS operational status. Figure 21 also shows recommended instrumentation hardware with the sample rate, output signal and resolution for the signal.

2.4 Low Temperature Payload Concepts

There is a possibility that certain of the MEC Biological experiments will require cooling at a lower temperature than those assumed in the Design Requirements shown in Figure 5. Some cooling at about 40°F can be required. Methods of meeting these cooling requirements while also cooling the higher temperature experiments were investigated.

Since the reference concept PS delivers 35°F fluid to the payload heat exchanger an attempt was made to use the low temperature out of the heat exchanger prior to mixing to the 91.7°F required for the high temperature cooling. In order to operate the heat exchanger at the higher payload temperatures the minimum heat exchanger outlet is 54°F as shown in Figure 22. The cooling available to the experiment is therefore significantly greater than the desired 40°F. A second approach to low temperature cooling is illustrated in Figure 23. A separate heat exchanger is used to provide the low temperature only to the experiment where it is needed. The experiment cooling loop could be used to provide the fluid flow for these cases so another fluid loop would not be required. This approach, however, would not be possible if the split loop arrangement with high temperatures in the payload loop (Concept B) were used. The Split Loop 250°F Limit Concept (Concept B1), however, could be used if the payload heat exchanger outlet were further limited to provide a lower radiator outlet.

Two other approaches are illustrated in Figure 24. Cooling is provided by a vapor compression or a thermoelectric refrigeration system which rejects heat to the higher temperature MEC loop. The required power input of the experiments is increased as indicated to 8 kW for the vapor compression and 18 kW for the thermoelectric in order to operate the refrigeration

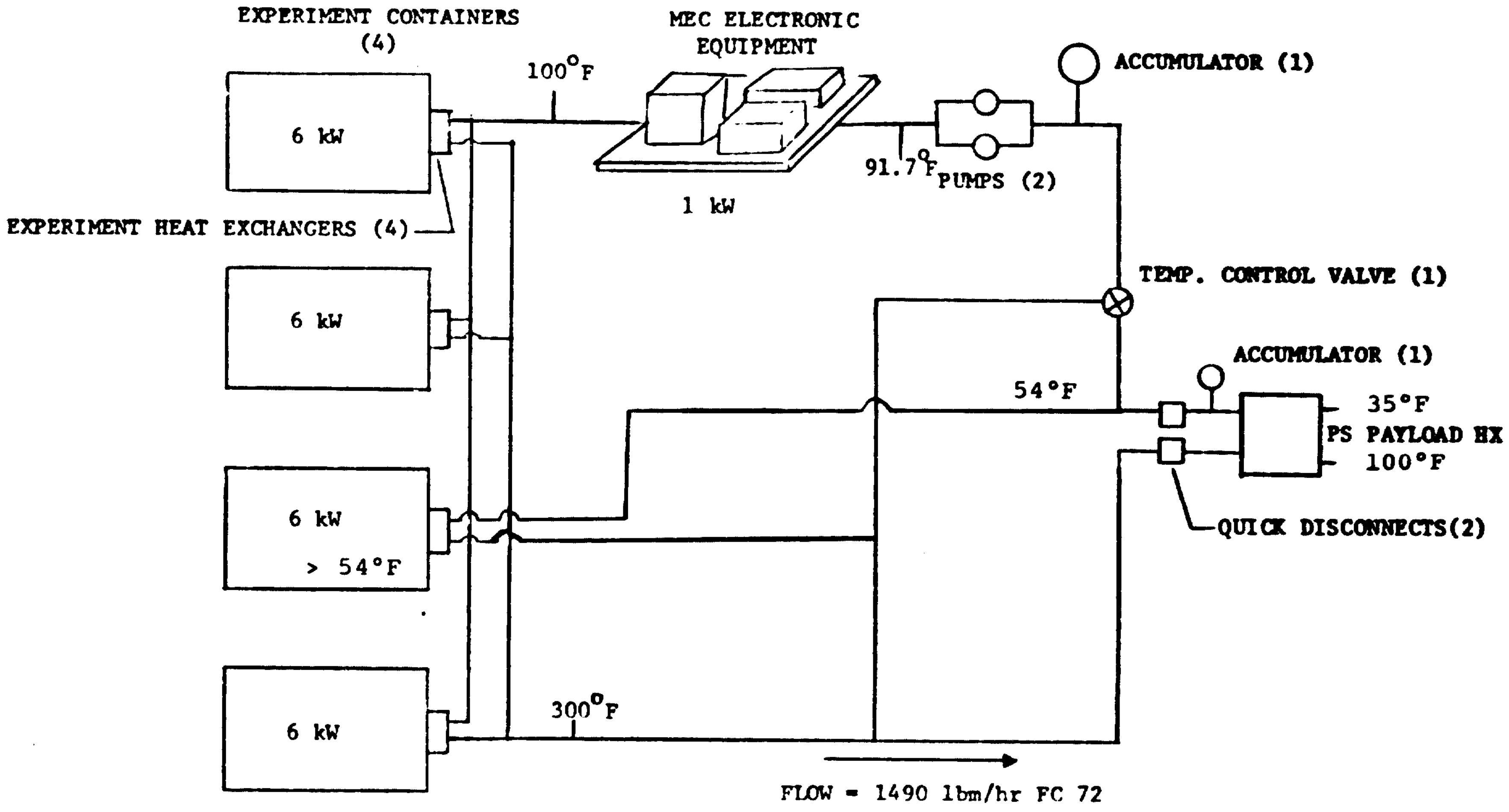


FIGURE 22 MLC COOLANT LOOP SCHEMATIC - LO TEMP PAYLOAD

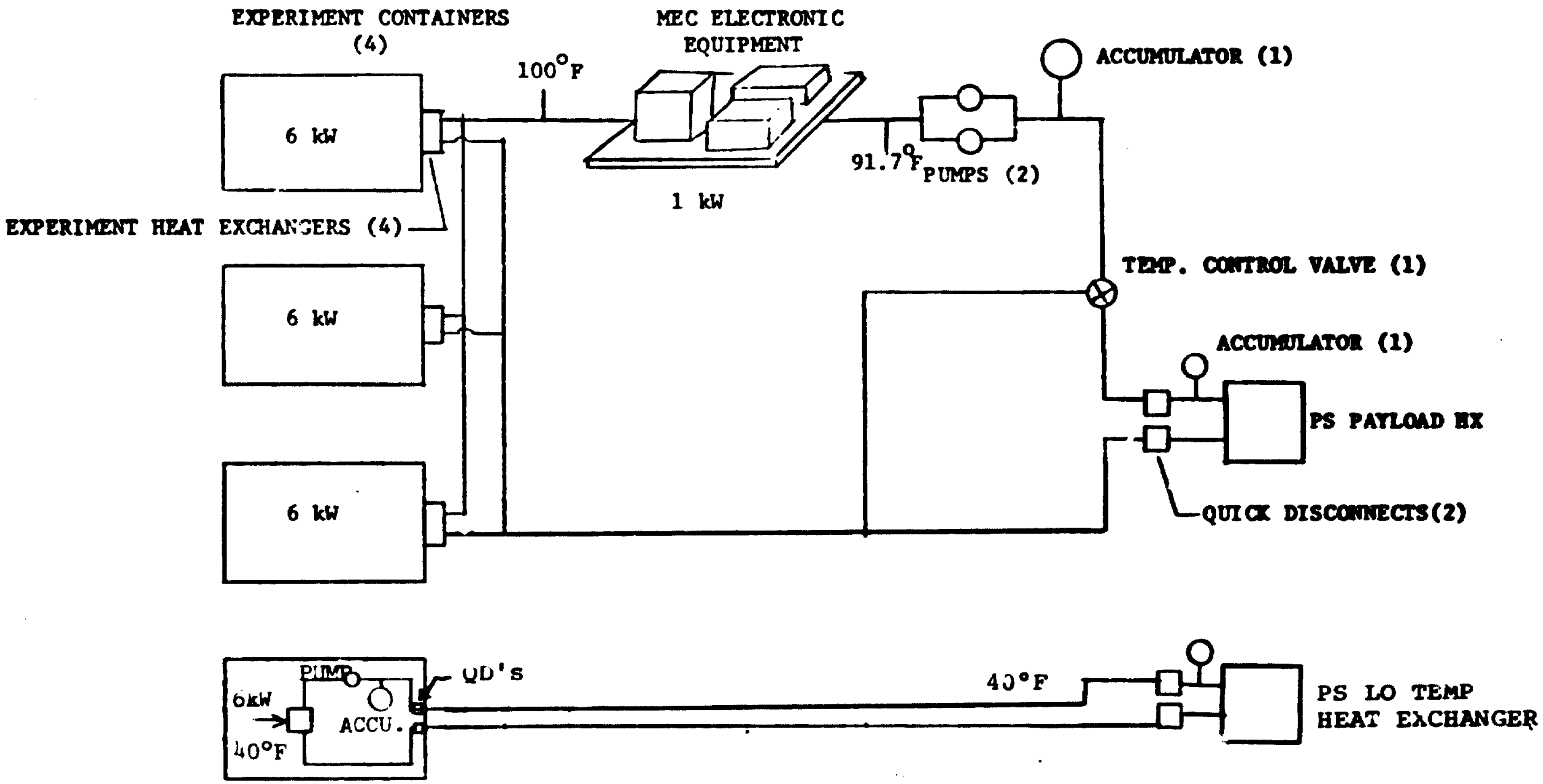


FIGURE 23 MEC COOLANT LOOP SCHEMATIC - LO TEMP PAYLOAD

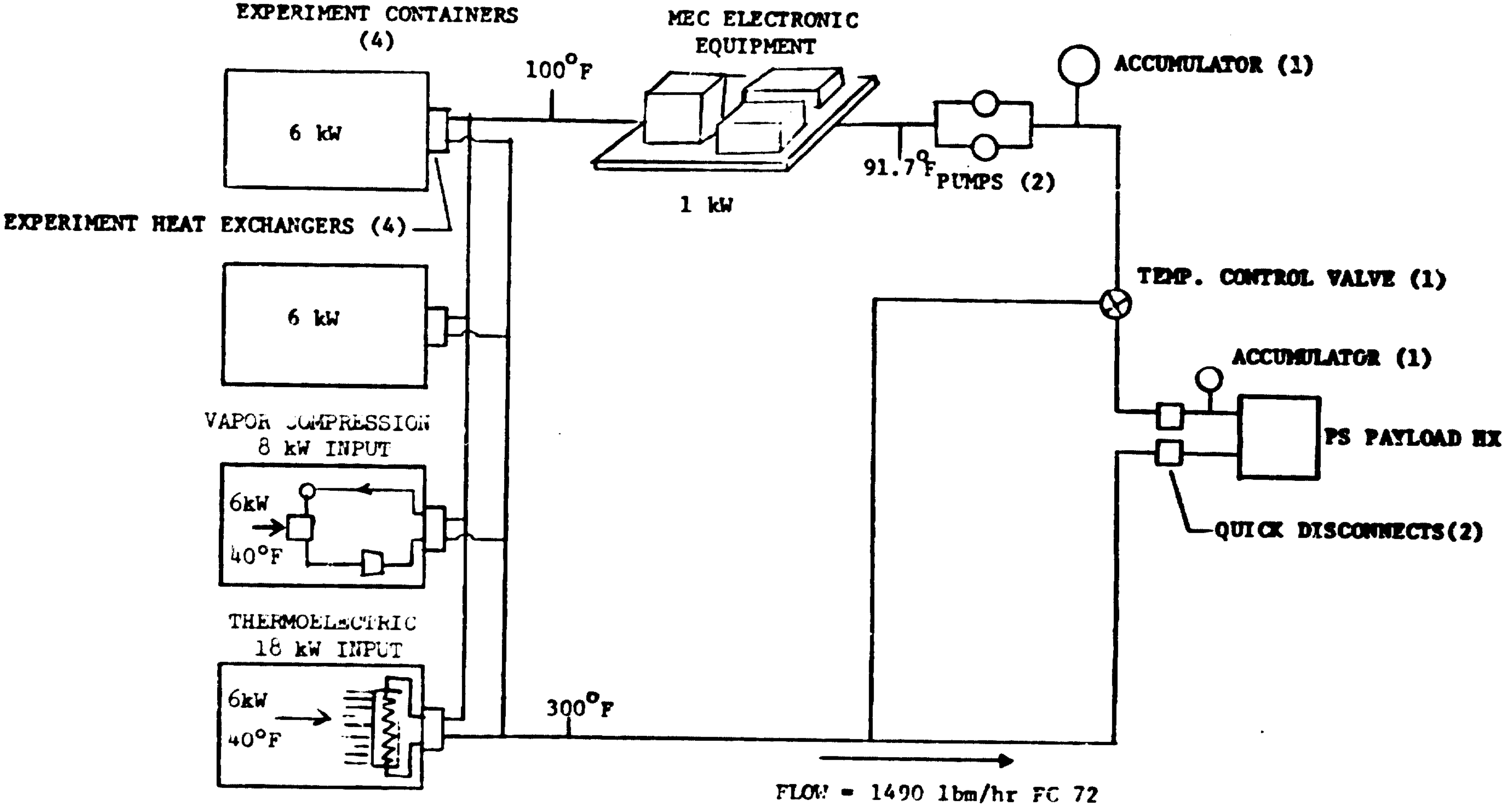


FIGURE 24 MEC COOLANT LOOP SCHEMATIC - LO TEMP PAYLOAD

systems. These power requirements assume the entire 6 kW heat load requires the lower temperature. If only a small amount of low temperature cooling is required the thermoelectric approach might be more attractive due to the simplicity and inherent reliability of this approach.

3.0 MEC COOLANT LOOP FLUID TRADE STUDY

The high operating temperatures of the MEC TCS result in different fluid requirements than for the Orbiter or Power System. R-21 is the fluid used in the Orbiter ATCS and was assumed for the PS Reference Concept, however, R-21 recently has been discovered to be considerably more toxic than previously thought. A recommendation is currently under consideration to reduce allowable levels in inhabited areas from the current 1000 parts per million to as low as 10 ppm. In addition, there is no current supplier of R-21 in the U.S. or, as far as can be determined, Europe either. R-21 vapor pressure at 300°F is 475 psi which could possibly prohibit use of Orbiter components in the MEC loop with R-21. For these reasons a trade study to investigate other fluids for the MEC loop was initiated.

The fluids considered in the trade study are listed in Figure 25, along with their key properties over a range of temperatures from 100°F to 300°F. Consideration was limited to fluids for which properties data was available from previous studies and fluids with critical temperatures above 300°F.

Three combinations of the candidate fluids' thermophysical properties were calculated and compared over the 100°F to 300°F temperature range. The first of these was the pumping power parameter:

$$\frac{\mu}{\rho^2 \; Cp^{2.75}}$$

Where: μ = viscosity
ρ = density
Cp = specific heat

This parameter, plotted in Figure 26, indicates the relative power required to transport a given amount of heat using the fluid, thus, higher numbers indicate more power required and lower numbers less power. The second combination is the heat transfer parameter for turbulent flow:

$$\frac{k^{1/5}}{Pr^{7/15}}$$

Where: k = thermal conductivity
Pr = Prandtl Number

FIGURE 25
FLUIDS CONSIDERED IN MEC FLUID TRADE STUDY

FLUID	VAPOR PRESSURE @ 300°F	CRITICAL TEMP °F	DENSITY (LBM/FT³)			SPECIFIC HEAT (BTU/LBM-°F)			VISCOSITY (LBM/FT-HR)			THERMAL CONDUCTIVITY (BTU/HR-FT-°F)			FREEZE POINT
			100°F	200°F	300°F	100°F	200°F	300°F	100°F	200°F	300°F	100°F	200°F	300°F	
FREON 21	475	353	83.6	74.2	61.5	0.260	0.304	0.368	0.694	0.530	0.417	0.0563	0.043	0.027	-212
FREON 11	300	388	90.2	80.9	68.7	0.214	0.220	0.248	0.905	0.496	0.350	0.0485	0.035	0.024	-168
FREON 114B2	177	418.1	131.0	121.1	110.4	0.168	0.172	0.178	1.500	0.985	0.645	0.0260	0.0202	0.01423	-166.8
FREON 113	177	417.4	95.8	86.7	75.8	0.232	0.248	0.283	1.346	0.783	0.500	0.419	0.0353	0.0287	- 31
FC 78	164.4	352.4	102.0	93.0	83.6	0.260	0.283	0.307	1.385	0.721	0.454	0.0324	0.0268	0.0251	-130
FC 77	61.9	483	108.9	100.5	91.7	0.253	0.286	0.299	2.703	1.247	0.693	0.0362	0.0335	0.0306	-164
FC 104	61.9	446	107.3	98.6	89.9	0.257	0.279	0.301	2.539	1.147	0.662	0.0361	0.0337	0.0310	- 85
FC 75	56.1	440	108.0	99.8	90.5	0.253	0.276	0.299	2.763	1.277	0.702	0.0364	0.0340	0.0314	-126
FC 40	12.4	530	113.6	106.2	98.5	0.2525	0.274	0.295	7.487	1.853	0.802	0.0388	0.0386	0.0383	- 70
FC 43	6.6	577	114.5	107.0	99.3	0.2525	0.274	0.295	7.993	2.075	0.847	0.0390	0.0387	0.0385	- 58
FC 70	1.7	638	119.2	112.6	105.9	0.2595	0.279	0.299	29.12	5.677	2.875	0.0412	0.0410	0.0409	- 13
THERMINOL 66 (MOD ESTER)	0	FP 355	62.4	59.3	56.8	0.380	0.430	0.480	67.8	10.10	3.750	0.0703	0.0687	0.0670	0°
THERMINOL 55	0	FP 355	54.8	52.4	50.1	0.472	0.522	0.572	61.5	10.30	4.09	0.0784	0.0753	0.0724	- 40
THERMINOL 44	0	FP 405	57.1	54.1	51.5	0.476	0.508	0.542	8.05	2.34	1.07	0.0806	0.0760	0.0709	- 80
DC 331 SILICONE	0	FP 400	57.7	54.6	51.6	0.429	0.447	0.465	18.50	8.046	4.002	0.0763	0.0711	0.0654	-148
HYDRAULIC FLUID ORONITE 7277B	0	FP 420	54.7	52.5	50.4	0.450	0.496	0.545	154.4	15.63	8.79	0.0725	0.0697	0.0670	- 35
GLYCOL/WATER 62.5 / 37.5			66.0	63.0	59.5	0.745	0.840	0.900	7.8	2.50	1.75	0.217	0.206	0.180	- 80
DOWTHERM A THERMINOL VP-1	<1 ATM	USE TO 750	65.27	62.46	59.5	0.388	0.426	0.463	6.29	2.57	1.40	0.0805	0.0765	0.0725	54
DOWTHERM G	<1 ATM	USE TO 700	68.0	65.24	62.49	0.395	0.420	0.454	36.20	7.00	2.90	0.755	0.0748	0.0725	19.4
DOWTHERM J	<1 ATM	USE TO 572		51.47*			0.470*			1.089*			0.0738*		PUMPABLE to -100
COOLANOL 25R	0	FP 325	55.0	52.4	49.7	0.459	0.516	0.578	9.18	3.56	2.03	0.0753	0.0721	0.0688	-120
COOLANOL 35	0	FP 350	54.4	51.5	48.6	0.459	0.507	0.560	14.77	5.00	2.45	0.0758	0.0714	0.0690	-180
COOLANOL 45	0	USE TO 400	55.2	52.5	49.9	0.459	0.507	0.560	34.27	8.76	4.83	0.0770	0.0729	0.06	- 85

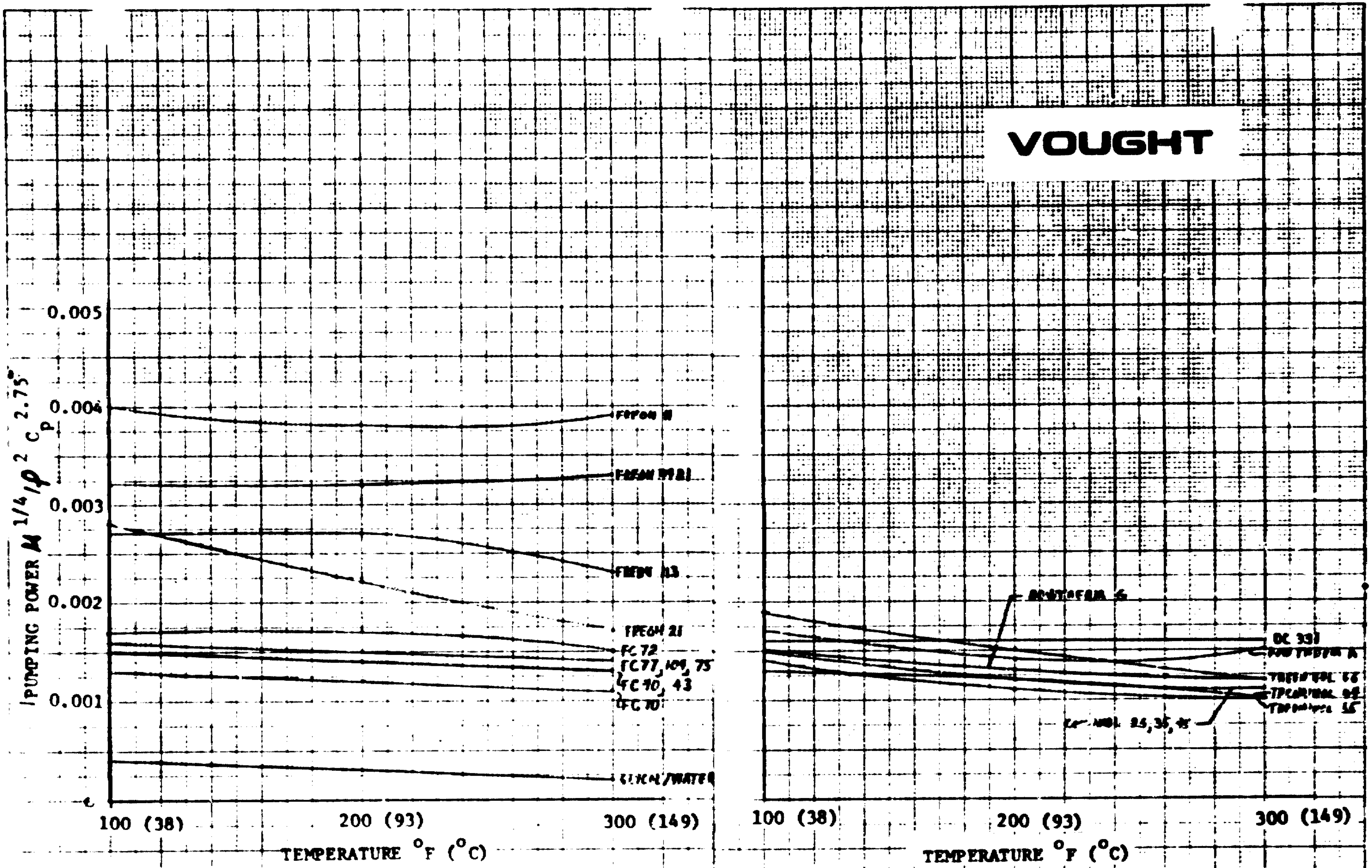


FIGURE 25

FLUID TRADE STUDY - PUMPING POWER PARAMETER COMPARISON

This parameter, plotted in Figure 27, indicates the efficiency which the fluid can effect forced convective heat transfer in turbulent flow. The third combination is a heat exchanger performance parameter derived in a previous study (Reference 4):

$$\frac{k^{2/3} Cp^{1/3} \rho^{1/2}}{\mu^{1/6}}$$

This parameter, plotted in Figure 28, indicates the efficiency with which a fluid will effect heat transfer in a typical compact heat exchanger core.

In addition to these comparisons the fluid performance in a pumped liquid radiator was investigated. Optimum radiator designs were generated for each fluid for a radiator rejecting 9 kW with a 300°F inlet and 100°F outlet temperature. The area, weight, required flowrate and radiator pressure drop for these radiator designs are shown in Figure 29.

From these studies five fluids were selected which indicated superior properties for the MEC applications. A comparison of these five fluids is given in Figure 30. The selected fluids were Freon 21, 60/40 mixture of Glycol Water, FC72, FC77 and FC75. The limitations and problems of R-21 have already been discussed. Glycol/water problems with aluminum at high temperatures make it less attractive although its other characteristics are excellent. The three FC fluids which are manufactured by 3M Company, are fully flourinated hydrocarbons, thus avoiding practically all of the usual Freon problems (toxicity, imcompatibility, damage to ozone layer). Of these three the most attractive for this application is FC72. Although the vapor pressure is higher, it is at an easily manageable level at 300°F. Its heat transfer properties are superior to FC77 and 75. It is, however, only marginally better than FC75 and if other considerations, such as existing qualified hardware, favored FC75 over FC72 then they would override the small differences in performance identified in this study. There are no known space qualified FC72 or FC75 flow components such as pumps, valves, accumulators, etc. Qualification of existing R-21 hardware with these fluids would seem plausible and desirable rather than development of new components. Nothing in this study indicated the R-21 components could not be used with FC72 or FC75.

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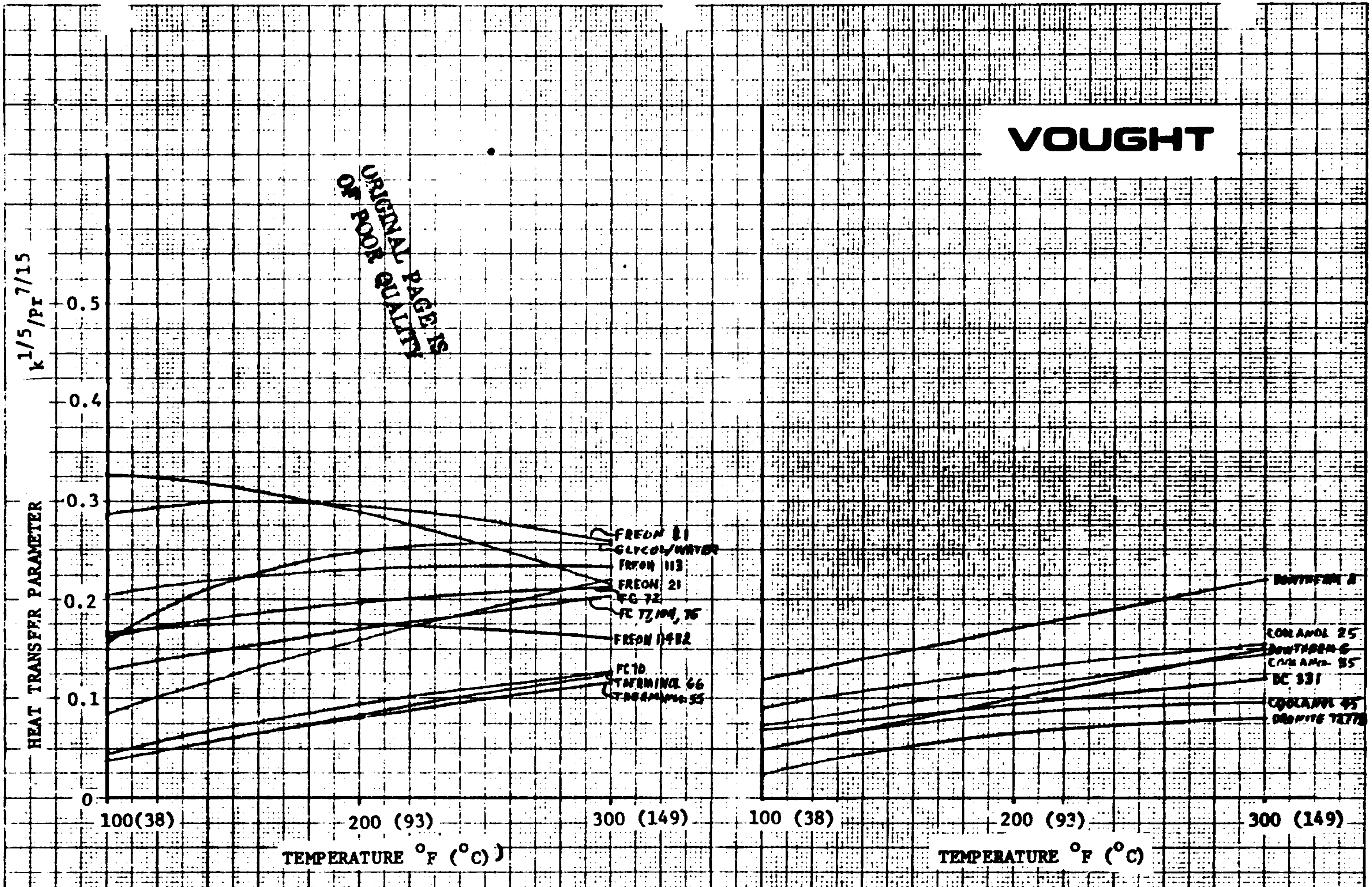


FIGURE 27

FLUID TRADE STUDY - HEAT TRANSFER PARAMETER COMPARISON

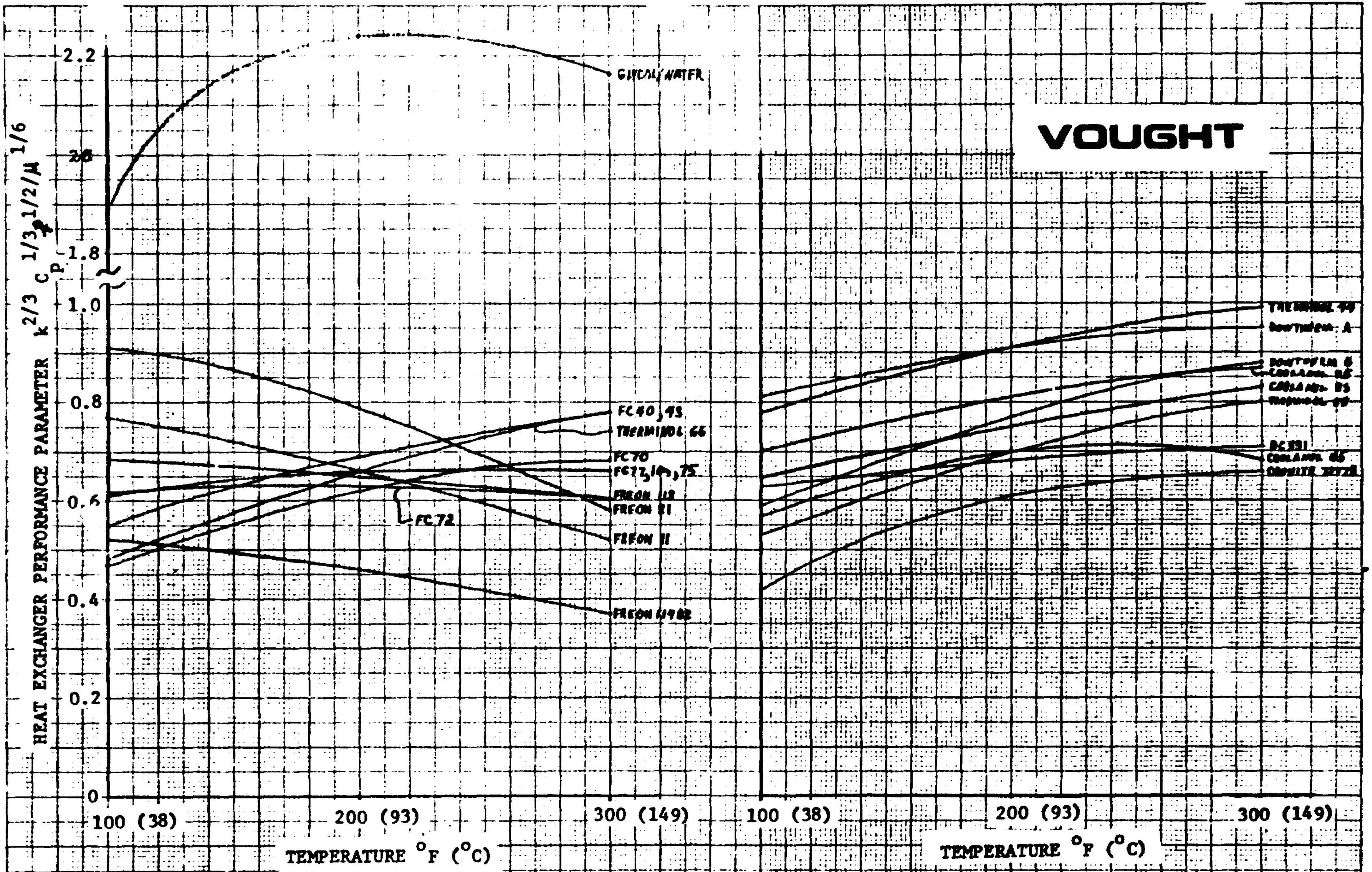


FIGURE 28

FLUID TRADE STUDY - HEAT EXCHANGER PERFORMANCE COMPARISON

FIGURE 29
FLUID PERFORMANCE IN RADIATORS

FLUID	WEIGHT OPTIMUM DESIGN WEIGHT (LBm)	AREA (FT^2)	FLOW (LBm/HR)	ΔP (PSI)
1. ORONITE 6294	165.1	161.3	302.4	15.9
2. FREON 21	106.3	103.6	539.2	8.5
3. FREON 11	108.3	104.0	715.8	7.8
4. FREON 114B2	116.2	110.1	952.6	11.6
5. FREON 113	109.9	106.1	559.2	9.5
6. FC 72	109.9	107.0	579.2	11.7
7. FC 77	114.0	11[illegible].4	557.2	16.7
8. FC 104	113.7	103.5	587.2	15.7
9. FC 75	114.1	110.6	548.2	18.3
10. FC 40	119.3	116.8	560.6	23.3
11. FC 43	123.6	118.7	560.6	29.2
12. FC 70	213.2	207.0	585.5	25.5
13. THERMINOL 66	169.4	161.5	380.8	17.0
14. THERMINOL 55	162.0	155.6	313.9	16.7
15. THERMINOL 44	155.1	155.4	322.6	9.8
16. DC 331	166.0	159.3	366.4	15.9
17. ORONITE 7277B	170.5	160.4	329.6	18.8
18. GLYCOL WATER	115.5	117.5	194.9	9.4
19. DOWTHERM A	155.4	155.0	384.6	10.2
20. DOWTHERM G	161.4	156.7	390.4	16.1
21. DOWTHERM J	110.7	110.5	326.9	13.8
22. COOLANOL 25	159.9	158.6	317.4	13.2
23. COOLANOL 35	162.4	159.1	323.2	14.1
24. COOLANOL 45	163.7	157.7	323.2	16.9

FIGURE 30
MEC FLUID SELECTION STUDY

FLUID	VAPOR PRESSURE @ 300°F	TOXICITY	FLAMMABILITY	FREEZE POINT (°F)	OPTIMUM RADIATOR DESIGN FOR 9 kW T_{IN}=300, T_{OUT}=100°F			HANDLING	MATERIAL COMPATIBILITY	HEAT TRANSFER RATING
					AREA (FT^2)	WEIGHT (LBm)	ΔP (PSI)			
FREON 21	475	TOXICITY PROBLEM	NON	-212	103.6	106.3	8.5	SPECIAL HANDLING REQUIRED	CANNOT USE SOME ELASTOMERS	2
GLYCOL/WATER	LOW	NON	FLAMMABLE	- 80	117.5	115.5	9.4	NO SPECIAL HANDLING	PROBLEM WITH AL [illegible]R. AT HI TEMP [illegible]D LONG LIFE	1
FC 72	164.4	NON	NON	-130	107.0	109.9	11.7	NO SPECIAL HANDLING	SWELLS SOME ELASTOMERS, COMP OTHERWISE	3
FC 77	61.8	NON	NON	-166	111.4	114.0	16.7	NO SPECIAL HANDLING	SWELLS SOME ELASTOMERS, COMP OTHERWISE	4
FC 75	56.1	NON	NON	-126	110.6	114.1	18.3	NO SPECIAL HANDLING	SWELLS SOME ELASTOMERS, COMP OTHERWISE	4

<u>RECOMMENDATION:</u> FC 72, LOWER ΔP, BETTER OVERALL HEAT TRANSFER, LOWER RADIATOR WEIGHT, NON TOXIC, GOOD COMPATIBILITY, LOW FREEZE POINT

4.0 MEC TO EXPERIMENT THERMAL INTERFACE STUDY

A design study was conducted to investigate two approaches to the MEC to experiment thermal interface. The two approaches were fluid-to-fluid compact heat exchangers and a mechanical interface contact heat exchanger. The two candidate MEC vehicle configurations shown in Figure 31 were assumed. These were the two configurations selected in the Reference 3 configuration study. The experiment container configuration was assumed to be that shown in Figure 32. The container is structurally integrated with the vehicle and the experiment payload elements are separable. One of the MEC configurations provides a cylindrical experiment container, the other a trapezoidal container.

From this study, three different types of configurations were developed. Each type of configuration is shown in the cylindrical MEC payload container and again in the trapezoidal segmented payload container.

Figures 33 and 34 illustrate a fluid interface heat exchanger. The heat exchanger used for this configuration is a derivative of the shuttle orbiter interchanger. The envelope dimensions used are the same as the Shuttle Orbiter design except the MEC system uses only one coolant loop from the MEC system and one coolant loop for specimen cooling rather than the two dual redundant cooling systems used in the Shuttle Orbiter interchanger. Quick disconnects have been mounted on the heat exchanger package to provide for automatic engagement of the MEC experiment coolant system when it is installed. Guide rails or a similar alignment system is required for installation of the experiment coolant system to insure proper engagement of the quick disconnects. A reservoir is installed with the heat exchanger to provide for thermal expansion of the experiment system fluid trapped in the heat exchanger when the experiment coolant loop is disconnected.

Figures 35 through 37 present an 8 segmented cylindrical contact heat exchanger configuration. Figures 35 and 36 show this configuration installed in the cylindrical payload container. The mating experiment heat exchangers shall be cylindrical in shape and made to fit inside of the MEC system heat exchangers shown. When the experiment system is used, the MEC system cylinder is pressurized with 300 psia nitrogen which causes it to clamp down on the experiment heat exchanger. To provide the pressure chamber for the eight heat exchanger segments, the segments are tied together with a thin stainless steel diaphragm of one convolution between each segment. The MEC

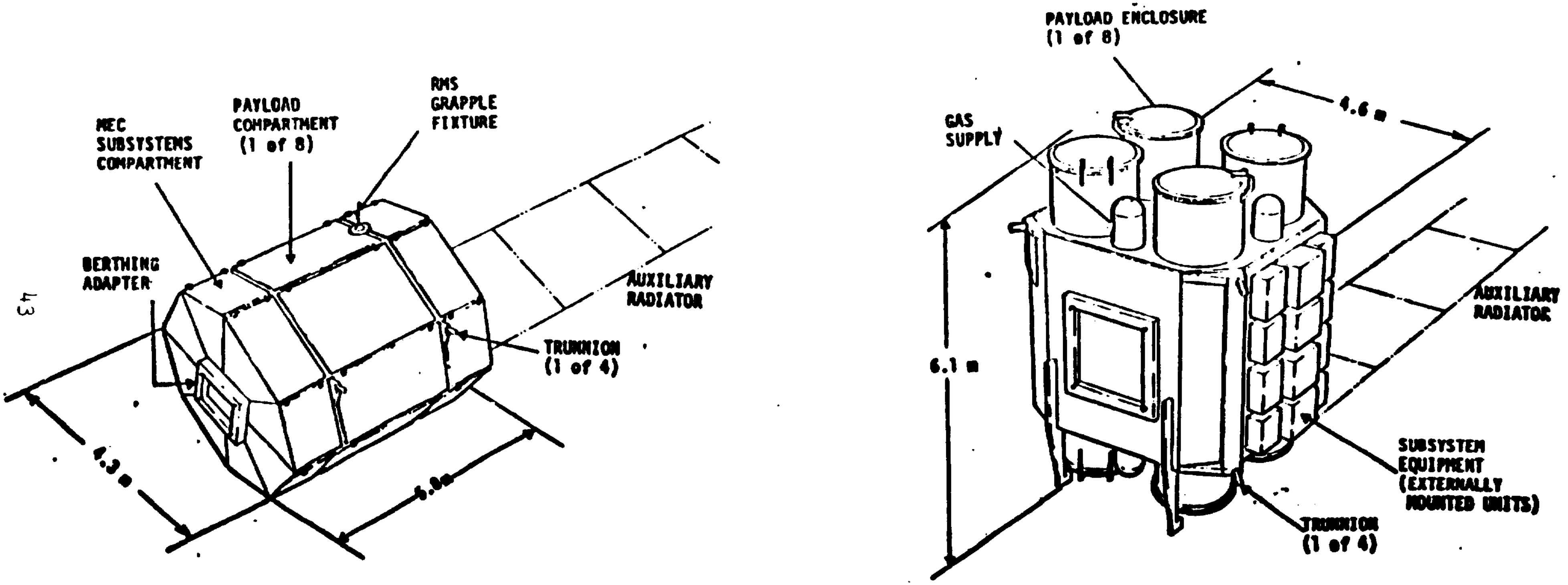
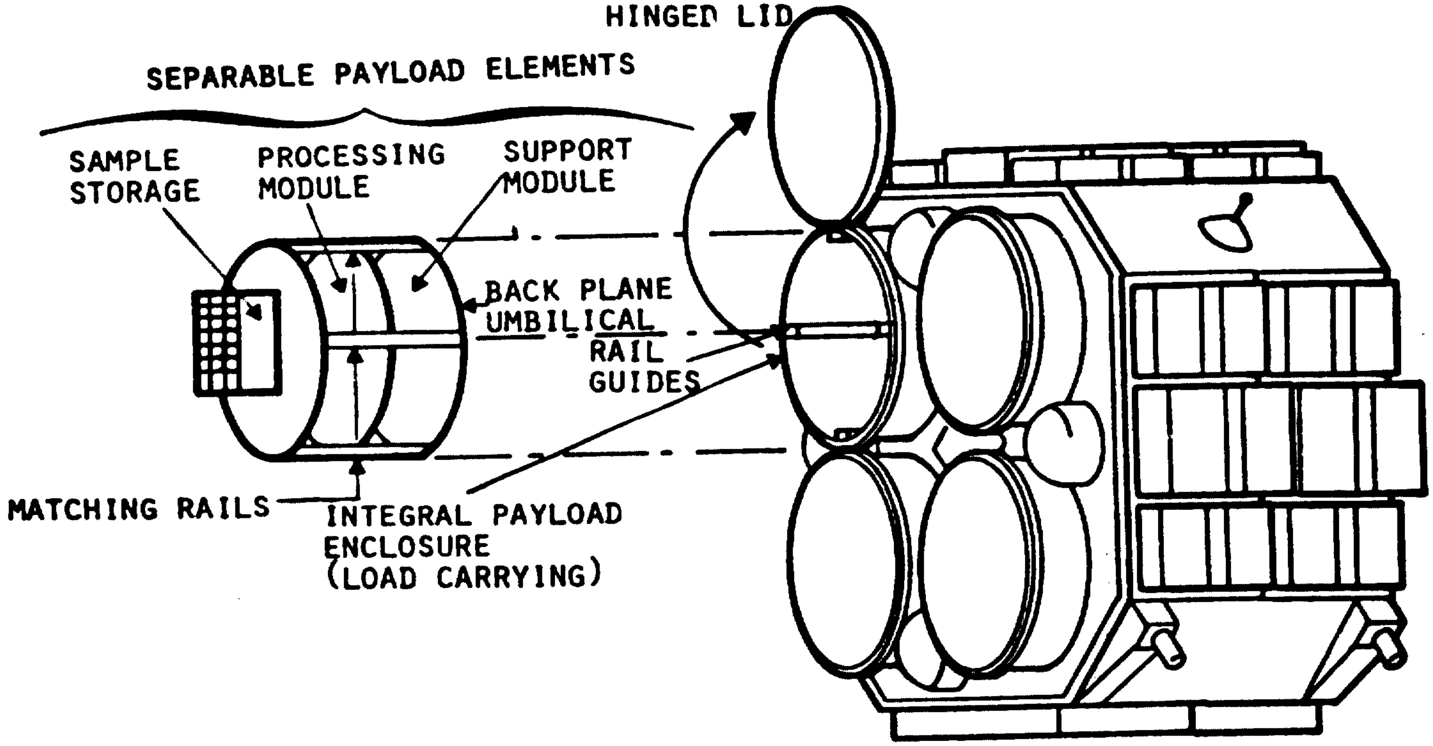


FIGURE 31
CANDIDATE MEC CONFIGURATIONS

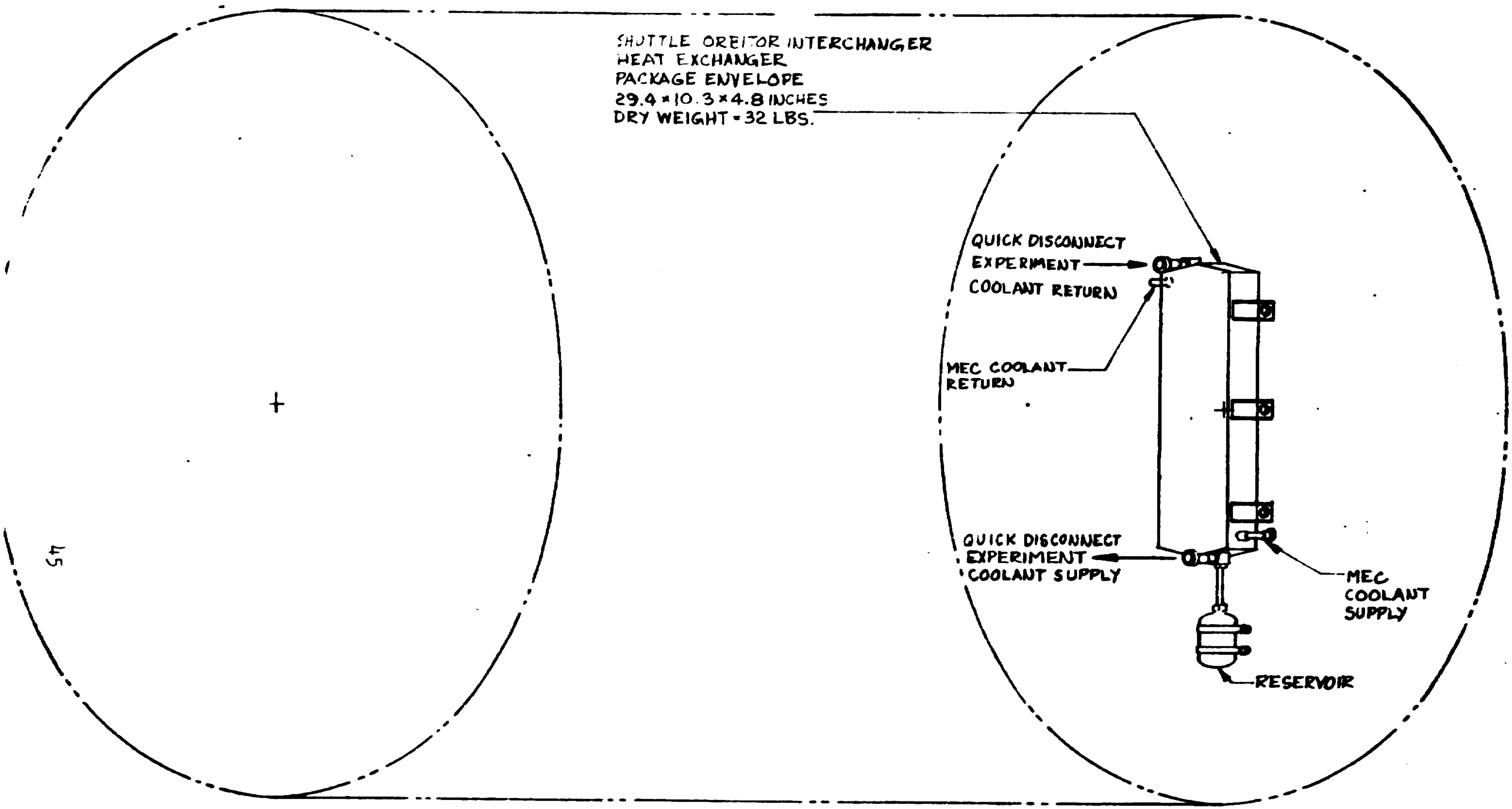


APPROACH

1. PAYLOAD ENCLOSURES ARE NOT REMOVABLE ONCE INTEGRATED INTO MEC STRUCTURE.
2. PAYLOAD ELEMENTS INTEGRATED AT PAYLOAD CENTER (MSFC OR PAYLOAD CONTRACTOR FACILITY); PLACED INTO A SHIPPING CONTAINER. SENT TO MEC/PL INTEGRATION SITE.
3. PAYLOAD INTEGRATION AND CHECKOUT PARALLEL TO MEC INTEGRATION
4. ON-ORBIT SERVICING: REMOVE AND REPLACE PAYLOAD AND/OR SAMPLE STORAGE ELEMENTS

ADVANTAGE: LOWER MEC STRUCTURAL WEIGHT

FIGURE 32 MEC INTEGRAL STRUCTURE PAYLOADS



MEC CYLINDERICAL PAYLOAD COUTAINER WITH FLUID INTERFACE HEAT EXCHANGER

FIGURE 55

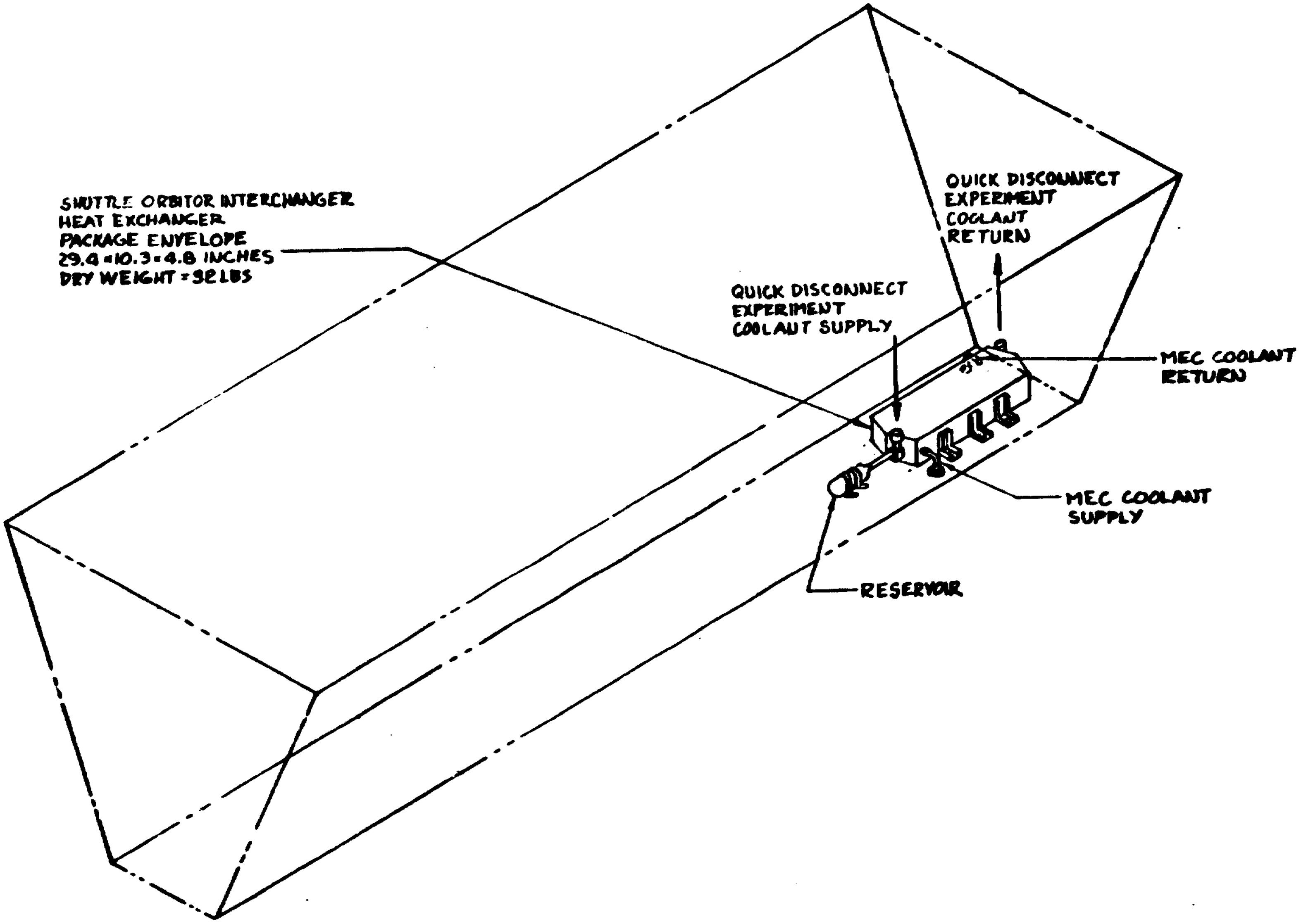


FIGURE 34 SEGMENTED MEC PAYLOAD CONTAINER WITH FLUID INTERFACE HEAT EXCHANGER

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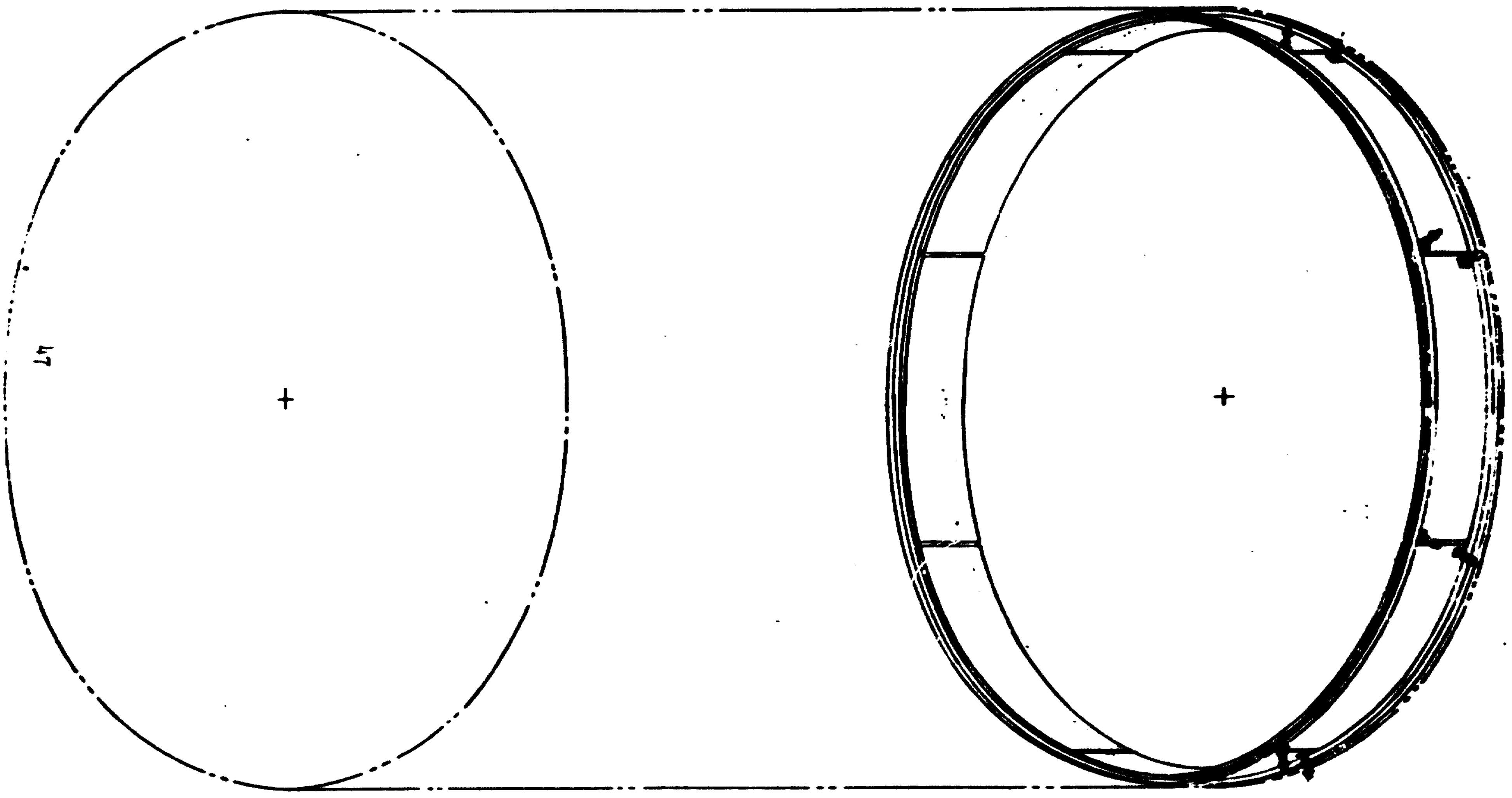
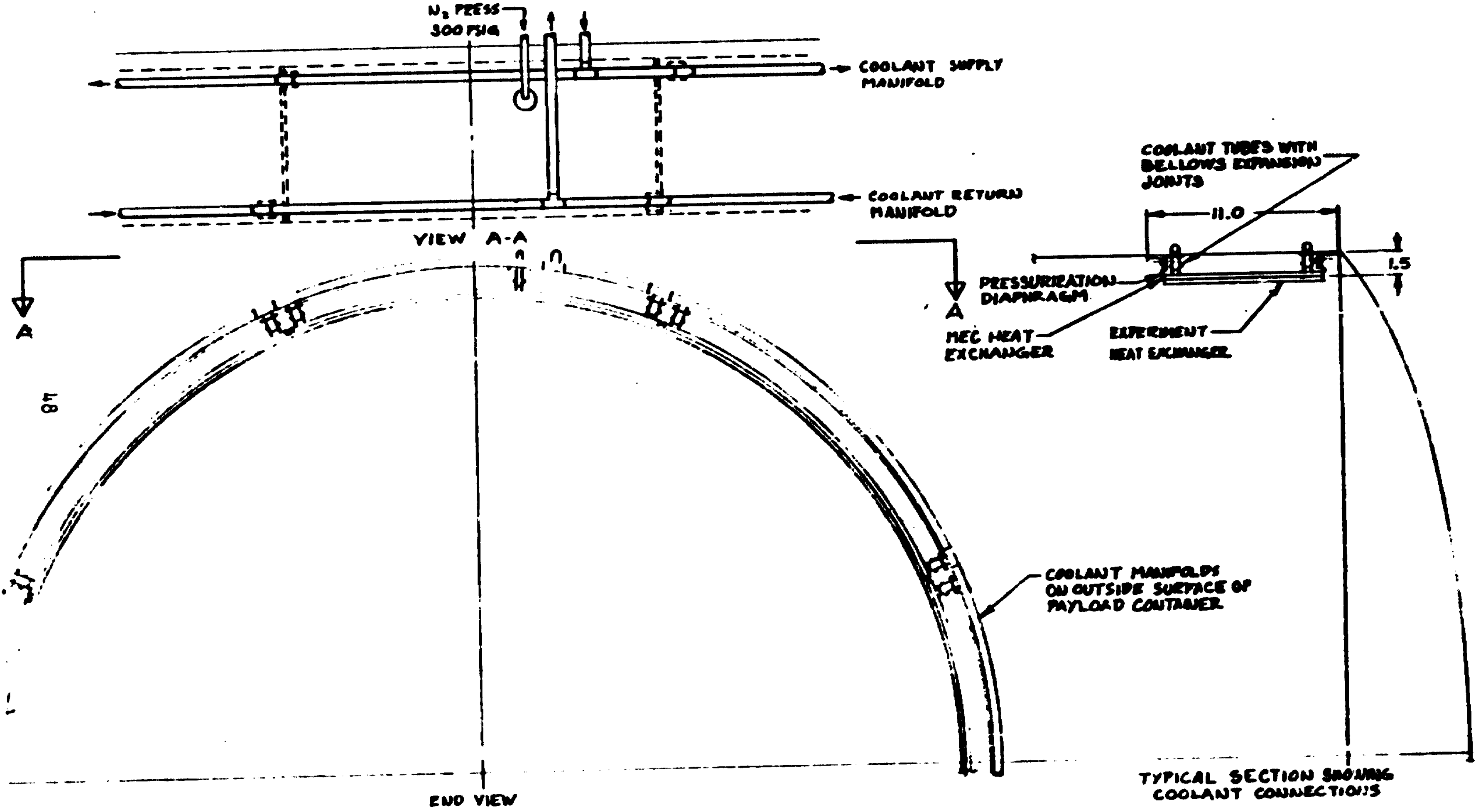
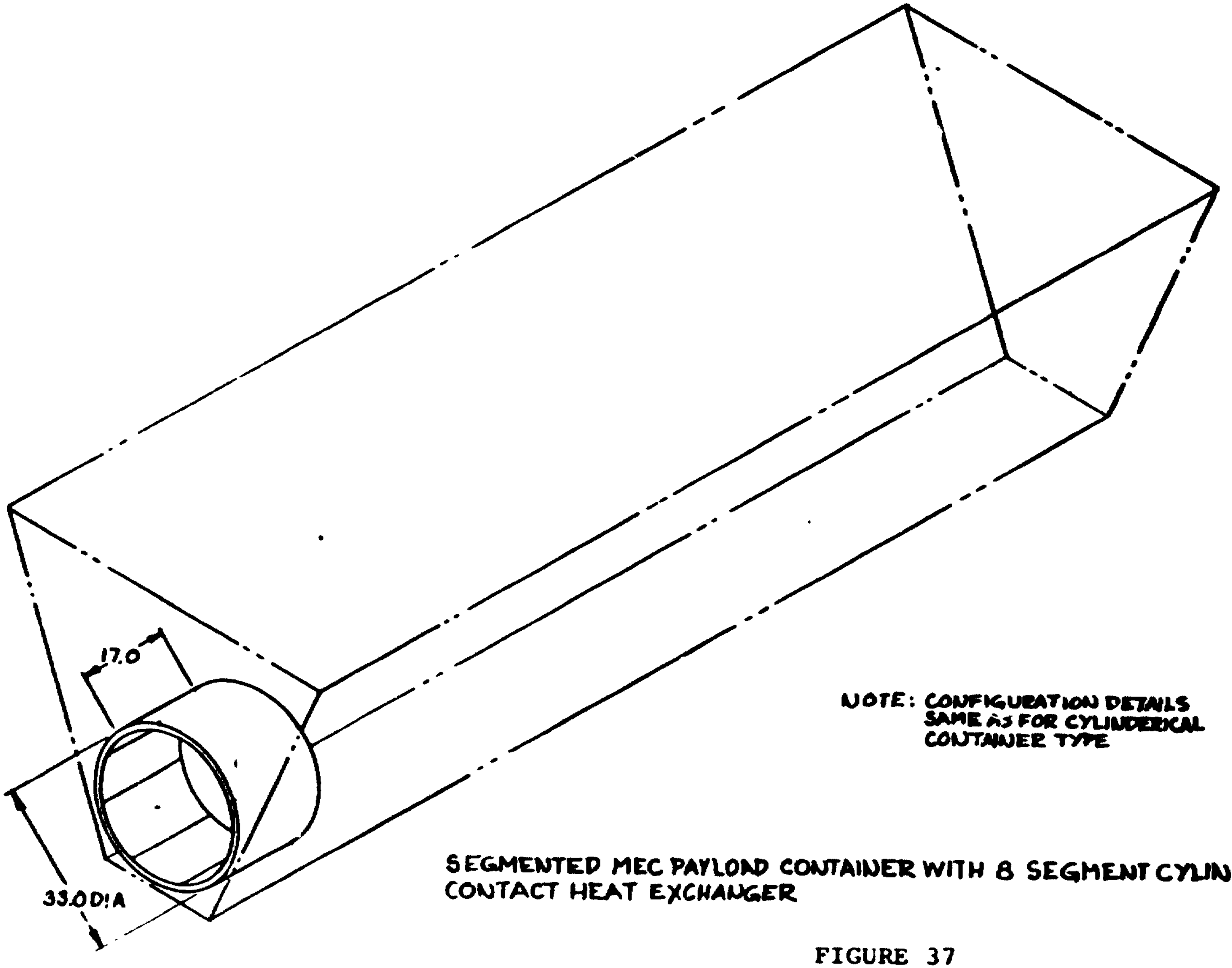


FIGURE 35 CYLINDRICAL CONTACT HEAT EXCHANGER



CYLINDERICAL PAYLOAD CONTAINER WITH 8 SEGMENT CYLINDRICAL CONTACT HEAT EXCHANGER EXTERNALLY PRESSURIZED

FIGURE 36



NOTE: CONFIGURATION DETAILS SAME AS FOR CYLINDERICAL CONTAINER TYPE

SEGMENTED MEC PAYLOAD CONTAINER WITH 8 SEGMENT CYLINDERICAL CONTACT HEAT EXCHANGER

FIGURE 37

payload container is the outside wall of the pressure chamber. The fluid manifolds are mounted on the outside of the MEC payload container as shown. Each short tube connecting the MEC coolant manifold to the heat exchanger contains a single bellows convolution to allow for motion of the heat exchangers during clamping actuation. This system maintains a 300 psig force over the interface contact surface of the heat exchangers. It also requires that the MEC payload container be sealed for 300 psig nitrogen pressure where it is used as part of the pressure chamber around the heat exchanger.

Figure 37 shows a cylindrical heat exchanger of the same type installed in the trapezoidal segmented MEC payload container. In this configuration, the speciman heat exchanger would also fit inside of the MEC system eight segmented cylindrical heat exchanger. The 33 inch outside diameter of the cylinder used to pressurize the heat exchanger just fits adjacent to the bottom and two sides of the payload container.

Vought is presently developing and testing cylindrical contact heat exchangers similar to the configuration shown here.

Figures 38 throuh 40 show a pattern of eight flat round contact heat exchangers mounted on a cylinder. This system is similar to the eight segmented cylindrical syntem except it permits the use of conventional round bellows in place of the cylindrical diaphragm. It would require less development and be less expensive than the cylindrical type.

As illustrated in Figure 39, each heat exchanger is connected to the payload container by a conventional single convolution bellows assembly. Likewise the coolant supply and return lines, which are mounted on the outside of the payload container, are connected to each heat exchanger by a tube having a single convolution bellows. The cavity behind the heat exchanger is pressurized by a 300 psig nitrogen source through a supply fitting from a manifold line on the outside of the payload container. The mating experiment contact heat exchangers are mounted on a cylindrical drum which installs inside of the ring of MEC coolant system heat exchangers. An even distribution pressure on the flat contact heat exchangers is maintained by use of a lightweight cylindrical backup structure.

Figure 40 shows a similar configuration of eight round flat heat exchangers mounted in the trapezoidal segmented configuration MEC payload contaier. In this configuration a cylindrical drum would be required to mount

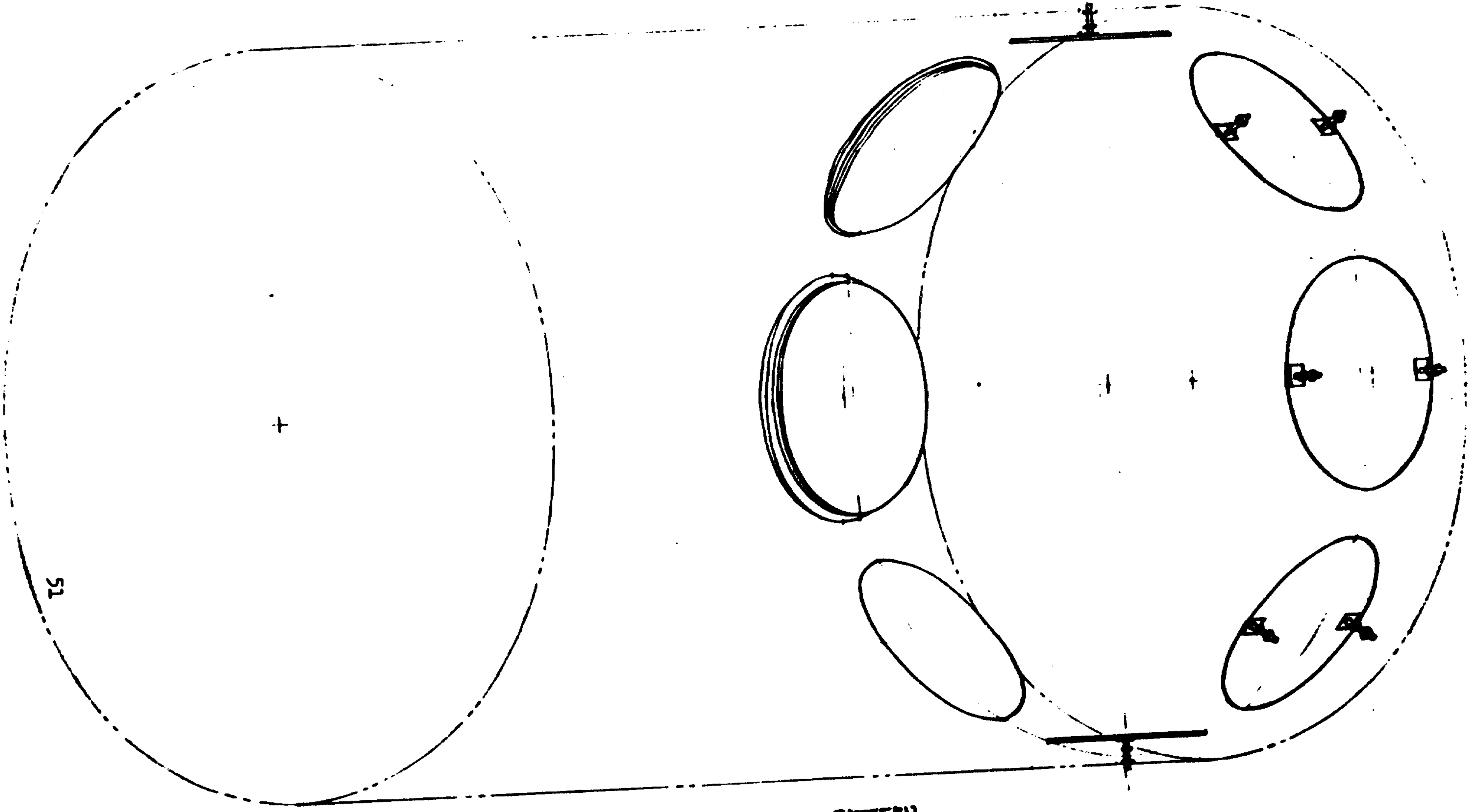


FIGURE 38 DISC SHAPED CONTACT HEAT EXCHANGERS IN OCTAGONAL PATTERN

VOUGHT

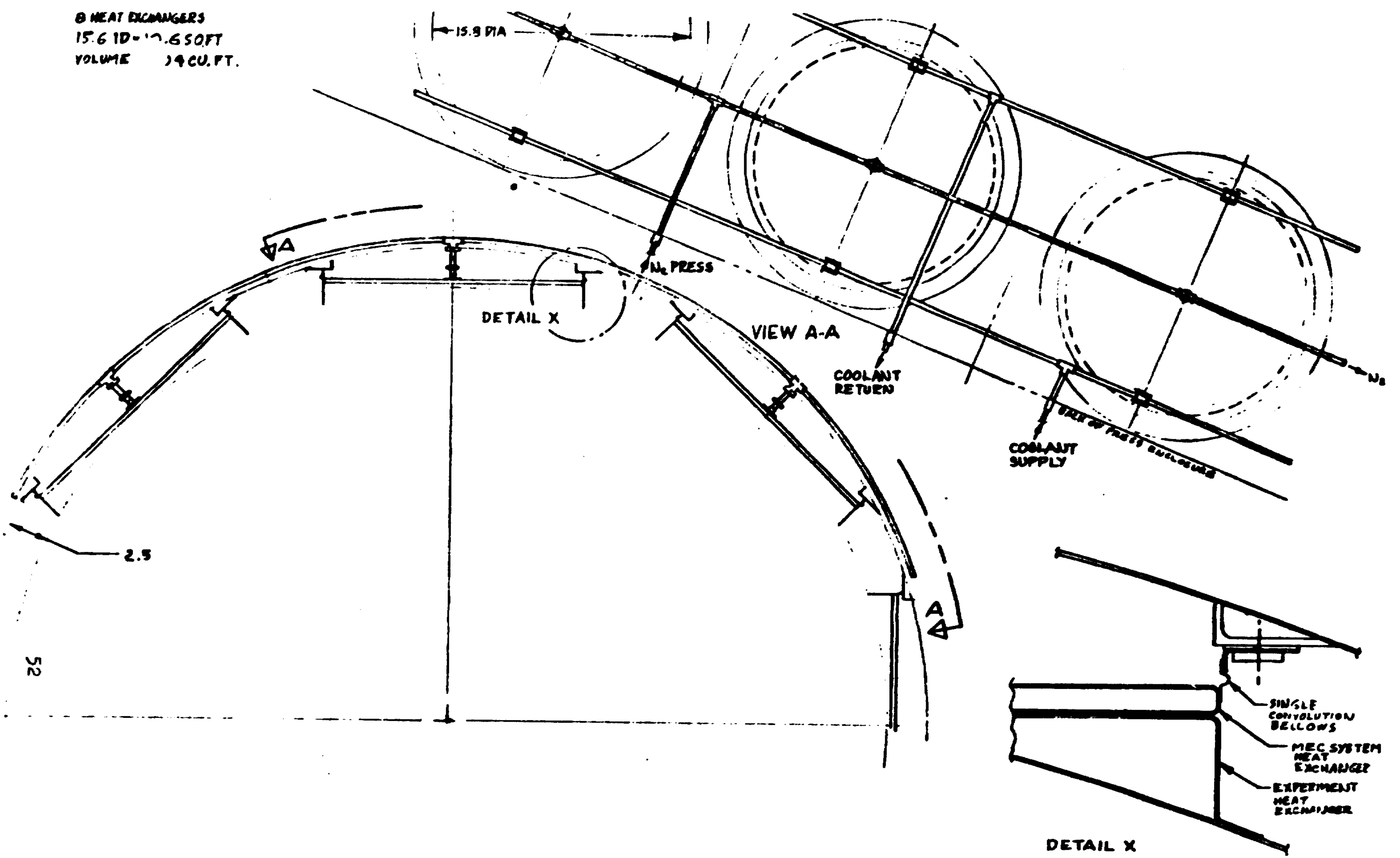


FIGURE 39 DISC SHAPED CONTACT HEAT EXCHANGERS

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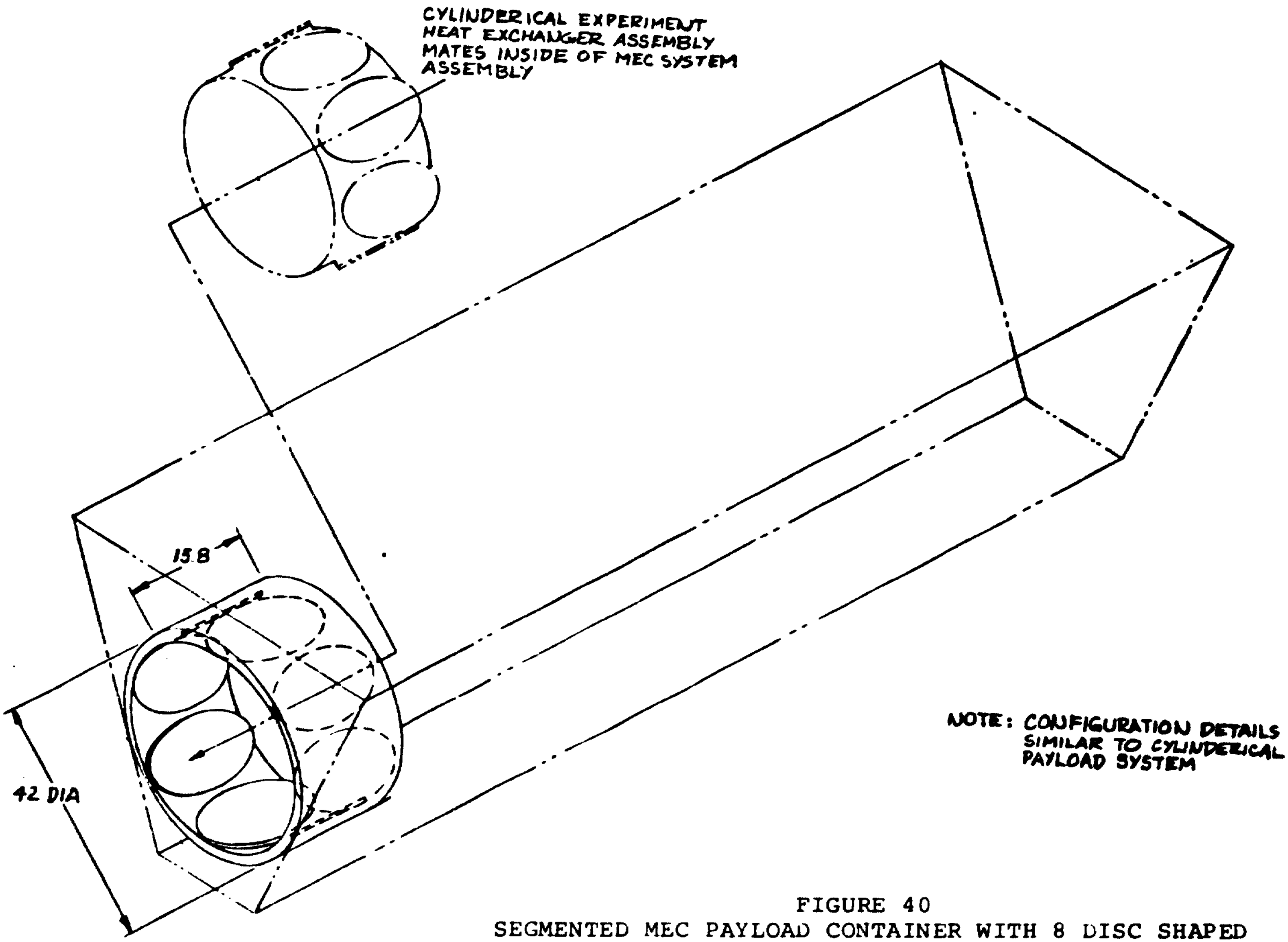
10-15-80

VOUGHT



NOTE: CONFIGURATION DETAILS SIMILAR TO CYLINDERICAL PAYLOAD SYSTEM

FIGURE 40
SEGMENTED MEC PAYLOAD CONTAINER WITH 8 DISC SHAPED CONTACT HEAT EXCHANGERS MOUNTED ON A CYLINDER

the heat exchangers rather than the MEC payload container as the outer part of the nitrogen pressure chamber. The 42 inch diameter drum is tangent to the sides of the payload container and leaves a 6.5 inch space at the bottom for installation of controls and interface plumbing.

As illustrated in Figure 41, for a 9kW design, contact heat exchangers are considerably heavier than conventional compact designs. These studies indicate the additional volume and complexity involved. If the convenience of the contact mechanical joint is desired from operational considerations, the disc shaped approach appears to be the design with the least technical risk. Contact heat exchangers will require a technology development program. Compact heat exchangers require development of a quick disconnect which accommodates the "dead head" fluid on the experiment side of the heat exchanger.

5.0 MEC THERMAL CONTROL COATING REVIEW

A review was conducted of available thermal control coatings for both the MEC vehicle and MEC radiators. A summary of the vehicle coatings review is shown in Figure 43. For the MEC vehicle where handling and durability is of prime importance the recommended coatings are the anodized and alodine treated aluminum surfaces. An alternate where greater stability of optical properties is required is silver or aluminum backed Teflon. These coatings are easily cleaned. For the MEC radiator applications silver backed Teflon or Zinc Orthotitanate are recommended. Some development on adhesives for greater than 250°F temperatures would be required if the silver Teflon is used. The Zinc Orthotitanate will require flight qualification and development of specification and is costly to process. Both of these coatings, however, have good optical properties stability in orbital conditions.

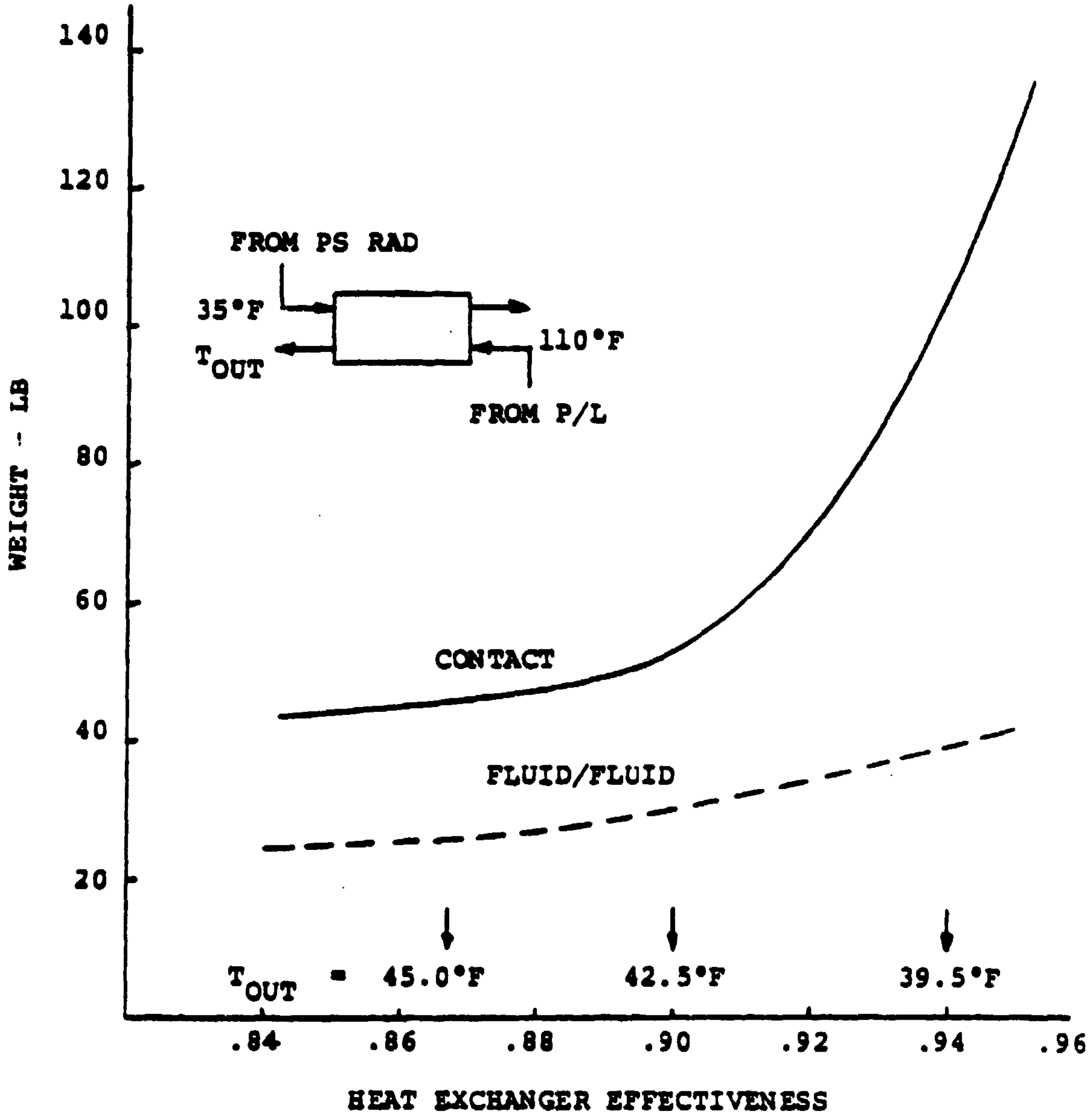
6.0 THERMAL CONTROL SYSTEM TECHNOLOGY DEVELOPMENT RECOMMENDATIONS

The results of these studies were reviewed to identify items which will require technology development. A list of the items identified are shown in Figure 44. The items which require development will depend on MEC program decisions on the TCS cofiguration ultimately selected.

FIGURE 41

POWER SYSTEM/PAYLOAD INTERFACE HEAT EXCHANGER WEIGHT

16 kW



VOUGHT CORPORATION

FIGURE 42
MEC VEHICLE COATING

COATING	SOLAR ABSORPTANCE	NORMAL EMITTANCE	MAX. USE TEMP.	THERMAL VACUUM STABILITY	INSTALL. PROCESS APPEARANCE	HANDLEABILITY DURABILITY	EASE OF CLEANING	REFURBISHMENT METHOD	COST-MAT'LS/ INSTALL.	PRIOR USE	SPECIFICATION	APPROX. WT.
Clear Anodize-Aluminum	0.15 $\Delta\alpha$ = 0.1 -0.2 @ 700 ESH	0.75	350°F	Excellent	Tank electro-process-modified sulphuric acid	Excellent	Excellent solvent wipe	Tank strip & tank electro-process details; hard to refinish assembled details; alodine touch up for small defects	nil material moderate labor	None requires lab work & spec preparation	None - lab process exists AFML Lab	-0-
Barrier Layer Anodic	0.12 $\Delta\alpha$ = 0 @ 1500 ESH	0.38		Excellent	Ammonium tartarate anodize 1199 Al	Projected good	Projected good		similar to sulphuric acid anodize	OSO III expt.	Boeing, flight experiment	-0-
A-276	0.22 $\Delta\alpha$ 0.15 after 1000 hrs, solar low earth orbit	0.8	200°F	<0.1%VCM <1.0%TML afterbake	Spray paint white polyurethane binder	Excellent	Excellent solvent wipe	Brush or spray touch up each flight if necessary	\$100/400 ft^2 moderate labor; conventional spray paint	Orbiter hardware	In preparation Rockwell	0.02 gm/in^2
Koropon 515-700	0.38 Unknown	0.8	350°F	<0.1%VCM <1.0%TML afterbake	Spray paint green	Excellent resists R-21	Excellent solvent wipe	Brush touch up	\$70/400 ft^2 moderate labor; conventional spray paint	Orbiter hardware	Yes, Rockwell	0.01 gm/in^2
Chromate Conversion Aluminum (Alodine)	0.05-0.15 $\Delta\alpha$ = 0.09 @ 1800ESH	0.35-0.50	350°F	Excellent	Brush or dip; mottled streaky appearance-tan	Good; can be scratched	Excellent solvent wipe	Brush on assemblies; dip or brush on details	nil material low labor	Orbiter Pegasus	Yes, MIL Spec	-0-
NS55F Inorganic Yellow Coating Static Change (Goddard)	0.55 $\Delta\alpha$ = 0-0.02 @ 1000 ESA	0.90	300°F	Excellent afterbake	Spray paint yellow, $ZnO + Al_2O_3 + Co_3O_4$, silicate binder	Good expect ground	Fair deionized water	Unknown	Unknown lab quantities only at present high labor	ISEE spacecraft	No, hand made at Goddard or GE	60 gm/ft^2
Any of specialized coatings from MEC Radiator Study if cost and refurbishment time can be justified												

FIGURE 43
MEC RADIATOR COATING

COATING	SOLAR ABSORPTANCE	NORMAL EMITTANCE	MAXIMUM USE TEMP	THERMAL VACUUM STABILIZE	INSTALLATION PROCESS - APPEARANCE	HANDLEABILITY-DURABILITY	EASE OF CLEANING	REFURB METHOD	COST MATERIAL/ INSTAL.	PRIOR USE	SPEC	APPROX. WEIGHT
S13G-LO	0.22 spec 0.17 typ $\Delta\alpha \doteq .07$ @ 1500 ESH (S13G, OSO-III)	0.84 spec 0.89 typ	300°F	< 0.1% VCM < 1.0% TML	Spray Paint	Fair-Chips easily 0.010 inches thick	Fair Solvent Wipe	Brush	\$400/20 ft^2 high labor 45 min pot life-very short	Orbiter Hardware Numerous Satellite	Yes Rough:	0.2 gm/in^2 Heavy
Silver Teflon Embossed	0.08 $\Delta\alpha \pm 0.01$ to 0.03 @ 8000 ESH	0.80	250°F or 300°F if use 350° cure	< 0.1% VCM < 1.0% TML after bake	Hand layup autoclave cure-silver	Scratches easily; degrades in solar radiation after scratching	Fair Solvent Wipe	Hand layup-laborious	\$1400/33 ft^2 high labor	Orbiter Rads-P/L Bay door liner, Numerous Satellite	Yes Rough:	0.215 gm/in^2 Heavy
Chromate Conversion Aluminum (Alodine)	0.05-0.15 $\Delta\alpha/\varepsilon$ = 0.09 @ 1800 ESH	0.35-0.5	350°F	Excellent	Brush or Dip-Mottled Streaky appearance-tan	Good-Can be scratched	Excellent Solvent Wipe	Brush	nil Matl. low labor	Orbiter Rads, Door Side FCA base plate, Pegasus	Yes MIL	-0-
Clear Anodize Aluminum	0.15 $\Delta\alpha$ = 0.1 - 0.2 @ 700 ESH	0.75	350°F	Excellent	Tank electro-process-modified sulphuric acid	Excellent	Excellent Solvent Wipe	Tank Strip & Tank Electro process	nil Matl. Moderate Labor	None - Requires Lab work & Space Prep.	Some AFML Lab.	-0-
A-276	0.22 $\Delta\alpha$ = 0.15 after 1000 hrs solar radiation	0.8	200°F	< 0.1% VCM < 1.0% TML after bake	Spray Paint White, polyurethane Binder	Excellent	Excellent Solvent Wipe	Brush or Spray Touch Up	\$100/400 ft^2 Moderate Labor	Orbiter Hardware	Yes Rockwell	0.02 gm/in^2
Koropon	0.38 $\Delta\alpha$ Unknown	0.8	350°F	< 0.1% VCM < 1.0% TML after bake	Spray Paint Green Epoxy Binder	Excellent After Solar Radiation, Resists R-21	Excellent Solvent Wipe	Brush Touch Up	\$70/400 ft^2 Moderate Labor	Orbiter Hardware	Yes Rockwell	0.01 gm/in^2

FIGURE 43 (CONT'D)

MEC RADIATOR COATING

COATING	SOLAR ABSORPTANCE	NORMAL EMITTANCE	MAXIMUM USE TEMP	THERMAL VACUUM STABILIZE	INSTALLATION PROCESS - APPEARANCE	HANDLEABILITY-DURABILITY	EASE OF CLEANING	REFURB METHOD	COST MATERIAL/ INSTAL.	PRIOR USE	SPEC	APPROX. WEIGHT
NS43C Inorganic Yellow Coating-Static Charge Relief (Goddard)	0.20 Δα = 0-0.02 @ 1000 ESH	0.92	300°F	Excellent After Bake	Spray Paint Yellow/White $ZnO + Al_2O_3$ Silicate Binder	Fair, expect ground Δα	Fair - Deionized Water	Unknown	Unknown-lab quantities only at present high labor	ISEE	No, Hand Made At Goddard or G.E.	60 gm/ft^2 Heavy
Zinc Ortho-titanate (Zn_2TiO_4) (Marshall)	0.14 Δα = 0.01 after 5000 hrs, low orbit, 0.10 inches thick	0.88	+600°F	Excellent	Spray Paint White Potassium silicate binder	Poor, expect ground Δα	Not Cleanable	Strip & Re-Spray No Brushing	Hand Made Pigment by IITRI High Labor	AF Sat. by Aero-space α = 0.17 α = 0.24 after 1 yr GEO orbit	Same as Z-93 for Process, None for Pigment	Twice that of Z-93, heavy
MS-74 (Goddard)	α/ε = 0.19 = 0.23 Δα/ε = 0.01 OSO-H @ 8000 ESH		+500°F	Excellent	Spray Paint White, $ZnO + Al_2O_3 + TiO_2$; Potassium silicate	Fair, expect ground Δα, 3 yr shelf life	Unknown-Wrap in Poly Bag to Protect, light Sanding to Clean	Brush Touch Up	Hand Made Pigment by NASA Goddard High Labor	OSO-H, IMP-H, ATS-b, Apollo experi.	No, Tech Memo 75186 gives MS P details	0.036 lb/ft^2
Z-93	0.17 Δα = 0 @ 2500 ESH	0.9	+600°F	Excellent	Spray Paint Zinc Oxide, Potassium Silicate	Poor, Δα = 0.05 on ground	Not Cleanable	Brush Touch Up	Hand Made Pigment by IITRI High Labor	Numerous Apollo Radiator	Yes	Approx. 0.04 lb/ft^2

FIGURE 44

THERMAL CONTROL SYSTEM TECHNOLOGY DEVELOPMENT ITEMS

RADIATORS

- HIGH TEMPERATURE ($\geq$ 250°F) RADIATOR COATINGS

FLUID LOOP

- CERTIFICATION OF COMPONENTS FOR USE WITH FC72 AT HIGHER TEMPERATURES
- VARIABLE SET POINT TEMPERATURE CONTROL VALVE

INTERFACES

- ZERO LEAKAGE HIGH FLOW QUICK DISCONNECTS WHICH ACCOMMODATE DEAD HEAD FLOW PATH THERMAL EXPANSION
- MECHANICAL INTERFACE CONTACT HEAT EXCHANGERS

EXPERIMENTS

- SOURCE OF LOW TEMPERATURE COOLING FOR BIOLOGICAL EXPERIMENTS

7.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations resulted from this study:

1. Adding four additional radiator panels to the existing PS reference configuration will provide 25 kW payload heat rejection capability but will violate the current reference concept envelope.
2. A split loop Power System TCS will provide high flexibility and some growth potential at a competitive cost if radiator panel temperatures are limited to 250°F.
3. A radiator on the MEC vehicle will meet the requirements at a competitive cost but results in a higher total weight to orbit after one MEC launch.
4. The split loop arrangement appears favorable and should be considered to meet MEC and similar heat rejection requirements for payloads.
5. Low temperature cooling is best provided by a separate low temperature heat exchanger if the low temperature fluid is avaiable. More study is recommended to define the best method if the low temperature fluid is not available.
6. FC 72 fluid is recommended for the high temperature MEC loop. FC75 is an alternative.
7. Payload thermal interfaces can be integrated into either candidate MEC vehicle configuration with contact or fluid/fluid compact heat exchangers. Both will require technology development items.

8.0 REFERENCES

1. Materials Experiment Carrier Payloads Heat Collection and Rejection Subsystem Concept Definition Study, Vought Report No. 2-53020/OR-52462, 15 June 1980.
2. "Study of Thermal Control Systems for Orbiting Power Systems", Final Briefing, 15 May 1980. (Contract NAS8-33560)
3. Materials Experiment Carrier Concepts Definition Study Final Report Volumes 1 - 5, Contract NAS8-33688, TRW Report Nos. MPS.6-80-285 through MPS.6-80-289, October 1980.
4. Alternate Fluid Trade Studies for the Orbiter Active Thermal Control Subsystem, Vought DIR 2-30320/ODIR-02, March 1980.