

N72-11535

Code G3

Category 22

Pages 261

NASA CR-72945

SNAP-8

POWER CONVERSION

SYSTEM

CONCEPTUAL DESIGN

REVIEW

CASE FILE COPY

AEROJET REPORT NO. 4017

JUNE 1970

Power Systems Operations
AEROJET NUCLEAR SYSTEMS COMPANY
Azusa, California

This document contains the conceptual design review material of the SNAP-8 Power Conversion System. This material was prepared by the Power Systems Operation of the Aerojet Nuclear Systems Company under NASA Contract NAS 3-13458.

The conceptual design and supporting analysis indicate that no significant change in scope or technical emphasis is required to meet the goal of delivering a PCS for combined systems test in the Plumbrook facility.

Approval of the Design Review Board to proceed to detail design is requested.

PCS CONCEPTUAL DESIGN REVIEW

AGENDA

I. INTRODUCTION

A. EVOLUTION OF PCS CONFIGURATION

1. Conical PCS with Reactor Shadow Shield
2. Conical PCS with 4W Shield
3. Rectangular Parallelopiped PCS with 4W Shield

B. CURRENT PCS CONCEPT

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2. Redundancy Aspects
3. Maintenance Aspects
4. Structure and Piping Approach

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3. Operating Environment
4. Components

II. REVIEW OF CST/PCS DESIGN

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1. Component Arrangement
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3. Electrical Subassembly Description
4. Interface Locations
5. Component List

PCS CONCEPTUAL DESIGN REVIEW

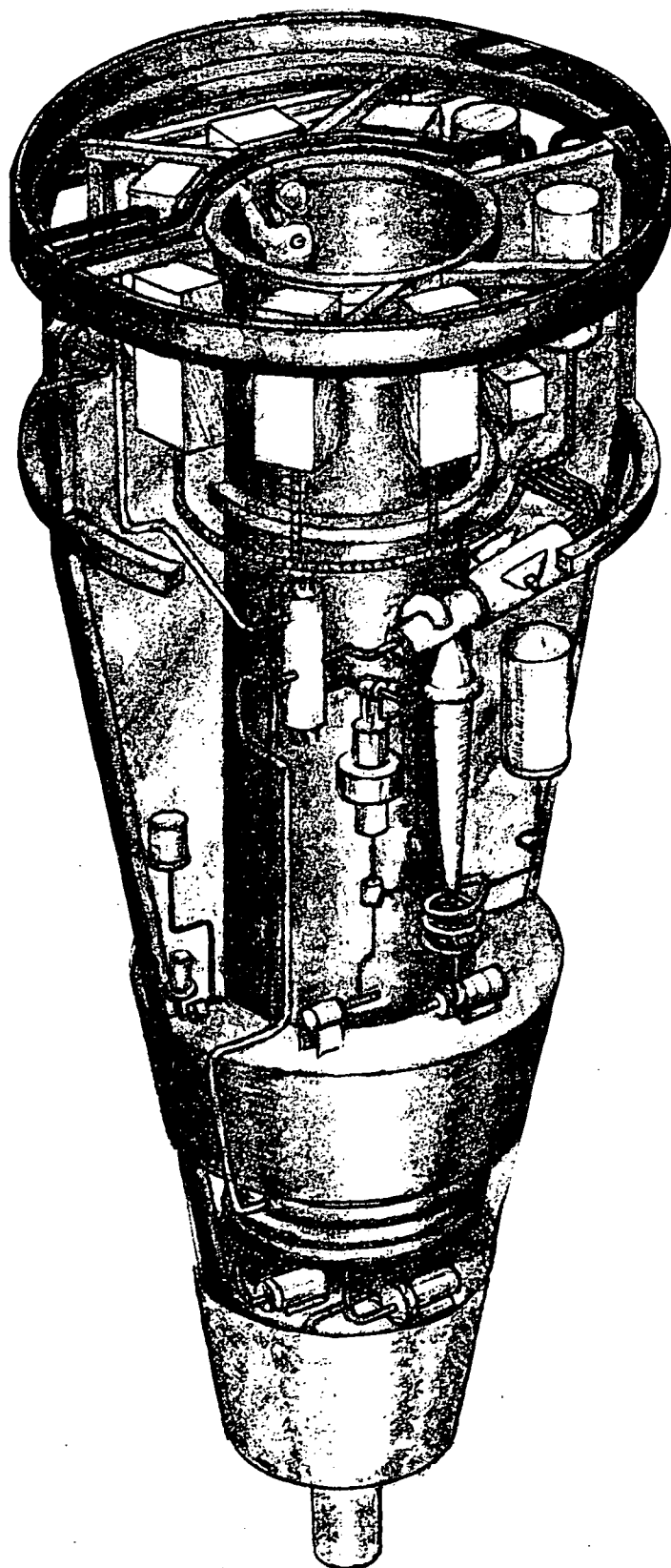
I. INTRODUCTION

The SNAP-8 Electrical Generating System configuration has evolved from a shadow-shielded reactor with conical PCS to a 4-pi shielded reactor with a rectangular parallelopiped PCS. This report will discuss the conceptual design of the current concept. Figures IA1 to IA4 in this section present illustrations of the various EGS concepts which have been considered. Figures IB1 and IB2 portray the current concept with "straight" and "s-shaped" boilers. Either configuration is compatible with the PCS concept being presented. The final boiler configuration will be selected during the post-conceptual design review phase.

Figures IB1 and IB2 in this section show the fully redundant Power Conversion System concept with the boiler concepts currently under consideration. The overall envelope is a rectangular parallelopiped. Although all PCS components are shown, the Combined System Test PCS will include only one set of PCS subsystems. The concept shown is designed primarily for accessibility for component maintenance. Mechanical components can be replaced through the front face of the PCS, and electrical modules would be serviced from the top of the unit. The PCS mates with the facility at the lower plane of the PCS, although it is designed for lifting from the top plane for handling purposes without the RPL, radiator, and shield.

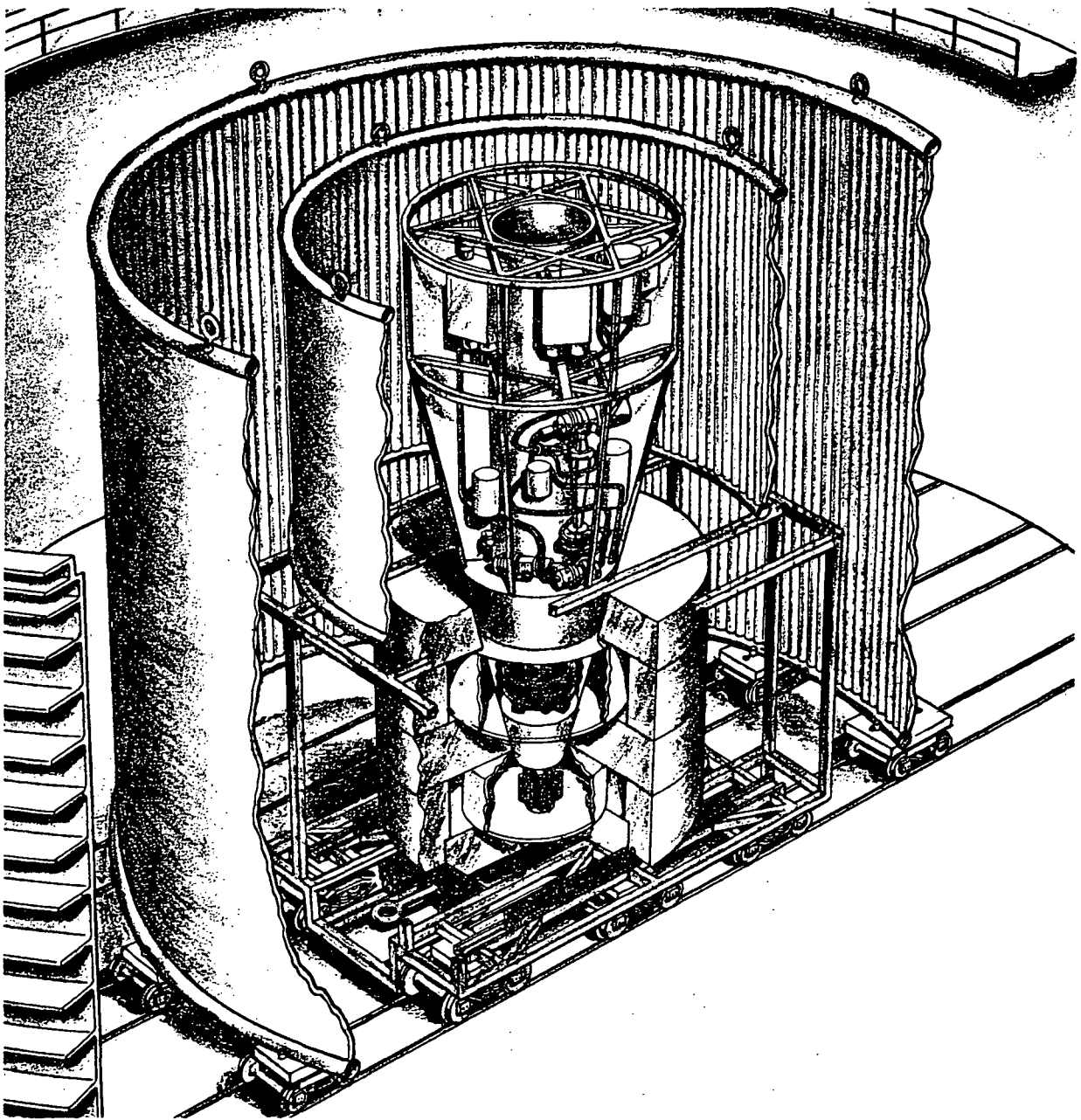
The PCS structure is a basic truss configuration which enhances the maintainability of the system and provides the structure and components with a view of the cold sink. The piping configuration accommodates thermal growth of the interconnecting piping between components without use of bellows.

The design ground rules, which form the basis for this PCS concept, are presented in Figure IC1.



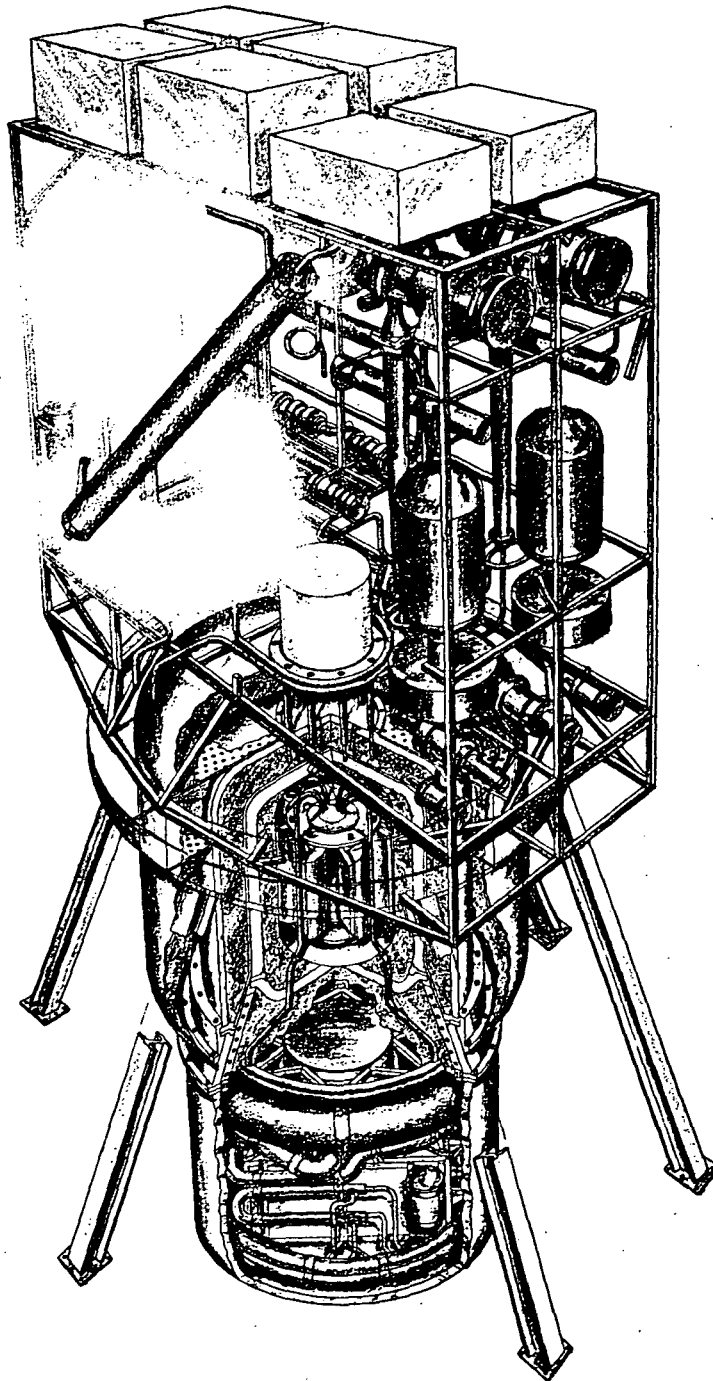
SNAP-8 POWER CONVERSION SYSTEM WITH SHADOW SHIELDED REACTOR

photo # 670-006 Black & white
CN 670-001 Color



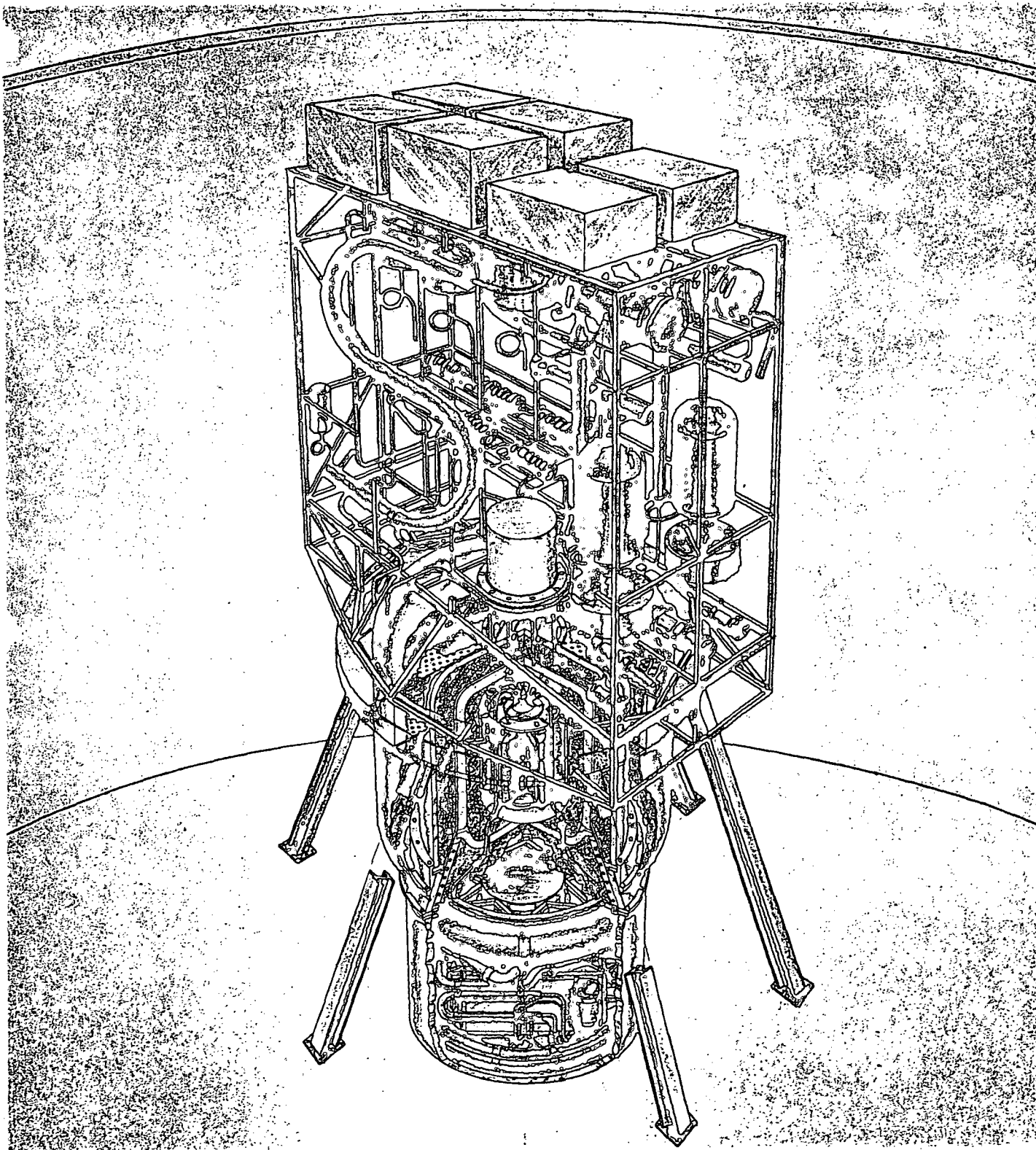
SNAP-8 COMBINED SYSTEM TEST-NASA PLUMBROOK SPF
PCS WITH BOILERS IN THE REACTOR COOLANT LOOP

photo # 670-007 black & white
CNC70-002 Color



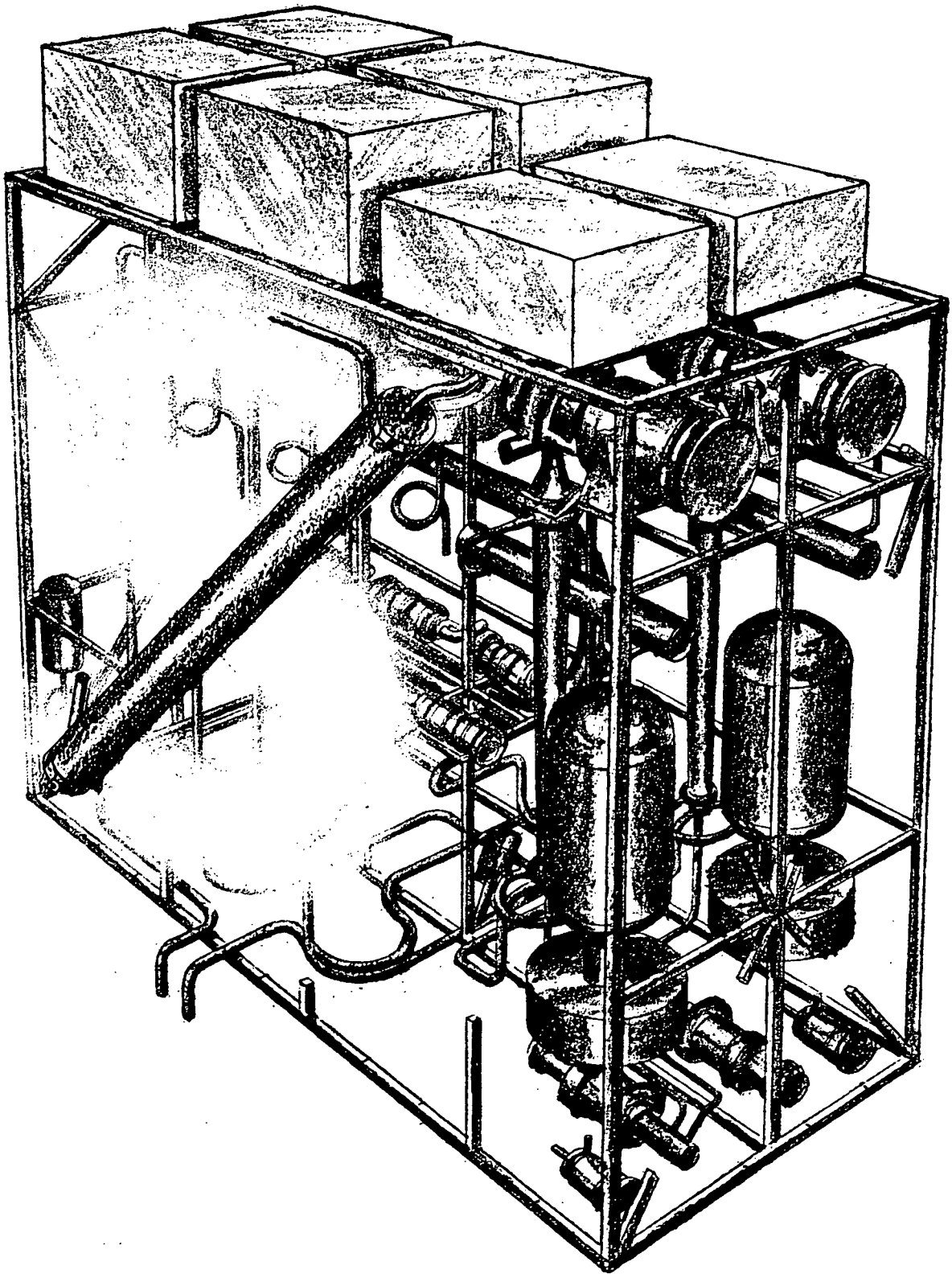
SNAP-8 POWER CONVERSION SYSTEM AND NUCLEAR SYSTEM

photo # 670-010



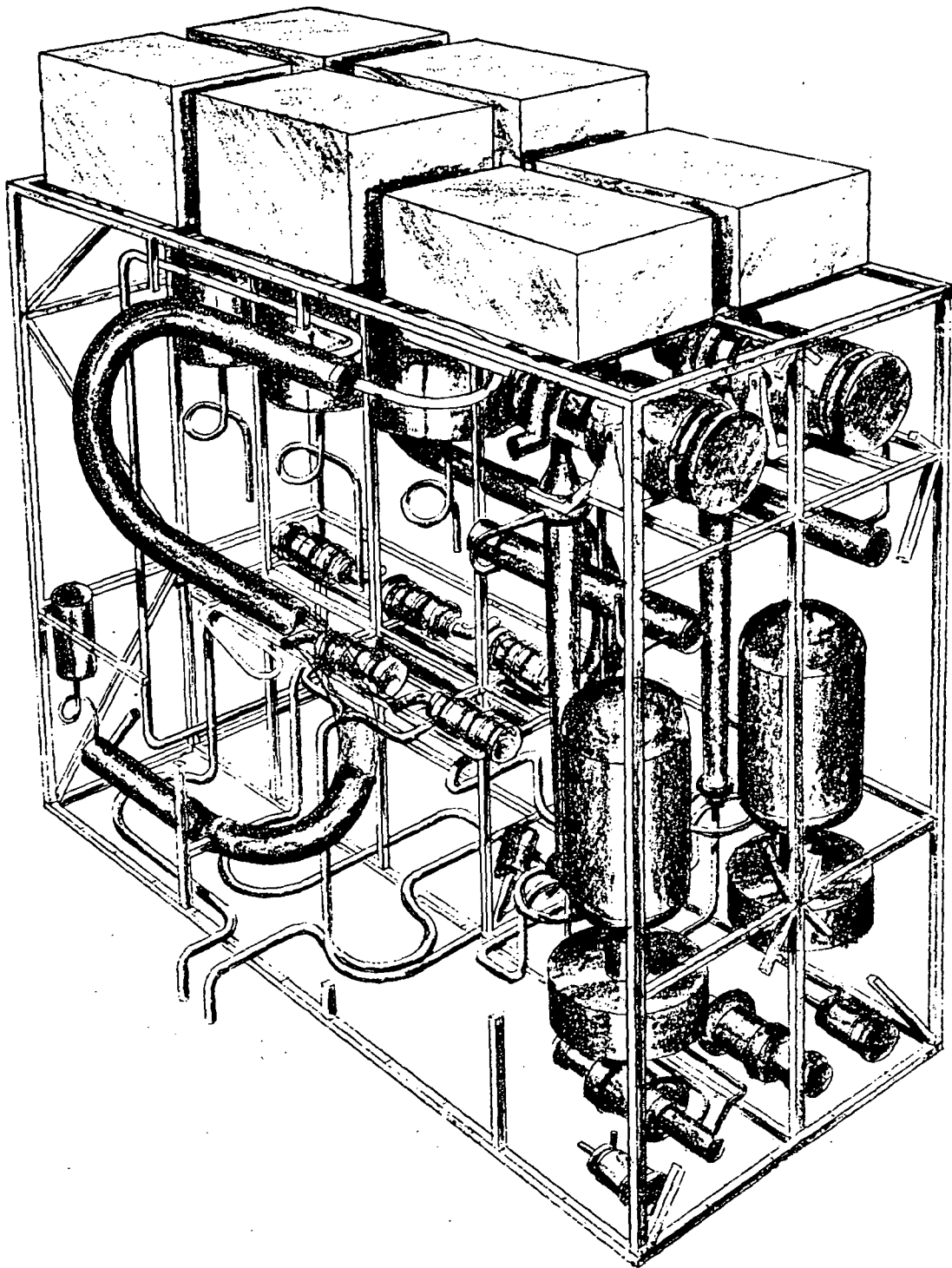
SNAP-8 POWER CONVERSION SYSTEM AND NUCLEAR SYSTEM

FIGURE 1A-4 photo # CN 670-003



SNAP-8 POWER CONVERSION SYSTEM

photo # 670-009



SNAP-8 POWER CONVERSION SYSTEM

photo # CN-670-04

PCS DESIGN CRITERIA

● PERFORMANCE

- POWER DELIVERED TO VEHICLE LOAD - 50 KWE, MIN.
- BOILER NaK INLET TEMPERATURE - 1200°F NOMINAL
- OPERATING LIFE - 5 YEARS

● CONFIGURATION

- ENVELOPE TARGET DIMENSIONS: 4 FEET X 12 FEET X 10 FEET (HEIGHT)
- MAINTENANCE ACCESS: TOP PLANE AND FRONT FACE

● ENVIRONMENT

- THERMAL: L/C RADIATOR WITH POTENTIAL FOR HRL RADIATOR
- LOADING: OPERATING SYSTEM: 1-G VERTICAL
NON-OPERATING: 2-G VERTICAL
1-G LATERAL

- RADIATION: 5-YEAR INTEGRATED DOSE
FAST NEUTRONS GAMMA
(ENERGY 0.1 MEV)

NON-SOLID STATE ELECTRONICS	5×10^{12} nvt	5×10^7 rads (c)
SOLID STATE ELECTRONICS	1×10^{11} nvt	1×10^6 rads (c)

- COMPONENTS: USE EXISTING DESIGNS WHEREVER PRACTICABLE.

EGS FLOW SCHEMATIC AND STATE-POINT

The hydraulic schematic shown in Figure IIA1 was developed during the past 7-8 months to factor the following major changes into the SNAP-8 concept:

- o Inclusion of the intermediate heat exchanger
- o Removal of the boilers from within the biological shield
- o Inclusion of EM Pumps in the Primary Loop

The state-point described in Figure IIA1-1 reflects the following changes in SNAP-8 requirements:

- o Increased net electrical output of 50 Kwe (minimum)
- o Reactor outlet temperature (nominal) reduced to 1220°F
- o Reduced turbine back-pressure to 8 psia

This new state-point required that the boiler, turbine, and mercury pump motor assembly designs be modified.

Figure IIA1-2 describes the reference low-pressure-injection start system which was designed for the boilers-in-the-galley SNAP-8 concept. A qualitative assessment of the modified SNAP-8 indicates that the reference startup concept will be compatible. This position will be confirmed by analysis to be performed by NASA

SNAP-8 EGS FLOW SCHEMATIC

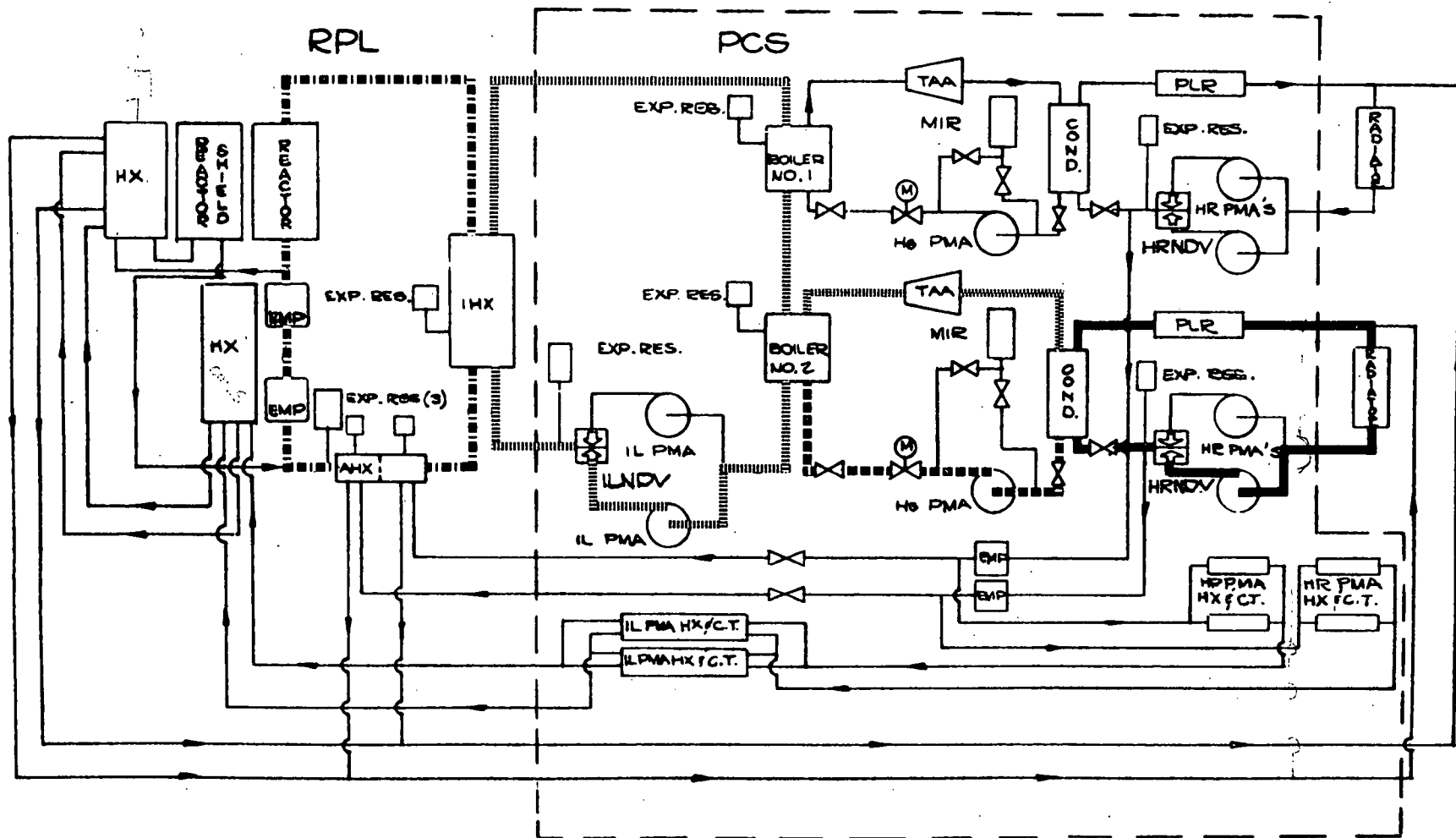


FIGURE IIA-1 (I)



DATE 4/21/70

ENGINEERING FILE NO. _____

W.O. 1475-01-0121

EDF SERIAL NO. _____

SA 0042

SNAP-8

ENGINEERING DESIGN FILE

SUBJECT:

PCS-G STATE POINT CONDITIONS - Revision date 4/21/70

ABSTRACT:

1. As a result of the meeting with NASA on 4/15/70, system and component changes were agreed to which affect the PCS-G state point conditions. Therefore, the state point conditions of 3/3/70 (Ref. SA 0030) are superseded by information presented herein and on the accompanying diagrams, SA 0042/F1 & F2.
2. The following items represent the latest information:
 - Turbine: 65% efficiency.
 - Boiler: double contained, multiple tube with swirl wire.
 ΔP - 35 psi with $\Delta T_{pp} = 35^{\circ}F$ at design condition
 - Reactor Power: assume 600 KWT available to intermediate loop and no heat losses from reactor loop.
 - Condenser: assume condenser will operate satisfactorily with NaK inlet temperature, approx. $415^{\circ}F$ (mercury side will be operating at choked conditions).
3. State-point conditions have been defined, using the information in Paragraph 2, for the system design condition (at reactor lower deadband temperature, see Fig.#1) and for an off-design condition (at reactor upper deadband temperature, see Fig.#2). All significant system temperature, pressure, flow and power values have been entered on the appropriate state-point diagrams.
4. It should be noted that condenser operating conditions have been estimated by preliminary evaluation of recent condenser mapping tests conducted with PCS-1. The condenser conditions will be updated after a complete evaluation of the test data. It is expected that only minor changes in condenser temperature and NaK flow conditions will result.
5. The results of the latest state-point iteration show that the lowest net electrical power (52.3 KWe) occurs at the reactor upper deadband condition, but the system must be designed for the lower reactor deadband temperature condition when the net electrical power is 53.2 KWe.

DISTRIBUTION:

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KEY WORDS:

PCS-G, State-Point, Design Conditions

AUTHOR R.G. Geimer	DATE 4/21/70	REVIEWED	DATE	APPROVED <i>RUMJ</i>	DATE 4/23/70
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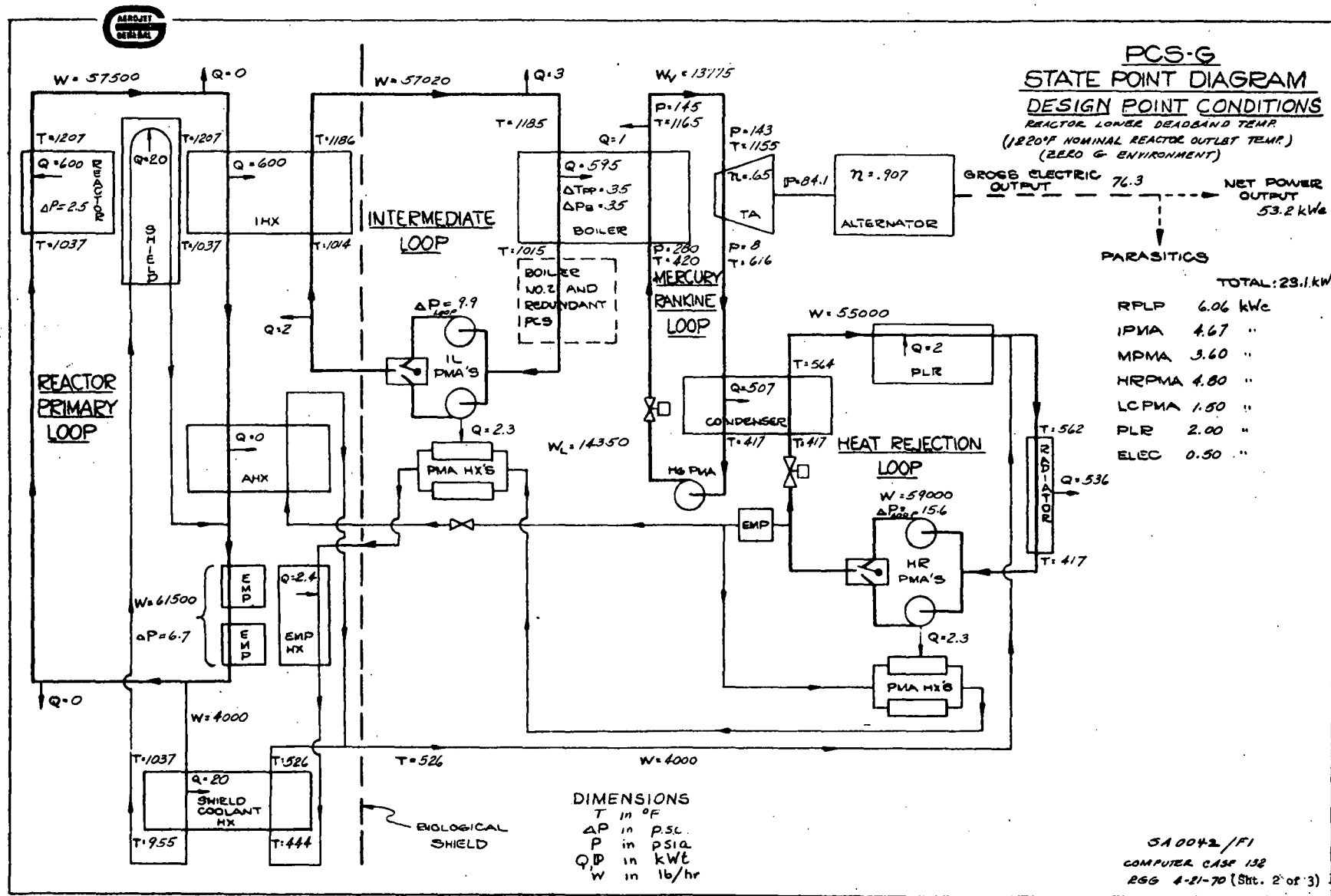


FIGURE IIA-1 (2)

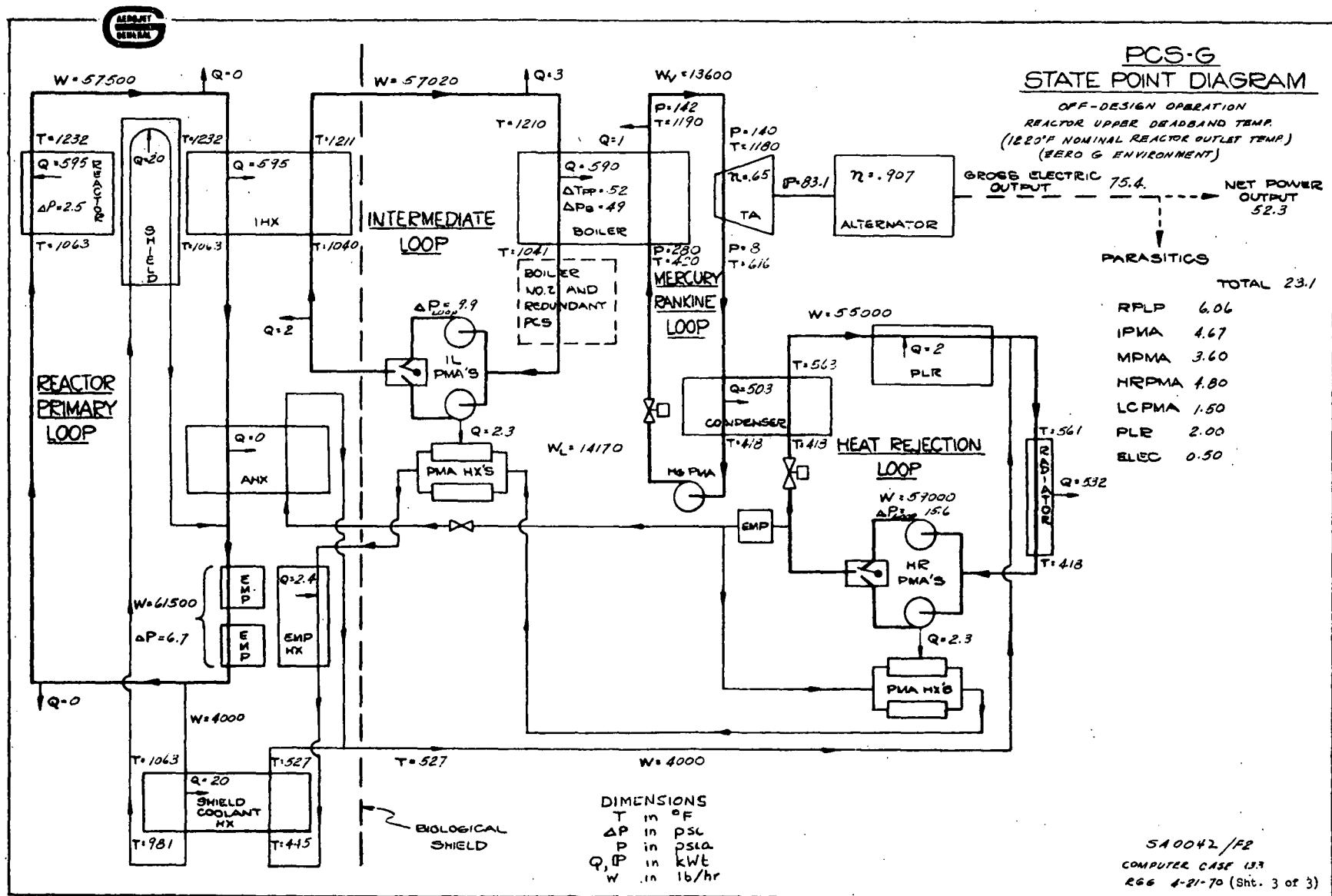


FIGURE IIA-1 (3)

INTEROFFICE MEMO



AEROJET-GENERAL CORPORATION

TO: J. Coff

DATE 7 October 1969
4942-69-0080:RGg:bjc

FROM: R. G. Geimer/L. R. Favero

SUBJECT: PCS-G Restart Component Requirements - Part I Specification

COPIES TO: B. L. Amstadter, W. F. Banks, S. L. Bradley, B. Breindel, E. G. Brittain,
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Enclosure: (1) PCS-G Restart System Schematic
(2) Mercury Injection Reservoir and Actuating System
(3) Restart System Valve Requirements
(4) Heat Rejection Loop Flow Control Valve Requirements
(5) Programmer Requirements

This memorandum transmits the latest revisions to the component requirements for the restart system and the startup and shutdown sequences derived from analysis and test results.

The requirements are based on a low pressure mercury injection system which is actuated by the differential pressure generated by the LC PMA. The requirements do not take into account the effects of recently discussed system changes related to incorporation of a cold wall circuit in the primary loop to provide for external reactor cooling.

It is requested that Part I component specifications be prepared or revised and that the system specification AGC-10512 be revised to reflect the overall system requirements included in the enclosures.

The cognizant Task Managers are requested to review the enclosed material and coordinate comments and requests for revisions with the undersigned.

Approved:

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Fig. II A 1-2 a

Mercury Injection Reservoir and Actuating System

A. General Purpose and Operation

1. The restart system for PCS-G requires the use of a reservoir which acts to store, supply, and receive mercury during repeated operating cycles of startup and shutdown.

2. Pressure for injecting mercury into the loop, upstream of the Hg PMA, will be supplied by an actuating system. The actuating system consists of a hydraulic piston which operates from the differential pressure generated by the LCPMA. The direction of movement of the actuator piston and, therefore, the mercury reservoir diaphragm is controlled by the mercury reservoir actuator valve (MRV). The mercury injection pressure is determined by the ratio of the reservoir diaphragm area to the hydraulic piston area. The mercury reservoir and actuating system is shown schematically in Figure 2-1.

3. A diaphragm position sensor in the mercury reservoir will be used to indicate when the proper amount of mercury has been injected into the loop.

4. During normal shutdown the majority of the mercury loop inventory will be pumped back into the mercury reservoir by the Hg PMA through the mercury reservoir recharge valve (MRRV). As a final step the remainder of the loop inventory will be returned to the mercury reservoir by actuating the mercury reservoir actuator valve to the "dump" position thereby driving the mercury reservoir diaphragm to the maximum volume position and providing a low pressure sink. The remaining loop inventory will return to the reservoir through the mercury injection valve.

5. During emergency shutdown, the mercury loop inventory will be returned to the mercury reservoir by actuating the mercury reservoir actuator valve to the "dump" position thereby making the reservoir a low pressure sink. The loop inventory will return to the reservoir through the mercury injection valve.

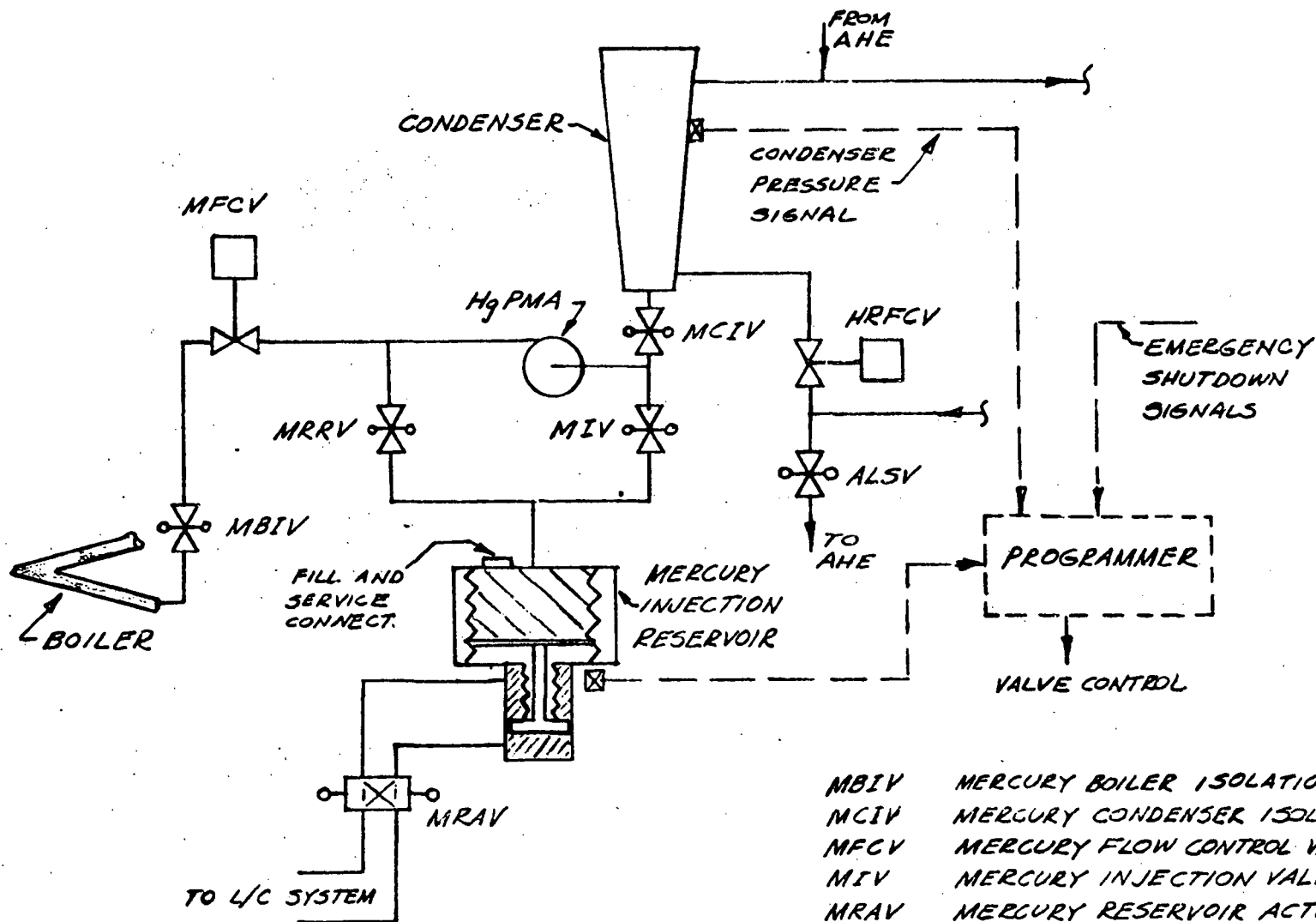
B. Design and Operational Requirements

1. Mercury Injection Reservoir (MIR)

a. The reservoir shall be designed to contain mercury at temperatures in the range of 50 F to 600 F and sized to expel 320 pounds of liquid at a temperature of 50 F.

b. The reservoir shall be designed to withstand internal pressures up to 75 psia.

c. The design shall be such that intermixing of the actuating fluid and the mercury which will be expelled into the system can occur only if a double failure of the containment vessel occurs.



MBIV MERCURY BOILER ISOLATION VALVE
 MCIV MERCURY CONDENSER ISOLATION VALVE
 MFCV MERCURY FLOW CONTROL VALVE
 MIV MERCURY INJECTION VALVE
 MRV MERCURY RESERVOIR ACTUATOR VALVE
 MRRV MERCURY RESERVOIR RECHARGE VALVE
 ALSV AUXILIARY LOOP SHUTOFF VALVE
 HRFCV HEAT REJECTION LOOP FLOW CONTROL VALVE

PCS-G RESTART SYSTEM SCHEMATIC

ENCLOSURE (1)

ENCLOSURE (1)

FIG. II A 1-2 c

d. The reservoir shall contain a diaphragm position sensor for determining the quantity of mercury expelled from the reservoir during any injection cycle. The position sensor shall provide an electrical signal proportional to the position of the diaphragm from the zero to full inventory positions.

e. Assuming the mercury reservoir is designed in a cylindrical shape, the height of the cylinder should be minimized so as to reduce the effect of mercury elevation head, differences on the reservoir outlet pressure. However, the height of the reservoir must be consistent with the requirement to measure the amount of inventory injected to within ± 3 pounds.

f. The mercury reservoir port shall be furnished with a weld stub for butt type welding to 1.0" x .049 wall CRES 316 SS tubing. A fill and servicing port shall also be provided which shall be compatible with TSE requirements (to be determined) and shall not incorporate any valves permanently attached to the reservoir.

2. Mercury Reservoir Actuator

a. The mercury reservoir actuator shall consist of bellows-sealed chambers filled with lubricant/coolant fluid (Mix 4P3E) and separated by a piston. The chambers shall be designed to withstand fluid pressures up to 100 psia with fluid temperatures from 50 F to 250 F.

b. The actuator will develop a force by a differential pressure of 70 psi (produced by the LC PMA) acting across the actuator piston.

c. The actuator must be of a flexible design to permit use in applications where the gravity field may be within the range of 0 "g" to 1.5 "g". The gravity field will be constant for any specific application. The flexibility requirement is reflected in the need to generate pressures at the mercury reservoir outlet of from 13.0 psia when in a 0 "g" application to 38.4 psia when in a 1.5 "g" application. The flexibility may be achieved by means such as utilizing actuator pistons of different diameters with mating sleeves to match a fixed housing diameter. The housing size should be based on the requirement that a 70 psi actuator differential pressure will produce 38.4 psia at the mercury reservoir outlet

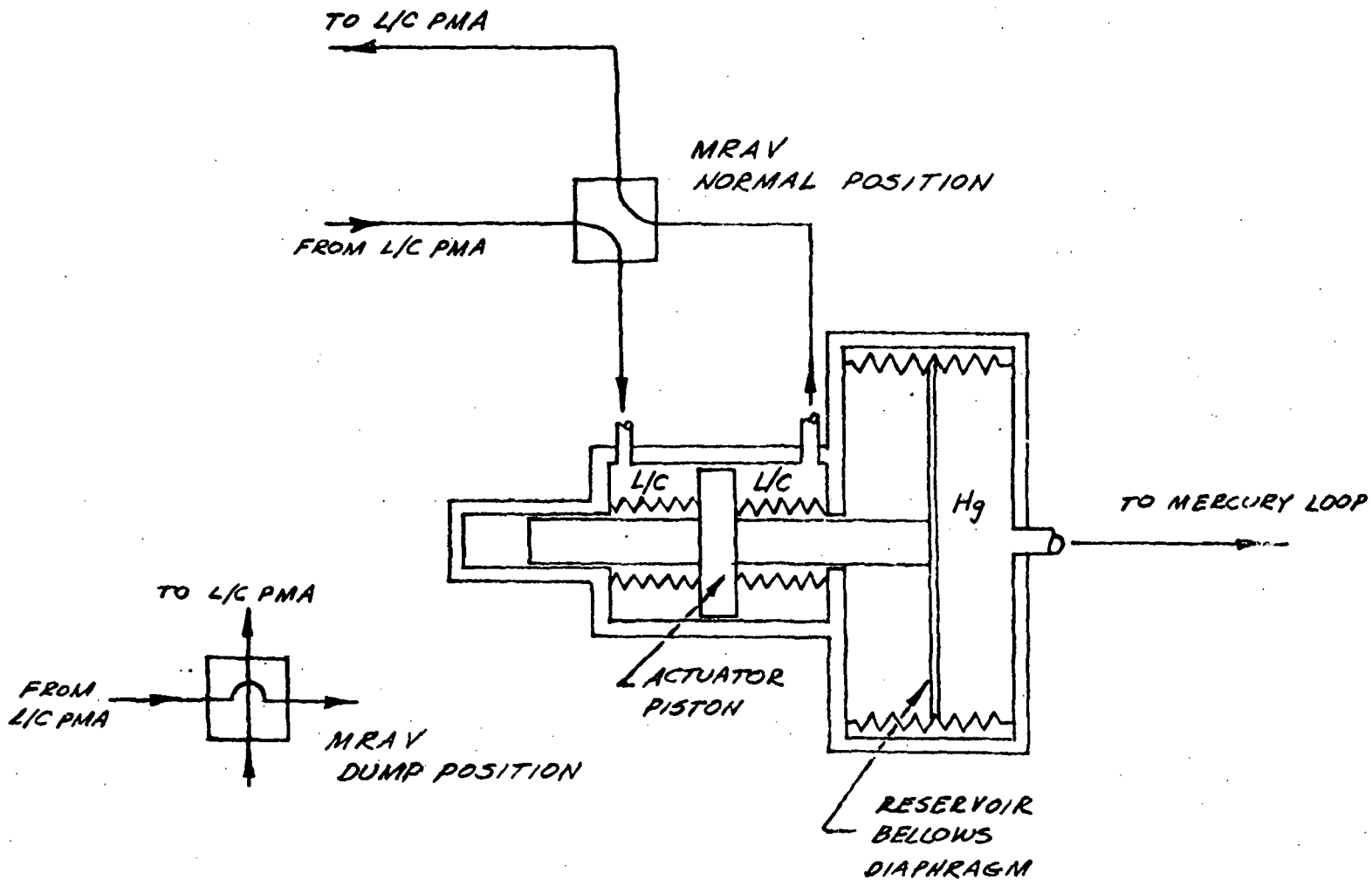
d. The initial actuator design shall be for a 1 "g" application thereby requiring a mercury reservoir outlet pressure of 29.9 psia.

e. Leakage of fluid (Mix 4P3E) across the actuator piston with a differential pressure of 70 psi shall be kept to a minimum.

f. The fluid ports in the two actuator chambers shall be furnished with weld stubs for butt type welding to 1/2" x .035 wall CRES 316 SS tubing.

B. Mercury Reservoir Actuator Valve (MRAV)

1. The valve required to direct fluid to the mercury reservoir actuator shall be a four-way, two-position, solenoid operating latching valve using 28 vdc power.
2. The valve shall be designed to operate with lubricant/coolant fluid (Mix 4P3E) at pressures up to 100 psi; with fluid temperatures from 50 F to 250 F.
3. The valve ports shall be provided with weld stubs for butt type welding to 1/2" x .049 wall CRES 316 SS tubing.
4. Flow passages within the valve shall have cross-sectional areas equivalent to 1/2" x .049 wall tubing.
5. Leakage between flow passages within the valve shall be kept to a minimum when operating with differential pressures up to 70 psi.



MERCURY RESERVOIR & ACTUATING SYSTEM SCHEMATIC

RESTART SYSTEM VALVE REQUIREMENTS

The PCS-G restart system requires the use of eight valves during various phases of startup and shutdown. The valves are required with mercury, eutectic NaK or Mix 4P3E as the service fluid. The specific requirements for each valve are identified in the following paragraphs.

A. Mercury Flow Control Valve (MFCV)

The requirements for the mercury flow control valve are contained in Specification AGC-10627, "Valve, Motor Driven, Flow-Control, Mercury, 600°F", with the following exceptions:

1. The valve can be considered to have three operating regions as defined in Figure 3-A. Each of these operating regions is utilized when the valve is operated to open and when it is operated to close.
2. The first operating region, region A as shown in Figure 3-A, provides for opening the valve to an initial flow setting of 360 lb/hr (approximately 3% rated flow). The valve must be capable of stopping at this position during either the opening or closing cycle and providing the required flow rate to within $\pm 5\%$. The voltage required to move the valve to this position from the full closed position may be any constant value up to 28 vdc.
3. The second operating region, region B as shown in Figure 3-A, provides for increasing the flow rate to an intermediate value of 6600 lb/hr in a rapid linear function. The valve must be capable of stopping at this position during either the opening or closing cycle and providing the required flow rate to within $\pm 2\%$. The time required to make the flow change during region B operation must be variable between 30 and 100 seconds. The voltage required to move the valve during this period and over the time range specified may be any constant value up to 28 vdc.
4. The third operating region, region C as shown in Figure 3-A, provides for increasing the flow rate to a maximum value of 13,500 lb/hr in a slow linear function. The valve must be capable of providing the required flow rate at the full open position to within $\pm 3\%$. The time required to make the flow change during region C operation must be variable between 500 and 1200 seconds. The voltage required to move the valve during this period and over the time range specified may be any constant value up to 28 vdc.
5. The orifice characteristics for the mercury flow control valve will be modified in the future. The characteristics as specified on Figure 1 in AGC-10627 are to be used as a guide only for general trends.

B. Mercury Boiler Isolation Valve (MBIV)

The requirements for the mercury boiler isolation valve can be obtained from Specification AGC-10638, "Valve, Shut-Off, 28 vdc, Two Position" with exceptions. Most of the valve requirements are met by the valve specified as AGC-10638-124. The significant exception is that although the normal service fluid temperature is 500°F, the environmental temperature will normally be 1300°F. The environmental temperature can exist with and without fluid flowing through the valve throughout the operating life.

C. Mercury Condenser Isolation Valve (MCIV)

The requirements for the mercury condenser isolation valve can be obtained from Specification AGC-10638, "Valve, Shut-Off, 28 vdc, Two Position". The valve requirements are met by the valve specified as AGC-10638-222.

D. Mercury Injection Valve (MIV)

The requirements for the mercury injection valve can be obtained from Specification 10638, "Valve, Shut-Off, 28 vdc, Two Position". The valve requirements are met by the valve specified as AGC-10638-222.

E. Mercury Reservoir Recharge Valve (MRRV)

The requirements for the mercury reservoir recharge valve can be obtained from Specification AGC-10638, "Valve, Shut-Off, 28 vdc, Two Position". The valve requirements are met by the valve specified as AGC-10638-124.

F. Mercury Reservoir Actuator Valve (MRAV)

The requirements for the mercury reservoir actuator valve are contained in Enclosure (2) of this memorandum.

G. Auxiliary Loop Shut-Off Valve (ALSV)

The requirements for the auxiliary loop shut-off valve can be obtained from Specification AGC-10638, "Valve, Shut-Off, 28 vdc, Two Position". The valve requirements are met by the valve specified as AGC-10638-233.

H. Heat Rejection Loop Flow Control Valve (HRFCV)

The requirements for the heat rejection loop flow control valve are contained in Enclosure (4) of this memorandum.

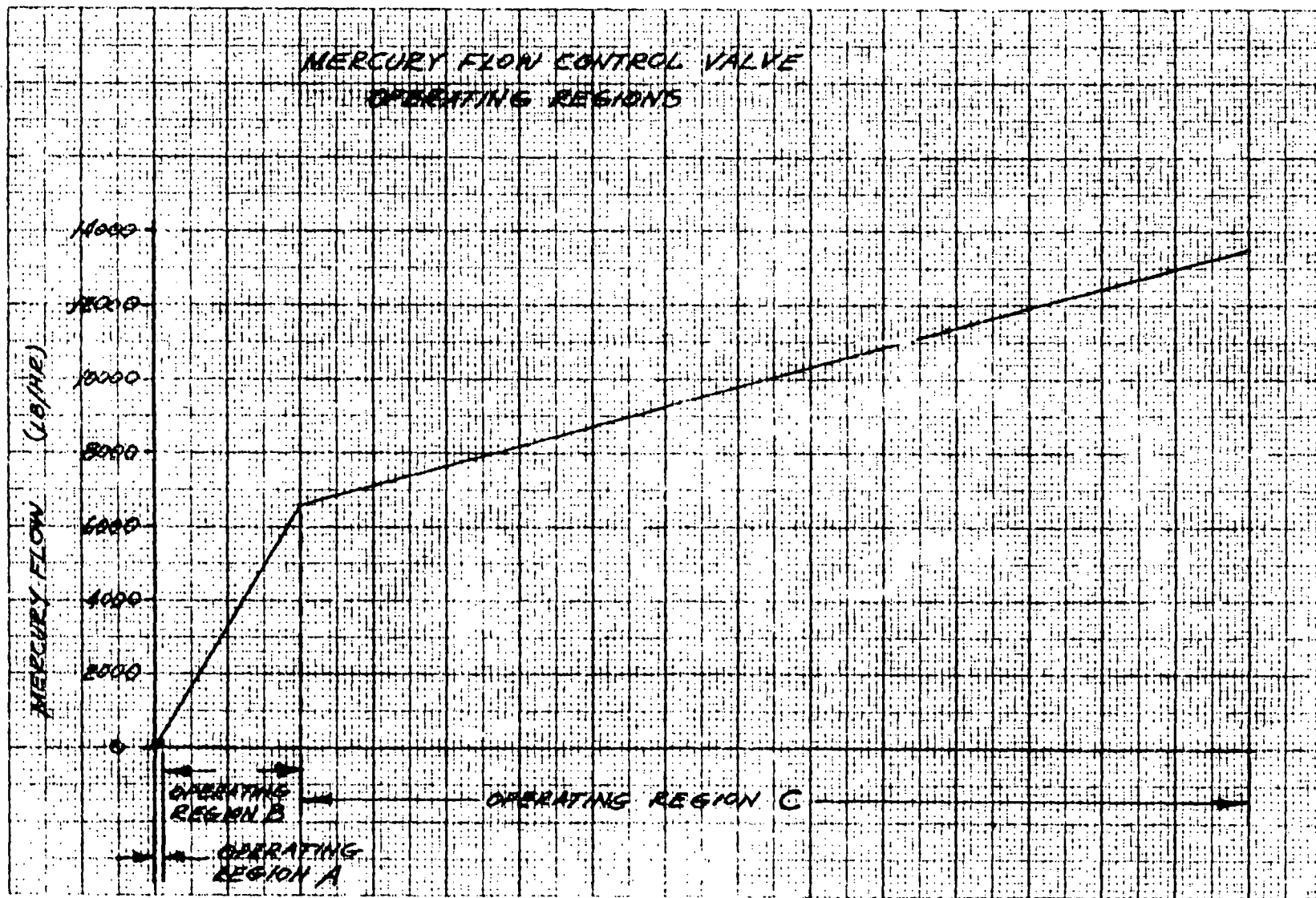


FIGURE II A 1-21

ENCLOSURE (3)
FIGURE 3-A

Heat Rejection Loop Flow Control Valve (HRFCV) Requirements

A. General Purpose and Operation

1. The restart system for PCS-G requires the use of a flow control valve for the heat rejection loop flow through the condenser. The initial and final positions and movement of the valve will be controlled by electrical signals from the PCS-G programmer.
2. Prior to mercury injection, the HRFCV will be signalled to move from the fully closed position to an initial flow position which will provide for a minimum initial flow through the condenser. The valve position will not be changed throughout the reactor startup and mercury injection periods until the condenser pressure reaches a value of 14 psia. After the condenser pressure reaches 14 psia the HRFCV will be signalled to move, at a constant rate, in a direction to increase the flow through the condenser if the condensing pressure exceeds the upper limit (14 psia) of a deadband control range, in a direction to decrease the flow through the condenser if the condensing pressure is below the lower limit value (11 psia) of the deadband control range or to remain stationary if the condenser pressure stays within the upper and lower limit values.
3. After startup has proceeded to the point where rated mercury flow is obtained, the HRFCV will be signalled to move to the fully open position which will establish rated flow in the heat rejection loop.
4. During shutdown, the HRFCV will be signalled to move in a manner so as to maintain condensing pressure within the deadband control range. Electrical signals will be provided by the programmer to move the valve, at a constant rate, in the proper direction. (The valve will tend to be signalled to move in a direction to decrease the flow through the condenser.)
5. After shutdown of the mercury loop the HRFCV will be signalled to move to the fully closed position.

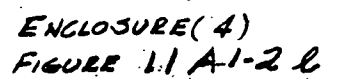
B. Design and Operational Requirements

1. The majority of the requirements for the heat rejection loop flow control valve are contained in Specification AGC-10640, "Valve, Motor Driven, Flow-Control, NaK, 600 F", with the following exceptions:
 - a. The valve will be required to operate over the range of positions from full closed to full open and control the flow over a range from 0 to 40,000 lbs/hr. When in the full closed the leakage across the seat shall not exceed 1000 cc/hr of NaK at 500 F.

b. When signalled to move in either direction, the valve shall be designed to move at a nominal rate corresponding to 0.35% of full travel per second when supplied with dc power at a constant voltage. The rate of movement shall be adjustable so that the valve can be made to move over a range of from 50% slower to twice as fast as the nominal rate. Changing the voltage supplied to the valve may be used as a method for varying the rate of movement of the valve over the range specified.

c. When the valve is in the full open position the pressure drop across the valve shall not exceed 3.0 psi with a NaK flow rate of 40,000 lb/hr.

d. Plots of valve pressure drop, flow rate and effective area as functions of percentage of full travel are presented in Figures 3-H-1 and 3-H-2. These figures supercede Figure 1 of Specification AGC-10640.



WRECV AREA CHARACTERISTICS

METHOD OF COMPUTATION

$$A_c = W / 12.5 P A_r$$

$$C = 10 \text{ WRECV}$$

CORROSION

2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

PERCENT OPEN - %

ENCLOSURE (4)
FIGURE 11 A 1-2m

PROGRAMMER REQUIREMENTS

1. This document specifies the system requirements for the PCS-G programmer. The programmer for the PCS-G is an assemblage of electromechanical devices packaged in a container. The purpose of the programmer is to time and control the various events and sequences associated with the normal startup, normal shutdown, emergency shutdown, and decay heat removal operating modes of the PCS-G. Logic circuitry, timers and associated relays, necessary to produce various signals to perform the events called out in the sequences described later in this document, must operate in conjunction with signals received from various sensors in the PCS, signals from the nuclear system controller and external command signals.
2. The programmer will be activated by remote signals from the facility control console or the astronaut's control console. The signals shall cause the programmer to perform the following major functions:
 - a. Provide a startup signal for the nuclear system controller.
 - b. Startup the PCS.
 - c. Normal shutdown of the PCS.
 - d. Provide a signal to the nuclear system controller for normal shutdown.
 - e. Emergency shutdown of the PCS.
 - f. Provide a signal to the nuclear system controller for emergency shutdown.
 - g. Trim (or adjust) mercury inventory.

Signals to the programmer are carried through electrical conductors from several sources. Power to the programmer will be unregulated 28 vdc power (nominal) from either a battery or facility power supply.
3. The programmer shall control the operation of the following equipment:
 - a. Provide 28 vdc power (unregulated) to the nuclear system controller.
 - b. Control the inverter frequency at 45 Hz and over the range from 95 Hz to 220 Hz. Control the output voltage of the inverter (high, medium, and low) by controlling a contact actuator which is part of the inverter assembly.
 - c. Control the motor transfer contactors to start the PNPMA, the LCPMA, and the HRLPMA at 45 Hz.

- d. Control the motor transfer contactor such that the primary, HRL, and LC PMA's may be jointly switched from inverter to alternator at a specific alternator frequency (nominally 220 Hz). The frequency sensing circuits shall be part of the programmer.
 - e. Control the position of the MFCV from a full-closed position to a full-open position. The opening of the Hg FCV shall be accomplished in three stages.
 - f. Control the operation of the TAA and Hg PMA bearing prelube sub-system.
 - g. Control the two TAA L/C solenoid valves.
 - h. Control the two Hg PMA L/C solenoid valves.
 - i. Control the mercury injection system valves to open or close.
 - j. Provide the necessary controlled field flashing current for the alternator.
 - k. Provide the necessary initial "off" bias for the saturable reactor.
 - l. Control the actuation of the TAA and Hg PMA lift-off seals.
 - m. Control the vehicle load breaker to be open or closed.
 - n. Control the operation of the HRFCV.
 - o. Control the LCL heaters.
 - p. Control opening of the mercury condenser isolation valve (MCIV) and closing of the mercury injection valve (MIV) upon receipt of signals that:
 - (1) Condensing pressure has reached a minimum value of 3.5 psia.
 - (2) A minimum amount of mercury has been injected into the mercury loop. The amount of mercury injected will be determined by an indication from the mercury injection reservoir (MIR) diaphragm position sensor that the MIR diaphragm has moved a specified distance.
4. The programmer shall accept the following signals while performing required functions:
- a. Frequency signal from TAA.
 - b. Condenser pressure signal (0-5 volt).
 - c. Mercury injection reservoir position signal (0-5 volt).

- d. Signal indicating flow rates in the heat rejection and primary loops.
 - e. Signal indicating TAA output voltage (0-5 volt).
 - f. Relay closure signal from the nuclear system controller indicating that the reactor is in a shutdown mode.
 - g. Relay closure signal from the nuclear system controller indicating that the reactor is operating on long-term control. This signal shall be 28 ± 4 vdc 100 milliamperes for a minimum of 30 milliseconds to a maximum of 30 seconds.
 - h. Alternator output electrical power level signal (0-5 volt).
5. The programmer shall provide signals as follows:
- a. One ampere inductive 28 vdc rated contact closure signal to the nuclear system controller upon failure of the PCS.
 - b. One ampere 28 vdc rated contact closure signal to the nuclear system controller upon receipt of an automatic or manual shutdown signal to the programmer.
6. The programmer shall include all of the necessary timers and logic circuitry to perform the following major functions:
- a. Normal startup - see Appendix A for detailed sequence.
 - b. Normal shutdown - see Appendix B for detailed sequence.
 - c. Emergency shutdown - see Appendix C for detailed sequence.
 - d. Mercury inventory trim - At various times during steady-state system operation the mercury loop inventory will require adjustment (trimming). When inventory adjustment is required an external signal will be supplied to the programmer (e.g., from the astronaut's console). Upon receipt of this signal the programmer shall perform the following functions:
 - (1) Provide a signal to open the mercury injection valve (MTV).
 - (2) Start a 15 minute timer to allow for mercury inventory adjustment and stabilization of system transients.
 - (3) Provide a signal to close the mercury injection valve at the end of the 15 minute time period.

7. The components selected for use in the programmer shall meet the environmental requirements of AGC-10660. The programmer shall be designed for a minimum life of 40,000 hours.

8. The programmer will be provided with coolant (4P3E) at a nominal temperature of 140 F. The flow rate required shall be mutually determined between the designed and systems engineering.

Appendix A

Normal Start Sequence. The PCS-G programmer, when provided with 28 vdc power, shall initiate and control the start sequence upon receipt of an external command signal. The start sequence of events, utilizing the restart system shown in Figure 1 shall be as described below and as shown diagrammatically in Figure A-1. The "T" numbers in the left-hand column refer to the time periods shown in Figure A-1.

- | | |
|------------------|---|
| T-1
(1 hour) | (1) Provide a signal to override the emergency shutdown circuits of Conditions 1, 2, 3, and 5 as listed in paragraph 1 of Appendix C. |
| | (2) Provide a signal to supply power to the LCL heaters to raise the fluid temperature from 50°F to 125°F. |
| T-2
(10 sec.) | (1) Provide a signal to start the inverter with 28 vdc power and maintain a speed corresponding to a frequency of 45 Hz. |
| | (2) Provide a signal to supply power to actuate the HRFCV from the closed position to the initial flow position. |
| | (3) Provide a signal to open the auxiliary loop shut-off valve (ALSV). |
| | (4) Provide a signal to supply power from the inverter high voltage taps to the PNPMA. |
| | (5) A flow indication signal must be received by the programmer before the end of this time period. If no flow signal has been received the programmer shall switch off. |
| T-3
(10 sec.) | (1) Provide a signal to supply power from the inverter high voltage taps to the HRLPMA. |
| T-4
(10 sec.) | (1) Provide a signal to supply power from the inverter high voltage taps to the LC PMA. |
| T-5
(10 sec.) | (1) Provide a signal to change the supply power to the inverter from 28 vdc to 56 vdc. The inverter speed will then increase to a value which corresponds to an output frequency of 95 Hz. The inverter frequency shall be maintained at 95 Hz. |

Appendix A (Cont'd.)

Enclosure (5)
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Page 2

T-6
(4 - 5
hours)

- (1) Provide a signal to transfer the PMA loads from the high voltage to the low voltage taps of the inverter. (The inverter frequency shall remain at 95 Hz.)
- (2) Provide unregulated 28 ± 3 vdc power of 60 to 500 watts to the nuclear system controller for a period of 4 ± 1 , -0 hours. The nuclear system start sequence shall be as specified in AGC-10660 and shall be controlled by the nuclear system controller.
- (3) Provide 28 vdc power to the LCL heaters to raise the LCL fluid temperature from an initial temperature of 125°F to $200^{\circ}\text{F} + 10^{\circ}$, -0 within one hour. The source of power to the heaters shall be external to the programmer.
- (4) When the temperature of the NaK in the hot leg of the PNL is $1288 - 1330^{\circ}\text{F}$, the nuclear system controller will switch to the long-term temperature control mode and send a signal to the PCS-G programmer.

T-7
(10 min.)

- (1) Start a 10 minute timer to allow for stabilization of the PNL temperatures.
- (2) Provide a signal to remove the 28 vdc power from the LCL heaters.
- (3) Cycle the lift-off seals. Unseat then seat.

T-8
(5 min.)

- (1) Provide a signal to transfer the PMA electrical loads to the medium voltage taps of the inverter.
- (2) Provide a signal to increase the inverter speed and frequency. The inverter speed shall be increased to produce a frequency of 220 Hz; the frequency shall not increase at a rate faster than 2.0 Hz/sec.
- (3) Start a 5 minute timer to allow for attainment of 220 Hz inverter frequency.
- (4) Provide a signal to actuate the mercury flow control valve (MFCV) to a position corresponding to a flow of approximately 3% of rated.

T-9
(5 min.)

- (1) Start a 5 minute timer to allow for stabilization of PNL temperature transients resulting from the pump speed and flow change.
- (2) Provide a signal to supply power from the inverter to the Hg PMA.
- (3) Provide a signal to open the mercury injection valve (MIV) to permit mercury to flow from the mercury reservoir and fill the lines between the boiler isolation valve and the condenser isolation valve.

Appendix A (Cont'd.)

- T-10
(15 sec.
minimum)
- (1) Provide a signal to open the mercury boiler isolation valve (MBIV).
 - (2) Start a * second timer to permit filling of the boiler inlet manifold.
 - (3) Sense mercury reservoir bellows position to obtain reference location.
 - (4) Provide a signal to open the VLB.
- T-11
(30 sec.
minimum)
- (1) Provide a signal to open the MFCV to a position equivalent to a flow rate of 6600 lb/hr at a nominal rate of 210 lb/hr/sec.
 - (2) Provide a signal to initiate alternator field flashing.
 - (3) Provide a signal to turn on saturable reactor bias.
 - (4) Provide a signal to transfer the PMA electrical loads to the alternator at an alternator frequency of 220 Hz.
 - (5) Provide a signal to open valves SV-5 and SV-6 at the TAA and provide a signal to unseat the lift-off seals. The TAA speed shall be 8000 ± 150 rpm.
 - (6) Provide a signal to open valves SV-3 and SV-4 at the Hg PMA and provide a signal to unseat the lift-off seals. The TAA speed shall be 8000 ± 150 rpm.
 - (7) Provide a signal to turn off the saturable reactor bias. The TAA frequency shall be 385 ± 4 Hz.
- T-12
(10 - 15
min.)
- (1) Start a 10 to 15 minute timer to permit stabilization of system transients.
 - (2) Provide a signal to stop the opening motion of the MFCV. The MFCV will be in a position to provide a flow rate of 6600 lb/hr with the TAA at rated speed.
 - (3) Provide signals to close the MBIV and open the mercury condenser isolation valve when the mercury reservoir bellows position sensor indicates a displacement equivalent to the injection of 70 lbs of mercury and the condenser pressure sensor indicates a pressure of 3.5 psia has been obtained or exceeded.
 - (4) Provide power to the HRFCV upon signal from the condensing pressure sensor that a condensing pressure of 14 psia has been reached.

Fig. IIA 1-2t

Appendix A (Cont'd.)

Enclosure (5)
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Page 4

- T-13
(10 - 15
min.)
- (1) Start a 10 to 15 minute timer to permit increasing the mercury flow to rated.
 - (2) Provide a signal to turn off the alternator field flashing current.
 - (3) Provide a signal to turn off the inverter power.
 - (4) Provide a signal to transfer the nuclear system electrical load to the alternator.
 - (5) Provide a signal to close the auxiliary loop shut-off valve.
 - (6) Provide a signal to resume opening of the MFCV at a nominal rate of 6.33 lb/hr/sec. Note: A change in voltage supplied to the MFCV may also be required at this time.
 - (7) Provide a signal to open the MIV if the HRFCV reaches the position equivalent to rated flow in the heat rejection loop. Power supplied to the HRFCV shall be removed when the HRFCV reaches the position equivalent to rated flow.
 - (8) Provide a signal to open the MIV in the event the condenser pressure exceeds 17 psia and a signal to close it when the pressure reduces to 14 psia.
- T-14
(10 - 15
min.)
- (1) Start a 10 to 15 minute timer to permit mercury inventory trim and allow system transients to stabilize.
 - (2) Provide a signal to open the HRFCV to the position equivalent to rated flow in the heat rejection loop. Power supplied to the HRFCV will be removed when the HRFCV reaches the rated flow position.
 - (3) Provide a signal to open the MIV. (This signal will open the MIV only if the valve was not actuated previously per item (7) of time period T-13.)
- T-15
- (1) Provide a signal to close the MIV.
 - (2) Provide a signal to close the VLB. Rated output power shall have been attained.
 - (3) Provide a signal to trickle charge the battery from alternator output.

PCS-G PROGRAMMER — START SEQUENCE

ENCLOSURE (5)
FIGURE A-1

INVERTER VOLTAGE (OUTPUT)

INVERTER VOLTAGE (INPUT)

INVERTER FREQUENCY

PH PMA POWER

HRL PMA POWER

LC PMA POWER

H₂ PMA POWER

LCL HEATER POWER

N₂ POWER SUPPLY

TAA & H₂ PMA BRG. OUTLET VALVES

TAA & H₂ PMA BRG. INLET VALVES

TAA & H₂ PMA LIFT-OFF SEALS

SATURABLE REACTOR BIAS

ALTERNATOR FLASH CURRENT

VEHICLE LOAD BREAKER

MERCURY BOILER ISOLATION VALVE

MERCURY CONDENSER ISOLATION VALVE

MERCURY INJECTION VALVE

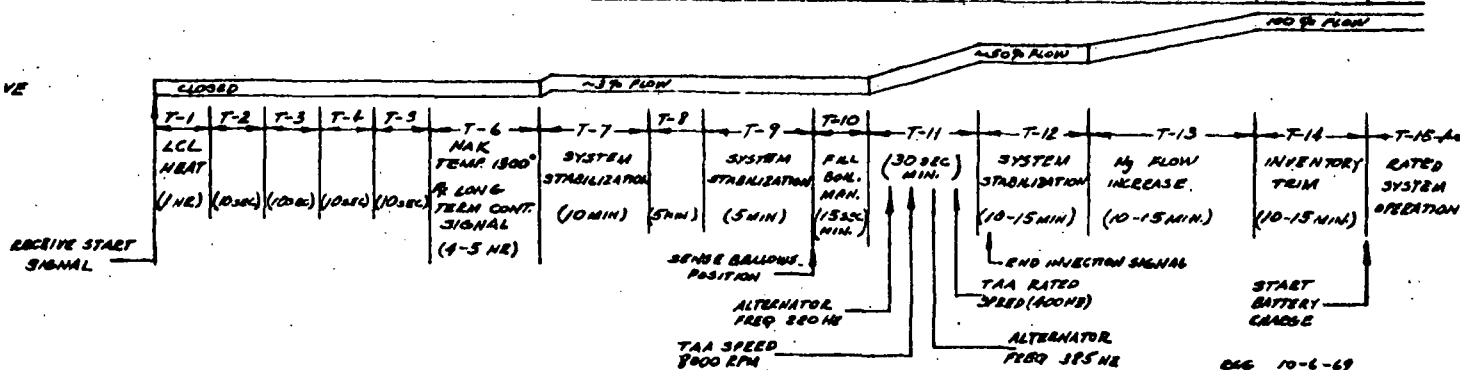
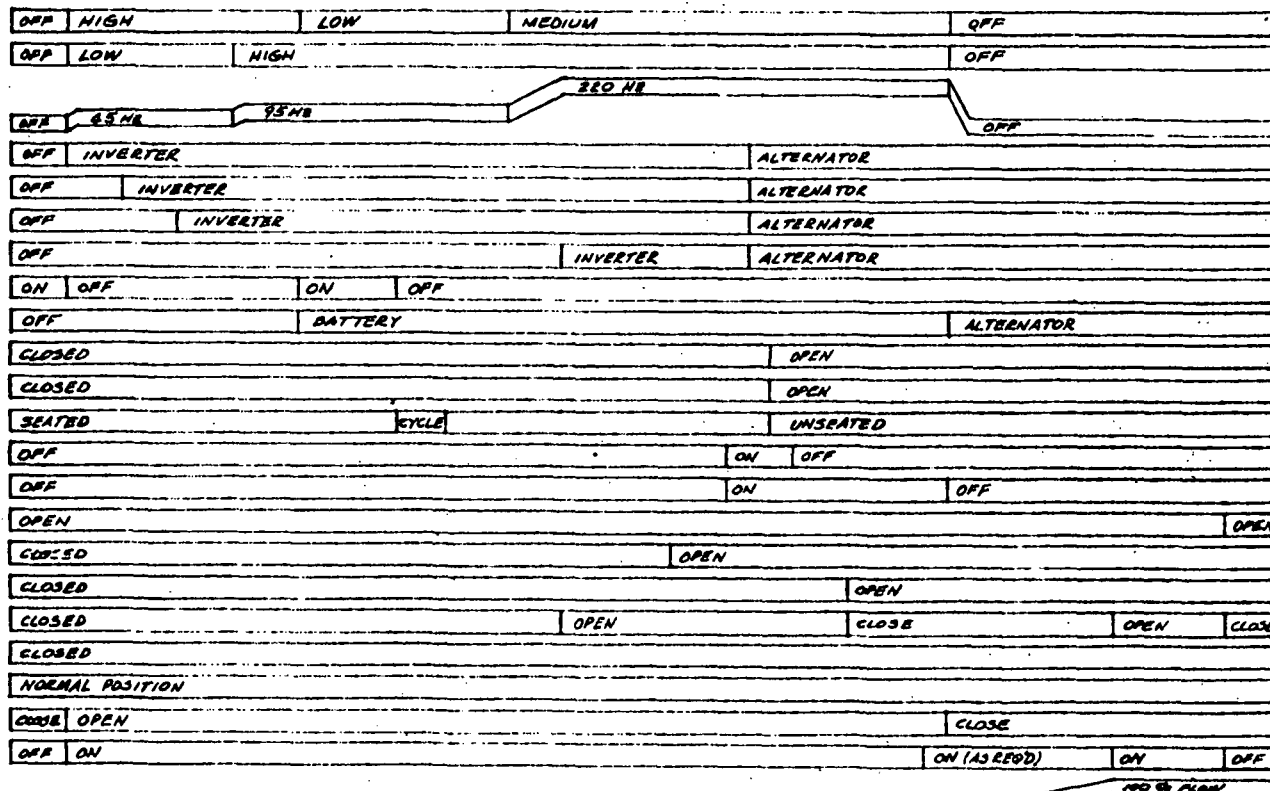
MERCURY RESERVOIR RECHARGE VALVE

MERCURY RESERVOIR ACTUATOR VALVE

AUXILIARY LOOP SHUTOFF VALVE

HRL FLOW CONTROL VALVE POWER

MERCURY FLOW CONTROL VALVE



Appendix B

Normal Shutdown Sequence.- On receipt of an external command signal the normal shutdown sequence of events shall be as described below and as shown diagrammatically in Figure B-1.

- T-1
(10 - 15
minutes)
- (1) Provide a signal to open the VLB.
 - (2) Provide a signal to close the MFCV at a nominal rate of 6.33 lb/hr/sec.
 - (3) Activate the HRFCV to control condenser pressure at nominal conditions, i.e., between 11 and 14 psia.
- T-2
(10 - 15
minutes)
- (1) Provide a signal to stop the MFCV at a position equivalent to a flow rate of 6600 lb/hr.
 - (2) Start a 10 to 15 minute timer to permit system transients to stabilize as the reactor power is reduced.
- T-3
(50 - 150
seconds)
- (1) Provide a signal to resume closing of the MFCV at a rate equivalent to 62 lb/hr/sec. The MFCV will be closed to a position which corresponds to a flow of approximately 3% of rated. Note: A change in voltage supplied to the MFCV may also be required at this time.
 - (2) Provide a signal to start the inverter and supply 56 vdc power for operation at 220 Hz.
 - (3) Provide a signal to transfer the nuclear system electrical load to the battery.
 - (4) Provide a signal to open the auxiliary loop shut-off valve (ALSV).
 - (5) Provide a signal to close valves SV-5 and SV-3 and seat the TAA lift-off seals when the TAA speed decreases to 8000 ± 150 rpm.
 - (6) Provide a signal to close valves SV-6 and SV-4 and seat the Hg PMA lift-off seals when the TAA speed decreases to 8000 ± 150 rpm.
 - (7) Provide a signal to transfer all PMA electrical loads to the inverter when the TAA frequency decreases to 220 Hz. The TAA frequency will increase after the electrical loads are transferred. The PMA's should not transfer back to the alternator.

Appendix B (Cont'd.)

Enclosure (5)
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Page 2

- T-4 (100 - 200 seconds) (1) Provide a signal to start a 100 to 200 second timer to permit stabilization of system transients.
- T-5 (100 - 200 seconds) (1) Provide a signal to open the mercury reservoir recharge valve (MRRV).
- T-6 (10 sec.) (1) Provide a signal to close the MRRV.
(2) Provide a signal to open the MIV.
(3) Provide a shutdown signal to the nuclear system controller to initiate a reactor fast setback.
(4) Provide a signal to remove the Hg PMA electrical load from the inverter.
(5) Provide a signal to actuate the mercury reservoir actuator valve (MRAV) to the "dump" position.
(6) Provide a signal to actuate the MFCV to the full closed position.
(7) Provide a signal to close the mercury boiler isolation valve (MBIV).
- T-7 (5 min.) (1) Provide a signal to reduce the inverter frequency to 95 Hz at a rate not to exceed 2.0 Hz/sec.
- T-8 (8 hours) (1) Provide a signal to transfer the PMA electrical loads to the low voltage taps of the inverter.
(2) Continue operation of PMA's at 95 Hz for 8 hours.
- T-9 (100 sec.) (1) Provide a signal to actuate the HRFCV to the full closed position. Power supplied to the HRFCV shall be removed when the valve reaches the full closed position.
(2) Provide a signal to close the mercury condenser isolation valve (MCIV).
(3) Provide a signal to remove the PMA electrical loads from the inverter.
(4) Provide a signal to remove dc power from the inverter.
(5) Provide a signal to close the ALSV.
(6) Provide a signal to close the mercury injection valve (MIV).
- T-10 (1) Reset the programmer for startup, then remove power from the programmer.

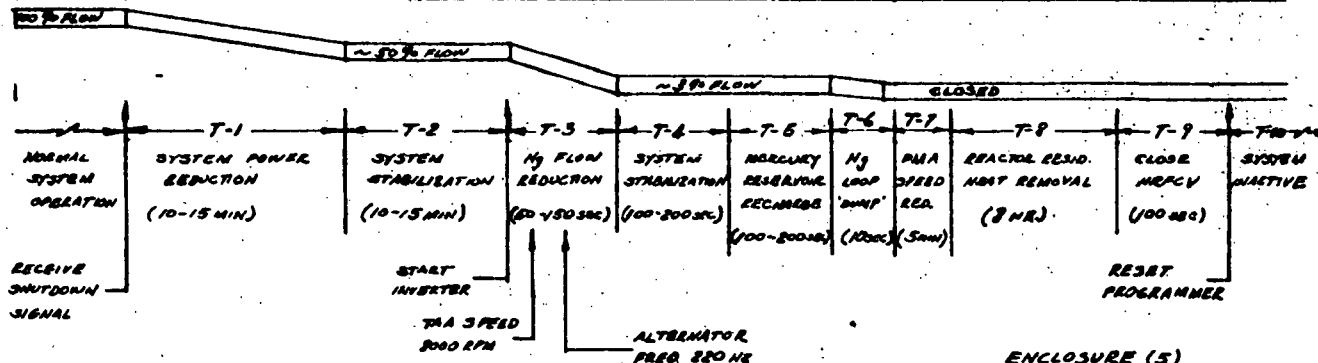
INVERTER VOLTAGE (OUTPUT)
 INVERTER VOLTAGE (INPUT)
 INVERTER FREQUENCY
 PNPMA POWER
 NRL PMA POWER
 LC PMA POWER
 H₂ PMA POWER
 N₂ POWER SUPPLY
 TAA & H₂ PMA BRS. OUTLET VALVES
 TAA & H₂ PMA BRS. INLET VALVES
 TAA & H₂ PMA LIFT-OFF SEALS
 SATURABLE REACTOR BIAS
 ALTERNATOR FLASH CURRENT
 VEHICLE LOAD BREAKER
 MERCURY BLOWER ISOLATION VALVE
 MERCURY CONDENSER ISOLATION VALVE
 MERCURY INJECTION VALVE
 MERCURY RESERVOIR RECHARGE VALVE
 MERCURY RESERVOIR ACTUATOR VALVE
 AUXILIARY LOOP SHUTOFF VALVE
 NRL FLOW CONTROL VALVE POWER

MERCURY FLOW CONTROL VALVE

PCS-G PROGRAMMER — NORMAL SHUTDOWN SEQUENCE

ENCLOSURE (5)
 FIGURE B-1

OFF	MEDIUM	LOW	OFF
OFF	HIGH		OFF
ZONE			
OFF		ZONE	OFF
ALTERNATOR	INVERTER		OFF
ALTERNATOR	INVERTER		OFF
ALTERNATOR	INVERTER		OFF
ALTERNATOR	INVERTER	OFF	
ALTERNATOR	BATTERY		
OPEN	CLOSED		
OPEN	CLOSED		
UNSEATED	SEATED		
OFF			
OFF			
CLOSED	OPEN		
OPEN		CLOSE	
OPEN			CLOSE
CLOSED		OPEN	CLOSE
CLOSED		OPEN	CLOSE
NORMAL POSITION		DUMP POSITION	NORMAL POSITION
CLOSED	OPEN		CLOSE
OFF	ON (AS REQD)		ON OFF



ENCLOSURE (5)
 FIGURE B-1

MSG 10-6-69

Appendix C

Emergency Shutdown

1. Emergency Shutdown Conditions.- The system shall shut down in accordance with the emergency shutdown sequence when the following conditions occur:

- Condition 1. *PNL flow decay to 50% of nominal (anytime after TAA reaches rated speed during startup and anytime prior to TAA deceleration to 220 Hz on shutdown).
- Condition 2. *PNL flow decay to 10% of nominal during startup prior to time when TAA reaches rated speed.
- Condition 3. *HRL flow decay to 10% of nominal (anytime after completion of startup sequence and prior to initiation of shutdown sequence).
- Condition 4. *TAA frequency equal to or greater than 440 Hz.
- Condition 5. *(U-UV2) Undervoltage - Unbalanced voltage conditions specified in TM 4936:68-537 for manned applications.
- Condition 6. *Condenser pressure greater than 40 psia.
- Condition 7. Reactor fast setback signal.
- Condition 8. External command.

2. Emergency Shutdown Sequence.- Upon receipt of a proper emergency condition signal the programmer shall shut down the system in the following sequence:

- T-1
(3 seconds)
 - (1) Transfer the nuclear system electrical load to the battery.
 - (2) Provide a signal to the nuclear system controller to initiate a reactor fast setback.
 - (3) Start the inverter on 56 vdc battery power for 220 Hz operation.
 - (4) Close the mercury boiler isolation valve (MBIV).
 - (5) Open the mercury condenser isolation valve (MCIV).

* (Two out of three separate sensors associated with this measurement are required to indicate the condition before emergency shutdown is initiated.)

Appendix C (Cont'd.)

- (6) Provide a signal to fully close the MFCV using maximum allowable voltage.
 - (7) Provide a signal to actuate the mercury reservoir actuator valve (MRAV) to the "dump" position.
 - (8) Open the mercury injection valve (MIV).
 - (9) Open the VLB.
 - (10) Open the auxiliary loop shut-off valve (ALSV).
 - (11) Activate the HRFCV (operation to be determined).
 - (12) Turn off saturable reactor bias.
 - (13) Close valves SV-5 and SV-6 and seat the TAA lift-off seals.
 - (14) Close valves SV-3 and SV-4 and seat the Hg PMA lift-off seals.
 - (15) Start a 3 second timer to provide a delay between indication of emergency shutdown condition and transfer of PMA's to the inverter.
- T-2
(10 seconds)
- (1) Transfer the PMA electrical loads to the inverter. The PMA electrical loads shall not transfer back to the alternator if the TAA speed subsequently increases above 220 Hz.
- T-3
(5 minutes)
- (1) Provide a signal to reduce the inverter frequency to 95 Hz at a rate not to exceed 2.0 Hz/sec.
- T-4
(8 hours)
- (1) Provide a signal to transfer the PMA electrical loads to the low voltage taps of the inverter.
 - (2) Provide a signal to remove the Hg PMA from the inverter.
 - (3) Continue operation of the PN, HRL, and LC PMA's at 95 Hz for 8 hours.
- T-5
(5 minutes)
- (1) Provide a signal to actuate the HRFCV to the full closed position. Power supplied to the HRFCV shall be removed when the valve reaches the full closed position.
 - (2) Provide a signal to close the mercury condenser isolation valve (MCIV).
 - (3) Provide a signal to remove the PMA electrical loads from the inverter.

Appendix C (Cont'd.)

- (4) Provide a signal to remove dc power from the inverter.
- (5) Provide a signal to close the ALSV.
- (6) Provide a signal to actuate the mercury reservoir actuator valve to the "normal" position.

T-6

- (1) Reset the programmer for startup, then remove power from the programmer.

3. In the event of an external electrical fault as signified by U-UVI, the VLB shall be cycled. This system concept shall be as defined in TM 4936:68-537 for the manned application.

PCS REDUNDANCY CONSIDERATIONS

It has been a program ground-rule since 1966 for SNAP-8 to contain redundancy features wherever feasible. This requirement developed simultaneously with the "man rating" of SNAP-8. Consequently, the concept of redundant Hg loops and primary PMAs is an inherent part of the SNAP-8 EGS. During the current conceptual design phase, further analysis of redundancy features was performed. The following items represent the highlights of our redundancy analysis.

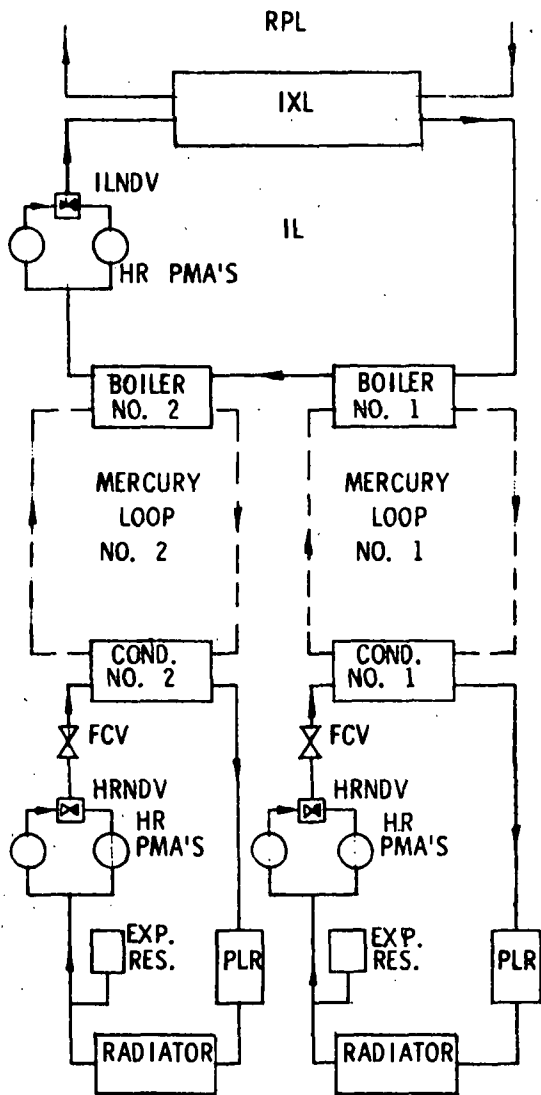
1. HRL. The flow diagrams shown in Figure IIA2-1 indicate that some simplification can be achieved by utilizing the single HRL circuit. However, the analysis shown in Figure IIA2-2 indicates that higher reliabilities can be achieved with a dual radiator -- therefore, dual HRL approach. It must be noted, that such higher reliabilities can only be achieved with (1) heavily armored radiators and (2) highly reliable HRL and Hg L components.

2. L/C Loop. The quantitative analysis made for the HRL loop apply qualitatively to the L/C loop; hence, the decision to use two separate L/C circuits (shown in Figure IIA2-3) versus the single circuit approach (shown in Figure IIA2-4).

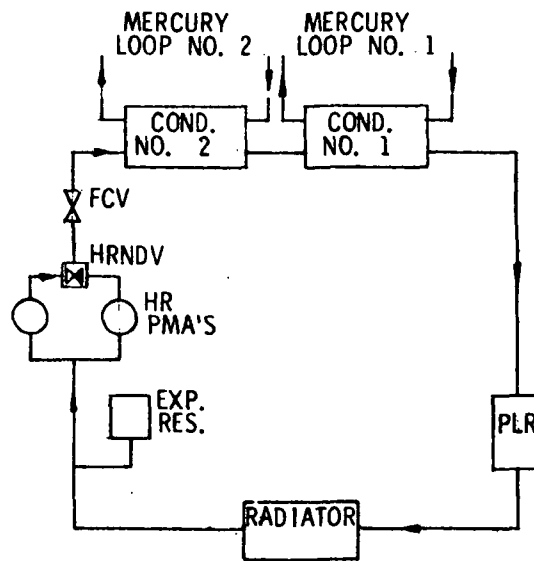
3. Electrical Controls. Figure IIB3-4 in Section IIB is an electrical block diagram representing the reference controls for one PCS in a dual PCS design. A similar set is required for the second PCS. Figure IIA2-5 shows an arrangement whereby a single set of electrical equipment (with the exception of the programmer) can be used to serve two PCSs. The switchgear required in the latter case represents a decrease in reliability over the reference approach.

A comparison of the various methods of arranging programmers, electrical controls, and PCSs is indicated in Figure IIA2-6. The choice of two programmers over one to control two PCSs is based on the excessive amount of switchgear required for the one programmer approach. A comparison of system 2B versus system 1B in Figure IIA2-6 supports the decision of selecting the independent electrical system approach since the total amount of switchgear is reduced.

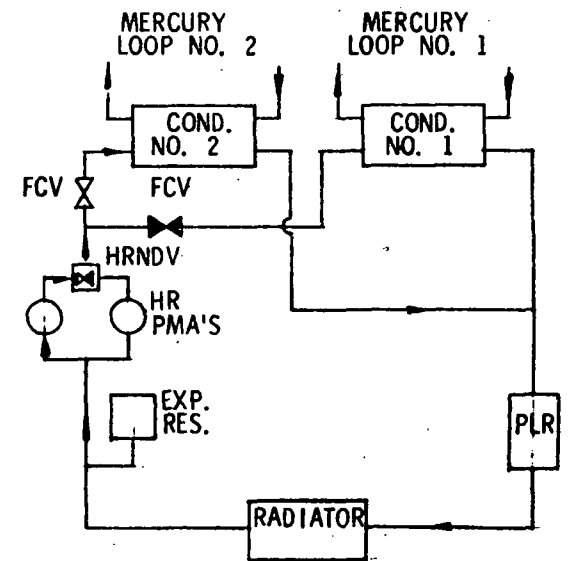
HRL REDUNDANCY CONCEPTS



REFERENCE



ALTERNATE NO. 1



ALTERNATE NO. 2

FIGURE 11 A 2-1

INTEROFFICE MEMO



AEROJET-GENERAL CORPORATION

TO: Distribution

DATE 30 January 1970
4925-70-0006:BLA:bm
Bldg. 160, X6302

FROM: Power Systems Design Assurance

SUBJECT: Reliability Comparison of Single- and Dual-Tube Radiator Configurations for PCS-G.

COPIES TO: W. F. Banks, S. L. Bradley, B. Breindel, R. H. Chesworth, F. J. Curtis, C. E. Hawk, A. H. Kreeger, L. P. Lopez, R. W. Marshall, U. A. Pineda, J. R. Pope

NASA-LeRC: M. J. Saari, G. M. Thur

NASA-Hq: P. R. Miller

AGC-Cleveland: W. L. Snapp

REF: TM 5282:69-608 dated 7 January 1970

INTRODUCTION:

A further analysis of the relative reliabilities of single- and dual-tube radiator systems was performed, taking into account not only the HR loop but also the Hg loop. The analysis employed mathematical models comparable to those delineated in TM 5282:69-608. Radiator weights, armor thicknesses, and probabilities of meteoroid penetrations are calculated in the same manner as shown in the TM. Figure 1 depicts associated logic diagrams and Figures 2 through 13 provide pictorial reliability comparisons.

DISCUSSION:

1. The following points pertain to the four logic diagrams in Figure 1.

- A. . Separate PCS systems from boiler through radiator
 - . When failure occurs, entire PCS is switched over
 - . No valves; 2 simple or 1 complex auxiliary start heat exchanger, dual-tube radiator
 - . Simple condenser
- B. . Separate Hg loops from boiler through condenser
 - . Separate HR loops from condenser through radiator
 - . Each HR loop goes through both condensers in series
 - . Complex condensers, with 1 Hg and 2 independent NaK paths
 - . No valves; 2 simple or 1 complex auxiliary start heat exchanger
 - . Either HR loop can be used with either Hg loop
 - . Dual-tube radiator
- C. . Separate Hg loops from boiler through condenser
 - . Separate HR loops for NaK PMA
 - . 2 Double Solenoid NaK isolation valves in each HR loop - no leakage permitted (2 3-way valves can be used in place of the 4 2-way valves)
 - . 2 simple or 1 complex auxiliary start heat exchanger
 - . Dual-tube radiator; simple condensers
 - . Either HR loop can be used with either Hg loop

- D. . Separate Hg loops from boiler through condenser
 - . Single HR loop with redundant NaK PMAs
 - . HR loop can be used with either Hg loop
 - . Simple 2-position flapper valve, internal leakage permitted
 - . Simple auxiliary start heat exchanger
 - . Single tube radiator, simple condensers
- 2. Because of the impracticality of the condenser design in configuration B and the requirement for four leak-proof NaK valves in configuration C, the analysis was limited to comparisons of configurations A and D. Configuration A has two independent sets of Hg loop and HR loop components. Any failure in the first set requires switching the entire set of components. Configuration D consists of two sets of Hg loop components, two HR NPMAs and 1 radiator. Either NPMA can be used with either Hg loop. A simple flapper valve, not requiring internal leak tightness, and having a very high reliability is the only additionally required mechanical component.
- 3. The analysis is depicted graphically in Figures 2 through 13. The solid lines represent system reliability (failure probability) for dual-tube radiators. Since each set of Hg and HR loop components are in series and there are no crossovers, the total reliability of one set of these components (excluding the radiator which is a separate variable) is evaluated as a single number.

The shaded area represents the possible system reliabilities associated with a single-tube radiator system of equal weight. The total reliability of one set of Hg and HR loop components (excluding the radiator) is the same as for the dual-tube configuration. However, because crossover is possible between the Hg loops and the HR NPMAs, the total reliability of this set of components is divided into two parts whose product provides the same total as above. If the reliabilities of the Hg loop and NPMAs are equal, the upper limit of the shaded area is obtained. If all of the probability of failure is associated with either the Hg loop components or the HR NPMA and the other part is perfect (again giving the same total), the lower limit is obtained. Due to the relative reliabilities of the various components, it is estimated that the overall reliability of a single-tube radiator system will be approximately in the middle of the shaded area.

4. The reliability goal of .95 for the SNAP-8 System for 5 years using redundant mercury loops and HR PMAs leads to a reliability requirement of about .99 for the redundant Hg loops and HR PMAs, .99 for the radiator, and .97 for the reactor and remaining components. Using the .99 value for the redundant loops and HR PMAs, each set must have a reliability of about .90. This is considered to be a realistic goal for a 40,000 hour life.

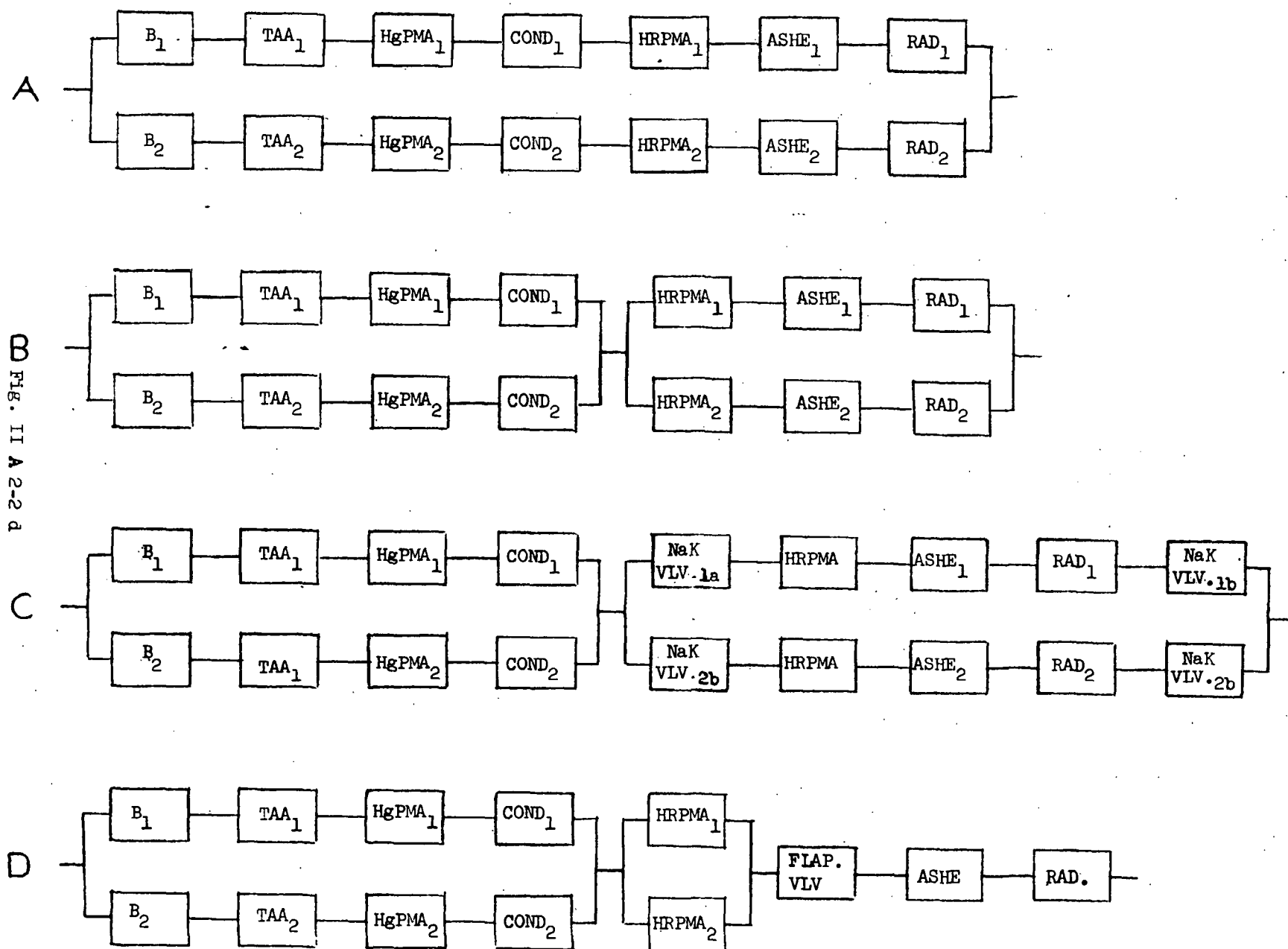
CONCLUSIONS

The analysis shows, Figures 2 through 13, that for anticipated reliability values of the Hg loop components and NaK PMAs (.85 to .95 total), the single-tube radiator configuration results in a significant advantage. For light weight radiators, (approximately 2500 pounds) a reduction in failure probability of about 2/3 (1/3 as much) as compared with the dual-tube configuration. As the radiator weight increases, the overall reliability also increases, but the advantage of the single-tube configuration is reduced. For heavy radiators (approximately 5000 pounds), the single-tube configurations failure probability is about 3/4 of that of the dual-tube, or a reduction of about 1/4. The average failure probability of the single-tube configuration is about one-half of that for the dual-tube for those weights and component reliability values that are most probable. (Note that this analysis does not include electrical components. Based on analytical analyses and actual tests, their reliabilities should be very high, approaching unity. However, the little unreliability will slightly reduce the significant advantage of the single-tube configuration, but not enough to invalidate the conclusions.)

B. L. Amstadter

B. L. Amstadter, Supervisor
Design Assurance
Power Systems Department

Figure 1. LOGIC DIAGRAMS OF FOUR POTENTIAL CONFIGURATIONS OF Hg LOOP AND HR LOOP OF PCS-G



COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

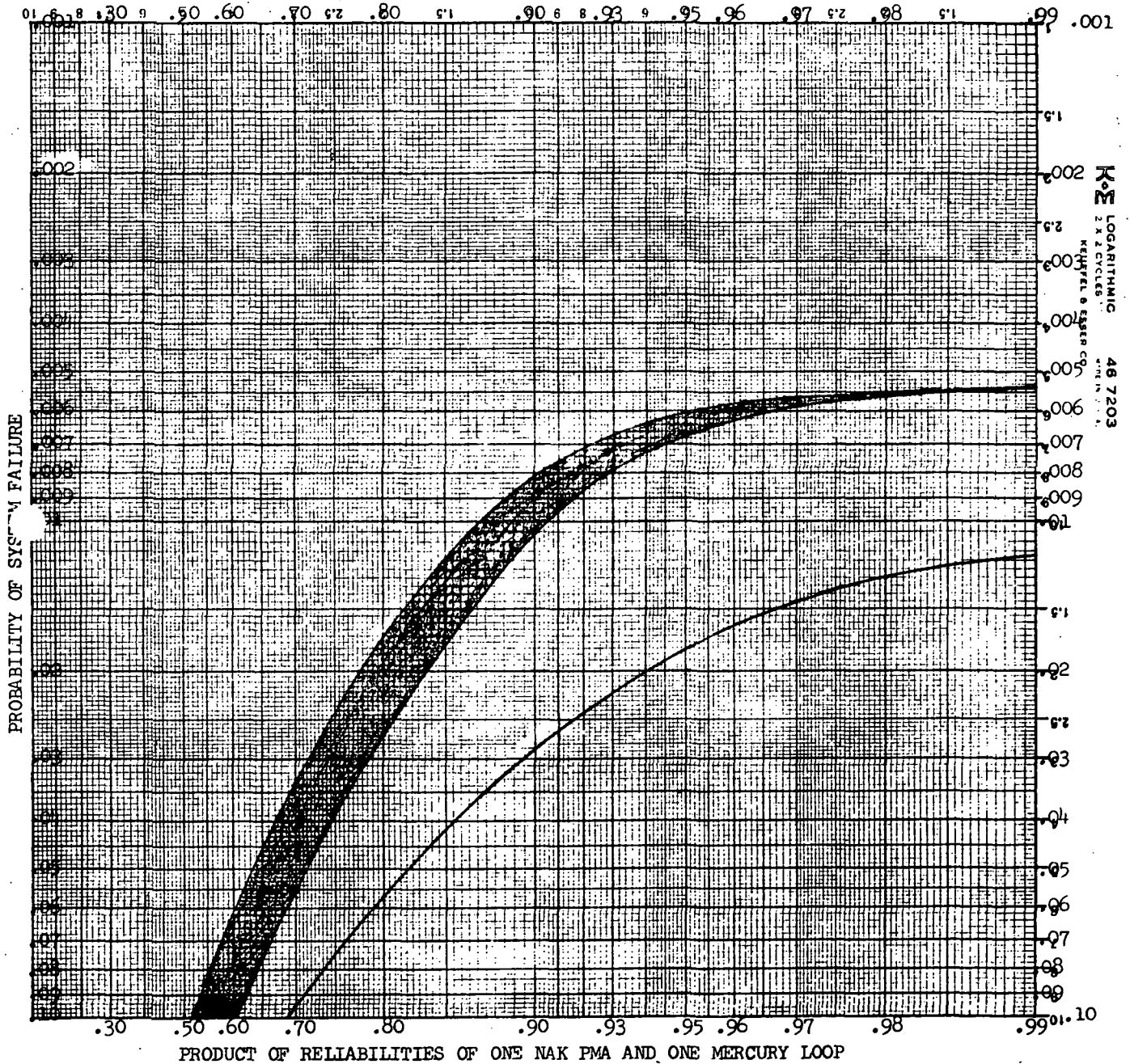


Figure 2

$R_{\text{one set of tubes, dual-tube radiator}} = .900$

$R_{\text{single-tube radiator}} = .9946$

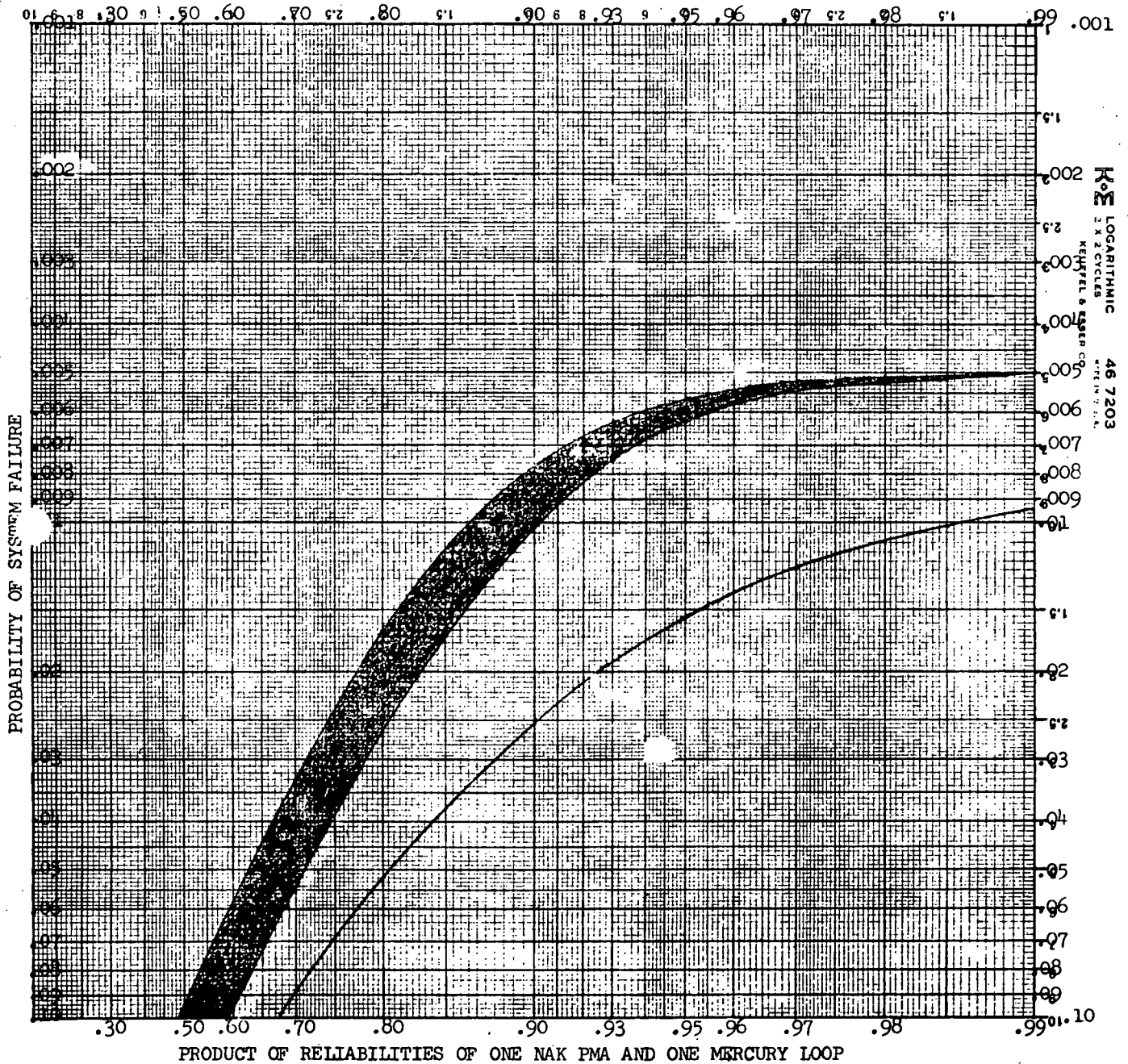
Radiator Weight (pounds) = 2472

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)



$R_{\text{one set of tubes, dual-tube radiator}} = .910$

$R_{\text{single-tube radiator}} = .9950$

Radiator Weight (pounds) = 2517

Fig. II A 2-2 f

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

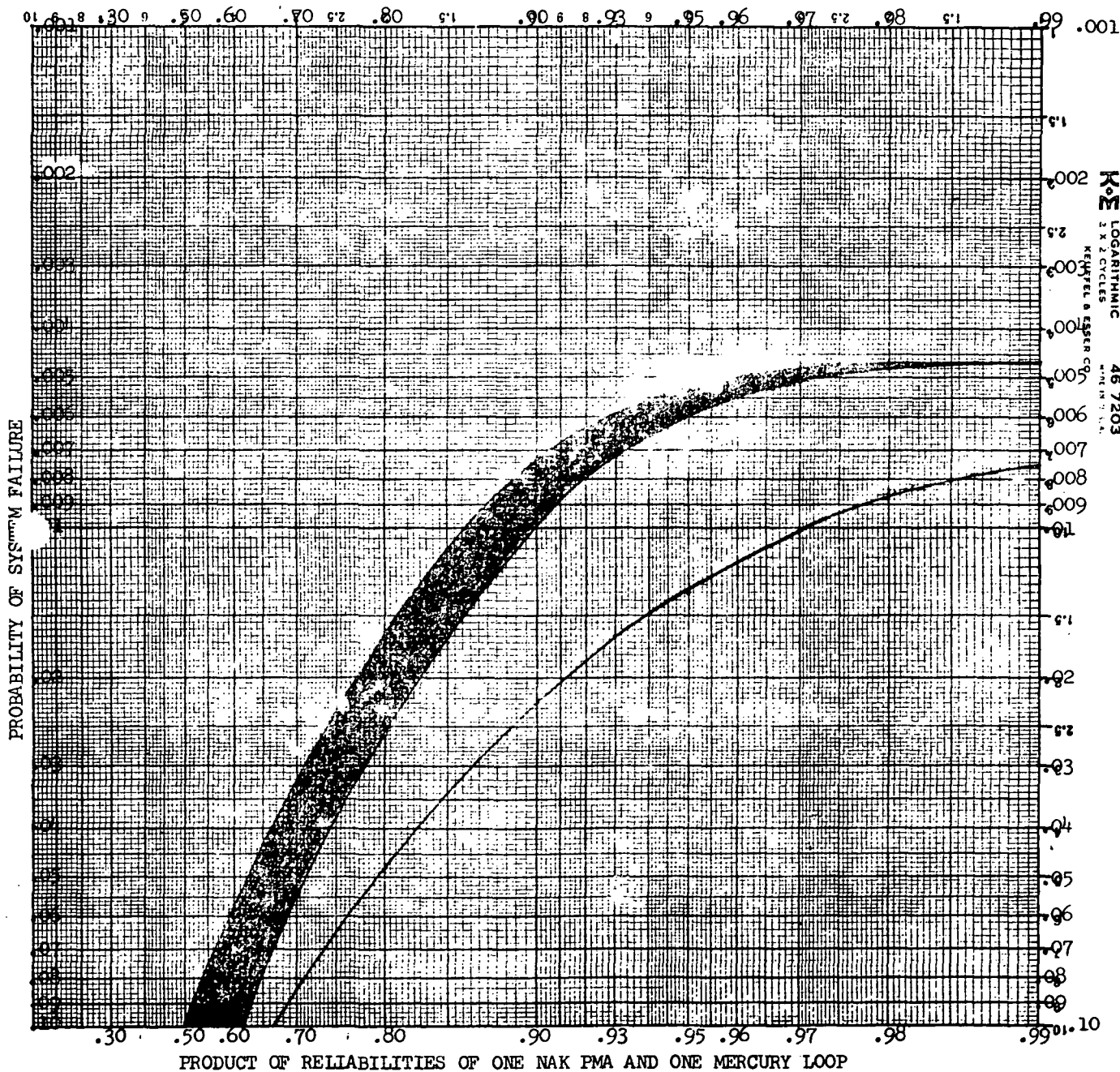


Figure 4

$R_{\text{one set of tubes, dual-tube radiator}} = .920$

$R_{\text{single-tube radiator}} = .9954$

Radiator Weight (pounds) = 2562

Fig. II A 2-2 g

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

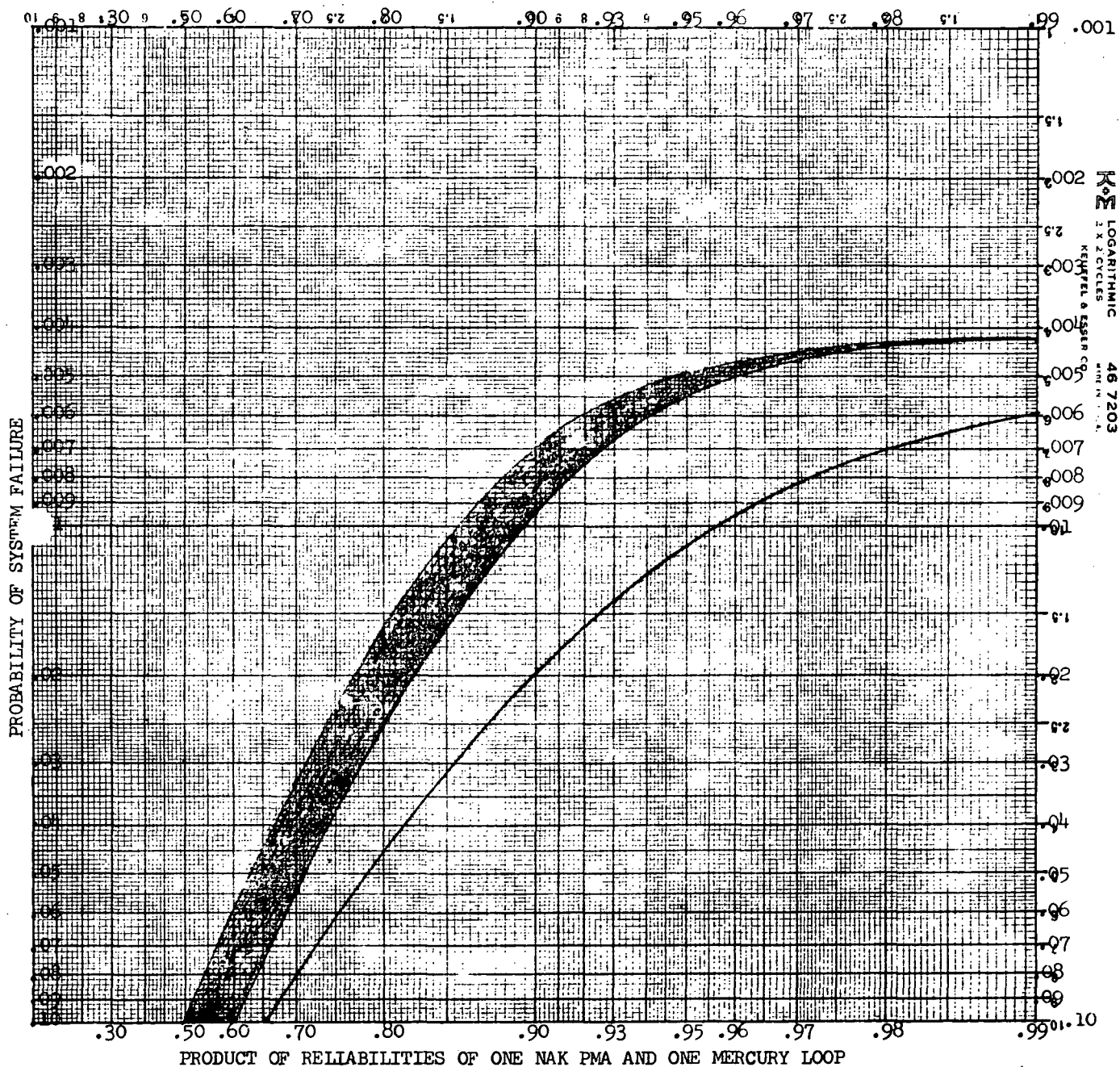


Figure 5

$R_{\text{one set of tubes, dual-tube radiator}} = .930$

$R_{\text{single-tube radiator}} = .9958$

Radiator Weight (pounds) = 2620

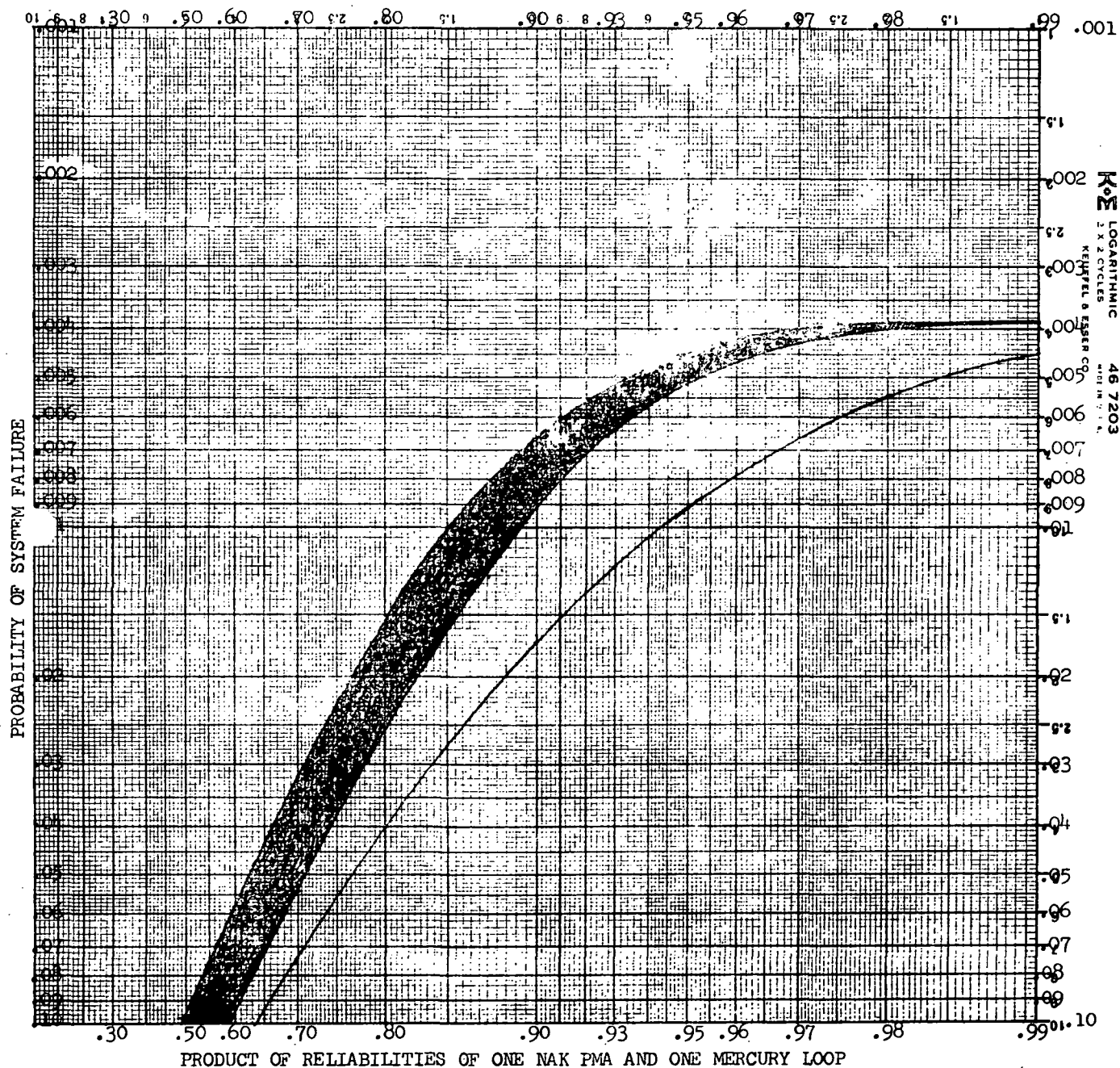
Fig. II A 2-2 h

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)



$R_{\text{one set of tubes, dual-tube radiator}} = .940$

$R_{\text{single-tube radiator}} = .9962$

Radiator Weight (pounds) = 2690

Fig. II A 2-2 1

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

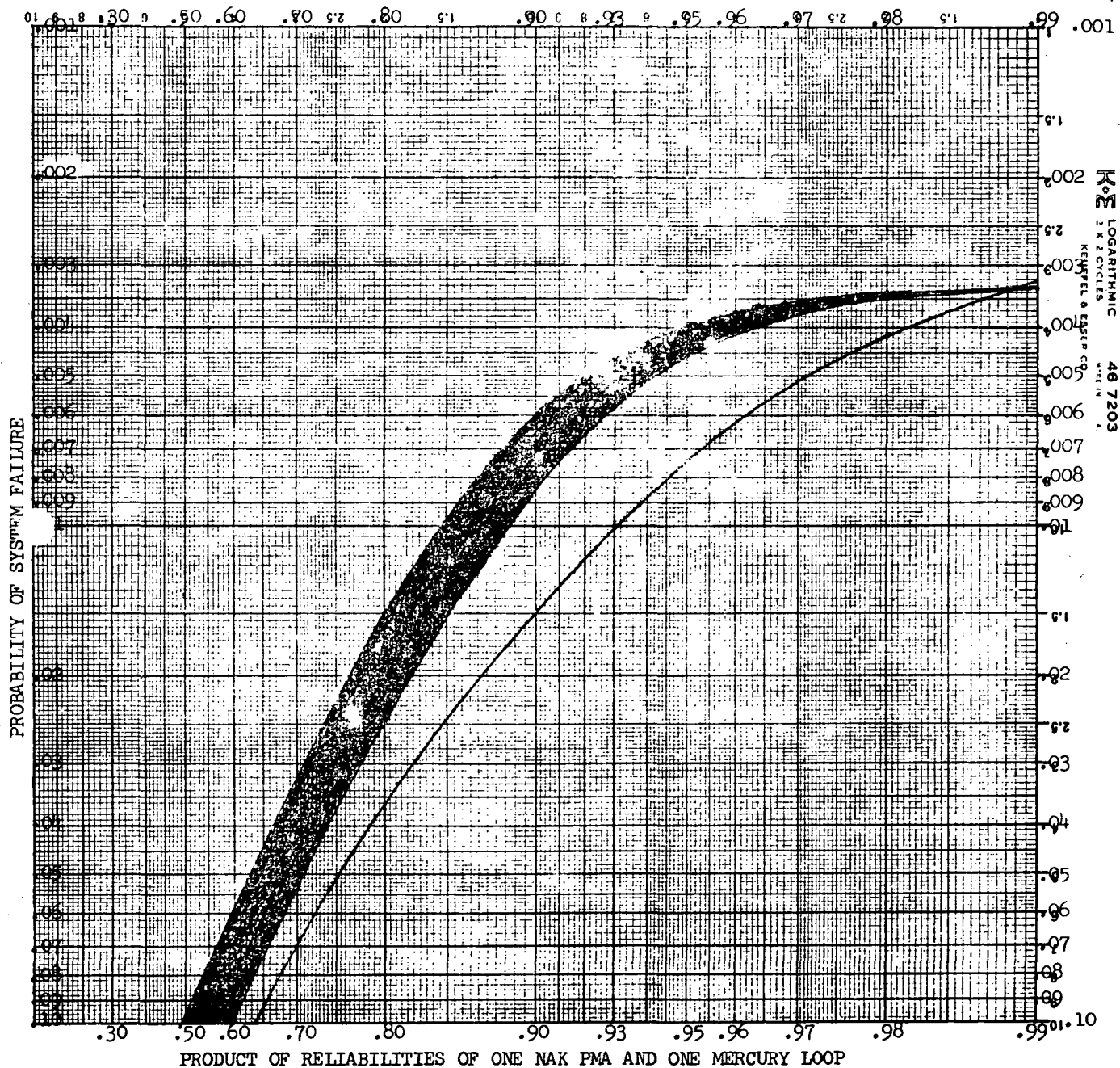


Figure 7

$R_{\text{one set of tubes, dual-tube radiator}} = .950$

$R_{\text{single-tube radiator}} = .9967$

Radiator Weight (pounds) = 2778

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

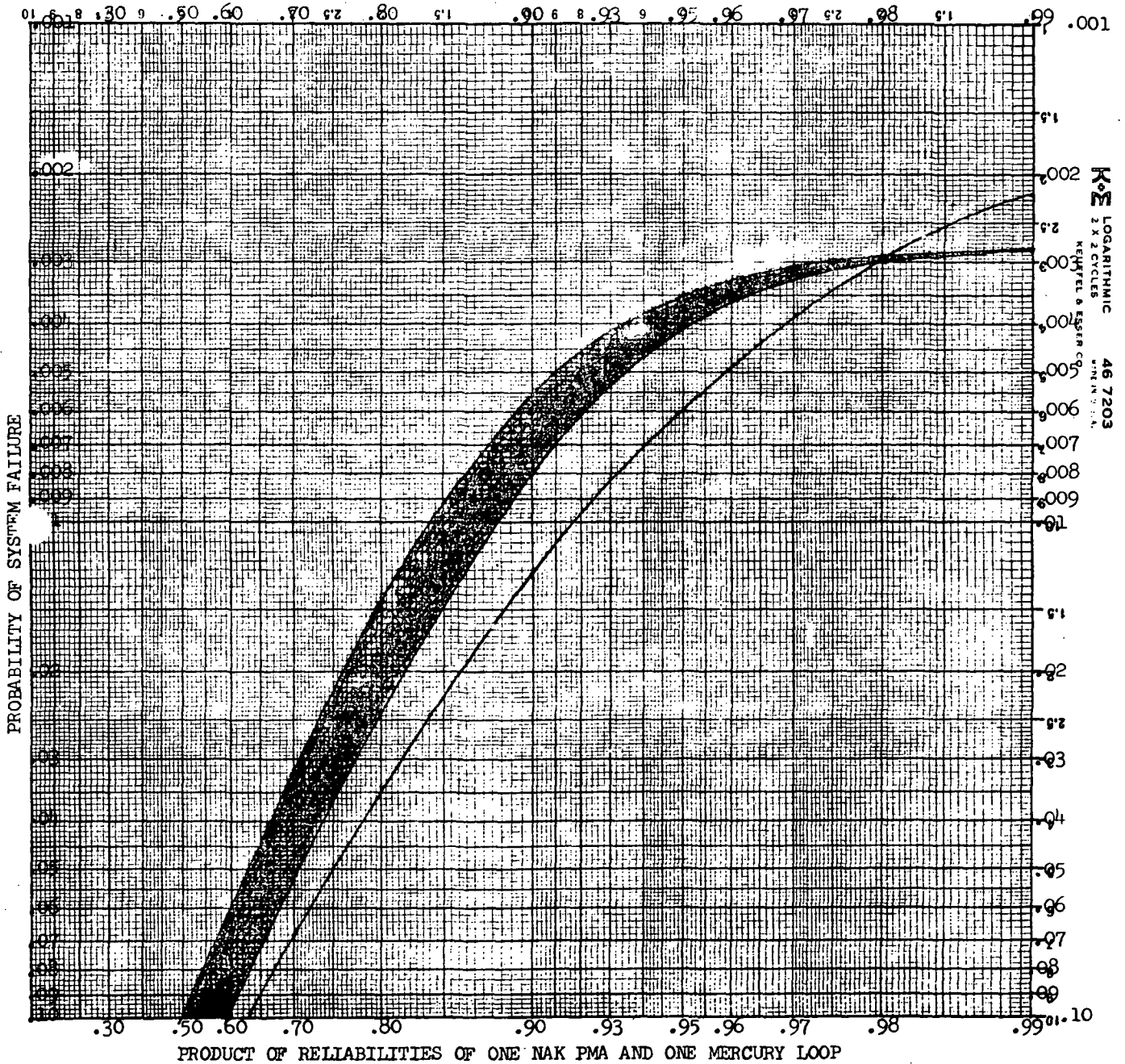


Figure 8

$R_{\text{one set of tubes, dual-tube radiator}} = .960$

$R_{\text{single-tube radiator}} = .9972$

Radiator Weight (pounds) = 2892

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

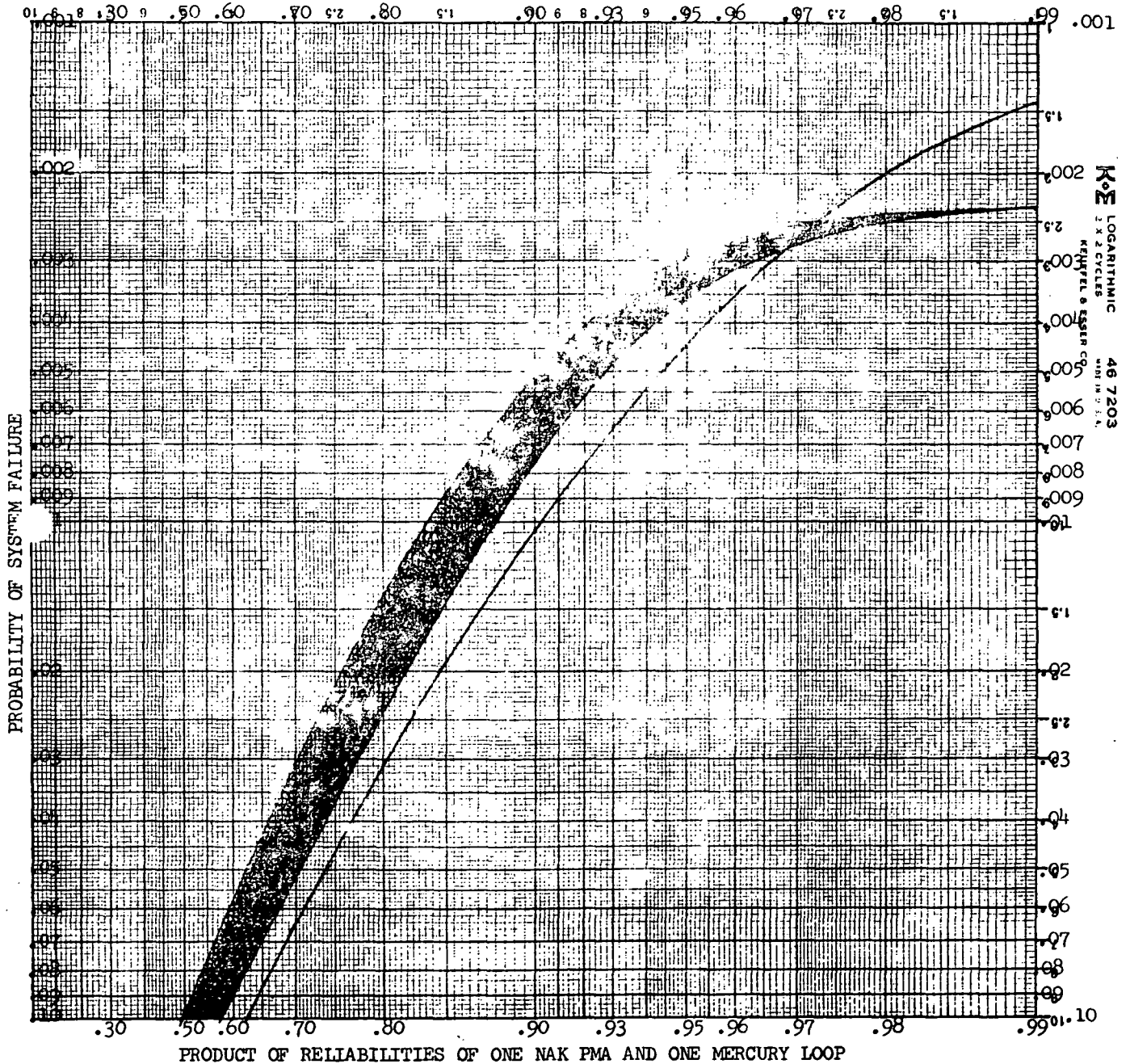


Figure 9

$R_{\text{one set of tubes, dual-tube radiator}} = .970$

$R_{\text{single-tube radiator}} = .9977$

Radiator Weight (pounds) = 3054

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

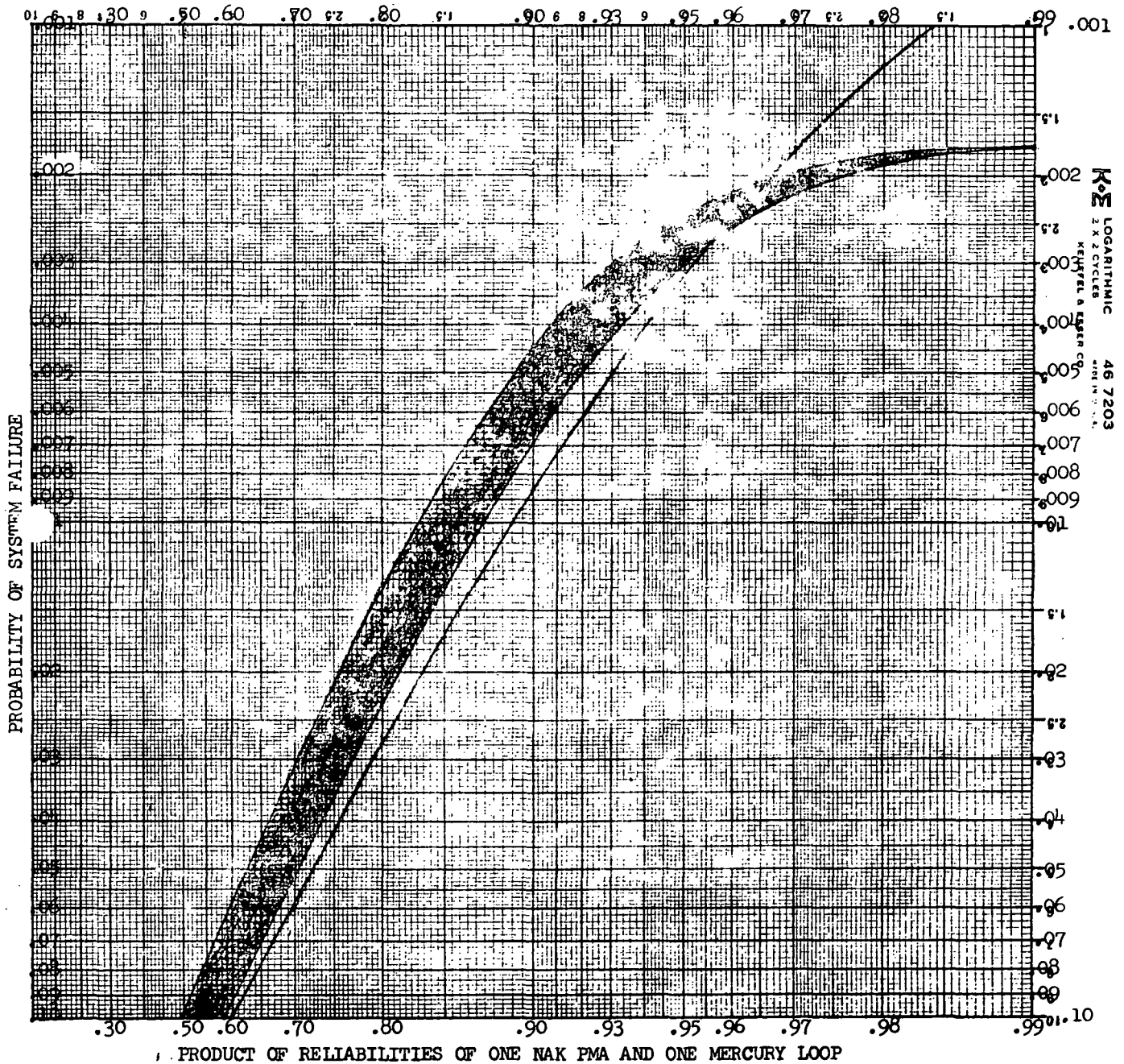


Figure 10

$R_{\text{one set of tubes, dual-tube radiator}} = .980$

$R_{\text{single-tube radiator}} = .9983$

Radiator Weight (pounds) = 3313

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

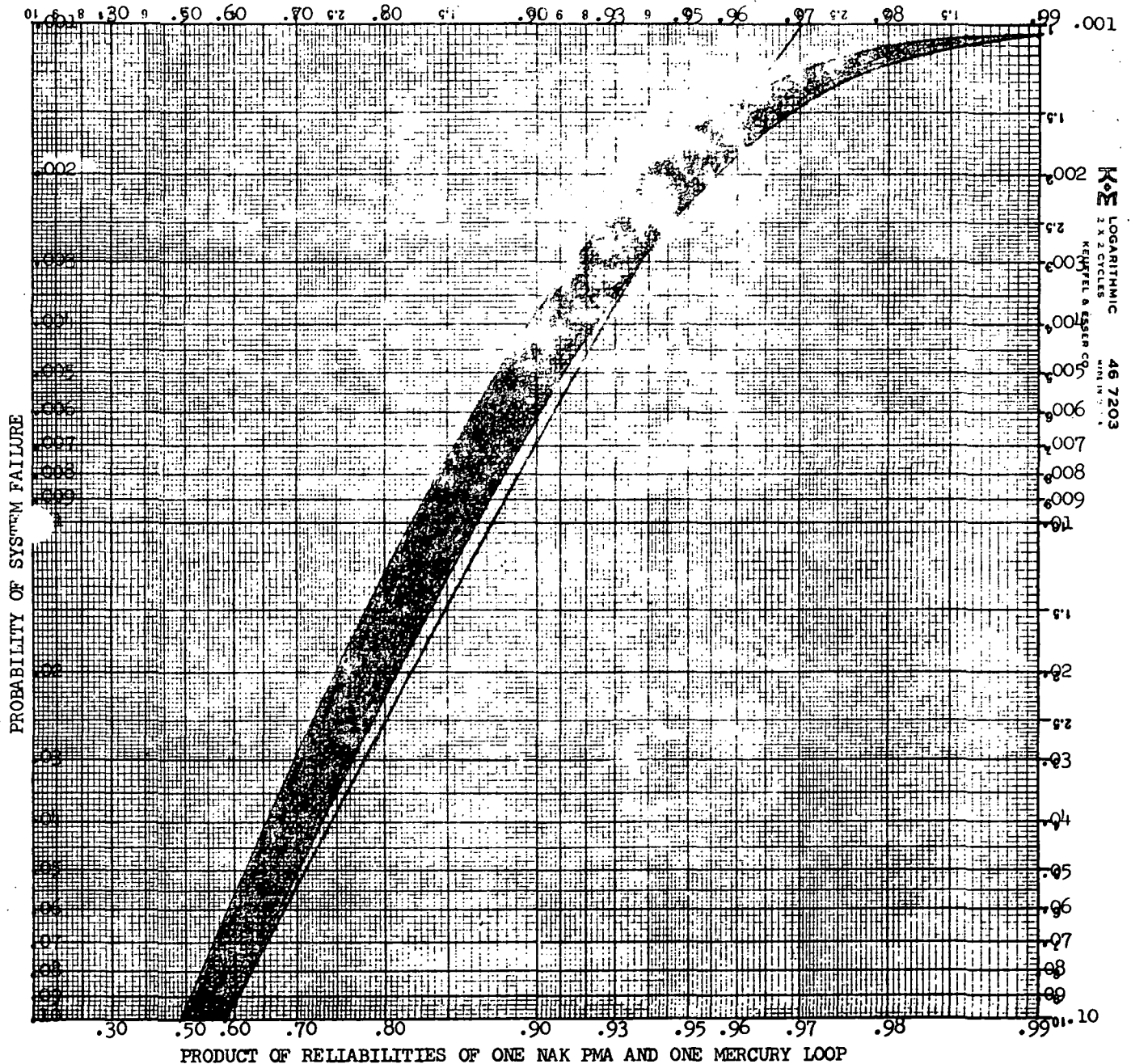


Figure 11

$R_{\text{one set of tubes, dual-tube radiator}} = .990$

$R_{\text{single-tube radiator}} = .99901$

Radiator Weight (pounds) = 3855

Fig. II A 2-2 n

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

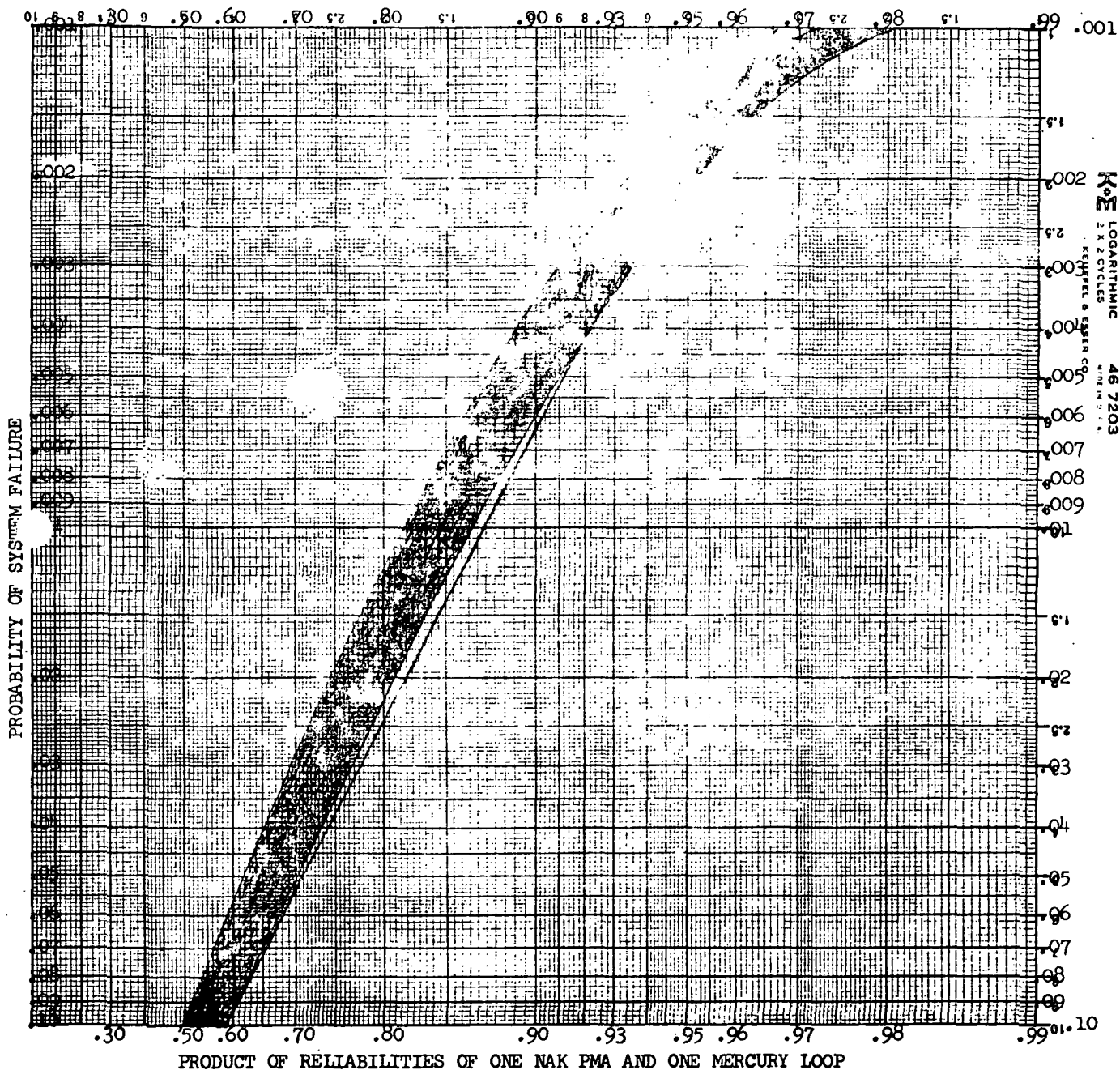


Figure 12

$R_{\text{one set of tubes, dual-tube radiator}} = .9925$

$R_{\text{single-tube radiator}} = .99921$

Radiator Weight (pounds) = 4126

COMPARISON OF RELIABILITIES OF SINGLE-AND DUAL-TUBE RADIATOR SYSTEMS OF EQUAL WEIGHT

SINGLE LINE = RELIABILITY OF DUAL-TUBE RADIATOR SYSTEM

SHADED AREA = RANGE OF RELIABILITY OF SINGLE-TUBE RADIATOR SYSTEM

(Reliability = 1.00 - Probability of System Failure)

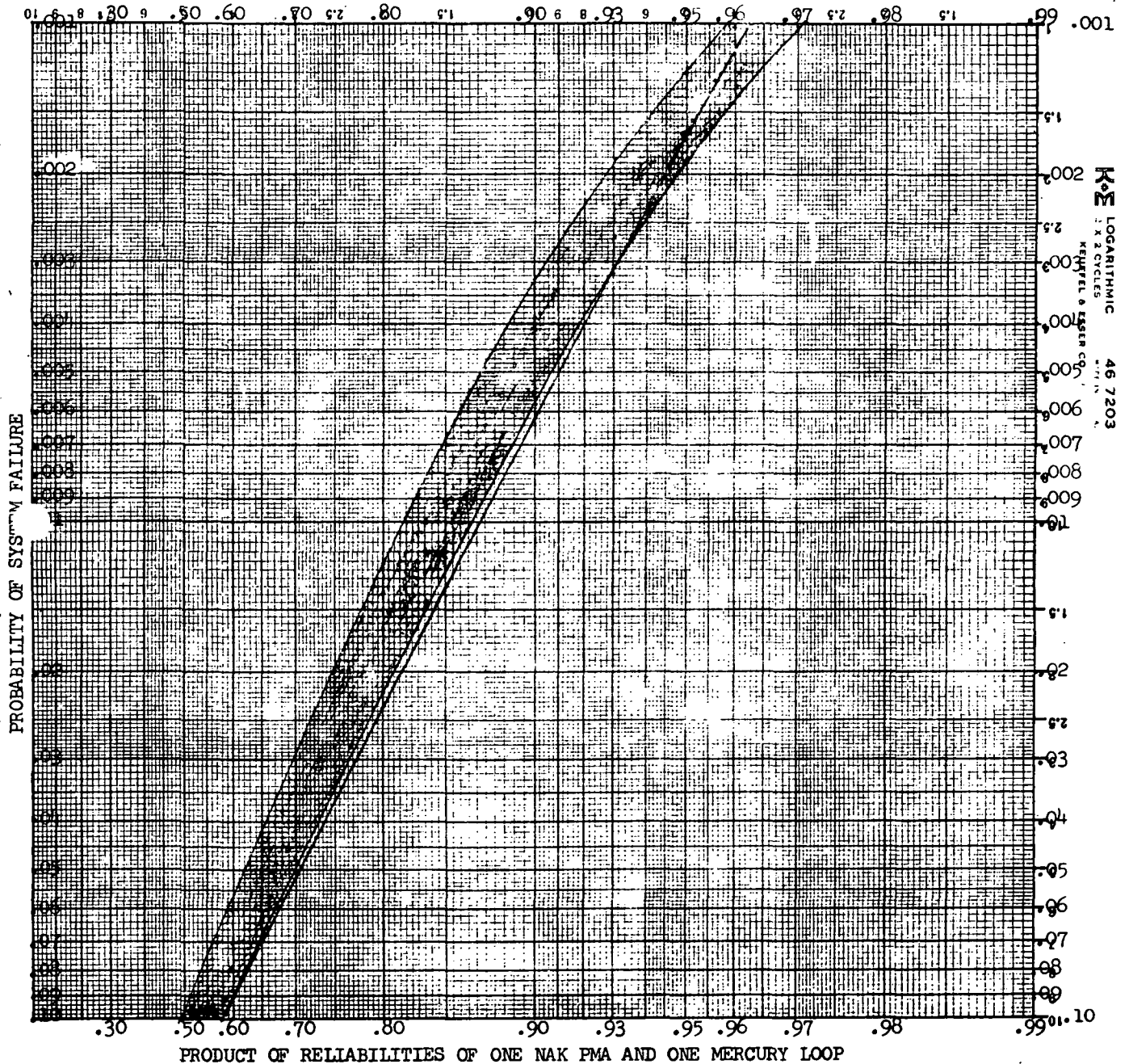


Figure 13

$R_{\text{one set of tubes, dual-tube radiator}} = .995$

$R_{\text{single-tube radiator}} = .99943$

Radiator Weight (pounds) = 4564

PCS L/C SYSTEM SCHEMATIC
REFERENCE

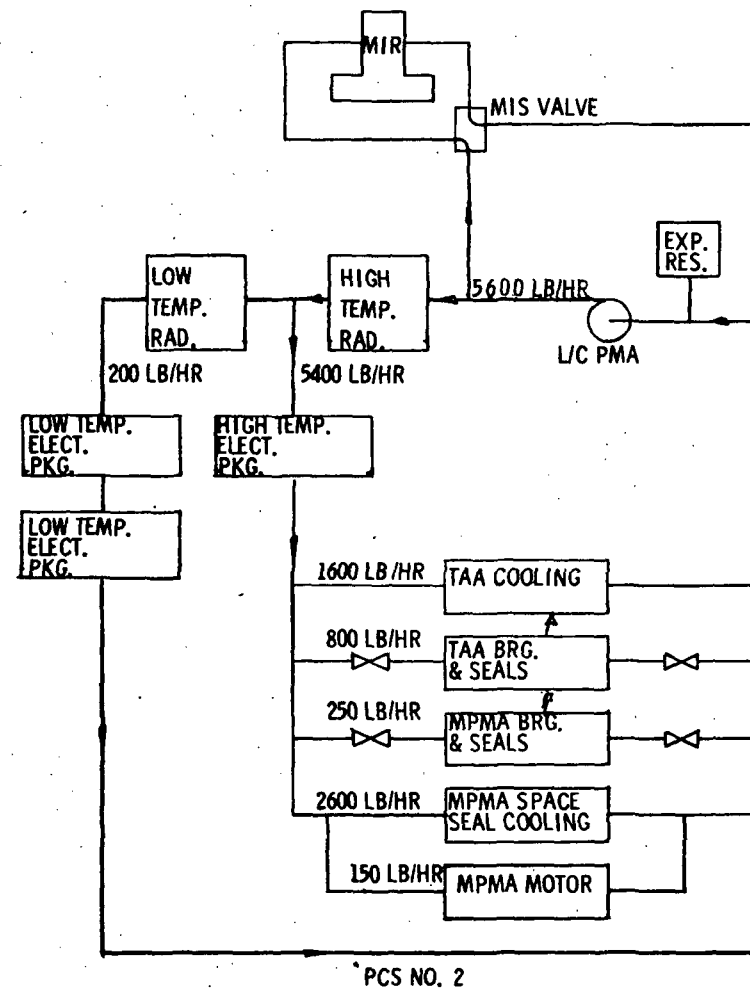
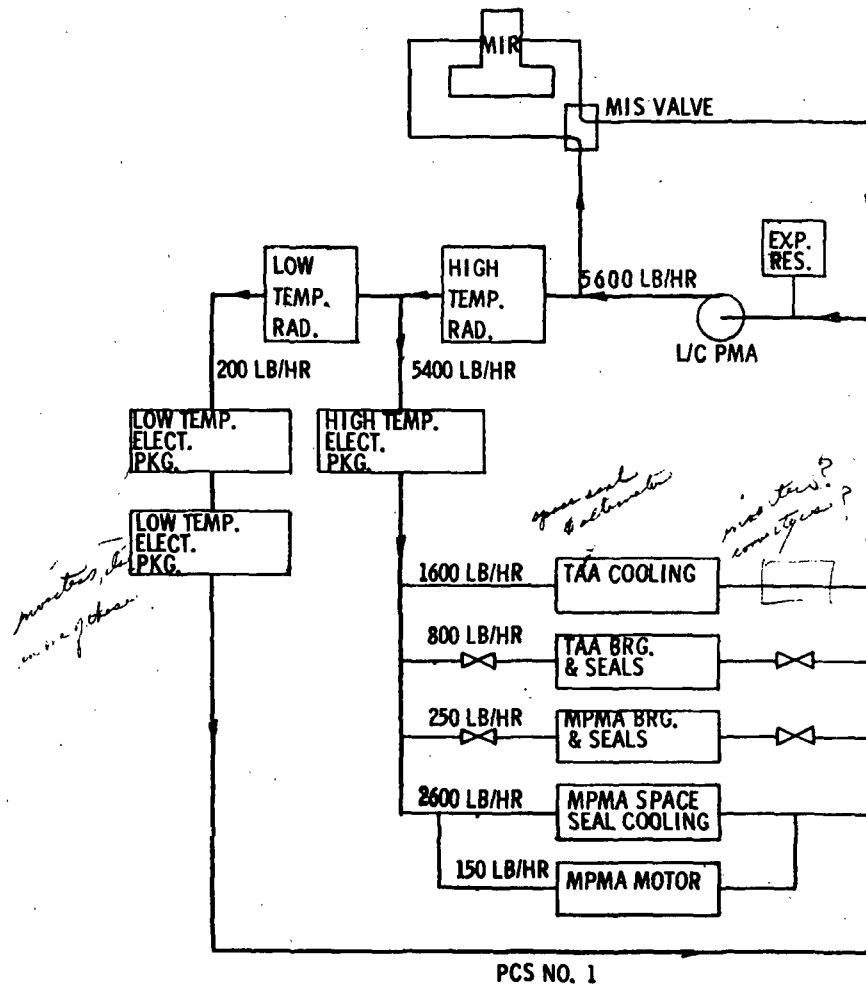


FIGURE IIA-2-3

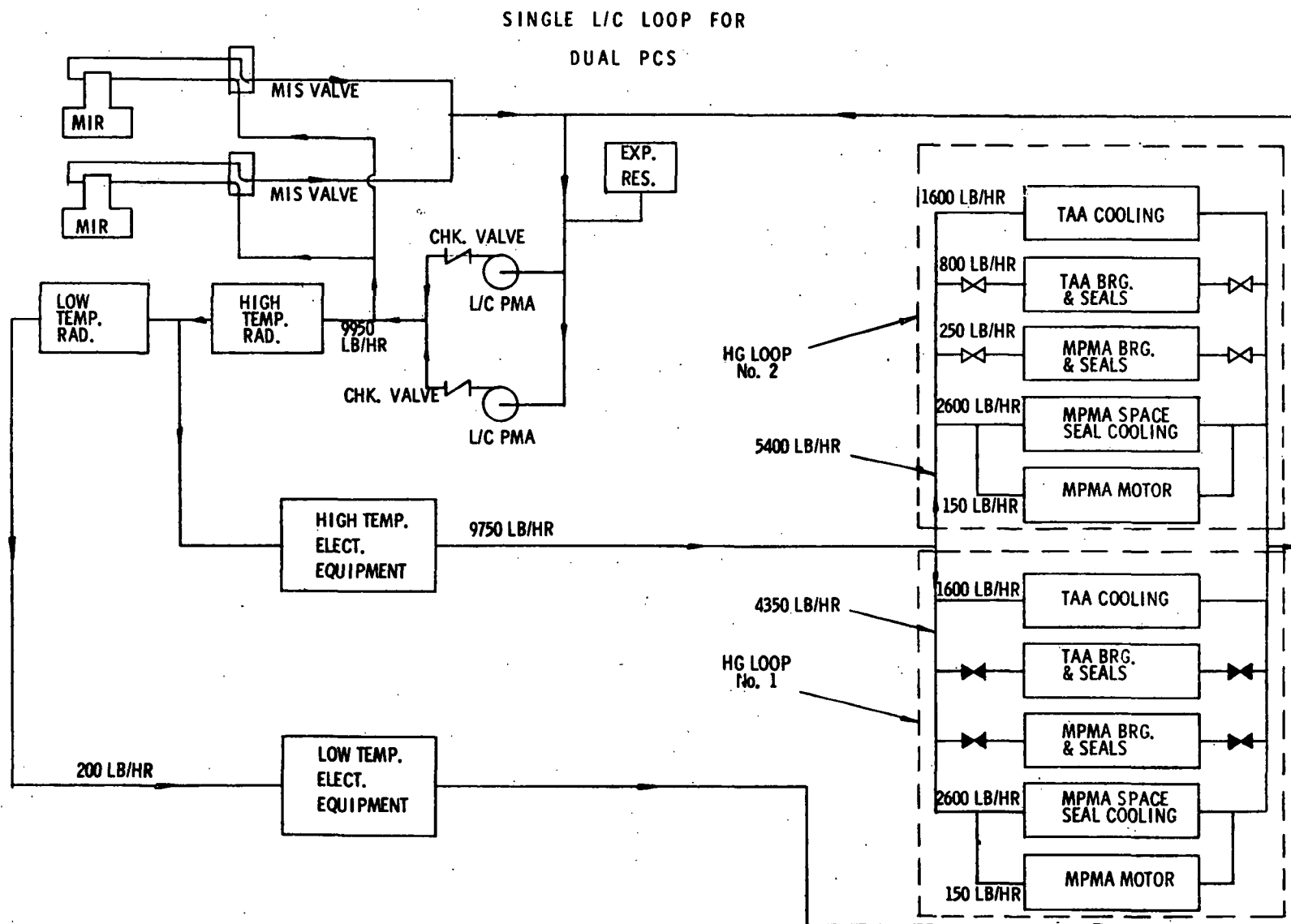


FIGURE IIA-2-4

ENGINEERING ANALYSIS OF ELECTRICAL CONTROLS INTO PCS-G MOD-A

E - Electrical System Excluding Programmer

P - Programmer

PCS - Power Conversion System

1 - 1 set of electrical controls

A - 1 programmer

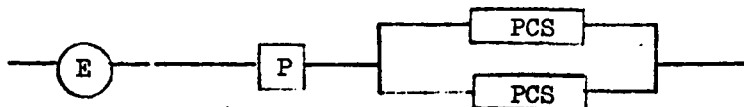
2 - 2 sets of controls, 1 for each PCS

B - 2 programmers, 1 for each PCS

3 - 2 sets of controls, interchangeable

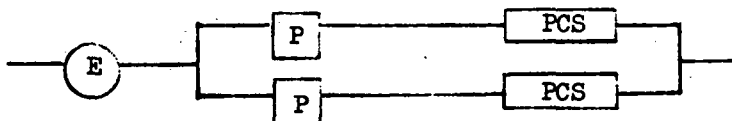
C - 2 programmers, interchangeable

System 1A



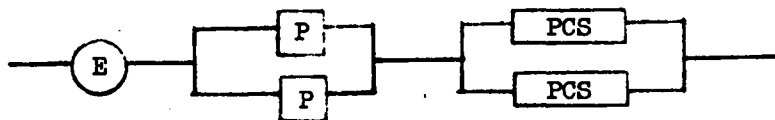
		<u>Total</u>
1. Control Transfer Contacts	13	43
1a. Valve Transfer Contacts	30	
2. Emergency Shutdown Transfer Contacts	0	0
3. Control Diodes	0	30
3a. Valve Diodes	30	
		<u>73</u>

System 1B



		<u>Total</u>
1. Control Transfer Contacts	16	16
1a. Valve Transfer Contacts	0	
2. Emergency Shutdown Transfer Contacts	8	8
3. Control Diodes	8	8
3a. Valve Diodes	0	
		<u>32</u>

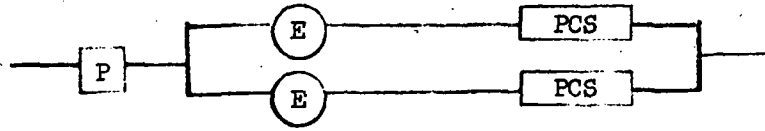
System 1C



		<u>Total</u>
1. Control Transfer Contacts	24	54
1a. Valve Transfer Contacts	30	
2. Emergency Shutdown Transfer Contacts	10	10
3. Control Diodes	16	46
3a. Valve Diodes	30	
		<u>110</u>

Figure IIA2-6
Sheet 1 of 3

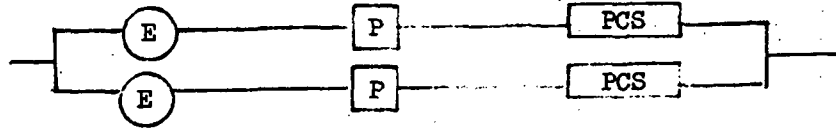
System 2A



Total

- | | | |
|---|---|--------------|
| 1. Control Transfer Contacts | } | (Same as 1B) |
| 1a. Valve Transfer Contacts | | |
| 2. Emergency Shutdown Transfer Contacts | | |
| 3. Control Diodes | | |
| 3a. Valve Diodes | | |

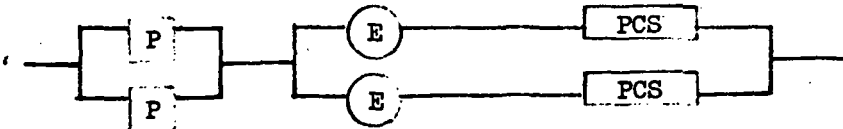
System 2B



Total

- | | | | |
|---|---|---|-----------|
| 1. Control Transfer Contacts | 8 | } | 8 |
| 1a. Valve Transfer Contacts | 0 | | |
| 2. Emergency Shutdown Transfer Contacts | 0 | | 0 |
| 3. Control Diodes | 2 | } | 2 |
| 3a. Valve Diodes | 0 | | |
| | | | <u>10</u> |

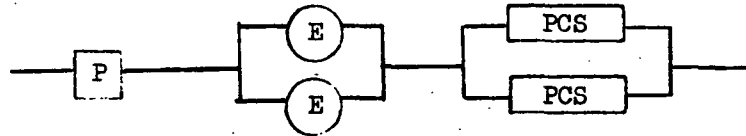
System 2C



Total

- | | | | |
|---|----|---|------------|
| 1. Control Transfer Contacts | 30 | } | 60 |
| 1a. Valve Transfer Contacts | 30 | | |
| 2. Emergency Shutdown Transfer Contacts | 20 | | 20 |
| 3. Control Diodes | 32 | } | 62 |
| 3a. Valve Diodes | 30 | | |
| | | | <u>142</u> |

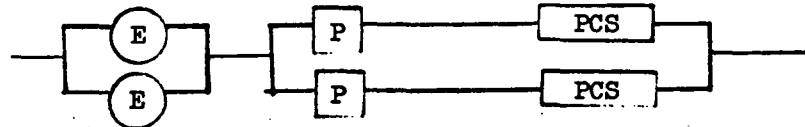
System 3A



Total

- | | | |
|---|---|--------------|
| 1. Control Transfer Contacts | } | (Same as 1C) |
| 1a. Valve Transfer Contacts | | |
| 2. Emergency Shutdown Transfer Contacts | | |
| 3a. Valve Diodes | | |

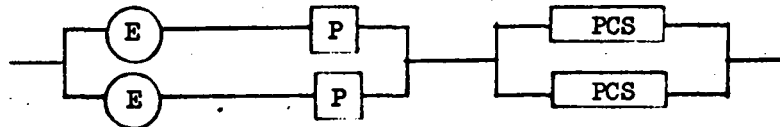
System 3B



Total

- | | | | |
|---|----|---|----|
| 1. Control Transfer Contacts | 16 | } | 16 |
| 1a. Valve Transfer Contacts | 0 | | |
| 2. Emergency Shutdown Transfer Contacts | 20 | | 20 |
| 3. Control Diodes | 12 | } | 12 |
| 3a. Valve Diodes | 0 | | |
| | | | 48 |

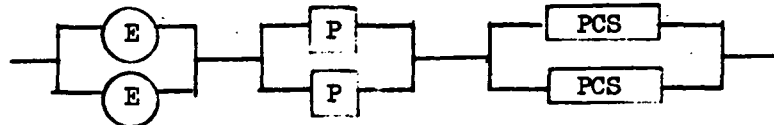
System 3Ca



Total

- | | | |
|---|---|--------------|
| 1. Control Transfer Contacts | } | (Same as 1A) |
| 1a. Valve Transfer Contacts | | |
| 2. Emergency Shutdown Transfer Contacts | | |
| 3a. Valve Diodes | | |

System 3Cb



Total

- | | | | |
|---|----|---|-----|
| 1. Control Transfer Contacts | 40 | } | 70 |
| 1a. Valve Transfer Contacts | 30 | | |
| 2. Emergency Shutdown Transfer Contacts | 20 | | 20 |
| 3. Control Diodes | 42 | } | 72 |
| 3a. Valve Diodes | 30 | | |
| | | | 162 |

DIVISION Power Systems
TM 5282:69-608
DATE 7 January 1970
W.O. 1139-78-2000

TECHNICAL MEMORANDUM

AUTHOR(S): B. L. Amstadter

TITLE: SNAP-8 Single Versus Double Tube Radiator Reliability Analysis

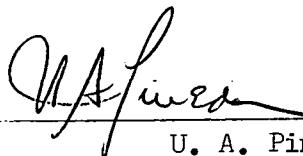
ABSTRACT

This technical memorandum documents a study of the reliabilities of two alternative PCS-G heat rejection loop configurations, reflecting two radiator design concepts. The ground rules and assumptions used for the study are delineated and a set of curves is provided which compares the reliabilities of the two configurations under a number of different conditions. The reliability block diagram and associated mathematical expressions are discussed. Neither configuration has a clear-cut advantage with respect to reliability for all conditions, and the choice of radiator designs depends on the reliabilities of the HR NaK PMAs and associated equipment as well as on the allowable weight of the radiator.

KEY WORDS: Reliability, PCS-G, radiator, heat rejection

APPROVED:

DEPARTMENT HEAD



U. A. Pineda

NOTE: The information in this document is subject to revision as analysis progresses and additional data are acquired.



AEROJET-GENERAL CORPORATION

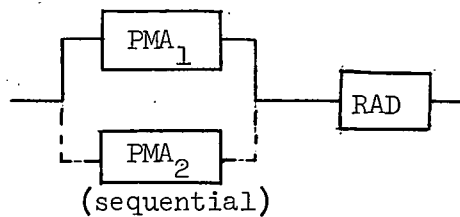
SUMMARY

This study compares the reliabilities of two alternative radiator subsystems. The first subsystem consists of two NaK PMAs in a sequentially redundant (one operating, one standby) configuration, and in series with a single-tube radiator. The second subsystem consists of a dual-tube radiator and two NaK PMAs and associated equipment. Each PMA is connected to one set of tubes, and the PMAs and tubes are in two independent, sequentially operated, heat rejection loops. The results indicate that the choice of configurations (with respect to reliability) is a function of NaK PMA reliability and radiator weight. For total radiator weight below 2670 pounds, a single-tube radiator is preferred, regardless of PMA reliability. Above 2670 pounds, the choice of radiator configuration depends on the reliability of the NaK PMA and associated equipment. A set of curves is included, comparing the reliability of the two configurations with equal weight radiators. An additional curve indicates the reliability break-even points of single vs. dual-tube radiators over the range of radiator weights and PMA reliabilities.

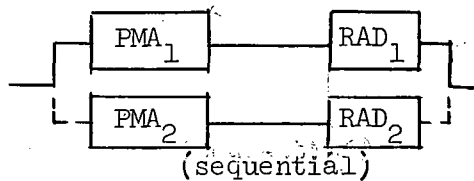
DISCUSSION

In order to determine the optimum radiator configuration, the relative reliabilities of single and dual-tube radiators must be analytically compared. However, since the entire heat rejection (HR) loop configuration is affected by the radiator design, it is necessary to consider the heat rejection loop as a subsystem and to evaluate the overall reliability of the loop. This is a function of radiator weight and the reliability of the NaK PMA and associated equipment. Radiator weight is used as an independent variable since, given a basic radiator design, the radiator reliability is a function of armor plate thickness which, in turn, can be defined in terms of total weight of the radiator.

The subsystem schematic for the two candidate configurations of the HR loop can be represented pictorially by the block diagrams in figure 1.



a. Single-tube Radiator Subsystem



b. Dual-tube Radiator Subsystems

Figure 1. Reliability Block Diagrams of Heat Rejection Loop

Configuration a. of figure 1 indicates that PMA₁ operates first with a single-tube radiator and, in case of failure of the first PMA, the second PMA is started and uses the same set of radiator tubes. A simple flapper-type valve, with reliability approaching unity, would be used to prevent a recirculating NaK flow between the two pumps. This valve and other equipment for failure detection and electrical switching are assumed to be significantly more reliable than the PMA and are not shown in the diagram. The single-tube radiator would have additional armor thickness to compensate for the difference in weight between single and dual-tube radiators, thereby permitting direct comparisons of subsystems with equal weight radiators.

Configuration b. depicts, in a reliability logic diagram, two independent loops, each with a pump and radiator. The dual-tube radiator is a single integrated component containing two separate and independent sets of tubes, one set of tubes for each PMA. In case of failure of the first PMA or leakage from the first set of radiator tubes, the second PMA and second set of tubes are used. There are no cross connections in the actual system, and no valving is required. Failure detection and electrical switching equipment are assumed to be highly reliable and are not shown in the diagram.

A number of assumptions and criteria were formulated to provide a clear basis and set of ground rules for the comparison. Some of these have been indicated above but will be repeated here in more detail. It is important that these assumptions and their implications be fully understood since changes in the ground rules could affect the conclusions.

1. Comparisons are made between subsystems with radiators of equal weight. A single-tube radiator will have sufficient additional armor to compensate for the higher tube, manifold, and fluid inventory weight of a dual-tube radiator.
2. In a single-tube radiator subsystem, a simple flapper-type check valve is sufficient to prevent the recirculating flow of NaK between the two PMAs.
3. The PMA-radiator configuration for a dual-tube radiator consists of two physically independent loops, each with a PMA and one set of radiator tubes.
4. The PMAs operate sequentially. One PMA operates until a failure is incurred; then the second PMA is started. In the single-tube radiator configuration, the failure is that of the PMA; in the dual-tube configuration, the failure of either the first PMA or first set of radiator tubes results in switchover.
5. Failure detection and switching are sufficiently reliable and rapid such that the switchover to the second PMA can be accomplished without affecting the performance or reliability of the rest of the system.
6. In the case of the dual-tube configuration, NaK leakage from either set of tubes (but not both) can be tolerated and does not affect the rest of the system. As long as one PMA and its associated set of radiator tubes is intact, heat rejection can be accomplished.

7. The PMAs are not susceptible to failure in their non-operating state.
8. Failure of the radiator is due to meteoroid impingement. The failure rate while non-operating (in the case of the dual-tube configuration) is the same as the operating failure rate.
9. Probability of radiator damage and its relationship to armor thickness is determined from the equation in the 20 August 1965 memorandum by S. Lieblein of LeRC, based on Whipple's 1963A data.* Radiator design data are derived from R. Geimer's computer program NAKRAD, dated 1-12-67.**
10. All computations are based on a 40,000 hour mission.
11. The weight of armor for a dual-tube radiator is exactly twice that for a single-tube radiator with equal armor thickness.

The first step in the analysis is to relate armor thickness to reliability for 40,000 hours. Using Lieblein's equation and Geimer's data, the following relationships are derived:

$$a) \quad t_{10,000} = C \frac{T_1^{1/4}}{-\ln P_0}$$

$$b) \quad t_{40,000} = C \frac{T_2^{1/4}}{-\ln P_0}$$

where t = thickness; T_1 = time₁ = 10,000 hours; T_2 = time₂ = 40,000 hours;

P_0 = probability of no meteoroid damage = .90 (= reliability); and C is a constant which accounts for the geometry, material, meteoroid velocity, and other factors in Lieblein's equation.

* Memorandum, S. Lieblein to Space Power Systems Division (C. J. Daye), "Meteoroid Protection Criteria", dated 20 August 1965.

** Memorandum, R. G. Geimer and R. J. Huang, "HRL and LCL Radiator Configuration for PCS-G", dated 26 January 1967.

Using Geimer's data, $t_{10,000} = .162$

$$t^4 = c' \left(\frac{T_1}{-\ln P_0} \right) \quad \text{where } c' = c^4$$

$$c' = \frac{-\ln P_0 t^4}{T_1} = \frac{0.10536 (0.162)^4}{10,000} = 0.7256644 \times 10^{-8}$$

$$c = 0.922962 \times 10^{-2} = 0.00922962$$

Since $T_2 = 40,000$ hours is a constant,

$$c \times T_2^{1/4} = \text{a constant} = 0.130525$$

Therefore, the equation relating armor thickness to reliability for a 40,000 hour mission for one set of tubes is:

$$T = 0.130525 / (-\ln R)^{1/4}$$

The second step in the analysis is to determine armor weight as a function of thickness. Since weight is directly proportional to cross-section area (for a given material and design), the cross-section area is determined first, using the dimensions in figure 2.

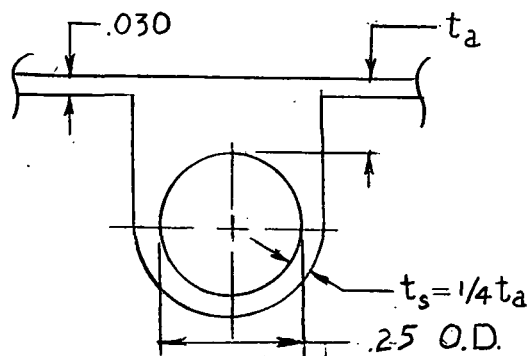


Figure 2. Cross-section of armor showing tube O.D.

$$A = (t_a + 0.125) (0.25 + 1/2 t_a) + \frac{\pi}{2} (0.125 + 1/4 t_a)^2 - \pi (0.125)^2$$

$$A = 0.598175 t_a^2 + 0.410675 t_a + 0.00670637$$

Using Geimer's data and the above equations, a thickness of 0.162" yields a cross-section area of 0.088934 sq. in. and an armor weight of 422.9 pounds for a single set of radiator tubes.

By increasing t_a in small increments, a set of thickness-weight-reliability numbers is obtained for a single set of radiator tubes.

Subsequently, expressions for the reliability of one set of tubes in a dual radiator and the reliability of a single radiator whose total weight is equal to the total weight of a dual-tube radiator are developed. The difference in weight between single and dual-tube radiators is 372.1 pounds plus the weight of the armor for one set of tubes. This difference is added to the weight of armor of the single-tube radiator, and the corresponding thickness and reliability are calculated.

The appropriate equations have been incorporated into computer programs and tabulations have been made of armor thickness, reliability of a single-tube radiator, reliability of each half of a dual-tube radiator, and total weight. Table 1 provides a condensed tabulation of these data.

TABLE 1

Armor Thickness, Reliability, and Weight Data

<u>Armor Thickness (Inches)</u>	<u>Total Weight (Lbs.)</u>	<u>40,000 Hour Reliability of Half of Dual-Tube Radiator</u>	<u>40,000 Hour Reliability of Single-Tube Radiator</u>
.3244	1807	.200	.9741
.3364	1853	.300	.9776
.3486	1901	.400	.9805
.3618	1953	.500	.9832
.3776	2017	.600	.9858
.3976	2100	.700	.9884
.4267	2225	.800	.9913
.4810	2472	.900	.9946
.4906	2517	.910	.9950
.5000	2562	.920	.9954
.5120	2620	.930	.9958
.5225	2670	.938	.9961
.5262	2690	.940	.9962
.5440	2778	.950	.9967
.5672	2892	.960	.9972
.5971	3054	.970	.9977
.6444	3313	.980	.9983
.7365	3855	.990	.99901
.7515	3948	.991	.99909
.7697	4062	.992	.99917
.7797	4126	.9925	.99921
.7906	4196	.993	.99926
.8154	4358	.994	.99934
.8462	4564	.995	.99943
.8859	4837	.996	.99953
.9405	5227	.997	.99963
.9760	5489	.9975	.99968
1.0239	5856	.998	.99974
1.1875	7204	.999	.99985

The reliabilities of heat rejection loop configurations with equal weight radiators can be computed from appropriate mathematical models developed from the block diagrams in figure 1. The mathematical model for the reliability of a single-tube radiator configuration in figure 1a, with sequential operation of the PMAs and no non-operating failure rate is given by equation 1.

$$R_{\text{single}} = e^{-F_{\text{PMA}}} \left[1 + F_{\text{PMA}} \right] \times e^{-F_{\text{RAD}}} \quad (1)$$

where F_{PMA} is the PMA failure rate for a 40,000 hour mission; and

F_{RAD} is the operating failure rate for a single-tube radiator for a 40,000 hour mission.

Note that the general case, e^{-F} , is the expression for the reliability of a single, non-redundant component so that in equation 1, $e^{-F_{\text{PMA}}}$ and $e^{-F_{\text{RAD}}}$ are the expressions for the reliabilities of a single PMA and a single radiator, respectively.

The reliability of the dual-tube radiator configuration in figure 1b, with each PMA and corresponding set of radiator tubes in independent, sequentially-operated HR loops is given by equation (2).

$$R_{\text{dual}} = \left[e^{-F_{\text{PMA}}} \times e^{-F_{\text{RAD}}} \right] + \left[\frac{F_{\text{PMA}} + F_{\text{RAD}}}{F_{\text{NON-OP}}} \right] \left[e^{-F_{\text{PMA}}} \times e^{-F_{\text{RAD}}} \right] \left[1 - e^{-F_{\text{NON-OP}}} \right]^* \quad (2)$$

where F_{PMA} is again the PMA failure rate for a 40,000 hour mission;

F_{RAD} is the operating failure rate for one set of tubes in a dual-tube radiator for a 40,000 hour mission; and

$F_{\text{NON-OP}}$ is the system non-operating failure rate for a 40,000 hour mission.

* This equation is derived from the standard reliability expression for two sequentially-operated systems with equal operating failure rates and a non-operating failure rate for the standby system.

Since the non-operating failure rate of the PMA is assumed to be zero while that of the radiator is equal to its operating failure rate, equation 2 can be changed to:

$$R_{\text{dual}} = \left[e^{-F_{\text{PMA}}} \times e^{-F_{\text{RAD}}} \right] \left[1 + \left(\frac{F_{\text{PMA}} + F_{\text{RAD}}}{F_{\text{RAD}}} \right) \left(1 - e^{-F_{\text{RAD}}} \right) \right] \quad (2a)$$

Note that, in equation 2a, $e^{-F_{\text{PMA}}}$ is again the reliability of one PMA while $e^{-F_{\text{RAD}}}$ is the reliability of one set of tubes in a dual-tube radiator.

By assuming a particular weight radiator (or its equivalent - a radiator configuration with a specific reliability) and by varying the reliability of the PMA, the reliabilities of single and dual-tube radiator systems of equal weight can be compared. System reliability curves have been plotted for a number of radiator reliabilities from 0.90 to 0.9975. (These reliabilities refer to one set of tubes in a dual-tube radiator.) System reliability curves for single-tube radiator systems of equal weight are plotted on the same graphs - figures 3 through 15. For example, the comparison of system reliabilities for a dual-tube radiator system with a 0.99 reliability for each half and a single-tube radiator system of equal weight is shown in figure 12. This figure indicates that, if the reliability of the NaK PMA and associated equipment is less than 0.93, a system with a single-tube radiator (figure 1a) is slightly more reliable. For higher NaK PMA reliabilities, a dual-tube radiator system is more reliable, and its advantage increases significantly as the reliability of the NaK PMA approaches unity.

Note that, for dual-tube radiators with each set of tubes having a reliability below 0.94 (total weight less than 2670 pounds) a single-tube radiator system provides higher reliability for all values of PMA reliability.

On the other hand, for heavy radiators and high NaK PMA reliabilities, the dual-tube configuration is preferred. Also, for heavy radiators, there is essentially no difference in the reliabilities of the two configurations when the NaK PMA reliability is below 0.95.

A final curve, figure 16, shows the break-even points for reliability of the two HR loop configurations. For combinations of PMA reliability and radiator weight which fall on the curve (e.g., $R_{PMA} = .968$, radiator weight = 3,054 pounds) the reliabilities of both configurations are the same (0.9972). For combinations falling below the curve, the single-tube radiator configuration provides higher reliability; for combinations above the curve, the dual-tube configuration is more reliable. Figure 16 does not provide specific system reliability information for combinations not on this curve. The actual system reliabilities and the differences in reliability between the two configurations should be determined from the curves in figures 3 through 15.

In addition to showing radiator weight on the vertical axis of figure 16, two additional scales are provided. One scale shows the corresponding reliability of one set of tubes of a dual-tube radiator whose total weight is given by the weight scale. The second shows the corresponding reliability of a single-tube radiator of equal total weight.

CONCLUSIONS

For radiator weights below 2670 pounds, the single-tube configuration is more reliable. The extent of the advantage depends on actual weight and PMA reliability. As radiator weight increases, the dual-tube radiator configuration has higher reliability for high PMA reliabilities (the exact break-even point varies from about 0.95 to 0.99 PMA reliability) while there is some preference for the single-tube radiator below this level. For radiator weights above 4000 pounds and PMA reliabilities below 0.95, reliabilities of the two configurations are essentially the same.

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS

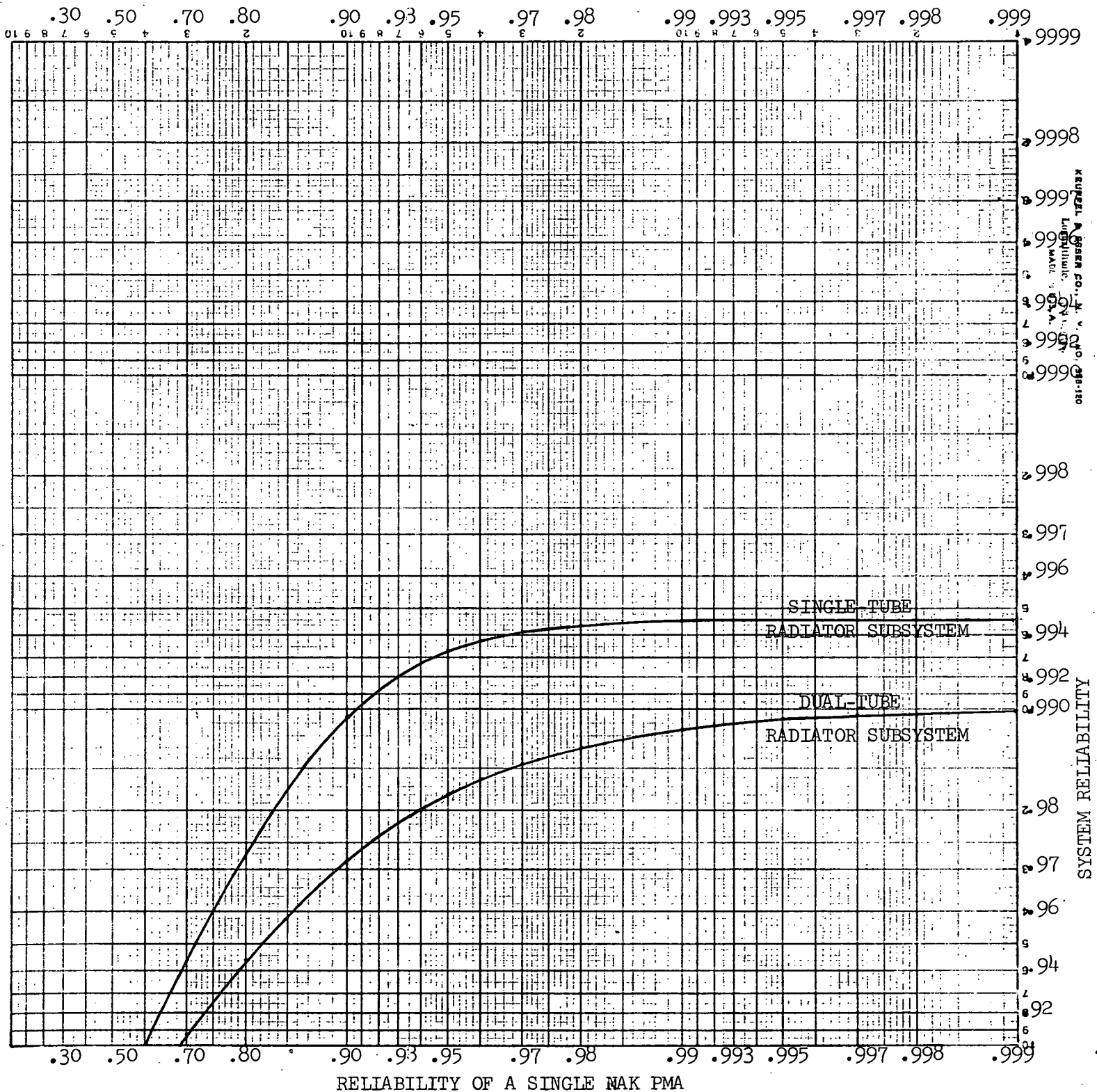


Figure 3

$R_{\text{one set of tubes, dual-tube radiator}} = .900$
 $R_{\text{single-tube radiator}} = .9946$
 Weight (pounds) = 2472

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS

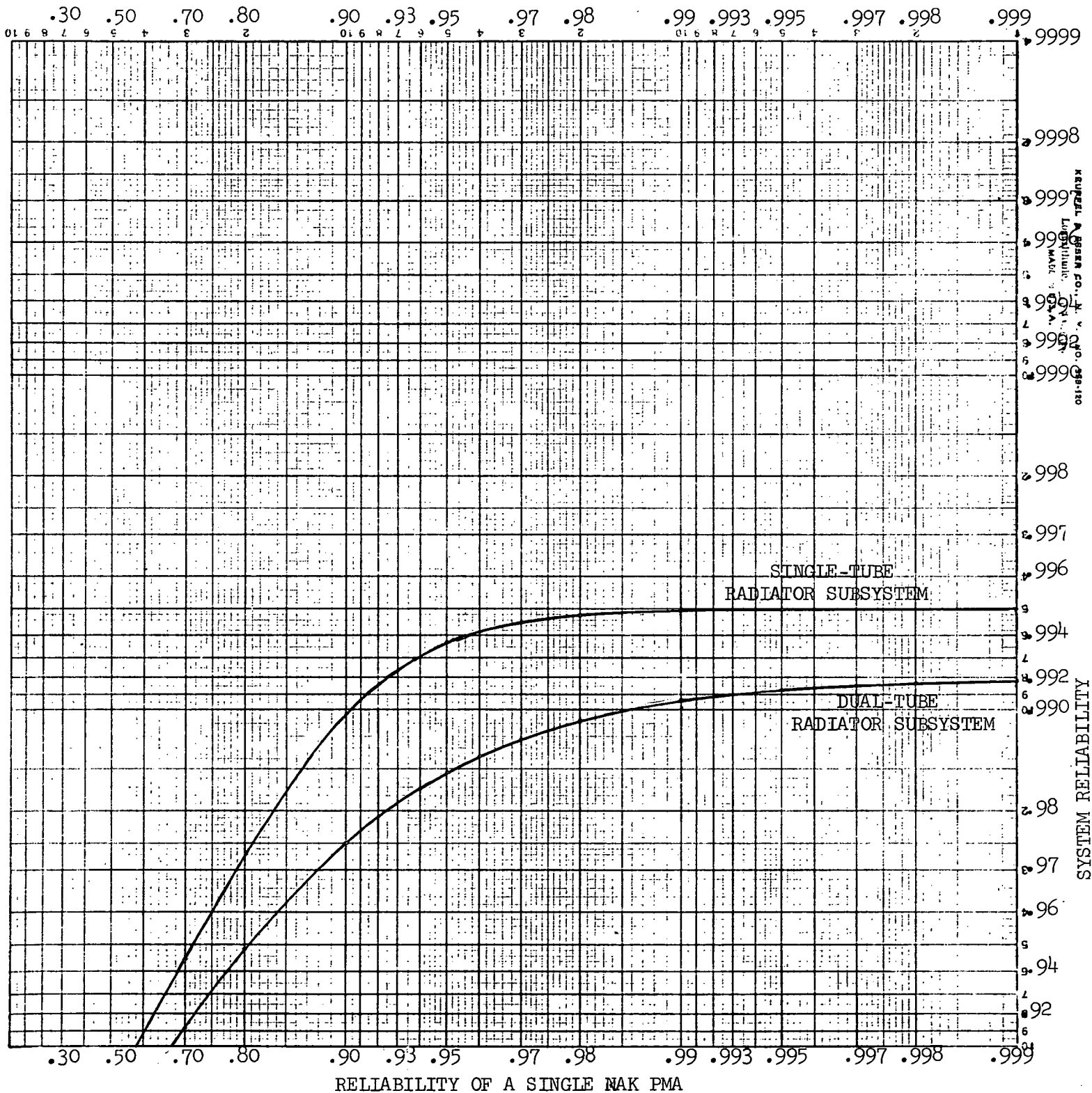


Figure 4

$R_{\text{one set of tubes, dual-tube radiator}} = .910$

$R_{\text{single-tube radiator}} = .9950$

Weight (pounds) = 2517

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS

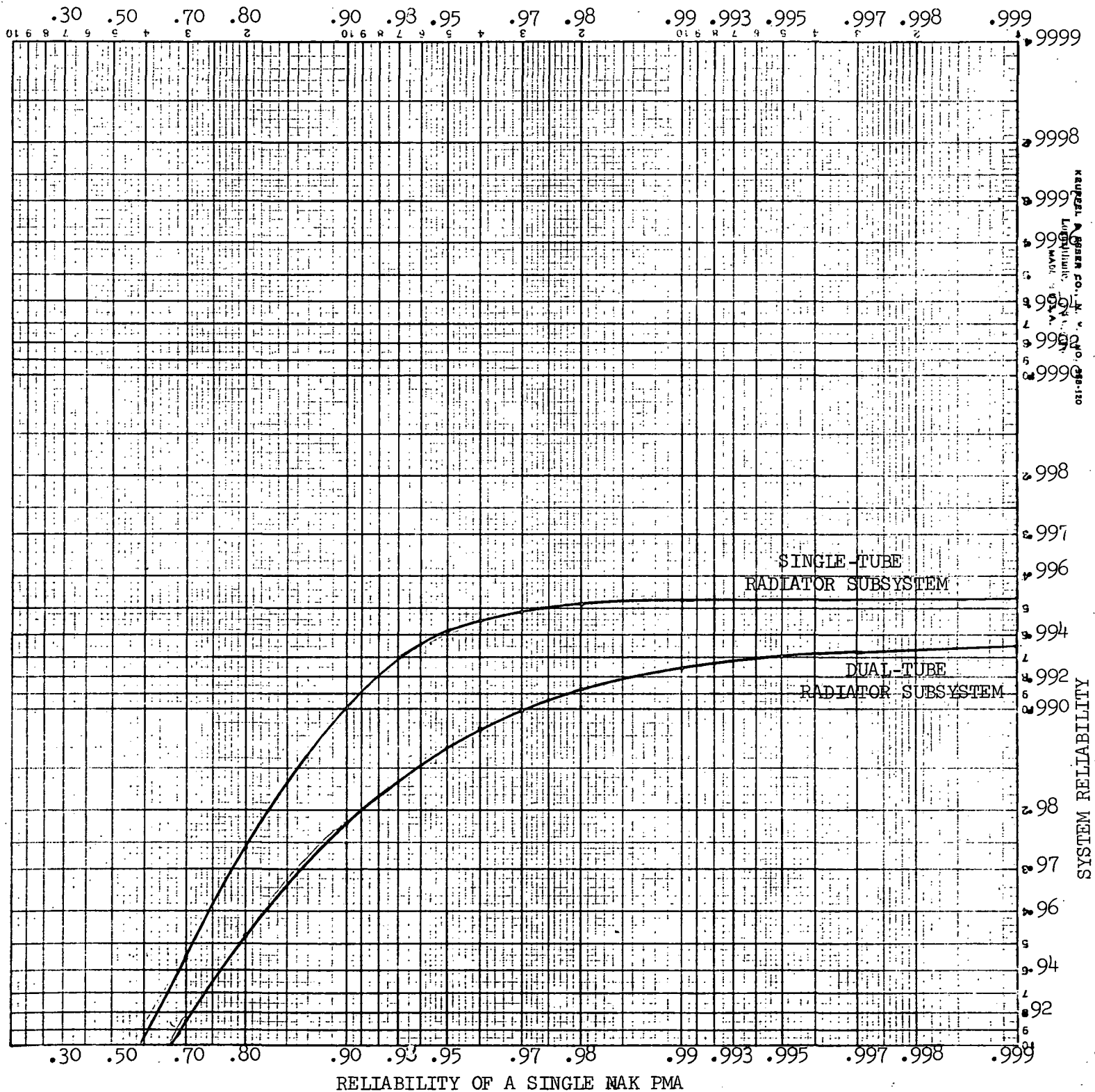
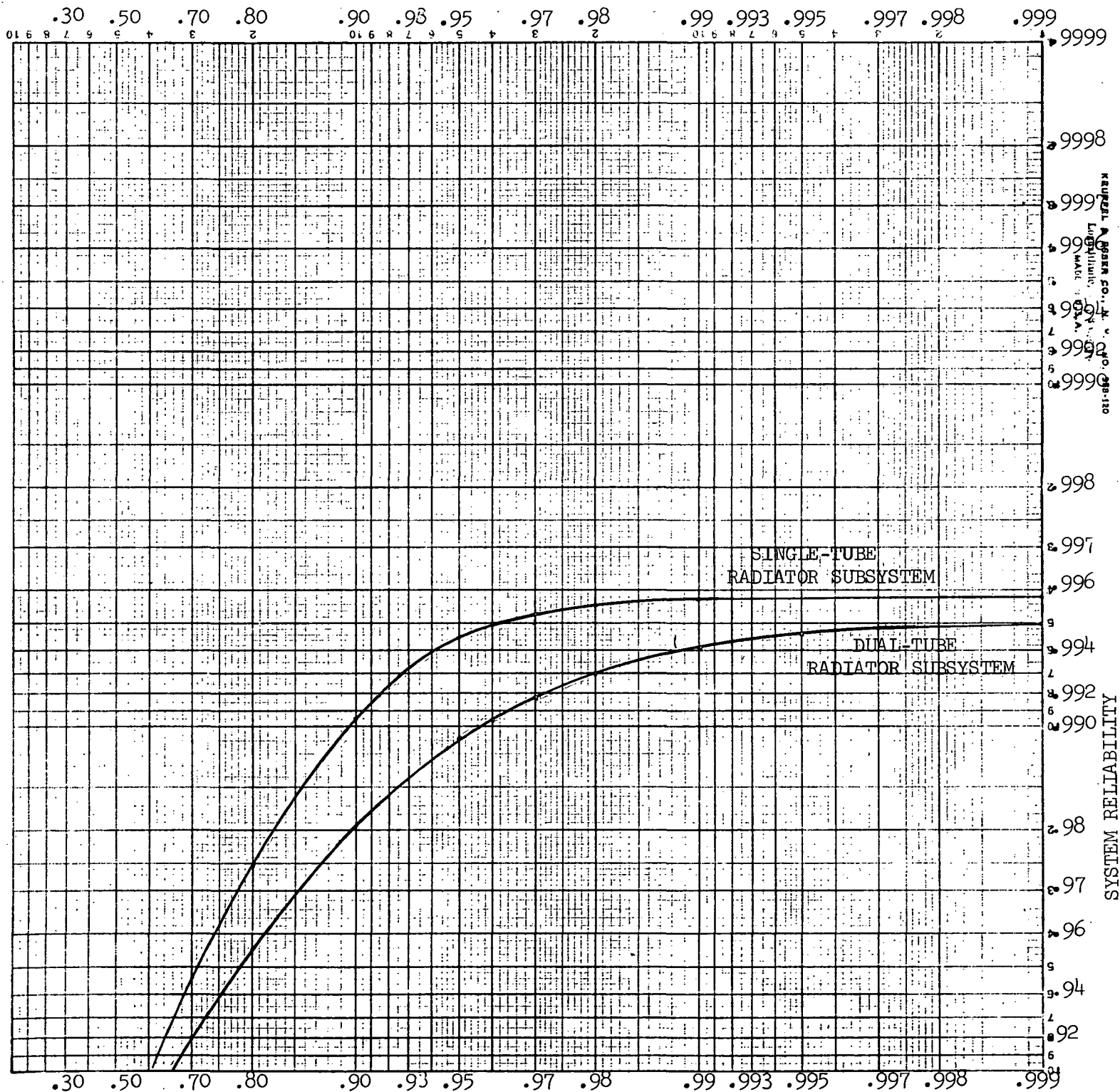


Figure 5

$R_{\text{one set of tubes, dual-tube radiator}}$	= .920
$R_{\text{single-tube radiator}}$	= .9954
Weight (pounds)	= 2562

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS



RELIABILITY OF A SINGLE NAK PMA

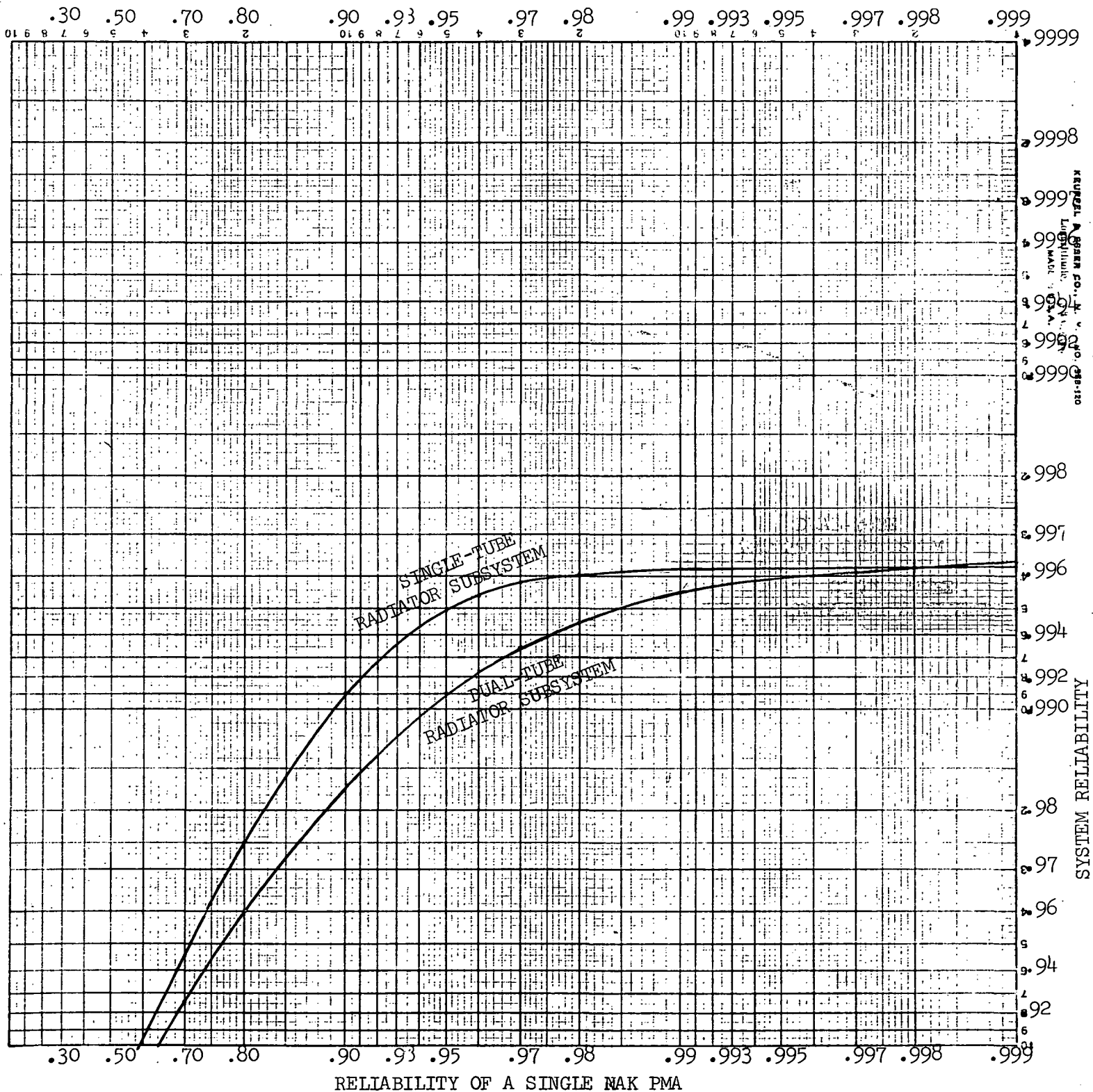
Figure 6

$R_{\text{one set of tubes, dual-tube radiator}} = .930$

$R_{\text{single-tube radiator}} = .9958$

Weight (pounds) = 2620

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS



RELIABILITY OF A SINGLE NAK PMA

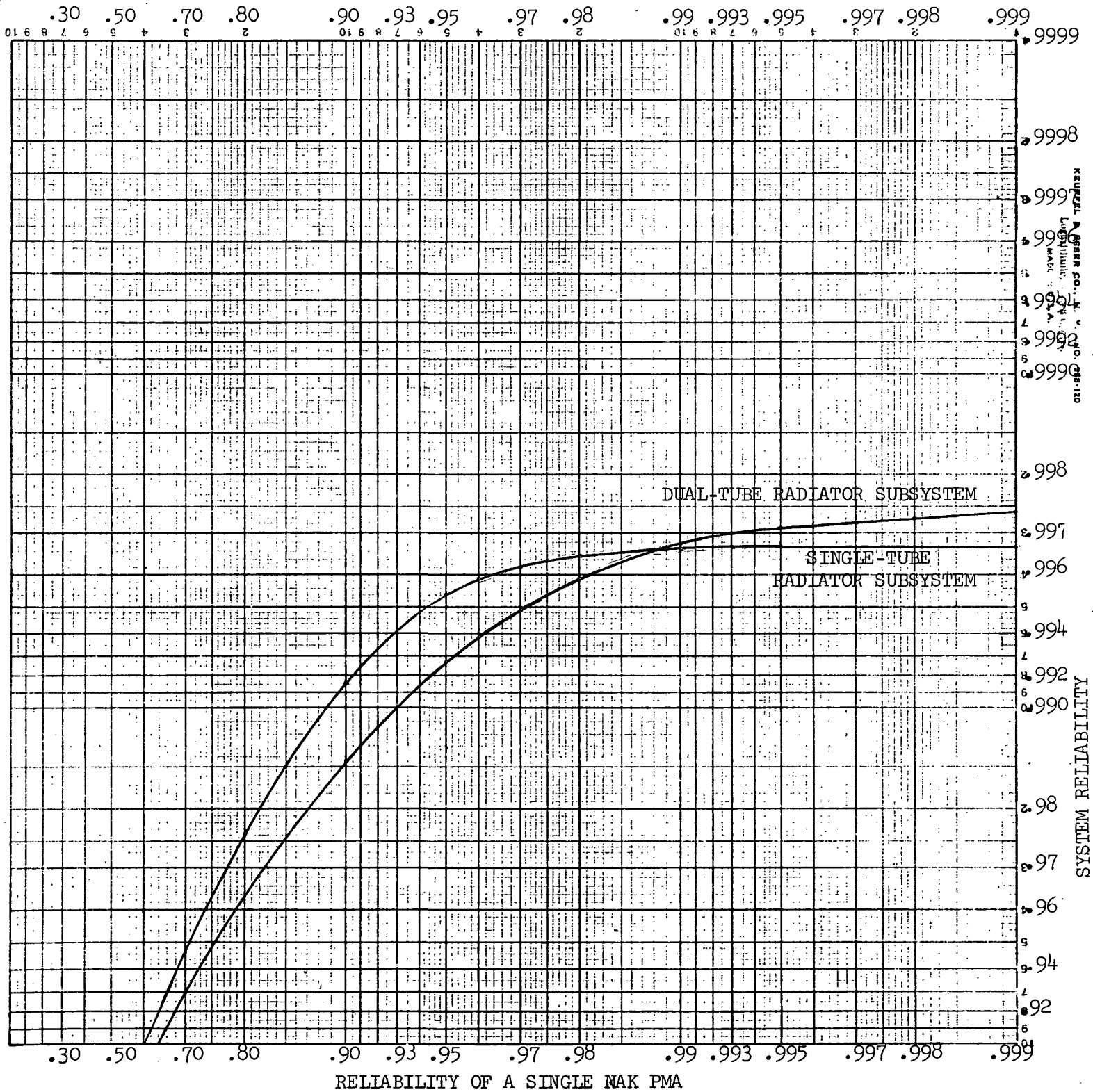
Figure 7

$R_{\text{one set of tubes, dual-tube radiator}} = .940$

$R_{\text{single-tube radiator}} = .9962$

Weight (pounds) = 2690

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS



RELIABILITY OF A SINGLE NAK PMA

Figure 8

$R_{\text{one set of tubes, dual-tube radiator}} = .950$

$R_{\text{single-tube radiator}} = .9967$

Weight (pounds) = 2778

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS

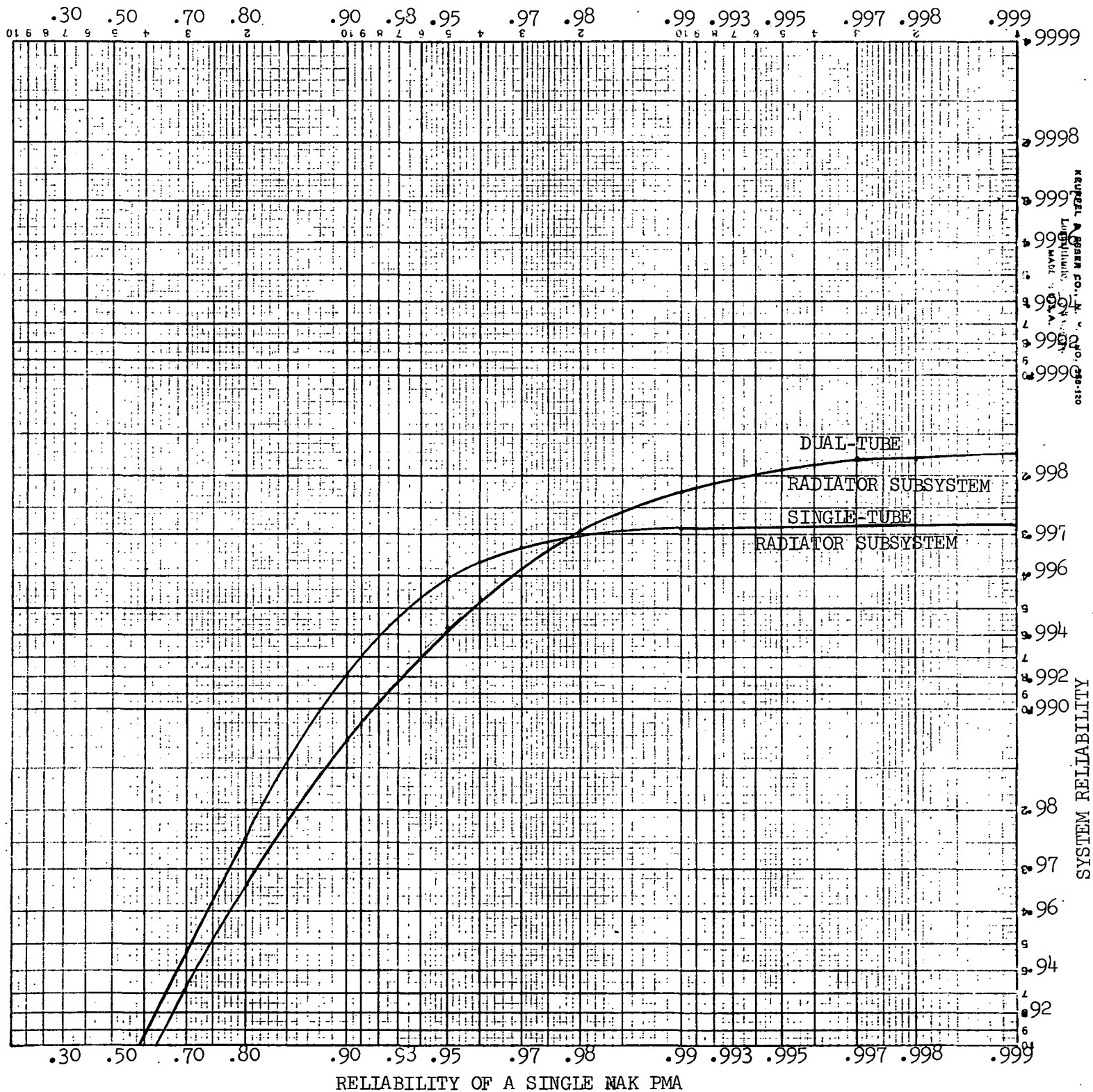


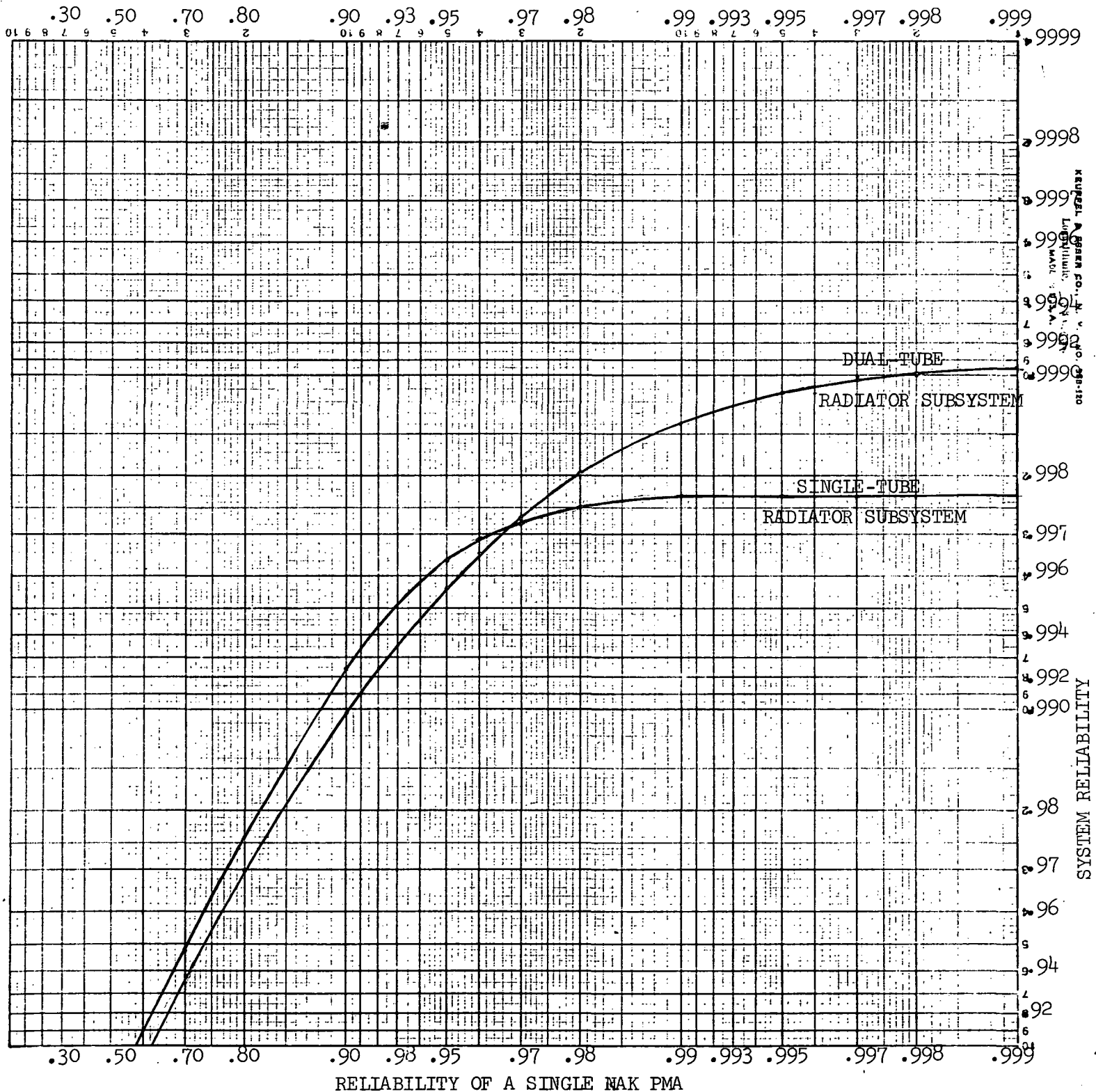
Figure 9

$R_{\text{one set of tubes, dual-tube radiator}} = .960$

$R_{\text{single-tube radiator}} = .9972$

Weight (pounds) = 2892

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS



RELIABILITY OF A SINGLE NAK PMA

Figure 10

$R_{\text{one set of tubes, dual-tube radiator}} = .970$

$R_{\text{single-tube radiator}} = .9977$

Weight (pounds) = 3054

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS

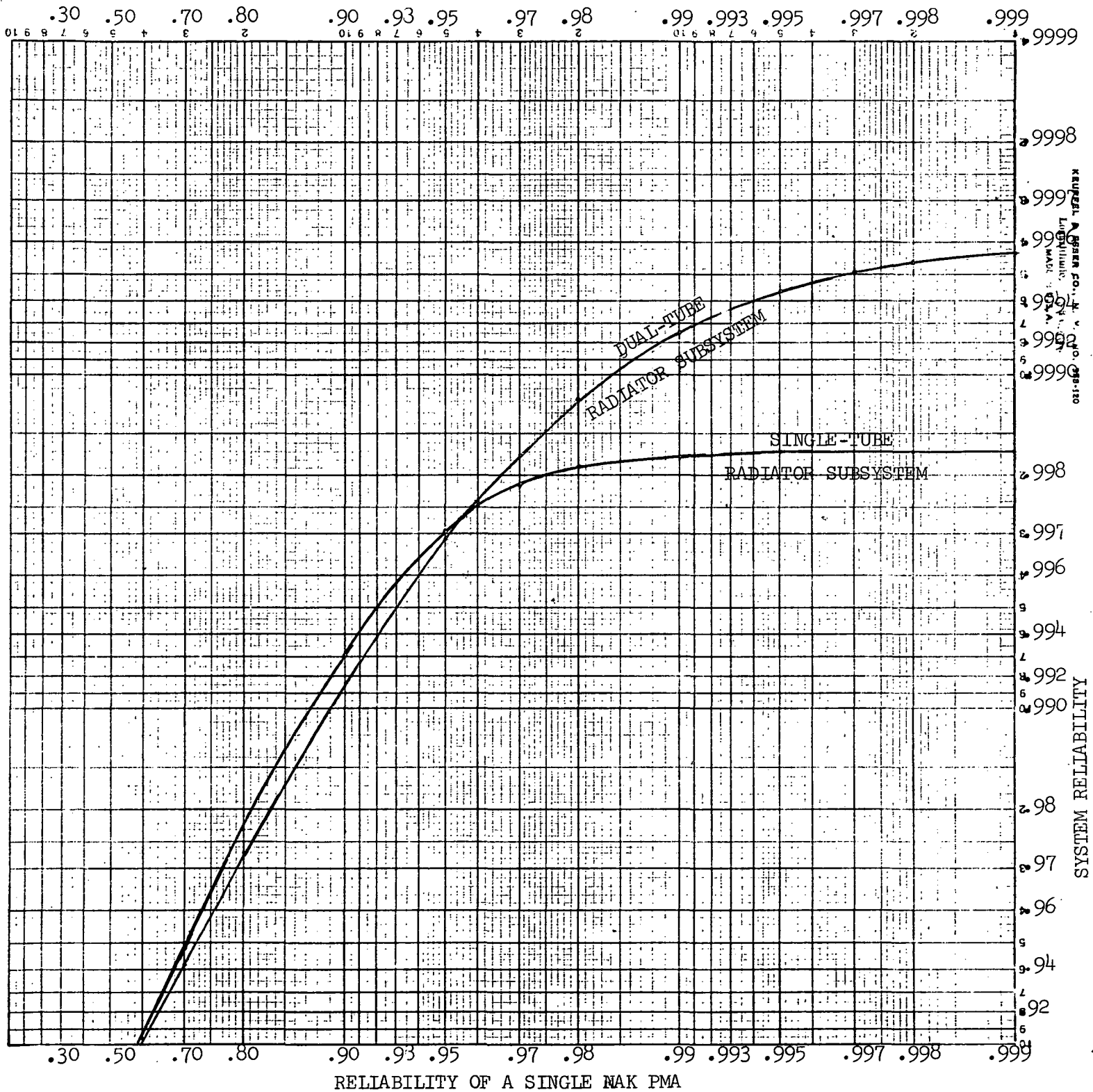


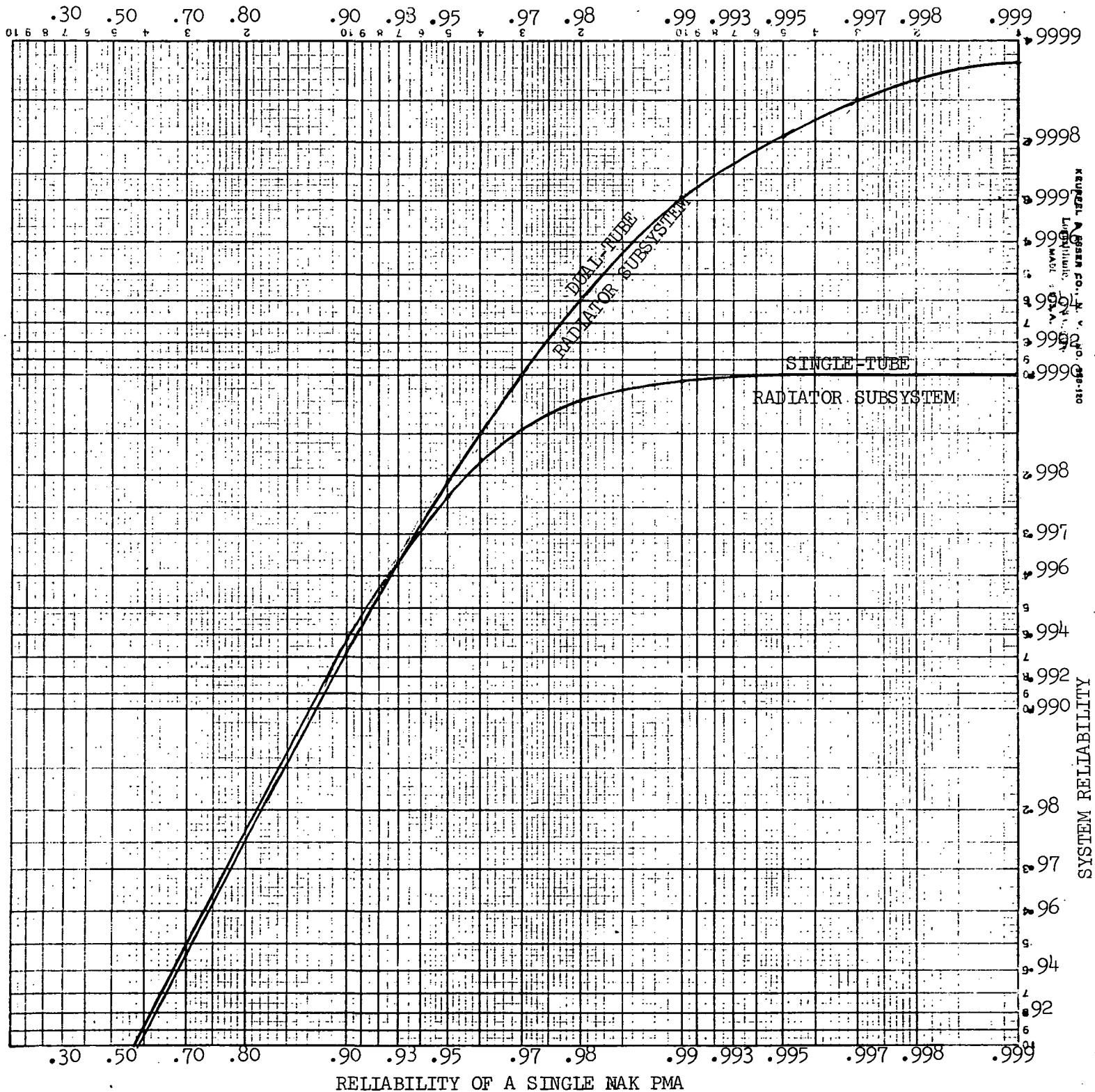
Figure 11

$R_{\text{one set of tubes, dual-tube radiator}} = .980$

$R_{\text{single-tube radiator}} = .9983$

Weight (pounds) = 3313

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS



RELIABILITY OF A SINGLE NAK PMA

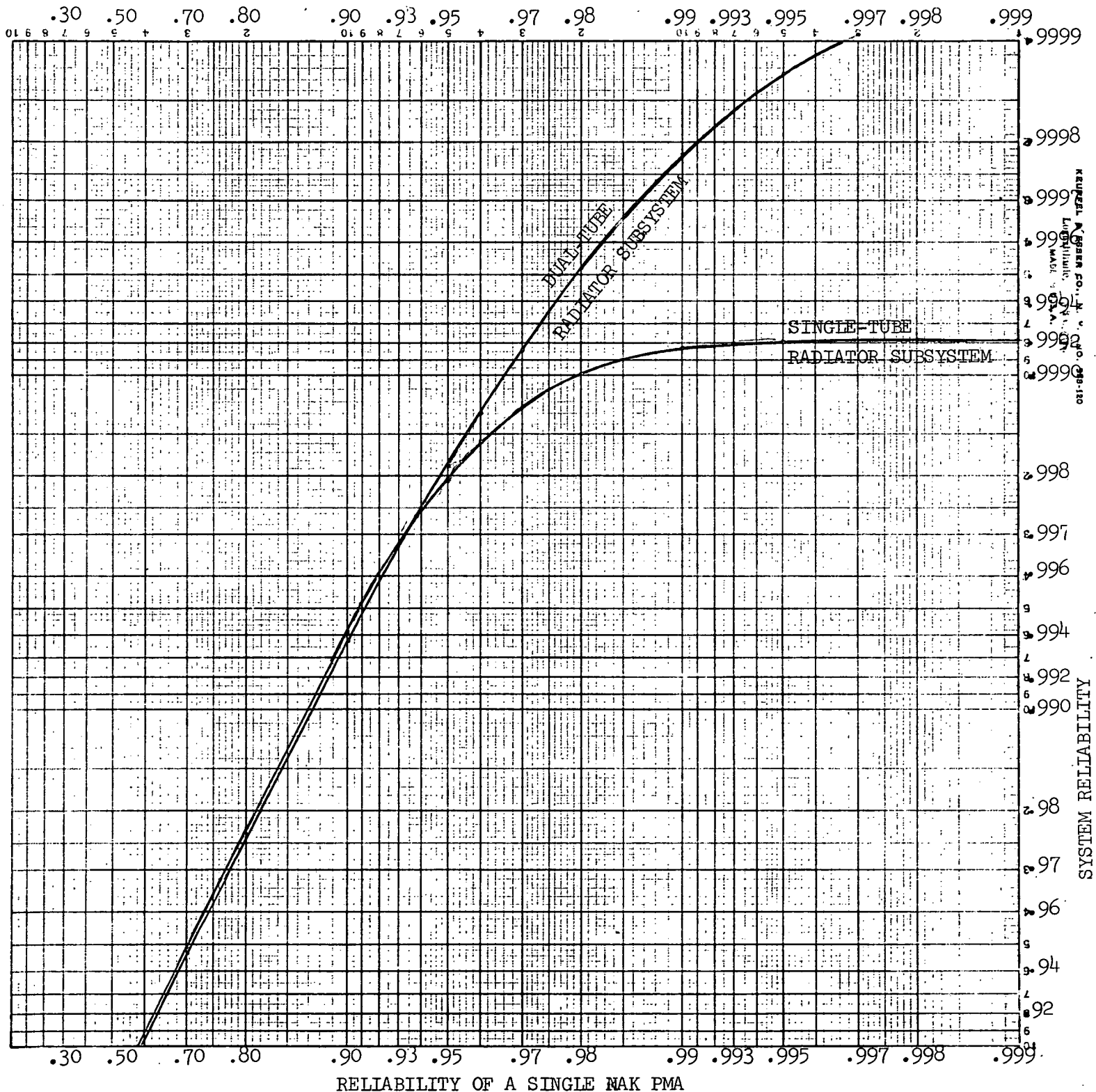
Figure 12

$R_{\text{one set of tubes, dual-tube radiator}} = .990$

$R_{\text{single-tube radiator}} = .99901$

Weight (pounds) = 3855

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS



RELIABILITY OF A SINGLE NAK PMA

Figure 13

$R_{\text{one set of tubes, dual-tube radiator}} = .9925$

$R_{\text{single-tube radiator}} = .99921$

Weight (pounds) = 4126

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS

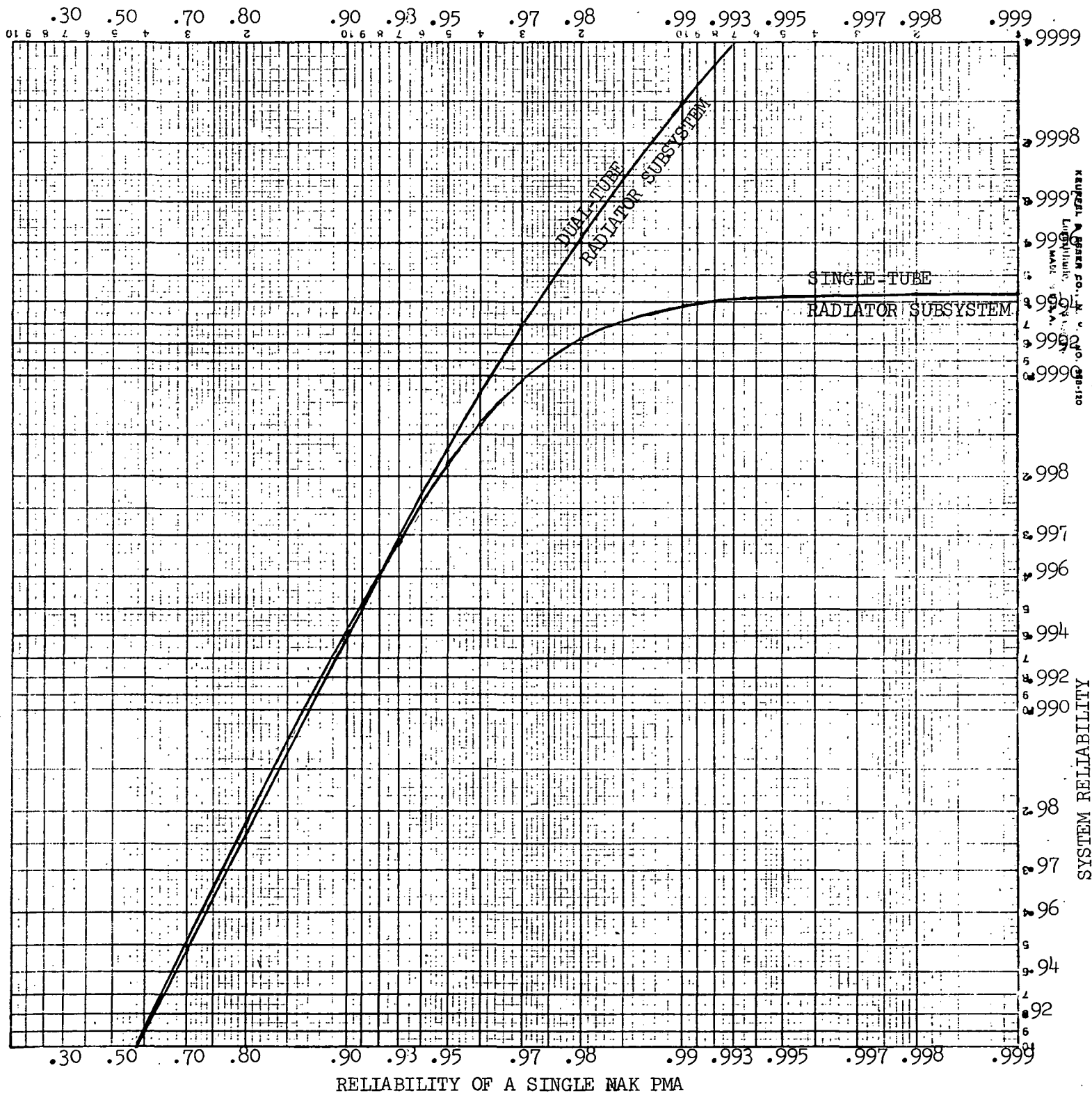
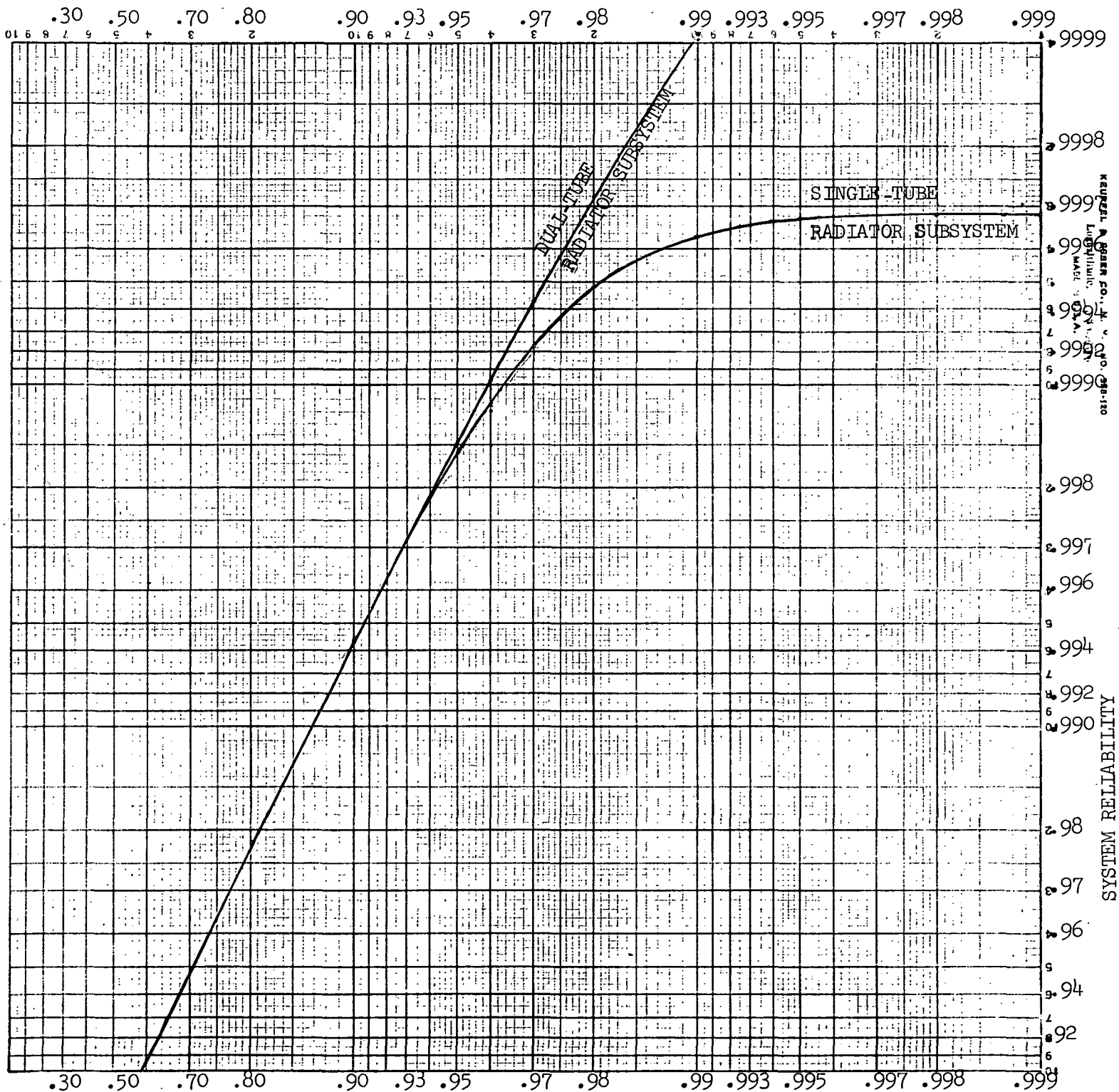


Figure 14

$R_{\text{one set of tubes, dual-tube radiator}} = .995$
 $R_{\text{single-tube radiator}} = .99943$
 Weight (pounds) = 4564

COMPARISON OF RELIABILITIES OF SINGLE AND DUAL TUBE RADIATORS



RELIABILITY OF A SINGLE NAK PMA

Figure 15

$R_{\text{one set of tubes, dual-tube radiator}} = .9975$
 $R_{\text{single-tube radiator}} = .99968$
 Weight (pounds) = 5489

BREAK EVEN CURVE FOR RELIABILITY OF SINGLE-TUBE VS. DUAL-TUBE RADIATOR SUBSYSTEM

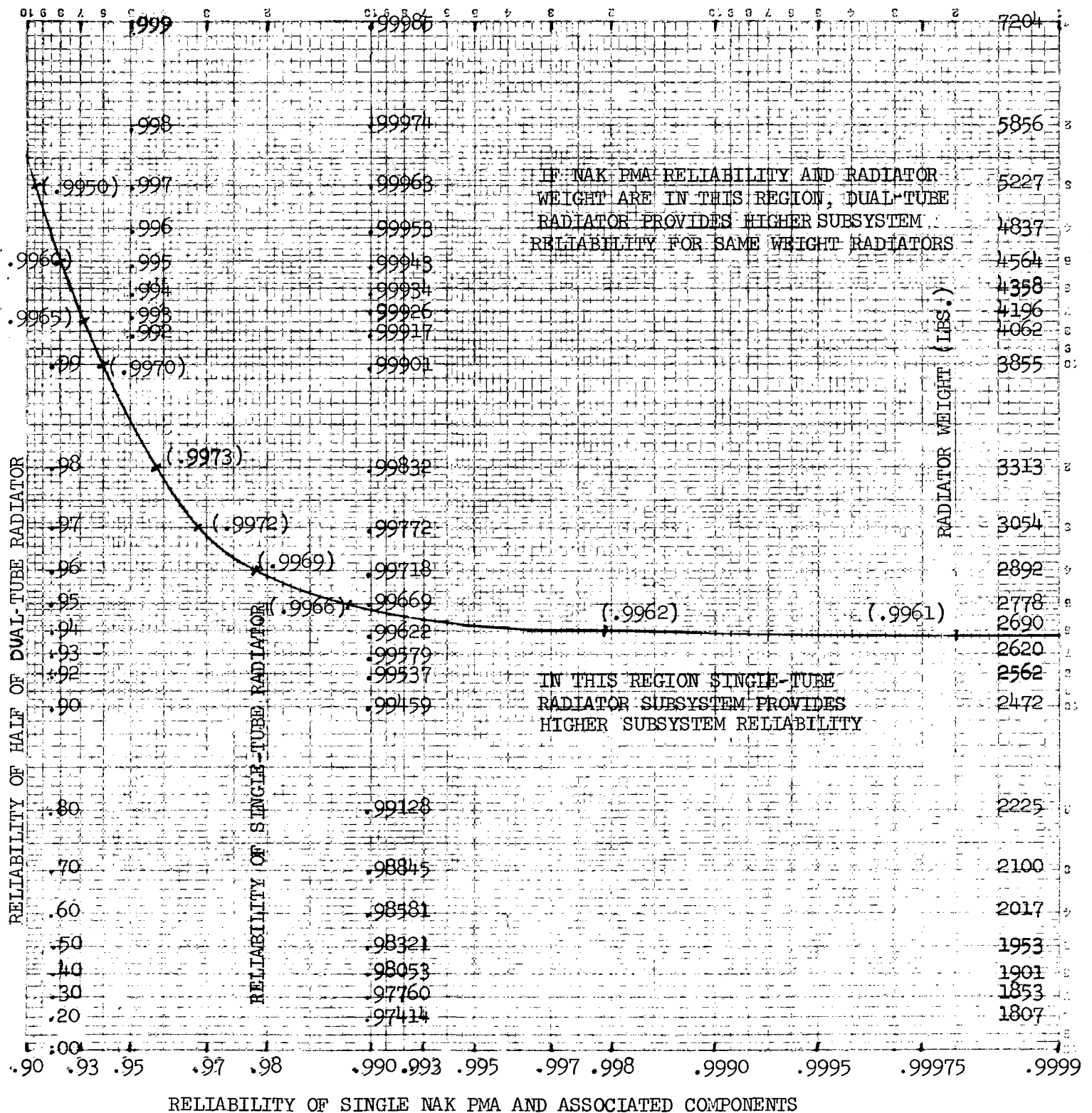


Figure 16

B. OVERALL DESCRIPTION OF LAYOUT

1. Component Arrangement

Figure IIB1-1, Sheet 1, presents the overall PCS component arrangement for the dual PCS configuration concept. The conceptual layout includes the components and piping for redundant mercury and heat rejection loops and the electrical subsystem. The Intermediate Loop has redundant components. The PCS delivered to the NASA Space Power Facility (Plum Brook Station, Sandusky, Ohio) will contain single mercury and heat rejection loops and one electrical subsystem. The Intermediate Loop will be fabricated with redundant components. The conceptual layout has been prepared with redundant system layouts for the following reasons: (1) in order to demonstrate that the PCS envelope selected can include a fully redundant PCS, and (2) to provide information concerning the regions which are available for electrical and instrumentation harness and Lubricant/Coolant Loop routing without interfering with components and piping.

The current component configurations were presented on the PCS layout where possible; thus, there will be no change in the envelope of the following components: alternator, NaK Pump Motor Assembly, Mercury Pump Motor Assembly, and Parasitic Load Resistor. Minor changes are expected for the condenser, turbine assembly, and mercury flow control valve. These changes do not greatly modify the current envelopes for these components, and they were shown on the layout as they are presently designed. For example, the condenser NaK side connections have been changed to 3 inches O.D. tubing and can withstand higher piping loads than previously. The boiler configuration has been changed from a helical coil (54.25-inch mean diameter, 5-inch shell O.D., 6-inch pitch) to a planar configuration. Figure IIB1-2 describes boiler configuration conceptual designs. For the Combined System Test, the second boiler will be associated with the operating PCS. The reservoir envelopes are based on the current specification, AGC-10623; a final revision will be made for these reservoirs

following approval of the conceptual design layouts. Some increase in reservoir inventory is anticipated, due to the fact that the system piping is larger in diameter than the piping which partially influenced the original reservoir requirements; this piping was 2-2 $\frac{1}{2}$ inches in diameter as opposed to the current 3-inch size. Also, the current boiler has about twice the previous boiler's NaK inventory (~200 pounds versus ~100 pounds); there is room on the layout for increased reservoir length to compensate for the increased loop inventories. The HRL Flow Control Valve and Mercury Injection Reservoir configurations are based upon previous conceptual designs for these components prepared to the prior Part I specifications for these components. The electrical equipment housings have been modified for the new PCS envelope and will be discussed in the next section.

The TAA and condenser are close-coupled in order to minimize the pressure loss between the TA exhaust and condenser since the net system electrical power output is decreased by about 1 Kwe for every 1 psia of pressure increase in TA back pressure. The TAA is oriented horizontally since it has been designed for operation and tested in this position. Similarly, the condenser operates with its longitudinal axis within 5 degrees of the environmental gravity vector. Note that the section width is established by the sum of the widths of the two TAAs and associated support structure.

The reservoirs (Heat Rejection and Intermediate Loops) are located between the boilers in order to minimize the overall section width. The reservoirs are oriented so that the fluid inventory does not place a side load on the bellows; i.e., the centerline of the bellows is parallel to the local gravity vector.

The L/C loop components are located near the components that are serviced by the Lube/Coolant circuit (Mercury Pump Motor Assembly, Turbine Alternator Assembly, Mercury Injection system, and Electrical System). This should

result in minimum L/C piping. Note that the NaK Pump Motor Assemblies will be NaK-cooled in the PCS.

The Mercury Pump Motor Assembly is located below the condenser to eliminate pump NPSH problems during ground test. The mercury pump should be located so that the suction pressure does not exceed ~ 40 psia which is the pump visco seal limit. The mercury injection reservoir is located adjacent to the condenser to help eliminate gravity effects in mercury loop inventory control; i.e., the reservoir pressure would equal the state-point condensing pressure. The reservoir is oriented with the bellows center line parallel to the local gravity vector to eliminate side loads on the bellows convolutions due to the reservoir inventory during normal system operation.

The condenser mercury discharge valve is located close to the condenser so that the line between the condenser and mercury pump motor assembly is filled from the reservoir and does not have to be filled by condensing mercury on startup.

The boiler mercury outlet is located as close to the TAA inlet as possible in order to minimize stresses in the mercury vapor line due to thermal expansion of the line.

The electrical components are located as far from the nuclear radiation source as possible, and can be readily isolated from the higher temperature loop components and piping.

The NaK Pump Motor Assemblies are oriented horizontally since the NaK Motor Assembly has been designed for operation and tested in this position. The discharge connection is outboard of the PCS section in order to improve access for pump installation, removal, and replacement.

2. Piping Arrangement

The PCS piping configuration is based upon the system schematic in Figure IIA1-1. The piping configuration for a dual PCS is shown in Figure

IIB1, Sheet 2. The main flow piping in the Intermediate and Heat Rejection Loops is 3 inches O.D. x 0.083 inch wall, 316 stainless steel, with the exception of the piping near the NaK Pump Motor Assemblies. The NaK Pump Motor Assemblies have 2 inches O.D. x 0.065 inch wall suction and discharge connections, and these will not be changed for the Combined System Test PCS. The Heat Rejection Loop piping, to and from the facility heat sink, will be anchored at the frame interface for several reasons: first, this will de-couple the Heat Rejection Loop piping from the facility piping which is an advantage since greater facility piping loads can be imposed upon the frame than upon the PCS components (which would be the case if the facility piping were directly coupled to the PCS piping); secondly, as a consequence of the above, the pressure losses in the lines to the Heat Rejection Loop heat sink can be decreased by using larger diameter piping than the PCS piping. The Lubricant/Cooling piping will also be anchored at the PCS structure periphery. The piping to the Reactor Primary Loop will also be anchored to de-couple the PCS from the RPL.

The lubricant/cooling loop piping will be added, following approval of the PCS conceptual design. It consists of low temperature, small diameter tubing, and it is not expected to be a problem in routing.

3. Electrical Subassembly Description

The electrical subassemblies are shown in Figure IIB3-1. The location of individual modules are presented on Figure IIB3-2. The LTEA-1 is required to provide power to the redundant RPL EM Pump. This configuration reflects the following ground rules:

(a) Start programmer elements are not part of the electrical assemblies, but will be located in the control room during the PCS/CST.

(b) Electromagnetic Interference filters will not be included in the electrical assemblies for the PCS, but there is some space available for these in the High Temperature Electrical Assembly.

(c) Space for static inverters (for rotating and electromagnetic pumps) has been provided in the assemblies.

(d) Low Temperature Electrical Assembly 1A contains existing (developed) electrical modules, LTEA 1B contains new electrical modules, and HTEA contains existing (developed) electrical modules.

(e) The assemblies consist of a cold plate with a vented protective cover fastened to the base plate.

(f) In order to remove and replace modules, the protective cover would be removed from the top.

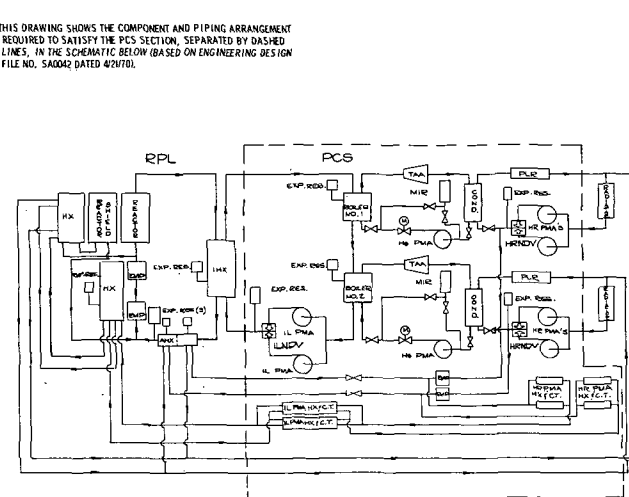
Figure IIB3-3 describes the overall guidelines which will govern the harness design. Finally, the Figure IIB3-4 presents the electrical system schematic.

4. Interface Locations

PCS facility mechanical interfaces will be located at the front face of the PCS to simplify mating with SPF TSE. The regions of the PCS which have been assigned for mechanical, electrical, and instrumentation interfaces are shown on Figure IIB4-1. The mechanical and electrical interfaces are itemized in Figures IIB4-2 and IIB4-3. The instrumentation channel requirements are listed in Figure IIF2.

5. Component List

The major components required for assembly of a CST/PCS are listed in Figure IIB5. Government Furnished Equipment is distinguished from Aerojet Nuclear System Company delivered components.



2. THE GENERAL OVERALL SIZE AND COMPONENT ARRANGEMENT IS BASED ON A QUARTER SCALE MOCKUP BUILT BY NASA PERSONNEL AT THE LEWIS RESEARCH CENTER, CLEVELAND, OHIO.
3. THE COMPONENT ENVELOPE SIZES SHOWN ARE THE PRESENT SNAP-8 DEVELOPMENT HARDWARE WITH THE EXCEPTION OF THE FOLLOWING:

- A. BOILER
THE BOILER SHELL IS 7.50 OD $\times$ 23 FT. 10 IN. LONG
CIRCUMFERENCE OF BOTH 180° TURNS:
DIA. = 45.00
C = 3.14 $\times$ 45.00
C = 141.3 OR 11 FT. 9.3 IN.
DISTANCE FROM UPPER END OF BOILER TO START OF UPPER
180° TURN = 66.50
DISTANCE BETWEEN UPPER AND LOWER 180° TURN = 29.75
DISTANCE FROM LOWER END OF BOILER TO START OF LOWER
180° TURN = 48.45
(BOILER PLUG IS TOTALLY WITHIN STRAIGHT SECTION)
TOTAL LENGTH = 145.3
66.5
29.75
48.45

- 26.75
 48.45
 286.00 OR 29.10 FT. IN.
 N. EXPANSION RESERVOIRS (SPEC. AG-100 ENVELOPE)
 1/4" - 22.00 DIA. (A) 30.00 DIA. (B) 100MM PER. INSULATOR ENVELOPE
 1/4" - 30.00 DIA. (A) 34.00 DIA.
 100R - 18.00 DIA. (A) 40.00 DIA.
 C. ELECTRICAL CABLE RESERVOIR - 7.00 DIA. (A) 3.00 DIA.
 ROYAL CANADIAN PACKAGES - THE CONFIGURATIONS SHOWN
 ARE BASED ON PRELIMINARY PACKAGING CONCEPTS CONTAINED
 IN ENCLOSEURE 10 OF LETTER NO. TWO, DATED 2 MAY 1971.
 (SEE 1. N. BRADLEY TO A. M. NICE.)
 D. NUCLEAR SYSTEM ELECTRICAL CONTROLS - THE PACKAGE ENVELOPE
 IS BASED ON AREA REQUIREMENTS FOR CONTROLS SUPPLIED BY A
 60.00 FT. (1).
 E. MERCURY INJECTION RESERVOIR - THE CONFIGURATION IS
 BASED ON A CONCEPTUAL DESIGN BY METAL BELGIONS COMP.
 INC. (1961).
 F. SM PUMP - ENVELOPE IS BASED ON ASSUMED SIZE OF ONE
 CLERIC FLOW.

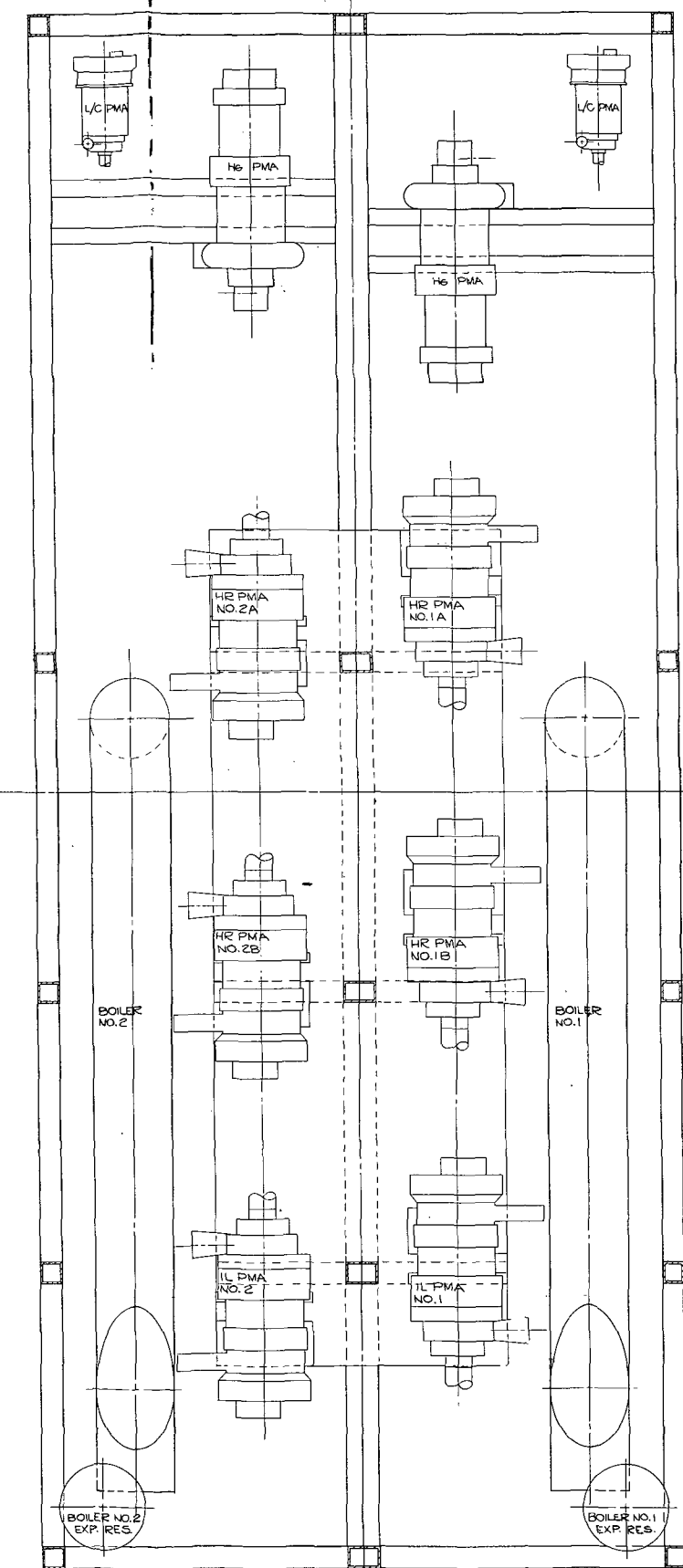
- 4. COMPONENT LOCATIONS:**
- A. TURBINE CONDENSER ASSEMBLY**
DISTANCE FROM TOP OF FRAME PROVIDES CLEARANCE FOR ELECTRICAL TERMINALS. DISTANCE FROM END OF FRAME PROVIDES CLEARANCE FOR U/C TUBING AND ELECTRICAL CONNECTOR. WIDTH OF TAA AND MOUNTS ESTABLISHED 30.0- INCH WIDE FRAME FOR EACH TAA MAKING THE PCS SECTION 60.0 INCHES WIDE.
- B. BOILER**
BOILERS ARE LOCATED AS LOW AS POSSIBLE TO MINIMIZE DRAINAGE FROM THE HG VAPOR LINE INTO THE TAA. THEY ARE LOCATED ON THE W/TER FRAME STRUCTURE TO CLEAR THE HG AN IL RESERVOIR. THE HG VAPOR OUT INTERFAS IS POSITIONED NEAR THE TAA TO MINIMIZE STRESSES IN THE HG VAPOR LINE.

- C. HERE, IIR
THESE RESERVOIRS ARE CENTERED BETWEEN VERTICAL FRAME
MEMBERS, THIS PROVIDES FOR SUPPORT AT THEIR IIR G.
THE IIR AND IIR PUMP-S ARE CENTERED ON THE SAME VERT
FRAME MEMBERS. THE RESERVOIRS ARE LOCATED 40 INCHES
FROM THE TOP OF THE FRAME TO PROVIDE ACCESS TO PRESSU
AND VENT CONNECTIONS. LOCATING THEM HIGH IN THE ASSE
PROVIDE AREA FOR FLEXIBILITY LOSS AND DRAINAGE.
- D. HERE AN IIR PUMP-S
THE PUMP(S) SELECTED HAS TO PROVIDE ACCESS BETWEEN
THE BOILER, AREA BELOW FOR TUBING AND DIVERTER VALVES
AND ORANGE. THEY ARE PLACED NEAR THE CENTER FRAME
AND ORANGE SO THAT PUMP SUCTION AND DISCHARGE LINE
ARE ACCESSIBLE FOR OUTSIDE THE FRAME.

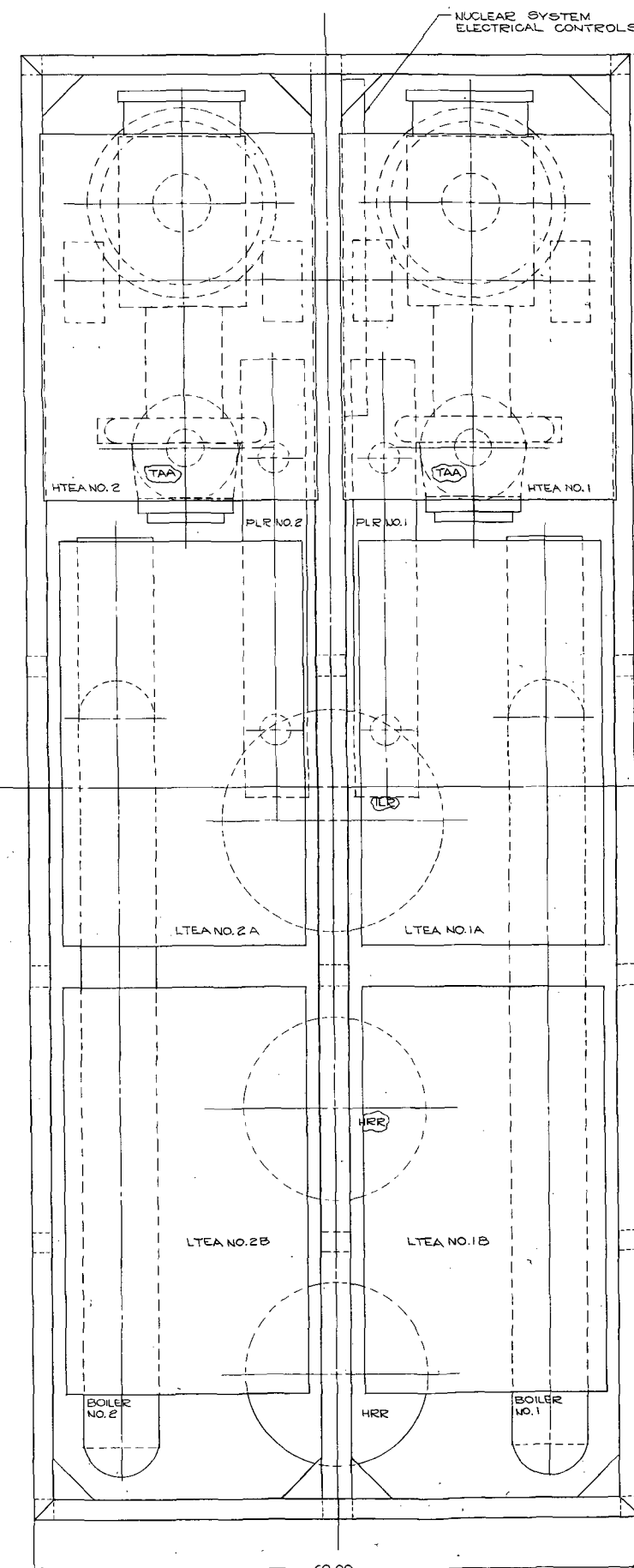
- F. HEAT AND PUMP
THESE COMPONENTS ARE LOCATED NEAR THE H_2 OIL CONDENSER INTERFACES TO MINIMIZE LEAKING LENGTHS IN THE INC. AND THEREFORE, PRESSURE LOSS IN THE PUMP SECTION LINE.
- G. HEAT'S AND LIT'S
THESE UNITS ARE LOCATED ON THE TOP OF THE FRAME WHERE THEY CAN BE EASILY REACHED FROM THE PCS. ELEC. HARNESS ROUTING CAN BE EASILY ACCOMPLISHED WITH THE UNITS LOCATED TOGETHER AND AT THE TOP. THEY ARE LOCATED AS REMOTELY FROM THE RADIATION SOURCE AS POSSIBLE.
- G. LIC PMA'S
THE LIC PMA'S ARE LOCATED TO PROVIDE SAMPLE TUBE ROUT TO COMPONENTS IN THE LIC SYSTEM. THEY ARE ALSO LOCATED IN THE LOWEST TEMPERATURE AREA.
- H. ROLLER EXPANSION SERVISOIRS

5. **STRUCTURAL PHILOSOPHY:**
THE CENTER FRAME STRUCTURE IS CONSIDERED THE PRIMARY STRUCTURE SINCE IT SUPPORTS COMPLETELY, OR PARTIALLY, MOST OF THE COMBINATION OF THE OTHERS. THE SECONDARY STRUCTURE IS THE STRUCTURE FORMING THE OUTER ENVELOPE OF THE PCS, THE TAA'S, KOLA'S, AND LEGA'S ARE PARTIAL SUPPORTED AND THE BOLTERS COMPLETELY SUPPORTED BY THIS STRUCTURE.
6. THE KL PIPING, IL AND HR PIPA'S RECIRCULATION SYSTEMS AND ASSOCIATED PIPING ELECTRICAL AND INSTRUMENTATION HARDWARE ARE NOT SHOWN ON THIS LAYOUT.
7. THE FOLLOWING IS A DESCRIPTION OF THE TUBING SHOWN ON SHEET 2:
MATERIAL: TYPE 316 CRS
SIZE:

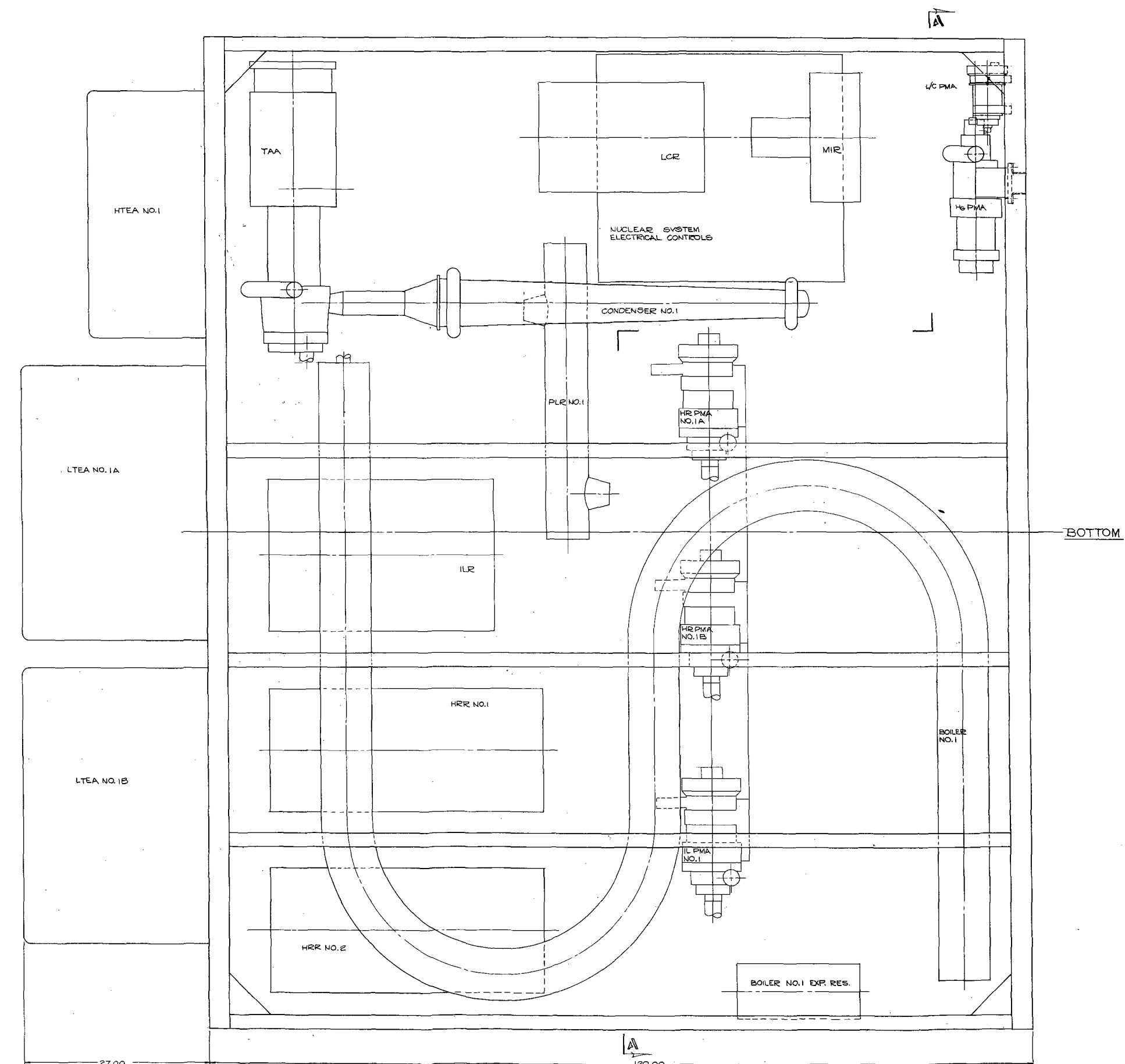
- | NO. | DESCRIPTION | QTY | UNIT | PRICE | TOTAL |
|-----|-----------------------|-----|--|-------|-------|
| 1 | 3.00 O.D. x .083 WALL | 1 | MANIFOLD LINES | | |
| 2 | 2.00 O.D. x .065 WALL | 1 | 11 AND HG PMA'S SUCTION
DISCHARGE LINES | | |
| 3 | 1.50 O.D. x .065 WALL | 1 | EM PUMP LINES | | |
| 4 | 1.00 O.D. x .065 WALL | 1 | RESERVOIR LINES | | |
| 5 | 2.50 O.D. x .120 WALL | 1 | VAPOR LINES | | |
| 6 | 1.00 O.D. x .065 WALL | 1 | CONDENSER TO JET PUMP L | | |
| 7 | 0.75 O.D. x .083 WALL | 1 | JET PUMP TO HG PMA LINES | | |
| 8 | 0.50 O.D. x .065 WALL | 1 | HG PMA TO BOILER LINES | | |



SECTION A - A

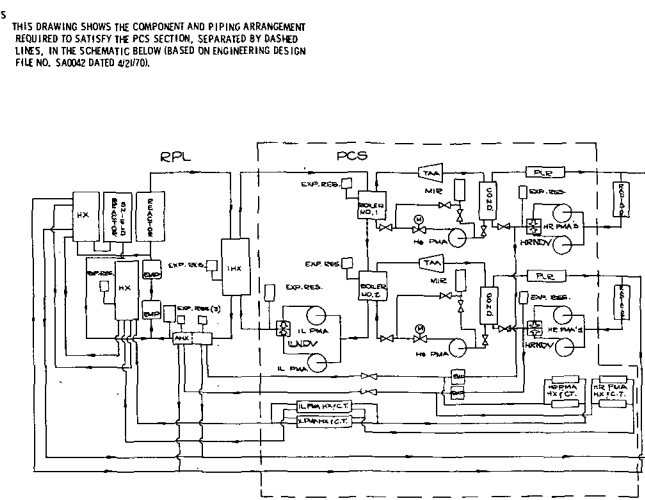


VIEW BELOW SECTION A-A CUTTING PLANE NOT SHOWN



-BOTTOM

[illegible]



2. THE GENERAL OVERALL SIZE AND COMPONENT ARRANGEMENT IS BASED ON A QUARTER SCALE MOCKUP BUILT BY NASA PERSONNEL AT THE LEWIS RESEARCH CENTER, CLEVELAND, OHIO.
3. THE COMPONENT ENVELOPE SIZES SHOWN ARE THE PRESENT SNAP-8 DEVELOPMENT HARDWARE WITH THE EXCEPTION OF THE FOLLOWING:
 - A. BOLLER

- DEVELOPMENT HARDWARE WITH THE EXCEPTION OF THE FOLLOWING:
- A. BOILER
- THE BOILER SHALL BE 5.7' 00" OD X 23.1' 10" IN. LONG
CIRCUMFERENCE OF BOILER 188" TURNS.
- CIA - 45.00
- C - 3.14 X 45.00
- C - 141.3' 00" IN. FT. 9.3' IN.
- DISTANCE FROM UPPER END OF BOILER TO START OF UPPER
188" TURN - 66.50
- DISTANCE BETWEEN UPPER AND LOWER 188" TURN - 29.75
- DISTANCE FROM LOWER END OF BOILER TO START OF LOWER
188" TURN - 46.45
- BOILER PLUG IS TOTALLY WITHIN STRAIGHT SECTION
- TOTAL LENGTH - 141.3'
66.5'
29.75'

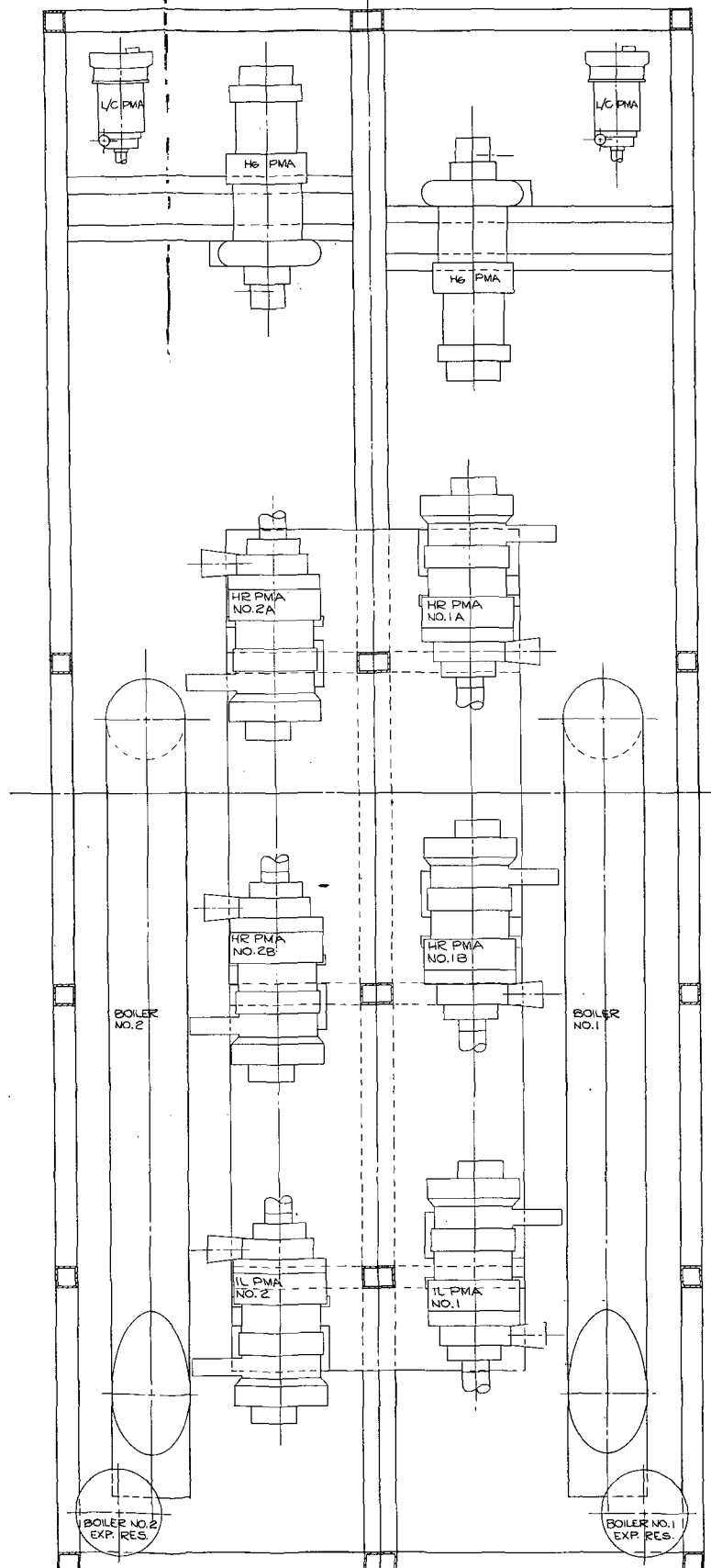
- 25.00 TO 27.75, 20 IN.
- D. EXPANSION RESERVES OF CSP, AGC-10025 ENVELOPES
15.2 - 22.0 IN. X 21.0 IN. FORMER PAPER ENVELOPE LONG
10.0 - 16.0 IN. X 24.0 IN. L.
- HDR - 18.0 IN. DIA. X 40.0 L.
- BOILER STEEL MAX. RESIDUAL STRESS, 8.0 DIA. X 16.0 L.
- E. ELECTRICAL CONTROL PACKAGES - THE CONFIGURATIONS CON-
SIDERED ARE BASED ON PRELIMINARY PACKAGING CONCEPTS CONTAIN-
ING ENCLOSURE (2) OF 10.0 IN. DIA. X 16.0 L. (2) 7.0 IN. DIA.
X 15.0 L. X BRADLEY TO D. W. NICE.
- F. NUCLEAR SYSTEM ELECTRICAL CONTROLS - THE PACKAGE DESIG-
N IS BASED ON AREA REQUIRED FOR NETWORKS SUPPLYING A 2.0
IN. DIA. X 12.0 L.
- G. MERCURY THERMISTOR DESERVATOR - THE CONFIGURATION IS
BASED ON A CONCEPTUAL DESIGN BY METAL BELLWORKS CORP.
(ENCL. 59967).
- H. IN. PUMP - ENVELOPE IS BASED ON ASSUMED SIZE OF ONE
CIRC. FLOW.

4. COMPONENT LOCATIONS:
- A. PRESSURE-CONTAINER ASSEMBLY
1. DISTANCE FROM TOP OF FRAME PROVIDES CLEARANCE FOR ELECTRICAL TERMINALS. DISTANCE FROM END OF FRAME PROVIDES CLEARANCE FOR THE PRESSURE-CONTAINER AND CONNECTOR. WIDTH OF TAA AND MOUNTS ESTABLISHED 30-INCH WIDE FRAME FOR EACH TAA MAKING THE PCS SECTION 60.00 INCHES WIDE.
2. BOILER
- BOLLERS ARE LOCATED AS LOW AS POSSIBLE TO MINIMIZE DRAINAGE FROM THE VAPOR LINE INTO THE TAA. THEY ARE LOCATED ON THE OUTER FRAME STRUCTURE TO CLEAR THE HOT AIR RESERVOIRS AND PROVIDE THE TAA A DRIP NOT INTERFERENCE. IT IS POSITIONED NEAR THE TAA TO MINIMIZE STRESSES IN THE VAPOR LINE.
- C. HEAT EXCHANGER
- THESE RESERVOIRS ARE CENTERED BETWEEN VERTICAL FRAME MEMBERS. THIS PROVIDES FOR SUPPORT AT THEIR C.G. AND MINIMIZES THE STRESS ON THE TAA AND THE CASE.

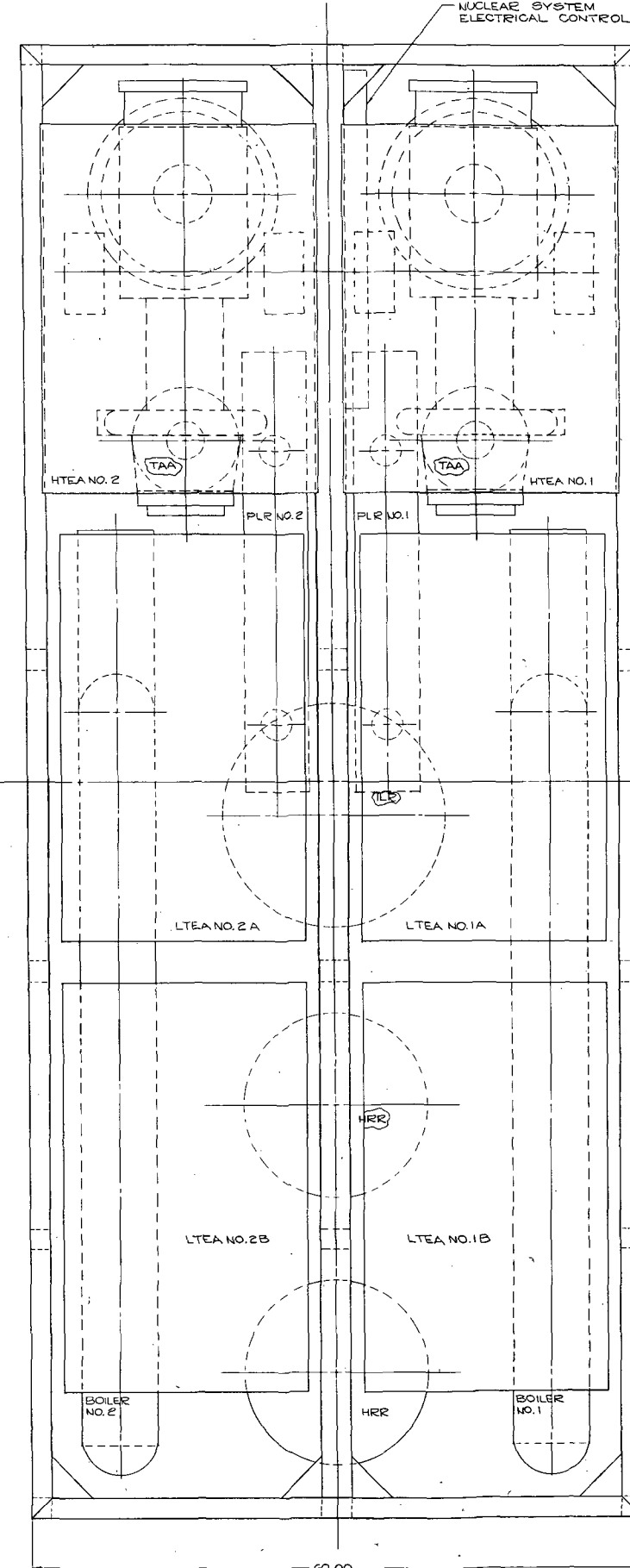
- D. FRAME MEMBERS. THE RESERVOIRS ARE LOCATED 6 INCHES FROM THE TOP OF THE FRAME TO PROVIDE ACCESS TO INSIDE AND VENT CONNECTIONS. THEY ARE LOCATED 18 INCHES FROM EACH OTHER FOR FLEXIBILITY LOOPS AND DRAINAGE.
- E. HEAT EX. PANA'S
THE ELEVATION SELECTED WAS TO PROVIDE ACCESS BETWEEN THE BOILER AREA BELOW FOR TUBING AND OVERFLOW VALVES AND DRAINAGE. THEY ARE PLACED NEAR THE CENTER FRAME AND ORIENTED SO THAT PANAS' FLAME SIDE CONDUITS LINE ARE ACCESSIBLE FOR OUTSIDE THE FRAME.
- F. MINT & MD PANAS'
THESE COMPONENTS ARE LOCATED NEAR THE PG OUT CONDUITS INTERFACE TO MINIMIZE TURNING LENGTHS IN THE H₂O AND THEREFORE, PRESSURE LOSS IN THE PUMP SECTION LINE.
- G. PHMA'S & LGA'S
THESE UNITS ARE LOCATED ON THE TOP OF THE FRAME WHERE THEY CAN BE REACHED BY HAND. THEIR ELECTRICAL WIRING ROUTING CAN BE EASILY ACCOMPLISHED WITH THE

- D. THE PRIMARY STRUCTURE OF THE REACTOR BUILDING IS LOCATED TOGETHER AND AT THE TOP; THESE ARE LOCATED AS REMOTELY FROM THE RADIATION SOURCE AS POSSIBLE.
 - E. THE IC PMA'S ARE LOCATED TO PROVIDE SIMPLE TUBE ROUTES TO COMPONENTS IN THE LOW TEMPERATURE AREA.
 - F. THE IC PMA'S ARE LOCATED TO PROVIDE SIMPLE TUBE ROUTES TO COMPONENTS IN THE LOW TEMPERATURE AREA.
 - G. BOILER EXPANSION RESERVOIRS
 - H. THESE RESERVOIRS ARE LOCATED NEAR THE ENDS OF THE BOILER WHEN THE STATIC NUC CONNECTION WILL BE LOCATED.
5. **STRUCTURAL PHILOSOPHY**
- The CENTER FRAME STRUCTURE IS CONSIDERS THE PRIMARY STRUT SYSTEM IT SUPPORTS COMPLETELY, OR PARTIALLY, MOST OF THE COMBINED WEIGHT OF THE SECONDARY STRUCTURE IS SUPPORTED BY THE PERIMETER WALLS. THE PERIMETER OF THE PCS, HEAT EXCHANGERS, HEATS, & LARS ARE PARTIAL SUPPORTED AND THE BOILERS COMPLETELY SUPPORTED BY THIS STRUCTURE. THE IC PIPING, FLARE GAS PURGE SYSTEMS AND INSTRUMENTATION ARE NOT CUPPING IN THIS LAYOUT.

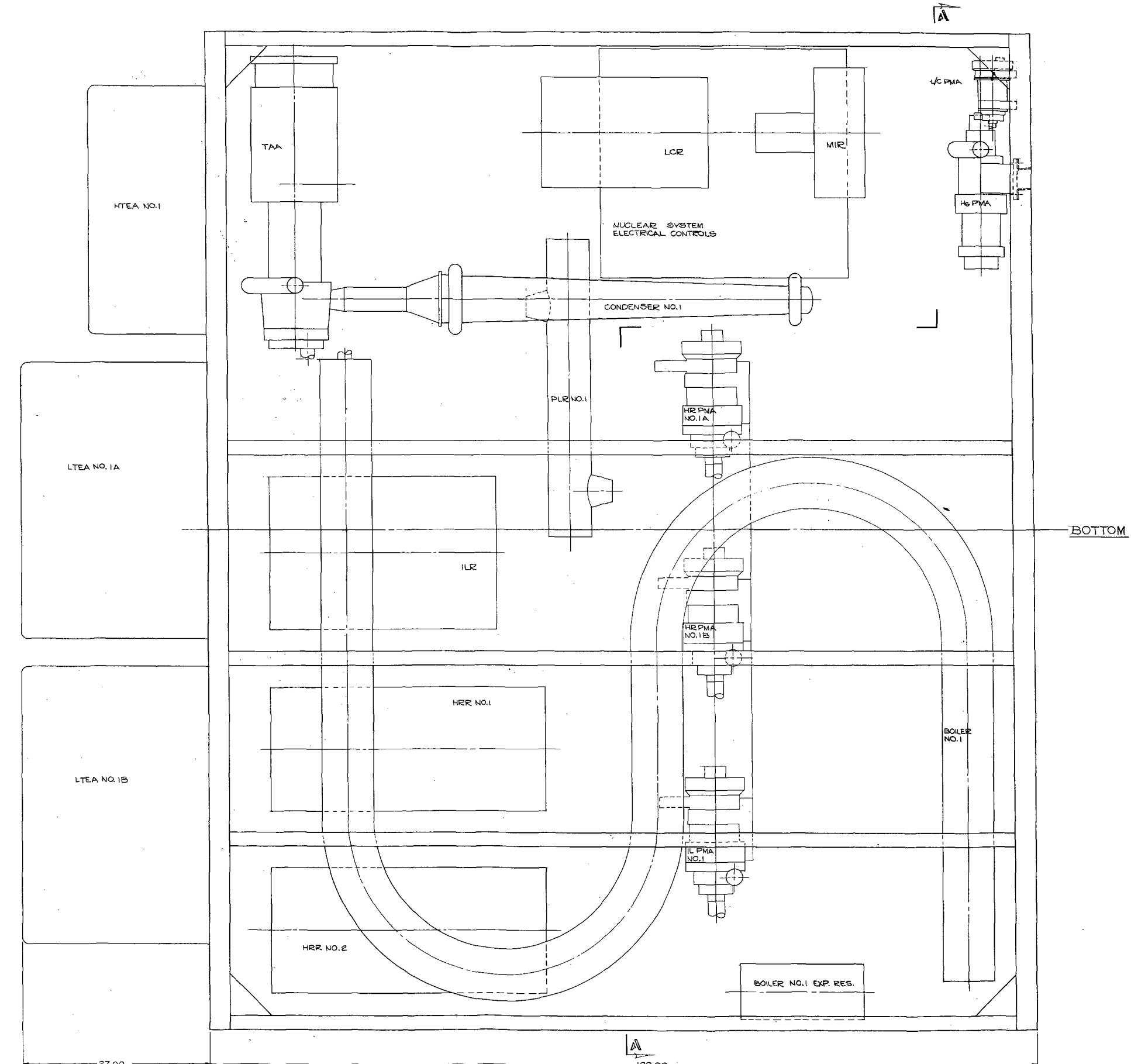
7. THE FOLLOWING IS A DESCRIPTION OF THE FLEBING SHOWN ON SHEET 2:
- | WATERLINE TYPE VALVE SIZE | |
|---------------------------|--|
| <u>HAND/L</u> | 3.00 O. D. x .005 WALL
2.00 O. D. x .005 WALL |
| <u>WGL</u> | 3.00 O. D. x .120 WALL
1.00 O. D. x .005 WALL
2.50 O. D. x .120 WALL
1.00 O. D. x .005 WALL
0.75 O. D. x .005 WALL
0.50 O. D. x .005 WALL |
| | MAN-IFOLD LINES
BLAND HRI PMA'S SUCTION
DISCHARGE LINES
EN PUMP LINES
RESERVOIR LINES
VAPOR LINES
CONDENSER TO JET PUMP L
JET PUMP TO THE PMA LINES
MG PMA TO BOILER LINES |



SECTION A = A



VIEW BELOW SECTION A-A CUTTING PLANE NOT SHOWN



120.00

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AEROJET-NUCLEAR SYSTEMS COMPANY

Interoffice Memo

27 May 1970

7973:70:0007:AJS:ESC:mrs

TO: Distribution

FROM: E.S.Chalpin/A.J.Sellers

SUBJECT: SNAP-8 13 Tube Boiler (BRDC #5) Designs for Revised System
State Point Conditions

DISTRIBUTION: W.F.Banks, R.Chesworth, H.Derow, C.Hawk, J.Hodgson, A.Kreeger,
G.Lombard, L.Lopez, U.A.Pineda, R.W.Marshall, Jr., L.Breindel, File 7973

ENCLOSURES: Table I - SNAP-8 PCS-G BRDC #5, Boiler Design Specifications
and Operating Parameters

Fig. 1 - SNAP-8 PCS-G BRDC #5, BODEPE Temperature and Pressure Profiles
2 - 13 Tube Double-Containment Array
3 - through 8 - Boiler Geometries

REFERENCES: (1) "BODEPE - IBM 360 Computer Code for SNAP-8 Boiler Heat and
Momentum Transfer Analysis," TM 4921:68-551, Oct. 1968.
(2) "PCS-G State Point Conditions - Revision late 4/21/70,"
EDF Serial N.SA0014

This memo presents the summary of the bare refractory double contained 13 tube boiler design analysis. Per NASA-LeRC direction (5-19-70), the mercury flow containment in the oval/round SS-Ta tube assembly with a multipassage plug insert (MPP) and swirl wire (SW) internal geometry was assumed to be identical to that of BRDC #4. To meet the revised PCS-G state point conditions (Reference 2) the tube count was increased from 7 to 13. Lower boiler operating pressure level and pressure drop, and increased mercury flow rate were reasons for the increase in the tube count.

Relatively good agreement between the BODEPE code design predictions and the test results of the SB-2, SF-1A and BRDC #4 boilers is the basis for the new boiler design approach. The heat and momentum transfer correlations used in this analysis are those established from the wetting and non-wetting two-phase flow models in a helical flow passage (Reference 1).

The summary of the thermal design analysis is presented in Table I. It specifies the assumed boiler cross section geometry and the calculated boiler MPP and total length requirements for low NaK inlet temperature schedule as well as the boiler operating thermal and dynamic parameters for the prescribed PCS-G systems state point conditions. Figure 2 shows the graphical interpretation of the predicted boiler performance characteristics at low and high NaK inlet temperatures. The boiler cross section geometry and the proposed boiler overall configurations are depicted in Figure 2 and Figures 3 through 7 respectively.

Figure 8 depicts a 19 tube, bimetal boiler with a single-fluted helix replacing the swirl wire as an example of a different approach to boiler design.

Figures 3 through 7 list some advantages and disadvantages of each design. The boiler shown in Figure 3 is the most preferred from a boiler design point because of its vertical mercury inlet. The other designs (Figures 4 through 7) are shown in descending order of preference.

Figure 2 shows a typical 13 tube array. The major axis of the static NaK tubes will vary dependent on the boiler configurations as shown in Figures 3 through 7. The NaK shell size can be 7.5 "O.D. or 8.0" O.D., dependent on the boiler configuration. The reason for this is that Ladish 180° turns are standard at 8.0" O.D.

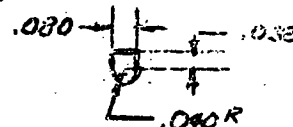
E. S. Chalpin
E. S. Chalpin, Head
Static Components
Power Systems Operations

A. J. Sellers
A. J. Sellers
Aerothermodynamics
Technical Resources
Engineering Department

TABLE I
SNAP-8 PCS-G BRDC No. 5

BOILER DESIGN SPECIFICATIONS AND OPERATING PARAMETERS

MECHANICAL

Design Concept:	"Once Through" mercury preheat, boiling and superheat
Boiler Type:	Parallel counterflow NaK-To-HG heat exchanger
Design Configuration:	Parallel tube Bundle-In-Tube
Number of HG Tubes	13
Hg Containment:	In round TA tube contained in oval 321SS tube with stagnant NaK in annular space
TA Tube	.750" OD x .049" wall
Oval 321SS Tube:	.880"/1.265" x .049" wall
Effective MPP Length:	2.25 Ft., Tantalum
Number of Helical MPP Flow Passages:	16
MPP Flow Pass. Pitch:	6"
MPP Flow Passage Crosssection:	
Swirl Wire:	.062" Dia. x 2" Pitch. 90% Ta-10%
NaK Shell Tube:	7.500" OD x .120" wall, 316SS

Boiler Crosssection:

See Figure 2

Effective Boiler Length:

22 Ft.

Proposed Geometry:

See Figures 3 through 8

THERMAL

Item	Parameter	Sim bol	Dimen sion	NaK Inlet Temp. Schedule	
				Low	High
1.	NaK Flow Rate	W_N	LB/HR	57148	57148
2.	NaK Inlet Temp.	T_{Nbi}	$^{\circ}F$	1185	1211
3.	NaK Temp. Drop	ΔT_N	$^{\circ}F$	170	167
4.	NaK Pressure Drop	P_N	PSI	~ 3	~ 3
5.	HG Flow Rate	W_{HG}	LB/HR	13775	13600
6.	HG Exit Pressure	P_{Hbo}	PSIA	148	145
7.	HG Exit Temp.	T_{Hbo}	$^{\circ}F$	1165	1190
8.	HG Inlet Temp.	T_{Hbi}	$^{\circ}F$	420	420
9.	HG Vapor Region Pres. Drop	ΔP_{HG}	PSI	26	39
10.	HG Flow Restr. Pres. Drop	ΔP_R	PSI	143	140
11.	HG Inlet Pressure	P_{Hbi}	PSIA	317	324
12.	Pinch Point Temp. Diff.	ΔT_{pp}	$^{\circ}F$	44	63
13.	Terminal NaK-To-HG T	ΔT_t	$^{\circ}F$	20	20
14.	Vapor Superheat	ΔT_{SH}	$^{\circ}F$	197	228
15.	Mean Preheat Flux	q''_{PH}	B/HR-FT ²	195858	227497
16.	Mean MPP Boiling Flux	q''_{MPP}	"	53774	81099
17.	Mean SW Boiling Flux	q''_{SW}	"	56264	60368
18.	Mean Superheat Flux	q''_{SH}	"	4875	5454
19.	Boiling Termination Point	L_{100}	FT	14.3	12.6
20.	MPP Vapor Exit Quality	X_{PL}	%	12	19
21.	Thermal Power Req'd.	q_t	KW	598	599
22.	External Power Loss (Assumed)	q_{HL}	"	5	5

CLEARPRINT

SNAP-8 PCS-G BRDC#5 - BODEPE TEMPERATURE AND PRESSURE PROFILES

AT $\dot{W}_N = 57148 \text{ LB/HR}$, $T_{NBL} = 1185 \text{ TO } 1210^\circ\text{F}$, $\Delta T_N = 170^\circ\text{F}$, $\dot{W}_{NG} = 13775 \text{ TO } 13600 \text{ LB/HR}$, $P_{NBL} = 148 \text{ TO } 145 \text{ PSIA}$.

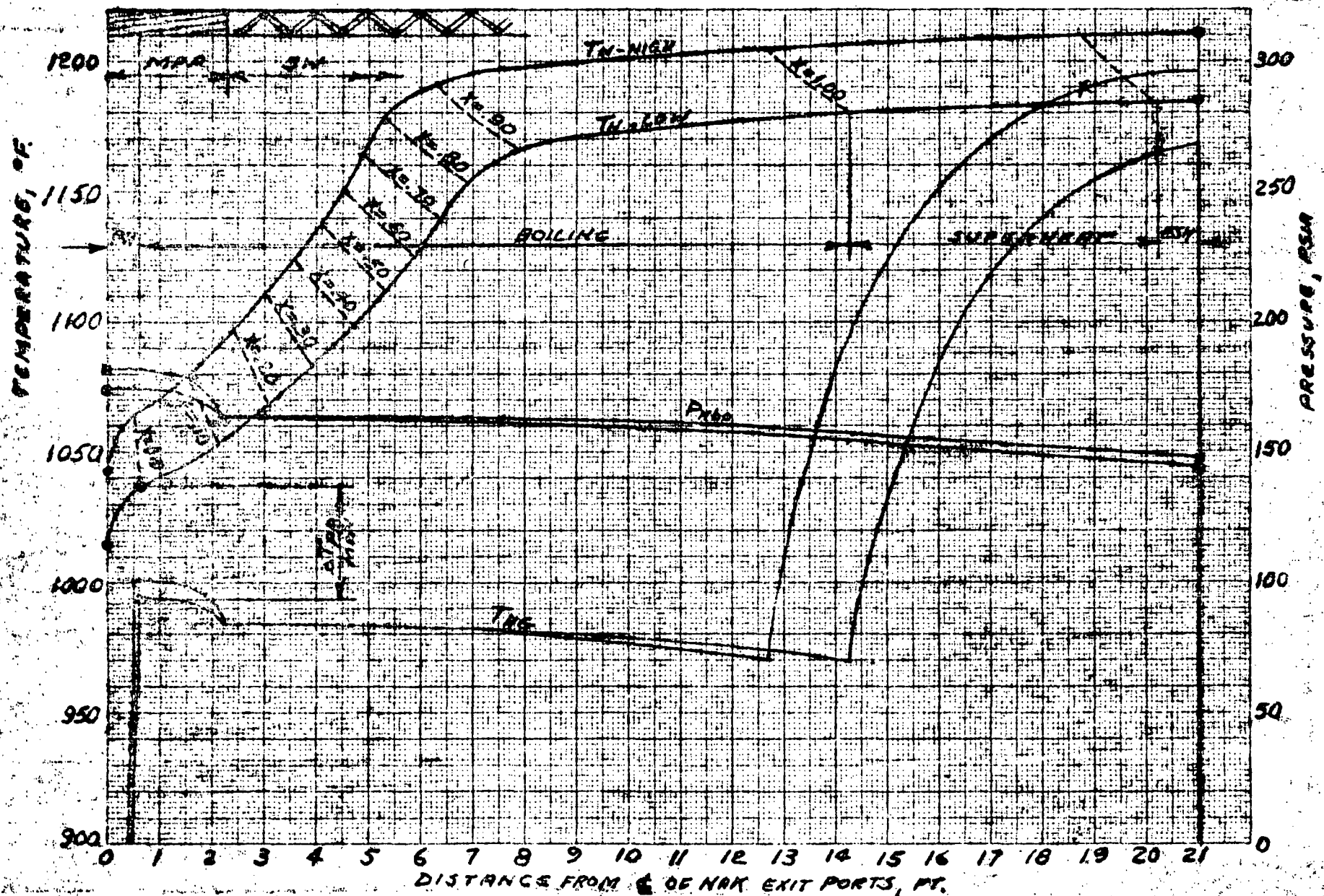


FIGURE 1

13 TUBE DOUBLE-CONTAINMENT ARRAY

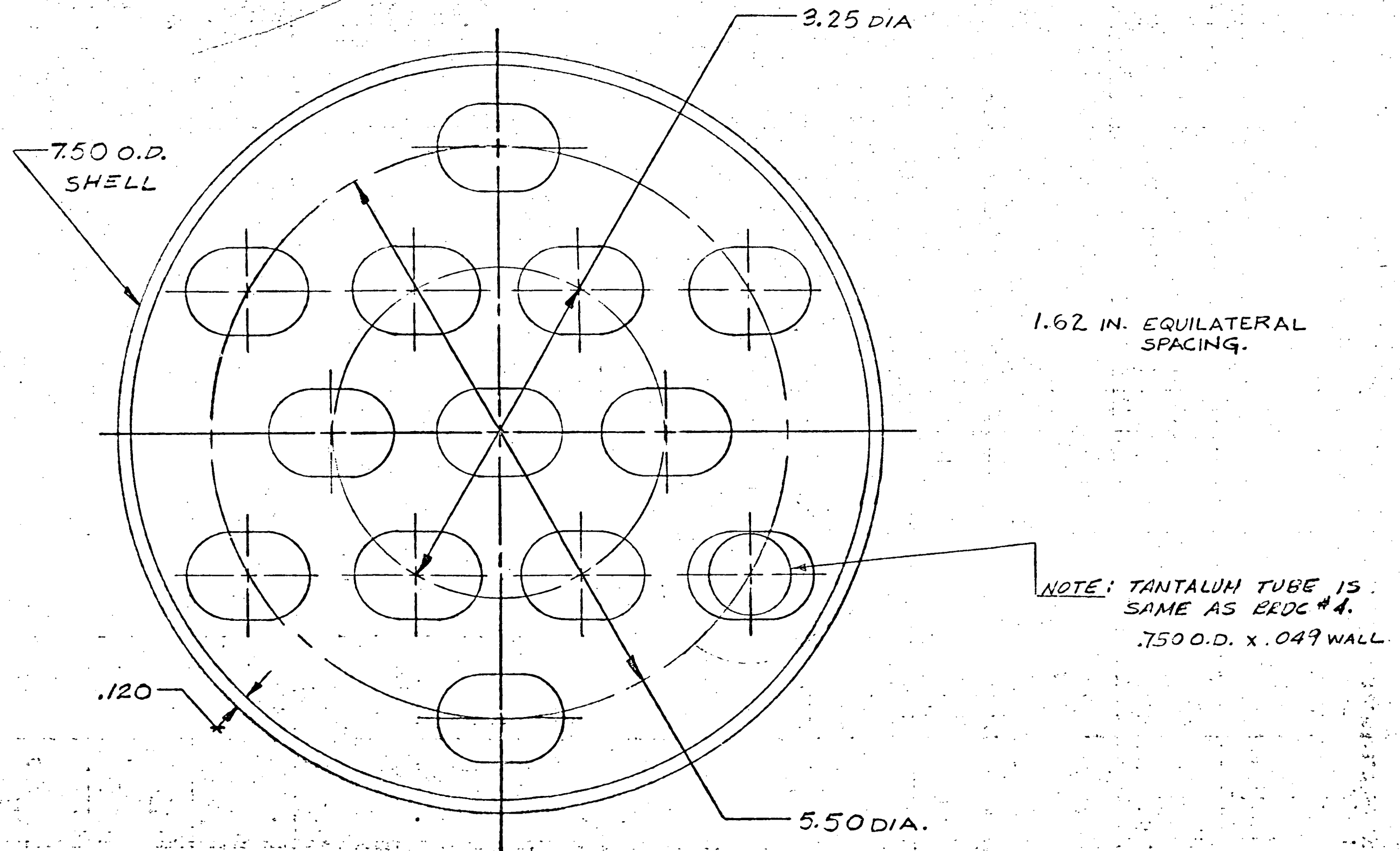


FIGURE 2

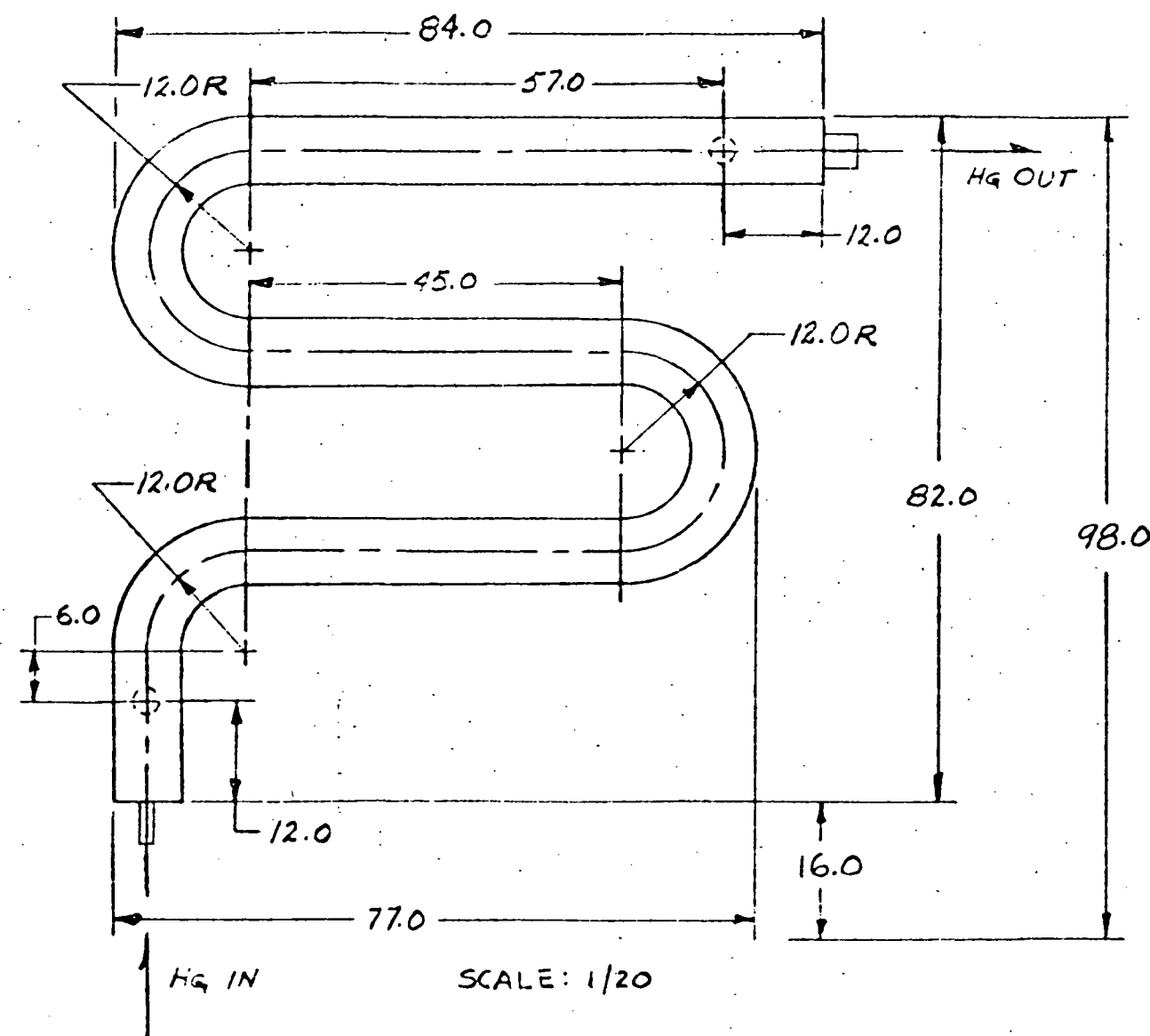


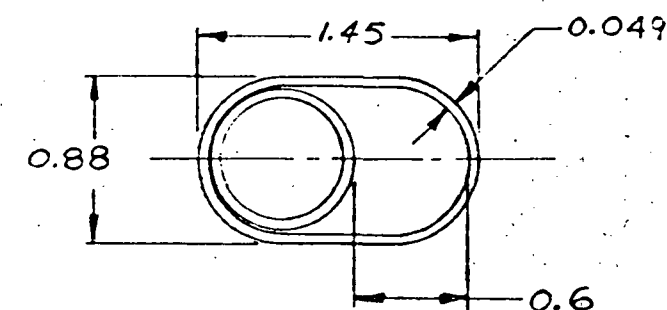
FIGURE 3 BOILER GEOMETRIES

ADVANTAGES

1. Vertical mercury inlet ensures even flow distribution to all 13 tubes in a gravity field. No circumferential thermal gradient.
2. Overall length of 23 ft. will fit in PCS-G package.
3. 180° and 90° turns are standard Ladish items.

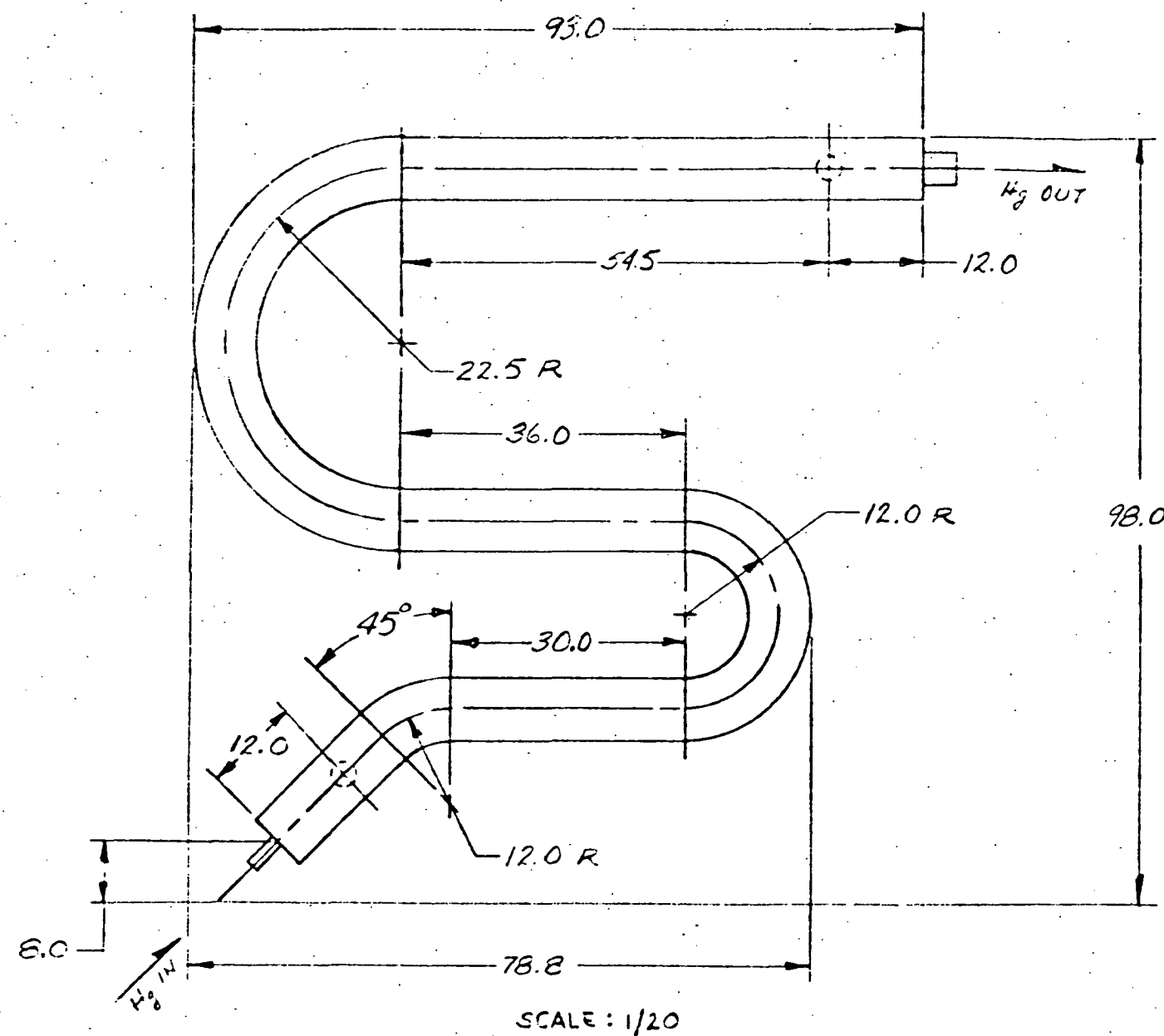
DISADVANTAGES

1. Removal of reservoirs and NPMA's from PCS-G is more difficult.
2. Static NaK tubes must go from oval in turns to round in straight sections to facilitate fabrication.
3. Slight difference in mercury tube lengths due to odd number of bends assuming tubes are not coiled.



NOTES:

1. LENGTH BETWEEN NAK IN & NAK OUT IS 20.5 FT. = 246.0 IN.
2. SHELL SIZE IS 8.00 IN. OD X .120 IN. WALL
3. NUMBER OF TUBES = 13.

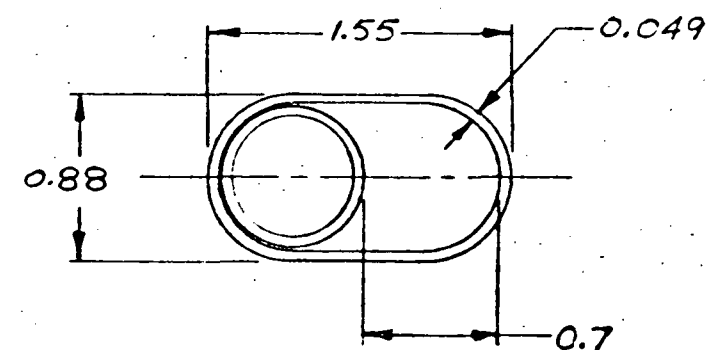


ADVANTAGES

1. 45° mercury inlet allows better distribution of mercury to all 13 tubes than horizontal inlet in a gravity field.
2. Overall length of 23 ft. will fit in PCS-G package.
3. Upper loop radius of 22.5 inches allows for reservoir and NPMA removal from PCS-G.

DISADVANTAGES

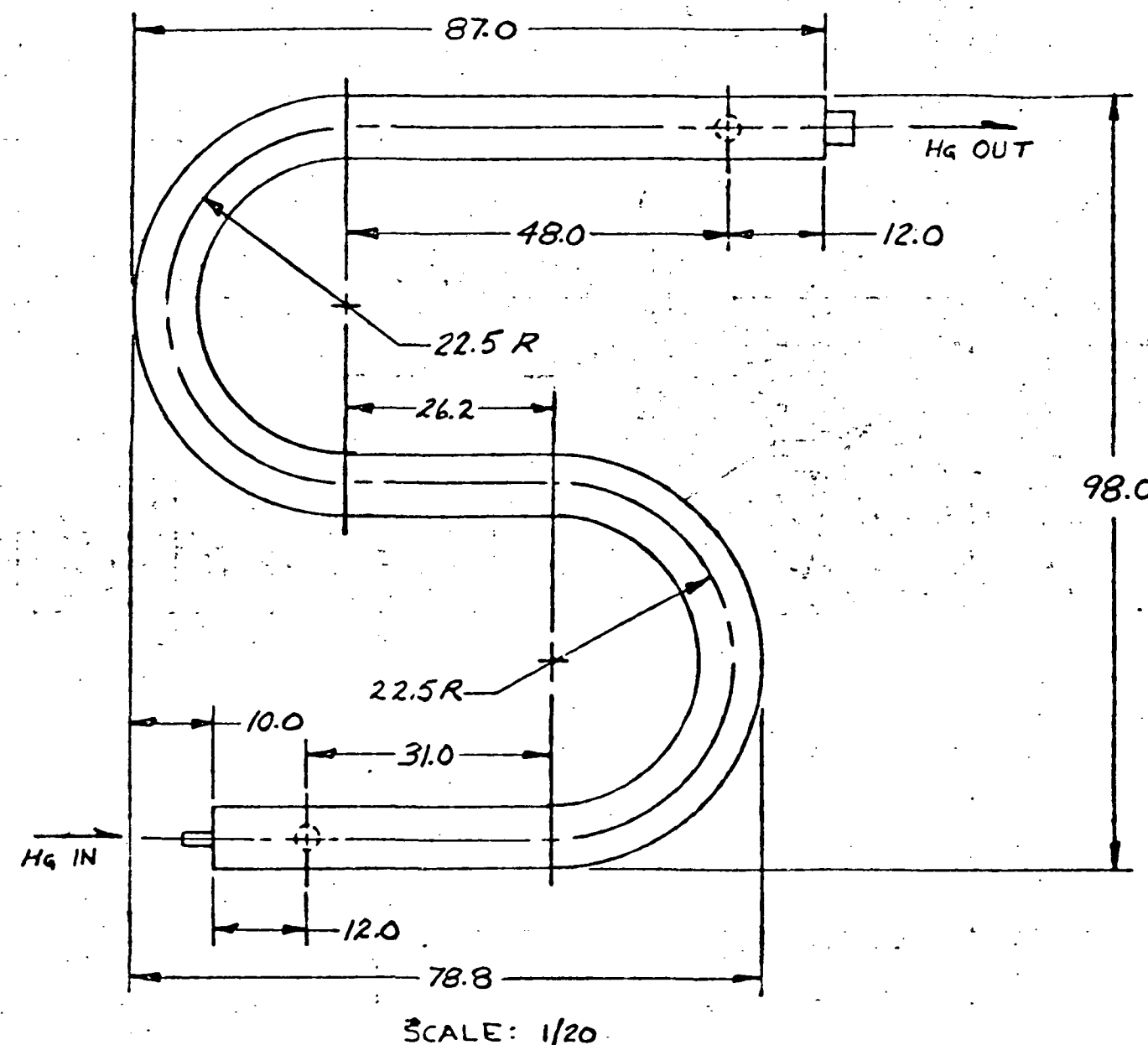
1. Static NaK tubes must go from oval in turns to round in straight sections to facilitate fabrication.
2. Complexity of mercury tube bending is increased due to changes in bend radii.
3. Slight difference in mercury tube lengths due to odd number of bends assuming tubes are not coiled.



NOTES:

1. LENGTH BETWEEN NAK IN & NAK OUT IS 20.5 FT. = 246.0 IN.
2. SHELL SIZE IS 8.00 IN OD X .120 IN WALL
3. NUMBER OF TUBES = 13.

FIGURE 4 BOILER GEOMETRIES

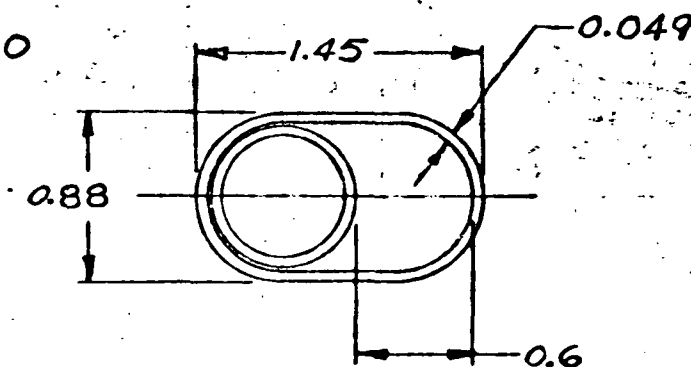


ADVANTAGES

1. Overall length of 23 ft. will fit in PCS-G package.
2. Reservoir and NPMA removal from PCS-G is possible.
3. Even number of turns results in equal length mercury tubes.

DISADVANTAGES

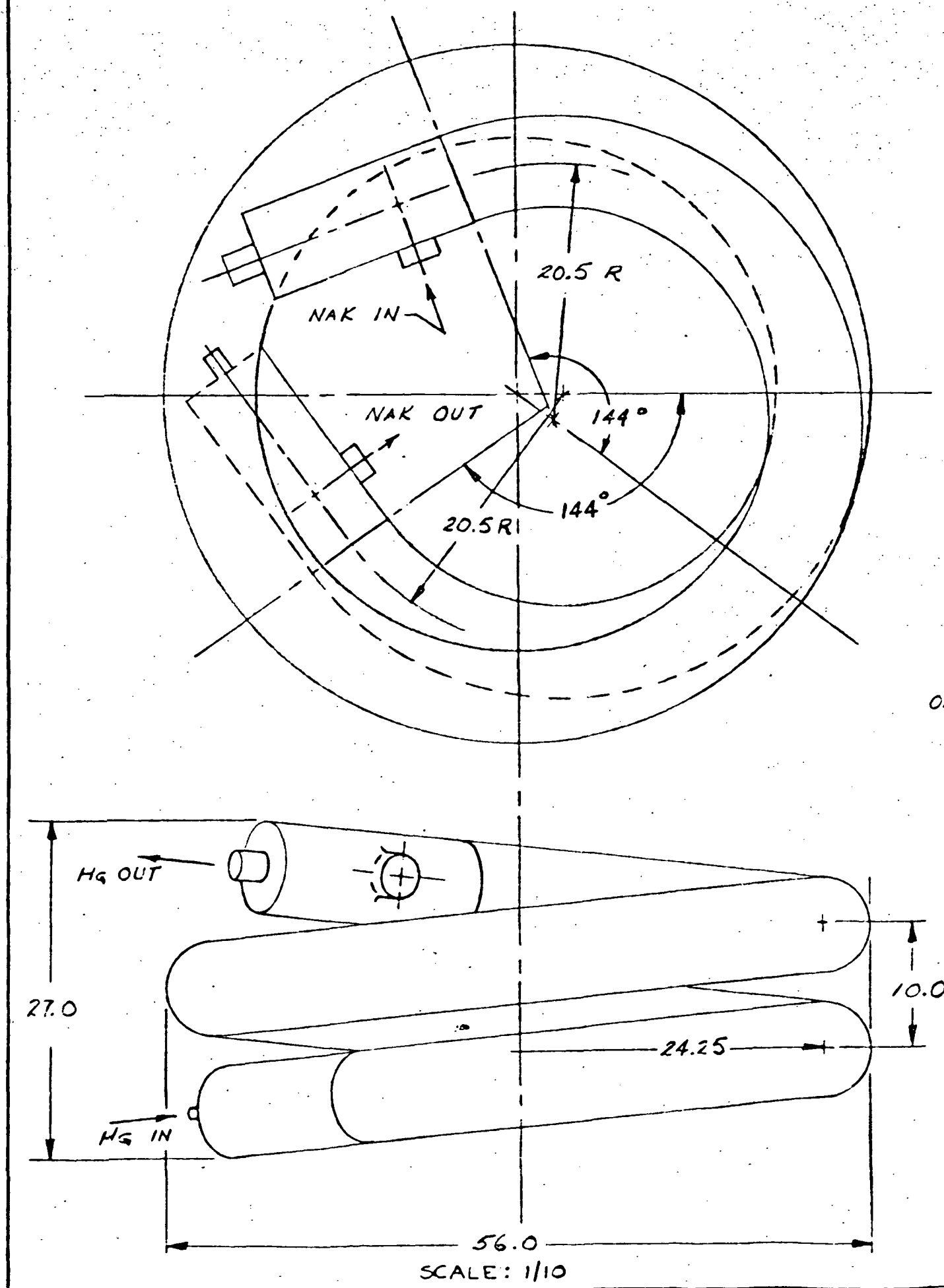
1. Horizontal mercury inlet will result in uneven flow distribution of mercury to all 13 tubes in a gravity field. A circumferential thermal gradient can result at the mercury inlet.
2. Static NaK tubes must go from oval in the turns to round in the straight sections to facilitate fabrication.



NOTES:

1. LENGTH BETWEEN NAK IN & NAK OUT IS 20.5 FT. = 246.0 IN.
2. SHELL SIZE IS 7.50 IN. OD X .120 IN WALL.
3. NUMBER OF TUBES = 13.

FIGURE 5 BOILER GEOMETRIES



ADVANTAGES

1. Method of fabrication has been used successfully in BRDC boilers #1, 2, 3 & 4.
2. Boiler will fit in PCS-G package with greater accessibility to other components.

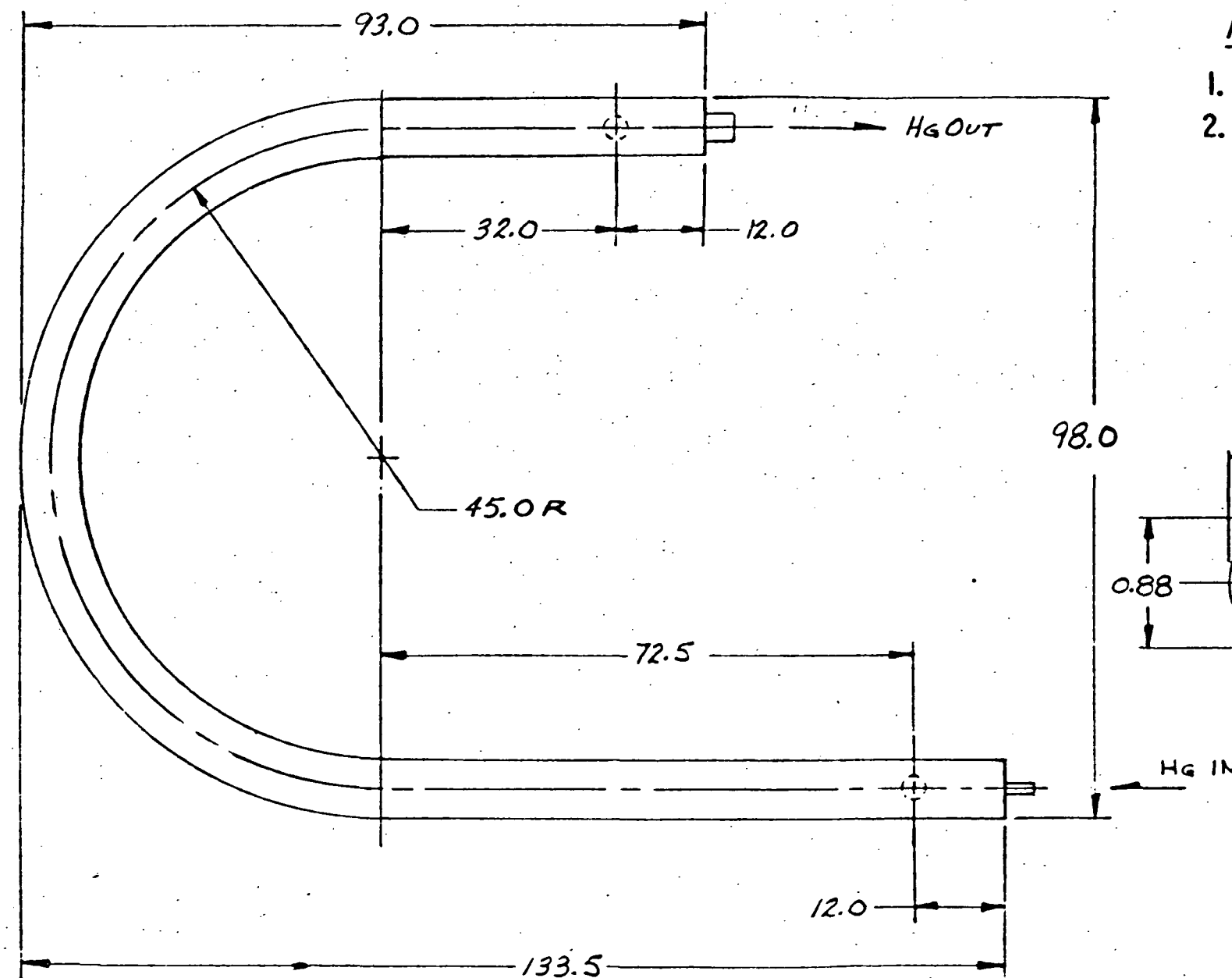
DISADVANTAGES

1. Installation of boilers in PCS-G more difficult. Reservoirs must be repositioned.
2. Slight difference in mercury tube lengths assuming tubes are not twisted.
3. Nearly horizontal mercury inlet will result in uneven flow distribution of mercury to all 13 tubes in a gravity field. A circumferential thermal gradient can result at the mercury inlet.
4. Boilers must be stacked one on top of the other.

NOTES:

1. LENGTH BETWEEN NAK IN & NAK OUT IS 20.5 FT. = 246. IN.
2. SHELL SIZE IS 7.50 IN OD X .120 IN WALL.
3. NUMBER OF TUBES = 13.

FIGURE 6 BOILER GEOMETRIES

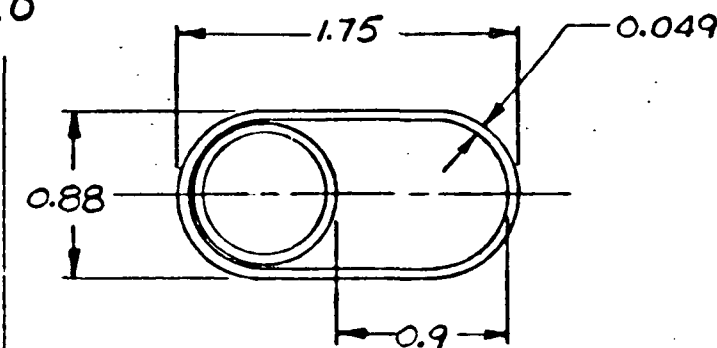


ADVANTAGES

1. Simple construction
2. Reservoirs and NPMA's can be easily removed from PCS-G.

DISADVANTAGES

1. Static NaK oval must be large to compensate for differential expansion between stainless steel and tantalum.
2. Difficulty in fitting this configuration into PCS-G package.
3. Horizontal mercury inlet will result in uneven flow distribution of mercury to all 13 tubes in a gravity field. A circumferential thermal gradient can result at the mercury inlet.
4. Large difference in mercury tube lengths due to odd number of bends assuming tubes are not coiled.

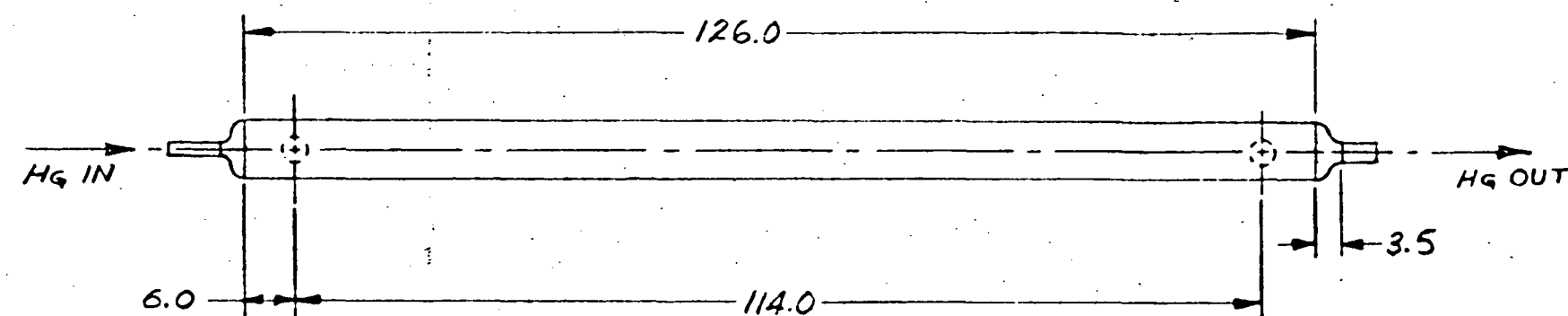


NOTES:

1. LENGTH BETWEEN NAK IN & NAK OUT IS 20.5 FT = 246.0 IN.
2. SHELL SIZE IS 8.50 IN OD X .120 IN WALL.
3. NUMBER OF TUBES = 13.

SCALE: 1/20

FIGURE 7 BOILER GEOMETRIES



SCALE : 1/20

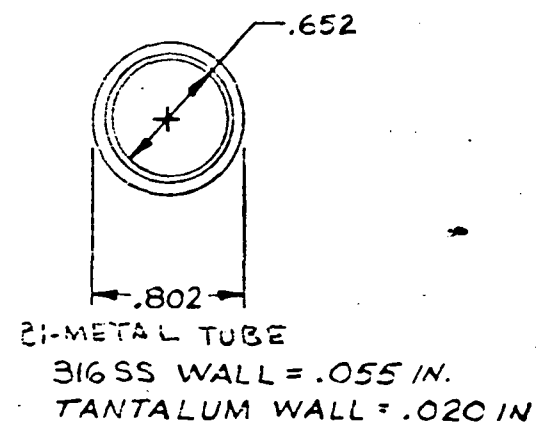


FIGURE 8 BOILER GEOMETRIES

ADVANTAGES

1. Boiler will take up the least amount of space in comparison to boilers shown in Figures 3 through 7.
2. One header only required for each end of boiler.
3. No transition joints required.
4. No static NaK tubes or expansion reservoir required. Differential expansion between tantalum and stainless steel is not a problem.
5. Can be mounted vertically thus ensuring even distribution of mercury to all 13 tubes in a gravity field.
6. Simplicity of boiler support in PCS-G.

DISADVANTAGES

1. Double-containment using circular static NaK tubes would require two headers for each end of boiler thus increasing complexity.
2. Mercury tubes would increase from 13 to 19.
3. No extensive test history for full scale boiler of this design (bimetal mercury tubes and single fluted helix).

NOTES:

1. NUMBER OF TUBES = 19.
2. SHELL SIZE IS 7.00 IN OD X .120 IN. WALL.

PCS ELECTRICAL PACKAGES

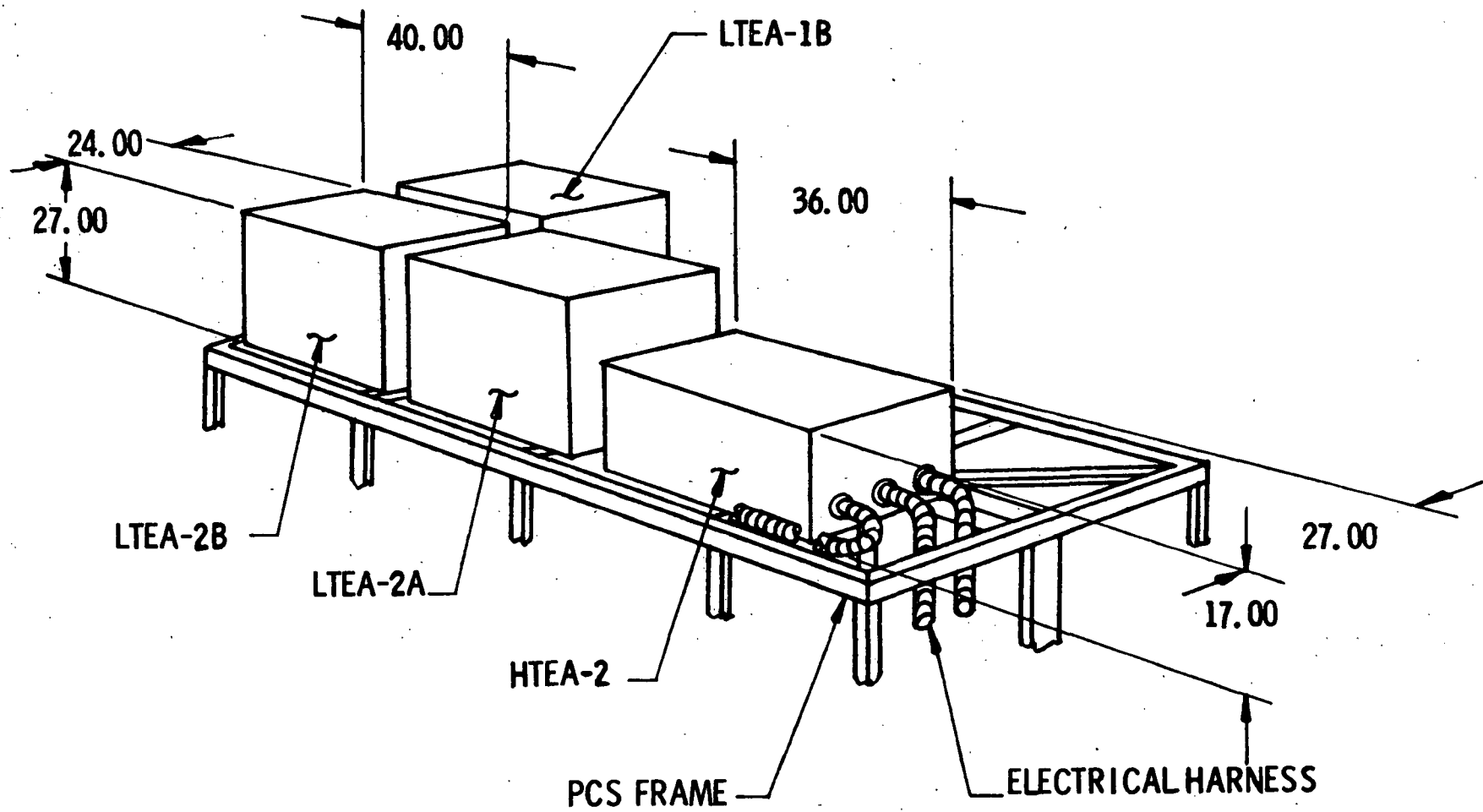
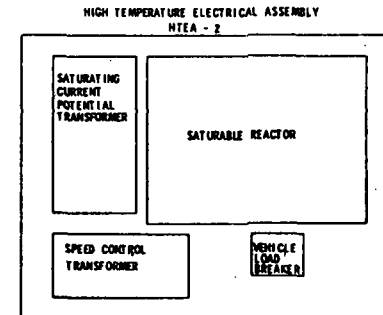
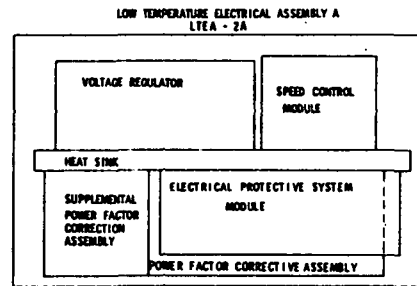
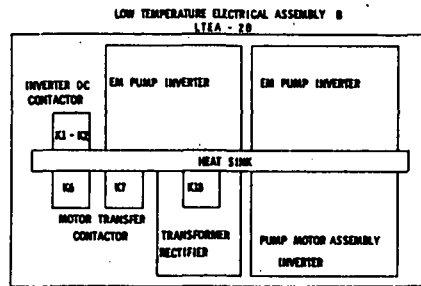
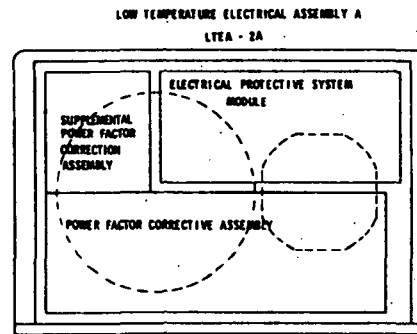
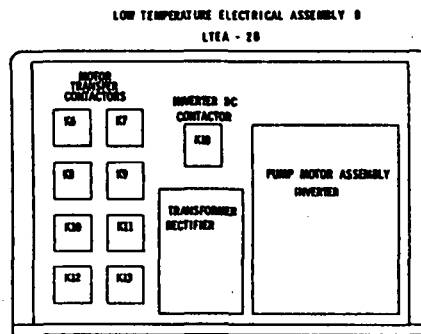


FIGURE IIB-3-1

PCS ELECTRICAL PACKAGES



PLAN VIEW



ELEVATION VIEW

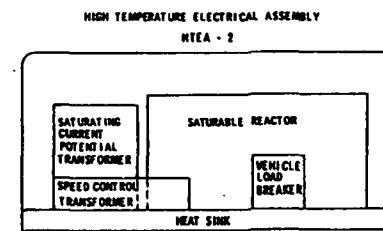
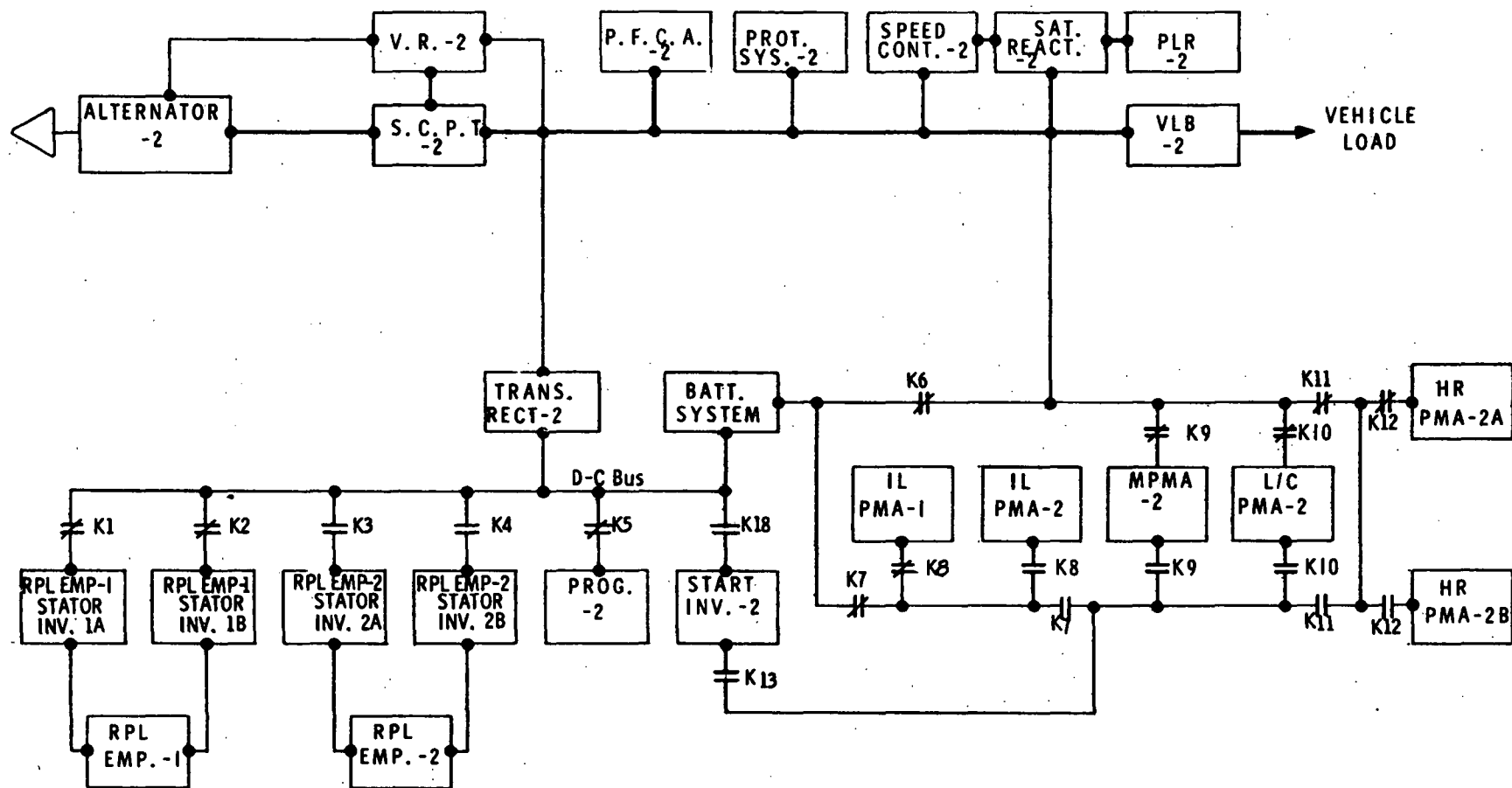


FIGURE IIB-3-2

ELECTRICAL HARNESS DESIGN CONCEPTS

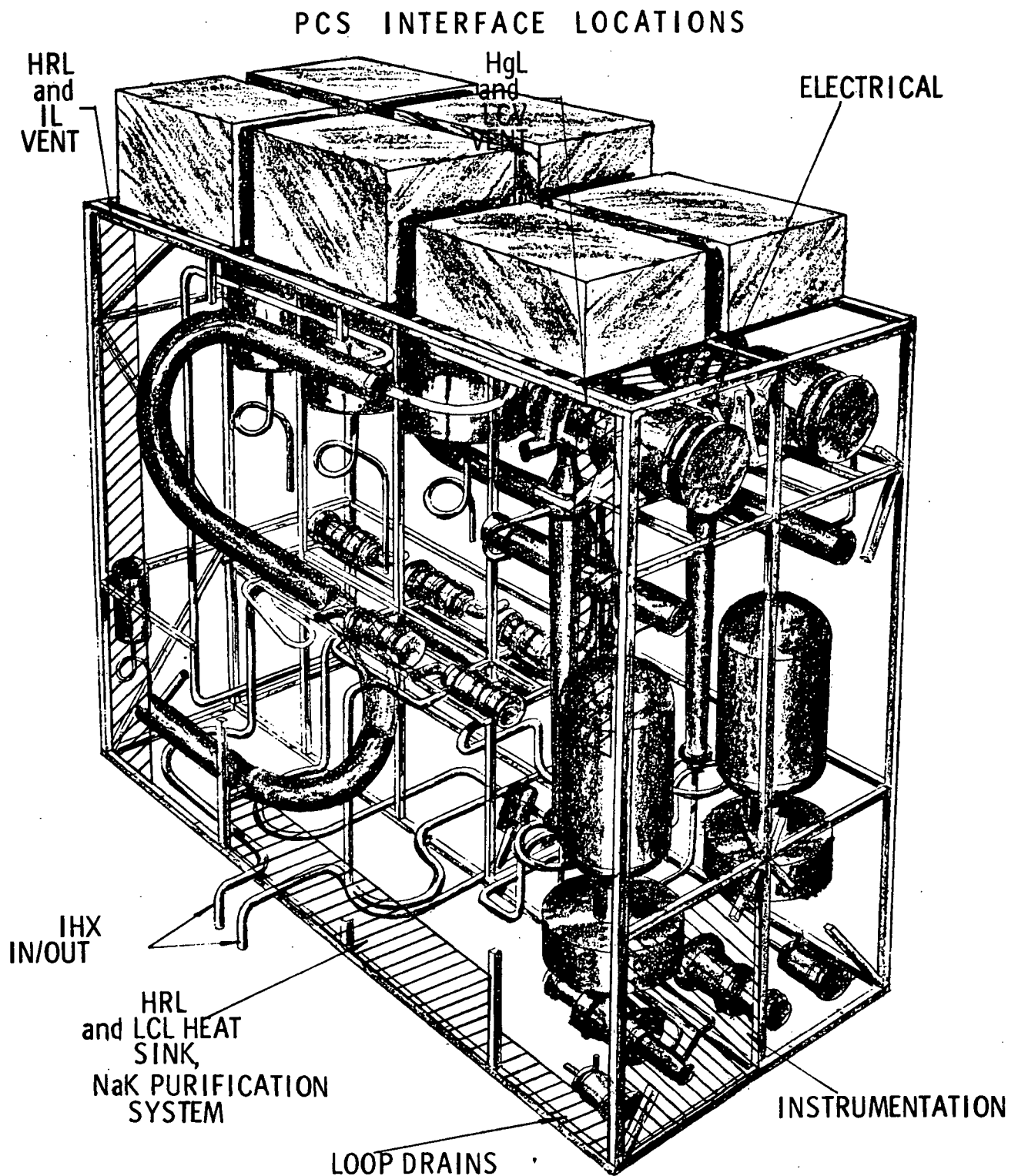
- . ROUTING WILL BE DETERMINED ON FULL SCALE MOCKUP**
- . CONDUCTORS WILL BE WELDED TO TERMINALS**
- . HARNESS CABLE TO BE ROUTED IN BUNDLES AND CLAMPED
TO NON-REMOVABLE STRUCTURE**
- . CONDUCTOR INSULATION DESIGNED FOR VACUUM ENVIRONMENT**

FIGURE IIB-3-3



CST/PCS ELECTRICAL SYSTEM DIAGRAM

FIGURE IIB-3-4



SNAP-8 POWER CONVERSION SYSTEM

FIGURE ~~IB-2~~ II B 4-1

SUMMARY OF CST/PCS MECHANICAL INTERFACES

INTERMEDIATE LOOP		MERCURY LOOP		HEAT REJECTION LOOP		LUBE/COOLANT LOOP	
VACUUM/VENT	4	VACUUM VENT	3	VACUUM VENT	4	VENT/VACUUM	1
FILL/DRAIN	3	LOOP DRAIN	1	FILL/DRAIN	3	FILL/DRAIN	1
NaK		RESERVOIR FILL	1	NaK		RESERVOIR	
PURIFICATION	2			PURIFICATION	2	PRESSURIZATION	1
RESERVOIR				RESERVOIR		HEAT SINK	3
PRESSURIZATION	3			PRESSURIZATION	1		
IHX INLET/OUTLET	2			RPL EMPUMP AND			
				REACTOR SHIELD			
				COOLANT HEAT			
				EXCHANGER	3		
	14		5		15		

STRUCTURE: PCS BASE BOLTED TO RPL STRUCTURE AT 12 EXTERIOR COLUMNS.

FIGURE IIB-4-2

SUMMARY OF CST/PCS RPL and FACILITY
ELECTRICAL INTERFACES

<u>RPL</u>	<u>CONDUCTORS</u>
EM PUMP HARNESS (2 Pumps with 2 Stators each)	12
REACTOR CONTROL DRUM MOTORS	<u>20</u>
	32
<u>PROGRAMMER (CONTROL ROOM) TO PCS</u>	
MOTOR CONTRACTOR (4)	2
DC BIAS SPEED CONTROL (5)	2
SIGNAL TO CONTROL VEHICLE LOAD BREAKER	2
INVERTER HIGH/LOW TAP	2
5 INVERTER TO TEMP (4), PMA (1) DC CONTRACTORS	10
5 L/C ON-OFF SOL. VALUES	15
5 MIS " " " "	15
HG FC VALVE	3
HR FC VALVE	3
DC POWER SUPPLY TO INVERTERS	10
LCH POWER	2
FREQUENCY SET POINT	2
VOLTAGE " "	2
ALTERNATOR FLASHING CURRENT	2
	<u>64</u>
<u>PCS TO VEHICLE LOAD</u>	
ALTERNATOR OUTPUT TO LOAD	4
	<u>110</u>

Figure II B 4-3

CST/PCS PARTS LIST

<u>ITEM</u>	<u>QUANTITY</u>
* STRUCTURE	1
* BOILER	2
TURBINE ALTERNATOR ASSEMBLY	1
CONDENSER	1
PARASITIC LOAD RESISTOR	1
PUMP MOTOR ASSEMBLY, HEAT REJECTION LOOP	2
PUMP MOTOR ASSEMBLY, INTERMEDIATE LOOP	2
PUMP MOTOR ASSEMBLY, MERCURY LOOP	1
PUMP MOTOR ASSEMBLY, L/C LOOP	1
* RESERVOIR, EXPANSION, HEAT REJECTION LOOP	1
* RESERVOIR, EXPANSION, INTERMEDIATE LOOP	1
* RESERVOIR, EXPANSION, BOILER STATIC NaK	2
* RESERVOIR, EXPANSION, L/C LOOP	1
RESERVOIR, MERCURY INJECTION	1
* VALVE, NaK DIVERter, HEAT REJECTION LOOP	1
* VALVE, NaK DIVERter, INTERMEDIATE LOOP	1
VALVE, FLOW CONTROL, HEAT REJECTION LOOP	1
VALVE, FLOW CONTROL, MERCURY LOOP	1
VALVE, SHUT OFF, MERCURY LOOP	4
VALVE, SHUT OFF, HEAT REJECTION LOOP	1
VALVE, SHUT OFF, L/C LOOP	5
HEAT EXCHANGER and COLD TRAP, HEAT REJECTION LOOP PUMP MOTOR ASSEMBLY	2
HEAT EXCHANGER and COLD TRAP, INTERMEDIATE LOOP PUMP MOTOR ASSEMBLY	2
* HIGH TEMPERATURE ELECTRICAL ASSEMBLY NO. 2	1
TRANSFORMER ASSEMBLY, SPEED CONTROL	1
TRANSFORMER, SATURATING CURRENT-POTENTIAL	1
BREAKER, VEHICLE LOAD	1
SATURABLE REACTOR	1

* GOVERNMENT FURNISHED EQUIPMENT

CST/PCS PARTS LIST (continued)

<u>ITEM</u>	<u>QUANTITY</u>
* LOW TEMPERATURE ELECTRICAL ASSEMBLY NO. 2A	1
VOLTAGE REGULATOR	1
SPEED CONTROL	1
POWER FACTOR CORRECTION ASSEMBLY	1
PROTECTIVE SYSTEM	1
* LOW TEMPERATURE ELECTRICAL ASSEMBLY NO. 2B	1
* INVERTER, EM PUMP	2
* INVERTER, NaK PUMP MOTOR ASSEMBLIES	1
* TRANSFORMER - RECTIFIER	1
CONTACTOR - INVERTER DC	3
CONTACTOR - MOTOR TRANSFER	8
* LOW TEMPERATURE ELECTRICAL ASSEMBLY 1B	1
* CONTACTOR - INVERTER DC	2
* INVERTER, EM PUMP	2
ELECTRICAL HARNESS	1
* ELECTRICAL CONTROLS ASSEMBLY, NUCLEAR SYSTEM	1
FLOWMETER, EM, INTERMEDIATE LOOP	3
FLOWMETER, MERCURY LOOP	1
FLOWMETER, EM, HEAT REJECTION LOOP	3
FLOWMETERS, LUBE/COOLANT LOOP	5
* PUMP, EM, HEAT REJECTION LOOP	1
LINE HEATERS, L/C	1 set

* GOVERNMENT FURNISHED EQUIPMENT

C. STRUCTURAL CONCEPT

The PCS structural concept is shown in Figure IIC-1 with overall dimensions and member sizes. It can be seen that the structure is a truss concept. The center plane and supporting end faces form the basic structure. The members comprising these sections could be welded together since it is not necessary to remove any of them for component initial installation or subsequent maintenance. The center plane lends itself to a truss-type arrangement since the reservoirs penetrate it and part of the system piping traverses it. The top plane of the central "I" section is supported by columns in the front and rear face of the structure. Note that the structure was designed to support a dual PCS in order to properly assess the required member sizes.

The elements comprising the basis for member selection are shown on Figure IIC-2. Square and rectangular members were used instead of round members in order to simplify joint design and component mounting. In addition, for a given envelope, a round member is heavier than a square member for a given stiffness or conversely, a round member of equal weight and stiffness to a square member requires more envelope.

Aluminum, carbon steel, and stainless steel were considered for the structure material. Aluminum was eliminated for the following reasons: (1) use of aluminum would preclude installation of the HRL radiator around the PCS during system test. At 600°F, aluminum has poor strength characteristics (see Figure IIC-3). Secondly, it is felt that the overall cost of fabricating an aluminum structure would exceed the cost of a steel structure despite the lower material costs (\$1,000 versus \$3,300 for stainless steel); this is because a large aluminum structure would require use of special fixturing and heat treatment in order to eliminate distortions during fabrication. It is estimated that for similar deflection allowables an aluminum frame would weigh about 100 pounds less than a

steel frame. At this point, a final selection of stainless versus carbon steel has not been made.

Stress analysis results for member stresses and deflections are shown in Figures IIC-4, IIC-5, and IIC-6 for vertical and lateral loads. The structure and system weights, and overturning moment results appear in Figure IIC-7. Finally, a sample stress analysis for part of the PCS structure appears as Figure IIC-8.

PCS-STRUCTURE CONCEPT

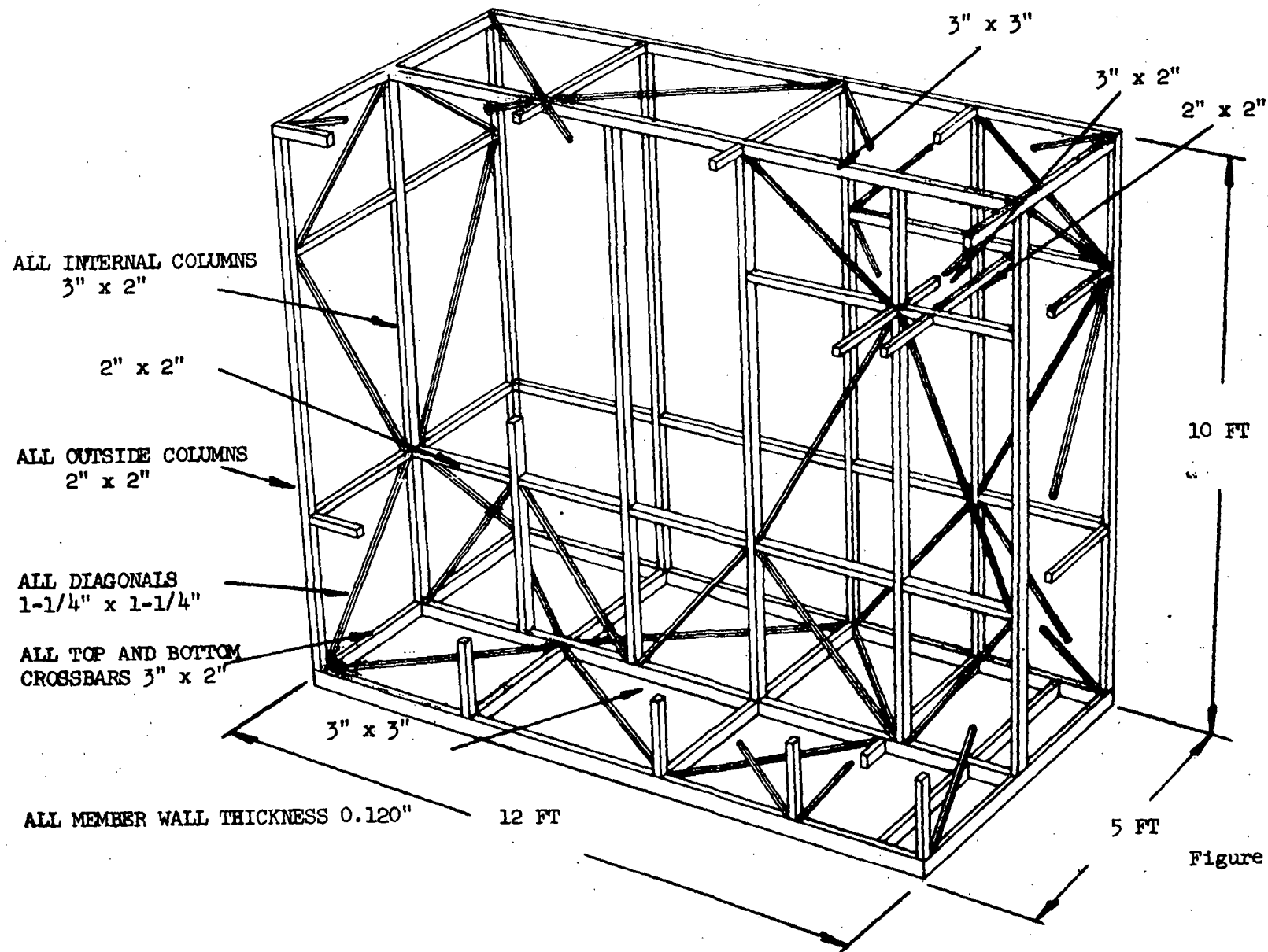


Figure II C 1

PCS STRUCTURE
FEATURES

MEMBER SHAPE AND SIZE

SQUARE, 1-1/4" x 1-1/4", 2" x 2", 3" x 3"

RECTANGULAR 2" x 3"

WALL THICKNESS: .120"

MATERIAL

STEEL (FINAL SELECTION TO BE DETERMINED)

CARBON STEEL VS STAINLESS

WEIGHT - 1484 LB

JOINT CONFIGURATION

FIXED - WELDED OR BOLTED

PCS STRUCTURE
FEATURES

MEMBER SHAPE AND SIZE

SQUARE, 1-1/4" x 1-1/4", 2" x 2", 3" x 3"

RECTANGULAR 2" x 3"

WALL THICKNESS: .120"

MATERIAL

STEEL (FINAL SELECTION TO BE DETERMINED)

CARBON STEEL VS STAINLESS

WEIGHT - 1484 LB

JOINT CONFIGURATION

FIXED - WELDED OR BOLTED

YIELD STRENGTH VERSUS TEMPERATURE

1015 CARBON STEEL

316 STAINLESS STEEL

5083-O ALUMINUM

6063-T5 ALUMINUM

- REFERENCES (A) ASTM STP 124
(B) ASTM STP 180
(C) AL STD AND DATA AL ASSOCIATION, 1969
(D) KAISER AL DATA

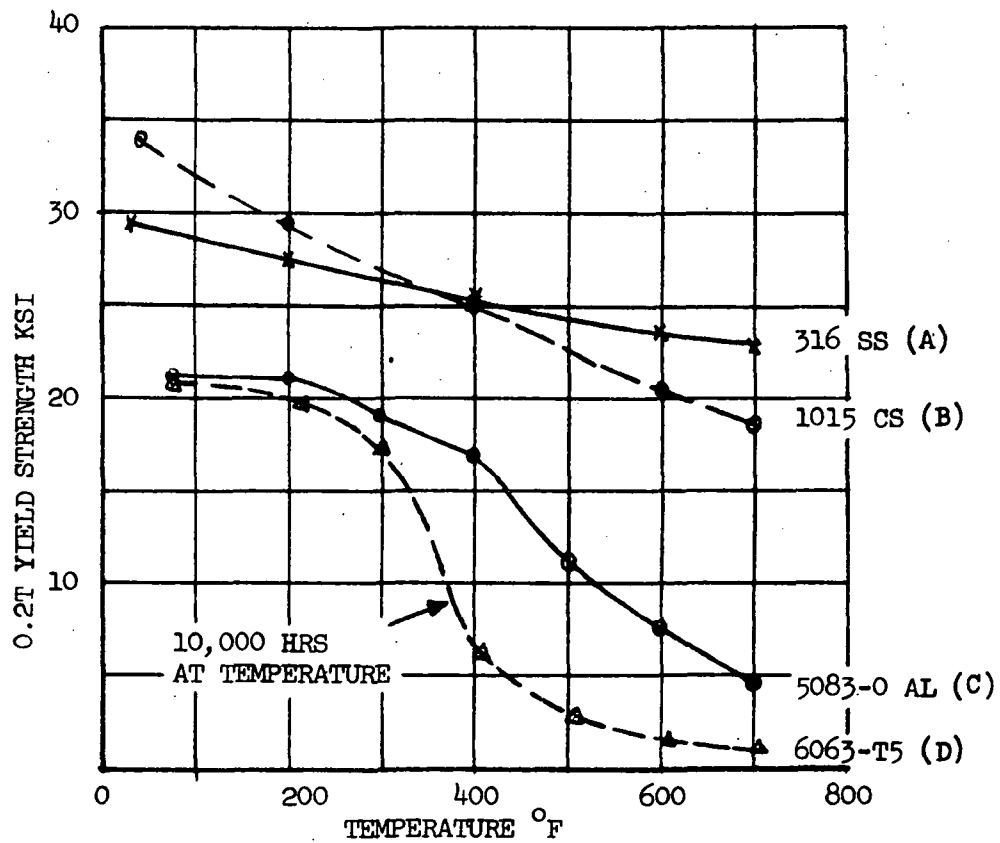


Figure IIC-3

PCS STRUCTURE DEFLECTION AND AXIAL STRESS SUMMARY
5-G VERTICAL LOAD

- AXIAL STRESS PSI
- VERTICAL DEFLECTION - INCHES

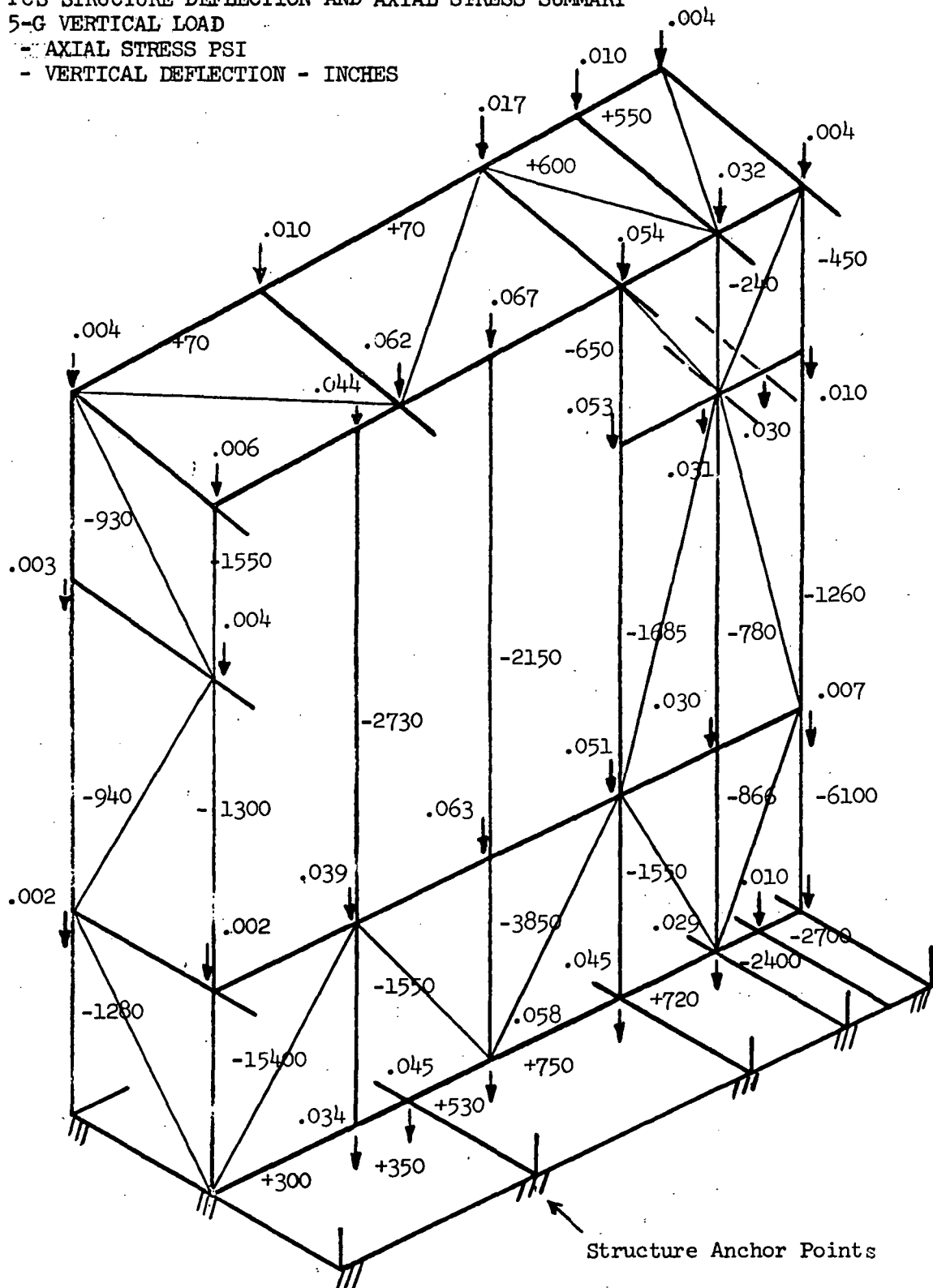


Figure IIC-4

PCS STRUCTURE
 LATERAL DEFLECTION AND AXIAL STRESS SUMMARY
 2-G LATERAL LOAD
 - AXIAL STRESS - PSI
 - LATERAL DEFLECTION - INCHES

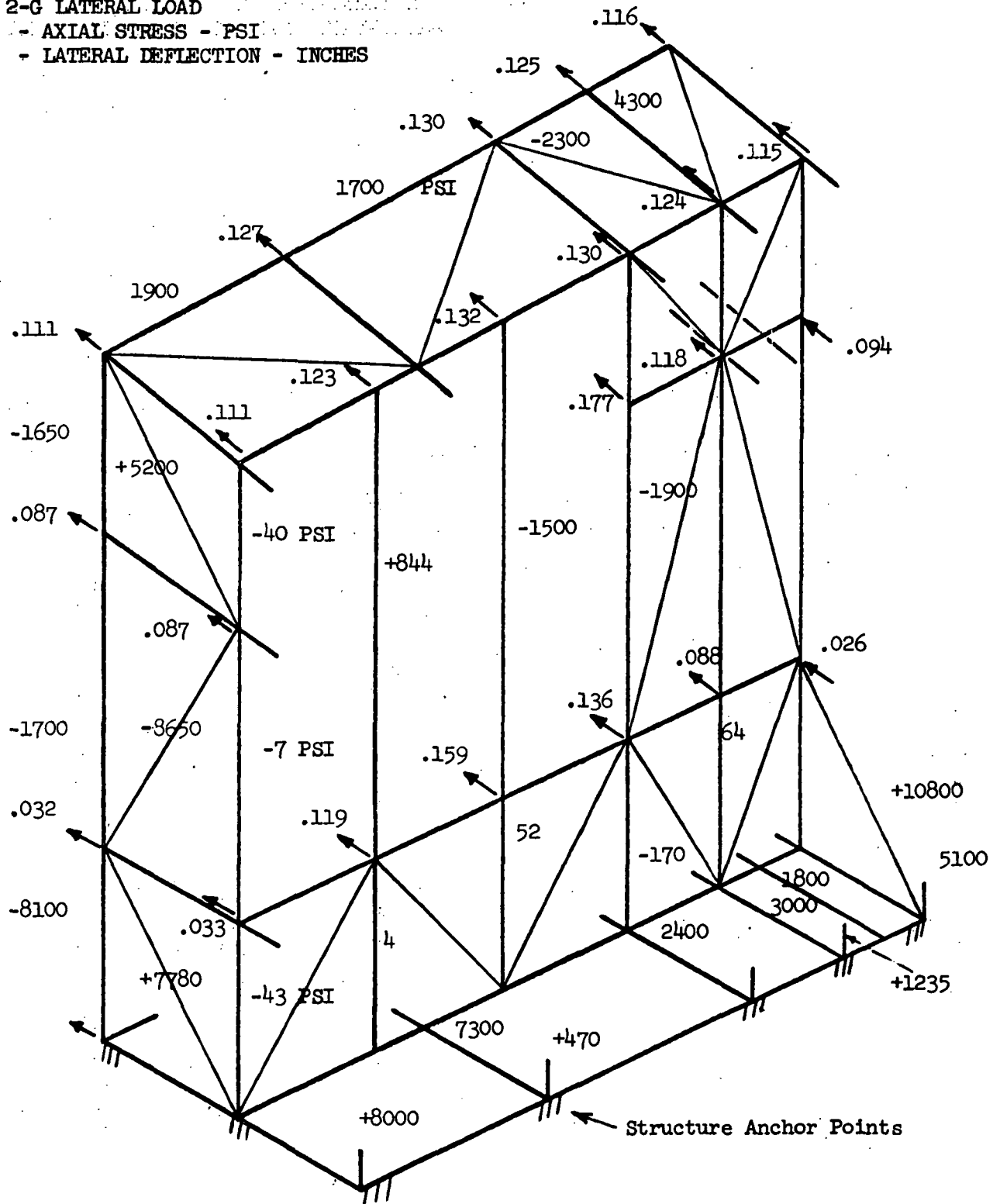


Figure IIC-5

PCS STRUCTURE MAXIMUM STRESS SUMMARY FOR
COMBINED LOAD - 5-G. VERTICAL AND 2-G LATERAL
MAXIMUM COMBINED STRESS PSI

Structure Anchor Points

Figure IIC-6

FRAME WEIGHT (Steel)

CENTER FACE

6 Vert. Columns	3" x 2"	10' x 6 = 60'
2 Horiz.	3" x 3"	12' x 2 = 24'
1 Horiz. @ 38"	3" x 2"	12' x 1 = 12'
1 TAA	3" x 2"	5' x 1 = 5'
1 1/4" x 1 1/4" Diagonal	33'	= 33'

FRONT FACE = REAR FACE x 2

5 Vert. Col.	2" x 2"	10' x 5 = 50' (x2) = 100'
2 Horiz.	3" x 2"	12' x 2 = 24' (x2) = 48'
1 Horiz. @ 38"	2" x 2"	12' x 1 = 12' (x2) = 24'
1 1/4" x 1 1/4" Diagonal	23'	23' (x2) = 46'

CROSS BARS BOTTOM AND TOP

Bottom 6	3" x 2"	5' x 6 = 30'
Top 5	3" x 2"	5' x 5 = 25'

BOTTOM DIAGONALS 1 1/4" x 1 1/4" 28' (1.93) = 54 LB

TOP DIAGONALS 1 1/4" x 1 1/4" 35' (1.93) = 68 LB

TOTALS

		<u>LB/FT</u>	<u>LB S.S.</u>
3" x 3"	24'	(4.8)	115
3" x 2"	180'	(3.98)	715
2" x 2"	124'	(3.07)	380
1 1/4" x 1 1/4"	142'	(1.93)	274
			1,484 LB

AL. 7% LIGHTER 1,484 LB (.07) - 104 LB LESS

1,484 LB - 104 LB = 1,380 LB

PCS WEIGHT TOTALS

TEST ARTICLE

Single PCS	Boiler	1,100
2 Boilers	TAA and Cond.	823
	ILR	250
	HRR	250
4,277 PCS Components	4 NaK PMA	900
1,400 Frame	L/C RES	250
1,860 El. Comp.	Misc.	400
1,100 +1 Boiler	Hg PMA	184
	PLR	<u>120</u>
8,637		4,277 LB
1,000 Fluids		
<u>1,000</u> Insulation		
10,637 LB		

DUAL PCS

PCS	4,277
PCS	3,827 (2 PMAs removed)
Frame	1,400
El. Comp.	1,860
Fluids	1,000
Insl.	<u>1,000</u>
	13,354 LB

NOTE: Above does not include Pipes, Brackets, and Radiators

TEST ARTICLE

C. G. LOCATION

<u>Component</u>	<u>WT. (LB)</u>	<u>Ly (")</u>	<u>Lz (")</u>	<u>IN-LB x 1,000</u>	
				<u>My</u>	<u>Mz</u>
Boiler	1,100	55	9	60.0	9.9
TAA and Cond.	823	107	16	88.0	13.2
ILR	250	96	30	24.0	7.5
HRR	250	91	30	23.0	7.5
NaK PMA (4)	900	46	30	41.5	27.0
L/C RES	250	50	16	12.5	4.0
Misc.	400	21	16	8.4	6.4
Hg PMA	184	9	16	1.65	2.9
PLR	120	74	24	9.0	2.5
Frame	1,400	60	30	84.0	42.0
	<u>5,677</u>			<u>352.05</u>	<u>122.9</u>
El. Comp.	1,860	130	20	242.00	37.2
	<u>7,530</u>			<u>594.05</u>	<u>159.1</u>
No. 2 Boiler	1,100	60	53	60.0	58.4
	<u>8,630</u>			<u>654.05</u>	<u>217.5</u>

$$My = 654,050$$

$$Mz = 217,500$$

$$Ly = \frac{654,050}{8,630}$$

$$Lz = \frac{217,500}{8,630}$$

$$Ly = 75"$$

$$Lz = 25.2"$$

30	122.	1.	1.
88	40.	38.	59.
64	28.	77.	30.
62	55.	87.	30.
91	40.	91.	59.
87	84.	38.	59.
99	126.	91.	59.
85	142.	38.	59.
102	117.	66.	59.
59	84.	91.	30.
57	126.	91.	30.
53	106.	74.	30.
54	117.	66.	30.
43	142.	38.	30.
18	142.	91.	1.
56	142.	91.	30.
98	142.	91.	59.
5	143.	1.	1. S
21	143.	66.	1.
38	55.	1.	30.
81	40.	1.	59. S
82	84.	1.	59. S
46	55.	38.	30.
50	28.	67.	30.

Joint Computer Input Sheet:

For Example:

Joint No. 57

x, y, z Coordinate

126", 91", 30"

PCS STRUCTURE

Sample Computer Stress Analysis Input/Output

Computer Program: "Integrated Civil Engineering

System-Structural Design Language"

(ICES - STRUDL)

Member Incidences (For Example - Member 548 is between Joints 71 and 72)

531	50	64
532	51	63
533	63	62
534	52	59
535	62	61
536	64	67
537	74	66
538	66	68
539	68	69
540	67	69
902	69	121
903	121	70
542	61	70
543	70	71
544	60	71
545	59	60
546	59	58
547	58	71
548	71	72
549	58	72
550	58	73
551	58	57
552	57	56
553	55	56

Member Properties Data

512	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
514	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
516 TO 521	AX	.90	IY	.55	IZ	.55	IX	1.1	SY	.55	SZ	.55
522	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
524	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
526 TO 538	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
539	AX	1.4	IY	1.91	IZ	1.91	IX	3.82	SY	1.27	SZ	1.27
540	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
542	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
543	AX	1.4	IY	1.91	IZ	1.91	IX	3.82	SY	1.27	SZ	1.27
544 TO 545	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
546	AX	.90	IY	.55	IZ	.55	IX	1.1	SY	.55	SZ	.55
548	AX	1.4	IY	1.91	IZ	1.91	IX	3.82	SY	1.27	SZ	1.27
549	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
551 TO 555	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
556	AX	1.4	IY	1.91	IZ	1.91	IX	3.82	SY	1.27	SZ	1.27
557	AX	1.15	IY	.75	IZ	1.4	IX	2.15	SY	.75	SZ	.935
507	AX	.42	IY	.057	IZ	.057	IX	.114	SY	.114	SZ	.114
509	AX	.42	IY	.057	IZ	.057	IX	.114	SY	.114	SZ	.114
511	AX	.42	IY	.057	IZ	.057	IX	.114	SY	.114	SZ	.114
513	AX	.42	IY	.057	IZ	.057	IX	.114	SY	.114	SZ	.114
515	AX	.42	IY	.057	IZ	.057	IX	.114	SY	.114	SZ	.114
523	AX	.42	IY	.057	IZ	.057	IX	.114	SY	.114	SZ	.114
525	AX	.42	IY	.057	IZ	.057	IX	.114	SY	.114	SZ	.114

Applied Load at Joints Input

814 10 815 ZC 3. YD 2. ZC 1.5 YC 1.
 813 ZC 1. YD 2. ZC .5 YC 1.
 750 10 752 ZC 3. YD 2. ZC 1.5 YC 1.
 CONSTANTS E 30000000. ALL
 BETA 0. ALL
 LOA 'ONE' 'VERTICAL'
 JOI 21 101 7 86 LOA FOR X -85.
 JOI 22 102 6 85 LOA FOR X -85.
 JOI 54 43 LOA FOR X -170.
 JOI 55 44 LOA FOR X -170.
 JOI 6 7 43 44 85 86 LOA FOR Y -154.
 JOI 21 22 55 101 102 LOA FOR Y -104.
 JOI 21 22 85 86 LOA FOR Z -85.
 JOI 101 102 6 7 LOA FOR Z -85.
 JOI 49 59 71 66 LOA FOR X -256.
 JOI 51 52 60 62 65 69 LOA FOR X 256.
 JOI 68 71 LOA FOR Y -1170.
 JOI 49 51 60 62 65 66 LOA FOR Y -312.
 JOI 50 61 63 64 67 69 70 LOA FOR Y -624.
 JOI 3 9 11 45 46 47 48 87 88 89 56 58 LOA FOR Y -50.
 JOI 12 15 16 17 72 73 92 95 96 97 LOA FOR Y -858.
 JOI 24 104 LOA FOR Y -2500.
 JOI 13 93 LOA FOR Y -1250.
 JOI 52 59 LOA FOR Y -612.

Member Depths for Stress Calculation

500	ZD 3.	YD 3.	ZC 1.5	YC 1.5
502 TO 505	ZD 3.	YD 3.	ZC 1.5	YC 1.5
506	ZD 2.	YD 2.	ZC 1.	YC 1.
508	ZD 3.	YD 2.	ZC 1.5	YC 1.
510	ZD 2.	YD 2.	ZC 1.5	YC 1.
512	ZD 2.	YD 2.	ZC 1.5	YC 1.
514	ZD 3.	YD 2.	ZC 1.5	YC 1.
516 TO 521	ZD 2.	YD 2.	ZC 1.	YC 1.
522	ZD 3.	YD 2.	ZC 1.5	YC 1.
524	ZD 3.	YD 2.	ZC 1.5	YC 1.
526 TO 538	ZD 2.	YD 2.	ZC 1.5	YC 1.
539	ZD 2.	YD 3.	ZC 1.5	YC 1.5
540	ZD 3.	YD 2.	ZC 1.5	YC 1.
542	ZD 3.	YD 2.	ZC 1.5	YC 1.
543	ZD 3.	YD 3.	ZC 1.5	YC 1.5
544 TO 545	ZD 3.	YD 2.	ZC 1.5	YC 1.
546	ZD 2.	YD 2.	ZC 1.	YC 1.
548	ZD 2.	YD 3.	ZC 1.5	YC 1.5
549	ZD 3.	YD 2.	ZC 1.5	YC 1.
551 TO 555	ZD 3.	YD 2.	ZC 1.5	YC 1.
556	ZD 3.	YD 3.	ZC 1.5	YC 1.5
557	ZD 3.	YD 2.	ZC 1.5	YC 1.
597	ZD 1.	YD 1.	ZC .5	YC .5
599	ZD 1.	YD 1.	ZC .5	YC .5

JOINT	ΔX	ΔY	ΔZ	$\Delta \theta_x$	$\Delta \theta_y$	$\Delta \theta_z$
87	-0.0072	-0.0069	0.0437	0.1047	0.0289	0.0051
99	-0.0183	-0.0131	-0.0003	-0.0678	-0.0056	-0.0137
85	-0.0055	-0.0012	0.0002	-0.0041	0.0279	0.0129
102	-0.0107	-0.0061	0.0146	-0.0209	0.0386	0.0216
59	-0.0172	-0.0534	0.0200	0.0001	0.0000	0.0408
57	-0.0174	-0.0302	0.0000	-0.0000	0.0000	0.0285
53	0.0005	-0.0491	-0.0000	0.0002	-0.0000	0.0649
54	-0.0069	-0.0308	-0.0001	0.0003	-0.0001	0.0230
42	-0.0008	-0.0075	-0.0000	0.0000	-0.0004	0.0222
18	-0.0184	-0.0042	-0.0006	0.0061	0.0005	0.0345
56	-0.0174	-0.0097	-0.0003	-0.0000	0.0000	0.0541
98	-0.0184	-0.0042	0.0005	-0.0061	-0.0004	0.0345
21	-0.0136	-0.0028	0.0033	-0.0045	-0.0129	0.0082
060 38	0.0007	-0.0579	0.0000	-0.0001	0.0000	-0.0251
46 46	0.0084	-0.0627	0.0000	0.0001	0.0001	-0.0496
50	-0.0076	-0.0415	0.0001	0.0001	-0.0000	0.0716
45 95	0.0028	-0.0507	-0.0001	0.0000	0.0003	-0.0044
44	0.0007	-0.0301	-0.0003	0.0004	-0.0002	0.0187
41	0.0010	-0.0105	0.0000	0.0006	0.0000	0.0778
80	-0.0009	-0.0007	0.0024	0.0291	-0.0093	0.0108
107	-0.0080	-0.0035	0.0338	0.0563	-0.0354	0.0120
63	0.0313	-0.0654	0.0001	0.0001	0.0001	0.0422
90	-0.0110	-0.0043	0.0428	0.0466	-0.0310	0.0212
86	-0.0063	-0.0036	0.0187	0.0222	0.0450	0.0056
101	-0.0136	-0.0028	-0.0033	0.0045	0.0130	0.0082
52	-0.0068	-0.0529	-0.0000	0.0002	0.0001	0.0421
55	-0.0087	-0.0087	-0.0000	-0.0000	-0.0002	0.0077
51	0.0341	-0.0647	0.0001	0.0002	0.0001	-0.0108
108	0.0000	-0.0018	-0.0000	-0.0350	-0.0005	0.0061

COMPUTER ANALYSIS PRINTOUT OF JOINT TRANSLATIONAL AND ROTATIONAL DISPLACEMENTS

Member	Joint	FORCES AND MOMENTS IN MEMBERS					
		Axial (x)	Shear (y)	Shear (z)	Torsional (x)	Bending (y)	Bending (z)
550	58	-1684.3701	-4.0644	0.0123	-0.0407	-0.1689	-97.3114
550	73	1684.3701	4.0644	-0.0123	0.0407	-0.3028	-57.9906
551	58	15.6758	1220.9226	0.2261	-1.0932	-2.2223	3961.7207
551	57	-15.6758	-1220.9226	-0.2261	1.0932	0.1877	7026.5820
552	57	25.9266	-850.8691	0.6647	0.1637	-5.1510	-8331.2031
552	56	-25.9266	850.8691	-0.6647	-0.1637	-6.1484	-6127.5703
553	55	1349.2861	155.4025	0.0142	-3.9073	-0.4657	582.7461
553	56	-1349.2861	-155.4025	-0.0142	3.9073	0.1102	3302.3169
554	54	895.8420	-108.8464	-0.1610	-1.8365	-3.8777	-969.0010
554	58	-895.8420	108.8464	0.1610	1.8365	7.9029	-1752.1587
555	56	513.3484	143.5706	-0.1860	0.2671	-1.3213	2514.3694
555	73	-513.3484	-143.5706	-0.1860	-0.2671	-3.8874	1505.6060
556	72	1234.5840	-135.1498	-0.0916	5.8277	1.0979	-1363.5024
556	73	-1234.5840	135.1498	0.0916	-5.8277	1.0225	-2150.3916
557	65	872.1401	-162.6084	0.0229	-0.2859	0.3043	-558.7214
557	74	-872.1401	162.6084	-0.0229	0.2859	-0.6253	-1717.7954
558	53	-1069.1211	-22.7895	-0.0199	0.1237	-0.1703	-145.2402
558	58	1069.1211	22.7895	0.0199	-0.1237	0.5725	-312.2109
560	41	-1186.9185	62.3603	0.1653	1.3652	-3.7897	1445.6549
560	43	1186.9185	-62.3603	-0.1653	-1.3652	-2.5905	962.0828
600	79	0.0	0.0	0.0	0.0	0.0	0.0
600	81	0.0	0.0	0.0	0.0	0.0	0.0
601	81	0.0	0.0	0.0	0.0	0.0	0.0
601	82	0.0	0.0	0.0	0.0	0.0	0.0
602	82	0.0	0.0	0.0	0.0	0.0	0.0
602	83	0.0	0.0	0.0	0.0	0.0	0.0
603	83	-3.9629	385.5830	5.7559	1050.5386	-29.3936	2592.8254
603	109	3.9629	-385.5830	-5.7559	-1050.5386	-56.9451	3190.9199
604	84	878.3533	-5.3068	-5.7338	-173.8622	74.4504	-198.2873
604	85	-878.3533	5.3068	5.7338	173.8622	137.7018	1.9369
605	83	1157.1963	0.2794	-1.7313	-10.8288	26.3557	-2.1714
605	85	-1157.1963	-0.2794	1.7313	10.8288	51.9344	14.8066
606	83	2612.9316	-17.4697	-45.2037	-280.3882	1009.1716	-366.9434
606	86	-2612.9316	17.4697	45.2037	280.3882	663.3667	-279.4363
607	83	97.8525	1.3128	0.3585	23.8679	-66.7011	35.6119
607	87	-97.8525	-1.3128	-0.3585	-23.8679	48.9264	29.4758
608	82	5067.6758	-21.7426	-38.6467	-167.7311	1529.5732	-441.9058
608	87	-5067.6758	21.7426	38.6467	167.7311	-99.6456	-362.5691
609	80	2217.5879	-22.2537	-33.7158	236.9197	780.3965	-246.8594
609	88	-2217.5879	22.2537	33.7158	-236.9197	163.6467	-376.2449
610	81	2217.5879	-22.2537	-33.7158	236.9197	1083.8389	-447.1428
610	80	-2217.5879	22.2537	33.7158	-236.9197	-780.3965	246.8594
611	79	1157.5176	-15.0479	3.6138	194.6282	-25.2191	-357.7085
611	89	-1157.5176	15.0479	-3.6138	-194.6282	-108.4926	-159.0626
612	89	16.1484	21.6007	-11.0464	-317.5999	266.3452	462.8384
612	88	-16.1484	-21.6007	11.0464	317.5999	166.0389	375.5906

STRESSES IN MEMBERS

FROM START	AXIAL	Y SHEAR	Z SHEAR	Y BENDING	Z BENDING	MAX NORMAL	MIN NORMAL
0.010 FR	-13.6311	0.0	0.0	2.9359	-4119.6094	4108.9102	-4136.1719
0.500	-13.6311	0.0	0.0	1.6067	1638.9626	1626.9377	-1654.2002
0.980	-13.6311	0.0	0.0	0.3045	7280.0117	7266.6797	-7293.9414

MEMBER 552

LOADING ONE VERTICAL

DISTANCE	STRESS						
FROM START	AXIAL	Y SHEAR	Z SHEAR	Y BENDING	Z BENDING	MAX NORMAL	MIN NORMAL
0.010 FR	-22.5449	0.0	0.0	8.7174	8762.0781	8746.2461	-8791.3359
0.500	-22.5449	0.0	0.0	-0.6649	1181.6228	1159.7427	-1204.8323
0.980	-22.5449	0.0	0.0	-7.8965	-6244.1289	6229.4766	-6274.5664

MEMBER 553

LOADING ONE VERTICAL

DISTANCE	STRESS						
FROM START	AXIAL	Y SHEAR	Z SHEAR	Y BENDING	Z BENDING	MAX NORMAL	MIN NORMAL
0.010 FR	-1173.2525	0.0	0.0	0.6162	-581.7061	-590.9702	-1755.6147
0.500	-1173.2525	0.0	0.0	0.3840	1454.3159	281.4072	-2627.5922
0.980	-1173.2525	0.0	0.0	0.1564	3448.7842	2275.6479	-4622.2305

MEMBER 554

D. PIPING STRESS ANALYSIS RESULTS

The piping for the intermediate, mercury, and heat rejection loops shown on Figure IIB1-1, sheet 2, was thermally stressed at the system operating temperatures. In addition, the piping interface loads were calculated for gravity loading in 1-g for unsupported piping. The computer code "MEC-21" was used in performing these calculations. The maximum allowable line stresses are based upon Specification AGC-10650, "Structural Design Criteria, SNAP-8." This will be discussed in more detail below. The allowable rotating machinery interface loads are based upon existing configuration control drawings for those components. It was assumed that static components which have not been designed or are being modified can withstand interface loads comparable to that which the connecting piping can accept.

For pipe stress, AGC-10650 has been interpreted as follows:

1. Maximum allowable thermal stress = $2 \times \text{material yield strength at temperature} = 2 \sigma_y$
2. Maximum allowable primary stress = σ_p (creep strength or yield strength, depending upon operating temperature)
3. Maximum combined thermal and primary stress = $2 \times \sigma_y$
4. Maximum allowable pipe stress = $(2 \sigma_y - \sigma_p) / \text{S.F.}$
5. Applied safety factor = $\text{S.F.} = 1.5 \times K(\text{calculation}) / K(\text{material})$
where $K(\text{material}) = 0.85$ to allow for variations in material properties from curve data

$K(\text{calculation}) = 1.51$ and allows for manufacturing variations, dimensional variations, and load/model uncertainty

Thus, $\text{S.F.} = 1.5 \times 1.51 / 0.85 = 2.665$

For example, at 1200°F: $\sigma_y = 19,200$ psi

$\sigma_p = 6,800$ psi (1% creep in 40,000 hrs.)

$\sigma_{\text{allowable (maximum)}} = (2 \times 19,200 - 6,800)/2.665$

$= 11,850$ psi

A sample of the analysis that was performed in stressing the PCS piping appears in Figures IID2-1, IID2-2 and IID2-3. Based on the engineering layout a sketch of the line to be stressed is prepared (Figure IID2-1); computer input is prepared and the line is analyzed (Figure IID2-2); finally an engineering evaluation of the computer output is prepared to determine the acceptability of the line. A summary of the interface loads imposed upon the components in the Intermediate, Heat Rejection and Mercury loops appears in Figures IID3-1, IID3-2 and IID3-3. The stress results on the basis of "minimum factor of safety" appear in Figure IID3-4. In some places, the stresses exceeded those allowed by the design criteria; these are a small percentage of the line elements analyzed and will be eliminated during the next design phase.

Some of the general results of the piping stress analysis follow:

1. In order to limit stresses in the Intermediate Loop NaK pump suction lines, the boiler movement will be limited to about 1/2 inch of the full 1 inch travel downward that the boiler height and operating temperature would dictate.
2. The mercury vapor line is located in a horizontal plane so that thermal expansion bending moments and pipe forces applied at the turbine interface are transmitted to the TAA center-of-gravity support and not to the turbine exhaust.
3. Some of the pipe lines do not require additional supports in the 1-g environment (see Figures IID-1, -2, and -3).
4. The intermediate loop and heat rejection loop lines to and from the radiator are anchored at the PCS structure interface.
5. The NaK diverter valves are considered to be part of the piping and will not be supported independently.

6. The HRL Flow Control Valve is allowed to move with the line. If the valve were anchored, additional piping would be required to reduce the stresses in the lines between the NaK pump and condenser.

7. The boiler is considered to be anchored at the mercury vapor outlet end in order to minimize the required line length for the mercury vapor line. The mercury vapor line should be as short as possible in order to minimize the boiler/turbine inlet line pressure loss and the amount of vapor line preheat (on startup) required.

8. In general, the only place where the requirement to maintain 1300°F capability for the system piping had a serious impact was in the mercury vapor line. This is because the vapor line pressure is also affected by temperature. At the lower temperatures and associated pressure, a 2-1/2-inch x 0.065-inch or 0.083-inch vapor line would be adequate.

PCS PIPE STRESS CRITERIA
(BASED ON SPECIFICATION AGC-10650*)

MAXIMUM ALLOWABLE THERMAL STRESS = 2 X YIELD STRENGTH

MAXIMUM ALLOWABLE PRIMARY STRESS = YIELD STRENGTH OR 1% CREEP IN 5 YEARS

MAXIMUM COMBINED STRESS = 2 X YIELD STRENGTH

MINIMUM SAFETY FACTOR = 1.50

MAXIMUM STRESS = MATERIAL ALLOWABLE

MATERIAL ALLOWABLE = 0.85 X CURVE VALUE

MAXIMUM STRESS = 1.51 X CALCULATED STRESS

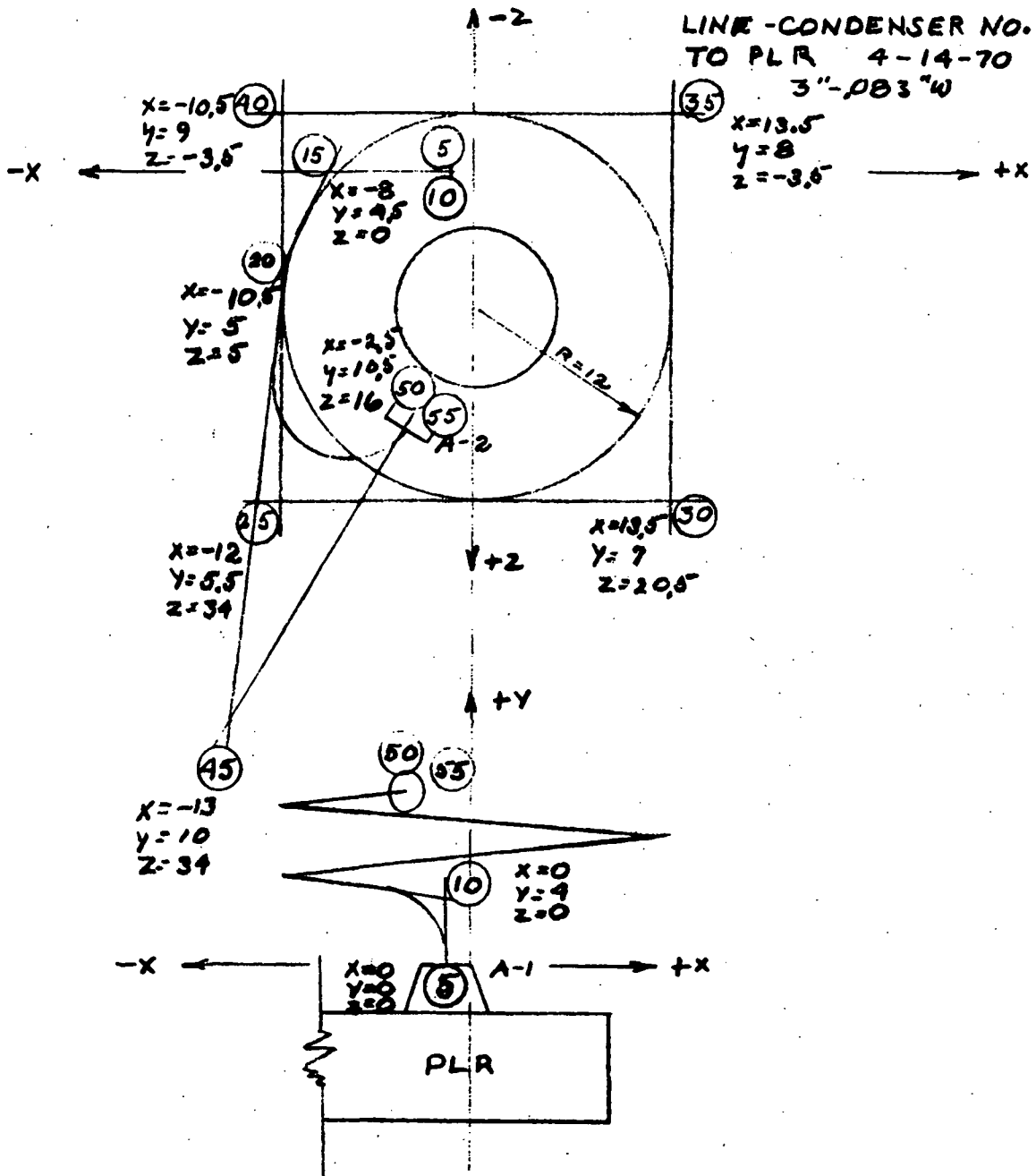
- REFLECTS USAS B31.7 - "CODE FOR NUCLEAR POWER PIPING"

FIGURE II D I-1



HRL-PROBLEM NO.110

LINE-CONDENSER NO.1
TO PLR 4-14-70
3"-OD 3"W



PLR GROWTH @ 495°F (12" FROM V ANCHOR)
 ΔT FROM 75° = 420°F
 $\alpha = 9.75 \times 10^{-6}$ IN/IN-OF MAX. REF. H-100
 GROWTH = $9.75 \times 10^{-6} (420) 12 \text{ IN} = .049 \text{ IN.}$

POISSONS RATIO = 0.3 - H-100

$E = 26.4 \times 10^6 \text{ PSI (STATIC)}$

$\epsilon = 9.75 \times 10^{-6} (420) 10^3 = 4.095 \text{ MILS/IN.}$

WTP = 0.612 LBS/IN³ see Problem No. 108

" = LBS OF PIPE, CONTENTS & 1/2" INSULATION PER IN³ PIPE METAL

SCALE 0.1IN. = 1.0IN.

FIGURE II D 2-1

RUN NO. 0

PIPING FLEXIBILITY ANALYSIS PROGRAM MFC-21CE

PAGE 2 OF 12

** DATA CARD DISPLAY WITH DIAGNOSTIC NOTES **

STRESS CONDENSER NO-1 TO PLP 4-14-70

PROBLEM NO. 110

RUN TIME 1.182 MIN

TYPE ONE CARDS

CNO	PT	COORDINATES	DIAM	THCK	RAD	SPECIAL	COORDINATES	F	DIAGNOSTIC NOTES
		XIN / YIN / ZIN				V / VV / VIN / VXIN		YLA / ZIN / VV	
51	0101					C3CCCC83			ZERO COORDINATES.
10	1		+000400			C3CCCC8300425			
15	1		-000800+000450			C3CCCC8300449			
20	1		-001050+000500+000500			0300008301200			
25	1		-001200+000550+002050			C3CCCC8301200			
30	1		+001350+000700+002050			C3CCCC8301200			
35	1		+001350+000800-000350			C3CCCC8301200			
40	1		-001050+000900-000350			C3CCCC8301200			
45	1		-001300+001000+003400			C3CCCC8300449			

TYPE TWO CARDS

CNO	CMPT	DATA	OR	ANCHOR	RESTRAINT	FLEX	C	CG-R	STR	LCC-A	COS	CP
/	E /	F /	F /	E /	E /	EX	/	/	Y /	/	Z /	/ VV
5												
10												
15												
20												
25												
30												
35												
40												
45												

TYPE THREE CARDS

CNO	EXPAN	E	MU	LOAD	RHO	PSI	ULOAD	F	COS	ANK	DELTA	ANK	ROT	RSNT	MOVE
	/	V	VV	VV	VV	/	VV	V	VX	/	Y	Z	X	Y	Z
5															+00490
10	4095264300														+0612
15	4095264300														+0612
20	4095264300														+0612
25	4095264300														+0612
30	4095264300														+0612
35	4095264300														+0612
40	4095264300														+0612
45	4095264300														+0612

FIGURE 11 D 2-2
11 pages

PIPING FLEXIBILITY ANALYSIS PROGRAM MEC-210F
** DATA CARD DISPLAY WITH DIAGNOSTIC NOTES **

STRESS CONDENSER NO-1 TO PLP 4-14-70

PROBLEM NO. 110

[illegible]

XIN / YIN / ZIN / V / VV / VIN / VXIN / YIN / ZIN / VV

50 1 -000250+001050+001600030000083

551 0102 -000250+001050+001600030009083

CNC CMPT DATA OR ANCHOR, RESTRAINT FLEX C CG-R STR LOC-A COS CR

/ E/ E/ E/ E/ E/ EX / / Y / / Z / / VV

50

55

CNOEXPAN F MU LOAD RHO PSI ULOAD F COS, ANK DELTA ANK FCT, RSHT MOVE

... / V VV VV VV / VV / VV V/ VX / Y / Z / x// y// z//

5004095264300 +0612

5.5

** THERMAL LOADING EFFECTS **

STRESS CONDENSER NO-1 TC PLR 4-14-70

PROBLEM NO. 110

ELEMENT ID	FLEM	ELEM	ELEMENT	POINT	COORDS	LENGTH	DIAM	THICK	RADIUS	THETA	DISPLACEMENTS, INCHES		
CRD-BR-ELM	TYPE	PONT	X, IN.	Y, IN.	Z, IN.	IN.	IN.	IN.	IN.	DEG.	DELTA X	DELTA Y	DELTA Z
55-02-001	ANKR	BINP	-2.500	10.500	16.000		3.000	0.083			-0.000	0.000	0.000
50-01-018	TGNT	BINP	-2.500	10.500	16.000	1.849	3.000	0.083			-0.000	0.000	0.000
45-01-017	BEND	END	-3.431	10.456	17.597	12.021	3.000	0.082	4.490	153.4	-0.004	-0.000	0.007
45-01-016	TGNT	END	-11.737	9.495	15.053	7.386	3.000	0.083			-0.035	-0.007	-0.005
40-01-015	BEND	END	-11.246	9.298	7.696	18.038	3.000	0.083	12.000	86.1	-0.026	0.002	-0.035
40-01-014	TGNT	END	0.705	8.533	-3.500	0.827	3.000	0.083			0.040	0.029	-0.062
35-01-013	BEND	END	1.531	8.499	-3.500	18.829	3.000	0.083	12.000	89.9	0.044	0.031	-0.061
35-01-012	TGNT	END	13.500	7.501	8.469	0.071	3.000	0.083			0.081	0.045	0.006
30-01-011	BEND	END	13.500	7.498	8.540	18.820	3.000	0.082	12.000	89.9	0.081	0.045	0.006
30-01-010	TGNT	END	1.550	6.297	20.500	0.384	3.000	0.083			0.039	0.050	0.070
25-01-009	BEND	END	1.167	6.275	20.500	19.992	3.000	0.083	12.000	95.4	0.038	0.050	0.070
25-01-008	TGNT	END	-10.730	5.077	7.379	0.140	3.000	0.083			-0.035	0.065	0.039
20-01-007	BEND	END	-10.717	5.072	7.239	4.450	3.000	0.083	12.000	21.2	-0.036	0.065	0.038
20-01-006	TGNT	END	-9.497	4.799	2.995	0.507	3.000	0.083			-0.036	0.067	0.019
15-01-005	BEND	END	-9.232	4.746	2.463	4.956	3.000	0.082	4.490	63.2	-0.036	0.067	0.016
15-01-004	TGNT	END	-5.241	4.323	0.0	1.258	3.000	0.083			-0.022	0.066	0.003
10-01-003	BEND	END	-3.985	4.249	0.0	6.411	3.000	0.083	4.250	86.4	-0.017	0.066	0.002
10-01-002	TGNT	END	0.0	0.007	0.0	0.007	3.000	0.083			-0.000	0.049	0.000

Condenser

STRESS CONDENSER NO-1 TO PLR 4-14-70

PROBLEM NO. 110

ELEMENT NO CRD-BP-ELM	ELEM TYPE	ELEM POINT	ROTATIONS, RADIANS			RSMT LOAD	FORCES, LBS.			MOMENTS, IN.-LBS.			STRESS, PS
			PHI X	PHI Y	PHI Z		FX	FY	FZ	MX	MY	MZ	
55-02-001	ANKR	BINP	0.0000	0.0000	-0.0000		-11	-75	-48	388	134	-6	
50-01-018	TGNT	BINP	0.0000	0.0000	-0.0000		11	-75	-48	-388	-134	6	76
45-01-017	BEND	END	0.0000	0.0000	-0.0000		11	-75	-48	-511	-107	-64	261
45-01-016	TGNT	END	0.0012	-0.0009	0.0012		11	-75	-48	-365	327	-706	312
40-01-015	BEND	END	0.0012	-0.0010	0.0015		11	-75	-48	185	388	-671	172
40-01-014	TGNT	END	0.0002	-0.0018	0.0016		11	-75	-48	997	-67	227	195
35-01-013	BEND	END	0.0001	-0.0018	0.0016		11	-75	-48	996	-108	290	202
35-01-012	TGNT	END	-0.0005	-0.0003	0.0004		11	-75	-48	37	-830	1188	312
30-01-011	BEND	END	-0.0005	-0.0003	0.0004		11	-75	-48	32	-831	1188	312
30-01-010	TGNT	END	-0.0000	0.0018	-0.0008		11	-75	-48	-935	-384	266	212
25-01-009	BEND	END	-0.0000	0.0018	-0.0008		11	-75	-48	-936	-365	237	207
25-01-008	TGNT	END	0.0009	0.0015	-0.0006		11	-75	-48	2	366	-680	164
20-01-007	BEND	END	0.0009	0.0015	-0.0006		11	-75	-48	12	367	-679	164
20-01-006	TGNT	END	0.0009	0.0012	-0.0004		11	-75	-48	321	356	-590	164
15-01-005	BEND	END	0.0009	0.0012	-0.0004		11	-75	-48	359	349	-570	249
15-01-004	TGNT	END	0.0008	0.0004	-0.0000		11	-75	-48	526	182	-272	207
10-01-003	BEND	END	0.0007	0.0004	-0.0000		11	-75	-48	522	121	-177	160
10-01-002	TGNT	END	0.0000	-0.0000	0.0000		11	-75	-48	314	-73	76	176

RUN NO. 0

PIPING FLEXIBILITY ANALYSIS PROGRAM MEC-21CE

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** THERMAL LOADING EFFECTS **

STRESS CONDENSER NO-1 TC PLR 4-14-7C

PROBLEM NO. 110

ELEMENT ID	ELFM	ELFM	ELEMENT POINT COORDS			LENGTH	DIAM	THCK	RADIUS	THETA	DISPLACEMENTS, INCHES		
CRD-BR-ELM	TYPE	PONT	X, IN.	Y, IN.	Z, IN.	IN.	IN.	IN.	IN.	DEG.	DELTA X	DELTA Y	DELTA Z
5-01-001	ANKR	END	0.0	0.0	0.0		3.000	0.083			0.000	0.049	0.0

PLR

RUN NO. 0

PIPING FLEXIBILITY ANALYSIS PROGRAM MEC-2ICE

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** THERMAL LOADING EFFECTS **

STRESS CONDENSER NO-1 TC PLR 4-14-70

PROBLEM NO. 110

ELEMENT	IC	ELEM	ELEM	ROTATIONS, RADIANS			RSNT	FORCES, LBS.			MOMENTS, IN.-LBS.			STRES
CRD-BR-ELM	TYPF	PONT		PHI X	PHI Y	PHI Z	LOAD	FX	FY	FZ	MX	MY	MZ	SE, PS
5-C1-001	ANKR	END		0.0	0.0	0.0		11	-75	-48	314	-73	76	61

PLR

RUN NO. 0

PIPING FLEXIBILITY ANALYSIS PROGRAM MEC-21CE

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** WEIGHT LOADING EFFECTS **

STRESS CONDENSER NO-1 TO PLR 4-14-70
PROJECT NO.

PROBLEM NO. 110

SUMMATION OF REACTIONS ON THE STRUCTURE

FX, LBS.	FY, LBS.	FZ, LBS.	MX, IN.-LBS.	MY, IN.-LBS.	MZ, IN.-LBS.
-0.	-54.	-0.	472.	-0.	94.

SUMMATION OF WEIGHT AND UNIFORM LOADING EFFECTS

FX, LBS.	FY, LBS.	FZ, LBS.	MX, IN.-LBS.	MY, IN.-LBS.	MZ, IN.-LBS.
0.	-54.	0.	472.	0.	94.

CENTER-OF-FORCES COORDINATES

X, IN.	Y, IN.	Z, IN.
-1.7	0.0	8.7

CENTER-OF-GRAVITY COORDINATES

X, IN.	Y, IN.	Z, IN.
-1.7	7.3	8.7

SUMMATION OF REACTIONS ON THE BRANCH INTERSECTION POINTS

BINP NO.	FX, LBS.	FY, LBS.	FZ, LBS.	MX, IN.-LBS.	MY, IN.-LBS.	MZ, IN.-LBS.
1	-0.	0.	-0.	-0.	-0.	-0.

** WEIGHT LOADING EFFECTS **

STRESS CONDENSER NO-1 TC PLR 4-14-70

PROBLEM NO. 110

ELEMENT ID	ELEM TYPE	ELEM POINT	ELEMENT POINT COORDS			LENGTH	DIAM	THICK	RADII	THEIA	DISPLACEMENTS, INCHES		
CRD-BR-ELM			X, IN.	Y, IN.	Z, IN.	IN.	IN.	IN.	IN.	DEG.	DELTA X	DELTA Y	DELTA Z
55-02-001	ANKR	BIMP	-2.500	10.500	16.000		3.000	0.083			0.000	0.000	0.000
50-01-018	TGNT	BIMP	-2.500	10.500	16.000	1.849	3.000	0.083			0.000	0.000	0.000
45-01-017	BEND	END	-3.431	10.455	17.597	12.021	3.000	0.083	4.490	153.4	0.000	-0.000	0.000
45-01-016	TGNT	END	-11.737	9.495	15.053	7.386	3.000	0.083			0.001	-0.001	-0.000
40-01-015	BEND	END	-11.246	9.298	7.686	18.039	3.000	0.083	12.000	86.1	0.001	0.002	-0.000
40-01-014	TGNT	END	0.705	8.533	-3.500	0.827	3.000	0.083			0.002	0.011	-0.000
35-01-013	BEND	END	1.531	8.499	-3.500	18.829	3.000	0.083	12.000	89.9	0.002	0.011	-0.000
35-01-012	TGNT	END	13.500	7.501	8.469	0.071	3.000	0.083			0.005	0.013	-0.002
30-01-011	BEND	END	13.500	7.498	8.540	18.820	3.000	0.083	12.000	89.9	0.005	0.013	-0.002
30-01-010	TGNT	END	1.550	6.297	20.500	0.384	3.000	0.083			0.008	0.019	0.002
25-01-009	BEND	END	1.167	6.275	20.500	19.982	3.000	0.083	12.000	95.4	0.008	0.020	0.002
25-01-008	TGNT	END	-10.730	5.077	7.379	0.140	3.000	0.083			0.002	0.042	0.006
20-01-007	BEND	END	-10.717	5.072	7.239	4.450	3.000	0.083	12.000	21.2	0.002	0.042	0.006
20-01-006	TGNT	END	-9.497	4.799	2.995	0.597	3.000	0.083			0.001	0.046	0.005
15-01-005	BEND	END	-9.232	4.746	2.463	4.956	3.000	0.083	4.490	63.2	0.001	0.047	0.005
15-01-004	TGNT	END	-5.241	4.328	0.0	1.258	3.000	0.083			-0.000	0.049	0.003
10-01-003	BEND	END	-2.985	4.249	0.0	6.411	3.000	0.083	4.250	86.4	-0.000	0.049	0.003
10-01-002	TGNT	END	0.0	0.007	0.0	0.00	3.000	0.083			-0.000	0	0.000

Condenser-1

RUN NO. 0

PIPING FLEXIBILITY ANALYSIS PROGRAM MFC-210E

PAGE 10 OF 12

** WEIGHT LOADING EFFECTS **

STRESS CONDENSER NO-1 TO PLR 4-14-70

PROBLEM NO. 110

ELEMENT ID CRD-BR-ELM	ELEM TYPE	ELEM POINT	ROTATIONS, RADIAN			RSMT LOAD	FORCES, LBS.			MOMENTS, IN.-LBS.			STRESS SE, PS
			PHI X	PHI Y	PHI Z		FX	FY	FZ	MX	MY	MZ	
55-02-001	ANKR	BIND	0.0000	0.0000	0.0000		2	13	3	138	22	46	
50-01-018	TGNT	BIND	0.0000	0.0000	0.0000		-2	-13	-3	-138	-22	-46	27
45-01-017	BEND	END	0.0000	0.0000	0.0000		-2	-14	-3	-160	-15	-58	90
45-01-016	TGNT	END	0.0004	-0.0001	0.0004		-2	-19	-3	-109	5	-192	73
40-01-015	BEND	END	0.0004	-0.0001	0.0005		-2	-23	-3	47	-13	-181	35
40-01-014	TGNT	END	0.0000	0.0000	0.0004		-2	-31	-3	336	-77	158	78
35-01-013	BEND	END	0.0000	0.0000	0.0004		-2	-31	-3	336	-80	184	82
35-01-012	TGNT	END	0.0000	0.0003	-0.0004		-2	-40	-3	-114	-92	605	118
30-01-011	BEND	END	0.0000	0.0003	-0.0004		-2	-40	-3	-117	-91	605	118
30-01-010	TGNT	END	0.0006	0.0004	-0.0008		-2	-49	-3	-645	-25	56	120
25-01-009	BEND	END	0.0006	0.0004	-0.0008		-2	-49	-3	-645	-24	37	120
25-01-008	TGNT	END	0.0011	0.0003	-0.0004		-2	-58	-3	78	-15	-587	109
20-01-007	BEND	END	0.0011	0.0003	-0.0004		-2	-58	-3	86	-15	-586	110
20-01-006	TGNT	END	0.0010	0.0003	-0.0003		-2	-61	-3	339	-29	-512	115
15-01-005	BEND	END	0.0010	0.0003	-0.0003		-2	-61	-3	372	-31	-495	128
15-01-004	TGNT	END	0.0009	0.0003	0.0000		-2	-63	-3	523	-50	-245	163
10-01-003	BEND	END	0.0008	0.0003	0.0000		-2	-64	-3	523	-54	-164	133
10-01-002	TGNT	END	0.0000	-0.0000	0.0000		-2	-67	-3	500	-67	104	287

RUN NO. C

PIPING FLEXIBILITY ANALYSIS PROGRAM MEC-210E

PAGE 11 OF 12

** WEIGHT LOADING EFFECTS **

STRESS CONDENSED NO-1 TO PLR 4-14-70

PROBLEM NO. 110

ELEMENT ID	ELEM	ELEM	ELEMENT POINT COORDS.			LENGTH	DIAM	THICK	RADIUS	THETA	DISPLACEMENTS, INCHES			
CRD-BP-ELM	TYPE	POINT	X, IN.	Y, IN.	Z, IN.	IN.	IN.	IN.	IN.	DEG.	DELTA X	DELTA Y	DELTA Z	
5-01-001	ANKR	END	0.0	0.0	0.0	3.000	0.033				-0.000	0.049	0.0	

PLR

RUN NO. 0

PIPING FLEXIBILITY ANALYSIS PROGRAM MEC-2100

PAGE 12 OF 12

** WEIGHT LOADING EFFECTS **

STRESS CONDENSER NO-1 TO PLR 4-14-70

PROBLEM NO. 110

ELEMENT ID	ELEM TYPE	FLEM POINT	ROTATIONS, RADIANS			RSMT LOAD	FORCES, LBS.			MOMENTS, IN.-LBS.			STRESS SF, PS
			PHI X	PHI Y	PHI Z		FX	FY	FZ	MX	MY	MZ	
5-01-001	ANKR	END	0.0	0.0	0.0		-2	-67	-3	509	-67	104	97

FILE



AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

QUADRILLE WORK SHEET

PAGE _____ OF _____ PAGES

DATE 5-30-70SUBJECT 3 IN. LINE CONDENSER TO PLR BY COZINE

WORK ORDER _____

FROM COMPUTER RUN PROBLEM 110, 4-14-70 AT T=564°F

	FORCE, LB			MOMENT, IN-LB		
	F_x	F_y	F_z	M_x	M_y	M_z
CONDENSER OUTLET						
ALLOWABLE	± 96.5	± 100	± 96.5	$\pm 1,160$	$\pm 1,200$	$\pm 1,160$
REF. AGC STRESS						
ANALYSIS SA-C-127						
FROM COMPUTER	-11.0	+75.0	+48.0	+338.0	+134.0	-6.0
RUN						
PLR INLET						
ALLOWABLE	± 100	± 100	± 100	± 1200	± 1200	± 1200
REF. AGC-10631						
FROM COMPUTER	-11.0	+75.0	+48.0	-314.0	+73.0	-76.0
RUN						

FIGURE II D 2-3

3 pages



AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

QUADRILLE WORK SHEET

PAGE 1 OF PAGESDATE SUBJECT 3 IN LINE CONDENSER TO PLR BY WORK ORDER

3 IN OD TUBE, 0.083 IN WALL, $d = 2.834$ IN

FROM COMPUTER:

$$M_x = 32, M_y = -831, M_z = 1188 \text{ IN-LBS}$$

$$M_z = 1188 \text{ IN-LBS (TORSION)}$$

$$M_{x-y} = \sqrt{(32)^2 + (-831)^2} = 832 \text{ IN-LBS}$$

$$I = 0.049 (0.4 - d^4) = 0.049 (3^4 - 2.834^4)$$

$$I = 0.049 (81 - 64.5) = 0.81 \text{ IN}^4$$

$$Z = \frac{2I}{D} = \frac{2(0.81)}{3} = \frac{1.62}{3} = 0.54 \text{ IN}^3$$

$$h = \frac{0.083(12)}{(146)^{2/3}} = 0.467$$

$$i = \frac{1.95}{(0.467)^{2/3}} = \frac{1.95}{.602} = 3.24$$

$$S_b = \frac{M_b}{Z} i = \frac{832}{.54} (3.24) = 5000 \text{ PSI}$$

$$S_T = \frac{M_T}{2Z} = \frac{1188}{2(0.54)} = 1100 \text{ PSI}$$

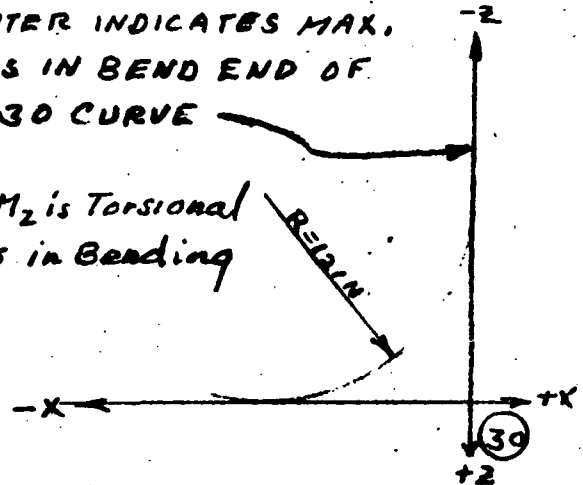
$$S_E = \sqrt{S_b^2 + 4S_T^2} = [(5 \times 10^3)^2 + 4(1.1 \times 10^3)^2]^{1/2} = [2.5 \times 10^6 + 4.84 \times 10^6]^{1/2} = 5460 \text{ PSI}$$

The stress run was made at 495°F but operating T = 564°F
Correcting to operating Temperature

$$\frac{564 - 75}{495 - 75} (5460) = 6350 \text{ PSI}$$

COMPUTER INDICATES MAX.
STRESS IN BEND END OF
POINT 30 CURVE

Then M_z is Torsional
 M_{x-y} is in Bending



Ref. Nuclear Piping Code
The stress intensification
factor for a 90° bend
is $\frac{1.95}{h^{2/3}}$

$$h = \frac{TR}{r^2} \quad T = \text{Tube Wall} = .083 \text{ IN}$$

$$R = \text{Bend Radius} = 12 \text{ IN}$$

$$r = \text{mean tube r} = \frac{D+d}{4}$$

$$r = \frac{3 + 2.834}{4} = 1.46 \text{ IN}$$



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QUADRILLE WORK SHEET

PAGE 2 OF _____ PAGES

DATE _____

SUBJECT _____ BY _____ WORK ORDER _____

CALCULATE THE PRIMARY OR WEIGHT LOADING STRESS
FROM COMPUTER OUTPUT. - POINT 30.

$$M_x = -117, M_y = -91, M_z = 605 \text{ IN-LBS}$$

$$M_z = 605 \text{ IN LBS (TORSION)}$$

$$M_{x-y} = \sqrt{(-117)^2 + (-91)^2} = (13,700 + 8,290)^{1/2} = 148.2 \text{ IN LBS}$$

$$S_b = \frac{M_b}{Z} = \frac{148.2}{.54} (3.24) = 888 \text{ PSI}$$

BENDING

$$S_T = \frac{M_T}{Z} = \frac{605}{2(.54)(1.08)} = 560 \text{ PSI}$$

$$S_E = [888^2 + 4(560)^2]^{1/2} = [79 \times 10^4 + 80.8 \times 10^4]^{1/2}$$

$$S_E = [1.598 \times 10^6]^{1/2} = 1,264 \text{ PSI in accordance with the Nuclear Code = Primary Stress } S_p$$

$$2\% \text{ Yield Stress at } 564^\circ\text{F} = 23,896 \text{ PSI}$$

$$S_A = 2S_y - S_p = 2(23,896) - 1,264 = 46,528 \text{ PSI}$$

$$\text{Factor of safety based on yield per AGC-10650} = 2.665$$

$$\frac{46,528}{2,665} = 17,500 \text{ PSI}$$

$$\frac{17,500}{6,350} = 2.76$$

This is compared to 1.5 required
per AGC-10650

HEAT REJECTION LOOP PIPING/COMPONENT INTERFACE LOAD SUMMARY

INTERFACE DESCRIPTION	FORCE (LB)			MOMENT (IN.-LB)			LOAD TYPE
	Fx	Fy	Fz	Mx	My	Mz	
NPMA (No. 2A) Discharge 2" O.D. x .065" Wall, 316 SST	+14.7 -7.0 +7.7	-10.5 -56.0 -66.5	-12.6 +17.0 +4.4	322 928 1,250	118 128 246	133 345 478	Thermal, T = 417°F, ΔT = 342 Weight - Combined
NPMA (No. 2B) Discharge 2" O.D. x .065" Wall, 316 SST	-28.4 +3.0 -25.4	-4.2 -52.0 -56.2	15.8 -10.0 +5.8	-149 +708 +559	-550 +98 -452	-419 -8 -427	Thermal, T = 417°F, ΔT = 342 Weight - Combined
NPMA Allowable (Ref. AGC Dwg. 098617)	±70.7	±70.7	±100	±530	±530	±750	Applied Separately
Condenser Inlet 3" O.D. x .083" Wall, 316 SST	12.6 3.0 15.6	14.7 -37.0 -22.3	-2.1 -7.0 -9.1	-174 +451 +277	103 -9 +94	-124 -204 -328	Thermal, T = 417°F, ΔT = 342 Weight - Combined
Condenser Allowable (Inlet) (Ref. AGC Stress Analysis SA-C-127)	±28.2	100.0	±28.2	±850	±1,200	±850	
Condenser Outlet 3" O.D. x .083" Wall, 316 SST	-12.9 2 -10.9	87.9 13.0 100.9	56.1 3 59.1	455 138 593	157 22 179	-7 46 39	Thermal, T = 564°F, ΔT = 489 Weight - Combined

HEAT REJECTION LOOP PIPING/COMPONENT INTERFACE LOAD SUMMARY

INTERFACE DESCRIPTION	FORCE (LB)			MOMENT (IN.-LB)			LOAD TYPE
	Fx	Fy	Fz	Mx	My	Mz	
Condenser Allowable (Outlet) (Ref. AGC Stress Analysis SA-C-127)	+96.5	+100.0	+96.5	+1,160	+1,200	+1,160	
PLR Inlet 3" O.D. x .083" Wall, 316 SST	+12.9 -2 +10.9	-87.9 -67 -154.9	-56.1 -3 -59.1	368 509 877	-85.5 -67 -152.5	89 104 193	Thermal, T = 564°F, ΔT = 48° Weight - Combined
PLR Outlet 3" O.D. x .083" Wall, 316 SST	-45.6 0 -45.6	64.4 -23 +41.4	-31.6 -3 -34.6	-358 +78 -280	337 +78 415	976 -235 741	Thermal, T = 564°F, ΔT = 48° Weight - Combined
PLR Allowable (Ref. (Inlet and Outlet) AGC- 10631)	+100	+100	+100	+1,200	+1,200	+1,200	
HLR/Structure Interface (to Heat Sink Inlet)	+45.6 0 45.6	-64.4 -49 -113.4	+31.6 3 +34.6	+469 -178 +291	-371 +11 -360	-1,200 -246 -1,446	Thermal, T = 564°F, ΔT = 48° Weight - Combined
HRL/Structure Interface (from Heat Sink Outlet)	+13.8 +9 +22.8	-74.8 -17 -91.8	-20 +4 -16	+424 69 +493	-232 175 -57	+1,160 271 +1,431	Thermal, T = 417°F, ΔT = 342° Weight - Combined

HEAT REJECTION LOOP PIPING/COMPONENT INTERFACE LOAD SUMMARY

INTERFACE DESCRIPTION	FORCE (LB)			MOMENT (IN.-LB)			LOAD TYPE
	Fx	Fy	Fz	Mx	My	Mz	
NPMA Suction (No. 2A) 2" O.D. x .065" Wall, 316 SST	-10.5 -7 -17.5	+67.4 -43 +24.4	+7.4 -2 +5.4	-410 +249 -161	-58 +1 -57	-147 -37 -184	Thermal, T = 417°F, ΔT = 342 Weight - Combined
NPMA Suction (No. 2B) 2" O.D. x .065" Wall, 316 SST	-2.1 -1 -3.1	+7.4 -30 -22.6	+11.6 -1 +10.6	-154 +165 +11	+62 29 +91	-59 +41 -18	Thermal, T = 417°F, ΔT = 342 Weight - Combined
NPMA Allowable (Ref. AGC Dwg. 098617)	+70.7	+70.7	+100	+530	+530	+750	Applied Separately

INTERMEDIATE LOOP : ING/COMPONENT INTERFACE LOAD

INTERFACE DESCRIPTION	FORCE (LB)			MOMENT (IN.-LB)			LOAD TYPE
	Fx	Fy	Fz	Mx	My	Mz	
NPMA-1 Discharge 2" O.D. x .065" Wall, 316SS	-25 - 1 -26	16 -65 -49	0 -3 -3	85 -39 46	245 48 293	-44 -332 -376	Thermal, 1014°F, $\Delta T = 939^\circ F$ Wt. Total
NPMA-2 Discharge 2" O.D. x .065" Wall, 316SS	-40 -11 -51	19 -63 -44	-11 0 -11	50 -52 -2	-345 -54 -399	-344 63 -281	Thermal, 1014°F, $\Delta T = 939^\circ F$ Wt. Total
Boiler No. 1 Inlet 3" O.D. x .083" Wall, 316SS	+17.7 -1.4 3.7	-67 +85 18	+26.6 + 4 30.6	-434 -659 -1093	-276 -259 -535	-504 +347 -157	Thermal, 1185°F, $\Delta T = 1110^\circ F$ Wt. Total
Boiler No. 1 Outlet 3" O.D. x .083" Wall	-1 -95 -96	2 -29 -27	11 -10 1	388 494 882	-234 -2010 -2244	102 1545 1647	Thermal, 1185°F, $\Delta T = 1110^\circ F$ Wt. Total
Boiler No. 2 Inlet 3" O.D. x .083" Wall	-1 -95 -96	2 -123 -121	11 -10 1	-513 402 -111	440 90 530	-183 -1024 -1207	Thermal 1185°F, $\Delta T = 1110^\circ F$ Wt. Total
NPMA No. 1 Suction 2" O.D. x .065" Wall, 316SS	5 - 27 -22	-44 -200 -244	-28 37 9	628 141 769	199 -99 100	-300 -1498 -1798	Thermal, 1015°F, $\Delta T = 940^\circ F$ Wt. Total

INTERMEDIATE LOO. PIPING/COMPONENT INTERFACE LOAD

INTERFACE DESCRIPTION	FORCE (LB)			MOMENT (IN.-LB)			LOAD TYPE
	Fx	Fy	Fz	Mx	My	Mz	
NEMA No. 2 Suction 2" O.D. x .065" Wall, 316SS	-54	33	25	-30	-35	-799	Thermal, 1015°F $\Delta T = 940^\circ F$
	-11	5	-5	394	-55	-397	Wt.
	-65	38	20	364	-90	-1196	Total
NEMA Allowable	± 70.7	± 70.7	± 100	± 530	± 530	± 750	Applied Separately

MERCURY LOOP PIPING/COMPONENT LOAD SUMMARY

INTERFACE DESCRIPTION	FORCE (LB)			MOMENT (IN.-LB)			LOAD TYPE
	Fx	Fy	Fz	Mx	My	Mz	
Hg PMA Suction Allowable	50 lb Vector Sum			200 in lb			
Hg PMA Suction	15.8	-5.25	5.25	4.2	-105	-101	Thermal, T = 417°F
	6.3	-6.3	1.05	-95	-38	-82	Weight
	22.1	-11.55	6.30	-90.8	-143	-133	Combined
Hg PMA Discharge Allowable	25 lb Vector Sum			100 in lb			
Hg PMA Discharge	2.1	0	0	-2.1	-4.2	31.6	Thermal, T = 417°F
	2.1	-8.4	0	-31.6	-5.25	-119	Weight
	4.2	-8.4	0	-33.7	9.45	-87.4	Combined
Boiler Hg Outlet	-15.1	-10.1	39.4	433	414	283	Thermal, T = 1190°F
	-12	-9	285	333	267	235.5	Weight
	-27	-19.1	67.9	766	681	518	Combined
TAA Inlet Allowable	37 lbs Radial			960 in lbs - Bending			
	~~45~~ 52 lbs	Radial	~~39~~	~~161~~ 192 in lbs	- Torsion		
TAA Inlet	-15	-10	39	161	517	203	Thermal, T = 1180°F
2" O.D. x 18.8" Wall,	-19.5	43.5	48	-718	605	-790	Weight
316 SST	-34.5	33.5	87	-557	1122	-587	Combined
Boiler Hg Inlet	-2.1	0	0	0	19.1	-4.25	Thermal, T = 417°F
	2	-8	0	-49	-20	-250	Weight
	-.1	-8	0	-49	0.9	-254.5	Combined

Figure IID3-3

SUMMARY OF PCS PIPING THERMAL STRESS

ANALYSIS RESULTS

LOOP	MINIMUM FACTOR OF SAFETY	
	1200°F SYSTEM	1300°F SYSTEM
INTERMEDIATE	1.25	1.1
MERCURY	3.43	2.86
HEAT REJECTION	1.38	1.16

DESIGN CRITERIA: MINIMUM FACTOR OF SAFETY = 1.50

- PIPING / COMPONENT APPLIED INTERFACE LOADS ARE WITHIN ALLOWABLES

E. FLUID ANALYSIS

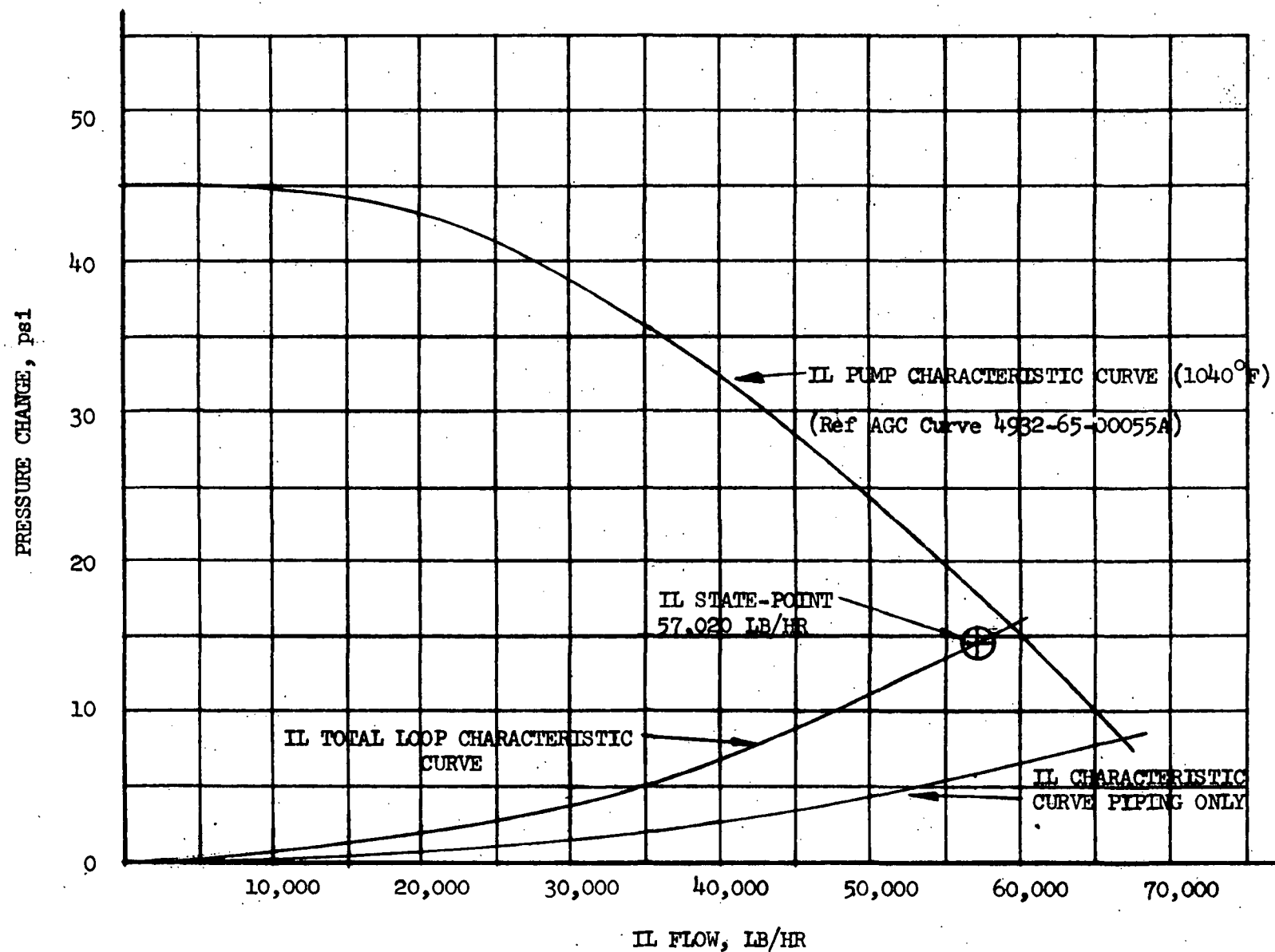
The main criteria used in calculating the PCS loop pressure losses is the existing pump motor assemblies head-capacity characteristics. In addition, in order to minimize the volume occupied by piping, the piping diameters were selected to be as small as possible without providing pressure losses in excess of the PCS pump capabilities.

Pressure Loss calculations were performed for the intermediate loop, mercury loop, and heat rejection loops. The results of this analysis appear in Figures IIE2-1, IIE2-2, IIE3-1, IIE3-2, and IIE4-1, including a loop schematic for each system with the calculated pressure losses and a system pressure loss and pump head rise curve versus system flow for the NaK loops. The loop schematics include the system pressure losses appearing on the state-point diagram.

Component pressure losses are based upon component test data wherever possible (see Fig. IIE3-3 and IIE3-4 for example). In addition, the Intermediate Heat Exchanger pressure losses were calculated as part of an IHX conceptual design (Fig. IIE2-3). A sample analysis of the type used in calculating system pressure losses appears in Fig. IIE2-4.



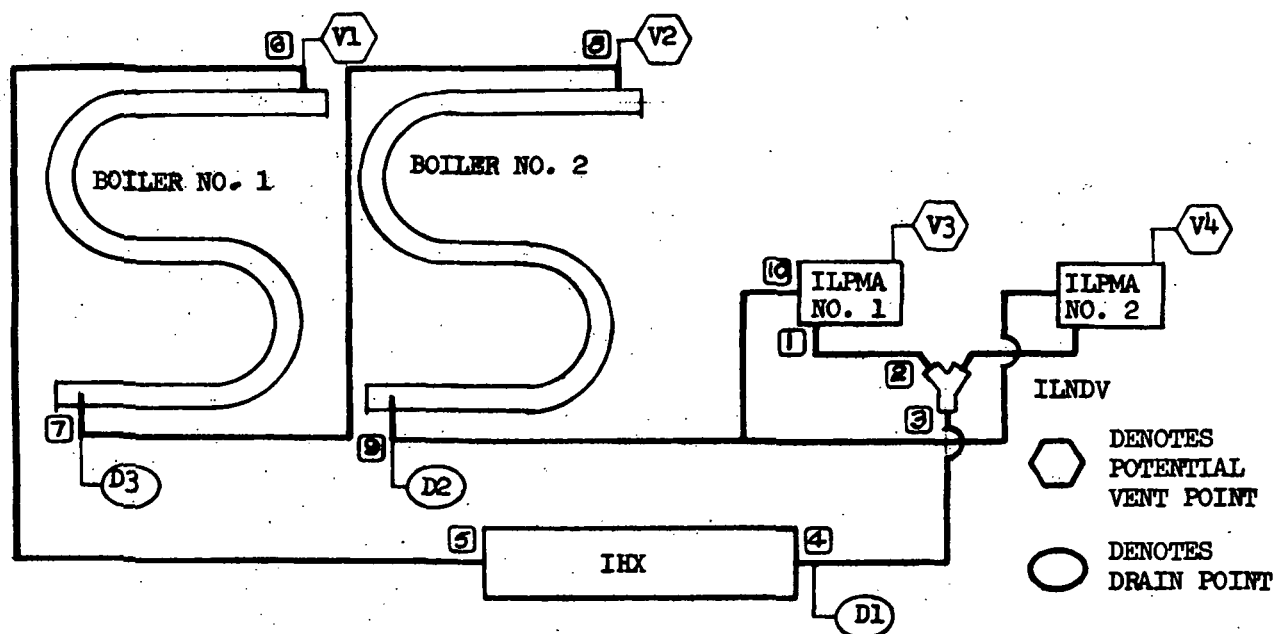
PCS INTERMEDIATE LOOP FLOW CHARACTERISTICS



PCS INTERMEDIATE LOOP FLOW CHARACTERISTICS

PCS INTERMEDIATE LOOP

PRESSURE LOSSES



INTERMEDIATE LOOP COMPONENTS		ΔP (PSID) AT 57,020 LB/HR	
END POINTS	DESCRIPTION	CALCULATED FROM LAYOUT	STATE-POINT VALUES
1-2	LINE - ILPMA TO ILNDV	0.85	—
2-3	VALVE - ILNDV	1.00	1.00
3-4	LINE - ILNDV TO PCS/RPL INTERFACE	0.80	—
4-5	RPL IHX and Piping in RPL	2.50	1.54
5-6	LINE - PCS/RPL INTERFACE TO BOILER NO. 1	1.20	—
6-7	BOILER NO. 1	2.50	2.50
7-8	LINE - BOILER NO. 1 TO BOILER NO. 2	0.51	—
8-9	BOILER NO. 2	2.50	2.50
9-10	LINE - BOILER NO. 2 TO ILPMA NO. 1	2.39	—
NOTE: CALCULATED ΔP TOTAL		TOTAL ΔP -	TOTAL ΔP -
ILPMA PRESSURE RISE		LOOP 14.25	LOOP 9.85
MARGIN (ΔP)		LINES 5.75	LINES 1.31

FIGURE IIE-2-2

DATE 2-2-70 ENGINEERING FILE NO. S-303.35W.O. 1139-01-0501 EDF SERIAL NO. D4964-70-0460

SNAP-8

ENGINEERING DESIGN FILE

SUBJECT:

INTERMEDIATE HEAT EXCHANGER PRELIMINARY DESIGN

ABSTRACT:

The following calculations were performed to determine a conceptual configuration for a double contained tube-in-shell, 600 KWT, intermediate heat exchanger (IHX) for the PCS-G RPL section (reference memo 4964-70-0024 dated 13 February 1970, titled Tube-in-Shell Intermediate Heat Exchanger, Conceptual Design (see attachment)). IHX initial requirements were: heat load - 600 KW, flow - 65,000 lb/hr, fluid (all passages) - NaK, RPL inlet temperature - 1200°F, LMED - 20°F, IHX material - 316 SS and structural design temperature - 1400°F. An initial pressure drop analysis was performed using a 7 1/2 in. O.D. shell and 8 configurations of tubing varying from 3/16 in. O.D. IL tube - 7/16 in. O.D. static NaK tube to 1 1/4 in. O.D. IL tube - 1 1/2 in. O.D. static NaK tube. Limiting parameters were 3 psi max tube side pressure drop, 1 psi max shell side pressure drop and max IHX length of 20 ft. Initial analysis results showed that the smaller tube configurations produced excessive pressure drop and the larger tube configurations provided poor heat transfer properties. A thermal analysis was performed on the remaining mid-range configurations and the results indicated that a 1/2 in. x .035 in. wall IL tube and a 5/8 in. x .035 in. wall static NaK tube provided the best combination of low pressure drop and adequate heat transfer. An additional analysis was performed, varying the shell size while keeping the tubing configuration fixed. The results indicated that by utilizing a 9 1/2 in. I.D. shell, 121 tubes could be used resulting in a IHX that formed only one flat coil in the gallery envelope. An eccentric shell type manifold was designed to provide equal flow radially into the shell from the RPL inlet line. The IL inlet and outlet manifolds were designed considering resistance coefficient (k) values. A sudden expansion for the inlet manifold and a gradual contraction for the outlet manifold provides the smallest "K" values.

The quantity and weight of NaK in the RPL, IL, and static loops was determined and the weight of the IHX was determined.

The results are as follows:

Shell	- 9.88 in. O.D. x .120 in. wall
Number of tubes	- 121

DISTRIBUTION:

None

KEY WORDS: Intermediate Heat Exchanger, SNAP-8, Reactor Primary Loop, PCS-G, Combined System Test

AUTHOR <u>R. L. Tome</u>	DATE <u>2-2-70</u>	REVIEWED	DATE	APPROVED <u>[Signature]</u>	DATE <u>2/23/70</u>
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ENGINEERING DESIGN FILE SUMMARY

D4964-70-0460
2-2-70

IL fluid tube	- 1/2 in. x .035 in. wall
Static NaK tube	- 5/8 in. x .035 in. wall
Pitch/diameter	- 1.252
Tube length	- 103.5 in.
Tube ΔP	- .286 psi
Shell ΔP	- .066 psi
IL inlet - sudden expansion - $K = .79$	$\Delta P = .355$ psi
IL outlet - gradual contraction - $K = .04$	$\Delta P = .018$ psi
Wt of RPL NaK @ 75°F	= 122.45 lb
Wt of IL NaK @ 75°F	= 67.01 lb
Wt of static NaK @ 75°F	= 19.84 lb
Total wt of full IHX @ 75°F	= 844.49 lb
Vol of RPL NaK	= 3914 in ³
Vol of IL NaK	= 2145.48 in ³
Vol of static NaK	= 633.9 in ³
TOTAL IL $\Delta P = .67$ psi	

SAMPLE SYSTEM PRESSURE LOSS CALCULATION USING
MULTIPLE-LOOP FLOW ANALYSIS COMPUTER PROGRAM
(MUFAN)

***** MUFAN CARD INPUT LISTING ***** 05/14/70 TIME

CARD
SEL.
NO.

CARC COLUMNS

00C0G0001111111112222222222333333333344444444445555555555666666666677777777778
1234567890123456789012345678901234567890123456789012345678901234567890

[illegible]

***** MUFAN CARD INPUT LISTING ***** 05/14/70 TIME ...

CARD COLUMNS

00C0C000C1111111112222222233333333334444444455555555666666667777777778

1234567890123456789012345678901234567890123456789012345678901234567890

31	M	58	59	1.33	3.0	.083		1			.00004
32	M	59	60	.33	3.0	.083		99	.2	2.0	.00004
33	M	60	61	.50	2.0	.069		1			.00004
34	M	61	62	.375	2.0	.069		1			.00004
35	M	62	64	.375	2.0	.069	180	14			.00004
36	M	64	66	.25	2.0	.069		1			.00004
37	M	66	68	2.08	3.0	.083		1			.00004
38	M	68	70	.375	3.0	.083	90	14			.00004
39	M	70	72	.33	3.0	.083		99	.2	2.0	.00004
40	M	72	74	.33	2.0	.069		1			.00004
41	M	74	76	.375	2.0	.069	90	14			.00004
42	M	76	78	.375	2.0	.069	180	14			.00004
43	M	78	80	.33	2.0	.069		1			.00004
44	M	80	100	.001	3.0	.083		1			.00004
45	L NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS										
46	M	100	102	.375	3.0	.083	90	17			.00004
47	M	102	104	.812	3.0	.083		1			.00004
48	M	104	106	.375	3.0	.083	180	17			.00004
49	M	106	108	3.08	3.0	.083		1			.00004
50	M	108	110	.375	3.0	.083	180	14			.00004
51	M	110	112	.16	3.0	.083		1			.00004
52	M	112	113	.375	3.0	.083	90	17			.00004
53	M	113	117	.375	3.0	.083		1			.00004
54	M	117	119	.375	3.0	.083	90	17			.00004
55	M	119	121	1.05	3.0	.083		1			.00004
56	M	121	123	.375	3.0	.083	90	17			.00004
57	M	123	125	.375	3.0	.083	135	14			.00004
58	M	125	127	.67	3.0	.083		1			.00004
59	M	127	129	.375	3.0	.083	180	14			.00004
60	M	129	131	.67	3.0	.083		1			.00004

***** MUFAN CARD INPUT LISTING ***** 05/14/70 TIME ...

CARD SEC. NO.	CARD COLUMNS									
	0	1	2	3	4	5	6	7	8	9
61	M	131	133	.375	3.C	.083	90	17		.00004
62	M	133	135	1.87	3.C	.083		1		.00004
63	M	135	137	.375	3.C	.083	90	17		.00004
64	M	137	139	.67	3.C	.083		1		.00004
65	M	139	141	.375	3.C	.083	180	14		.00004
66	M	141	145	3.06	3.C	.083		1		.00004
67	M	145	147	.375	3.C	.083	90	17		.00004
68	M	147	149	3.32	3.C	.083		1		.00004
69	M	149	151	.375	3.C	.083	90	17		.00004
70	M	151	153	.35	3.0	.083		1		.00004
71	M	153	155	.375	3.C	.083	15	14		.00004
72	M	155	157	.08	3.C	.083		1		.00004
73	M	157	301					1		
74	M	301	303	.125	3.C	.083		1		.00006
75	M	303	304	.375	3.C	.083	95	14		.00006
76	M	304	306	.875	3.C	.083		1		.00006
77	M	306	307	.375	3.C	.083	90	17		.00006
78	M	307	310	1.958	3.C	.083		1		.00006
79	M	310	311	.375	3.C	.083	90	17		.00006
80	M	311	313	1.375	3.0	.083		1		.00006
81	M	313	315	.375	3.C	.083	180	14		.00006
82	M	315	317	1.375	3.C	.083		1		.00006
83	M	317	318	.375	3.0	.083	90	17		.00006
84	M	318	320	1.583	3.C	.083		1		.00006
85	M	320	321	.375	3.C	.083	90	17		.00006
86	M	321	323	2.290	3.C	.083		1		.00006
87	M	323	325	.375	3.C	.083	180	14		.00006
88	M	325	328	1.633	3.C	.083		1		.00006
89	M	328	329	.375	3.C	.083	90	17		.00006
90	M	329	331	1.083	3.C	.083		1		.00006

***** MUFAN CARD INPUT LISTING ***** 05/14/70 TIME

CARD SEQ. NO.	CARD COLUMNS																															
	00	01	11	11	11	11	22	22	22	22	33	33	33	33	44	44	44	44	55	55	55	55	66	66	66	66	77	77	77	77	88	
	12	34	56	78	90	12	34	56	78	90	12	34	56	78	90	12	34	56	78	90	12	34	56	78	90	12	34	56	78	90		
91	M	331	332			.375	3.0	.083	90	17																					.00006	
92	M	332	334			.250	3.0	.083																							.00006	
93	M	334	335			.375	3.0	.083	90	17																					.00006	
94	M	335	337			1.125	3.0	.083																							.00006	
95	M	337	339			.375	3.0	.083	180	14																					.00006	
96	M	339	341			2.290	3.0	.083																							.00006	
97	M	341	342			.375	3.0	.083	90	17																					.00006	
98	M	342	344			1.833	3.0	.083																							.00006	
99	M	344	345			.375	3.0	.083	90	17																					.00006	
100	M	345	346			.375	3.0	.083	90	17																					.00006	
101	M	346	348			.625	3.0	.083																							.00006	
102	M	348	349			.375	3.0	.083	90	17																					.00006	
103	M	349	352			3.250	3.0	.083																							.00006	
104	M	352	353			.375	3.0	.083	90	17																					.00006	
105	M	353	356			2.920	3.0	.083																							.00006	
106	M	356	357			.375	3.0	.083	45	14																					.00006	
107	M	357	425																													
108	M	425	427			.66	3.0	.083																							.00004	
109	M	427	429			.812	3.0	.083	180	14																					.00004	
110	M	429	431			.25	3.0	.083																							.00004	
111	M	431	433			.33	3.0	.083	90	17																					.00004	
112	M	433	435			2.33	3.0	.083																							.00004	
113	M	435	437			1.0	3.0	.083	90	17																					.00004	
114	M	437	439			5.5	3.0	.083																							.00004	
115	M	439	441			1.0	3.0	.083	90	17																					.00004	
116	M	441	443			1.82	3.0	.083																							.00004	
117	M	443	445			1.0	3.0	.083	30	14																					.00004	
118	M	445	447			.08	3.0	.083																							.00004	
119	M	447	448																													
120	CC	P	1	10000	20000	30000	40000	45000	50000	55000	60000	65000	70000																			

***** MUFAN CARD INPUT LISTING ***** 05/14/70 TIME

CARD SEQ. NU.	CARD COLUMNS												
	0000000001111111112222222222333333333344444444445555555555666666666677777777778												
	1234567890123456789012345678901234567890123456789012345678901234567890												
121	CP P 1 .13 .25 .45 .75 .95 1.2 1.4 1.7 2.0 2.3												
122	CQ P 3 10000 20000 30000 40000 45000 50000 55000 60000 65000 70000												
123	CP P 3 .20 .40 .75 1.25 1.6 1.9 2.3 3.0 3.5 4.1												
124	CC P 4 10000 20000 30000 40000 45000 50000 55000 60000 65000 70000												
125	CP P 4 .20 .40 .75 1.25 1.6 1.9 2.3 3.0 3.5 4.1												

BOILER TO NPMAS OP LOSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	*	10 - 12	*	12 - 14	*	14 - 16	*	16 - 18	*
TYPE	*	TUBING BEND	*	STRAIGHT PIPE	*	TUBING BEND	*	STRAIGHT PIPE	*
LENGTH, FT.	*	*****	*	1.500	*	*****	*	1.660	*
O.D., IN. (D1)	*	3.000	*	3.000	*	3.000	*	3.000	*
WALL THICKNESS, IN	*	0.0830	*	0.0830	*	0.0830	*	0.0830	*
RADIUS, FT.	*	0.375	*	*****	*	0.375	*	*****	*
ANGLE, DEG.	*	90.0	*	*****	*	90.0	*	*****	*
D2, IN.	*	*****	*	*****	*	*****	*	*****	*
ROUGHNESS, IN.	*	*****	*	.40E-04	*	*****	*	.40E-04	*
EQUIV. L/D	*	*****	*	*****	*	*****	*	*****	*
K-FACTOR	*	0.262	*	*****	*	0.262	*	*****	*
LABEL	*		*		*		*		*

MEMBER	*	18 - 20	*	20 - 22	*	22 - 24	*	24 - 26	*
TYPE	*	TUBING BEND	*	STRAIGHT PIPE	*	TUBING BEND	*	STRAIGHT PIPE	*
LENGTH, FT.	*	*****	*	0.812	*	*****	*	1.700	*
O.D., IN. (D1)	*	3.000	*	3.000	*	3.000	*	3.000	*
WALL THICKNESS, IN	*	0.0830	*	0.0830	*	0.0830	*	0.0830	*
RADIUS, FT.	*	0.375	*	*****	*	0.375	*	*****	*
ANGLE, DEG.	*	90.0	*	*****	*	90.0	*	*****	*
D2, IN.	*	*****	*	*****	*	*****	*	*****	*
ROUGHNESS, IN.	*	*****	*	.40E-04	*	*****	*	.40E-04	*
EQUIV. L/D	*	*****	*	*****	*	*****	*	*****	*
K-FACTOR	*	0.262	*	*****	*	0.262	*	*****	*
LABEL	*		*		*		*		*

BCILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLMA 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 26 - 28 *	* 28 - 30 *	* 30 - 32 *	* 32 - 34 *
TYPE	TUBING BEND	STRAIGHT PIPE	TUBING BEND	STRAIGHT PIPE
LENGTH, FT.	*****	0.812	*****	1.660
C.D., IN. (D1)	3.000	3.000	3.000	3.000
WALL THICKNESS, IN	0.0830	0.0830	0.0830	0.0830
RADIUS, FT.	0.375	*****	0.375	*****
ANGLE, DEG.	90.0	*****	90.0	*****
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	*****	.40E-04	*****	.40E-04
EQUIV. L/D	*****	*****	*****	*****
K-FACTOR	0.262	*****	0.262	*****
LABEL				

MEMBER	* 34 - 36 *	* 36 - 38 *	* 38 - 40 *	* 40 - 42 *
TYPE	TUBING BEND	STRAIGHT PIPE	TUBING BEND	STRAIGHT PIPE
LENGTH, FT.	*****	0.812	*****	1.700
O.D., IN. (D1)	3.000	3.000	3.000	3.000
WALL THICKNESS, IN	0.0830	0.0830	0.0830	0.0830
RADIUS, FT.	0.375	*****	0.375	*****
ANGLE, DEG.	90.0	*****	90.0	*****
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	*****	.40E-04	*****	.40E-04
EQUIV. L/D	*****	*****	*****	*****
K-FACTOR	0.262	*****	0.262	*****
LABEL				

BOILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 42 - 44 *	* 44 - 46 *	* 46 - 48 *	* 48 - 50 *
TYPE	TUBING BEND	STRAIGHT PIPE	TUBING BEND	STRAIGHT PIPE
LENGTH, FT.	*****	0.812	*****	0.750
O.D., IN. (D1)	3.000	3.000	3.000	3.000
WALL THICKNESS, IN	0.0830	0.0830	0.0830	0.0830
RADIUS, FT.	0.375	*****	0.375	*****
ANGLE, DEG.	90.0	*****	90.0	*****
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	*****	.40E-04	*****	.40E-04
EQUIV. L/D	*****	*****	*****	*****
K-FACTOR	0.262	*****	0.262	*****
LABEL	*	*	*	*

MEMBER	* 50 - 52 *	* 52 - 54 *	* 54 - 56 *	* 56 - 58 *
TYPE	STRAIGHT PIPE	TUBING BEND	STRAIGHT PIPE	TUBING BEND
LENGTH, FT.	1.330	*****	0.812	*****
O.D., IN. (D1)	3.000	3.000	3.000	3.000
WALL THICKNESS, IN	0.0830	0.0830	0.0830	0.0830
RADIUS, FT.	*****	0.375	*****	0.375
ANGLE, DEG.	*****	90.0	*****	90.0
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	.40E-04	*****	.40E-04	*****
EQUIV. L/D	*****	*****	*****	*****
K-FACTOR	*****	0.262	*****	0.262
LABEL	*	*	*	*

BOILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPMAS 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 58 - 59 *	* 59 - 60 *	* 60 - 61 *	* 61 - 62 *
TYPE	STRAIGHT PIPE	K-FACTOR INPUT BY USER	STRAIGHT PIPE	STRAIGHT PIPE
LENGTH, FT.	1.330	*****	0.500	0.375
O.D., IN. (D1)	3.000	3.000	2.000	2.000
WALL THICKNESS, IN.	0.0830	0.0830	0.0690	0.0690
RADIUS, FT.	*****	*****	*****	*****
ANGLE, DEG.	*****	*****	*****	*****
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	.40E-04	*****	.40E-04	.40E-04
EQUIV. L/C	*****	*****	*****	*****
K-FACTOR	*****	0.200	*****	*****
LABEL				

MEMBER	* 62 - 64 *	* 64 - 66 *	* 66 - 68 *	* 68 - 70 *
TYPE	TUBING BEND	STRAIGHT PIPE	STRAIGHT PIPE	TUBING BEND
LENGTH, FT.	*****	0.250	2.080	*****
O.D., IN. (D1)	2.000	2.000	3.000	3.000
WALL THICKNESS, IN.	0.0690	0.0690	0.0830	0.0830
RADIUS, FT.	0.375	*****	*****	0.375
ANGLE, DEG.	180.0	*****	*****	90.0
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	*****	.40E-04	.40E-04	*****
EQUIV. L/C	*****	*****	*****	*****
K-FACTOR	0.235	*****	*****	0.262
LABEL				

BOILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPMA 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 70 - 72 *	* 72 - 74 *	* 74 - 76 *	* 76 - 78 *
TYPE	* K-FACTOR INPT BY USER *	* STRAIGHT PIPE *	* TUBING BEND *	* TUBING BEND *
LENGTH, FT.	* ***** *	* 0.330 *	* ***** *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 2.000 *	* 2.000 *	* 2.000 *
WALL THICKNESS, IN	* 0.0630 *	* 0.0690 *	* 0.0690 *	* 0.0690 *
RADIUS, FT.	* ***** *	* ***** *	* 0.375 *	* 0.375 *
ANGLE, DEG.	* ***** *	* ***** *	* 90.0 *	* 180.0 *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* ***** *	* .40E-04 *	* ***** *	* ***** *
EQUIV. L/C	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* 0.200 *	* ***** *	* 0.171 *	* 0.235 *
LABEL	* * *	* * *	* * *	* * *

MEMBER	* 78 - 80 *	* 80 - 100 *	* 100 - 102 *	* 102 - 104 *
TYPE	* STRAIGHT PIPE *	* STRAIGHT PIPE *	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *
LENGTH, FT.	* 0.330 *	* 0.001 *	* ***** *	* 0.812 *
O.D., IN. (D1)	* 2.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0690 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .40E-04 *	* .40E-04 *	* ***** *	* .40E-04 *
EQUIV. L/C	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* ***** *	* 0.550 *	* ***** *
LABEL	* * *	* * *	* * *	* * *

BCILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO INX PRESSURE LOSS

MEMBER	* 104 -106 *	* 106 -108 *	* 108 -110 *	* 110 -112 *
TYPE	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *	* TUBING BEND *	* STRAIGHT PIPE *
LENGTH, FT.	* ***** *	* 3.080 *	* ***** *	* 0.160 *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* 0.375 *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* 180.0 *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* ***** *	* .40E-04 *	* ***** *	* .40E-04 *
EQUIV. L/C	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* 0.550 *	* ***** *	* 0.361 *	* ***** *
LABEL	* * *	* * *	* * *	* * *

MEMBER	* 112 -113 *	* 113 -117 *	* 117 -119 *	* 119 -121 *
TYPE	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *
LENGTH, FT.	* ***** *	* 0.375 *	* ***** *	* 1.050 *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* ***** *	* .40E-04 *	* ***** *	* .40E-04 *
EQUIV. L/C	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* 0.550 *	* ***** *	* 0.550 *	* ***** *
LABEL	* * *	* * *	* * *	* * *

BOILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPA 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 121 -123 *	* 123 -125 *	* 125 -127 *	* 127 -129 *
TYPE	LONG 90 DEG ELBOW	TUBING BEND	STRAIGHT PIPE	TUBING BEND
LENGTH, FT.	*****	*****	0.670	*****
O.D., IN. (D1)	3.000	3.000	3.000	3.000
WALL THICKNESS, IN	0.0830	0.0830	0.0830	0.0830
RADIUS, FT.	*****	0.375	*****	0.375
ANGLE, DEG.	*****	135.0	*****	180.0
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	*****	*****	.40E-04	*****
EQUIV. L/D	*****	*****	*****	*****
K-FACTOR	0.550	0.319	*****	0.361
LABEL				

MEMBER	* 129 -131 *	* 131 -133 *	* 133 -135 *	* 135 -137 *
TYPE	STRAIGHT PIPE	LONG 90 DEG ELBOW	STRAIGHT PIPE	LONG 90 DEG ELBOW
LENGTH, FT.	0.670	*****	1.870	*****
O.D., IN. (D1)	3.000	3.000	3.000	3.000
WALL THICKNESS, IN	0.0830	0.0830	0.0830	0.0830
RADIUS, FT.	*****	*****	*****	*****
ANGLE, DEG.	*****	*****	*****	*****
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	.10E-06	*****	.40E-04	*****
EQUIV. L/D	*****	*****	*****	*****
K-FACTOR	*****	0.550	*****	0.550
LABEL				

BOILER TO NPMAS DP LOSS, INT. LCCP, ASSUME INLPA 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 137 -139 *	* 139 -141 *	* 141 -145 *	* 145 -147 *
TYPE	* STRAIGHT PIPE *	* TUBING BEND *	* STRAIGHT PIPE *	* LONG 90 DEG ELBOW *
LENGTH, FT.	* 0.670 *	* ***** *	* 3.060 *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* 0.375 *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* 180.0 *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .40E-04 *	* ***** *	* .40E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.361 *	* ***** *	* 0.550 *
LABEL	* * *	* * *	* * *	* * *

MEMBER	* 147 -149 *	* 149 -151 *	* 151 -153 *	* 153 -155 *
TYPE	* STRAIGHT PIPE *	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *	* TUBING BEND *
LENGTH, FT.	* 3.330 *	* ***** *	* 0.350 *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* 0.375 *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* 15.0 *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .40E-04 *	* ***** *	* .40E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.550 *	* ***** *	* 0.058 *
LABEL	* * *	* * *	* * *	* * *

BCILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 155 -157 *	* 157 -301 *	* 301 -303 *	* 303 -304 *
TYPE	* STRAIGHT PIPE *	* COMPONENT XX *	* STRAIGHT PIPE *	* TUBING BEND *
LENGTH, FT.	* 0.080 *	* ***** *	* 0.125 *	* ***** *
C.D., IN. (D1)	* 3.000 *	* ***** *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* ***** *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* 0.375 *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* 95.0 *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .40E-04 *	* ***** *	* .60E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* ***** *	* ***** *	* 0.269 *
LABEL	* * *	* * *	* * *	* * *

MEMBER	* 304 -306 *	* 306 -307 *	* 307 -310 *	* 310 -311 *
TYPE	* STRAIGHT PIPE *	* LONG 90 DEG *	* STRAIGHT PIPE *	* LONG 90 DEG *
LENGTH, FT.	* 1 *	* ***** *	* 1.958 *	* ***** *
C.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .60E-04 *	* ***** *	* .60E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.550 *	* ***** *	* 0.550 *
LABEL	* * *	* * *	* * *	* * *

BOILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 311 -313 *	* 313 -315 *	* 315 -317 *	* 317 -318 *
TYPE	* STRAIGHT PIPE *	* TUBING BEND *	* STRAIGHT PIPE *	* LONG 90 DEG *
	* 1 *		* 1 *	* ELBOW *
LENGTH, FT.	* 1.375 *	* ***** *	* 1.375 *	* ***** *
O.D., IN. (O1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* 0.375 *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* 180.0 *	* ***** *	* ***** *
DZ, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .60E-04 *	* ***** *	* .60E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.361 *	* ***** *	* 0.550 *
LABEL	* * *	* * *	* * *	* * *

MEMBER	* 318 -320 *	* 320 -321 *	* 321 -323 *	* 323 -325 *
TYPE	* STRAIGHT PIPE *	* LONG 90 DEG *	* STRAIGHT PIPE *	* TUBING BEND *
	* 1 *	* ELBOW *	* 1 *	
LENGTH, FT.	* 1.583 *	* ***** *	* 2.290 *	* ***** *
O.D., IN. (O1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* 0.375 *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* 180.0 *
DZ, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .60E-04 *	* ***** *	* .60E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.550 *	* ***** *	* 0.361 *
LABEL	* * *	* * *	* * *	* * *

BOILER TO NPMAS DP LOSS. INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO INX PRESSURE LOSS

MEMBER	* 325 -328 *	* 328 -329 *	* 329 -331 *	* 331 -332 *
TYPE	* STRAIGHT PIPE *	* LONG 90 DEG *	* STRAIGHT PIPE *	* LONG 90 DEG *
	* 1 *	* ELBOW *	* 1 *	* ELBOW *
LENGTH, FT.	* 1.833 *	* ***** *	* 1.083 *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .60E-04 *	* ***** *	* .60E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.550 *	* ***** *	* 0.550 *
LABEL	* * *	* * *	* * *	* * *

MEMBER	* 332 -334 *	* 334 -335 *	* 335 -337 *	* 337 -339 *
TYPE	* STRAIGHT PIPE *	* LONG 90 DEG *	* STRAIGHT PIPE *	* TUBING BEND *
	* 1 *	* ELBOW *	* 1 *	* * *
LENGTH, FT.	* 0.250 *	* ***** *	* 1.125 *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* 0.375 *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* 180.0 *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .60E-04 *	* ***** *	* .60E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.550 *	* ***** *	* 0.361 *
LABEL	* * *	* * *	* * *	* * *

PCILER TO NPMAS DP LOSS.INT. LCCP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 339 -341 *	* 341 -342 *	* 342 -344 *	* 344 -345 *
TYPE	* STRAIGHT PIPE *	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *	* LONG 90 DEG ELBOW *
LENGTH, FT.	* 1 *	* ***** *	* 1.833 *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .60E-04 *	* ***** *	* .60E-04 *	* ***** *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.550 *	* ***** *	* 0.550 *
LABEL	* * *	* * *	* * *	* * *
MEMBER	* 345 -346 *	* 346 -348 *	* 348 -349 *	* 349 -352 *
TYPE	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE *
LENGTH, FT.	* ***** *	* 0.625 *	* ***** *	* 3.250 *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* ***** *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* ***** *	* .60E-04 *	* ***** *	* .60E-04 *
EQUIV. L/D	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* 0.550 *	* ***** *	* 0.550 *	* ***** *
LABEL	* * *	* * *	* * *	* * *

BCILER TO NPMAS DP LCSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	* 352 -353 *	* 353 -356 *	* 356 -357 *	* 357 -425 *
TYPE	* LONG 90 DEG ELBOW *	* STRAIGHT PIPE 1 *	* TUBING BEND *	* COMPONENT XX *
LENGTH, FT.	* ***** *	* 2.920 *	* ***** *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* ***** *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* ***** *
RADIUS, FT.	* ***** *	* ***** *	* 0.375 *	* ***** *
ANGLE, DEG.	* ***** *	* ***** *	* 45.0 *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* ***** *	* .60E-04 *	* ***** *	* ***** *
EQUIV. L/C	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* 0.550 *	* ***** *	* 0.160 *	* ***** *
LABEL	* * *	* * *	* * *	* * *

MEMBER	* 425 -427 *	* 427 -429 *	* 429 -431 *	* 431 -433 *
TYPE	* STRAIGHT PIPE 3 *	* TUBING BEND *	* STRAIGHT PIPE 3 *	* LONG 90 DEG ELBOW *
LENGTH, FT.	* 0.660 *	* ***** *	* 0.250 *	* ***** *
O.D., IN. (D1)	* 3.000 *	* 3.000 *	* 3.000 *	* 3.000 *
WALL THICKNESS, IN	* 0.0830 *	* 0.0830 *	* 0.0830 *	* 0.0830 *
RADIUS, FT.	* ***** *	* 0.812 *	* ***** *	* ***** *
ANGLE, DEG.	* ***** *	* 180.0 *	* ***** *	* ***** *
D2, IN.	* ***** *	* ***** *	* ***** *	* ***** *
ROUGHNESS, IN.	* .40E-04 *	* ***** *	* .40E-04 *	* ***** *
EQUIV. L/C	* ***** *	* ***** *	* ***** *	* ***** *
K-FACTOR	* ***** *	* 0.208 *	* ***** *	* 0.550 *
LABEL	* * *	* * *	* * *	* * *

***** MUFAN MEMBER FLOW CHARACTERISTICS ** 05/14/70

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BCILER TC NPMAS DP LOSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	433 -435	435 -437	437 -439	439 -441
TYPE	STRAIGHT PIPE	LONG 90 DEG ELBCW	STRAIGHT PIPE	LONG 90 DEG ELBCW
LENGTH, FT.	3	*****	5.500	*****
U.D., IN. (D1)	3.000	3.000	3.000	3.000
WALL THICKNESS, IN	0.0830	0.0830	0.0830	0.0830
RADIUS, FT.	*****	*****	*****	*****
ANGLE, DEG.	*****	*****	*****	*****
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	.40E-04	*****	.40E-04	*****
EQUIV. L/C	*****	*****	*****	*****
K-FACTOR	*****	0.550	*****	0.550
LABEL				

MEMBER	441 -443	443 -445	445 -447	447 -448
TYPE	STRAIGHT PIPE	TUBING BEND	STRAIGHT PIPE	COMPONENT XX
LENGTH, FT.	3	*****	3	*****
U.D., IN. (D1)	1.820	3.000	0.080	*****
WALL THICKNESS, IN	3.000	0.0830	3.000	*****
RADIUS, FT.	0.0830	1.000	0.0830	*****
ANGLE, DEG.	*****	30.0	*****	*****
D2, IN.	*****	*****	*****	*****
ROUGHNESS, IN.	.40E-04	*****	.40E-04	*****
EQUIV. L/C	*****	*****	*****	*****
K-FACTOR	*****	0.067	*****	*****
LABEL				

NRBP= 0 NCUMBP= 1 NBRPT= 1

NLM, IBRPT, IBCCN, JBRPT	1	1	1	2
NLM, IBRPT, IBCCN, JBRPT	2	2	-1	1

BRANCH FLOW

1 1.000000 C4

BRANCH POINT PRESSURES

1 5.00000E C1

***** MUFAN FLOW AND PRESSURE DROP PRINTOUT * 05/14/70 **** ** PAGE 1 OF 5 *

BCILER TO NPMAS OP LOSS.INT. LOOP. ASSUME INLPMA 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	-----CUMULATIVE-----						REYNOLDS NO
	PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	

X							
..... BEGINNING OF BRANCH - FLOW= 10000. X							
10 - 12	0.2471E-C2	0.0	0.2471E-C2	0.2471E-02	0.0	0.2471E-02	.13257E 06
12 - 14	0.1019E-02	0.0	0.1019E-02	0.3489E-02	0.0	0.3489E-02	.13257E 06
14 - 16	0.2471E-C2	0.0	0.2471E-C2	0.5960E-02	0.0	0.5960E-02	.13257E 06
16 - 18	0.1127E-02	0.0	0.1127E-02	0.7087E-02	0.0	0.7087E-02	.13257E 06
18 - 20	0.2471E-C2	0.0	0.2471E-C2	0.9558E-02	0.0	0.9558E-02	.13257E 06
20 - 22	0.5514E-C3	0.0	0.5514E-C3	0.1011E-01	0.0	0.1011E-01	.13257E 06
22 - 24	0.2471E-C2	0.0	0.2471E-C2	0.1258E-01	0.0	0.1258E-01	.13257E 06
24 - 26	0.1154E-C2	0.0	0.1154E-C2	0.1373E-01	0.0	0.1373E-01	.13257E 06
26 - 28	0.2471E-C2	0.0	0.2471E-C2	0.1621E-01	0.0	0.1621E-01	.13257E 06
28 - 30	0.5514E-C3	0.0	0.5514E-C3	0.1676E-01	0.0	0.1676E-01	.13257E 06
30 - 32	0.2471E-C2	0.0	0.2471E-C2	0.1923E-01	0.0	0.1923E-01	.13257E 06
32 - 34	0.1127E-02	0.0	0.1127E-02	0.2036E-01	0.0	0.2036E-01	.13257E 06
34 - 36	0.2471E-C2	0.0	0.2471E-C2	0.2283E-01	0.0	0.2283E-01	.13257E 06
36 - 38	0.5514E-C3	0.0	0.5514E-C3	0.2338E-01	0.0	0.2338E-01	.13257E 06
38 - 40	0.2471E-C2	0.0	0.2471E-02	0.2585E-01	0.0	0.2585E-01	.13257E 06
40 - 42	0.1154E-C2	0.0	0.1154E-C2	0.2700E-01	0.0	0.2700E-01	.13257E 06
42 - 44	0.2471E-C2	0.0	0.2471E-C2	0.2947E-01	0.0	0.2947E-01	.13257E 06
44 - 46	0.5514E-C3	0.0	0.5514E-03	0.3002E-01	0.0	0.3002E-01	.13257E 06
46 - 48	0.2471E-C2	0.0	0.2471E-C2	0.3250E-01	0.0	0.3250E-01	.13257E 06
48 - 50	0.5093E-C3	0.0	0.5093E-C3	0.3300E-01	0.0	0.3300E-01	.13257E 06
50 - 52	0.9031E-C3	0.0	0.9031E-C3	0.3391E-01	0.0	0.3391E-01	.13257E 06
52 - 54	0.2471E-C2	0.0	0.2471E-C2	0.3638E-01	0.0	0.3638E-01	.13257E 06
54 - 56	0.5514E-C3	0.0	0.5514E-03	0.3693E-01	0.0	0.3693E-01	.13257E 06
56 - 58	0.2471E-C2	0.0	0.2471E-C2	0.3940E-01	0.0	0.3940E-01	.13257E 06
58 - 59	0.9031E-C3	0.0	0.9031E-C3	0.4030E-01	0.0	0.4030E-01	.13257E 06

***** MUFAN FLOW AND PRESSURE DROP PRINTOUT * 05/14/70 **** ** PAGE 2 OF 5 *

BOILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	-----CUMULATIVE-----			REYNOLDS NO
				PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	
				X			
. 59 - 60	0.1888E-C2	0.0	0.1888E-C2	0.4219E-01	0.0	0.4219E-01	.13257E 06
. 60 - 61	0.2550E-C2	0.0	0.2550E-C2	0.4474E-01	0.0	0.4474E-01	.20177E 06
. 61 - 62	0.1913E-C2	0.0	0.1913E-C2	0.4666E-01	0.0	0.4666E-01	.20177E 06
. 62 - 64	0.1193E-C1	0.0	0.1193E-01	0.5858E-01	0.0	0.5858E-01	.20177E 06
. 64 - 66	0.1275E-C2	0.0	0.1275E-C2	0.5986E-01	0.0	0.5986E-01	.20177E 06
. 66 - 68	0.1412E-02	0.0	0.1412E-02	0.6127E-01	0.0	0.6127E-01	.13257E 06
. 68 - 70	0.2471E-C2	0.0	0.2471E-C2	0.6374E-01	0.0	0.6374E-01	.13257E 06
. 70 - 72	0.1888E-C2	0.0	0.1888E-C2	0.6563E-01	0.0	0.6563E-01	.13257E 06
. 72 - 74	0.1683E-C2	0.0	0.1683E-C2	0.6731E-01	0.0	0.6731E-01	.20177E 06
. 74 - 76	0.8643E-C2	0.0	0.8643E-02	0.7596E-01	0.0	0.7596E-01	.20177E 06
. 76 - 78	0.1193E-C1	0.0	0.1193E-01	0.8788E-01	0.0	0.8788E-01	.20177E 06
. 78 - 80	0.1683E-C2	0.0	0.1683E-02	0.8957E-01	0.0	0.8957E-01	.20177E 06
. 80 - 100	0.6790E-C6	0.0	0.6790E-C6	0.8957E-01	0.0	0.8957E-01	.13257E 06
. 100 - 102	0.5192E-C2	0.0	0.5192E-C2	0.9476E-01	0.0	0.9476E-01	.13257E 06
. 102 - 104	0.5514E-C3	0.0	0.5514E-C3	0.9531E-01	0.0	0.9531E-01	.13257E 06
. 104 - 106	0.5192E-C2	0.0	0.5192E-C2	0.1005	0.0	0.1005	.13257E 06
. 106 - 108	0.2091E-C2	0.0	0.2091E-C2	0.1026	0.0	0.1026	.13257E 06
. 108 - 110	0.3410E-C2	0.0	0.3410E-C2	0.1060	0.0	0.1060	.13257E 06
. 110 - 112	0.1086E-C3	0.0	0.1086E-C3	0.1061	0.0	0.1061	.13257E 06
. 112 - 113	0.5192E-C2	0.0	0.5192E-C2	0.1113	0.0	0.1113	.13257E 06
. 113 - 117	0.2546E-C3	0.0	0.2546E-C3	0.1116	0.136	0.1116	.13257E 06
. 117 - 119	0.5192E-C2	0.0	0.5192E-02	0.1168	0.0	0.1168	.13257E 06
. 119 - 121	0.7130E-C3	0.0	0.7130E-C3	0.1175	0.0	0.1175	.13257E 06
. 121 - 123	0.5192E-C2	0.0	0.5192E-C2	0.1227	0.0	0.1227	.13257E 06
. 123 - 125	0.3014E-C2	0.0	0.3014E-C2	0.1257	0.0	0.1257	.13257E 06
. 125 - 127	0.4550E-C3	0.0	0.4550E-C3	0.1261	0.0	0.1261	.13257E 06
. 127 - 129	0.3410E-C2	0.0	0.3410E-C2	0.1295	0.0	0.1295	.13257E 06
. 129 - 131	0.4550E-C3	0.0	0.4550E-C3	0.1300	0.0	0.1300	.13257E 06

***** MUFAN FLOW AND PRESSURE DROP PRINTOUT * 05/14/70 **** ** PAGE 3 OF 5 *

BOILER TO NPMAS DP LOSS.INT. LOOP. ASSUME INLPMAS 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	-----CUMULATIVE-----			REYNOLDS NO
				PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	
				*			
• 131 -133	0.5192E-02	0.0	0.5192E-02	0.1352	0.0	0.1352	.13257E 06
• 133 -135	0.1270E-02	0.0	0.1270E-02	0.1365	0.0	0.1365	.13257E 06
• 135 -137	0.5192E-02	0.0	0.5192E-02	0.1416	0.0	0.1416	.13257E 06
• 137 -139	0.4550E-03	0.0	0.4550E-03	0.1421	0.0	0.1421	.13257E 06
• 139 -141	0.3410E-02	0.0	0.3410E-02	0.1455	0.0	0.1455	.13257E 06
• 141 -145	0.2078E-02	0.0	0.2078E-02	0.1476	0.0	0.1476	.13257E 06
• 145 -147	0.5192E-02	0.0	0.5192E-02	0.1528	0.0	0.1528	.13257E 06
• 147 -149	0.2261E-02	0.0	0.2261E-02	0.1550	0.0	0.1550	.13257E 06
• 149 -151	0.5192E-02	0.0	0.5192E-02	0.1602	0.0	0.1602	.13257E 06
• 151 -153	0.2377E-03	0.0	0.2377E-03	0.1605	0.0	0.1605	.13257E 06
• 153 -155	0.5436E-03	0.0	0.5436E-03	0.1610	0.0	0.1610	.13257E 06
• 155 -157	0.5432E-04	0.0	0.5432E-04	0.1611	0.0	0.1611	.13257E 06
• 157 -301	0.1300	0.0	0.1300	0.2911	0.0	0.2911	*****
• 301 -303	0.8551E-04	0.0	0.8551E-04	0.2912	0.0	0.2912	.14922E 06
• 303 -304	0.2622E-02	0.0	0.2622E-02	0.2938	0.0	0.2938	.14922E 06
• 304 -306	0.5986E-03	0.0	0.5986E-03	0.2944	0.0	0.2944	.14922E 06
• 306 -307	0.5357E-02	0.0	0.5357E-02	0.2997	0.0	0.2997	.14922E 06
• 307 -310	0.1339E-02	0.0	0.1339E-02	0.3011	0.0	0.3011	.14922E 06
• 310 -311	0.5357E-02	0.0	0.5357E-02	0.3064	0.0	0.3064	.14922E 06
• 311 -312	0.9406E-03	0.0	0.9406E-03	0.3074	0.0	0.3074	.14922E 06
• 312 -315	0.3518E-02	0.0	0.3518E-02	0.3109	0.0	0.3109	.14922E 06
• 315 -317	0.9406E-03	0.0	0.9406E-03	0.3118	0.0	0.3118	.14922E 06
• 317 -318	0.5357E-02	0.0	0.5357E-02	0.3172	0.0	0.3172	.14922E 06
• 318 -320	0.1083E-02	0.0	0.1083E-02	0.3183	0.0	0.3183	.14922E 06
• 320 -321	0.5357E-02	0.0	0.5357E-02	0.3236	0.0	0.3236	.14922E 06
• 321 -323	0.1567E-02	0.0	0.1567E-02	0.3252	0.0	0.3252	.14922E 06
• 323 -325	0.3518E-02	0.0	0.3518E-02	0.3287	0.0	0.3287	.14922E 06
• 325 -328	0.1254E-02	0.0	0.1254E-02	0.3300	0.0	0.3300	.14922E 06

BOILER TO NPMAS DP LOSS. INT. LOOP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

MEMBER	PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	-----CUMULATIVE-----		REYNOLDS NO
				PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	
• 328 -329	0.5357E-02	0.0	0.5357E-02	0.3353	0.0	•14922E 06
• 329 -331	0.7409E-03	0.0	0.7409E-03	0.3361	0.0	•14922E 06
• 331 -332	0.5357E-02	0.0	0.5357E-02	0.3414	0.0	•14922E 06
• 332 -334	0.1710E-03	0.0	0.1710E-03	0.3416	0.0	•14922E 06
• 334 -335	0.5357E-02	0.0	0.5357E-02	0.3469	0.0	•14922E 06
• 335 -337	0.7696E-03	0.0	0.7696E-03	0.3477	0.0	•14922E 06
• 337 -339	0.3518E-02	0.0	0.3518E-02	0.3512	0.0	•14922E 06
• 339 -341	0.1567E-02	0.0	0.1567E-02	0.3528	0.0	•14922E 06
• 341 -342	0.5357E-02	0.0	0.5357E-02	0.3582	0.0	•14922E 06
• 342 -344	0.1254E-02	0.0	0.1254E-02	0.3594	0.0	•14922E 06
• 344 -345	0.5357E-02	0.0	0.5357E-02	0.3648	0.0	•14922E 06
• 345 -346	0.5357E-02	0.0	0.5357E-02	0.3701	0.0	•14922E 06
• 346 -348	0.4276E-03	0.0	0.4276E-03	0.3706	0.0	•14922E 06
• 348 -349	0.5357E-02	0.0	0.5357E-02	0.3759	0.0	•14922E 06
• 349 -352	0.2223E-02	0.0	0.2223E-02	0.3781	0.0	•14922E 06
• 352 -353	0.5357E-02	0.0	0.5357E-02	0.3835	0.0	•14922E 06
• 353 -356	0.1998E-02	0.0	0.1998E-02	0.3855	0.0	•14922E 06
• 356 -357	0.1555E-02	0.0	0.1555E-02	0.3870	0.0	•14922E 06
• 357 -425	0.2000	0.0	0.2000	0.5870	0.0	*****
• 425 -427	0.4482E-03	0.0	0.4482E-03	0.5875	0.0	•13257E 06
• 427 -429	0.1962E-02	0.0	0.1962E-02	0.5895	0.0	•13257E 06
• 429 -431	0.1698E-03	0.0	0.1698E-03	0.5896	0.0	•13257E 06
• 431 -433	0.5192E-02	0.0	0.5192E-02	0.5948	0.0	•13257E 06
• 433 -435	0.1582E-02	0.0	0.1582E-02	0.5964	0.0	•13257E 06
• 435 -437	0.5192E-02	0.0	0.5192E-02	0.6016	0.0	•13257E 06
• 437 -439	0.3735E-02	0.0	0.3735E-02	0.6053	0.0	•13257E 06
• 439 -441	0.5192E-02	0.0	0.5192E-02	0.6105	0.0	•13257E 06
• 441 -442	0.1236E-02	0.0	0.1236E-02	0.6118	0.0	•13257E 06

***** MUFAN FLOW AND PRESSURE DROP PRINTOUT * 05/14/70 **** ** PAGE 5 OF 5 *

BOILER TO NPMAS DP LOSS.INT. LOCP. ASSUME INLPM 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

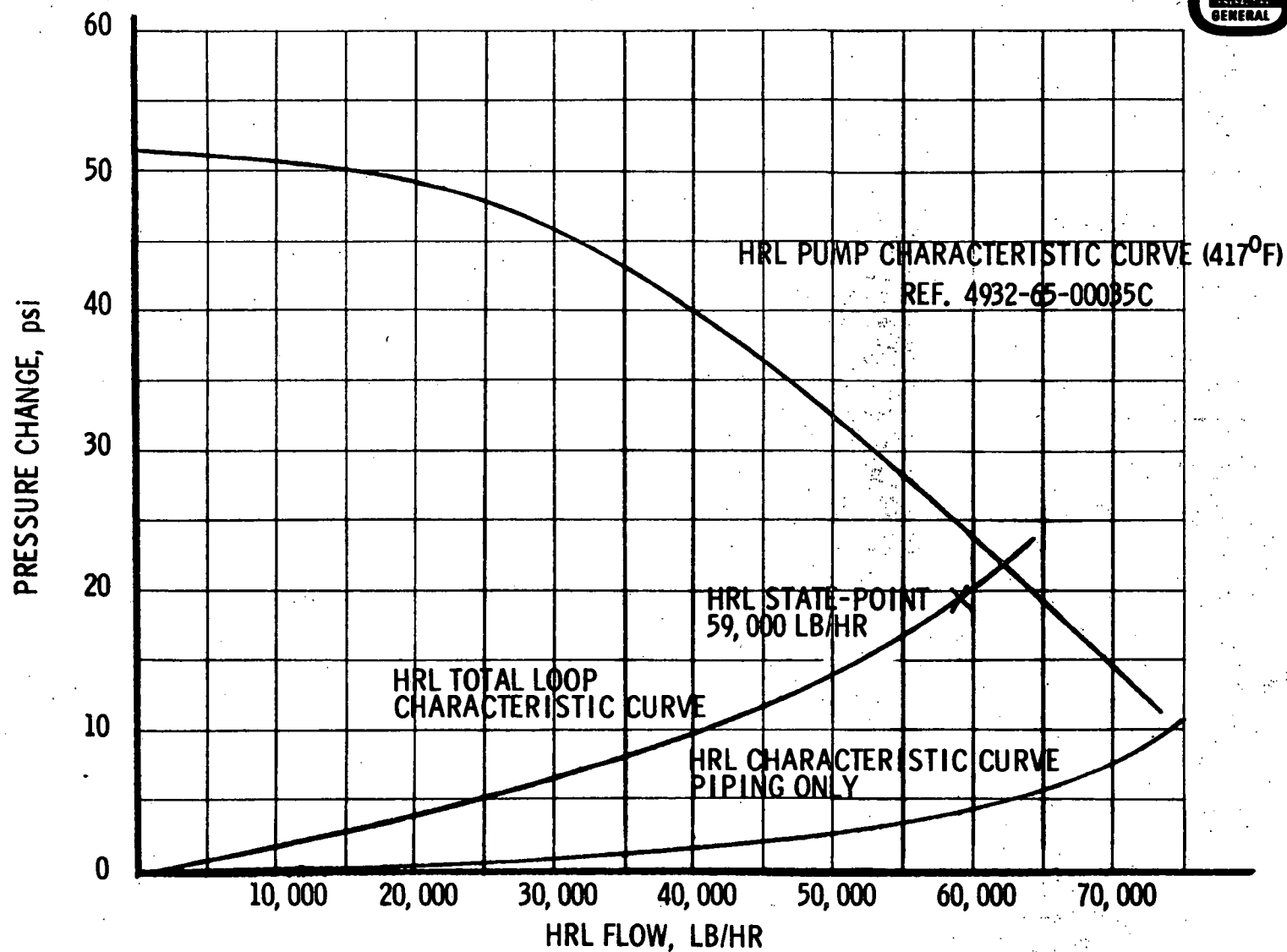
MEMBER	PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	-----CUMULATIVE-----			REYNOLDS NO
				PRESSURE DROP, PSI	ELEVATION PRESSURE DROP, PSI	FRICTION PRESSURE DROP, PSI	
. 443 -445	0.6282E-03	0.0	0.6282E-03	0.6124	0.0	0.6124	.13257E 06
. 445 -447	0.5432E-04	0.0	0.5432E-04	0.6124	0.0	0.6124	.13257E 06
. 447 -448	0.2000	0.0	0.2000	0.8124	0.0	0.8124	*****
..... END OF BRANCH - FLOW= 10000. X							

* Note, Cumulative pressure drop after valve 1/2 is .02 psi low
due to manual revision for diversion valve.

***** MUFAN PRESSURE PRINTOUT ***** 05/14/70***** ** PAGE 1 OF 1 *

BOILER TO NPMAS DP LOSS.INT. LOCP. ASSUME INLPA 2 IS WORST CONDITION
NPMAS AND CHECK VALVE TO IHX PRESSURE LOSS

NCDE	PRESSURE		NCDE	PRESSURE	NCDE	PRESSURE	NCDE	PRESSURE	NODE	PRESSURE
10	50.00	X	12	50.00	14	50.00	16	49.99	18	49.99
20	49.99		22	49.99	24	49.99	26	49.99	28	49.98
30	49.98		32	49.98	34	49.98	36	49.98	38	49.98
40	49.97		42	49.97	44	49.97	46	49.97	48	49.97
50	49.97		52	49.97	54	49.96	56	49.96	58	49.96
59	49.96		60	49.96	61	49.96	62	49.95	64	49.94
66	49.94		68	49.94	70	49.94	72	49.93	74	49.93
76	49.92		78	49.91	80	49.91	100	49.91	102	49.91
104	49.90		106	49.90	108	49.90	110	49.89	112	49.89
113	49.89		117	49.89	119	49.88	121	49.88	123	49.88
125	49.87		127	49.87	129	49.87	131	49.87	133	49.86
135	49.86		137	49.86	139	49.86	141	49.85	145	49.85
147	49.85		149	49.84	151	49.84	153	49.84	155	49.84
157	49.84		301	49.71	303	49.71	304	49.71	306	49.71
307	49.70		310	49.70	311	49.69	313	49.69	315	49.69
317	49.69		318	49.68	320	49.68	321	49.68	323	49.67
325	49.67		328	49.67	329	49.66	331	49.66	332	49.66
334	49.66		335	49.65	337	49.65	339	49.65	341	49.65
342	49.64		344	49.64	345	49.64	346	49.63	348	49.63
349	49.62		352	49.62	353	49.62	356	49.61	357	49.61
425	49.41		427	49.41	429	49.41	431	49.41	433	49.41
435	49.40		437	49.40	439	49.39	441	49.39	443	49.39
445	49.39		447	49.39	448	49.19	X			

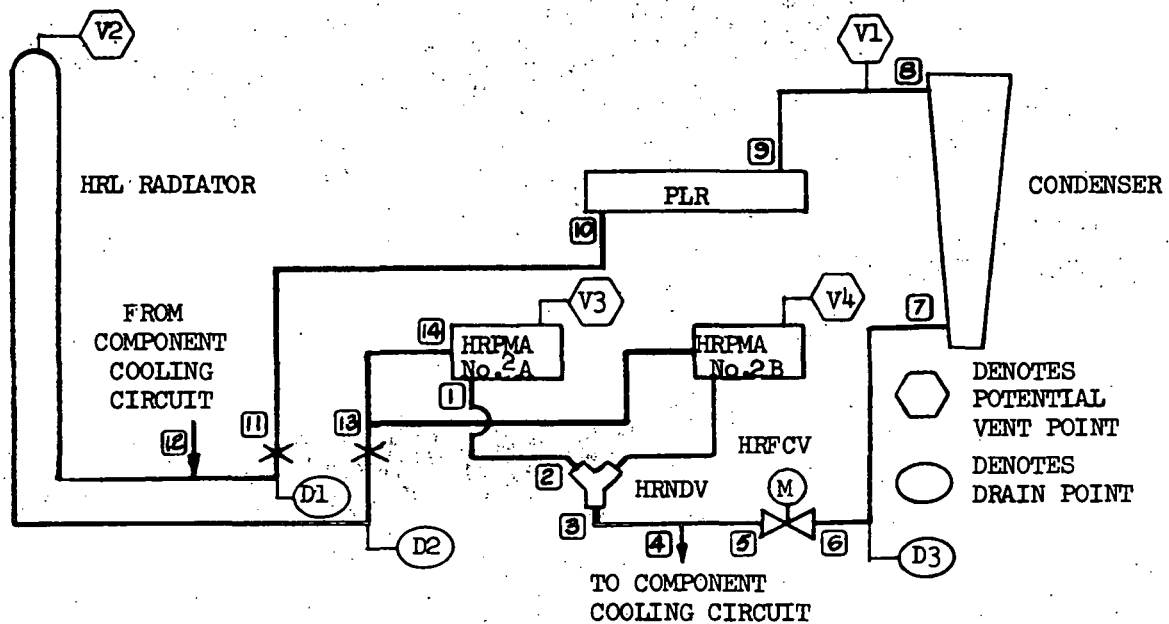


PCS HEAT REJECTION LOOP FLOW CHARACTERISTICS

10-087-118-1

FIGURE IIE-3-1

PCS HEAT REJECTION
LOOP PRESSURE LOSSES



HEAT REJECTION LOOP COMPONENTS		ΔP (PSID) AT 59,000 LB/HR PUMP FLOW	
END POINTS	DESCRIPTION	CALCULATED FROM LAYOUT	STATE-POINT VALUES
1-2	LINE - HRPMA TO HRNDV	.80	—
2-3	VALVE - HRNDV	1.07	1.07
3-5	LINE - HRNDV TO HRFCV	.32	—
5-6	VALVE - HRFCV	1.00	1.00
6-7	LINE - HRFCV TO CONDENSER	.14	—
7-8	CONDENSER	6.68	4.73
8-9	LINE - CONDENSER TO PLR	.28	—
9-10	PLR	.97	.97
10-11	LINE - PLR TO PCS INTERFACE	.85	—
11-13	LINE TO HRL RAD., HRL RAD., LINE FROM HRL RAD.	5.90	5.90
13-14	LINE PCS INTERFACE TO HRPMA	1.41	—
4-12	COMPONENT COOLING CIRCUIT	11.08	TO BE DETERMINED
NOTE: ΔP TOTAL 19.42		TOTAL ΔP -	TOTAL ΔP -
NEMA PRESSURE RISE 24.50		LOOP 19.42	LOOP 15.61
MARGIN (ΔP) +5.08		LINES 3.80	LINES 1.94

FIGURE IIE-3-2

SNAP-8 PARASITIC LOAD RESISTOR PRESSURE LOSS VS. NaK FLOW

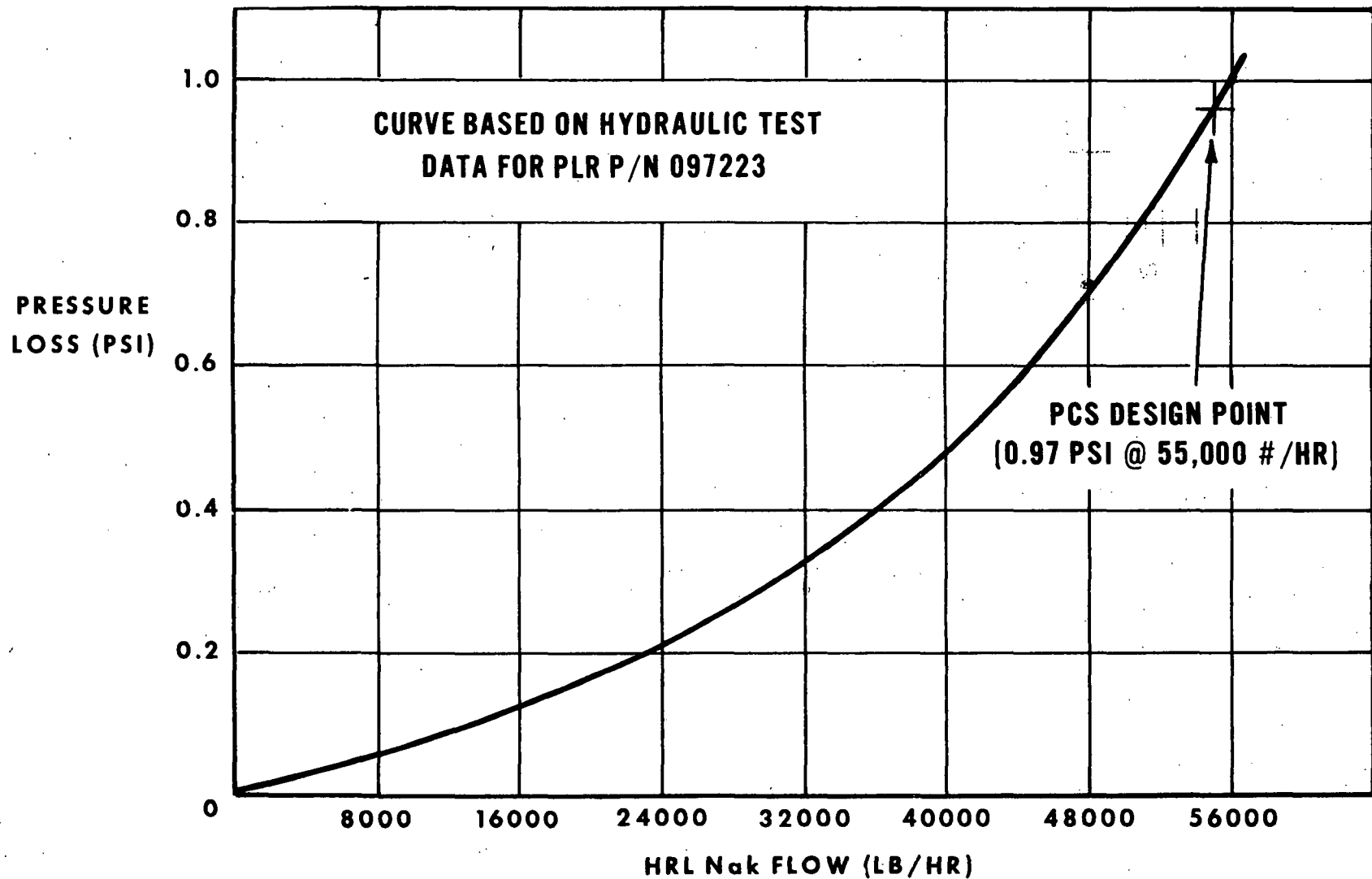


FIGURE IIE-3-3

SNAP-8 CONDENSER Nak SIDE PRESSURE LOSS VS. Nak FLOW

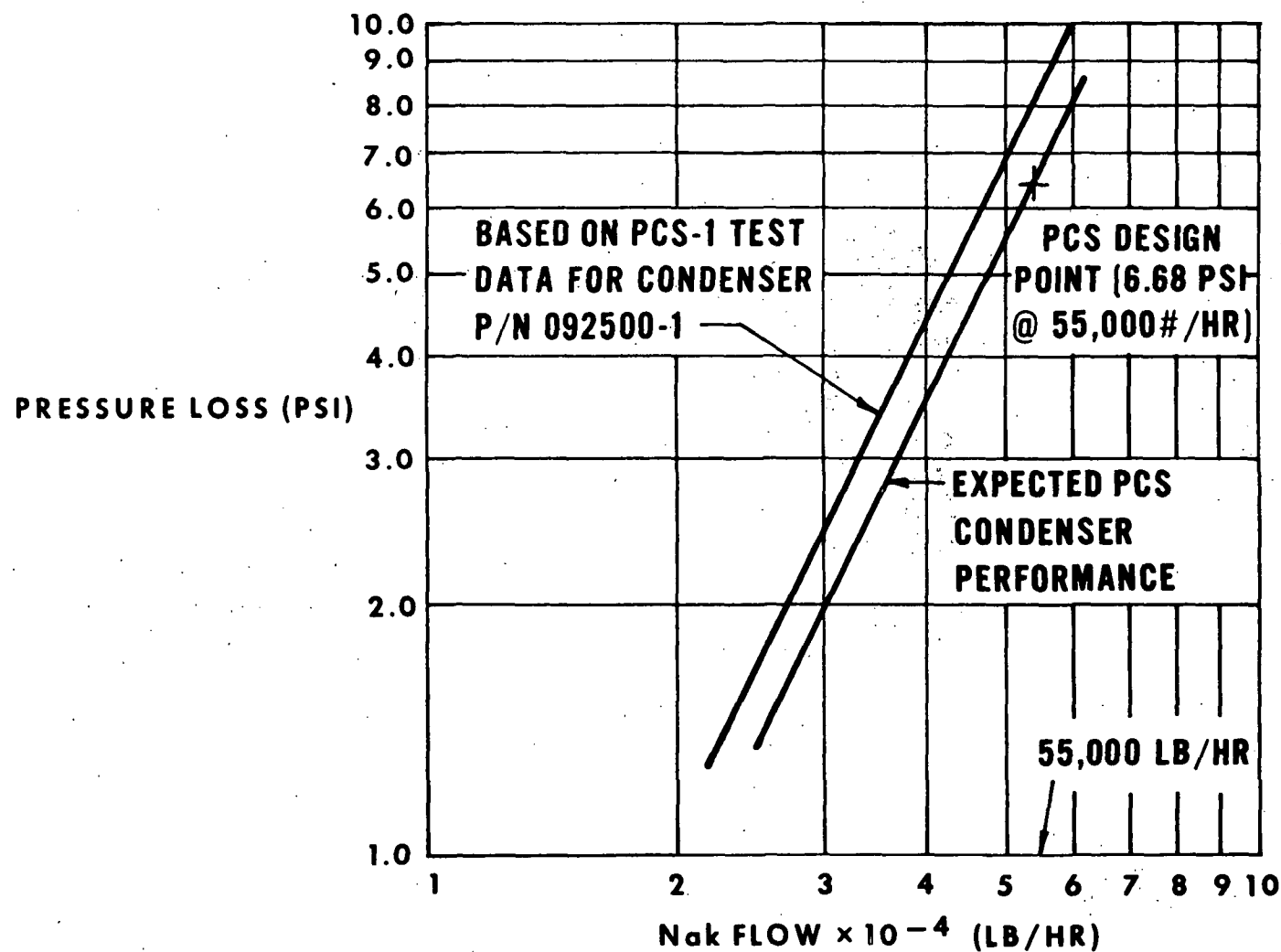
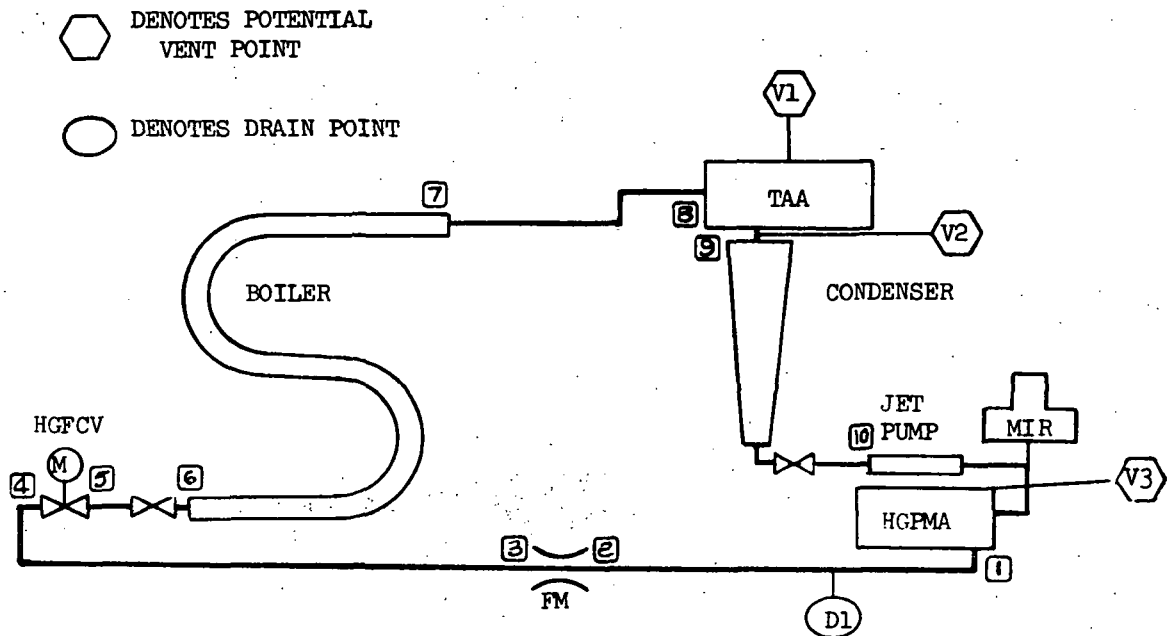


FIGURE IIE-3-4

PCS HG LOOP PRESSURE LOSSES



HG LOOP COMPONENTS		LOOP FLOW AT 13,775 LB/HR VAPOR 14,350 LB/HR LIQUID	
INTERFACE POINTS	DESCRIPTION	CALCULATED FROM LAYOUT	STATE-POINT VALUES
ΔP (PSID)			
2-3	FLOW METER	10.0	10.0
4-5	HG FCV .50 O.D. TUBE .75 O.D. TUBE	129.8 169.6	115.0
7-8	LINE, VAPOR	2.08	2.0
PRESSURE (PSIA)			
1	HG PMA DISCHARGE	510.9	490.0
6	BOILER INLET (LIQUID)	320.0	320.0
7	BOILER OUTLET (VAPOR)	145.1	145.1
8	TURBINE INLET	143.0	143.0
9	TURBINE OUTLET	8.0	8.0
10	JET PUMP INLET	29.4	8.5
NOTE			
HG PMA PRESSURE RISE 481.5			

FIGURE IIE-4-1

The CST/PCS Preliminary Measurement Requirements List presents the minimum number of instrumentation channels required for the operation of a single PCS. In compiling this list, a "2 out of 3" sensor philosophy for all automatic shutdown parameters has been used. This means that three separate sensors measure each automatic shutdown parameter, and that at least two out of each set of three sensors must indicate an alarm condition before an automatic emergency shutdown occurs.

CST/PCS INSTRUMENTATION SUMMARY

PCS MEASUREMENT REQUIREMENTS

- System Diagnostic	49
- Safety and Emergency Shut Down	24
- Start Up and Normal Shut Down	3
- Component Diagnostic	32
- Total Channels	<u>108</u>

TYPES OF MEASUREMENTS

- Temperature	29
- Pressure	27
- Flow	14
- Electrical	21
- RPM	2
- Acceleration	9
- Position	6
- Total Channels	<u>108</u>

FIGURE IIF-1

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: ELECTRICAL

LOOP: ALL

MEASURAND	PURPOSE	REMARKS
LL PMA #1 Input Current ϕ 1	Component Diagnostic	
LL PMA #2 Input Current ϕ 1	Component Diagnostic	
Hg PMA Input Current ϕ 1	Component Diagnostic	
HRL PMA #1 Input Current ϕ 1	Component Diagnostic	
HRL PMA #2 Input Current ϕ 1	Component Diagnostic	
Alternator Output Voltage ϕ 1	Emergency Shutdown	Signal goes to Programmer
Alternator Output Voltage ϕ 2	Emergency Shutdown	
Alternator Output Voltage ϕ 3	Emergency Shutdown	
Alternator Output Current ϕ 1	Component Diagnostic	
Alternator Output Current ϕ 2	Component Diagnostic	
Alternator Output Current ϕ 3	Component Diagnostic	
Alternator Output Power ϕ 1	Component Diagnostic	
Alternator Output Power ϕ 2	Component Diagnostic	
Alternator Output Power ϕ 3	Component Diagnostic	
PLR Input Current ϕ 1	System/Component Diagnostic	
PLR Input Current ϕ 2	System/Component Diagnostic	
PLR Input Current ϕ 3	System/Component Diagnostic	
L/C PMA Input Current ϕ 1	Component Diagnostic	
Vehicle Load Input Power ϕ 1	System Diagnostic	
Vehicle Load Input Power ϕ 2	System Diagnostic	
Vehicle Load Input Power ϕ 3	System Diagnostic	

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: FLOW

LOOP: Intermediate NaK

MEASURAND	PURPOSE	REMARKS
Intermediate Heat Exchanger Inlet	System Diagnostic	*EM Flowmeter
Intermediate Heat Exchanger Inlet	System Diagnostic	*EM Flowmeter
Intermediate Heat Exchanger Inlet	System Diagnostic	*EM Flowmeter
		*2 out of 3 philosophy - This measurement allows for switch-over to stand- by pump without reactor scram or fast setback.

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: FTON

LOOP: Mercury

[illegible]

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: FLOW

LOOP: Heat Rejection - NaK

MEASURAND	PURPOSE	REMARKS
HRL Condenser Inlet	Emergency Shutdown	*EM Flowmeter
HRL Condenser Inlet	Emergency Shutdown	*EM Flowmeter
HRL Condenser Inlet	Emergency Shutdown	*EM Flowmeter
Inlet to NaK Pump & Reactor Shield Bx Cooling Circuit	System Diagnostic	EM Flowmeter
Inlet to AHX Circuit	System Diagnostic	
		*2 out of 3 philosophy

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: ELON

LOOP: Lube Coolant

[illegible]

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: ~~CONFIDENTIAL~~ POSITION

LOOP: ALL

MEASURAND	PURPOSE	REMARKS
Intermediate Loop Expansion Reservoir Bellows Position	Safety/Component Diagnostic	
Hg Flow Control Valve (MFCV) Position	Control/Component Diagnostic	
Hg Injection Reservoir Bellows Position	Control & Start Up	Signal goes to Programmer
HRL Flow Control Valve (HRFCV) Position	Control/Component Diagnostic	
HRL Expansion Reservoir Bellows Position	Safety/Component Diagnostic	
L/C Loop Expansion Reservoir Bellows Position	Safety/Component Diagnostic	

Figure II F 2
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CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: PRESSURE

LOOP: Intermediate NaK

[illegible]

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: PRESSURE

LOOP: Mercury

MEASURAND	PURPOSE	REMARKS
Hg PMA Inlet/Condenser Outlet	Component & System Diagnostic	
Hg PMA Outlet	Component & System Diagnostic	
Boiler Outlet/TAA Inlet	Component & System Diagnostic	
TAA Outlet/Condenser Inlet	Start-up Control	Signal goes to Programmer
ΔP Across Hg Liquid Venturi	Component & System Diagnostic	
ΔP Across Hg Vapor Venturi	Component & System Diagnostic	
Condenser Inlet	Shutdown (Overpressure)	Pressure Switch, 2 out of 3
Condenser Inlet	Shutdown (Overpressure)	Pressure Switch, 2 out of 3
Condenser Inlet	Shutdown (Overpressure)	Pressure Switch, 2 out of 3
Stand-by Boiler Hg Outlet	Safety	Vacuum Measurement

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: PRESSURE

LOOP: Heat Rejection

[illegible]

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: PRESSURE

LOOP: Lube/Coolant

[illegible]

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: TEMPERATURE

LOOP: Intermediate NaK

MEASURAND	PURPOSE	REMARKS
Diverter Valve Outlet		
Boiler Inlet		
Boiler Outlet		
ILPMA #1 End Turn		
ILPMA #2 End Turn		

Figure II F 2
Page 11

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: TEMPERATURE

LOOP: Mercury

MEASURAND	PURPOSE	REMARKS
Hg PMA Outlet/Boiler Inlet	System Diagnostic	
Hg Boiler Outlet/TAA Inlet	System Diagnostic	
Hg TAA Outlet/Condenser Inlet	System Diagnostic	
Hg Condenser Outlet/Hg PMA Inlet	System Diagnostic	
Turb. Brng. Outer Race Anti-Drive End	Component Diagnostic	
Turb. Brng. Outer Race Drive End	Component Diagnostic	
Alt. Brng. Outer Race Anti-Drive End	Component Diagnostic	
Alt. Brng. Outer Race Drive End	Component Diagnostic	
Alternator End Turn	Component Diagnostic	
Alternator Stator	Component Diagnostic	
Hg PMA Bearing Anti-Drive End	Component Diagnostic	

Figure II F 2
Page 12

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: TEMPERATURE

LOOP: Lube Coolant

[illegible]

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: ROTATIONAL SPEED

LOOP: ALL

[illegible]

CST/PCS PRELIMINARY MEASUREMENT REQUIREMENTS LIST

PARAMETER: ACCELERATION

LOOP: ALL

MEASURAND	PURPOSE	REMARKS
IL PMA #1 Acceleration	Safety/Component Diagnostic	
IL PMA #2 Acceleration	Safety/Component Diagnostic	
ILg PMA Acceleration	Safety/Component Diagnostic	
TAA Acceleration (Horizontal)	Safety/Component Diagnostic	
TAA Acceleration (Vertical)	Safety/Component Diagnostic	
TAA Acceleration (Axial)	Safety/Component Diagnostic	
RL PMA #1 Acceleration	Safety/Component Diagnostic	
RL PMA #2 Acceleration	Safety/Component Diagnostic	
L/C PMA Acceleration	Safety/Component Diagnostic	

Figure 11 F 2
Page 16

POWER SYSTEM DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>1</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐		
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**	
FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM		5 6 REMARKS AND RECOMMENDATIONS	
1. Excessive fluid pressure in Mercury Injection Reservoir/Reservoir-loop isolation valve and connecting line.	Fluid Hammer following closure of isolation valve during start sequence.	Possible bellows rupture in MTR; Rupture of component housing or lines.	Loss of Hg inventory. Normal restart not possible.	Low	Critical	1a. Close couple valve to reservoir to decrease the valve critical closing time ($2 \times L/c$ where L =distance between valve and reservoir, c = speed of sound in Hg). 1b. Use Hg line diameters which decrease velocity of mercury, hence pressure rise on sudden valve closure. 1c. Specify minimum permitted closing time for valve.
2. Non-condensable gas buildup in Hg loop.	2a) Gases "desorb" from piping and component walls. b) Gases not completely removed from loop during initial evacuation. c) H_2 transport from reactor. c) Mix $4P3E$ decomposition.	Potential degradation of mechanical prop of Ta in boiler.	Decrease in system power output as condenser Hg pressure increases. Loss of PCS (failure of Hg containment in boiler)	Low	Minor to Critical	2a) Provide electric heaters for liquid lines to promote out-gassing of walls of loop during system evacuation. b) Intermediate loop significantly reduces H_2 transport to Hg loop. c) Consider design for TAA and HgFMA which vent Hg and L/C fluid separately from space seal (e.g. magnetic fluid seal). d) Hg valves should have controls independent of normal programmer functions so that they can be opened during initial loop evacuation.

* HIGH - Two or more occurrences of failure mode in testing.
 MODerate - One recorded occurrence.
 LOW - No recorded occurrences.

** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard.
 MAJOR - A failure or performance degradation in excess of tolerance limits.
 MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

FIGURE III, Page 1

POWER SYSTEM DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>2</u> OF FMEA DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐		
1 FAILURE MODE	2 FAILURE CAUSE	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**	
		COMPONENT	SYSTEM		5	6 REMARKS AND RECOMMENDATIONS
3. Loss of HRL flow to the Auxiliary Heat Exchanger.	3a) Oxide plugging of line from HRL to RPL. b) Return line from AHX to the HRL interface is not installed (but the interfaces are capped so that the NaK is "dead-ended" in the AHX. c) Valve in the line to the AHX (solenoid valve) does not open on signal.	On shutdown reactor would not be cooled and fuel elements could rupture -- reactor not re-startable.	PCS not re-startable if reactor is damaged. On startup, start operations would be terminated.	3a) MOD (FR 1083)	Critical	3. Switch to second PCS HRL. The reason for including failure cause 3b is to indicate that there are lines associated with the HRL which are not part of the PCS and will not be supplied with it. The return line from the AHX is connected to the HRL heat sink so that it is routed between the RPL and the "FRA" or its equivalent. Thus this line becomes a facility responsibility and this type of interface condition must be carefully monitored and controlled. To prevent oxide plugging consider: a) maintain flow through the AHX circuit during purification of the HRL so it is not a "dead-leg".
* HIGH - Two or more occurrences of failure mode in testing. MODerate - One recorded occurrence. LOW - No recorded occurrences. ** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.						

POWER SYSTEM DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>3</u> OF FMEA DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐	
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE*
FAILURE MODE.	FAILURE CAUSE	COMPONENT	SYSTEM		5
					6 CRITICALITY OF FAILURE**
3. continued (Loss of HRL flow to the AHX).					REMARKS AND RECOMMENDATIONS b) Purify HRL over a long time period to prevent large temperature gradients in the loop from occurring. c) Purify the HRL before the other NaK loops so that temperature gradients between the other NaK loops which have components cooled by the HRL and the HRL do not cause oxide precipitation in the HRL by induced temperature gradients. Analyze the system to see if it is possible to switch from one HRL to the second if the AHX coolant line is inoperative, in a timely manner. Reconsider providing a separate AHX NaK coolant loop.
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FIGURE III, Page 3

POWER SYTI DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION: _____		PAGE <u>4</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐	
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**
FAILURE MODE.	FAILURE CAUSE	COMPONENT	SYSTEM		5 REMARKS AND RECOMMENDATIONS
4. Loss of NaK pump motor gas fill in vacuum environment.	Leak in motor Thermo-couple installation.	Motor operates above its insulation temperature and shorts out.	Must shut down and switch to redundant pump. Loss of NaK inventory if electrical shorting puts hole in motor can.	MOD	Major to Critical Note: The NaK pump motor is gas filled to help heat transfer from stator to NaK coolant. At one time pump was run with motor evacuated but it could not always remain evacuated because of air leakage in; the converse problem now exists.
5. Low voltage delivered to pump terminals (all pumps).	Excessive voltage drop in lines from power supply to pump. Poor conductor/terminal contact.	Pump doesn't rotate.	No loop flow.	HIGH	Major to Critical Base harness design on full scale PCS mockup so that actual harness lengths can be the basis for sizing conductors. Weld conductors to terminals to prevent full or partial open circuits. Calculate harness temperature so that actual conductor electrical resistance can be figured into the design.
* HIGH - Two or more occurrences of failure mode in testing. * HIGH - Two or more occurrences of failure mode in testing. MODerate - One recorded occurrence. LOW - No recorded occurrences. ** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.					

POWER SYTE DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>5</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐		
1	2	3 EFFECT ON SNAP-8		4	5	6
FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM		PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**
						REMARKS AND RECOMMENDATIONS
6. Poor velocity profile of NaK entering NPMA.	Prerotation in NaK flow stream due to large number of bends in pump suction piping.	Increased losses in suction housing.	For a given NaK flow the head produced by the NPMA may not meet the required value for the system. Thus system flow rates may not be achieved and the net power output is reduced.	Low	Major	Tests of effect of NaK suction line configuration on pump performance are proposed for the NSL.
7. NPMA motor insulation temperature and NaK bearing temperatures exceed design values. (intermediate loop)	Heat input to standby IL NPMA from flowing system NaK.	Motor operates above its insulation temperature and shorts out; NaK film at bearings viscosity below design value; bearings gall/sieze on startup.	Standby pump becomes inoperative and system cannot be re-started. Loss of NaK inventory if can is damaged by electrical short.	Low	Major to Critical	Analysis currently in progress to evaluate need for cooling of standby IL NPMA.
* HIGH - Two or more occurrences of failure mode in testing. MODerate - One recorded occurrence. LOW - No recorded occurrences. ** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.						

FIGURE III, Page 5

POWER SYTE DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>6</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐	
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**
FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM		5 6 REMARKS AND RECOMMENDATIONS
8. NaK inventory in Hg loop.	Failure of weld joint between Hg loop and NaK HRL in condenser.	Loss of condenser containment of NaK.	Formation of Hg-NaK amalgam in lower temperature regions of the HgL with subsequent plugging of lines, Hg PMA, valves, etc.	Low	Critical Consider double containment of weld joints where NaK and Hg are opposite; e.g. PLE braze and weld joint design.
9. Gas leaks into L/C loop; loss of L/C inventory to environment.	a) L/C fittings assembled without ferrules. b) Poor fitup or mechanical damage of swagelok or conoseal fittings.	Loss of stable interface in bearing slingers.	Loss of L/C L inventory resulting in eventual PCS shutdown. Cavitation of LCPMA; possible flooding of bearings resulting in decreased system electrical output.	MOD (FRO415)	Minor to Critical QC surveillance of torquing operations and the preceding joint fitup. Replace all fittings with weld joints or brazed joints. In general, existing leaks would be discovered during system Helium leak check.

* HIGH - Two or more occurrences of failure mode in testing.
 MODerate - One recorded occurrence.
 LOW - No recorded occurrences.

** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard.
 MAJOR - A failure or performance degradation in excess of tolerance limits.
 MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

POWER SYSTEM DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>7</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐		
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**
FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM		5	6 REMARKS AND RECOMMENDATIONS
10. Incomplete seating of Mercury Injection Reservoir isolation valve.	Accumulation of dirt, debris, thermal distortion, mechanical damage, or valve fails to close due to solenoid malfunction; e.g. temperature degradation of insulation.	Minor	Mercury inventory in condenser set by reservoir pressure and variation of Hg head between condenser and reservoir. System may be forced to operate at an off-design condition.	High	Minor to Critical	a) Provide pressure regulation capability for L/C side of MR reservoir to provide capability of controlling mercury side inventory. b) Use high temperature solenoid valve and insure that the proper operating voltage is available at the valve terminals.
11. Current flow to solenoid valve coil and/or associated contactor exceeds electrical rating.	Component is exposed to large voltage surges following sudden deactivation of the solenoid.	As a worst case, valve cannot be operated.	Mercury, Heat Rejection Loop and/or Lube/Coolant Loops cannot perform operations requiring valve to change position.	Low	Critical	Diode circuit is placed in parallel with the solenoid coil and provides a current path during valve deactivation but an infinite resistance during actuation. This procedure is used during current SNAP-8 ground tests. This diode circuit
* HIGH - Two or more occurrences of failure mode in testing. MODERATE - One recorded occurrence. LOW - No recorded occurrences.						will be incorporated in the PCS programmer and the requirement for it imposed on the valve supplier during acceptance testing.
** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.						

POWER SYTE DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>8</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐	
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**
FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM		5 6 REMARKS AND RECOMMENDATIONS
12. Radioactive NaK in HRL.	Structural failure allowing mixing of RPL and HRL NaK.	Minor	Becomes non-man rated.	Low	Critical a) Current double containment of RPL components restricts the possibility of this happening; however, the point documented here is that the static NaK reservoirs for the double contained components should be independent so that a single failure in two different components does not permit radioactive NaK to enter the HRL. b) Instrument the PCS NaK loops to detect this failure.
13. Low flow to Hg PMA bearings.	L/C pressure at nozzle inlet is too low (1 psia) and any dirt accumulation will have major effect on flow.	Bearings run "hot" and life is curtailed. Pump doesn't rotate.	One PCS becomes inoperative.	Low	Critical a) Decrease the number of Hg Pump bearing nozzles to increase the required inlet pressure. This has been proposed and previously accepted. Followup to insure that it is accomplished.
* HIGH - Two or more occurrences of failure mode in testing. MODerate - One recorded occurrence. LOW - No recorded occurrences. ** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.					

FIGURE III, Page 8

POWER SYSTEM DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>9</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐	
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**
FAILURE MODE.	FAILURE CAUSE	COMPONENT	SYSTEM		5 6 REMARKS AND RECOMMENDATIONS
14.a. Decomposition of Mix 4P3E. b. Line heater open circuit. c. Line heater short circuit.	Poor heat transfer from line heater to L/C fluid or excessive heat flux for available area.	Line heater open circuited or shorted to ground.	a) Plugging of L/C loop components with 4P3E products. b) Penetration of L/C piping walls due to short circuit and loss of L/C inventory. c) Loss of ability to preheat L/C fluid and hence restart the system. d) Generation of gas products which cause mal-performance of L/C slingers in HGPMA and TAA.	Low	Minor to Critical a) Investigate methods of thermally bonding the line heaters to the piping to prevent local hot spots during vacuum operation. b) Distribute the line heaters over the entire piping system instead of providing localized heat sources in order to decrease the required heater watt density. c) Use heaters that operate below the decomposition temperature of Mix 4P3E (500°F to 600°F use temperature); for example, calrod heaters can operate at temperatures over 1600°F if heat transfer is poor.
* HIGH - Two or more occurrences of failure mode in testing. Moderate - One recorded occurrence. LOW - No recorded occurrences. ** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.					

FIGURE III, Page 9

POWER SYSTEMS DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION:		PAGE <u>10</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐	
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**
FAILURE MODE.	FAILURE CAUSE	COMPONENT	SYSTEM		5 6 REMARKS AND RECOMMENDATIONS
15. Decrease in L/C PMA suction pressure.	Loss of L/C reservoir inventory resulting in decreased reservoir gas pressure.	Pump cavitates	Loss of system flow in L/C requiring shutdown due to loss of cooling capability.	Low	Critical There are many paths for loss of L/C inventory - Increased leakage in HgPMA due to larger dynamic seal tolerances, (per TM 4932: 69-605, 6 times the original L/C losses are expected); storage of oil in the MPMA motor stator, startup/shutdown losses, etc. Towards the end of life or after many startup cycles the reservoir pressure will decrease markedly from the initial value unless there is a large inventory available. Increasing the initial pressure is not a satisfactory answer because that would directly increase pump and TAA slinger losses, and decrease net system power output. The recently proposed L/C jet pump would
* HIGH - Two or more occurrences of failure mode in testing. MODerate - One recorded occurrence. LOW - No recorded occurrences.				help to ameliorate this situation. In any event, the L/C reservoir requirements should be reviewed in light of increased inventory losses.	
** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.					

POWER SYSTEMS DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____ PART NAME <u>PCS</u> LOOP _____ ITEM NO. _____		DESCRIPTION OF FUNCTION: _____		PAGE <u>11</u> OF <u>FMEA</u> DATE <u>15 May 1970</u> INITIAL ☒ REVISION ☐	
1	2	3 EFFECT ON SNAP-8		4	PROBABILITY OF OCCURRENCE* CRITICALITY OF FAILURE**
FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM		5 6 REMARKS AND RECOMMENDATIONS
15. Loss of system inventories for standby PCS.	Rupture of fluid containment structure, due to failure of reservoir latching device to unlatch or to be unlatched.	Mechanical damage	PCS inopera-	Low	Critical The reservoir specification requires that the reservoir should be provided with some type of latching device to preclude damage during launch due to fluid hammer. During ground test the latching mechanism (e.g. valve at inlet to reservoir to keep loop fluids from surging during launch) should be deactuated so that the reservoirs can absorb thermal growth of the standby loop inventories.
* HIGH - Two or more occurrences of failure mode in testing. MODERATE - One recorded occurrence. LOW - No recorded occurrences. ** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard. MAJOR - A failure or performance degradation in excess of tolerance limits. MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.					

FIGURE III, Page 11

POWER SYSTEMS DIVISION
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. _____
PART NAME PCS
LOOP _____ ITEM NO. _____

DESCRIPTION OF FUNCTION:

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DATE 15 May 1970
INITIAL ☒ REVISION ☐

1	2	3		4	PROBABILITY OF OCCURRENCE*	
FAILURE MODE.	FAILURE CAUSE	EFFECT ON SNAP-8			5	CRITICALITY OF FAILURE**
		COMPONENT	SYSTEM			6
						REMARKS AND RECOMMENDATIONS
17. Cracking of IL piping near NPMA/fatigue and distortion effects in NPMA with resulting loss of NaK inventory.	Thermal shock resulting from switching from operating NPMA to standby NPMA after balance of Intermediate Loop is at operating temperature.	Containment walls fail.	PCS inoperable due to loss of NaK inventory.	Low	Critical	Maintain requirement that NaK diverter valve permit some recirculation of NaK through standby pump. Even though pump flow is marginal the several hundred pound/hour leakage should be maintained.

* HIGH - Two or more occurrences of failure mode in testing.
MODERATE - One recorded occurrence.
LOW - No recorded occurrences.

** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard.
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FIGURE III, Page 12

MAJOR PCS CONTINUATION ACTIVITIES

- RESOLVE CONCEPTUAL DESIGN REVIEW ACTION ITEMS
- FABRICATE A FULL SCALE PCS MOCKUP
- DETAILED DESIGN OF COMPONENT AND PIPE SUPPORTS
- PREPARE COMPONENT PART I SPECIFICATIONS

FIGURE IV A

PCS PROGRAM SUMMARY

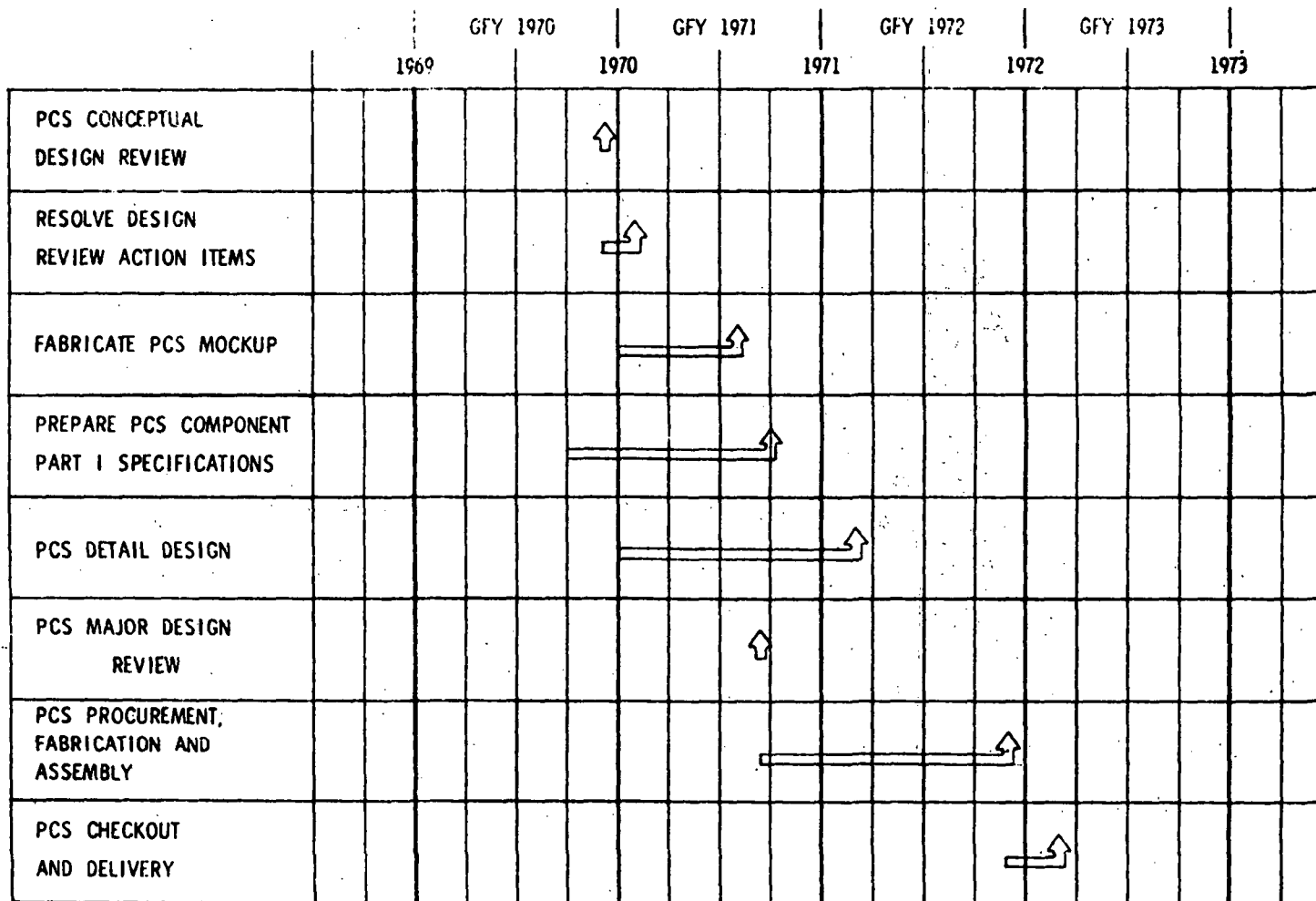
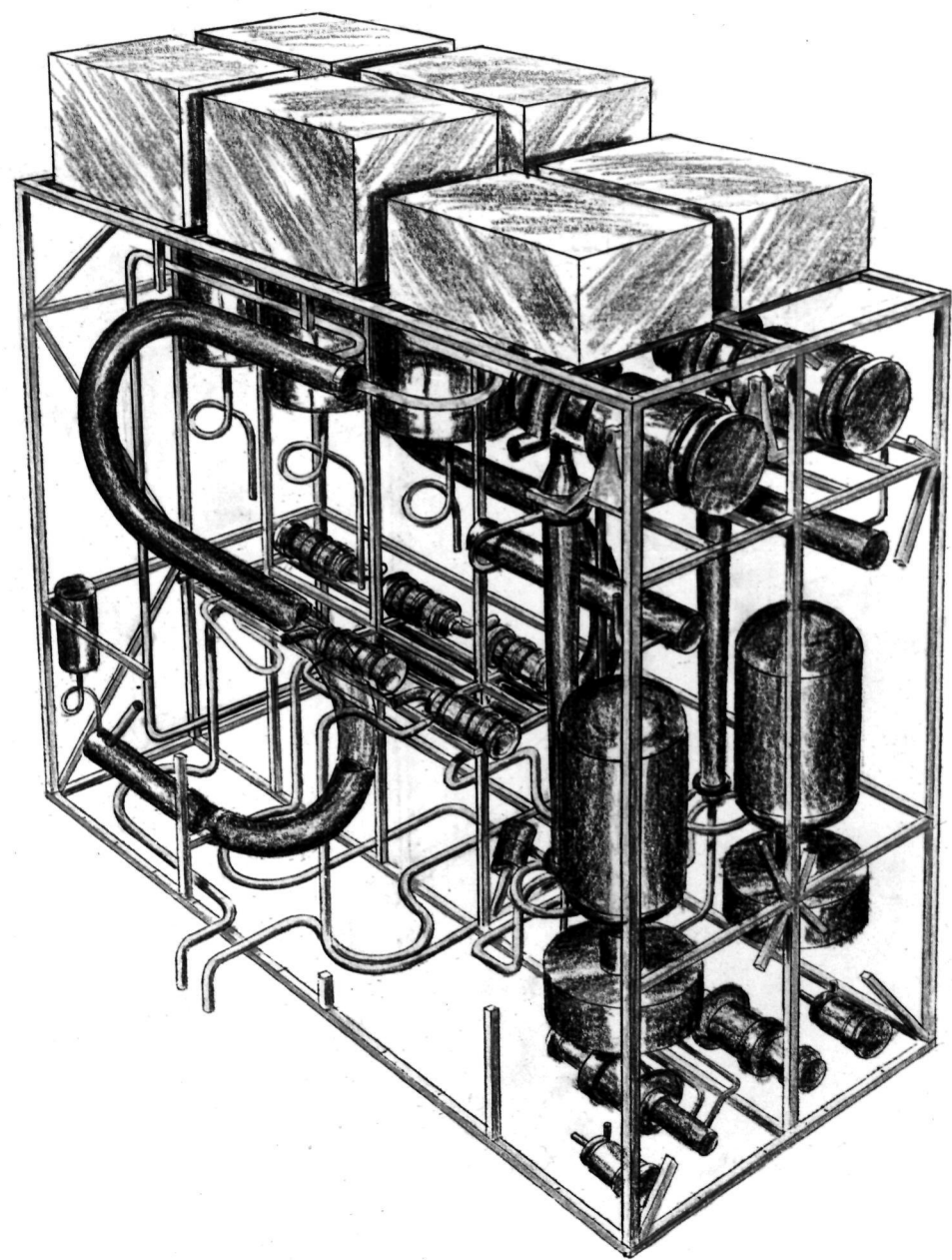


Figure IV B

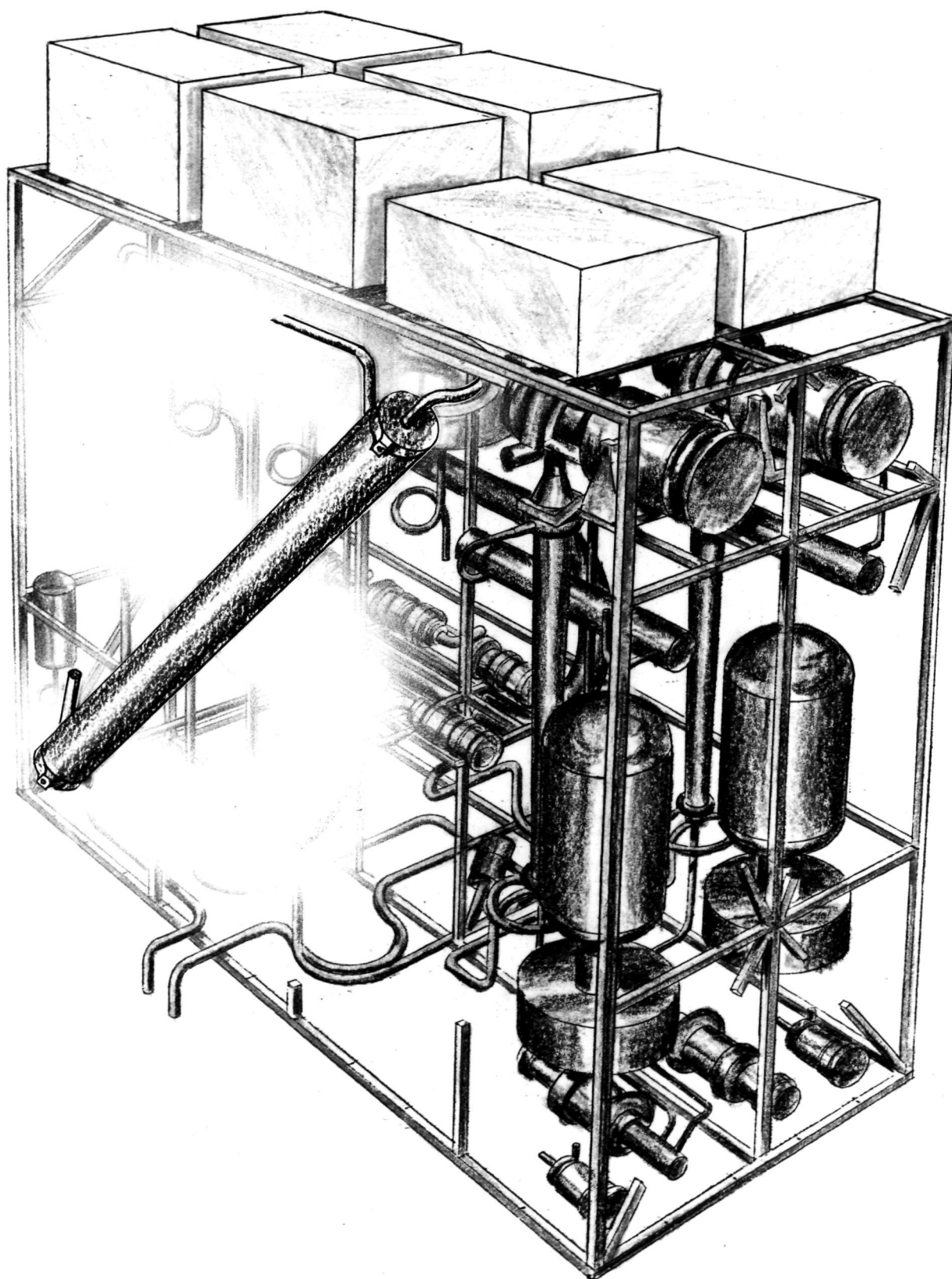


SNAP-8 POWER CONVERSION SYSTEM

CN-670-04

CN-670-04

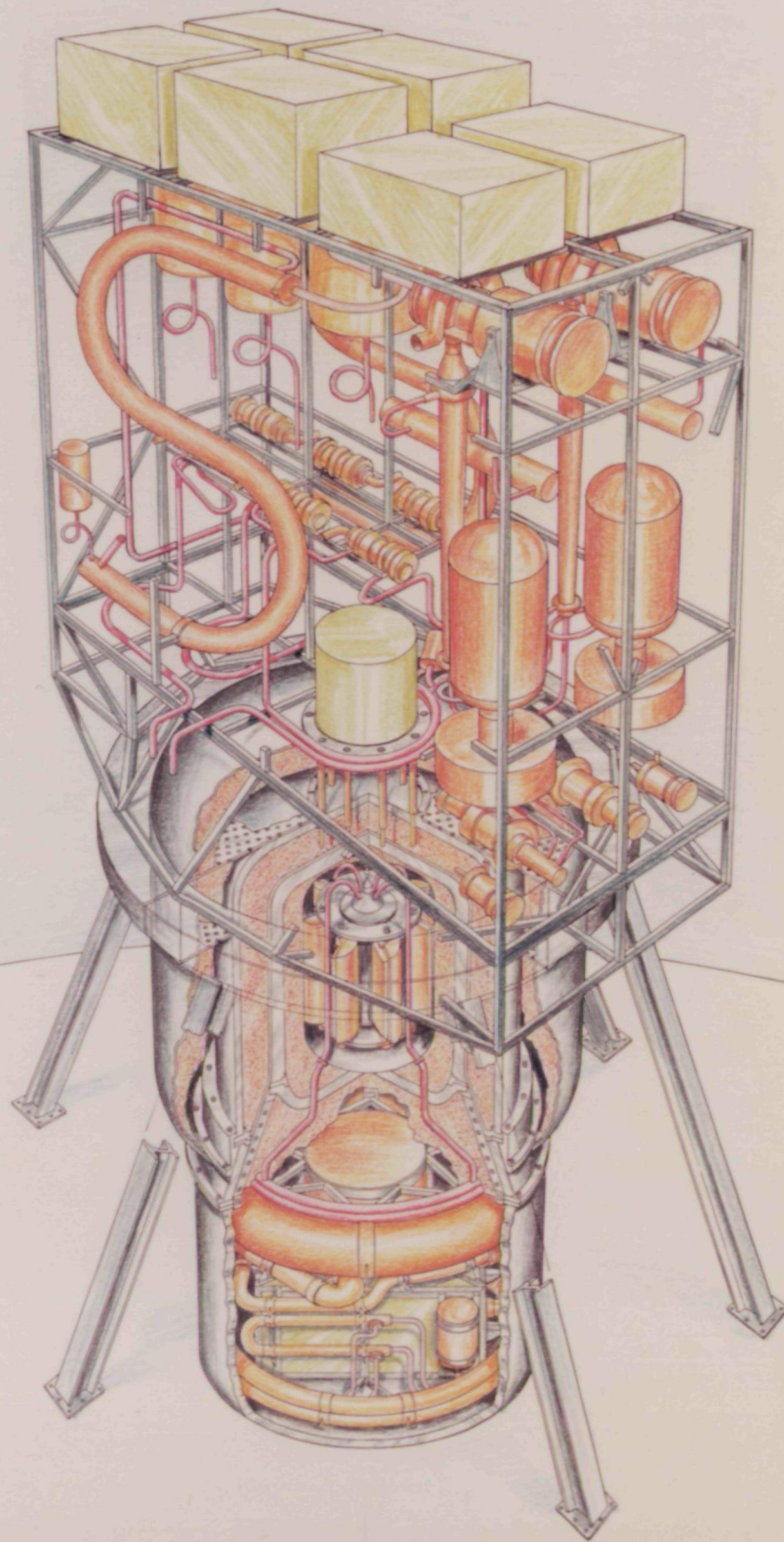
AEROJET-GENERAL CORP.
Technical Photography
Azusa, California



SNAP-8 POWER CONVERSION SYSTEM

670 009

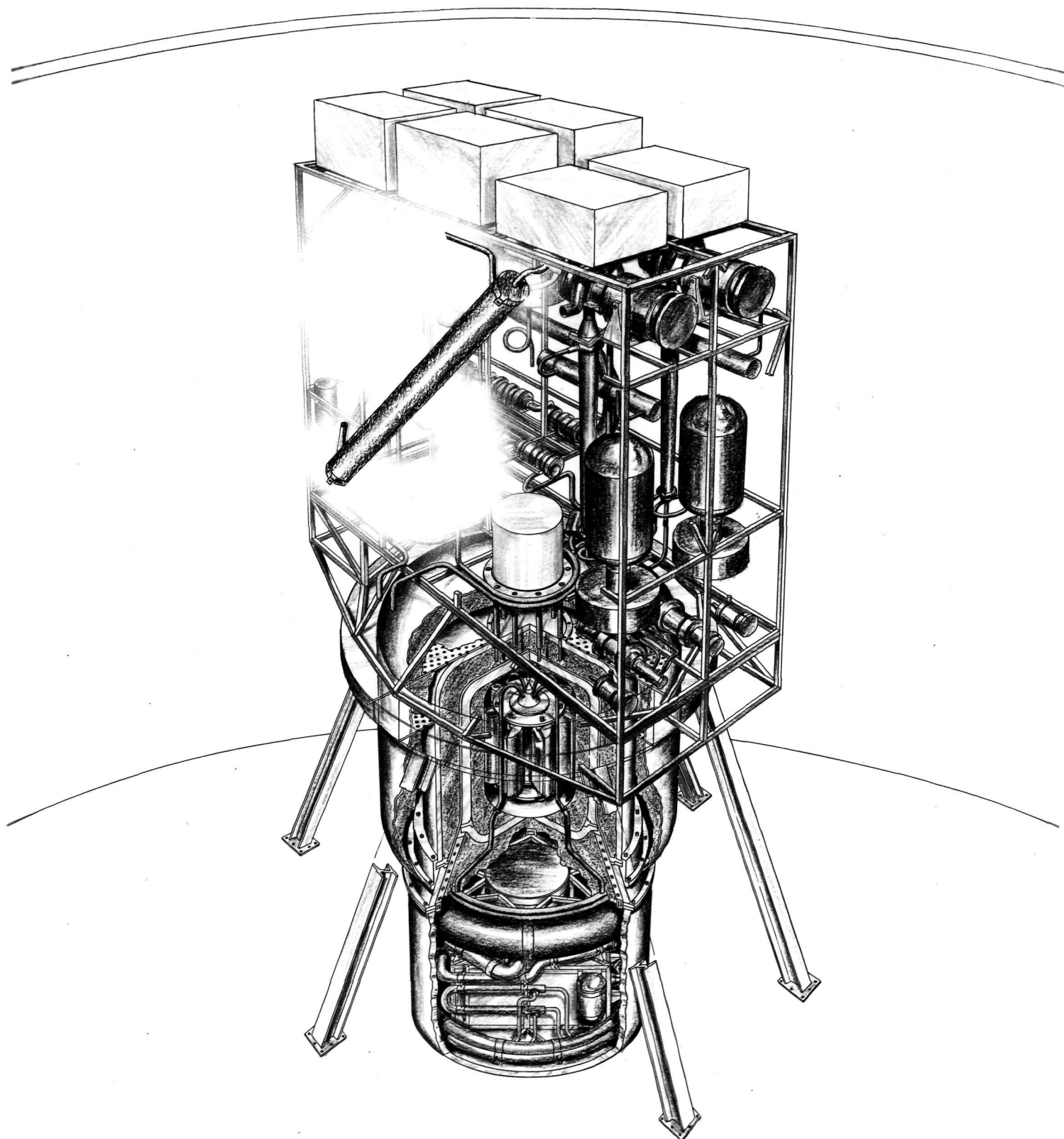
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Technical Photography
Azusa, California



SNAP-8 POWER CONVERSION SYSTEM AND NUCLEAR SYSTEM

AEROJET-GENERAL CORP.
Technical Photography
Azusa, California

CN 670-003

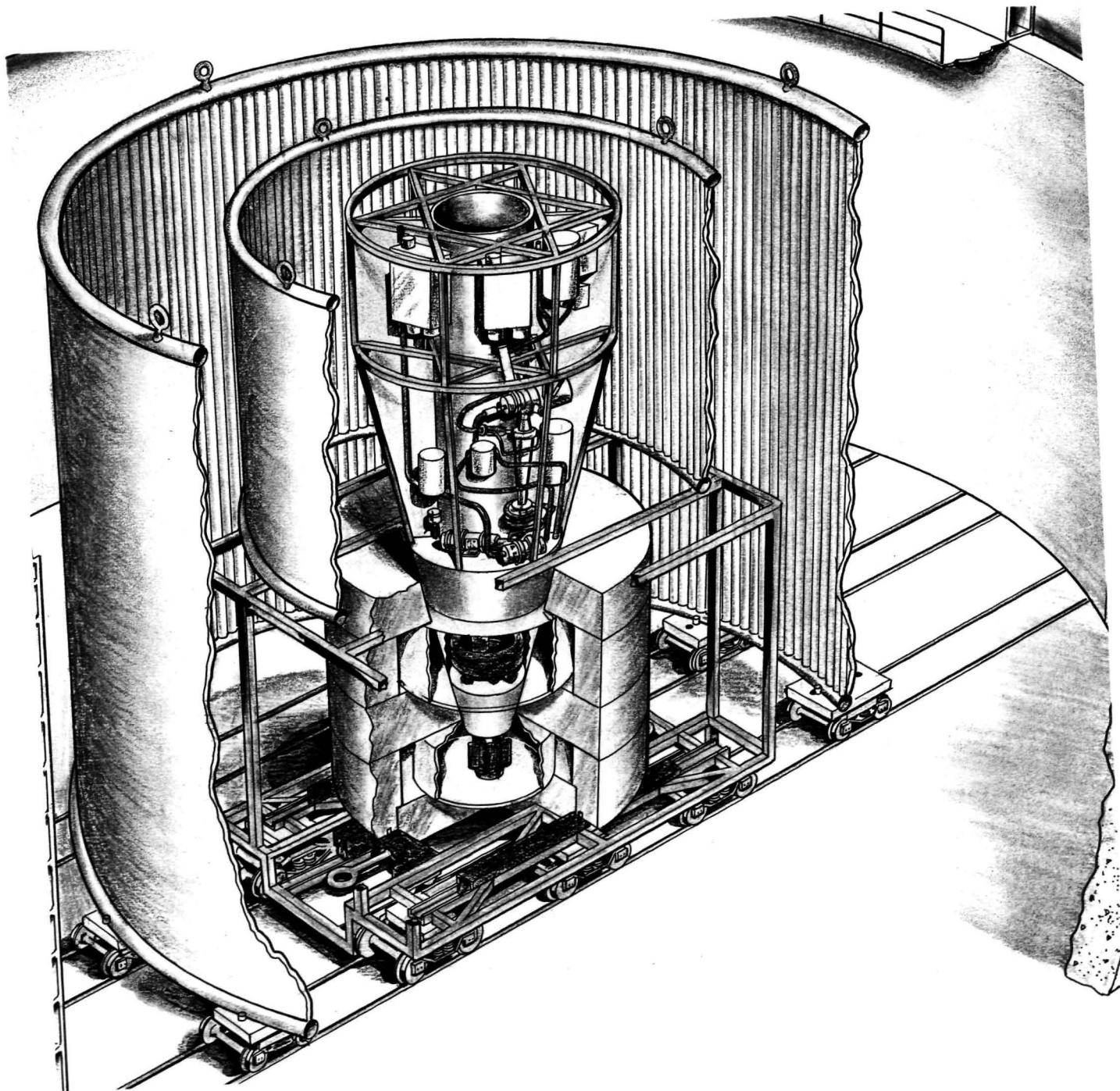


SNAP-8 POWER CONVERSION SYSTEM AND NUCLEAR SYSTEM

670 010

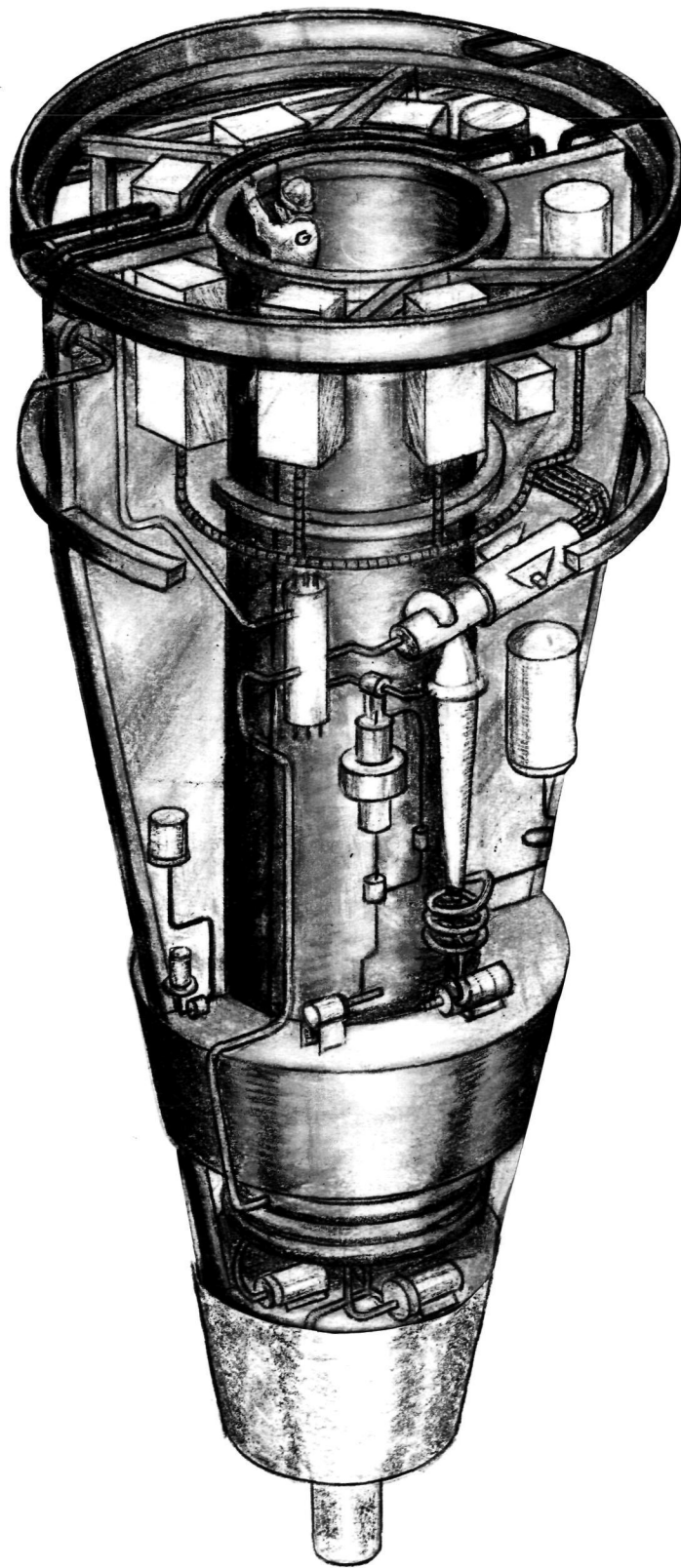
AERÖJET-GENERAL
Technical Photograph
Azusa, California

SNAP-8 COMBINED SYSTEM TEST-NASA PLUMBROOK SPF
PCS WITH BOILERS IN THE REACTOR COOLANT LOOP



670 007 → CN670-002

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Technical Photography
Azusa, California



SNAP-8 POWER CONVERSION SYSTEM WITH SHADOW SHIELDED REACTOR

670 006 → CN 670-001

AEROJET-GENERAL CORP.
Technical Photography
Azusa, California