

SNAP-8 ELECTRICAL GENERATING SYSTEM DEVELOPMENT PROGRAM

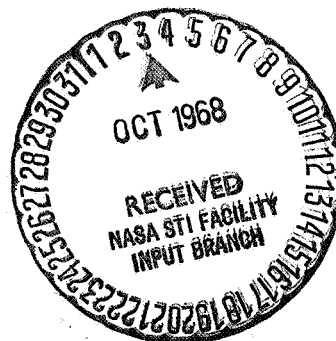
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DEVELOPMENT PROGRAM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT*

SNAP-8 is a turboelectric, nuclear, space power conversion system using a mercury Rankine cycle. The system incorporates three liquid metal loops. Sodium-potassium (NaK) in a primary loop is heated in a reactor, and, in turn heats mercury in a heat exchanger. The mercury vapor, in the second loop, expands through a turbine; it is then condensed, and pumped back through the boiler. A third loop, also containing NaK, transfers the heat from the mercury to a radiator where it is rejected to space. The fourth loop contains a polyphenyl ether that lubricates the bearings of the main rotating components and provides necessary cooling for the alternator, electric motors, and controls.

This report discusses the development progress of the power conversion system (turbine-alternator assembly, pump-motor assemblies, boiler, condenser, and electrical controls) during the first half of 1966.

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APPROVED:


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I. INTRODUCTION

The SNAP-8 electrical generating system is being developed by the National Aeronautics and Space Administration for use in various space applications. The system provides 35 kw of electrical power by converting heat from a nuclear reactor into electrical energy. Aerojet-General Corporation is developing the SNAP-8 power conversion system at its Von Karman Center in Azusa, California, under NASA Contract NAS 5-417. The effective starting date of the contract was 9 May 1960. The nuclear reactor is being built for the Atomic Energy Commission by Atomics International, Inc.

This report is the third in a series of Semiannual Progress Reports and includes a discussion and evaluation of the technical progress during the first half of 1966. This series of reports replaces the series of Quarterly Progress Reports published under the contract from its inception through 1964.

II. RATED POWER LOOP 2 (PCS-1 PHASE IV STEP 1)

Rated Power Loop 2 (PCS-1 Phase IV Step 1) Testing was conducted to obtain boiler and condenser performance data and to gain insight into system performance before initiating Steps 2 and 3.

This work was completed during the previous report period with the exception of the final test report. It was issued in the current report period as TM 4952:65-8-366 (Reference 1).

III. POWER CONVERSION SYSTEM 1 PHASE IV STEP 2 & 3

A. DESIGN AND FABRICATION

1. Step 2

At the beginning of the reporting period, the boiler, condenser, both NPMA's, PLR, and the TAA were installed. All step 2 piping had been completed and all welds had passed X-ray. Previously installed TAA -X electrical controls were used.

Early in the reporting period, the Step 2 mechanical drawings were upgraded and the Master Piping Arrangement (Dwg 098323) was released.

Design and fabrication of the electrical controls for Step 2 was divided into two parts: part 1 modified the existent electrical controls system (a soft-wired system); part 2 was designed as a hard-wired system for the new electrical controls that were to be installed. The design, fabrication, modification and checkout of the soft-wired system and hard-wired systems were completed on schedule. Operational use of the electrical controls for the Step 2 tests was very good. No major problems occurred during these tests.

The Step 2 instrumentation buildup and checkout was completed in early February 1966. Some of the more significant instrumentation tasks were:

a. Three TAA's (units 2/3, 5/2, and 6/1) were completely instrumented and tested in PCS-1 Phase IV. This entailed separate instrumentation drawings for each unit, transducer procurement, transducer calibration, and installation.

b. Installation and checkout of a continuous on-line vibration, recording, and monitor system.

c. Major modification of the typewriter systems for the Digital Data Acquisition System.

d. Installation, calibration, and hookup of 230 new transducers (pressure, temperature, flow, etc.).

e. Issuance of the Step 2 Instrumentation List as a controlled document (AGC STD 1290).

2. Step 3

The Step 3 design was initiated during 1965. At the beginning of the reporting period, Step 3 design was proceeding on the ASL (NaK/NaK heat exchanger), TCV, Hg PMA, MIS, control console, and the new PNL dump tank installation. In addition, the loop component installation and plumbing was modified to provide better assurance of long-term operation.

A new NaK cold trap was installed in the NaK purification system and the design of a new LN₂ supply system was started that would eliminate the use of portable carts. A phase separator was provided for the LN₂ cold trap to eliminate overflow and subsequent freezing of the O-ring. A drain was provided on the Hg PMA pump housing to assure that the pump would be free of mercury prior to startup testing. The mercury fill system was redesigned so that the loop always would be pre-filled downstream of the Hg PMA. Gross mercury separators were provided in the L/C loop downstream of the TAA and the Hg PMA.

Subsequently, the heat-rejection expansion tank was redesigned, changing it to a standoff tank. An oil separator was designed to separate oil from mercury in the mercury loop. The L/C loop was redesigned in order to supply lubricant and coolant to the additional components to be installed during Step 3.

At the end of the reporting period, the loop had been upgraded to a full system loop with complete documentation for all additions. The loop contains the PCS components required for operation of the primary, mercury, heat rejection, and lubricant/coolant loops. In addition, the -1 electrical system was installed in place of the -X electrical system used in Step 2.

At the end of the report period, the mechanical design work required to upgrade RPL-2 to a full system loop had been completed. Design work continued for the future installation of a mercury leak-detection system. This device will be utilized to measure leakage from the mercury system during endurance operation.

At the conclusion of Step 2 testing, the electrical control system was removed from the loop. This included the removal of the operating consoles, the main frame, the electrical controls installed in Cell 4, and the electrical harnessing installed in Cells 5 and 6. As soon as this work was completed, it was possible to install the hard-wired electrical controls system for Step 3 without compromising the design, fabrication, and installation of the electrical controls.

The design objective for Step 3 was to provide a completely hard-wired system for the electrical controls. A discussion of this hard-wired system versus the soft-wired system was presented in TM 4936:65-1-313 (Reference 2). This document describes the electrical controls system that was installed for Step 3.

The hard-wired system consisted of the following: the new facility cables; rewiring of the mezzanine area for direct electrical controls; a new operating console and modified facility console in the control room; a new intercom system; and new electrical control wiring for the valves, heaters, motors, and PCS electrical components in Cells 5 & 6. The hard-wired system also included the installation of the transformer/reactor assembly (Dwg 097760-1), low-temperature controls assembly (Dwg 097054-1), inverter (Dwg 967J412), TAA power panel (Dwg 097913-1), and the PMA power panel (Dwg 097914-1), and the required interconnecting harnesses.

To accomplish the above tasks, the design and installation of the facility cables and "J" box were started during the operational phase of Step 2. Also during this period, the electrical controls design (Dwg 098735) was started. The electrical design was completed by 1 March 1966.

As a result, it was possible to freeze the mechanical design of the graphic panel, the operating console, and the additional electrical assemblies that were required.

The console was designed as a module. Its mechanical fabrication, electrical assembly, and electrical checkout were accomplished in the Electrical Lab before it was installed in Building 180. This assured the Electrical Controls Group that the operating console (as a unit) was wired correctly and operating properly before its installation into the system, thereby simplifying the system checkout. The design, fabrication, and checkout of this console was completed on schedule and installed in Building 180.

Due to new requirements, the facility console was modified; controls for the cover gas system were simplified and a manual vehicle-load-bank control panel was installed. The mercury monitor and the DDAS assemblies were not electrically changed.

A new communication system was designed, fabricated, and installed for Step 3. This installation was completed prior to checkout so that it was possible to perform an expeditious checkout of the different systems in Building 180.

The motor control centers and their associated electrical contactors in the mezzanine area were rewired and integrated to operate with the new hard-wired system. New variable transformers were installed for additional heaters and new wiring for the DC circuit breakers were installed. New interface wiring to the facility cables also were completed.

The Step 3 instrumentation design, fabrication, and installation included major modifications to the control-room signal conditioning and cell areas. The Building 180 control-room recorders and controllers were rearranged and checked out; a 36-meter display of loop operating parameters was installed over the control console; a completely new level indicating system was designed and installed for the primary NaK dump tank, heat rejection dump tank, and heat rejection expansion tank; an electrical measuring

system, capable of measuring each phase of voltage, current, and power of each PCS component, was fabricated and installed in Cell 4; a control console instrument wing which is comprised of a 48-channel hard-wired temperature indicator and a 60-channel annunciator system, was provided; an air conditioning system was installed in the mezzanine of Building 180; 40 isolation amplifiers were added to the control room; and the entire thermocouple system of the building was upgraded to improve system reliability. EM flowmeters were installed in the three NaK loops (PNL, HRL, and ASL).

Other engineering tasks accomplished included the release of the Step 3 Instrumentation List (AGC STD 1295), upgrading Building 180 instrumentation wiring diagrams and drawings to an "as-built" condition; issuance of approximately a dozen thermocouple and pressure transducer standard applications designs; and issuance of approximately 15 calibration procedures and transducer specifications.

An extensive program was initiated to clean contaminated pressure transducers. Several transducer cleaning specifications were released and three trial batches of transducers were cleaned and successfully recalibrated for loop usage. This program should effect a considerable cost reduction for replacement transducers.

A summary of the results from the above efforts is presented in Tables III-1 and -2. Table III-1 presents the number of measuring elements installed for PCS-1 Phase IV Step 3 tests. Table III-2 presents a breakdown of final (readout) elements.

B. TEST OPERATIONS, RESULTS, AND ANALYSES

1. Summary

Step 2 of PCS-1 Phase IV was conducted to obtain performance data of the SNAP-8 components operating in a system, basic system performance data, and system performance data relative to the startup development tests of Step 3.

Step 2 testing covered the period of 30 January 1966 through 13 April 1966. During this time period there were eight system startups and one attempted startup. The total system operating time was 300 hours 31 minutes. Each of the testing dates, operating times, and causes of shutdown are summarized in Table III-3.

Portions of the Step 2 testing were not completed due to a shortage of test components and the fact that the boiler had become deconditioned. An estimated 62% of the total test objectives were accomplished. Table III-4 gives a detailed listing of the Step 2 objectives and accomplishments. Many regions of data and information not specifically planned for Step 2 testing also were acquired which enhanced the value of the testing. These supplementary accomplishments are listed in Table III-5. Those portions of Step 2 testing which were not completed have been scheduled for Step 3 testing.

Each of the SNAP-8 components used in Step 2 have been analyzed. In general, the agreement between Step 2 performance and component development data is good. Specific component problem areas were encountered with the TAA and PMA's. During the testing, all three TAA's experienced subcomponent failures; one HRL NPMA, three primary NPMA's, and one Hg PMA also experienced failures. Some of the problems were in the area of component design; others were the result of the facility and the mode of operation.

Valuable system performance data were obtained during Step 2. The HRL cooler bypass and louver control system were evaluated as radiator simulation methods for Step 3 startup testing. Simulations of mercury inventory variations and variations in reactor outlet temperature were analyzed and resulted in the accumulation of considerable system performance data. One of the more outstanding system accomplishments was the first demonstration of a completely stable, self-sustaining system. The system was operated with all PMA's driven by alternator power. Step 2 also marked the first demonstration of the ability to reliably switch 35 kw between the PLR and vehicle load in single steps.

In overall perspective, Step 2 testing was successful and provided valuable component and system performance data.

2. Chronological History of Step 2 Test Period

The initial mercury injection in PCS-1 Phase IV Step 2 was at 0245 hours on 30 January 1966. The startup proceeded smoothly and without incident. When steady-state was reached, it was observed that the L/C PMA discharge pressure was dropping. The L/C flow to the NaK PMA's (pumps not running) was stopped in an effort to recover some of the lost L/C pump head but the pressure continued to decrease. The L/C PMA was stopped and started two or three times to assist the passage of any gas through the pump. The L/C system vacuum also was noted to be lost (pegged at > 2 mm).

The loop was shutdown at 0307 hours (after 22 minutes of TAA operation) to protect the components from danger due to a further loss of L/C system pressure. The problem was found to be a leak, allowing air to enter the L/C system.

Several key observations, regarding the system and components during the run, are listed below:

- a. The TAA functioned well with a smooth acceleration and deceleration. The vibration level was low.
- b. The electrical power output was within the predicted range (19 kw at 4600 lb/hr).
- c. The electrical controls worked well and the system was completely stable.
- d. The boiler produced good superheat. The boiler pressure-drop indicated that a long conditioning period would not be required.

The second mercury injection in PCS-1 Phase IV Step 2 was made at 1342 hours on 4 February 1966. The startup again proceeded smoothly and without incident.

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Following the startup, the L/C PMA discharge pressure began to drop and became erratic. It was observed that L/C fluid was rapidly flowing into the alternator drain trap. The mercury loop was shutdown at 13⁴⁶ hours after four minutes of operation.

During the post-run investigation, it was determined that the problem was caused by a damaged mating plug (MS 3106-10SL-4S) on the TAA bearing discharge valve (LCV-15). As a result, the valve was not able to open and the L/C fluid overflowed into the alternator drain trap.

The third mercury injection was made at 0119 hours on 9 February 1966. This was the longest run of Step 2 (141 hours 25 minutes). Shutdown occurred at 22⁴⁴ hours on 14 February 1966 due to an apparent TAA degradation (TAA P/N 096800-1, unit 2/3).

The TAA performance problem was observed as a decrease in output power. The output power (extrapolated to unity power factor) had degraded from 54 kw, at the reference condition, to 48 kw. An analysis of the data also indicated a general decline of system pressures associated with the TAA performance degradation.

The TAA was removed and analyzed for possible degradation. The investigation revealed a change of approximately 10% in the effected area of the first stage nozzle. This change could account for the loss of power and the decrease of pressure level.

Start 4 of PCS-1 Phase IV Step 2 was made at 0004 hours on 16 March 1966. This was the first startup of the newly installed TAA (P/N 096800-1, unit 5/2). Shutdown occurred at 0232 hours on 16 March 1966 after 2 hours 28 minutes of operation. The shutdown was necessitated by a leak in the mercury vapor venturi visual pressure meter. The leak started as an oil leak from the oil filled bellows in the meter and subsequently became a Hg leak.

Start 5 was made at 2210 hours on 28 March 1966. Start 5 was terminated at 1322 hours on 30 March 1966 after 39 hours 12 minutes of

operation. The shutdown was automatic following a loss of speed control, an undervoltage condition, and a subsequent TAA overspeed. Also associated with the shutdown was a TAA seizure which was found when a restart could not be accomplished. The restart attempt was designated Start 6.

The 5th shutdown occurred during the time period that the system was operating with the reference electrical output of 35-kw vehicle load. The system had been operating at this condition for approximately 1-1/2 hours when it was decided to lower the system power level in order to decrease the HRL requirements because of a high ΔT in the NPMA recirculation loop and a high motor temperature. The shutdown was initiated when the mercury flow rate was accidentally decreased to the point where no more power was available to the PLR.

The next occurrence after the removal of all PLR power was an undervoltage signal. The undervoltage signal is designed to remove the vehicle load from the alternator (a safety precaution to protect the alternator against a shorting of the vehicle load). With the load removed, the TAA accelerated and went into an overspeed to approximately 17,000 rpm. The overspeed was followed by a rapid deceleration (about 5-6 seconds). This rapid deceleration was suspected to be due to internal TAA drag since there was no indication of any electrical load on the alternator. Subsequent examination revealed that the TAA rotor was locked in the alternator.

Start 7 of Step 2 testing was made at 1113 hours on 5 April 1966. This marked the first startup of the newly installed TAA (P/N 096800-1, unit 6/1, S/N A-3).

During this run, the electrical controls tests were conducted. Successful transfers of 35 kw between the vehicle load and the PLR were made.

The tests on the radiator-simulation characteristics of the heat rejection loop also were conducted during this run. These tests determined the time response and effects of the louver control systems and the cooler bypass.

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Start 7 was deliberately terminated at 1723 hours on 7 April 1966 (after 54 hours 10 minutes of operation) to remove the noncondensibles from the condenser prior to system mapping tests. The down time for removing the noncondensibles was 14 minutes. The system was restarted (Start 8) at 1737 hours on 7 April 1966. Start 8 was terminated at 0552 hours on 10 April 1966 when an electrical short in the HRL NPMA caused excessive alternator current which resulted in an undervoltage automatic shutdown.

Start 9 of PCS-1 Phase IV Step 2 was made at 2330 hours on 12 April 1966. The boiler had become deconditioned. The initial mercury flow established upon startup was 6300 lb/hr. At this flow rate, the superheat was 150°F as compared to about 350°F for conditioned operation. When the mercury flow was raised to 8000 lb/hr, the quality dropped to about 85%. The deconditioned state of the boiler was probably the result of oil in the mercury from the shutdown of 10 April 1966. This shutdown was automatic and the PMA's did not transfer to facility power. Consequently, oil flowed to the Hg PMA after rotation ceased and oil probably reached the mercury through the space seal.

At 0154 on 13 April 1966, a dip occurred in TAA speed. During the next few minutes, several dips took place. At 0205 hours, the system was shut down pending analysis of the speed variation problem.

It was decided to terminate Step 2 testing. This decision was based upon the following system problems:

- a. The boiler was deconditioned. In this deconditioned state, the maximum mercury flow rate obtainable with superheat would be about 7000 lb/hr.
- b. Both NPMA's were inoperative which would require using EM pumps. This condition would make the planned determination of the system minimum stable operating point less accurate.
- c. With the limited mercury flow rate, the maximum system electrical output would be less than the 51-kw requirement for the remaining planned electrical controls tests.

d. With the impaired boiler performance, the planned system testing would not be possible.

Thus, Step 2 testing terminated at 0205 hours on 13 April 1966. The total run time was 300 hours 31 minutes. Although Step 2 was terminated prior to completion of all the planned testing, a substantial part (approximately 62%) of the testing was completed.

3. Test Results

A complete discussion of the test results from the Step 2 testing is too extensive for inclusion herein. Listed below are brief summaries of the results. The details are presented in the PCS-1 Phase IV Step 2 Test Report, TM 4952:66-414 (Reference 3).

a. Boiler

The performance of the boiler during Step 2 was very good. From the beginning of testing, the boiler was conditioned. The only limitation on boiler performance was that it did not appear to be as completely conditioned as during previous testing in Step 1. No problems were experienced with the boiler during Step 2 until startup 9 on 12 April 1966. At the time of this startup, the boiler was deconditioned as a result of oil contamination during the preceeding shutdown.

The boiler performance was analyzed in terms of mercury pressure drop, outlet mercury pressure, stability, terminal temperature difference, inventory shift, liquid carryover, and NaK-side pressure drop. The data were correlated with Step 1 data.

b. Condenser

The scatter in overall heat-transfer coefficient values was considerable. The average overall coefficient based on a condensing area derived from pressure data was $1124 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ with a standard deviation of ± 217 . The average overall coefficient based on an area derived from NaK temperature profile data was $1306 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ with a standard deviation

of ± 337 . By contrast, Step 1 data indicated an overall coefficient of 1090 Btu/hr-ft²-°F with a standard deviation of ± 138 . Because of the lesser scatter of the Step 1 data, it is recommended that the overall coefficient of Step 1 remain the established reference value.

The condenser performance was mapped in terms of condensing pressure versus condensing length with HRL flow rate, NaK inlet temperature, and mercury flow rate as parameters. The data were correlated with Step 1 data.

c. Turbine-Alternator Assembly

Three TA assemblies were tested in Step 2 of PCS-1 Phase IV, bringing the number of SNAP-8 TA assemblies tested to date in the SNAP-8 Program to four. All of these units have been analyzed to determine their performance and have been interpreted on a comparative basis.

The following overall conclusions are drawn, regarding TAA performance in Step 2:

(1) The S/N A-2 unit 2/3 degraded after about 88 hours of operation.

(2) The 2/3 unit (before degradation) performed the same as, or slightly better than, the 3/2 unit.

(3) The S/N A-1 unit 5/2 and the S/N A-3 unit 6/1 performed essentially the same as unit 2/3 after degradation.

(4) The power performance of units 5/2 and 6/1 may, or may not, be due to degradation at startup. The poorer performance may be the result of differences in buildup tolerances, etc.

Table III-6 summarizes the history of all the TAA's. Included are run dates, total operating times, number of starts, and causes of failure.

d. Parasitic Load Resistor

The PLR performed well with no apparent problems. The NaK pressure drop compared well with Step 1 data. The data were checked to determine if there were any hot spots along the outer surface of the PLR. The surface thermocouples all indicated temperatures equal to, or less than, the PLR NaK outlet temperature. There appears to be no problem with localized heating.

e. Pump-Motor Assemblies

The performance of each pump-motor assembly used in Step 2 was analyzed and compared with earlier component test data. The following conclusions are drawn regarding the performance of the PMA's:

(1) Hg PMA

- The overall performance was good.
- The minor discrepancies noted in the head-capacity curve are probably due to instrumentation errors. Step 3 tests in PCS-1 Phase IV will provide the opportunity for verification of performance.
- The only problem was a failed motor due to mercury in the motor. This was an operating procedure problem and not a Hg PMA design problem.
- Step 2 operating time was 302 hours.

(2) L/C PMA

- The head-capacity performance was good.
- The power requirement was higher than usual. This is considered to be from extra drag due to mercury in the motor cavity.
- Step 2 operating time was 402 hours.

(3) HRL NPMA

- The head-capacity performance was good.

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- The PMA failed at the end of Start 8 after 264 hours due to a failed stator can and electrical short.

(4) Primary NPMA

- The head-capacity performance was good.
- The power requirement was low due to low friction losses because of insufficient fluid in the motor cavity.
- Failure occurred after 1.6 hours prior to Start 1 due to over-temperature from gas entrapment.

S/N A-2

- The head-capacity performance was good.
- The power requirement was high due to a faulty motor winding.
- The unit failed to develop adequate torque between Starts 3 & 4 due to substandard motor performance.
- The operating time was 49 hours.

S/N A-7

- The overall performance was good.
- The unit developed a rub between the impeller back vane and the pump housing during Start 9.
- The operating time was 270 hours.

f. Electrical Controls Tests

Testing of the speed controller and voltage regulator was interrupted at the end of the first of a 4-part series of tests but not before several significant items of information were obtained. The information obtained from the tests performed is as follows:

(1) Speed dip and rise is significantly reduced when the PMA's are operated on TAA 400 cps power as opposed to operating on facility 400 cps power.

(2) Speed dip and rise is further reduced when lagging power-factor vehicle loads are applied as compared to unity power-factor loads.

(3) Voltage dip and rise is increased when lagging power-factor vehicle loads are applied as compared to unity power-factor loads.

(4) Steady-state voltage and speed regulation from zero to full vehicle load is well within design limits.

(5) Optimum values of resistance and capacitance in the R-C rate feedback speed stabilization circuit were determined. Near-critical damping was realized when vehicle load was added; slightly under damped operation was obtained when vehicle load was removed. The exact values of resistance and capacitance are not critical as changes of 25% were barely detectable.

(6) Minimum parasitic load appears to be about 200 watts per phase or 600 watts total (3-phase). This agrees well with design calculations.

(7) Successful transfers of 35 kw between the vehicle load and the parasitic load resistor were made repeatedly during the testing of Step 2. This represents a major accomplishment since this is the most stringent condition the speed-control system experiences. During these load transfers, the recovery time and speed variations remained within their design objectives (± 20 cps with damping times less than five oscillations.)

g. Radiator-Simulation

One of the objectives of Step 2 testing in PCS-1 Phase IV was to determine the capabilities and limitations of the HRL cooler

and cooler bypass in order to simulate the response of a flight radiator during a startup.

The following conclusions are made from the testing:

(1) The time responses of the automatic and manual louver control systems is essentially the same.

(2) The manual control is preferable over the automatic control for radiator simulation work. The automatic control has secondary effects; i.e., the temperature overshoots and, on occasion, the temperature has been observed to start in the opposite direction from the setting it is seeking when the setting is changed slightly.

(3) The bypass flow rate is very controllable.

(4) The response to a change in bypass flow is very rapid; much faster than required for radiator simulation.

(5) The overall conclusion is that the response time of the loop appears to be sufficiently rapid that the cooler bypass will not be needed in Step 3 startups to simulate radiator effects. Radiator simulation can be achieved through manual louver control.

h. System Stability

The system stability indicated by the magnitude of boiler outlet pressure variations was good during Step 2. The design objective of maximum pressure variations of $\pm 2.5\%$ at a 30°F boiler pinch point temperature difference has essentially been met ($\pm 2.7\%$). Step 1 data indicated pressure variations which were somewhat less ($\pm 2.0\%$). The lesser pressure variations of Step 1 are likely due to a slightly greater degree of boiler conditioning.

An important question which has been answered from the testing is the relationship between boiler outlet pressure fluctuations and condensing pressure fluctuations. Variations occur at both of these system locations, but the question has previously been unanswered as to whether these

variations at these two locations are generated separately or are inter-related. Data have been gathered which provide conclusions. The pressure variations at the boiler and condenser were found to be directly related to one another in magnitude and were found to be in phase.

i. Operation With 35-kw Vehicle Load

The reference electrical output of SNAP-8 is 35-kw vehicle load. One of the objectives of Step 2 testing was to demonstrate stable operation at this reference condition. The 35-kw vehicle load condition was established on 30 March 1966. The system performed well at this condition with adequate stability. Actually, the power level was 1-2 kw greater than 35 kw because of losses between the alternator which need not be charged against the vehicle load.

Although the 35-kw vehicle load was established, it did not represent a completely satisfactory system operating point. In several aspects, the system was so far off-design that the test could not be considered a practical space-operational condition (mercury flow-rate, 13,200 lb/hr; boiler NaK inlet temperature held at higher end of reactor deadband; condenser NaK inlet temperature $\leq 425^{\circ}\text{F}$).

j. System Mapping - Constant Mercury Inventory

This phase of testing evaluated the effects of variations in boiler NaK inlet temperature with constant system mercury inventory. Primarily, the objective was to observe the system response to temperature variations simulating the perturbations to be imposed by the reactor. The testing was outlined to cover a range of NaK temperatures for greater than just the normal range of the reactor. The intent of the wider range was to gather basic off-design data for the system and components.

A summary of the system response is given in Table III-7. This table lists all the system parameters evaluated and gives the magnitude and cause of the particular response observed. A comparison has been made between the test data and the data obtained from the SCAN

computer program. The independent variables of the test data points were used as computer input. The computer results also are listed in Table III-7. The overall results look good. All the observed system trends are normal. The agreement between the test data and SCAN data is likewise satisfactory.

k. System Mapping - Variable Mercury Inventory

This phase of testing evaluated the system response to changes in the amount of mercury inventory in the system. Inventory variations, such as from space seal leakage, can potentially make significant changes in the system performance. The testing was outlined to cover a wide range of system inventory variations in order to obtain general off-design performance data in addition to the basic effects of inventory loss.

A typical example of the system response is given in Table III-8. This table is only for one particular combination of mercury flow, HRL flow, and NaK inlet temperature to the condenser and is included here as an example of the test results. Table III-8 lists the effects on various system parameter changes in system mercury inventory. A listing of the causes of the observed changes also is included. The SCAN computer program also was used here to provide a comparison with test data. The data are normal and consistent and a comparison between test data and SCAN data shows a good correlation of trends.

TABLE III-1

SUMMARY OF PCS-1 INSTRUMENTATION MEASURING ELEMENTS

<u>Type Element</u>	<u>No. of Units</u>	<u>% of Total</u>
AbS Press Transducers	66	9.1
Differential Pressure Transducers	22	3.0
Visual Pressure Gages	51	7.1
Thermocouples	292	40.3
Electrical (Voltron E.I.W.)	55	7.6
Electrical (Visual)	72	9.9
Misc.*	112	15.3
Spares Installed	56	7.7
Total	726	100

* Misc. includes items such as: flow, level, speed, vibration, valve position, counters and timers, etc.

TABLE III-2

SUMMARY OF PCS-1 INSTRUMENTATION - FINAL ELEMENTS

<u>Recorder or Indicator</u>	<u>No. of Units</u>	<u>% of Total</u>
DDAS*	269	43.7
Strip Chart Recorder (SR)	37	6.0
Brush	6	1.0
Dymec	4	0.6
Control Console Temp. Monitor	36	5.7
Overhead Meters	34	5.5
Alnor Heater Sheath Monitor	33	5.4
Visual Press	51	8.3
Event Recorder (ER)	17	2.8
Indicator (control console)**	14	2.3
Meters (Cell 4)**	59	9.6
Multipoint Recorder (MR)	56	9.1
Total	616	100

* Ten functions are on high speed DDAS sampling rate. Therefore, total DDAS channel utilized is 359.

** These meters and indicators are provided by the Electrical Controls Group.

Table III-2

TABLE III-3

TESTING HISTORY PCS-1 PHASE IV STEP 2

Start No.	TAA Used	Startup Time	Shutdown Time	Run Time	Cause of Shutdown
1	S/N 2/3	0245 - 1/30/66	0307 - 1/30/66	22 min	Loss of L/C flow due to air in-leakage.
2	S/N 2/3	1342 - 2/4/66	1346 - 2/4/66	4 min	Loss of L/C fluid into alternator drain trap.
3	S/N 2/3	0119 - 2/9/66	2244 - 2/14/66	141 hr 25 min	TAA degradation.
4	S/N 5/2	0004 - 3/16/66	0232 - 3/16/66	2 hr 28 min	Leak in mercury vapor venturi meter.
5	S/N 5/2	2210 - 3/28/66	1322 - 3/30/66	39 hr 12 min	TAA undervoltage, overspeed, and alternator seizing.
6	S/N 5/2	0135 - 3/31/66	0135 - 3/31/66	-0-	Restart attempt of 3/30/66 shutdown - no rotation.
7	S/N 6/1	1113 - 4/5/66	1723 - 4/7/66	54 hr 10 min	Planned shutdown to remove noncondensibles.
8	S/N 6/1	1737 - 4/7/66	0552 - 4/10/66	60 hr 15 min	Automatic shutdown due to undervoltage (possibly from Hr NEPA failure).
9	S/N 6/1	2330 - 4/12/66	0205 - 4/13/66	2 hr 35 min	Planned shutdown due to TAA speed dips.

 TOTAL RUN TIME = 300 hr 31 min

Table III-3

TABLE III-4
OBJECTIVES ACCOMPLISHED
PCS-1 PHASE IV STEP 2

Test	Change in Test Requirements*	Percent of Required Information Gathered**	Time to Perform Test (hr)	Further Testing Required***
Boiler Conditioning	Boiler conditioned	100	24	None
Establish Reference Condition	None	100	5	None
Monitor Reference Condition for Degradation	None	100	30	None
Establish 35 kw Vehicle Load Condition	None	100	5	None
TAA Mapping:				
S/N 2/3	Reduced by 25% due to TAA degradation	100	30	None
S/N 5/2	Reduced by 80% due to poor TAA performance	100	10	None
S/N 6/1	Reduced by 80% due to poor TAA performance	0	10	Test not completed due to termination of Step 2. No further testing planned.
System Mapping Constant Inventory	Reduced by 40%. All data points not necessary to accomplish objectives	25	25	Information will be obtained in Step 3.
System Mapping Variable Inventory	Reduced by 25%. All data points not necessary to accomplish objectives	100	36	None
Maximum Power Capability	None	100	5	None
Minimum Flow Capability	None	0	5	Information will be obtained in Step 3
HRL Cooler Control Response	Reduced by 40%. All data points not necessary to accomplish objectives	100	8	None
HRL Cooler By-Pass Evaluation	Reduced by 75%. All data points not necessary to accomplish objectives	100	8	None
L/C Temperature Variations	None	0	8	Information will be obtained in Step 3
Startup Tests	Reduced by 70%. All data points not required to accomplish objectives	0	12	Information will be obtained in Step 3
Electrical Controls Tests	Reduced by 50%. All data points not required to accomplish objectives	30	45	Information will be obtained in Step 3
Boiler & Condenser Mapping (From Step 1)	None	0	14	Information will be obtained in Step 3
Hg FCV Test	None	100	10	Specific test not run, but data are available
Hg FMA L/C Flow Tests	None	0	5	Information will be obtained in Step 3
NaK FMA Tests	None	20	24	Remainder to be done in LNL-3
			<u>319</u>	

TOTAL STEP 2 TESTING ACCOMPLISHED = 62%****

* Change in Test Requirements - As testing proceeded, some of the originally planned data points were eliminated. The data points retained represented those necessary to achieve the objectives of the test. As an example, since the turbine (S/N 2/3) degraded, it was not necessary to go through all the data points for a complete performance mapping. Data points also were eliminated on the basis of needing only three points on a curve rather than four (in the interest of saving time).

** Percent of Required Information Gathered - This is the percentage completed of the data required in the column "Change in Test Requirements."

*** Further Testing Required - This allows time for testing not completed in Step 2 to be completed in Step 3.

**** Total Step 2 Testing Accomplished - This is the percentage of the information needed from Step 2 that was actually obtained. The percentage is weighted according to the time required to perform each testing phase.

TABLE III-5

ADDITIONAL SIGNIFICANT ACCOMPLISHMENTS
PCS-1 PHASE IV STEP 2

1. Demonstrated that boiler conditioning is permanent and unaffected by start-ups and shutdowns provided oil and/or other contaminants are not introduced.
2. Established vacuum decay requirements for the Hg loop.
3. Determined performance of EM pumps and NaK PMA's in series.
4. Determined boiler start-up characteristics.
5. Delivered 35 kw vehicle load with all PMA's on TAA power.
6. Successfully transferred 35 kw between the PLR and the vehicle load bank.
7. Demonstrated high-temperature operations of NaK PMA's.
8. Demonstrated adequate voltage regulator and speed control stability and regulation.
9. Demonstrated the capability to shut down the system, remove noncondensibles, and reinject mercury in 14 minutes.
10. Found mechanical weaknesses of the turbine and alternator.
11. Learned that the NPMA impeller back-vane to housing clearance requires a change (increase).
12. Flowed the NPMA at 160 gpm (highest flow ever tested).

TABLE III-6

HISTORY OF SNAP-8 TURBINE-ALTERNATOR ASSEMBLIES
(P/N 096800-1)

Serial No.	Test Dates	Number of Starts	Total Operating Time	Cause of Failure
3/2	13 November 1964 through 22 June 1965	43	819 hrs 22 min	Thrust seal retaining ring came out of groove causing severe damage to first and second stages.
2/3	30 January 1966 through 14 February 1966	3	141 hrs 51 min	Shutdown because of observed degradation in performance.
5/2	16 March 1966 through 31 March 1966	2	41 hrs 40 min	Locked rotor in alternator due to rubbing on outboard visco seal.
6/1	5 April 1966 through 13 April 1966	3	117 hrs 0 min	No failure of TAA. Shutdown due to unexplained speed transients.

Table III-6

TABLE III-7

SYSTEM RESPONSE TO VARYING BOILER NaK INLET TEMPERATURE

Function	Effect of Varying Temperature From 1350 to 1280°F		Effect of Varying Temperature From 1260 to 1210°F		Explanation of Effect
	Test Data	SCAN Data	Test Data	SCAN Data	
Heat Input to Boiler	1% increase	1% increase	0.2% decrease	0.2% increase	Net effect of decreased heat transfer potential and increased mercury flow rate
Condensing Pressure	No noticeable change	0.1 psi increase	No noticeable change	0.1 psi increase	Net effect of increase in mercury flow rate and decrease in turbine exhaust enthalpy
Turbine Inlet Temperature	30°F decrease	50°F decrease	50°C decrease	50°F decrease	Boiler terminal temperature difference remains essentially constant. Difference between test and SCAN data possibly due to vapor line heaters
Turbine Inlet Pressure	0.8 psi decrease	0.6 psi decrease	1.2 psi decrease	0.8 psi decrease	Flow passes through turbine at lower pressure due to higher density caused by lower temperature and/or higher carryover
Boiler Mercury Outlet Pressure	0.8 psi decrease	0.5 psi decrease	2.4 psi decrease	1.1 psi decrease	Lower turbine inlet pressure
Boiler Mercury Outlet Temperature	45°F decrease	45°F decrease	45°F decrease	45°F decrease	Boiler terminal temperature difference remains essentially constant
Heat Rejection	No noticeable change	1 kw increase	No noticeable change	1 kw increase	Increased system heat input
Boiler Pinch-point Temperature Difference	45°F decrease	45°F decrease	35°F decrease	45°F decrease	Pinch-point follows NaK inlet temperature
Boiler Mercury Pressure Drop	3 psi decrease	6 psi decrease	8 psi decrease	10 psi decrease	Lower pinch-point temperature difference
Boiler Mercury Inlet Pressure	4 psi decrease	7 psi decrease	9 psi decrease	10 psi decrease	Greater mercury liquid flow rate
Condenser NaK Outlet Temperature	No noticeable change	No noticeable change	No noticeable change	No noticeable change	-
Condenser Inventory	4-lb decrease	5-lb decrease	8-lb decrease	10-lb decrease	Decrease in boiler pinch-point temperature difference causes increase in boiler inventory
Alternator Output	0.5 kw decrease	0.3 kw decrease	0.8 kw decrease	0.3 kw decrease	Lower turbine inlet temperature and more liquid carryover
Mercury Liquid Flow	100 lb/hr increase	100 lb/hr increase	100 lb/hr increase	100 lb/hr increase	Lower boiler mercury pressure drop and higher mercury vapor density
Boiler Outlet Pressure Instability	±1.0% increase	-	±1.3% increase	-	Lower boiler pinch-point temperature difference

TABLE III-8

SYSTEM RESPONSE TO VARIABLE MERCURY INVENTORY

Mercury Flow Rate = 11,500 lb/hr
 HRL Flow Rate = 42,000 lb/hr
 Condenser NaK Inlet Temperature = 450°F

Function	Effect of Varying Condenser Inventory		Explanation of Effect
	Test Data	SCAN Data	
Condensing Pressure	1 psi decrease	3 psi decrease	Increased condensing area in condenser
Condenser Mercury Outlet Pressure	14 psi decrease	15 psi decrease	Decreased liquid head in condenser and decreased condensing pressure
Hg PMA Suction Pressure	13 psi decrease	15 psi decrease	Decreased liquid head in condenser and decreased condensing pressure
Mercury Liquid Flow Rate	200 lb/hr decrease	100 lb/hr decrease	Decreased Hg PMA suction pressure resulting in decreased Hg PMA discharge pressure
Alternator Output Power	3 kw increase	3 kw increase	Lower turbine exhaust pressure more than compensates for decrease in mercury flow rate
Boiler NaK Outlet Temperature	No noticeable change	No noticeable change	-
Boiler Pinchpoint Temperature Difference	No noticeable change	No noticeable change	-
Boiler Mercury Pressure Drop	No noticeable change	-	SCAN data not included since SCAN boiler performance is based on Step 1 data and Step 2 boiler performance was different from Step 1 performance
Turbine Inlet Pressure	4 psi decrease	1 psi decrease	Decreased mercury flow rate
Turbine Inlet Temperature	No noticeable change	No noticeable change	-

TABLE III-8 (cont.)

Function	Effect of Varying Condenser Inventory		Explanation of Effect
	Test Data	SCAN Data	
	From 50 to 10 lb		
Condenser NaK Inlet Temp	No noticeable change	No noticeable change	Controlled parameter
Condenser NaK Outlet Temp	3° F decrease	3° F decrease	Less heat rejection due to higher cycle efficiency and decreased mercury flow

IV. POWER CONVERSION SYSTEM G (PCS-G)

A. NUCLEAR SYSTEM LIAISON

Detailed liaison with reference to the Ground Prototype Test Facility (GPTF) at Santa Susana was resumed in January. Since very little detailed observation of the NS system-shakedown test support equipment had taken place in the preceeding twelve months, steps were taken to obtain and review the facility system in the as-built condition.

In order to assure a consistent understanding between Aerojet-General Corporation and Atomics International on the allocation of space, piping penetrations, electrical services and facility constraints, AGC prepared a facility constraints document. Following an initial review by AI, additional data was considered desirable for inclusion in this interface document, including (1) anticipated access time to equipment within the vault and (2) the required provision for dissipation of decay heat following shutdown. Both of these matters have been defined; however, the system implications of decay heat removal await a coordinated design effort, which has not begun.

While no areas of incompatibility were disclosed by the interface review, discussions have been initiated to improve access for AGC piping and to modify the pressure drop in the primary loop.

At the request of AGC, AI supplied updated transient response and performance characteristics for the S8DS reactor. These are being employed in the updating and reevaluation of the reactor and power-conversion-system startup analysis.

B. POWER CONVERSION SYSTEM G

1. Analysis

Studies by the LeRC Project Office and Aerojet indicated that one of the long-range goals for SNAP-8 was a system that was both instrument

rated and man rated. For man-rating, it becomes highly desirable to incorporate redundancy, restart-capability, and maintainability.

Man rating dictated a major change in configuration: The reactor, which had been at the "top" (gravity-wise) in the instrument rated PCS, needed to be more remote; it was placed at the "bottom" (See Figure IV-1). This change was caused by the desire to place the reactor as far from the manned core of the space station as possible; e.g., at the outboard end of a rotating spoke. In addition, studies showed that for a lunar base application, it would be desirable to have the reactor "down"; i.e., on the ground where it could be more readily shielded by burying it or by placing shielding material around it.

Redundancy and maintainability demand that as much as possible of the PCS is available for maintenance; however, the radiation level also must be reduced sufficiently to permit manned access to the area. Consequently, a biological shield will be inserted between the highly radioactive primary loop (including the boiler) and the remainder of the PCS.

Exclusive of the primary loop, redundancy will be accomplished by mounting two PCSs, one in each half of the conical section, above the biological shield (see Figure IV-2).

An evaluation of the full impact of these new criteria (man rating, maintainability, redundancy, and restart capability) will occupy a major portion of the effort for the next six months.

A review of the location of the Parasitic Load Resistor (PLR) in the primary loop was undertaken. The PLR will be relocated in the hot leg of the heat rejection loop. The PLR was removed from the radioactive primary loop in order to improve accessibility.

Preliminary test plans and a PCS-G flow schematic (Dwg 095540), reflecting both requirements of the nuclear and nonnuclear tests, were prepared and issued. Preliminary input was given to the Specifications and Standards Section for preparation of a PCS-G specification. The format and

content of the PCS-G specification will be similar to Exhibit II of NASA Document MPC 500-1, the Apollo Configuration Management Manual.

2. PCS-G Performance Definition

A preliminary analysis of the PCS-G was made on the basis of available component performance information. The results indicate that it is unlikely that 35 kw will be available at the vehicle load without changes in component performance. Specific areas that require improvement include mercury boiler outlet pressure stability and carryover, and turbine performance.

Revised and updated component performance information was obtained. These data, in conjunction with the latest S8DS performance information, were used to develop performance envelopes of each of the major subsystems. Subsystems include the primary NaK loop, mercury loop, lubricant-coolant loop, heat-rejection loop, electrical controls system, and the integrated performance of the inverter and NaK PMAs. The updated component data indicated that boiler and turbine performance still require improvement in order to produce 35 kw.

The system output presumes a change in the vehicle-load power factor from .75 to .85, lagging. The allowed change in frequency control from 400 ± 1 to 400 ± 2 cps (as suggested by NASA) was not incorporated since it would represent no increase in net power output.

In the analysis, the primary loop operating point was based on the reactor operating envelope shown in Figure 1 of AI letter 66AT-1181, dated 30 March 1966, and a minimum boiler pinch-point temperature difference of 30°F. These two constraints resulted in the selection of an optimum boiler thermal power input and turbine inlet pressure of 500 kw and 237 psia, respectively. The available thermal power to the boiler results in a mercury vapor flow of 11,600 lb/hr. The resulting output power with no changes in the -1 components was 29.2 kw. The changes in components referred to above and the resulting increase in output are referenced to this value and are shown in

Table IV-1 with the state point shown in Figure IV-3. Recommended changes for obtaining system output power of 35 kw were submitted to NASA-LeRC for comment.

Subsequent to the submittal of the above recommended state point, NASA-LeRC indicated that AGC was not to pursue the modification of any components other than refining the aerodynamics of the turbine to improve its efficiency. In addition, Atomics International relaxed the reactor power $-\Delta T$ operating envelope to that shown in Figure 1 of AI letter 66AT-3446, dated 20 June 1966. The resulting allowable boiler thermal power and turbine inlet pressure are 535 kwt and 252 psia, respectively. The mercury vapor flow rate increases to 12,400 lb/hr. The reference output increases approximately 4 kw to 35 kwe. The turbine efficiency increase of 3 percentage points will increase the net electrical output to 36 kwe with no additional component changes. The results of this latter analysis were being forwarded to NASA-LeRC at the end of the report period and are shown in Figure IV-4 and Table IV-2.

3. PCS-G Design

The PCS-G design effort was pursued on a limited basis, pending completion of the system definition.

The changes proposed in the system and in the PCS configuration have been evaluated with respect to potential hardware design problems. No additional design problems have accrued from the proposed changes in the system and its configuration.

Preparation of computer codes for determining friction losses, hydraulic elevation heads, loop flow rates, hoop stresses, and hanger distances for the SNAP-8 piping systems constituted the other major technical effort during this period.

C. TEST SUPPORT EQUIPMENT

Documents which define the facility constraints on test support equipment design that are imposed by the GPTF in Santa Susana and by Building 187 at Von Karman Center, have been prepared. The document for GPTF ("Ground

Prototype Test Facility Constraints on Test Support Equipment for PCS-G") was prepared, reviewed with Atomics International, marked up with appropriate revisions, and is ready for forwarding to Atomics International for concurrence. The document for Building 187 ("Building 187 Test Facility Constraints on TSE for PCS-G"), including an addendum for instrumentation and control systems constraints, was issued as TM 4964:66-399, (Reference 4).

The test support equipment modules selected for planning purposes in early 1965 (in accordance with AGC Drawing 70143; "P & I Diagram, GPTF Test Equipment, Special Module Issue") were laid out on a gross basis such that each module could be assigned one or more rectangular configuration. These configurations were placed on isometric sketches of Cell 4, Building 187, and the GPTF. Two arrangements were developed for each facility and are shown in Figures IV-5, IV-6, IV-7, and IV-8. Arrangements for the two facilities have qualitative value only because of the uncertainty in module selection and sizing. Further work on facility layouts will be performed after development of new flow schematics and subsequent selection and sizing of new modules.

A rough draft of the PCS-G TSE Functional Requirements and Design Criteria has been prepared and issued for comments. A marked up copy of this draft is being utilized as the basis for preparation of a conceptual flow schematic for the test complexes in GPTF and in Bldg 187. A preliminary flow diagram for the PCS-G portion of the test complex has been completed and is shown in Figure IV-9. This diagram was developed from the PCS-G schematic (Dwg 095540) with some anticipated changes such as deletion of the second NaK pump-motor assembly in the primary loop. Also, the mercury injection system was shown as an undefined box only, due to lack of definition resulting from restart requirements. At this time, rough diagrams exist for the mercury loop, the lubricant-coolant loop and the primary loop test support equipment which are in the process of being added to the PCS-G portion.

The Test Complex Flow Schematics will be arranged to indicate the location of equipment in each section of the facility. At this time, priority is being given to development of the GPTF test complex flow schematic.

TABLE IV-1EFFECT OF COMPONENT CHANGES ON PCS-G OUTPUT POWER^{*}

<u>Change</u>	<u>Net Increase Over Reference Output of 29.2 KW</u>	<u>Total Net Output KW</u>
a. Increase the effective turbine η_t to 56%.	+ 3.0 kw	32.2 kw
b. Trim PNL, HRL, and L/C pump impellers.	+ .4 kw	32.6 kw
c. Reduce TAA slinger back pressure and increase L/C temperature into the bearings. Resulting increase in seal leakage is negligible.	+ .5 kw	33.1 kw
d. Close couple mercury PMA to the condenser outlet.	+ .5 kw	33.6 kw
e. Reduce requirement for mercury PMA NPSH by 1.2 psia.	+ 1.4 kw	35.0 kw
f. Incorporate condensing temperature control.	+ 2.5 kw	37.5 kw
g. Redesign or eliminate Hg PMA motor scavenger.	+ .7 kw	38.2 kw
h. Correct alternator power factor to .92.	+ 1.0 kw	39.2 kw
i. Reduce boiler $\Delta P/P$ to $\pm 1\%$.	+ 1.0 kw	40.2 kw
j. Reduce boiler carryover by 2% points from 4% to 2%.	+ 1.3 kw	41.5 kw
k. Change speed control system to solid state.	+ .5 kw	42.0 kw

^{*} Referenced to Reactor Constraint shown in AI letter 66AT-1181 dated 30 March 1966.

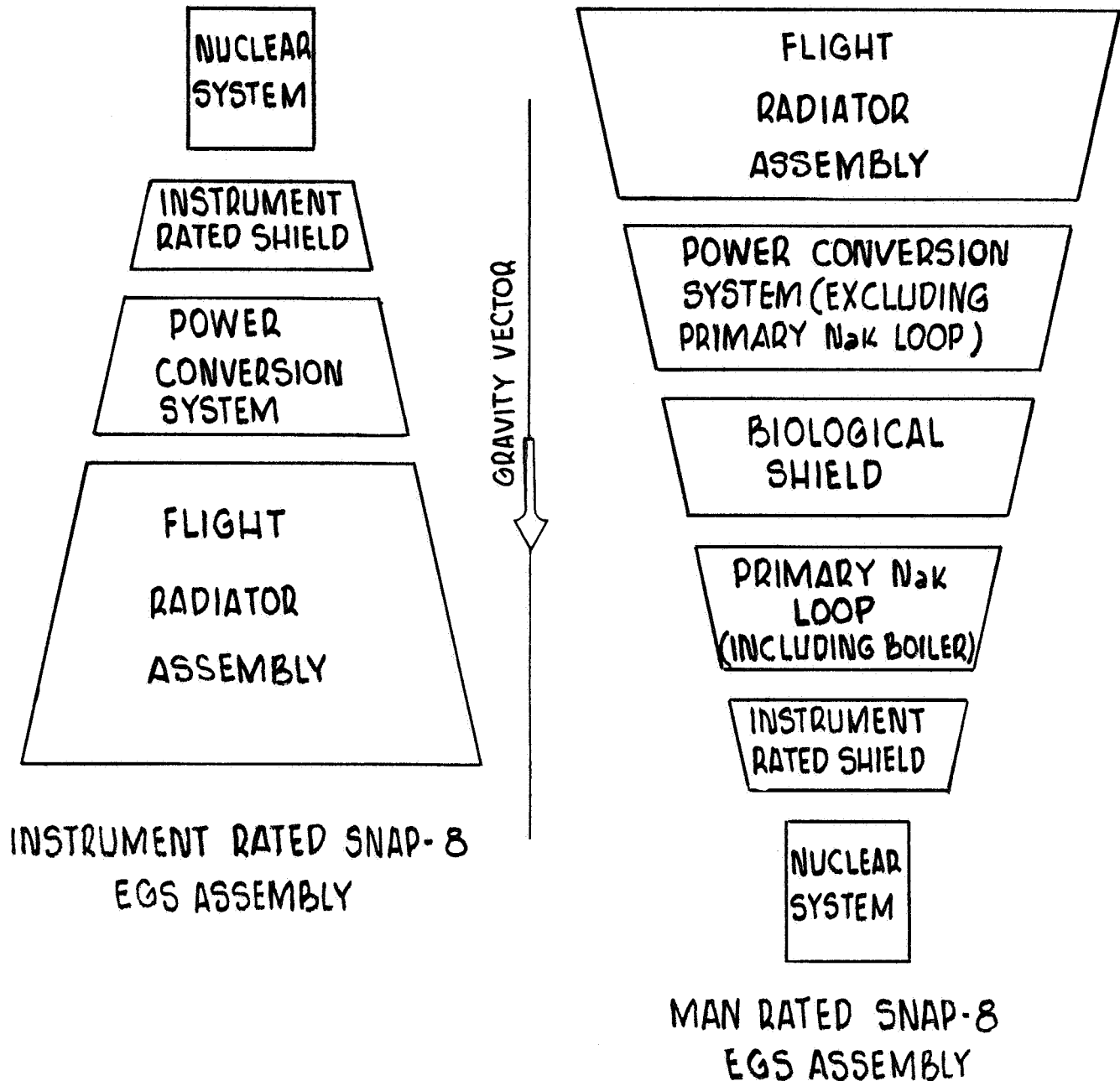
TABLE IV-2

EFFECT OF COMPONENT CHANGES ON PCS-G OUTPUT POWER*

Change	Net Increase Over Reference Output of 29.2 KW	Total Net Output KW
a. (No change.) Increase the effective turbine η_t to 56%.	+ 3.0 kw	36.0 kw
b. (Formerly Item i.) Reduce boiler $\Delta P/P$ to $\pm 1\%$.	+ 1.0 kw	37.0 kw
c. (Formerly Item j.) Reduce boiler carry-over by 2% points from 4% to 2%, thereby increasing effective turbine η_t to 57.3%.	+ 1.3 kw	38.3 kw
d. (Formerly Item h.) Correct alternator power factor to 1.00.	+ 1.6 kw	39.9 kw
e. (Formerly Item c.) Reduce TAA slinger back pressure and increase L/C temperature into the bearings. (No change.)	+ .5 kw	40.4 kw
f. (Formerly Item d.) Close couple mercury PMA to the condenser outlet. (No change.)	+ .5 kw	40.9 kw
g. (Formerly Item e.) Reduce requirement for mercury PMA NPSH by 1.2 psia.	+ 1.4 kw	42.3 kw
h. (Formerly Item f.) Incorporate condensing temperature control. (No change.)	+ 2.5 kw	44.8 kw
i. (Formerly Item g.) Redesign or eliminate Hg PMA motor scavenger. (No change.)	+ .7 kw	45.5 kw
j. (Formerly Item b.) Trim pump impeller. (Delete.)		
k. Solid State Speed Control. (Delete.)		

* Referenced to Relaxed Reactor Constraint shown in AI letter 66AT-3446 dated 20 June 1966.

766-066



Manned and Unmanned SNAP-8 Concepts

866-NF-1285

4 FOOT
DIAMETER
ACCESS
TUNNEL

CONICAL
SECTION
FOR ONE PCS

BIOLOGICAL
SHIELD

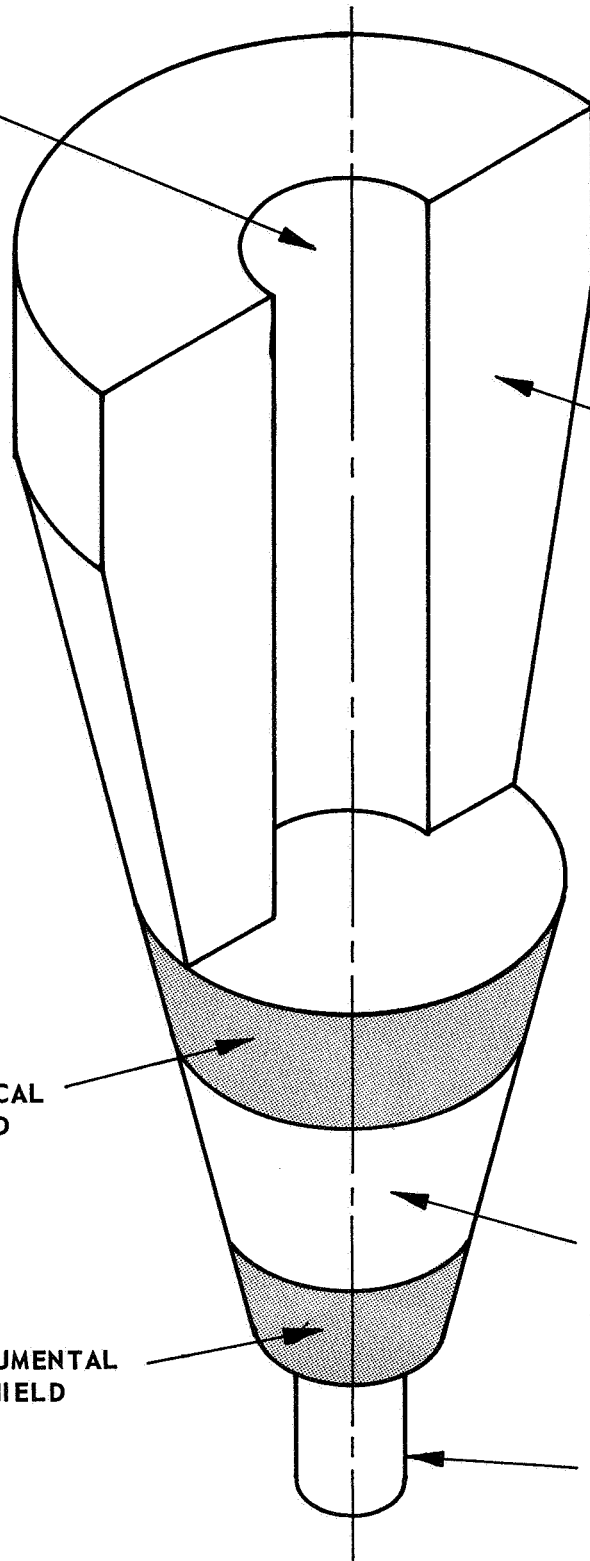
PRIMARY
LOOP
GALLERY

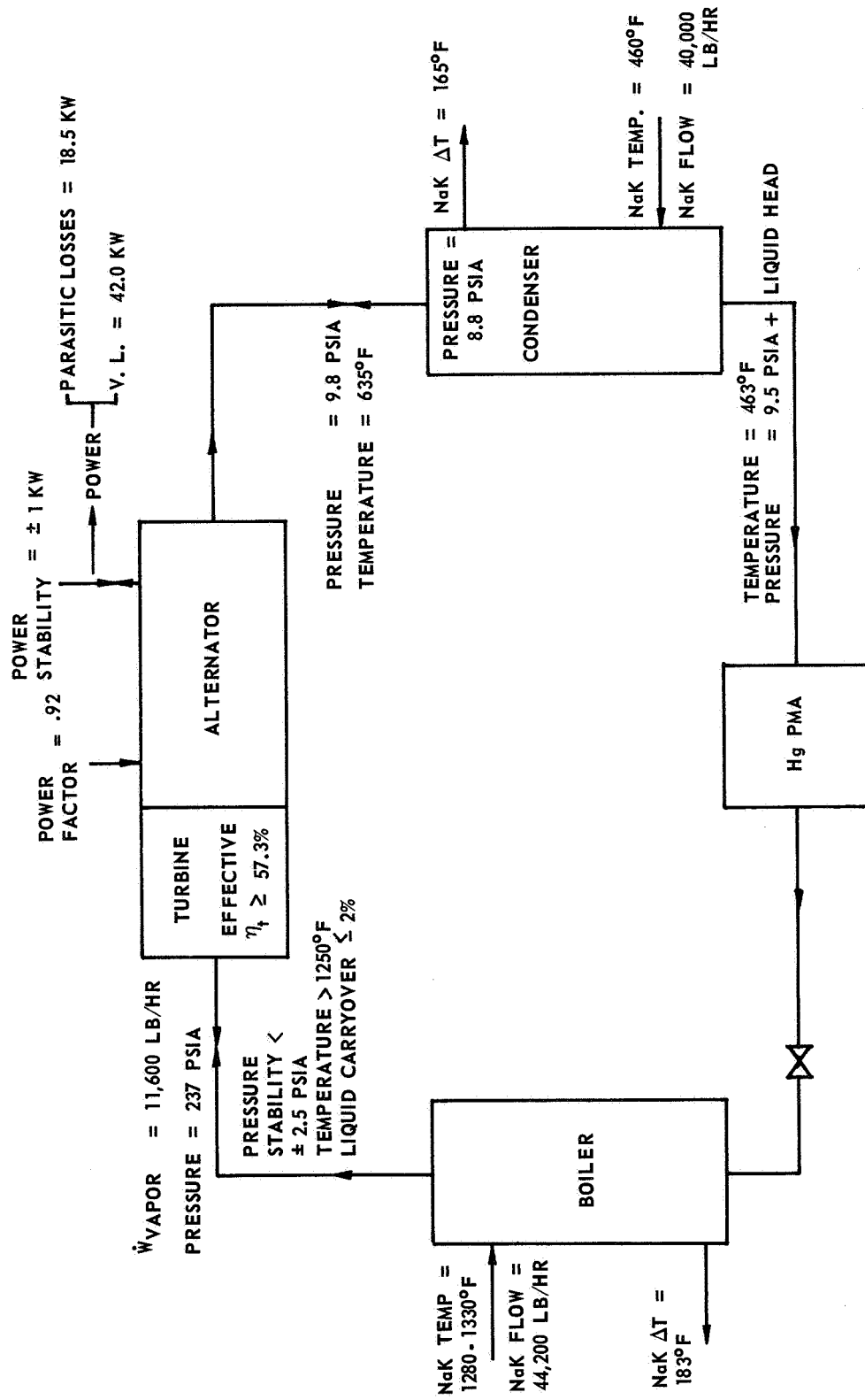
INSTRUMENTAL
SHIELD

REACTOR

Proposed Man-Rated Configuration

Figure IV-2

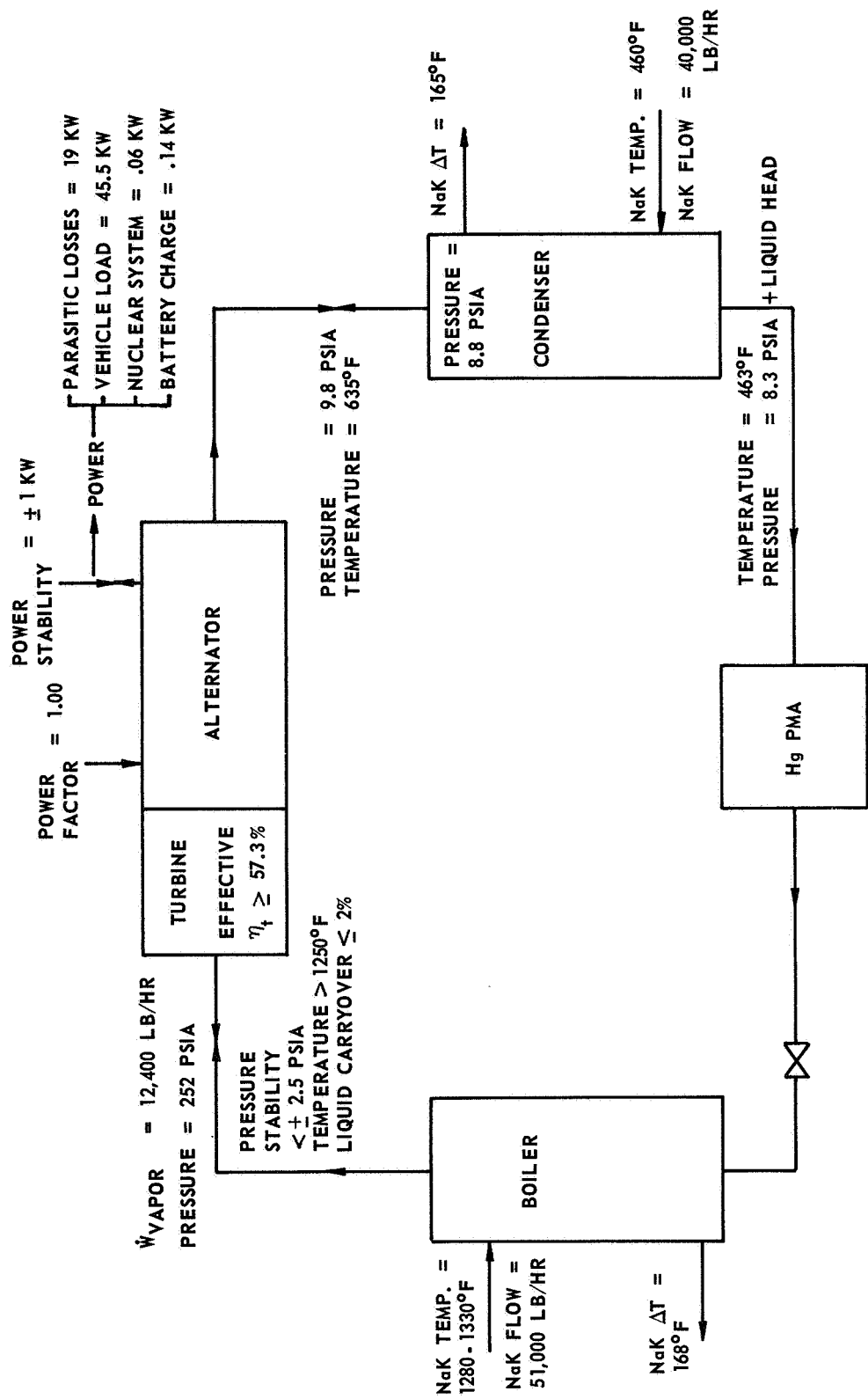




* REFERENCED TO REACTOR CONSTRAINT SHOWN IN AI LETTER 66AT-1181
DATED 30 MARCH 1966.

PCS-G Operating State Point

Figure IV-3

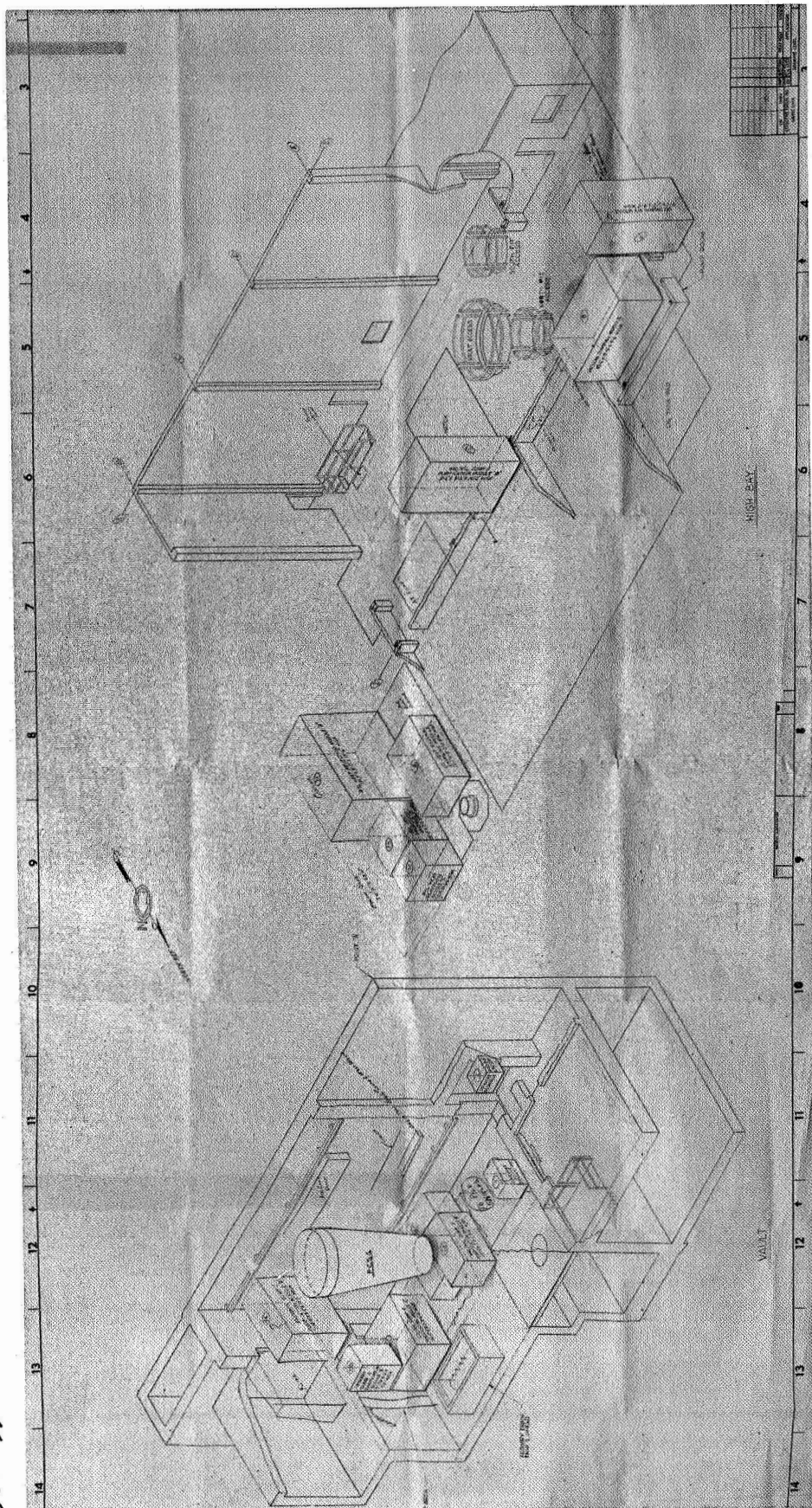


* REFERENCED TO RELAXED REACTOR CONSTRAINT SHOWN IN AI LETTER 66AT-3446 DATED 20 JUNE 1966.

PCS-G Operating State Point

Figure IV-4

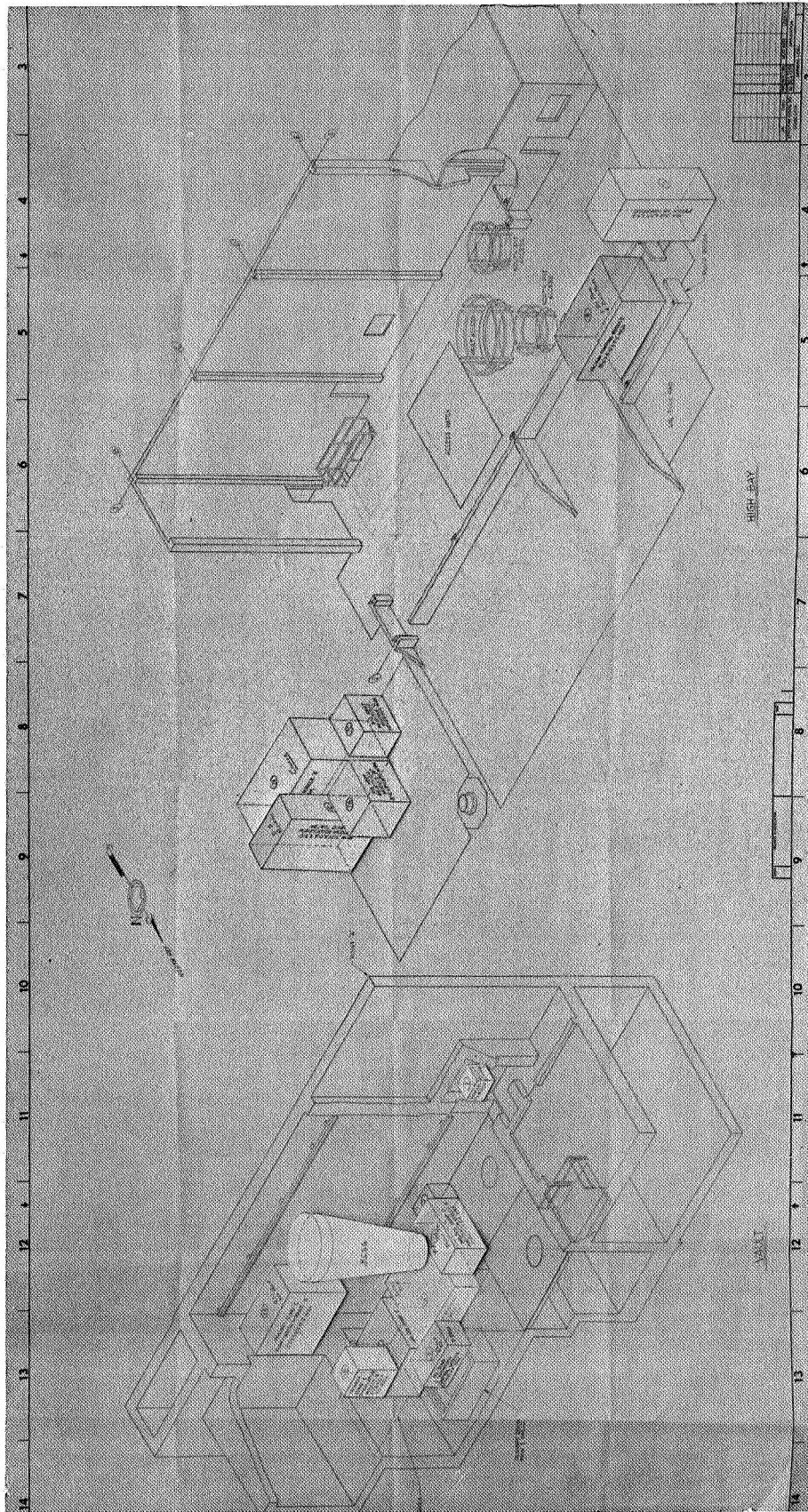
566-655



GPTF Module Arrangement 1

Figure IV-5

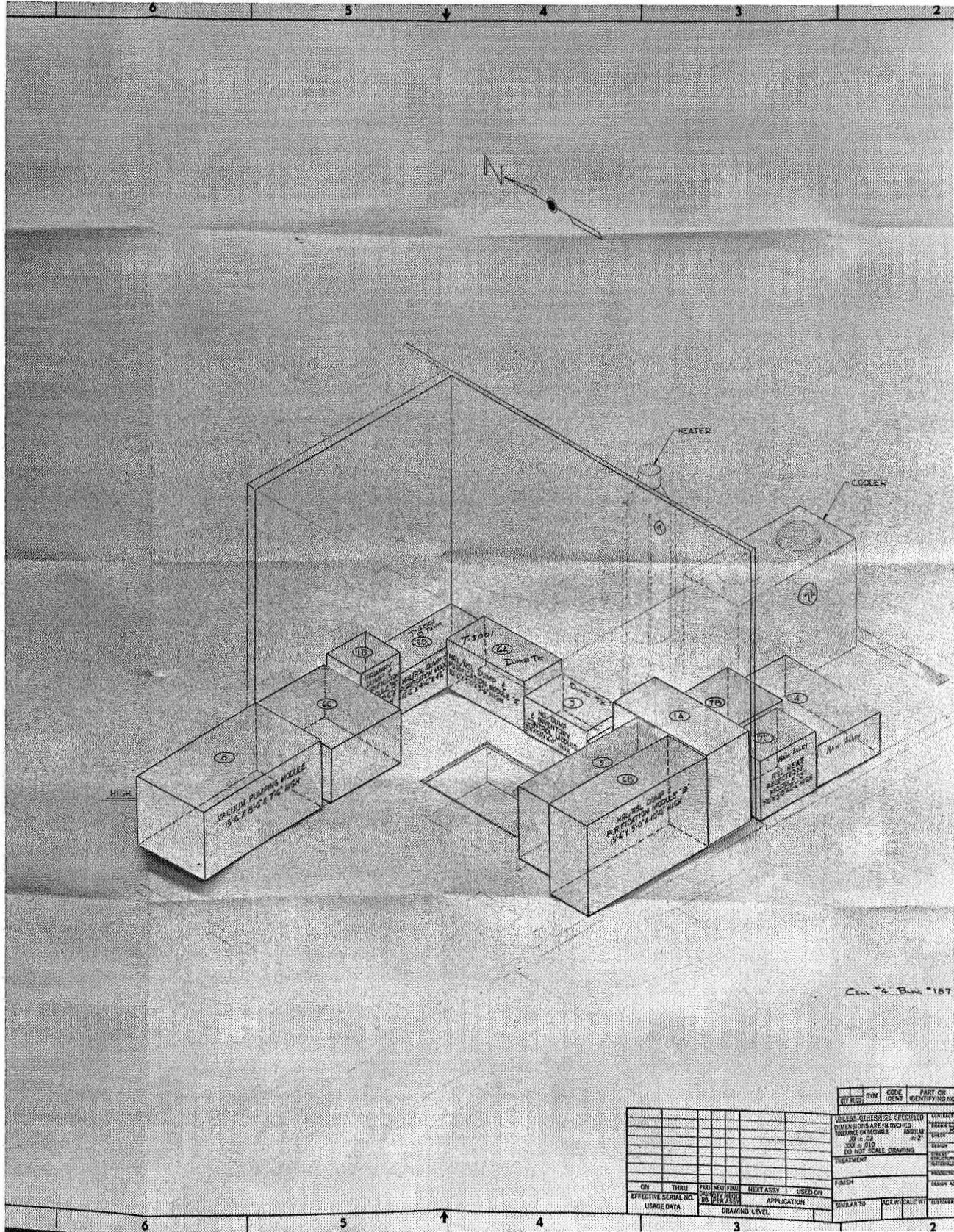
566-856



GPTF Module Arrangement 2

Figure IV-6

566-857



Building 187 Cell 4 Module Arrangement 1

Figure IV-7

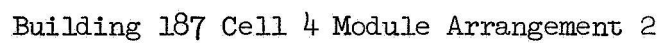
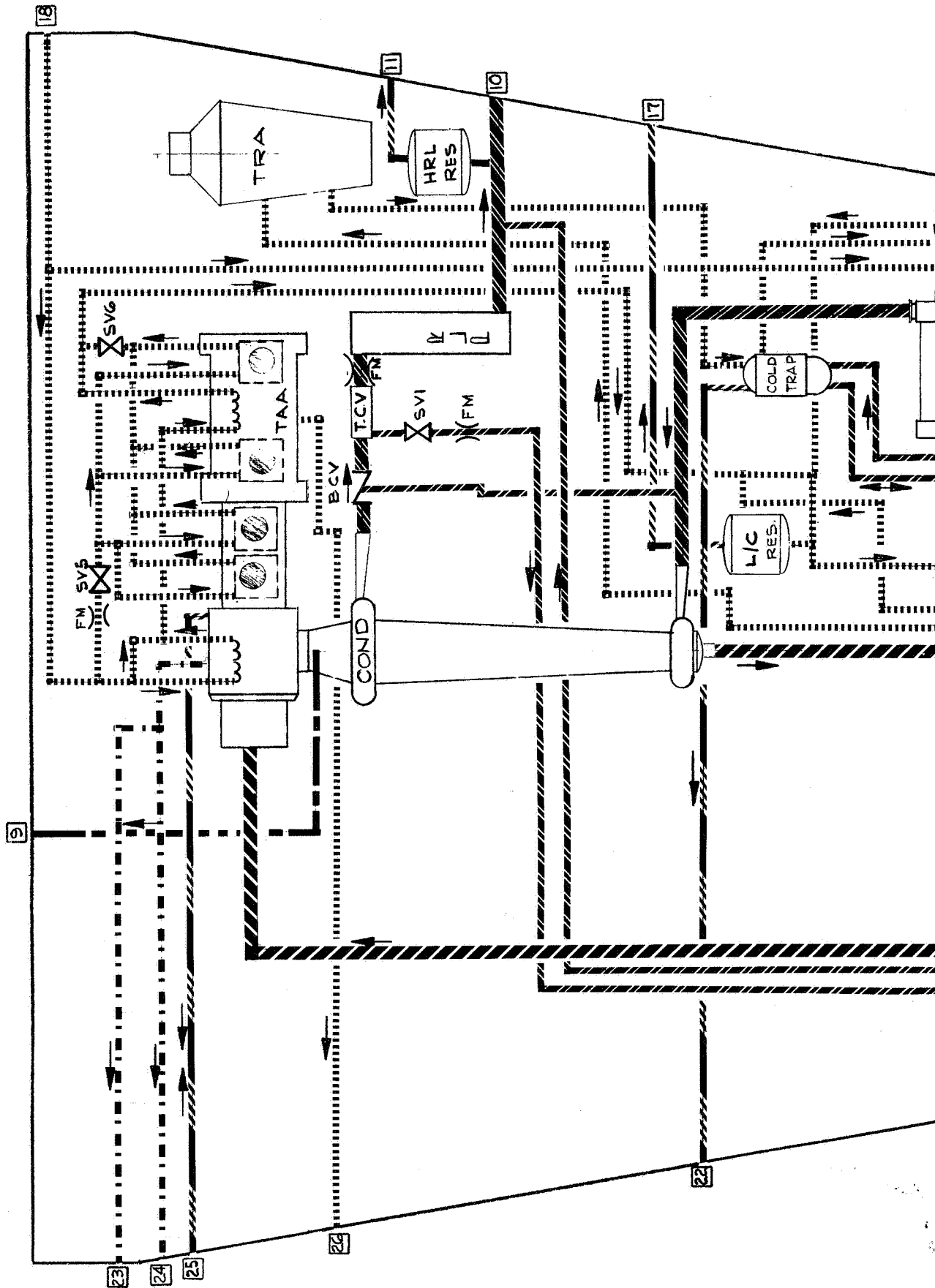


Figure IV-8

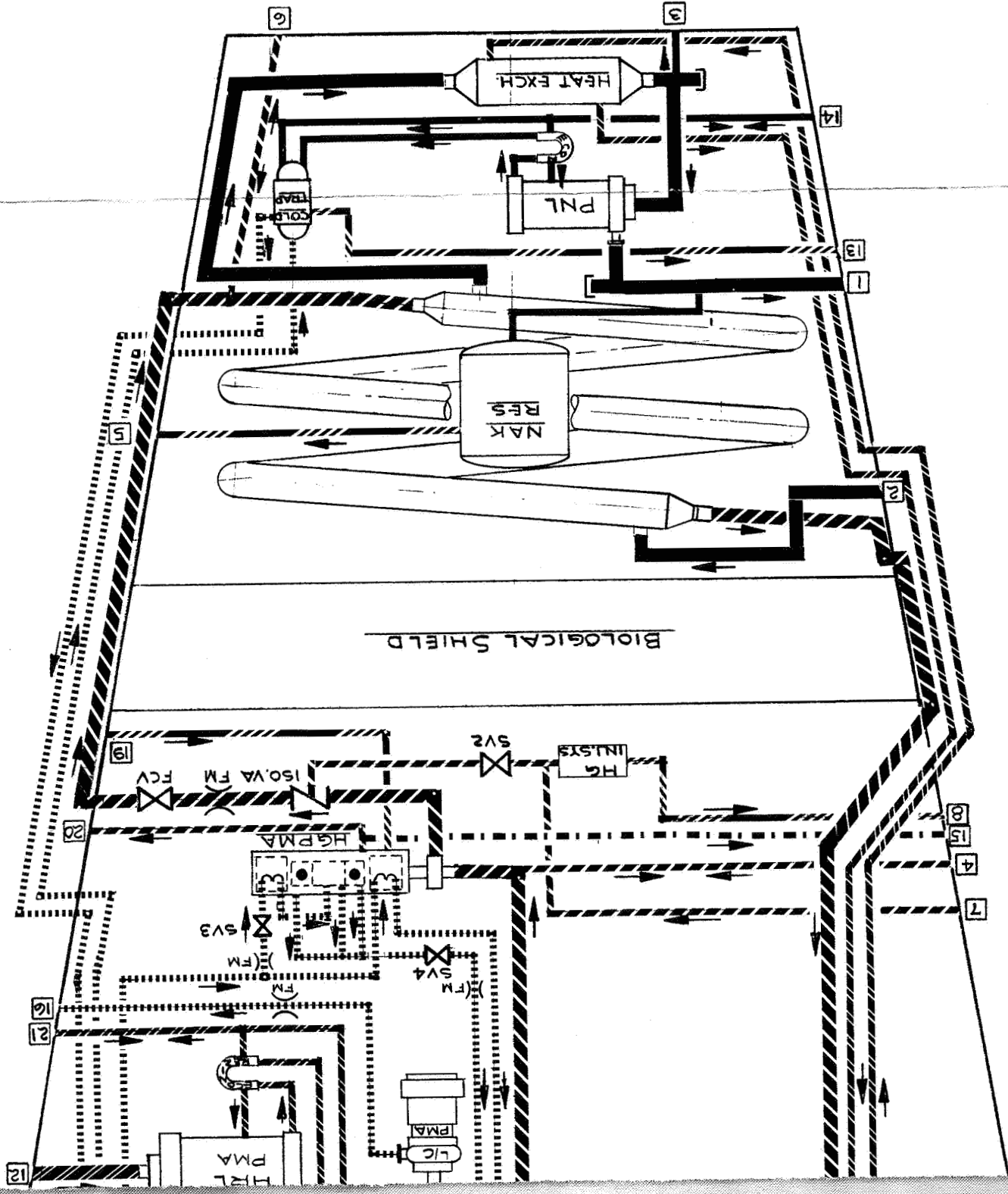
FOLDOUT FRAME 1



FOLD OUT FRAME 2

FOLD OUT FRAME 3

Report No. 3233



- PCS-G INTERFACE IDENTIFICATION
1. NAK to Heater
 2. NAK from Heater
 3. NAK to Dump Tank
 4. Vacuum, Vent, Pressure, Dump, Fill and Makeup
 5. To N₂ Gas Charge System
 6. Vacuum, Vent, Pressure and Dump
 7. Hg Fill
 8. Vacuum, Vent and Pressure
 9. To Degasifier
 10. HRL to Radiator Simulator and Purification System
 11. To N₂ Gas Charge System
 12. HRL from Radiator Simulator and Purification System
 13. Vacuum
 14. NAK Pump Fill and Drain
 15. Space Seal Vacuum System
 16. To L/C Heat Removal and Degasification
 17. To N₂ Gas Charge System
 18. From L/C Heat Removal
 19. Lift-Off Seal Pressure
 20. MPMA Space Seal Cavity Drain
 21. HRL Fill and Drain
 22. Vacuum
 23. Space Seal Vacuum System
 24. TAA Space Seal Cavity Drain
 25. Lift-Off Seal Pressure
 26. Alternator Cavity Drain

PCS-G Flow Diagram - Preliminary

V. COMPONENTS

A. TURBINE-ALTERNATOR ASSEMBLY (TAA) (0741-11)

1. Summary

In this report period, three TAA's were tested in the PCS-1 Phase IV facility during Step 2 testing. The total operating time for these TAA's was approximately 300 hours. Performance for TAA units 2/3*, 5/2, and 6/1 (Refer to Table 6), is compared to TAA 3/2 which exhibited severe mechanical design deficiencies culminating in a failure in June 1965; details of TAA 3/2 testing are discussed in the previous semiannual report (Reference 5). The demonstrated performance of the units tested during this report period indicate that the major problems associated with the failure of TAA 3/2 appear to have been solved. The more significant deficiencies remaining in the turbine are:

a. Second-stage nozzle assembly mechanical design

This is being redesigned in order to reduce the high thermal gradients which exist during the start transient. Also, the material is being changed from hexagonal close packed (HCP) Stellite 6B to either S 816 or 316 stainless steel, due to the extreme brittleness of HCP Stellite 6B.

b. Performance

Leakages around the first-stage nozzles and between the second-stage nozzle diaphragm and shroud have contributed to a lower efficiency in the turbine. These deficiencies have been resolved in the case of the first-stage nozzle assembly that is being used in TAA 2/4 during PCS-1 Phase IV Step 3 testing; the second-stage nozzle assembly currently being evaluated indicates that the leakage potential has been eliminated. The improved performance turbine with optimized flow control is presently in the fabrication

* First digit refers to TAA number, second digit is buildup number; e.g., TAA 2/3 is the third buildup of TAA 2.

stage and is expected to show an efficiency ranging from 56.7 to 57.7% with an allowance of 4% liquid carryover.

c. Space seal

The mercury visco ring seal to space is considered to be a possible deficiency. Modifications to the pumping coefficient have been successful in correctly positioning the liquid interfaces, but operating times have not been of sufficient duration to determine if this and the material change from Greek Ascalloy to Stellite 6B has satisfied the erosion problem that was experienced in TAA 3/2.

d. Alternator

Problems with the alternator have indicated a need for tighter quality control, particularly with regard to cleanliness in the bearing area. The cooling passage weld problem has been overcome by repair and proof testing.

In conclusion, it can be said that the major deficiencies in the SNAP-8 TAA are centered around the stationary elements of the turbine. These problems are recognized, and are associated with the severe thermal gradients caused by condensing mercury vapor on the cool surfaces during the start transient. Other than the space seal visco ring, the rotating assemblies have demonstrated good mechanical integrity.

2. Introduction

a. The SNAP-8 TAA is shown in Figure V-1. Out of the six units tested to date, four have operated with mercury and two with cold gas (Refer to Table 6 for operating times and numbers of starts for mercury operation). Performances for the various machines in mercury are illustrated by Figures V-2 through V-9.

b. Status prior to report period

A failure of TAA 3/2 after 820 hours of operation in June 1965 was discussed in the previous report and was presented in detail in Reference 6.

The principal deficiencies established from this failure were:

(1) Antirotation pins sheared in the interstage labyrinths, allowing the snap rings to disengage.

(2) The inlet nozzle assembly in Stellite 6B welded to 316 stainless steel housing showed severe cracks due to differential expansion.

(3) Stress concentrations in shroud members resulted in propagating cracks.

(4) Stellite 6B material generally transformed from the face-centered cubic (FCC) structure to the HCP condition, resulting in embrittlement and dimensional changes.

(5) Thermal stress failure in second-stage nozzle assembly due to severe thermal gradients during startup transients.

(6) Visco pump. Erosion of this element of the mercury seal to space was severe.

3. Accomplishments

The operation of TAA 2/3 demonstrated to a large extent that most of the deficiencies as outlined have been resolved successfully. A summary of the problems and corrective action for the various TAA units is shown in Table V-1.

a. Interstage labyrinths

The modified design eliminated the antirotation pins and provided positive axial clamping by means of a beveled snap ring. The result was a virtually fixed labyrinth, but with the feature of being able to force the labyrinth ring to a concentric position relative to the rotating elements at time of assembly. This design appears to have been successful, although some rubbing of the labyrinths has been noted (see Figure V-10) in

two of the units tested (TAA's 2/3 and 5/2). In the case of the most recent unit that was tested (TAA 6/1), negligible rubbing occurred. The failure of the alternator (Reference 7) undoubtedly contributed to the more severe rubbing with TAA 5/2 due to vibration effects. In all cases, rubbing of the thrust balance labyrinth is more intense than the interstage labyrinths since it is furthest from the supporting bearings. It is considered that the major cause of rubbing is due to housing thermal distortions, and to a lesser extent by shaft dynamic deflections. The current design has been modified in order to reduce the axial clamping force, supplying a maximum force of only 50 pounds to radially displace the labyrinths at assembly. Prior to this, the forces existent during assembly had measured approximately 120 pounds.

b. Inlet housing

The design modification to eliminate the Stellite 6B/316 stainless steel nozzle-to-housing weld was approached in two phases. The first was an interim design with a Stellite 6B nozzle held captive in the housing by a welded-in window piece. This was an expediency measure only and was successful in all units tested. The cracking problems which previously occurred in TAA 3/2 were not repeated, and the only deficiency apparent with this design occurred in one unit (TAA 2/3) where the nozzles cocked approximately .020 in. to .030 in. During testing of this turbine, a sudden degradation in performance was noted after 90 hours of operation, and it was concluded that the leakages around the cocked nozzle were a contributing factor (Refer to Figure V-10). The second and final phase of this design is shown in Figure V-11. It is seen that the nozzle vanes in Stellite 6B are inserted into slots cut in a 316 stainless steel block. The latter is then welded into a window cut in the face of the inlet housing. This feature will eliminate leakages around the nozzle insert and also avoid the problem of cocking of the nozzle. This design feature is included in the next buildup, TAA 2/4, which will be tested in PCS-1 Phase IV Step 3 early in the next report period.

c. Shroud stress concentrations

No repetition of these deficiencies has been noted in the redesigned shrouds for the TAA units tested.

d. Stellite 6B transformation

The pretransforming of this material was successfully achieved and incorporated; however, as indicated by the cracks in the second-stage nozzle/diaphragm in the last TAA tested (TAA 6/1), the resulting embrittlement poses a serious problem. Consequently, the decision was made to avoid the use of Stellite 6B in the HCP condition. The stabilization of Stellite 6B in the FCC condition which provides greater strength and ductility, is described in detail in the Materials section of this report.

e. Thermal stress failure of second-stage nozzle assembly

Deficiencies established in TAA 3/2 were due to high-temperature gradients between the diaphragm and shroud when the complete assembly consisted of a welded Stellite 6B construction. The redesign separated the diaphragm and nozzles from the shroud, and changed the shroud material from Stellite 6B to PH 15-7. The parts were assembled with a nominal .006-in. radial clearance; however, due to different expansion coefficients, the clearance would be eliminated at steady-state conditions. For reasons of expediency, the design change occurred in two phases. The first interim design (Mod. A) was comprised of existing hardware with a welded nozzle piece. This was tested successfully in the first two units (TAA's 2/3 and 5/2) but distortions of the diaphragm caused leakages and a consequent drop in performance (see Figures V-12 and V-13). In addition, a surface transformation and distortion of the PH 15-7 shroud occurred which aggravated the leakage problem. The combined distortion effect resulted in shearing of some of the roll pins which hold the shroud and diaphragm together. A second design (Mod. C) was included in the last unit tested (TAA 6/1). This consisted of a design similar to Mod. A except that it featured nozzle vanes machined from a one-piece Stellite 6B forging

in the pre-transformed HCP condition. Disassembly of this unit, following test, revealed two hairline cracks starting from the knife-edge corners of the nozzle vane trailing edges. The part also bowed approximately .008 in. High thermal gradients with associated high-stress levels were considered to be the cause of this problem. Figure V-14 shows the predicted temperature distribution during the startup cycle, and Figure V-15 illustrates the bowing condition. An analysis of the stress distribution resulting from this condition has been completed (Reference 8).

A design modification for this nozzle is currently being analyzed in order to correct the start-up problem. To accommodate the immediate needs of the PCS test program, the next turbine buildup (TAA 2/4) was assembled with a Mod. A design second-stage nozzle diaphragm with a welded insert like the one used previously. A turbine preheat method with controlled mercury injection at a reduced inlet temperature will be used to reduce the thermal gradients during start-up.

f. Visco pump erosion

The condition of severe erosion on the rotating ring of the mercury seal-to-space visco pump in the failed turbine (TAA 3/2) was attributed to the pump being too effective and resulting in a mismatch of the liquid interfaces relative to the space-seal heat exchanger. The fact that the interface temperatures and vapor pressures are higher than expected is thought to be major cause for the severe erosion condition.

The design change to the visco pump was made by machining a step in the O.D.; modified assemblies were included in subsequent units (TAA's 2/3, 5/2, and 6/1). Figure V-16 illustrates the visco seal area and the design change effected. In addition, the material of the rotating member was changed from Greek Ascalloy (modified 410) to the more erosion-resistant Stellite 6B.

Operating experience in the aforementioned TAA's has not been of sufficient duration to determine if these changes have been totally

successful. However, the interface location in the space seal has been satisfied (Figure V-17). Some current evaluations are in process which have the prospect of design improvements that will provide a higher confidence level. A supporting test program has been proposed.

4. Performance - Turbine-Alternator Assemblies

a. Testing

Counting the three turbine-alternator assemblies that were tested in Step 2 of PCS-1 Phase IV, a total of four units have been tested to date. Each of the units have been analyzed to determine their performance. Detailed analysis of TAA 3/2 is discussed in TM 4932:65-1-288 (Reference 9).

The first assembly tested in PCS-1 Phase IV Step 2 was unit 2/3 which incorporated several modifications as a result of the failure of unit 3/2. The unit differed from the previous unit (3/2) in the following manner:

(1) The Stellite 6B nozzle inserts used for the first stage (and situated in the inlet housing) were kept in place by a stainless steel retainer welded to the inlet housing, eliminating the 316 stainless steel-to-Stellite 6B weld.

(2) The second-stage nozzle diaphragm (Stellite 6B), still utilizing welded-in nozzle insert blocks, had a separate shroud of pH 15-7 Mo supported on pins. The cross section of this shroud and the shrouds of the other nozzle assemblies (third and fourth stage) were reduced in order to minimize thermal stress problems; areas of high-stress concentration also were eliminated.

(3) The thrust and interstage labyrinth seals were retained by a tapered snap-ring instead of a Spirolox retaining ring. The snap ring was retained and prevented from closing (which would allow it to come out of its slot) by a retaining ring welded to the inlet housing for the thrust seal; multi-lugged washer was used to retain the interstage seals.

(4) Triple-melt CEVM bearings were used in both the alternator and the turbine.

(5) The Greek Ascolloy runner of the visco pump was replaced by one fabricated from Stellite 6B material.

(6) The oversized thrust seal was replaced by one of the smaller design size.

Items 2, 3, and 6 were expected to provide an increase in turbine efficiency of 2 to 3 percentage points, assuming the changes to be 100% effective. The first part of item 2 was to have removed the nozzle vane tip leakage, while item 3 was to have eliminated the additional leakages due to eccentric operation of the seals. The smaller thrust seal also was to have contributed to improved efficiency by providing less leakage loss.

The efficiency expected, assuming the liquid carryover would again be 4 to 6% (as in RPL-2), was 56.7% to 57.7%.

The initial performance of TAA 2/3 indicated a turbine efficiency that was only 1.0 to 1.5 points better than the previous unit. It was apparent that some or all of the physical changes in the machine were not working with 100% effectivity. Nevertheless, the performance was basically in keeping with the predictions in that a significant improvement has been realized. During the early part of the testing there was some indication of a very slow decline in performance. This was indicated by the drop in pressure level of the turbine inlet and boiler outlet. After approximately 88 hours of operation and 3 starts (2 starts covering 24 minutes of operation), a distinct and comparatively rapid drop in performance occurred. For the same flow rate, the TAA was producing about 4 to 6 kw less. A plot of turbine inlet and boiler outlet pressure over the entire period of operation indicates a definite drop in pressure level between 80 and 100 hours of operation (Figure V-18).

Following removal of the unit from the test facility, the subsequent disassembly revealed some of the reasons for the degradation in performance. The post-run inspection revealed:

- (1) An increase in the first-stage nozzle flow area of 13% caused by displacement and cocking of the nozzle insert.
- (2) An increase in the second-stage nozzle flow area of 11% caused by displacement of the diaphragm relative to its shroud.
- (3) Eccentric operation of the thrust and first- and second-interstage seals as evidenced by rubbing and wear indications on the wheel hubs. The tapered snap rings evidently gave rise to axial restraining forces that made it impossible for the seals to center themselves about the rotor hub.
- (4) Some small leakage past the "K" seal at the nozzle shrouds.

The fact that the turbine did not provide the 2 to 3 point gain in efficiency expected indicates that some of the aforementioned deficiencies may have been in existence at the start of testing. For instance, the reduction in nozzle shroud cross section created higher pressure differentials across the "K" seals. This condition is more conducive to leakage, particularly since the cavity over the nozzle shrouds is presently being vented to turbine exhaust conditions. Previously, the pressure differentials across each shroud were limited at most to the differential between adjacent stages (e.g., 73 psi across the second-stage shroud compared with 130 psi using the modified shrouds).

Furthermore, despite the fact that the thrust and interstage seals were positioned concentrically on assembly, there is a possibility that they became eccentric while the unit was operating due to differential thermal movement and housing distortions. The degree of eccentricity could very well be a function of the number of thermal cycles to which the unit is subjected.

Of the 6 kw degradation in power, 3 kw can be accounted for by the change in first- and second-stage nozzle areas. The full eccentricity of the thrust and interstage seals may account for another 1.6 kw and the remaining 1.4 kw loss is attributed to leakage past the interstage K seals; however, the exact amount cannot be accurately determined.

Prior to the degradation, the TAA was able to attain the following performance:

	<u>Measured</u>	<u>Anticipated</u>
Power output (kw)	53.5	55.4
Mercury flow rate (lb/hr)	11,750	11,750
Inlet pressure (psia)	242	265
Inlet Temperature (°F)	1250	1250
Exit pressure (psia)	14-16.0	14.5
Liquid carryover (%)	4.0	4.0
TAA efficiency (%)	46.2	48.0
Power factor	0.625	0.625

Since the drop in performance was distinct, the unit was removed for disassembly and examination.

The next two units installed were TAA 5/2 and 6/1. Unit 5/2 was operated for 41 hours and 40 minutes before a seized alternator rotor terminated the test. Subsequently, unit 6/1 was installed and run for 117 hours; termination of this phase of testing was due to boiler deconditioning.

The performance of both these units appeared to start where the first unit tested in Step 2 (TAA 2/3) left off; i.e., the performance appeared to start at the degraded level of TAA 2/3. A certain amount of performance variation from unit to unit must be expected due to differences in buildup (fabrication tolerances, nozzle areas, etc.). As a matter of fact it should be noted that these units were not selectively assembled which can be contributive to variable performance. As an example, the three machines

tested in Step 2 each had progressively larger first-stage nozzle areas. This was determined from the results of the nitrogen flow tests which are as follows:

	<u>TAA 2/3</u>	<u>TAA 5/2</u>	<u>TAA 6/1</u>
A_e'	= 0.373 sq in.	0.395 sq in.	0.410 sq in.

The nozzle areas in the other stages varied from 0.0% to 9.0% small, resulting in stage mismatching which was a major factor in the poorer performance of the latter two units. In addition, disassembly of both units revealed that the thrust and interstage seals were functioning in an eccentric condition (the amount of rubbing, however, for TAA 6/1 was quite light) and second-stage shroud and diaphragm distortion had occurred. Displacement or cocking of the first-stage nozzle block also was evident but to a much lesser degree than had occurred with unit 2/3. A certain amount of "K" seal leakage also must have been present. The measured turbine efficiencies and alternator power output and TAA efficiencies of the three units are shown in Figures V-2 through V-9. A table of run times and number of starts for each unit is shown in Table 6.

b. Findings

Testing of TAA's in this report period has produced data which constitutes significant progress toward resolution of the problems previously discovered during operation of the SNAP-8 system. Experience gained from these tests has led to the following changes:

(1) The PH 15-7 shroud material will be eliminated from future designs because of phase transformation. The details of this transformation are discussed in Reference 10.

(2) Stellite 6B in the HCP condition will not be used in future assemblies because the second-stage nozzle assembly problem has indicated the need for a more ductile material; S 816 is the leading candidate material (Reference 11).

(3) Interstage pressure taps were included in all of the units tested. Since the turbine housings were in the finished condition, a braze joint was employed; it was this joint which gave rise to leakage problems. Although repairs were effected, the successful operation over a 10,000-hour endurance run is in doubt. Future turbine housings will include welded stub tubes for this purpose.

(4) Turbine performance is noticeably affected by leakages between shroud and diaphragm. Future designs will attempt to eliminate this by means of a one-piece welded design.

(5) A criterion needs to be established regarding the allowable amount of rubbing wear for the interstage and thrust balance labyrinths versus operating time. Also, a reduction in axial clamping force of the labyrinth retention device is desirable.

(6) Until such time as the second-stage nozzle assembly problem is resolved, the turbine preheat method will be included in the PCS start procedure.

(7) A failure of S/N 481491 alternator in TAA 5/3 is described in Reference 7. The failure occurred due to seizure of the screw seals when the unit ran to overspeed in an automatic facility shutdown. Seal clearance was reduced by the bearings operating without preload which provided a greatly increased radial clearance. The referenced failure analyses indicate a primary need for closer quality control and cleanliness of fabricated parts in the bearing and loading spring follower assembly, since much foreign debris was found in the bearing area. An added problem which occurred in several other alternators (S/N 481489, 481491, 481510) was leakage through the stator housing cooling passage seal weld. Basically, this is a welding problem and indicates the need for closer control in welding procedures. As a matter of fact, revised procedures have been used on later units and actual operation with TAA 6/1 has indicated that the problem is solved.

c. TAA Design Status

(1) Aerodynamic Design

An advanced turbine aerothermodynamic design has been completed. The work was done in close cooperation with the NASA (LeRC) research department, using the NASA LeRC turbine design philosophy.

The aerodynamic approach places greater emphasis on flow continuity through nozzle and rotor rows and the improvement of end wall treatment. In addition, the rotor blade solidity has been increased from 1.43 to 2.02. Rotor blade tip overlaps in each stage have been reduced considerably. The amount of overlap being used takes into account a tolerance on the aerodynamic requirement plus a tolerance due to fabrication and potential housing distortions.

The design will utilize identical nozzle vane profiles in each stage as well as identical rotor blade profiles. Although velocity triangle calculations indicate slightly different rotor efflux angles (particularly the first stage), the rotor blade heights have been adjusted to allow identical profiles in each stage. Rotor tip clearances vary from 0.030 in. in the first stage to .020 in. in the last stage. The velocity triangles are shown in Figure V-19 and the physical dimensions in Table V-2; an axial profile is shown in Figure V-20. It is expected that this turbine will be 3 to 4 percentage points better than that of TAA 2/3; e.g., an expected efficiency at 4% liquid carryover of 58 to 59%. The aerothermodynamic design will be covered in detail in a report presently being prepared.

(2) Nozzle/diaphragm assemblies

The redesign for the second stage currently is being thermally and stress analyzed. Designs for the third and fourth stages are in the conceptual stage. The primary objective in this redesign is the reduction of high thermal gradients during transient conditions.

(3) Thrust balance

A tradeoff study on performance potential improvements has been completed and a technical memorandum is being prepared. As a result of the study, it was determined that the present balancing piston bleedoff device should be replaced with larger bearings that will be capable of taking the thrust load and an auxiliary balancing device, such as a visco pump, should be mounted between the turbine bearings. The conclusion from the study was that there would be no performance gain with these alternate designs.

(4) Face seal liftoff device

Concepts are being pursued for a liftoff device for the start seals suitable for prototypical operations.

(5) Mercury visco seal

Layout drawings and designs are being evaluated with a view to reducing the erosion difficulties.

(6) Modifications to the composite housings design have been made. These include incorporation of welded pressure-tap stub tubes and, in general, bringing the drawings up to date.

d. Planned Activities

The activities which have been planned for the support of the previously described design effort are as follows:

(1) A seal test program to evaluate the visco pump erosion problem. Endurance tests are planned for this purpose.

(2) Thermal shock tests for the new design second-stage nozzle diaphragm assembly to verify its adequacy for the thermal transients.

(3) Antigalling and labyrinth tests in S 816 and Stellite 6B material.

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(4) Development tests for the start-seal liftoff device. This will be a cycling test at operating conditions.

(5) Rotor dynamic analysis. Critical speed and shaft-housing deflections will be evaluated; includes all design changes.

(6) Inlet housing design. A review of current design with emphasis on pipe loading stresses, etc.

The complete program plan for the TAA's is shown in Figure V-21. Availability of the design feature improvements as they appear in future turbines is shown in Table V-3.

e. Alternator Assembly

A final report (30-12-15-65), on the alternator design and development has been received from General Electric Company.

A report (31-4-1-66) on the condition of preprototype alternator (S/N 481488) also has been received from General Electric. This unit was tested in conjunction with TAA 3/2. The report indicates no serious problems with this machine; however, some unusual markings were noted on the bearing raceways. These bearings are, therefore, being reviewed in more detail at AGC.

A winding-temperature versus load-curve was prepared on a basis of stabilized test data obtained from all units tested to date at GE (see Figure V-22). This shows that the winding temperature limit of 200°C maximum satisfies a generator load of 87 kva .75 pf.

f. Bearing Test Program

A program to test the endurance characteristics of multiple remelt M-50 steel bearings lubricated by mix-4P3E (polyphenyl ether) was performed by the SKF Industries, Inc., Research Laboratory. Endurance data collected from the first two groups of bearings which were tested (lubricated with a mineral oil so that these tests could serve as a baseline fatigue test

against which tests in mix-4P3E could be compared), proved to be poor for a vacuum-remelted M-50 steel. These poor-life data were interpreted as having resulted from an unfavorable trace element content in this heat of steel.

As a result of these tests, the program was redirected and a second heat of steel equivalent to Aerojet Development Material Specification AGC 10354, Type 1 (air melted), Class 5 (Five consumable electrode vacuum remelt cycles) steel was purchased. This heat had a known favorable trace element index of $\theta = 2.5$ as compared to $\theta = 7.0$ for the first heat.

Estimates obtained from the failure data resulting from the baseline tests of the second heat of steel that were conducted in mineral oil indicated a B_{10} life of 76 million revolutions or 7.6 times the Bearing Catalog life, verifying that this heat has endurance properties that are likely to be better than those obtained from the first heat of steel. The details are discussed in previous SNAP-8 Quarterly Reports (References 12, 13, 14 and 5).

The endurance tests were conducted on test machines under a dead-weight radial load of 4240 lb ($c/p = 2.15$, AFBMA $L_{10} = 10$ million revolutions) and at a speed of 9700 rpm; specially designed housings and lubrication system directed the lubricant (mix-4P3E) through jets as the inner-race ball contact area. Lubricant flow rate was adjusted to allow the outer-ring operating temperature to be between 111 to 121°C.

Throughout this test series, the outer-ring operation temperature was controlled by an IBM 1710 control system, which monitored the temperature of each operating head at 6-minute intervals and gave an audible signal each time that this operating temperature was outside the preset limits (111 to 121°C). Manual adjustments of the oil flow were made at this time in order to maintain the bearing temperature within the specified limits. The oil-out temperatures were monitored by the same IBM system at 1-hour intervals and the oil-in temperatures and oil flow-rates were manually recorded at 8-hour intervals.

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The program encountered difficulties resulting from an excessive oil leakage through the test-equipment labyrinth seals. This oil leakage, which is considered "normal" for inexpensive mineral oil tests, was not tolerable for the mix-4P3E tests. As a result, the mix-4P3E lubrication system also was connected to the slave bearings. Although the oil leakage was not resolved, the mix-4P3E could be collected and put back into the system as it was no longer being diluted with mineral oil. Because only two machines, instead of three, could be operated as a result of this change (limitation of the lubrication system), the testing time had to be lengthened. All lubricant leaking through the test equipment seals was collected and filtered through a nominal 5-micron filter before being returned to the system through a pressure-tank filtering system. This corresponded to one filtration of the total charge per 100 hours of running time.

When early ball failures (which are not test elements) occurred at very low lives, ranging from 1.7 to 9.6 million revolutions, testing was suspended while the failures were examined in an attempt to pinpoint the cause. As soon as it was determined that the cause was not immediately apparent, the remaining bearings were disassembled and refitted with new balls. These balls had been fabricated from acid open-hearth 52100 material which indicated a relatively long life in previous SKF tests (in excess of an L_{10} life of 70 million revolutions).

Closer examination of inner rings taken from bearings that had experienced early ball failures, revealed that the damage (denting of the rings) caused by the flaked balls prevented refitting these bearings with new balls.

Two more bearings that were available from the same lot also were placed on test, increasing from 12 to 14 the number of bearings that were being tested in this program to gain more data on inner-ring failures.

Examination of the early ball failures indicates that the major cause of these failures was lubrication distress. This is probably

due to poor boundary lubricating characteristics of the mix-4P3E lubricant; balls from the same lot had good life in previous tests using mineral oil as a lubricant. The failures are considered unusual in that more than one spall occurred on a ball, and more than one ball spalled within a bearing.

A summary of the test results is shown in Table V-4.

Final results included the following: three inner-ring failures occurred at 12.1, 23.8, and 99.2 million revolutions; five bearings reached the time-up life of approximately 200 million revolutions; and six tests were suspended due to ball failures. Four of the suspended tests occurred due to early ball failures; the fifth suspended test due to ball failure had accumulated 72.2 million revolutions. The sixth test is considered a suspended test because the bearing was inadvertently remounted with the reversed direction of rotation after it was removed to refit it with new balls. The latter suspension occurred at 15.7 million revolutions due to a flaked inner ring.

An estimated life which is being evaluated for bearings made from this heat of steel (lubricated with mix-4P3E) compares unfavorably with the B_{10} life of 76 million revolutions or 7.6 times the catalog life (one sigma confidence limit for these tests results equals 5.4 times the catalog life), that was obtained for bearings from the same group tested during the previous year but using a mineral oil as the lubricant. Several early bearing failures occurred in this group that were attributable to surface pitting produced during the manufacture of the bearing balls. As a result, the evaluation of the life of these bearings was invalidated so that, in effect, the bearing group was actually much smaller.

The value for the B_{10} life is being studied in the light of actual and suspended tests as well as the lubricating conditions of the mineral oil and the mix-4P3E lubricants. Preliminary calculations indicate a reduced life as low as 1.2 times the catalog life.

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It must be recognized that endurance test results based on small test groups of 10 bearings (an adequate group is 30) exhibit very wide scatter. The addition or subtraction of one failure has a pronounced effect on the estimated B_{10} life of the group; therefore, any life estimates obtained from these groups must be considered only as an indication of life rather than a precise value.

The draft of the final report was received from SKF Industries during the week of 20 June 1966. The draft and test data are being reviewed for completeness prior to release.

Additional analysis will be made to determine how the relatively low life-test results in mix-4P3E will be interpreted relative to the ball bearings being used in SNAP-8 components.

g. Bearing Evaluation

Technical Memorandum 4932:66-413 (Reference 7) was published on 23 May 1966. This TM summarizes the bearing evaluation of the SNAP-8 failed alternator, P/N 094069, S/N 481491 (TAA Unit 5/2).

The alternator seized on 30 March 1966 during the PCS-1 Phase IV Step 2 system tests, following a loss of speed control, TAA overspeed, and an automatic shutdown. After the alternator was disassembled, preliminary examination revealed evidence of heavy rub on the alternator radial seals. As a result, the alternator bearings were examined in order to find some clues as to the reason for the seal rub.

Three items, debris and machining chips in the bearing assemblies, bearing outer-ring and jet-ring seizure, and the bearing preload mechanism being sensitive to cocking, were instrumental in causing the alternator failure. It should be noted that even separately each of these causes could lead to alternator failure.

During the bearing investigation, two potential problems were uncovered. One is a case of possible scoring of the bearing outer

ring and housing surfaces when relatively high assembly-disassembly loads are used because the bearings become self-wedging at high axial loads. The second is the possibility of operating the bearings partially unloaded such as would occur in the case of an unfavorable tolerance accumulation of bearing internal geometry and shaft fits, which might produce intolerable sliding in the bearings and result in a short wear life of the bearings.

h. Bearing Material

The Latrobe Steel Company of Latrobe, Pennsylvania, produced 1036 lb of bar stock (forged M-50 tool steel, 5 in. square with rounded corners) in accordance with Development Material Specification No. AGC-10354, "Requirements for AISI M-50 Bearing Steel." The new requirements are shown under the "Specified" column in Table V-5. Classification of the material is Type II (Vacuum-induction melted), Class 3 (three consumable-electrode vacuum-remelt cycles). This is a lower quantity than that of the estimated 1400 $\pm$ 100 lb from one heat of steel. However, this is sufficient for the current program needs.

Analyses of the chemical composition and gas content and all the required physical and inclusion-rating tests were conducted with the vacuum-induction, and the first and third consumable-electrode vacuum-remelt ingots. The results are shown under the "Reported" column in Table V-5. The results of the analyses indicate that the chemical composition and gas content are within specified limits. In addition, except for the annealed hardness (reported Brinell 248-302 rather than the specified Brinell 202-245) which is acceptable because of the reported satisfactory heat-treated hardness (reported Rockwell C 64.0, specified Rockwell 63), each of the other tests are within specification.

Studying the reported results we note that from the point of chemical composition and gas content there are no improvements except for a decrease in aluminum content and a small increase in nickel content, after the first vacuum consumable-electrode vacuum remelt. If it can be

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assumed that the physical tests also were satisfactory after the first remelt, then it might be concluded that for this material there would not be any appreciable improvement in the bearing fatigue life after a vacuum-induction melt of one consumable-electrode vacuum-remelt cycle.

Determination of the trace-element index (θ), which is the relative measure of a heat of steel from the standpoint of a high or low bearing fatigue life, is as follows:

$$\theta = \frac{\overline{Al}}{\overline{Al}} + \frac{\overline{Cu}}{\overline{Cu}} + \frac{\overline{Ni}}{\overline{Ni}}$$

where $\overline{Al}$, $\overline{Cu}$, and $\overline{Ni}$ are the percent content of each element; $\overline{Al}$, $\overline{Cu}$, and $\overline{Ni}$ are the mean percent content of each element.

A trace-element index for this material which is based on past experience with 52100 bearing steel and the endurance test program presently being conducted with multiple remelt M-50 bearing steel, is assumed to be:

$$\theta = \frac{\overline{Al}}{0.015} + \frac{\overline{Cu}}{0.060} + \frac{\overline{Ni}}{0.070} \leq 4.0$$

The trace-element index in accordance with the specified chemical composition (Table V-5) is $\theta = 3.0$.

The calculated trace-element index of aluminum, copper, and nickel for the third consumable-electrode vacuum-remelt ingot is:

$$\theta = \frac{0.010}{0.015} + \frac{0.010}{0.060} + \frac{0.070}{0.070} = < 1.834 < 4.0$$

which is acceptable.

The material was received during the week of 17 January 1966.

5. Conclusions

The development of the SNAP-8 TAA has uncovered many unforeseen problem areas in the turbine. Among these, the stabilization of Stellite 6B and the stresses due to high thermal gradients in the start transients have predominated. With this experience and the knowledge gained directly from testing, it is expected that these deficiencies will be resolved.

The problems regarding the alternator have been largely associated with inadequacies in the Quality Control procedures. From the performance standpoint, the alternator has exceeded the design requirements.

B. PUMP-MOTOR ASSEMBLIES

1. NaK Pump-Motor Assemblies

a. Technical achievements

NaK pump-motor assembly (P/N 093200-13) S/N A-5, see Figure V-23, after successfully completing 3,028 hours of planned endurance testing at 1100°F (Figure V-24) was decontaminated and disassembled. The component parts were found to be in excellent condition; there were no measurable signs of wear. This is a demonstration of successful longterm operation. Post-test photographs of the bearing are shown in Figures V-25, -26, -27, -28, -29, -30 and -31. The PMA parts, after being cleaned and inspected, have been reassembled for completion of the final 7,000 hours of endurance testing.

NaK pump-motor assemblies (P/N 093200-13) S/N A-4 and S/N A-7, successfully operated a combined total of approximately 530 hours under various system conditions. NaK PMA S/N A-7, in addition to operating as part of the power conversion system, has successfully operated at loop temperatures of 1290°F and 1330°F for approximately 4 hours, thereby meeting the requirements of the reference start-up sequence.

An efficient and safe method of decontamination and disassembly of the NaK PMA has been developed. This method employs the use of Dowanol E.B. fluid which is circulated through the PMA at a controlled rate, dissolving the NaK without experiencing the fire hazard that has been encountered with a water decontamination. The added benefit derived by using Dowanol E.B. fluid is that when the parts are removed they look new and extremely clean while those which have been decontaminated with water are darkened and discolored by heat staining that results from the high heat of reaction.

b. NaK PMA testing in PCS-1 Phase IV system

On 28 January 1966, the primary loop NaK PMA (P/N 093200) S/N A-6 was started and operated for 57 minutes before it was noted that high winding temperatures of 500 to 530°F were being experienced. Analysis of preceding events indicated that the PMA overtemperature was resulting from a lack of coolant flow within the motor. Because it was suspected that this was the result of gas entrapment within the motor, the PMA was shut down in order to attempt to clear the entrapped gas. Subsequent restart efforts were unsuccessful so that it was necessary to vent the motor; large quantities of gas were found, confirming the reason for the overtemperature condition.

A review of the test data (Figure V-32) showed rapid motor heating to a peak of 530°F in 57 minutes. The PMA's hydraulic performance indicated that it was equivalent to the previous NaK PMA's tested. However, the input power of the PMA was substantially lower than expected; approximately 600 to 700 watts low (Figure V-33). This reduction in power was attributed to the entrapped gas within the motor cavity which resulted in the reduction of rotor-friction and hydraulic losses. These losses correlate with the reduced power required.

Except for the motor-end journal bearing, subcomponents of the PMA were found to be in good condition. A number of circumferential scratches, including a small raised metal deformation, were found on the

running surface of the journal pads (Figures V-34 and -35). Discoloration of these pads confirmed the lack of lubrication and cooling which resulted in the bearing scoring that caused the inability of the PMA to restart.

The entrapped gas was traced to inadequate fill as the cause of this failure. As a result, the NaK PMA filling technique was modified, incorporating alternate steps of jogging and venting. As a further improvement, the venting operation subsequently would be performed through a large glass trap so that it would be possible to determine when adequate filling is accomplished, thereby reducing the false fill possibility. The modified technique has been demonstrated to be successful in several subsequent usages.

Acceptance performance tests were conducted on NaK PMA unit 5/2 (P/N 093200-13, S/N A-6). The testing consisted of starting torque locked-rotor determination and overall hydraulic and electrical performance. The test results listed below compare directly with the original starting-torque test motor values.

Frequency cps	Voltage -Volts (L-L) Ave	Unit	Torque In.-Lb	Amperage Amps Ave	Wattage
400	211	Present	18.8	51.6	2850
		Original	18.75	52	
95	39.3	Present	17.4	33.1	882
		Original	18.5	34.0	800
60	36.9	Present	61.4	48.5	1680
		Original	57.5	47.5	1700

The NaK PMA overall performance shown in Figure V-36 has a slight head-capacity improvement of about 1 foot head (attributed to the front vane clearance of the impeller being .001 inch less) over the original PMA tested and whose overall performance is shown on Figure V-37. The input power and overall efficiencies are very close to the same values.

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The motor pullout torque was related to the original NSL Phase II PMA that was tested by reducing the input voltage (L-N) while at the maximum motor input load of 5350 watts. This tested NaK PMA pulled out at 111.5 volts while the original took 114 volts, indicating that the tested PMA has better, or at least equal, torque capabilities than the original PMA.

NaK PMA (P/N 093200-13) S/N A-2, was installed in PCS-1 Phase IV as the replacement for PMA S/N A-6. After filling and performing several startups, the unit was started on the 60-cycle power supply and operated for 15 minutes for system checkout. In the next test, it was switched over to the 400-cycle power and also operated for 15 minutes. An overcurrent condition and high (450°F) winding temperatures were noted which necessitated a return to 60-cycle power. This sequence of events was repeated several times. The test was terminated to find the cause for a condition which indicated a serious motor fault. During investigative restart operations, it was determined that the pump-motor assembly could no longer attain the full system flow-rate required but would hover at an intermediate motor rotational speed (3,000 rpm nominal) as compared to a normal operating speed of 5,800 rpm. It was observed that an increasing flow rate resulted in a speed decay from 5,800 to 5,000 rpm with a resulting higher power consumption of .5 kw. The determination was made that the PMA could not accept additional hydraulic loading and the PMA was removed from the loop. Test points taken before the fault occurred are shown in Figure V-38. Testing performed on the motor after decontamination, resulted in the following findings:

Locked-rotor torque test indicated that the motor starting and running torques were approximately 80% of the standard value for the NaK motors but had a power consumption equal to the standard motor. The motor resistance taken and compared to original resistance readings revealed that an apparent loss of one of four parallel electrical paths had occurred. Surge comparison tests of the windings failed to reveal any abnormality between phases.

Careful removal of the hermetic cans and the ceramic potting insulation revealed a winding failure of one of the four parallel paths. The failure occurred in an area (Figure V-39) where all three phases are nested close together. The failed area (the diameter of a quarter) had all three phases fused together.

The only noted indication of the probable cause for failure was the presence of a 3/16 of an inch long sharp stone on top of the failed wires. It is postulated that during the cure cycle of the potting compound which is made up of magnesium oxide ceramic slurry that includes stone gravel for heat transfer (Figure V-40), potting shrinkage resulted in the stone's cutting through some of the insulation and causing a turn-to-turn short. Each succeeding cycle caused the wire growth to press on the stone, causing propagation of the short to a point where the heat generated was sufficient to melt all three phases.

NaK PMA (P/N 093200-13) S/N A-4, installed in the heat rejection loop of PCS-1 Phase IV, was operated in accordance with the test procedure throughout 264 hours after which time the PMA failed electrically. Performance prior to failure (Figure V-41) shows good comparison between Step 2 and LNL-3 data. Coincidentally with the PMA failure, the Data Acquisition System was inoperative and data on the PMA was not available for failure analysis. Investigation of the PMA revealed all phases, including the neutral, to be grounded. After decontamination and disassembly of this unit, the failure investigation has revealed that due to twelve separate penetrations into the stator can, the motor winding was completely flooded with NaK which resulted in the potting insulation and copper winding wire being severely deteriorated (Figures V-42, -43, and -44). Upon removal of the stator can and end cans, it was determined that the penetrations resulted from severe electrical arcing and subsequent melting of the Inconel can materials. It cannot be established whether a minor leak which allowed droplets of NaK to enter the motor stator cavity was the cause of an electrical failure, or whether an electrical failure within the motor stator cavity caused the burning of the stator can and the

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resultant flooding. The investigation is continuing in order to confirm the reason for the motor failure. A final failure analysis report will be written at the conclusion of the investigation.

NaK PMA (P/N 093200-13) S/N A-7, installed in the primary loop after accumulating approximately 265 operational hours of test, was restarted and operated at 400 cycles while the system was being heated from ambient to the 1150°F loop temperature. Several loop flow changes brought about excessive current demands on the motor with a sharp dropoff of speed from 5800 rpm to 5350 rpm and a current change that rose from 24 amps to 50 amps. A slow recovery to prechange conditions would always occur. It was determined that this phenomena was a function of changing system suction pressure. The problem was diagnosed as an impeller rub. The PMA was removed from the system and disassembled. Inspection of the PMA after disassembly confirmed the presence of an impeller back vane rub. All other components of the PMA were in excellent condition. Test performance data (Figure V-45) correlates well with LNL-3 data.

Review of the thermal growth of the pump housing and rotor shaft indicates that during steady-state operation a minimum clearance of .003 in. may exist. With thermal transients and pressure gradients superimposed, a rub could occur. In order to eliminate this rub possibility from recurring, the design was modified. The impeller back vane clearance was increased from .003 to .013 inches at operating temperature.

As a result of the impeller rub encountered in NaK PMA S/N A-7, NaK PMA's A-3 and A-8 were returned from LeRC to Aerojet for impeller back-face clearance modification. NaK PMA S/N A-8 was lock-rotor tested and found to be electrically substandard. The test results indicated that a voltage unbalance existed between the three phases, resulting in an uneven circumferential torque distribution. Unequal resistance of the three phases to neutral confirmed the reason for the motor behavior. As noted in Table V-6, this unit furnished, at a given average voltage, nearly the same

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starting torque but requiring more power and amperage. The badly unbalanced electrical values were confirmed by the electrical surge test showing phase I to neutral as different from the other two. Additional electrical evaluations are being made and additional information will be forthcoming.

LeRC unit 7, S/N A-3 has been lock-rotor torque tested and found to be a satisfactory unit. It is being prepared for return to LeRC.

NaK PMA (P/N 093200) S/N A-9 has been lock-rotor tested and found to be a satisfactory unit. Testing is being continued in order to determine the hydraulic and motor performance of the PMA prior to committing it to liquid-metal service.

c. Hardware status

Two NaK PMA's (P/N 093200-13) for PCS-1 Phase IV Step 3, S/N A-7 and S/N A-6, have been installed in the primary and HRL loops, respectively.

The motor for NaK PMA S/N A-10 was found to contain a discrepancy in its thermocouple terminals. This discrepancy is being corrected by installation of the correct terminals.

NaK PMA S/N A-1 has been installed in the LNL-3 test facility and is operating satisfactorily.

NaK PMA S/N A-5 (the unit which has previously run 3,028 hours) is being assembled for LNL-3 service as soon as the present test series is completed. Its program calls for 7,000 hours of operation which will conclude the 10,000 hours of endurance operation.

As part of the continuation program plan, requests for quotations are being prepared in order to obtain the necessary hardware for the program.

2. Liquid NaK Loop 3 (LNL-3)

Following the 3,000-hour test, the loop was drained of all fluids which were sent to the laboratory for analysis. The NaK PMA and the L/C PMA were removed from the loop, disassembled, and inspected. Decontamination of the loop by water and alcohol followed. Sections of 304, 316, and carbon steel piping which had been subjected to maximum loop temperatures (1225°F) were sent to the laboratory for metallographic analysis. No damage could be detected upon visual examination. The Fulton-Sylphon dump valve and the Powell flow-control valve also were removed for inspection. Examination of the dump valve revealed that a screw-type seat had loosened and was the cause of leakage experienced during the run. Slight scratches, caused by opening and closing, were the only damages evident on the flow-control valve which otherwise appeared to be in excellent condition. Post-test calibrations of pressure and electrical instrumentation were made where possible.

In February, a new test program and plans for reactivating LNL-3 were outlined; six reactivation plans also were considered. A NASA/AGC Program Management Review was conducted during 11-12 March 1966. It was decided that LNL-3 would be reactivated in accordance with TD 25 but with the addition of the parasitic load resistor and auxiliary start-loop heat exchanger in the main loop. LNL-4, which was proposed as an additional loop in the LNL-3 complex, was delayed pending further detailed substantiation of cost and schedules. Milestone charts for LNL-3 reactivation were prepared and the authorized work program was initiated. Reactivation actually started on 9 March 1966. It was subsequently decided that LNL-4, complete with PNL and HRL loops, should be built in Building 187. Planning for this installation is not yet completed.

3. LNL-3 Reactivation

Mechanical, electrical and instrumentation work was started and conducted concurrently. The main loop piping design was extensively

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revised. The dump tank, dump valve, and connecting piping were moved to a lower pressure point in the loop, downstream of the flow venturi. The parasitic load resistor (PLR) and the auxiliary heat exchanger (AHE) were installed in a bypass loop between the expansion tank and the NaK PMA. Analyses confirmed that the proposed configuration would not subject these components to excessive mechanical and thermal stresses. A new main loop flow venturi was fabricated of 316 stainless steel to replace the carbon steel venturi used in the 3,000-hour run. All main loop components were suspended or supported to allow for free movement in the horizontal plane.

The following SNAP-8 components were installed in LNL-3:

NaK PMA Unit 2/3, P/N 093200-13, S/N A-1

L/C PMA Unit 1/2, P/N TRW 253801-1, S/N 481501

AHE Unit 2, P/N 093607-1, S/N A-3

PLR Unit 3, P/N 098082-1, S/N A-1

Inverter, Unit 1 P/N 976J412 (Westinghouse), S/N 92640

With the time-limited construction schedule, only those valves which were on hand could be utilized. The PLR and AHE isolation and bypass valves and also a new dump valve were procured from SNAP-8 surplus. No suitable replacement could be found, so the main loop flow-control valve, used in the 3,000-hour run, was reassembled and reinstalled in the loop.

The MSA oxide control and indicating system (purification system), in anticipation of the construction of the second loop in Cell 2 of Building 152, was moved to a central location immediately south of the control room. The purification-system isolation valves were installed and then removed when it was decided that the LNL-4 loop would not be built in Building 152.

Extensive modifications were made to the facility's electrical system. All switches, circuit breakers, and current transformers were relocated in a common weatherproof housing which was located in Cell 2 west of the control room. The inverter installation accounted for about one third of the electrical expenditure.

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Instrumentation was refined, as required, for the new loop test program. Sensitive ΔP gages were installed to measure NaK PMA rotor ΔP and flow in the recirculation loop. A 60-lb ΔP gage was installed across the main loop flow venturi to replace a 30-lb gage formerly used. Running time meters were added to the L/C PMA and the inverter circuits. Electrical refinements include current and voltage meters on 60-cycle start system, current and voltage meters on the MSA piping heaters, and selective switching for both the NaK PMA and the L/C PMA. Shorting probes, previously used on the dump tank, were replaced with resistance-type probes for analog and digital indications of NaK levels. Excellent performance has been achieved in the time these probes have been in service, and similar probes are on order for installation in the expansion tank.

Metal sheathed resistance-type loop heaters have been replaced with a ceramic type which closely fits the 2-inch pipe used in the main loop. These heaters have a 2200°F capability and do not require thermal bonding. They are controlled by an autotransformer which allows an infinite range of heater settings and avoids the cycling associated with on-off temperature control devices. As a result, present loop heating may be accomplished either with the previously described heaters or by switching directly to the PLR. The PLR heaters, which total 18 in number, have been divided into three groups of six. Each set of six PLR heaters is approximately equivalent to the total heating capacity of the loop heaters. Therefore, only one set of six heaters will be run at a time. A blower has been installed to remove anticipated excess heat in the cell due to the increased heated surface of the new loop.

A Management Review was conducted 31 May 1966 which produced a total of nine action items contingent to unattended operation of the loop. These items were remedied. It also was concluded in this meeting that more detailed analysis for shutdown parameters and mechanisms would be required prior to unattended operations. In addition to the recommendations made by the Management Review Board, a field loss relay was added to the inverter field circuit to prevent overspeeding damage through the inverter.

4. Loop Operation

Wet shakedown electrical and instrumentation checkouts occupied the first two weeks in June. The SNAP-8 inverter was operated at 95 and 200 cps without load. The LNL-3 test plan in accordance with document SPS-004, was initiated 6 June 1966: a NaK PMA head-capacity test per section 3.5.1 of this document (Figure V-46); inverter and NaK PMA start tests per section 3.5.2 (Table V-7); tests of the inverter with capacitors energized at 95 cps per section 3.5.2.2 (Table V-8); and inverter start tests at 60 cps per 3.5.2.3 (Table V-9) were conducted during the latter part of June.

Inverter start tests were delayed by the discovery that "Voltron" current transducers, used to condition an a-c signal for d-c readout on the oscillograph, had a built-in 1/10th to 1/4 second time delay. As a result, the "Voltron" transducers were replaced with a resistor-transformer network that shows the resulting signal as a waveform on the oscillograph. Tests were resumed, following oscillograph recalibration.

Through 30 June 1966, the total hours and number of starts for the loop components were as follows:

Total starts and stops, NaK PMA:	40
Total starts and stops, L/C PMA:	86
Total Hours:	NaK PMA: 20.5
	L/C PMA: 36.0
	Inverter: 20.5

The extent of design changes in the LNL-3 reactivation is shown in the following illustrations: LNL-3 schematic, D/N 096176 (Figure V-47); building 152 facility, D/N 099352 (Figure V-48); LNL-3 instrumentation and controls (Figure V-49); LNL-3 loop, looking southwest (Figure V-50); LNL-3 loop, looking north (Figure V-51); parasitic load resistor and auxiliary start heat exchanger during construction of LNL-3 (Figure V-52); and bay 2, showing SNAP-8 inverter, load banks, D.C. power supply and auto-transformers (Figure V-53).

5. Lubricant-Coolant Pump-Motor Assembly

a. Testing

During this report period, L/C PMA (P/N 093580, S/N 481504) has operated successfully in PCS-1 Phase IV Step 2 for 672 hours. This PMA also operated in the PCS-1 Phase IV Step 1 test sequence for 163 hours, making its total of 835 hours. The performance of the L/C PMA during Step 2 is shown in Figure V-54. It should be noted that this figure does not match the original test data because mercury was found in the motor which increased the power loss, reduced the motor speed and caused a drop in pump head.

Because mercury had leaked into the lubricant and coolant fluids during test operations, the PMA was removed from the system for inspection of possible mercury damage.

The PMA was disassembled and found to contain approximately one tablespoon of mercury. The silver rotor resistance rings as well as a segment of the motor housing wall were plated with mercury and small droplets also were found within the insulation wraps. In order to remove the mercury, the PMA was cleaned with trichloro-ethylene and placed in a vacuum furnace bake at 300°F for 24 hours. However, upon completion of the baking process, it was discovered that some mercury droplets still remained in the winding. Consequently, the decontamination process was changed, increasing the temperature to 350°F and extending the baking time to two 24-hour periods (minimum vacuum levels of 100 microns were used). The process has been completed with an apparent successful cleanup of the unit. An electrical test has been performed, comprised of a momentary surge of 420 volts a-c, to confirm the adequacy of mercury removal. The L/C PMA is presently being reassembled to be utilized as a spare.

The PMA (S/N 481501) from the LNL-3 was disassembled and inspected after 4,534 hours of operation. Dimensional inspection was accomplished and results compared to those of the original assembly. Inspection showed no appreciable wear and all component parts appeared to be in excellent

condition. The PMA was reassembled and reinstalled in the LNL-3 complex; subsequent PMA operation has resulted in the accumulation of 26.5 additional hours with 37 starts and stops.

b. Hardware Status

L/C PMA unit 7 (S/N 481507) has been installed in the PCS-1 facility for Phase IV Step 3.

L/C PMA unit 4 (S/N 481504) has been assembled as a spare unit.

In accordance with CPP requirements, requests for quotations are being prepared for additional hardware.

6. Mercury Pump-Motor Assembly (Hg PMA) (0741-45)

a. Summary

During this report period mercury PMA (P/N 093347-5) S/N A-1 continued to operate in the PCS-1 Phase IV facility, bringing the total operating time for this PMA to 1099 hours with 101 starts.

Performance was in accordance with anticipated design limits, and disassembly revealed the unit to be in excellent condition. Some minor cavitation evidence was seen on the impeller surfaces; however, it is concluded that the mercury PMA will undoubtedly meet the SNAP-8 10,000-hour life requirement.

b. Introduction

At the beginning of this report period, three mercury PMA units had been operated successfully. The principal problem areas were centered around the start seal and start-seal liftoff bellows area. In addition, some severe cavitation erosion damage to the impeller and impeller locking bolt which occurred during pump development testing in LML-3 facility was considered to be a possible problem.

c. Accomplishments

Operation during this report period has confirmed that the cavitation/erosion damage which occurred in pump development testing was entirely due to the prolonged NPSH tests which took place, coupled with flow disturbances with the original "Allen" head type impeller retaining bolt. Performance in PCS-1 Phase IV with the "streamlined" head bolt has revealed only slight cavitation damage to this impeller after 806 hours of operation (Figures V-55, -56 and -57.) The actual PMA operating time was 1099 hours; however, as part of the cavitation /erosion study the impeller was replaced at 293 hours. Figures V-58 and -59 show the condition of the impeller from the Hg PMA which operated for 756 hours in the SL-1 facility. Again, only minor cavitation/erosion damage was noted.

Performance of the startup seal system could not be determined since it was known that the carbon face start-seals were worn prior to operation of the liftoff bellows.

Due to two previous failures of liftoff bellows actuated by pump discharge pressure (450 to 490 psi), the current bellows was actuated by gas pressure at 200 psia; there were no subsequent failure of this item.

No indication of performance degradation was apparent, although some performance points were plotted for pump head rise versus flow rate (H-Q) which indicated the the H-Q curve was 7 feet of mercury head less than that obtained from development tests in IML-3. The data curve obtained from the current test series is shown superimposed on the IML-3 curve (Figure V-60). Impeller clearances, runout, etc. were checked, and there is no apparent reason for this performance discrepancy. Normal variation due to manufacturing tolerances is estimated to be $\pm 3\%$ of the head (approximately 2 feet). It is assumed that the difference is largely due to instrumentation errors; however, the mercury PMA H-Q performance will be verified in PCS-1 Phase IV Step 3 testing which is scheduled to start early in the next report period.

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Replacement of the motor unit (stator and rotor) became necessary after 938 hours of operation when it was discovered that a leakage of mercury into the motor housing had caused an "open" circuit in all three phases at the phase junction; two of the phases "grounded" on the housing (Figure V-61 through -65). It was concluded that large quantities of mercury leaked through the startup seals when the latter became worn.

The mercury PMA from SL-1 was disassembled for inspection. A total of 756 hours and 38 starts had been accumulated on this unit prior to "mothballing" the facility in December 1965. The examination revealed minor cavitation/erosion damage but it was insignificant relative to performance over 10,000 hours of operation. A somewhat unusual condition of heat discoloration was noted on the motor-end shaft (Figure V-66). The cause for this is not known, although it is suspected that overheating may have occurred when the PMA was operated for short periods of time without lubricant-coolant fluid to the motor and bearings. An investigation will be made in this respect. No other damage was noted in this machine, although the startup seals were badly worn, as was expected, since no liftoff bellows was installed in this PMA. A cursory hand rotation check made on the bearings for this PMA and the unit removed from PCS-1 indicated that they were in good condition. A more detailed bearing investigation will be made during the next report period.

A report on the mercury pump development test program that was conducted in the LML-3 facility is being prepared, and is scheduled for release early in the next report period. The conclusion reached is that hydraulic performance (cavitating and noncavitating) exceeded the design objectives.

d. Conclusions

No further mercury PMA deficiencies have been established during this report period. Outstanding areas which require design effort are the start-seal and liftoff bellows system. This is currently being investigated along with the SNAP-8 TA start-seal system. For operation in

PCS-G, a prototypic actuation of the start seals is essential and for this purpose one design being considered is a central bellows chamber with a closed-loop fluid on the seal actuation side. Actuation of the central bellows would be by Hg PMA discharge pressure. A high confidence level in such a system could be expected since the central bellows would be large enough to permit X-ray inspection of the welds, etc.

The leakage of mercury into the motor in PCS-1 emphasizes the need for careful adherence to the valve operation procedures during the start cycle.

Leakage performance of the dynamic seal system has not yet been established since no measuring equipment has been installed in the facility. Leakage performance, however, is expected from the next phase of testing in PCS-1.

Based on operating history to date, it can be concluded that the SNAP-8 mercury PMA is a highly successful unit capable of operating for 10,000 hours with a high level of confidence.

e. Mercury PMA Bearings

Balls of nine bearings (P/N 095306) which were inspected during November 1965 for scratches made inadvertently during rework of bearing retainers by the vendor, were found unacceptable on the basis that the scratched areas had an average finish of 2.0 rms which is one order of magnitude too large. It was decided to refit the bearings with new balls, and 13 pounds of M-50 bearing steel was shipped to the vendor.

As a precaution, two of the best sets of balls (12 balls per set) out of the nine rejected sets had been put aside for use in an emergency until the new bearings were delivered.

Five complete bearings were delivered to Aerojet during the week of 13 June 1966. One bearing was rejected because its contact angle was about 2° in excess of the allowable tolerance. It will be determined

whether the bearing can be used in a mercury PMA where the shaft press fit of .0005 in. (the maximum design press fit) can bring the contact angle within the allowable angle of contact tolerance. This bearing, if accepted, will be treated as a selective type of assembly. A second bearing was rejected on the basis of excessive radial play, and a third bearing was rejected because of an inadequate finish. There was an insufficient number of balls to complete the nine bearings scheduled for completion during this report period.

Delivery of four outstanding bearings will be established by the vendor after receipt (or manufacture) of the remainder of balls from their ball plant.

7. Mercury PMA Bearing - Test Results

a. Summary of Bearing Life Test Results

Series of performance and checkout tests were conducted in several of the SNAP-8 test facilities with the mercury PMA, containing ball bearings P/N 092867. A summary of the test results covering a period from June 1964 to February 1966 is tabulated below:

Item	Bearing P/N	Hg PMA P/N	Test Facility	Bearing Test Time (hrs)	Bearing No. of Starts-Stops	Test Status
1	092867	093347-1	IML-3	120	72	Sept. 64-Dec. 64 Completed
2	092867	093340-1	SL-1	756	37	June 65-Nov. 65 Tests suspended
3	092867	093347-5	RPL-2	671	43	Jan. 65-June 65 Completed
			PCS-1 Ph. IV Step 1	123	15	Nov. 65-Dec. 65
			PCS-1 Ph. IV Step 2	144	16	Jan. 66-Feb. 66 On test
			TOTAL	938	74	

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The maximum operating time for any one pair of bearings during these tests was obtained with mercury PMA P/N 093347-5 (item 3) for a total accumulated time of 938 hours and 74 start-stop operations.

Most of the tests were performed with the lubricant at approximately 210°F and injected at a flow rate of 200 to 240 lb/hr to two bearings.

Prior to mercury PMA startup, the lubricant was degassed by circulation through a filtered bypass circuit for several hours at approximately 300°F and with a vacuum maintained in the supply tank. During operation, but prior to being injected into the bearings, the lubricant was passed through two filters that were placed in series; a lubricant-coolant filter with a 25-micron nominal rating and the mercury PMA lubricant filter, rated at 5 microns nominal. Preceding all runs where the unit had been idle for some time, lubricant at 210°F was injected into each bearing for 3 seconds at a flow rate of 100 lb/hr. After each startup, continuous lubricant flow was initiated when the unit reached an operating speed of 7800 rpm.

The majority of these tests were performed with no abnormal incidents related to the bearings or the lubrication system.

b. Bearing and Lubrication Operating Parameters Obtained from SNAP-8 Test Systems

(1) Tests in liquid mercury loop (IML-3)

Typical mercury PMA bearing outer-race temperatures (°F) obtained during tests in the IML-3 test facility on 13 October 1964 are shown below. The tests were conducted at 7800 rpm and the lubricant (mix-4P3E) inlet temperature was maintained at 210°F.

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Test No.	Bearing Location	Lubricant Flow Rate Per Bearing lb/hr				
		80	90	100	110	120
1	Motor End	251	245	239	233	228
		249	243	236	230	226
	Pump End	242	238	234	230	227
		240	236	232	227	224
3	Motor End	247	242	238	235	232
		245	241	237	234	232
	Pump End	239	236	234	233	231
		235	232	231	230	228

On the basis of bearing outer-race operating temperatures, the lubricant flow rates of 80 through 120 lb/hr are acceptable. However, based on overall bearing and seal power losses as well as the mercury PMA motor cooling requirements, the lubricant flow rate was established at 100 to 120 lb/hr/bearing.

(2) Tests in system loop (SL-1)

Bearing and lubrication operating parameters, recorded on 24 September 1965, during tests in the SL-1 test facility for a specific period of 24 hours of continued testing, are typical for the PMA bearings. The tests were performed at or near a speed of 7880 rpm. The values are tabulated below:

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Parameter	Unit Time	0200	0600	1000	1400	1530	2000
Lubricant inlet temperature	°F	211	210	210	211	211	211
Lubricant outlet temp. (at seal outlet)	°F	247	246	246	247	248	248
Lubricant inlet pressure	psia	0.6	0.6	0.6	0.6	0.6	1.05
Lubricant outlet pressure	psia	2.9	2.9	2.9	2.9	2.8	4.2
Lubricant flow rate (two bearings)	lb/hr	222	221	223	230	233	233
Bearing outer race temperature	°F	244	244	244	245	246	246

From the data it can be seen that the bearing outer-race temperature remains the same for a relatively steady lubricant flow rate (time 0200, 0600, and 1000). At an increased flow rate of 5% and an increased lubricant inlet temperature of 1°F, the outer-race bearing temperature increased only 2°F. The average lubricant temperature in the bearing is estimated at 230°F. The lubricant outlet temperature shown ranging from 246°F to 248°F is measured at the seal outlet, which also includes heat generated by the seal.

(3) Tests in PCS-1 Phase IV Step 1

A series of performance and checkout tests was performed for PCS-1 Phase IV (RPL-2, Step 1 and Step 2) system. There were no bearing and lubrication parameters measured as such, but a few important ones (system shutdown parameters) were recorded. A specific test period performed on 8 December 1965, covering approximately 10 hours of continuous testing that includes a period of bearing temperature stabilization after a start, is tabulated below. The lubricant was mix-4P3E at a nominal inlet temperature of 210°F. Neither lubricant outlet temperature nor lubricant inlet pressure were recorded.

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Parameter	Unit/ Time	1315	1325	1338	1429	1510	1557	1706	1800	1900	2003	2059	2200	2259
Hg PMA speed	rpm	7880	7880	7865	7865	7865	7860	7860	7860	7865	7865	7835	7880	7865
Lubricant flow rate	lb/hr	208	201	203	196	191	201	200	189	192	189	189	188	185
Lubricant outlet pressure	psia	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Motor end brg. temp.	°F	222	240	252	253	250	252	265	247	244	237	248	241	236
Pump end	°F	218	235	247	248	248	251	266	249	249	243	256	244	240

Data show that the bearing operating temperature is stabilized in approximately 20 minutes from the start. The fluctuations of the bearing temperature after temperature stabilization cannot be readily explained except that they may be caused by changing tests of mercury PMA and other system components. The warning bearing temperature is set at 275°F and shutdown is set at 300°F. The highest recorded bearing outer-race temperature of 266°F is well within the normal bearing operating temperature.

C. HEAT EXCHANGERS

The major work in the development of the heat exchange components for the past six months has been in the continued evaluation of performance in conjunction with PCS testing. Both the boiler and condenser have been evaluated during the PCS-1 Phase IV Step 2 test series and their performance compared with earlier tests of similar units. No significant component degradation was detected during operation, and overall performance was satisfactory. However, during the last series of tests, the boiler was contaminated with the organic L/C fluid and was deconditioned on the last startup.

The completion of component testing provided a basis for a revised mathematical model of the boiler and a computer program based on the model has been completed. The two-part program provides a boiler design based on fixed requirements and/or provides off-design performance based on a fixed design and variable operating conditions.

A boiler technology program has been initiated with the objective of improving boiler performance. Aspects of the boiler to be investigated include:

- Boiler conditioning
- Life/corrosion/erosion
- Liquid entrainment
- Outlet pressure oscillations

The test vehicle is a one-seventh scale system utilizing a NaK heated, single-tube boiler test section. Design of the test facility has been initiated.

1. Boiler

- a. Boiler description

The SNAP-8 tube-in-tube (T-T) boiler, P/N 097444-7, S/N A-1 shown in Figure V-67, is a counterflow heat exchanger where the entering subcooled mercury is preheated, evaporated and superheated in a single pass. The mercury flows in seven 30-ft long tubes which are nested within an outer tube. The NaK is in counterflow in the area between the tubes containing mercury and the outer tube. The entire assembly is coiled to complete the configuration. A "plug" to restrict flow is placed in the inlet of the seven parallel flow passages, giving a liquid velocity up to 6.5 ft/sec. The plug in this restricted flow section is a hollow rod spaced from the inside of the tube by either a spiral wire or machined threads; the mercury flowing in a spiral path in the annulus between the plug and tube. The pitch of the spiral flow varies with the boiler configuration. Downstream of the 5-ft long plug, the spiral flow is maintained by a spring insert which rests against the

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inside diameter of the tube. The .060-in. diameter spring coiled on a 2.5 in. pitch, serves to separate the high density liquid from the vapor in the high quality region of the boiler.

As reported earlier (Reference 5), the performance of the T-T boiler has been evaluated during component testing. The overall performance of the unit was satisfactory, but the system could benefit from modifications which would improve the boiler's startup conditioning requirement,* decrease the magnitude of outlet pressure oscillations, reduce the extent of liquid entrainment, and improve boiler life expectancy.

b. Performance evaluation

(1) Design point performance

The performance of the boiler at its nominal design conditions was evaluated each day during the 300 hours of operation accumulated over the PCS-1 Phase IV Step 2 test program. The purpose of the evaluation was to detect component degradation. With the exception of the last startup (discussed below), the boiler's performance was satisfactory with no change in performance noted. The design point performance during Step 2 testing is compared with the data obtained with comparable operating conditions during component tests (PCS-1 Phase IV Step 1) indicated below:

*Conditioning describes the time-dependent change in performance on initial startup of a new unit wherein outlet mercury conditions (quality and exit temperature) increase as a function of time.

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<u>Operating Conditions</u>	<u>Component Tests (Step 1)</u>	<u>Systems Tests (Step 2)</u>
NaK side		
Flow rate, lb/hr	44,900	42,250
Inlet temperature	1322	1329
Hg side		
Flow rate, lb/hr	12,000	11,800
Inlet temperature, °F	448	432
<u>Performance Parameters - Hg Side</u>		
Outlet temperature, °F	1296	1267
Pressure drop, psi	96	84
Liquid entrainment, %	**	4
Outlet Pressure Oscillations		
Magnitude, ±%	1.5	2.0
Frequency, cps		
Inventory, lb	18	**
Required Surface Area (%)	53	60

The NaK-side temperature profiles for Steps 1 and 2 were identical. A typical design-point temperature profile from Step 1 is shown (temperature data is corrected) in Figure V-68.

A reduced boiler pressure drop is the only performance parameter which changed appreciably between Steps 1 and 2; and, even this change is not considered significant from a system point of view. The reduced pressure drop was not reflected in the NaK-side temperature profiles but is considered to be caused by a change in thermal performance. It is postulated that in Step 1 tests, the plug insert was more effective and resulted in boiling taking place in the "tight-pitch" (3/8 in. pitch) section of the plug insert, while in Step 2 testing, the exit quality from the "tight-pitch" section was somewhat lower. The cause for the change in performance is unknown but may be associated with a change in surface wetting characteristics in the plug region of the boiler.

**Indeterminate from test data.

(2) Off-design performance

Off-design performance was previously correlated with pinch-point temperature difference (refer to Figure V-67). The pinch-point temperature difference is defined as the difference in temperature between NaK and mercury at the liquid vapor interface. This temperature difference represents the minimum thermal potential for evaporating the mercury within the boiler. It is a convenient parameter to use as it relates NaK flow rate, mercury pressure, mercury flow rate, and NaK inlet temperature in a common dependent variable. The following parameters were correlated with pinch-point during Step 2 tests:

Mercury-side pressure drop
 Outlet pressure oscillations
 Terminal temperature difference
 Inventory shift.

The data for mercury-side pressure drop are shown in Figure V-69 with the results for Step 1 (component tests) superimposed. The off-design performance is comparable to the design point evaluation in that the pressure drop is lower. The pressure drop data for the two test series were empiracally correlated by the equations shown below:

Step 1 Tests

$$\Delta P = \frac{W_H}{12,000} (64 + .13 \Delta T_P)$$

Step 2 Tests

$$\Delta P = \left(\frac{W_H}{12,000} \right)^{1.8} (77 + .37 \Delta T_P)$$

where

ΔP = Hg-side pressure drop, psi
 W_H = Hg-flow rate, lb/hr
 ΔT_P = Pinch-point temperature difference, °F

The pressure drop is less sensitive to flow rate and pinch-point temperature difference in the Step 2 tests. This again, reflects the reduced quality from the "tight-pitch" region of the plug insert and may have been caused by surface contamination. For example, a review of incident reports for Step 1 tests showed that a failure of an oil-filled differential pressure transducer occurred late in Step 1 testing which could have introduced a small amount of oil into the mercury loop boiler.

Data on boiler stability are shown in Figure V-70. The boiler is acceptably stable with an oscillation magnitude of $\pm 2.5\%$ at the nominal minimum pinch-point temperature difference of 30°F . The Step 1 data show somewhat greater stability ($\pm 2\%$ at a 30°F pinch-point) but no quantitative comparison is possible as data scatter can account for this difference.

Figure V-71 shows the terminal temperature difference as a function of pinch-point temperature difference. The data include wide variations in mercury flow rate without any distinction being possible. Since the terminal temperature difference is so small compared to the absolute magnitudes of the temperatures, data scatter can completely shroud any small trends. As an average, it can be stated that the terminal temperature difference is about 40°F . The average terminal temperature difference for Step 1 is about 20°F . The lower temperature difference of Step 1 likely indicates better performance during Step 1, but instrumentation inaccuracies preclude making a definite comparison.

Figure V-72 presents change in boiler inventory as a function of pinch-point temperature difference. Change in inventory is shown rather than actual inventory because the initial boiler inventory is not accurately known. A reference pinch-point temperature difference of 30°F is assumed in the plot. For changes in pinch-point (relative to 30°F), the plot presents the corresponding change in boiler inventory. The Step 1 data indicates a lesser degree of inventory shift than the Step 2 data. This is consistent with the assumption of poorer thermal performance in the plug insert,

as more inventory implies a lower quality and, hence, lower pressure drop in this region of the boiler. This is in keeping with a slight decrease in performance for Step 2. The inventory transferred to the boiler during Step 2 startups was noted to be greater for latter startups than for the initial startup.

(3) Deconditioned performance

The performance of the boiler on the last startup of Step 2 tests showed that the boiler was deconditioned. This deconditioned performance is shown by the NaK temperature profiles taken before and after the last startup (Figure V-73). The startup deconditioning was caused by oil contamination of the mercury tube when the lubricant-coolant fluid (mix-4P3E) was accidentally introduced into the mercury loop.

Oil was permitted to enter the mercury loop, following an automatic system shutdown when the MPMA did not shift automatically to facilitate 400 cps power and the manually operated shutoff valves controlling the lubricant-coolant flow could not be activated in time to prevent contamination. Activation of these valves is now automatic rather than manual and future recurrence is not expected.

The boiler was cleaned following Step 2 shutdown and will be restarted for Step 3 tests without the presence of oil contamination.

(4) SNAP-8 Boiler Computer Code

Two sets of computer codes were established for the SNAP-8 boiler design and performance analysis. The first is called "PROgrammed BOiler DEsign ANalysis." This computer code establishes the required boiler length and operating thermal and dynamic parameters on the basis of arbitrarily assumed mercury flow passage internal geometry, tube size and number of tubes. The boiler design specifications defined by the NaK and mercury flow rates, NaK inlet temperatures, mercury inlet and exit temperatures and exit pressure are used as arbitrary input parameters. A similar computer

code, called "PROgrammed BOiler PErformance ANalysis", was established to investigate the given boiler performance characteristics subject to arbitrary input conditions. This computer program utilizes the prescribed boiler mercury flow-passage internal geometry, tube size, number of tubes, and the total boiler length as established in the preceding program and determines the boiler operating parameters in terms of arbitrary input conditions. The computation results reconstructed in terms of NaK temperature profiles and Hg temperature and pressure profiles compare relatively well with the SNAP-8 boiler test data at high and low NaK temperature schedules. These profiles are shown in Figures V-74 and -75. The corresponding operating parameters are presented in Table V-10. For comparison purposes, Table V-10 is supplemented with actual T-T boiler test data. Relative to boiler overall heat transfer rates, the test data compare reasonably well with the analytical predictions. The boiler excess superheat length as obtained from the test is in close agreement with the computed values. The discrepancy is evident in the presented pressure drop data. This may be attributed to different test boiler exit-pressure operating conditions and the unknown pressure drop distribution in the test boiler plug-insert section. The test boiler plug-insert section was not internally instrumented with pressure measurement devices. The pressure drop in this section was estimated from the shape of the NaK temperature profile and the measured NaK and mercury flow rate. It is evident, however, that excessive boiler pressure drop can result when the small-pitch helical flow passage in the preheat section performs better than analytically predicted. It is intended to rectify this problem in the SSBP program where the experimental work will place attention on the boiler plug-insert section heat transfer and two-phase flow pressure drop.

(5) Fabrication

Fabrication of the T-T boiler, P/N 097444-31, S/N 481601 was completed.

(6) Boiler technology program

In general, the present SNAP-8 boiler meets system performance requirements. However, experience has shown that improvements are required in order to provide predictable and reproducible operation. The life of boiler material is questionable, the initial performance characteristics and attainment of 100%-quality vapor are uncertain and pressure fluctuations, while acceptable, require a system penalty. These areas of potential improvement are understood to a degree, in that variables affecting each factor have been noted; however, an experimental investigation is needed to obtain data on the design and operating parameters for reproducible performance. Consequently, a task was undertaken to define the specific problem areas and to plan an experimental program. The results of this task were presented in a report (Reference 15) which resulted in approval of the experimental program.

The design of the experimental facility has been initiated. The facility consists of a 1/7th scale NaK-heated mercury boiler with appropriate test support equipment to provide forced flow of NaK and mercury, heat addition and removal. The loop is schematically shown in the Process and Instrumentation Diagram, (Figure V-76). The boiler is divided into two sections, one containing the inlet insert plug and the other a boiler-superheater. The mercury and NaK sides of each section are instrumented.

Configuration variables will include design of the plug insert and downstream turbulation in the boiler-superheater. The only design restriction is that the basic size of the tube has been held at .652 in. I.D.

Testing is scheduled to start in the second quarter of Calendar Year 1967.

(7) Summary

The additional tests of the boiler during PCS-1 Phase IV Step 2 have provided confirmation of boiler performance. No significant change in performance was observed during operation, although thermal performance was slightly reduced over that observed during earlier component testing.

The tests of the boiler have formed the basis for a computer program which predicts off-design performance of a fixed-design boiler. The program also can be used to size a boiler for arbitrary requirements.

A boiler technology program has been initiated to study the effects of design on boiler performance. The goals of the program are to extend boiler life expectancy, provide consistent performance from unit-to-unit on startup, and to reduce pressure oscillations and liquid entrainment.

2. -1 Model Condenser

a. Description

The -1 Model condenser (P/N 092500-1) shown in Figure V-77 is a counterflow tube-in-shell (T-S) heat exchanger with fixed tube sheets. Seventy-three tapered tubes contain the condensing mercury with the coolant contained in the tapered shell. The shell-side coolant is the eutectic mixture of sodium and potassium (NaK) which flows through the condenser as part of the heat-rejection system. Tapered tubes are used to maintain vapor velocity in very low gravity operation through the condenser length, providing a continual movement of condensate toward the liquid-vapor interface by means of the vapor drag on the condensate droplets.

The component tests of the condenser, reported earlier (Reference 5), indicated that the unit was satisfactory. Performance was reviewed again in conjunction with systems tests performed during PCS-1 Phase IV Step 2. Approximately 300 hours of testing were accumulated.

b. Performance

The condenser performance has been analyzed and compared with data obtained during earlier component testing. Performance parameters evaluated were:

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Condensing pressure as a function of available area,
Condensing pressure oscillations,
Overall heat-transfer coefficient, and
Effects of noncondensable gas.

In general, there was no change in condenser performance. However, the data are on the overall coefficient of heat transfer which indicated a considerable scatter that is postulated to be caused by the presence of noncondensable gas. Evidence to support this postulate also is provided by considering the NaK-side temperature profiles.

The data on condensing pressure as a function of condenser length have been compared with earlier data (Figure V-78). These data show the effects of inventory removal, such as would occur due to space-seal leakage. The parameters independently established during the change in inventory were mercury flow rate, HRL flow rate, and NaK inlet temperature. The data are in reasonable agreement with Step 1 tests, falling within a realistic scatter band.

An important question which has been answered from the condenser testing, is the relationship between boiler-outlet pressure fluctuations and condensing pressure fluctuations. Variations occur at both of these locations, but it has not been determined whether these variations are generated separately or are interrelated. The magnitude of pressure oscillations in both the boiler and condenser are shown in Figure V-79. On a percentage basis, the boiler and condenser oscillations follow a one-to-one relationship. This leads to a sensitivity of condensing pressure oscillations to the boiler pinch-point temperature as shown in Figure V-80. It can be seen that the condenser variations correlate with pinch-point as do the boiler variations in pressure, indicating that condenser pressure oscillations are generated in the boiler. The question of whether the pressure variations at the boiler and condenser are in phase is of importance since TAA power variations are affected by the ratio of inlet-to-outlet pressure. If the turbine inlet and outlet

pressure oscillations are in phase, the power variations will be less than if the pressures are out of phase. Figure V-81 shows strip-chart recordings of boiler outlet and condenser inlet pressures (TAA inlet and outlet pressures). Inspection of the charts indicates that the pressure variations would be in phase within the accuracy of the instrumentation. The conclusion is that the TAA power output variations will not be subject to the more severe occurrence of out-of-phase turbine inlet and outlet pressures.

Heat transfer within the condenser was evaluated by determining an average overall heat transfer coefficient in the condensing region that was based on a condensing area derived from the pressure drop across the condenser and from the NaK-side temperature profiles. The average overall coefficient, based on a condensing area derived from the pressure drop, was 1124 btu/hr-ft²-°F with a standard deviation of ±217. The average overall coefficient based on a condensing area derived from the NaK temperature profile data is 1306 btu/hr-ft²-°F with a standard deviation of ±337. By contrast, Step 1 data indicated an overall coefficient of 1090 btu/hr-ft²-°F with a standard deviation of ±138. The overall coefficient data of Step 1 tests will remain the established reference value because of the lesser scatter that is associated with it and because it will give a more conservative analysis of condenser performance.

A review of the NaK-side profiles has shown that there is a section of tubing within the condenser where very little heat is transferred for long condensing lengths (large condensing areas). This is shown in Figures V-82 and -83 where NaK-side profiles are plotted for long and short condensing lengths, respectively. A reasonable explanation of this phenomena is that noncondensable gas within the vapor region of the mercury loop is "pumped" to the condenser where it accumulates. In the case of a long condensing length, the noncondensable gas accumulates within the condenser tube in the region described by the flat NaK profile, giving rise to a localized region of poor heat transfer. In the case of the short condensing lengths, the

noncondensable gas remains in the region of the condenser inlet manifold and does not appreciably affect heat transfer within the condenser. If this hypothesis is correct, it offers a method for venting the condenser during operation without extensive redesign of the condenser. That is, the loop mercury inventory can be increased thereby providing a short condensing length and forcing the noncondensable gas into the condenser inlet manifold. The manifold can then be vented through a restriction to a vacuum cold-trap system for ground test or to space during system operation. Verification of the hypothesis and the design of a TSE vent system is under consideration for future testing.

c. Summary

The tests of the condenser in conjunction with SNAP-8 system evaluation have been compared with the earlier testing performed during component evaluation. No significant change in condenser performance was observed; however, it is suspected that the presence of noncondensable gas in the system is giving significant scatter in evaluation of the overall heat transfer coefficient. The NaK-side temperature profile suggests that the location of the noncondensable gas can be controlled by mercury system inventory, leading to a possibility for venting the condenser during system operation.

D. VALVES AND CONTROLS (0741-57)

1. Temperature Control Valve (P/N A65078)

Two temperature control valves, which represent the current -1 design, were delivered by the Vinson Division of the Adel Manufacturing Co. The valves were assigned serial numbers of S/N 100G and S/N 101G.

Final acceptance tests conducted at the Adel Manufacturing Co. included flow-chamber and valve-body proof tests, control-chamber volume measurements, full-closed leakage, and flow tests at various valve positions. Pressures used for control-chamber and valve-body proof tests were 240 psig and 100 psig, respectively. The control chamber volume (with the valve in

full-open position) of the S/N 100G valve was 56.7 cubic inches and the control chamber volume of the S/N 101G valve 55.6 cubic inches. The calculated volume required to produce the desired valve motion was 56.7 cubic inches.

The valve control chambers were filled with NaK at Aerojet and temperature versus position calibrations were conducted. The data from these tests were combined with the data from flow tests conducted at the Adel Manufacturing Co. and plotted to produce the curves shown in Figures V-84 and -85. Noted on the plots are full-closed leakage and full-open pressure drop. The full-closed leakage was zero compared to the design requirement of eleven lb/hr. The full-open pressure drop was 0.9 psid and 0.45 psid, respectively, for a NaK flow rate of 39,500 lb/hr at 665°F for the S/N 100G and S/N 101G valves. The original design requirement was .3 psid. However, this was later relaxed to 1 psid for the design flow-rate of 39,500 lb/hr.

With reference to Figures V-84 and -85, note that the calibrated performance curves parallel the design performance curves for the greater portion of the opening temperature span and then deviate near the high temperature end. This is a result of the opening temperature span being approximately 150°F compared to the design value of 120°F. The calibrated performance curves may be shifted 15°F to the right or 15°F to the left by adjustment of the TCV set-point mechanism. Utilizing this adjustment, it may be seen that the greater portion of the calibrated performance curve may be made to fall almost directly on the design performance curve. The valve set-points were not adjusted after initial calibration to accomplish the above condition because the desired dispensation of the temperature overlap has not been made.

The two Vinson temperature control valves were heated to 800°F to check the adequacy of the relief feature and to calibrate the set-point mechanism. The relief feature in both cases proved to be adequate for 800°F operation. The opening set-point adjustment was determined to be 0.1 inch per 13°F change in set point for both valves. A photograph of the Vinson temperature control valve is shown in Figure V-86.

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Following temperature calibration, the S/N 100G valve was installed in the PCS-1 Phase IV Step 3 loop and the S/N 100G valve was packaged and delivered to LeRC.

A review meeting was held on 14 June 1966 to discuss design changes and review a preliminary specification (AGC 10424). No changes to the basic design were recommended.

2. Condenser Bypass Valve (CBV), P/N 610720

Assembly of a NaK fill loop was completed and fill and calibration fixtures were fabricated. The NaK control chamber for the CBV was charged with NaK, seal welded, and temperature calibrations performed.

Valve-position calibration tests indicated that the valve moves from the full-open position at 651°F to the full-closed position at 681°F. The design target values were 651°F and 665°F, respectively. Possible causes of this difference are a combination of a gas inclusion and an incorrect NaK volume, undersized control chamber (volume measured inaccurately), or a combination of these two. Conflicting data taken during the NaK fill process, precluded accurate assessment of the exact cause.

The overtemperature compensation feature of the valve was tested by heating the valve to the design temperature limit of 710°F.

The results of the temperature calibrations were combined with flow data generated by the Fox Valve Development Co. to produce the total performance curve shown in Figure V-87. Note that the total performance curve can be shifted 20°F to the right or 20°F to the left by adjustment of the set-point mechanism. The high sensitivity of this adjustment (1 turn per 5° change in set point) would indicate that a negligible amount of gas is present in the control chamber. Since the total performance of the CBV is considered acceptable for initial tests, no further activity is planned.

Experience gained during the NaK fill and temperature calibration period will be utilized as a basis for design changes in the next

complement of valves (i.e., variable control chamber volume). A photograph of the condenser bypass valve is shown in Figure V-88.

3. Double-Solenoid Latch Valves, P/N V-54600-06 and P/N V-54600-04

Evaluation of these valves was continued in PCS-1 Phase IV Step 2 testing. No incidents or failures of the V-54600-04 valves occurred. One incident and one failure occurred with respect to the V-54600-06 valves. An incident occurred when the discharge L/C valve on the TAA failed to open during startup. Investigation of this occurrence revealed that the valve mating connectors were carbonized and shorted. This probably was caused by high temperature resulting from the valve being energized for an extended period during the previous loop shutdown. The valve connectors were cleaned and mating connectors replaced and normal valve operation was resumed. After the final PCS-1, Phase IV Step 2 shutdown, mix-4P3E was discovered in the alternator cavity of the TAA. Upon investigation, both the inlet and outlet L/C valves were found in the closed position, which is the normal shutdown position. However, further investigation disclosed that the TAA, E/C outlet-valve closing solenoid was shorted. The valve was disassembled and inspected by the valve subcontractor. It was found that the solenoid had shorted turn-to-turn. A failure analysis has not been completed as yet. However, the cause of the failure is thought to be voltage breakdown of the ceramic insulation. This was probably caused by the presence of moisture in the solenoids which was introduced through a cracked glass connector seal during thermal cycling of the valve. The cracked connector resulted from the cleaning operation, following the previous incident.

A review meeting was held on 6 April 1966 to discuss design changes and to obtain final inputs for a valve specification for the next complement of valves. Basic changes to the valve design included the replacement of silver magnet wire with a nickel-iron clad copper wire. The reason for this change was the fact that silver produces isotopes with relatively long half-lives when irradiated which would lead to health and handling problems in the reference system configuration. Another change was the incorporation of a

ceramic-to-metal hermetic seal for the connector rather than a glass seal. The specification generated, including inputs resulting from the review meeting, is AGC-10504. An order, referencing this specification, for six valves has been placed with the Valcor Engineering Corporation, Kennilworth, New Jersey.

Additional tests with respect to the principle of utilizing a high-frequency a-c signal input to the solenoids as a means of detecting changes in valve position, were conducted and design of the required circuitry has been initiated.

A photograph of the double-solenoid latch valve is shown on Figure V-89.

E. START-UP SYSTEM

1. Mercury Injection System (P/N 094583)

A reworked safety valve was installed in the S/N 3 unit and checkout tests were conducted. In general, the valve operated in a sluggish manner, although it did move freely to the safety (closed) position. The S/N 3 unit was scheduled for use on a minimum acceptable basis and a replacement safety valve was ordered.

A decision was made to bench test the S/N 3 unit to demonstrate its capability under simulated operating conditions. In general, the objectives of the test are as follows:

- a. To measure the net expulsion of mercury.
- b. To operate the system through forty simulated injection cycles.
- c. To determine the condition at the bellows in the expulsion tank after forty injection cycles.

The bench test setup is shown in Figure V-90.

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During the test-setup checkout tests, it was noted that the Hg reservoir safety valve would not return from the closed position. The safety valve was removed and disassembled. Inspection of the parts disclosed carbonaceous matter caked to the safety valve piston which caused the piston to freeze in the valve cylinder; no metal-to-metal galling was noted. The origin of the carbonaceous matter is unknown. Although the caked condition probably resulted from local heating of the safety valve during welding and later when attempts were made to free the valve. A new safety valve has been fabricated and bench tests will proceed after the valve is installed in the S/N 3 unit.

The S/N 2 unit has been installed in the PCS-1 Phase IV Step 3 loop along with an isolation valve (P/N 098482), shown in Figure V-91, where they will function to support demonstrations of the reference system start-up.

The S/N A-1 Valcor mercury flow-control valve (P/N 097330) which was damaged during final electrical checkout tests, was repaired; a typical valve assembly is shown in Figure V-92. Electrical wiring additions were made and final operational checkouts completed. Valve indicator motion measured .4436 inches and total travel time was 9 minutes $\pm$ 10 seconds with a 28 VDC power input.

Tests of the S/N A-3 Valcor mercury flow-control valve were continued in PCS-1 Phase IV Step 2; no problem associated with the mercury flow-control valve were encountered. Approximate operating time during Step 2 tests was 300 hours. A total of nine start-ups and approximately 75 flow-rate changes were completed. Total operating time during PCS-1 Phase IV tests is approximately 422 hours.

Flow data has been plotted as a function of percentage travel between limit switches. A comparison of this data with bench calibration data is shown in Figure V-93. Note that the calibration curves closely parallel one another until approximately 75% open at which time the curve plotted from PCS-1 Phase IV Step 2 test data deviates from the design and calibration curves. The most probable reason for this deviation is inaccuracies in PCS-1 Phase IV instrumentation in the high-flow ranges where the deviations occurred.

After Step 2 tests, the mercury flow-control valve was removed from the test loop, inspected and cleaned, and re-installed in the loop for Step 3 tests; no corrosion or erosion was noted. However, the valve parts in contact with mercury were coated with mass transfer particles deposited from the mercury loop.

Work was initiated on replacement valve parts which would change the normal valve travel time from 600 seconds to approximately 300 seconds and a specification was initiated which covers upgrading of the valve actuator in order to meet reference system requirements.

2. Start Programmer (P/N 097260)

The -X start programmer, Figure V-94, has been mounted in the control console in Building 180 and is ready for Phase IV Step 3 testing. Figure V-95 shows the back of the control console with the potentiometer adjustments of the start programmer shown on the top right.

This unit has been designed and fabricated for ground testing only and is fully accessible so that changes can be made easily when start-up tests are conducted.

This start programmer does not include shutdown or restart capability and it is not packaged for flight application. Therefore, the unit must be packaged for flight and if multi-starts of the SNAP-8 EGS are required, additional circuitry must be designed and tested to provide for orderly shutdown and restart.

3. Inverter (Westinghouse P/N 976J412)

At the present time, one inverter is installed in Building 180 awaiting start-up tests in PCS-1 Phase IV operations.

A second inverter and power factor correcting capacitors are installed and ready for tests in INL-3. Some initial testing has been conducted.

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An investigation was conducted to determine the capability of the inverter to start up and operate the pump motors at 95 cps, and at 220 cps. The results of this investigation were published in TM 4936:66-409 (Reference 16).

The conclusions of this investigation are that:

- a. The inverter/PMA subsystem presently available will not start reliably.
- b. The load requirement of the PMA's at 95 cps is within the inverter rating and no problem is expected at 95 cps operation.
- c. The revised load requirements of the PMA's at 220 cps is higher than the rating of the inverter motor, and the motor will be overloaded during 220 cps operation.
- d. To make PMA starting more reliable, one or more of the following actions are recommended:
 - (1) Reduce the PMA bearing breakaway torque.
 - (2) Increase the PMA motor starting torque by increasing rotor resistance; using a larger induction motor or employing a PM synchronous motor.
 - (3) Increase the inverter peak capacity at 95 cps from 2.6 KVA to 8.5 KVA.
 - (4) Increase the starting capacity of the inverter/PMA subsystem by the addition of power-factor-correction capacitors during the start and remove them after the PMA has been started.

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- e. To solve the problem of inverter motor overload at 220-cps operation, one of the following possible actions are suggested:
- (1) Reduce the maximum PMA operating frequency during start-up from 220 cps to approximately 195 cps.
 - (2) Increase the inverter input voltage from 28 volts to 37 volts D.C. at 220 cps.
 - (3) Increase the horsepower rating of the inverter motor.

The existing inverter is designed to store the heat energy developed during its operation. At the end of a start-up run, the temperature of the unit is at the maximum allowed. If a restart run is required, it will be necessary to allow the inverter to cool to 40°C before a full restart run can be made. This requirement could be eliminated by providing a means of cooling for the inverter.

Any design change of the inverter must include consideration of any recycle requirements and the influence this has on the method of heat dissipation.

F. STEADY-STATE ELECTRICAL CONTROLS

1. Voltage Regulator-Exciter (VR-E)
(P/N 3SD2060DR135) and (P/N 440257911)

A prototype VR-E is mounted in the TRA and the LCA which are installed in Building 180. These units are wired into the system and are ready for Phase IV Step 3 tests.

Tests conducted on the preprototype VR-E during PCS-1 Phase IV Step 2 operations demonstrated steady-state and transient performance which satisfies all the known requirements. The results of these tests are published in TM 4936:66-423 (Reference 17) and in TM 4936:66-415 (Reference 18).

A summary of the performance of the VR-E as demonstrated by laboratory and loop tests is as follows:

- a. The VR-E maintains steady-state voltage regulation well within the specified range of $\pm 3\%$.
- b. The voltage dip, rise and recovery time, when full load is suddenly applied and removed, are within any known system or load requirements.
- c. The stability of the system during transient and steady-state operation is fully satisfactory for the known requirement.
- d. The system provides sufficiently high fault currents to allow for selective tripping of load breakers.

2. Speed Control (P/N 094897-3) (P/N 098613-3) (P/N 094680)

A prototype speed control is mounted in the TRA and the LCA which are installed in Building 180. These units are wired into the system and are ready for PCS-1 Phase IV Step 3 tests.

Tests conducted on the preprototype speed control during Step 2 operations, demonstrated steady-state and transient performance which satisfies all the known requirements.

- a. The speed control maintains steady-state speed regulation within the specified range of $\pm 1\%$.
- b. The speed dip, rise and recovery time when full load is suddenly applied and removed are within any known system or load requirements.
- c. The stability of the subsystem during transient and steady-state operation is fully satisfactory for the known requirements.

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- d. Wave form distortion is introduced by the saturable reactor control, but harmonic content is within the specification allowance.

The tests have established that there are two areas where performance of the speed control subsystem could be improved.

- a. When the frequency drops to approximately 370 cps, the present system begins to increase the parasitic load, continuing to apply additional load until the turbine has stopped. This could be eliminated by modification of the frequency sensing circuit.
- b. Steady-state operation at full vehicle load results in random variation in frequency of 3 to 4 cps. This is caused by random variation in pressure in the mercury loop. The frequency variations could be eliminated by eliminating the pressure variations, or it could be reduced by modifying the characteristic of the speed-control magnetic amplifier.

The results of these tests are published in TM 4936:66-422 (Reference 19) and TM 4936:66-423 (Reference 17).

- 3. Low-Temperature Control Assembly (LCA) (P/N 097054-1) and Transformer-Reactor Assembly (TRA) (P/N 097760-1)

The LCA and the TRA are mounted in Cell 4, Building 180. All cooling and electrical connections have been made, and they are ready for PCS-1 Phase IV Step 3 tests.

The housings of these two units are of the test-support-equipment type only and are not suitable for flight application.

To make these units capable of flight operation, the housings must be built so that they can be sealed and the electrical connections brought out through ceramic terminals.

A sealed TRA package has been designed and drawings completed; however, a sealed package has not been fabricated.

An LCA capable of flight operation has not been designed or fabricated and must be completely developed.

4. Parasitic Load Resistor (PLR) (P/N 097223)

A PLR is installed in the primary loop in Building 180. It is electrically connected to the speed-control system and is ready for tests in PCS-1 Phase IV Step 3 operations.

This unit was electrically connected during Phase IV Step 2 tests and successfully dissipated the speed-control parasitic power into the primary NaK. During this operation, the PLR unit successfully dissipated up to 46.5 KW of parasitic power.

This PLR has operated in the system loop for 302 hours, and three PLR Calrod elements have been operating at a wire temperature of approximately 1600°F for 19,800 hours without exhibiting significant degradation.

A second PLR is installed in LNL-3 where NaK will be circulated through the tank during NaK PMA tests. Because sufficient power to energize all the elements is not available only one third, or six of the eighteen Calrod elements, will be energized up to their full wattage rating.

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TABLE V-1

STATUS OF TAA FAILURE MODES & DEFICIENCIES

TAA Unit	Failure Mode/Deficiency	Correction	Correction Confirmed	Part in Previous Deficiency	First Occurrence	Repeated Occurrence
1/1 (GN ₂ S-1)	-Labyrinth Seals (antirotation pins sheared & snapping disengaged)	-Increase shear strength of antirotation pins	No		X	
3/2 (830-hr unit)	-Labyrinth Seals (anti-rotation pins sheared, snap-rings disengaged)	-Positive axial clamping, pins removed, beveled snapping with positive lock	(insufficient cycling)	X		X
	-Inlet Housing Assembly (316 SS/Stellite 6B weld crack)	-Eliminate 316 SS/Stellite 6B weld (a) modified design (b) new design	Yes		X	
	-Stress raisers in Stellite 6B	-Eliminate sharp corners	(insufficient cycling)		X	
	-Stellite 6B transformation to HCP	-Pretransform Stellite 6B to HCP	(insufficient lab work)		X	
	-2nd-Stage Diaphragm Ass'y (thermal stress failure)	-Separate shroud from diaphragm, nozzle blocks integral with diaphragm	(insufficient cycling)		X	
	-Visco Pump (erosion)	-(a) modify rotor material (b) modify heat exch. mat'l (c) redesign visco pump	(not enough exposure) No No		X	
2/3 (140 hr)	-Inlet housing ass'y (1st stage nozzle block cocked, modified design)	-Replace with new design, (b) above	No	X	X	
	-2nd-Stage Diaphragm Ass'y (diaphragm displaced in shroud)	-Correct machining procedure and investigate bowing of diaphragm	No	X	X	
	-Interstage Pressure Taps (9M/316 SS brazed joint leaked)	-(a) modify mat'l to 9M/9M (b) weld joint	(insufficient cycling) No		X	
	-Labyrinth Seal (rubbed rotor)	-Modify to limit displacement forces	No	X	X	X
	-2nd-Stage Diaphragm Shroud surface transformation	-Being investigated				
5/2 (41.7 hr)	-2nd-Stage Diaphragm Shroud growth/distortion	-Being investigated		X		
	-Labyrinth seal (rubbed rotor)	-Modify to limit displacement forces (as for 2/3)	No	X		
6/1 (117 hr)	-2nd-Stage Nozzle Diaphragm cracked	-Design modification to reduce thermal gradients in critical stress areas -Change diaphragm material for increased ductility	No	X		

Table V-1

TABLE V-2

TURBINE NOMINAL DIMENSIONS

		Stage							
		1		2		3		4	
(A) Nozzles									
Number		14	(14)	16	(14)	37	(37)	37	(37)
Percent Admission		38	(38)	49	(38)	100	(100)	100	(100)
T.E. Thickness, in.		.010	(.010)	.010	(.010)	.010	(.010)	.010	(.010)
Exit Angle, deg.		18.5	(17)	18.5	(17.0)	18.5	(17.0)	18.5	(17.0)
(B) Blade Rows									
Number		101	(79)	101	(79)	101	(79)	101	(79)
Blade Height, in.*		.261	(.324)	.349	(.464)	.335	(.372)	.631	(.655)
L.E. Thickness, in.		.010	(.020)	.010	(.020)	.010	(.020)	.010	(.020)
T.E. Thickness, in.		.006	(.010)	.006	(.010)	.006	(.010)	.006	(.010)
Chord, in.		.320	(.289)	.320	(.289)	.320	(.289)	.320	(.289)
Aspect Ratio		.812	(1.02)	1.09	(1.49)	1.048	(1.17)	1.97	(2.10)
Pitch/Chord Ratio		.495	(.7)	.495	(.7)	.495	(.7)	.495	(.7)

Legend

() Present Design

* These blade heights include overlap at OD and overlap at ID.

TABLE V-3

TAA ALLOCATION AND AVAILABILITY

TAA Unit	2/4	6/2	1/4	5/3	7/1	8/1	9/1
Aero Design				X	X	X	X
S 816 Rotor				X	X	X	X
New Thrust Balance Design							X
Space Seal							
Stellite 6B, Reduced Cavitation Intensity	X	X	X	X	X	X	
New Design							X
Diaphragm Design							
15-7 PH/6B } s816/s 816 }	X Current Design						
		X	X				
New Design				X	X	X	X
Pressure Taps Brazed	X	X		X			
Pressure Taps Welded					X	X	X
Allocation	PCS-1	LeRC	PCS-1 Spare	PCS-1	PCS-1 Spare	Component Test	
Available Date	July	Oct	Sept	Jan 67	Apr 67	Jun 67	Aug 67

Table V-3

TABLE V-4

SUMMARY OF BEARING TEST PROGRAM RESULTS

<u>Bearing S/N</u>	<u>Test Head No.</u>	<u>Accumulated Life Revolutions</u>	<u>Status</u>
32	006	198.0×10^6	TU
28	007	198.2×10^6	TU
27	009, 008	209.0×10^6	TU
21	009	209.0×10^6	TU
30	008	209.0×10^6	TU
18	006	12.1×10^6	F
22	007, 006	15.7×10^6	F (S)
24	006	23.8×10^6	F
26	009	99.2×10^6	F
23	009	1.7×10^6	ST (E)
35	006	2.3×10^6	ST (E)
33	008	5.4×10^6	ST (E)
29	009	9.6×10^6	ST (E)
31	008	72.2×10^6	ST

TU - Unfailed suspended test at required time-up

F - Fatigue failure of the inner ring

F (S) - Inner ring failure - suspended test

ST (E) - Suspended test due to early ball failure

ST - Suspended test due to ball failure

TABLE V-5

SPECIFIED AND REPORTED CHEMICAL COMPOSITION AND GAS CONTENT
 AISI M-50 BEARING STEEL (SECOND HEAT)
 (AEROJET SPECIFICATION AGC-10354)

A. Chemical Composition

Element	Symbol	Specified		Reported			Percent of Accuracy of Determination
		Minimum %	Maximum %	Vacuum Induction	1st Vacuum Arc Remelt	3rd Vacuum Arc Remelt	
Carbon	C	0.77	0.85	0.802	0.824	0.80	±5
Manganese	Mn	0.20	0.30	0.29	0.23	0.20	±5
Silicon	Si	0.15	0.25	0.22	0.20	0.20	±5
Chromium	Cr	3.75	4.25	4.22	4.22	4.23	±2
Molybdenum	Mo	4.00	4.50	4.18	4.35	4.35	±2
Vanadium	V	0.90	1.10	0.96	0.98	0.93	±2
Nickel	Ni		0.07	0.06	0.06	0.07	±2
Copper	Cu		0.08	0.03	0.01	0.01	±2
Aluminum	Al		0.01	0.01	0.01	<0.01	±2
Iron	Fe	Balance	Balance				±10
<u>Maximum Content of Trace Elements</u>							
Cobalt	Co		0.25	0.02	0.03	0.03	±10
Tungsten	W		0.25	0.04	NA ⁽¹⁾	0.04	±10
Titanium	Ti		0.30	<0.01	<0.01	<0.01	±10
Phosphorus	P		0.01	0.010	0.008	0.009	±10
Sulphur	S		0.01	0.007	0.007	0.006	±10
Arsenic	As		0.01	ND ⁽²⁾	ND	ND	±10
Lead	Pb		0.0005	ND	ND	ND	±10
Tin	Sn		0.05	0.02	<0.03	<0.03	±10
Magnesium	Mg		0.01	<0.01	<0.01	<0.01	±10
Columbium	Cb		0.1	<0.05	<0.05	<0.05	±10

(1) Not analyzed.

(2) Not detected <0.001.

TABLE V-5 (cont.)A. Chemical Composition (cont.)

<u>Element</u>	<u>Symbol</u>	<u>Specified</u>		<u>Reported</u>			<u>Percent of Accuracy of Determination</u>
		<u>Minimum %</u>	<u>Maximum %</u>	<u>Vacuum Induction</u>	<u>1st Vacuum Arc Remelt</u>	<u>3rd Vacuum Arc Remelt</u>	
Gold	Au		(3)	ND	ND	ND	<u>+10</u>
Bismuth	Bi			ND	ND	ND	<u>+10</u>
Zirconium	Zr			ND	ND	ND	<u>+10</u>
Silver	Ag			ND	ND	ND	<u>+10</u>
Antimony	Sb			ND	ND	ND	<u>+10</u>
Boron	B			ND	ND	ND	<u>+10</u>
Zinc	Zn			ND	ND	ND	<u>+10</u>
Cadmium	Cd		(3)	ND	ND	ND	<u>+10</u>

B. Gas Content

Nitrogen	N ₂	0.005	0.0040	NA	0.0045	<u>+15</u>
Oxygen	O ₂	0.005	0.0014	NA	0.0020	<u>+15</u>
Hydrogen	H ₂	0.001	0.0001	NA	<0.0001	<u>+15</u>

(3) These elements are not desirable; however, if they are expected to be traceable, the maximum percentage is to be reported to Aerojet for approval.

Jernkontoret Rating

<u>Specified</u>				<u>Worst Fields</u>	<u>* Reported</u>			
<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>		<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
1.0	1.00	1.0	1.0	Thin: Top	0	1.0	0	1.0
				Bottom	0	0	0	1.0
1.0	1.0	1.0	1.0	Thick: Top	0	0	0	0
				Bottom	0	0	0	0

Report No. 3233

TABLE V-5 (cont.)

Annealed Hardness

<u>Specified</u>	<u>Reported</u>
Brinell 202-245	Brinell 248-302

Heat-Treated Hardness

➤ Rockwell C 63	Rockwell C 64.0
-----------------	-----------------

Grain Size

(Fracture of Heat-Treated Condition)

➤ ASTM 5	ASTM 8-9
----------	----------

Magnetic Particle Rating
(per AMS-2300-A)

<u>Specified</u>		<u>Reported</u>
≤ 0.50	Frequency	(Top 0 Bottom 0)
≤ 1.00	Severity	(Top 0 Bottom 0)

Microstructure and Macrostructure

Satisfactory, as per Aerojet-General Specification for
AISI M-50 Bearing Steel No. AGC-10354, dated 30 July
1964.

TABLE V-6

COMPARISON OF NaK PMA UNIT 8/2 STARTING TORQUE
TEST RESULTS WITH ORIGINAL TEST

Frequency cps	Unit	Voltage, volts L-N (Phase)			Current, amps (Phase)			Torque in.-lb	Input Power kw
		1	2	3	Ave.	1	2	3	Ave.
400	Present	125.4	125.1	105.2	118.6	49.0	61.0	64.8	58.3
	Original	(Balanced within .6 volt)			118.6	(Balanced within .8 amp)			50.7
95	Present	23.4	22.5	19.1	21.7	31.0	35.5	38.0	34.8
	Original	(Balanced within .8 volt)			21.7	(Balanced within .4 amp)			32.3
60	Present	19.5	18.4	15.8	17.9	40.0	43.7	46.4	43.4
	Original	(Balanced within .8 volt)			17.9	(Balanced within .4 amp)			39.1

TESTED RESISTANCE VALUES

$T_1 - T_3$	0.2201 ohm	$T_1 - T_0$	0.1223 ohm
$T_2 - T_3$	0.2132 ohm	$T_2 - T_0$	0.1154 ohm
$T_1 - T_2$	0.232 ohm	$T_3 - T_0$	0.1031 ohm

TABLE V-7

EVENTS DURING LNL-3 PHASE I TEST PROGRAM

3.5 LNL-3 Test Operations

- 3.5.1 PMA Heat Capacity Test (complete 6/15/66)
- 3.5.2 LNL-3 Inverter/NaK PMA Start Test (95 cps hi voltage)
 - 3.5.2.1 NaK PMA Start Conditioning (as required)
 - 3.5.2.2 Inverter Starts with Capacitors Energized
 - 3.5.2.3 Inverter Starts at 60 cps (cold loop)
 - 3.5.2.4 NaK PMA Starts at 95 cps (low inverter voltage)
 - 3.5.2.4.1 NaK PMA Restart Test (35 starts)
 - 3.5.2.4.2 NaK PMA Minimum Torque Test (cold loop)
 - 3.5.2.5 NaK PMA operation at ~220 (inverter hi voltage)
 - 3.5.2.6 NaK PMA operation at ~95 (inverter low voltage)
 - 3.5.2.7 NaK PMA Steady State 95 and 220 Cycle Performance
 - 3.5.2.8 NaK and L/C PMAs Variable Performance
- 3.5.3 Inverter Start Tests
 - 3.5.3.1 Reduced Frequency Inverter Starts (45-50 cps)
 - 3.5.3.2 Inverter-Capacitor Start Testing
 - 3.5.3.3 Inverter Steady-State Testing
 - 3.5.3.4 Inverter Performance Test (full duty cycle)
- 3.5.4 L/C Flow Reduction Test (~400, 1160°F)
- 3.5.5 L/C Fluid Temperature Variation Test
- 3.5.6 NPMA Elevated Temperature Performance
 - 3.5.6.1 NPMA 500°F Performance Test
 - 3.5.6.2 NPMA 1160°F Performance Test
 - 3.5.6.3 NPMA 1200°F Minimum Torque Tests (see 3.5.2.4.2)
- 3.5.7 Elevated Temperature NPMA Restarts
- 3.5.8 NPMA Elevated Temperature Steady State OP's.
- 3.5.9 NPMA Restarts at 300, 600, and 1000 hr of 3.5.8
- 3.5.10 NPMA Minimum Torque Restart Tests

Table V-7

TABLE V-8

INVERTER TESTS AT 95 CYCLES

Test 3.5.2: Inverter/NaK PMA Start Test
95 cps - without capacitors energized

- A - L/C PMA
- B - NPMA
- C - L/C and NaK PMAs
- D - Inductive load, L/C and NaK PMAs

Test 3.5.2.2: Inverter/NaK PMA Start Test
95 cps - with capacitors energized

- A - L/C PMA
- B - NPMA
- C - L/C and NaK PMAs
- D - Inductive load, L/C and NaK PMAs

TABLE V-9

INVERTER TESTS AT 60 CYCLES

Test 3.5.2.3: Inverter/NaK PMA Start Test

60 cps - without capacitors energized (Runs 1-3)

A - L/C PMA

B - NPMA

C - L/C and NaK PMAs

D - Inductive load, L/C and NaK PMAs

60 cps - with capacitors energized (Runs 4-6)

A - L/C PMA

B - NPMA

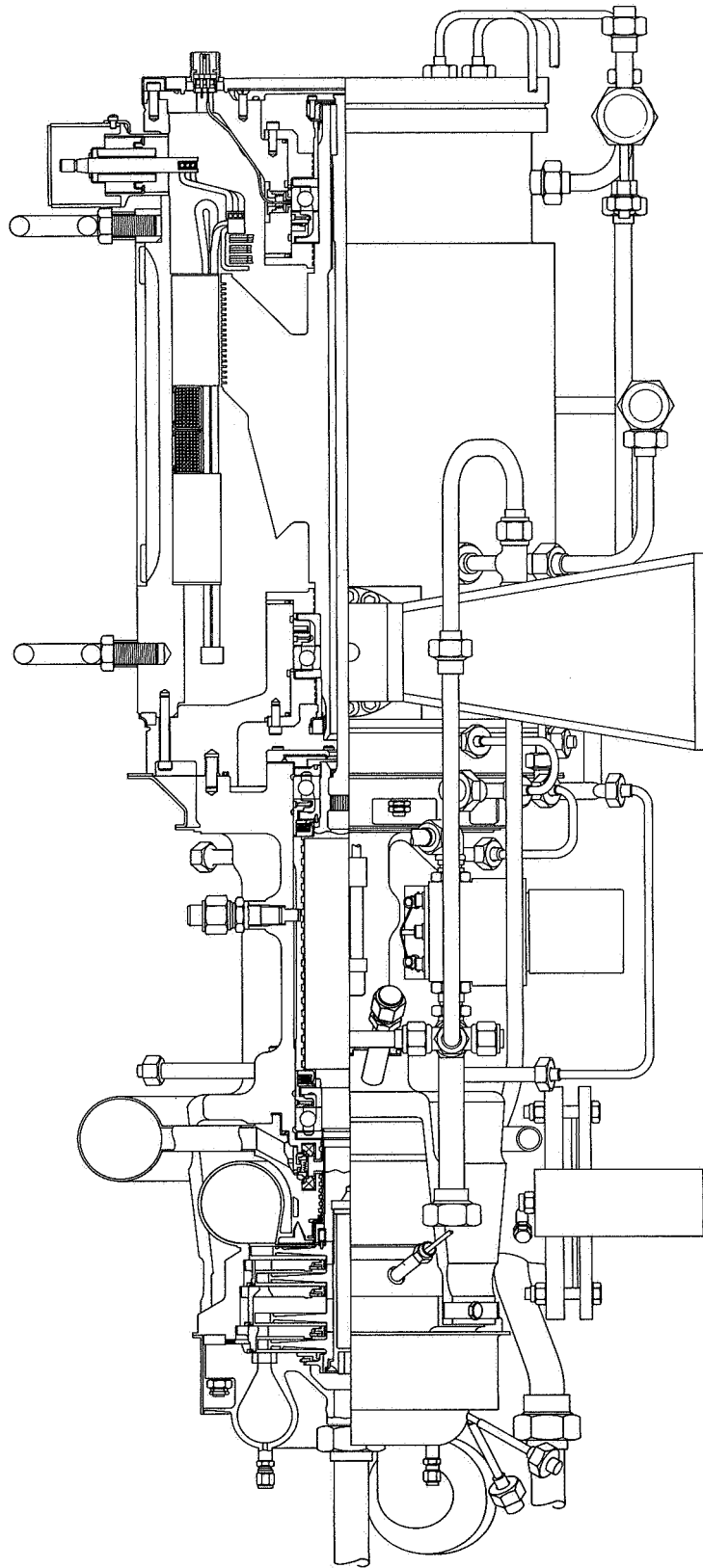
C - L/C and NaK PMAs

D - Inductive load, L/C and NaK PMAs

TABLE V-10

ANALYTICAL AND TEST DATA OF T-T BOILER

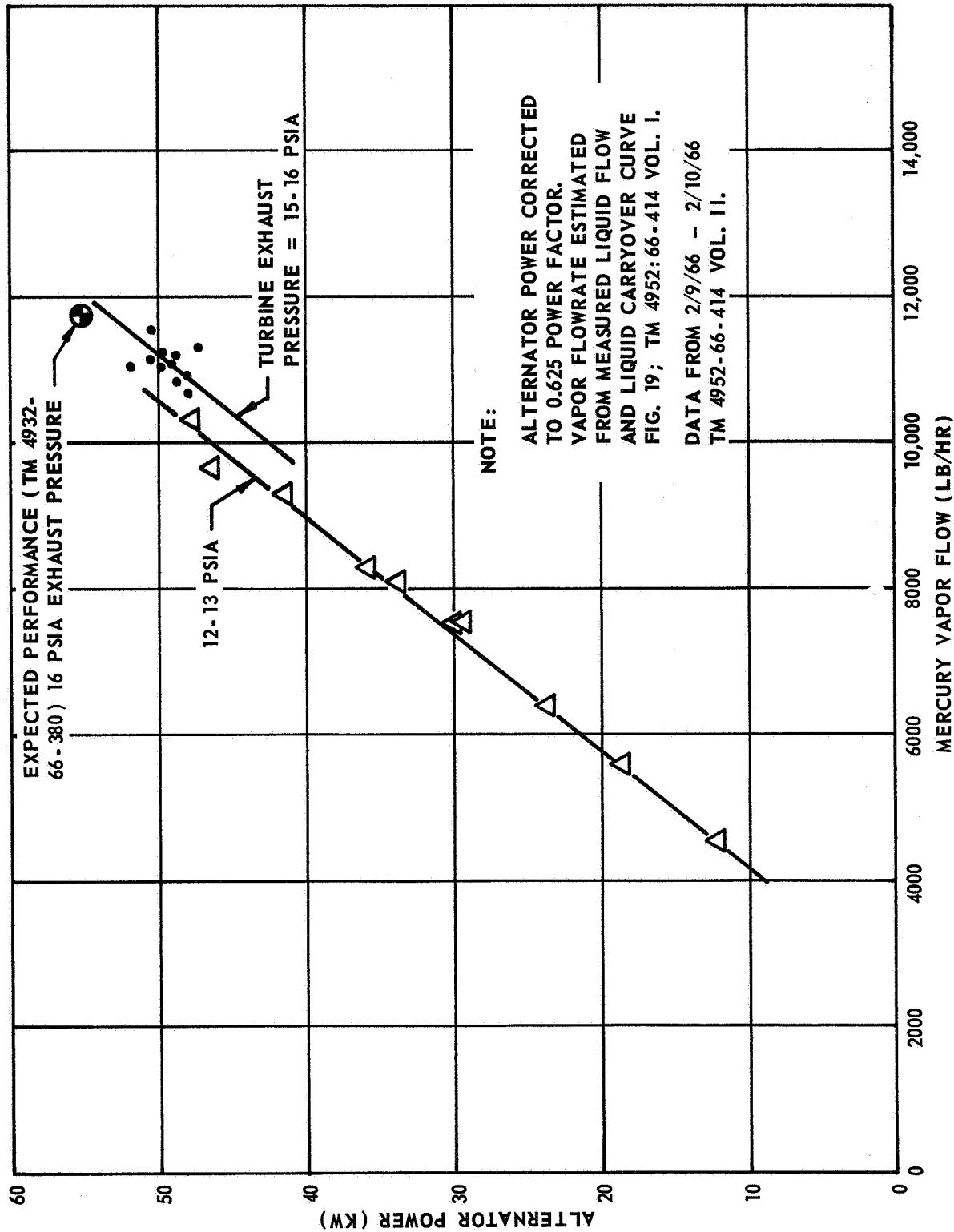
	Fig. No.	<u>Program Data</u>		<u>Test Data</u>	
		<u>Input</u>	<u>Output</u>	<u>Input</u>	<u>Output</u>
NaK Flow Rate, lb/hr	83	48500		45200	
NaK Inlet Temp., °F		1330		1330	
Boiler Heat Loss, kw		12			
Hg Flow Rate, lb/hr		11750		11900	
Hg Inlet Temp., °F		500		448	
Hg Exit Temp., °F		1300		1306	
Hg Exit Press., psia		270			261
Total ΔP, psi			87.6		93
Preheat Sect. ΔP, psi			7.1		10
Preheat Vap. Sect. ΔP, psi			28.4		30
Plug Ins. Vap. Sect. ΔP, psi			22.0		15
Pinch Point Temp. Diff., °F			62.0		50
Excess SH Length, ft			14.4		14.5
Plug Insert Exit Quality, %			44.4		35
NaK Side Temp. Diff., °F			171		198
NaK Flow Rate, lb/hr	84	48500		44900	
NaK Inlet Temp., °F		1280		1283	
Boiler Heat Loss, kw		12			
Hg Flow Rate, lb/hr		11500		11900	
Hg Inlet Temp., °F		500		450	
Hg Exit Temp., °F		1250			1255
Hg Exit Press., psia		270			257
Boiler Total ΔP, psi			60.5		78
Preheat Sect. ΔP, psi			9.0		12
Preheat Vapor Sect. ΔP, psi			0.0		23
Plug Ins. Vap. Sect. ΔP, psi			22.0		12
Pinch Point Temp. Diff., °F			30.0		10
Excess SH Length, ft			12.9		12
Plug Ins. Exit Quality, %			30.2		20
NaK Side Temp. Diff., °F			169		199



SNAP-8 Turbine-Alternator Assembly (P/N 096800-1)

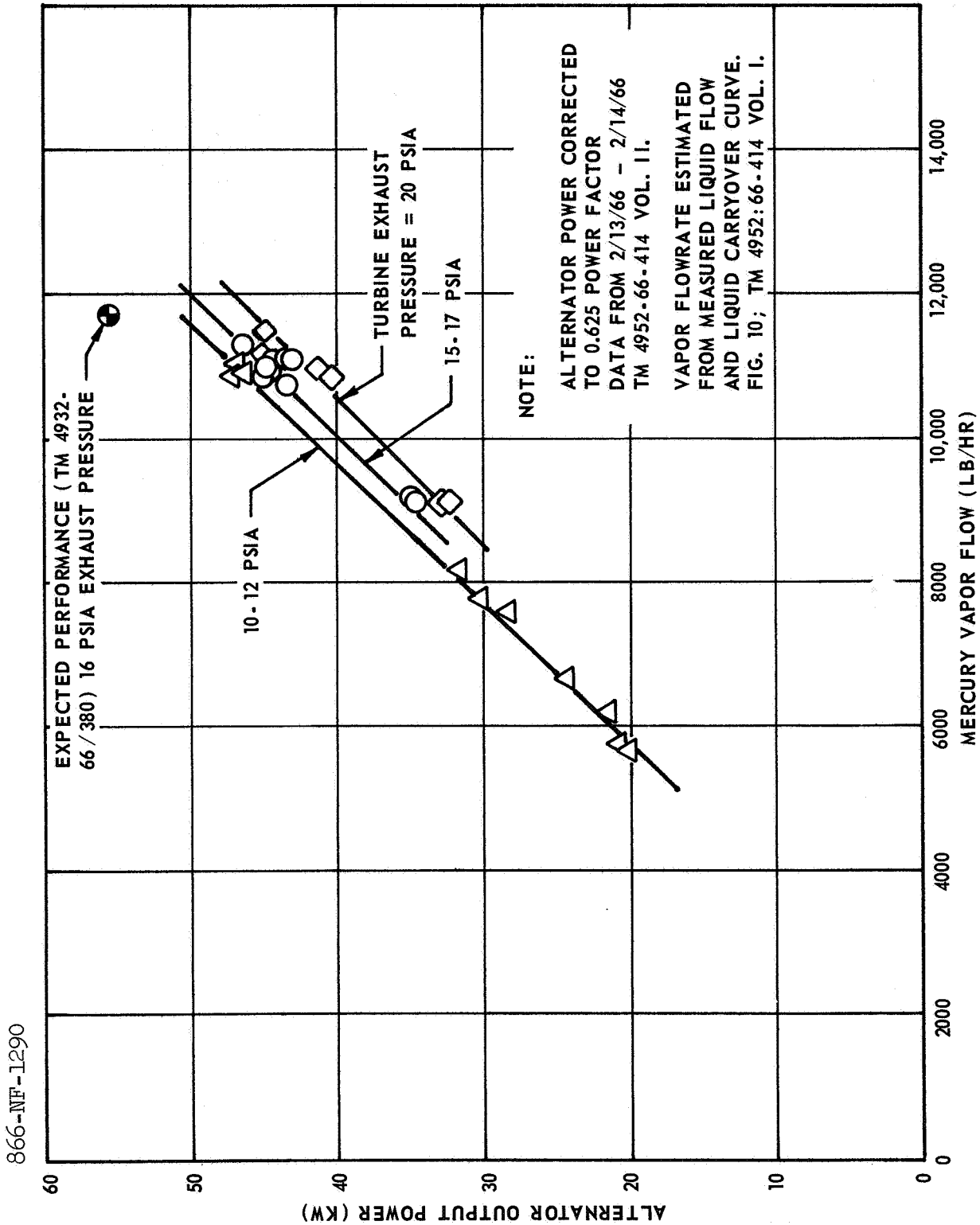
Figure V-1

866-NF-1288



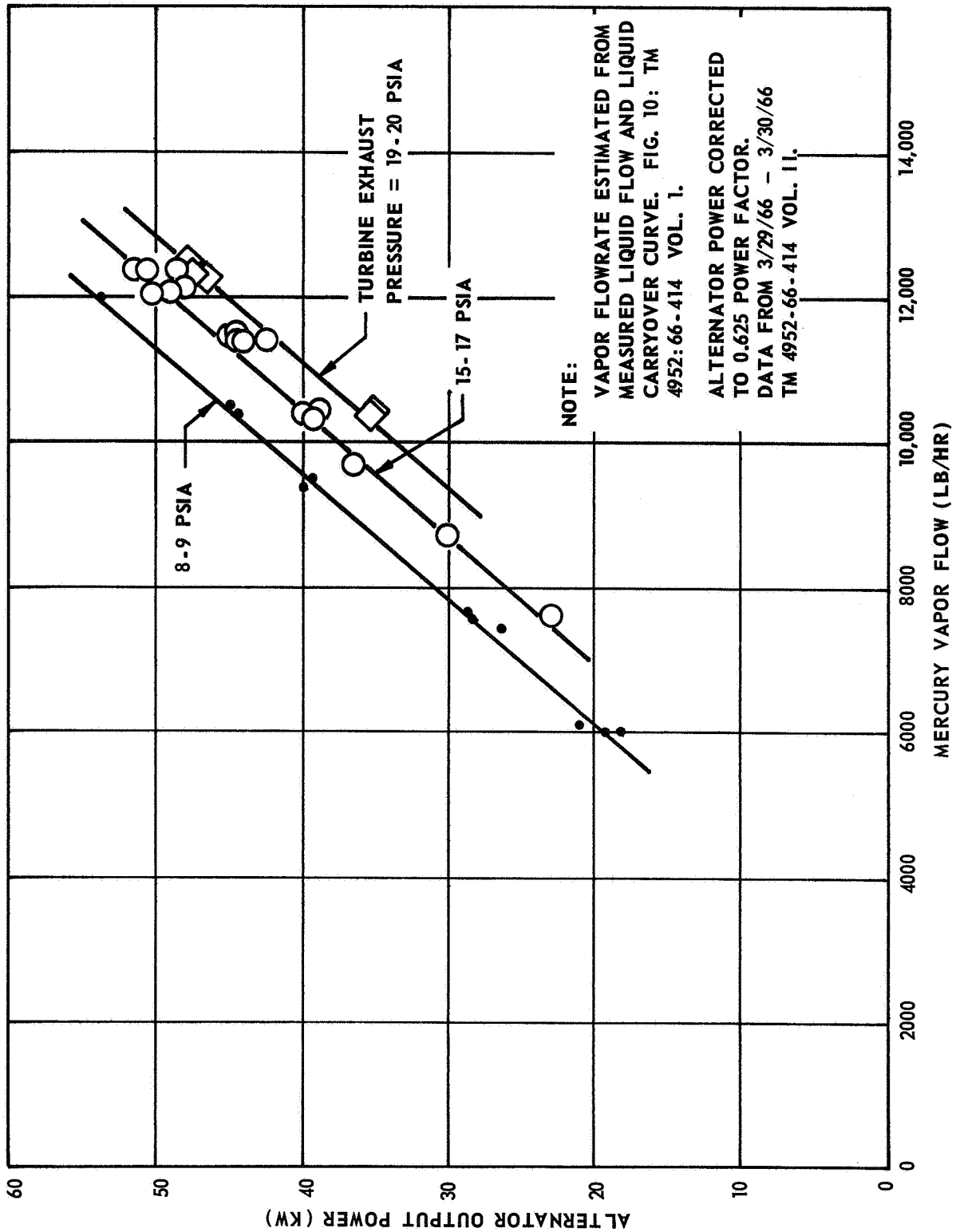
TAA (P/N 096800-1, Unit 2/3) Performance Before Degradation: Alternator Power vs Mercury Vapor Flow in PCS-1 Phase IV Step 2

Figure V-2



TAA (P/N 096800-1, Unit 2/3) Performance After Degradation: Alternator Power vs Mercury Vapor Flow in PCS-1 Phase IV Step 2

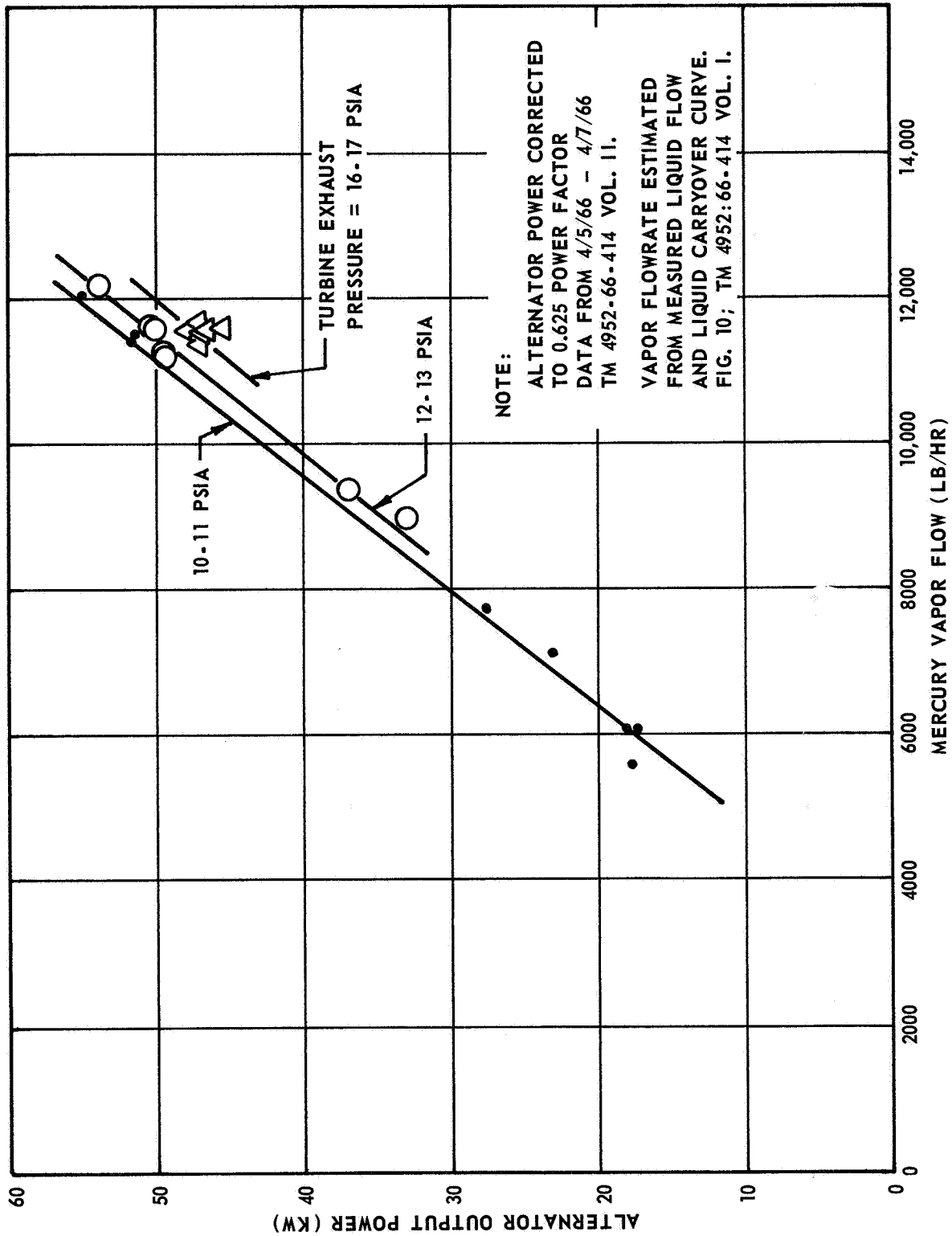
Figure V-3



TAA(P/N 096800-1, Unit 5/2) Performance:
 Alternator Power vs Mercury Vapor Flow in
 PCS-1 Phase IV Step 2

Figure V-4

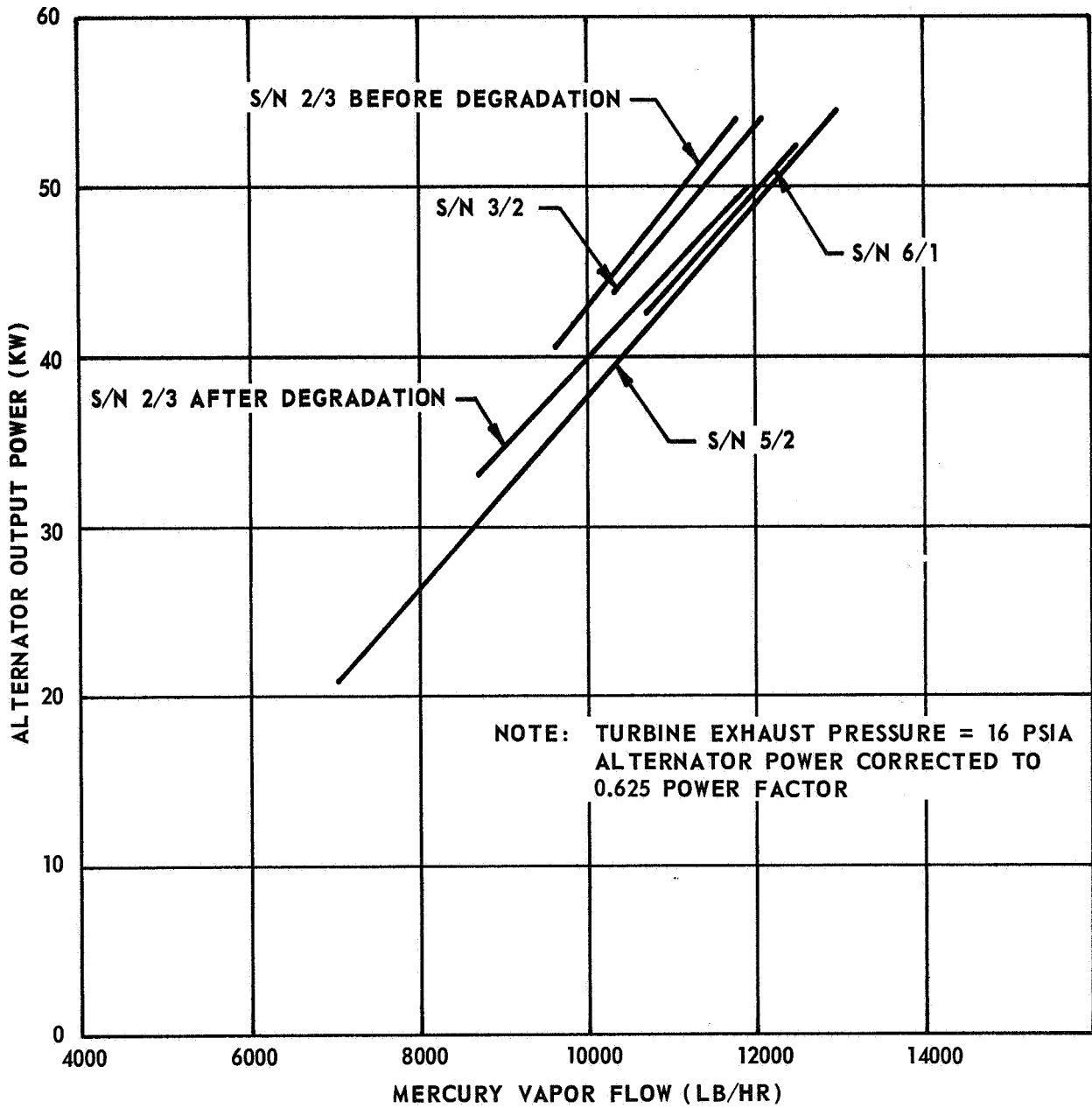
866-NF-1292



TAA(P/N 096800-1, Unit 6/l) Performance:
Alternator Power vs Mercury Vapor Flow in
PCS-1 Phase IV Step 2

Figure V-5

866-NF-1293



TAA Performance Comparison: Alternator Power vs Mercury Vapor Flow in PCS-1 Phase IV Step 2

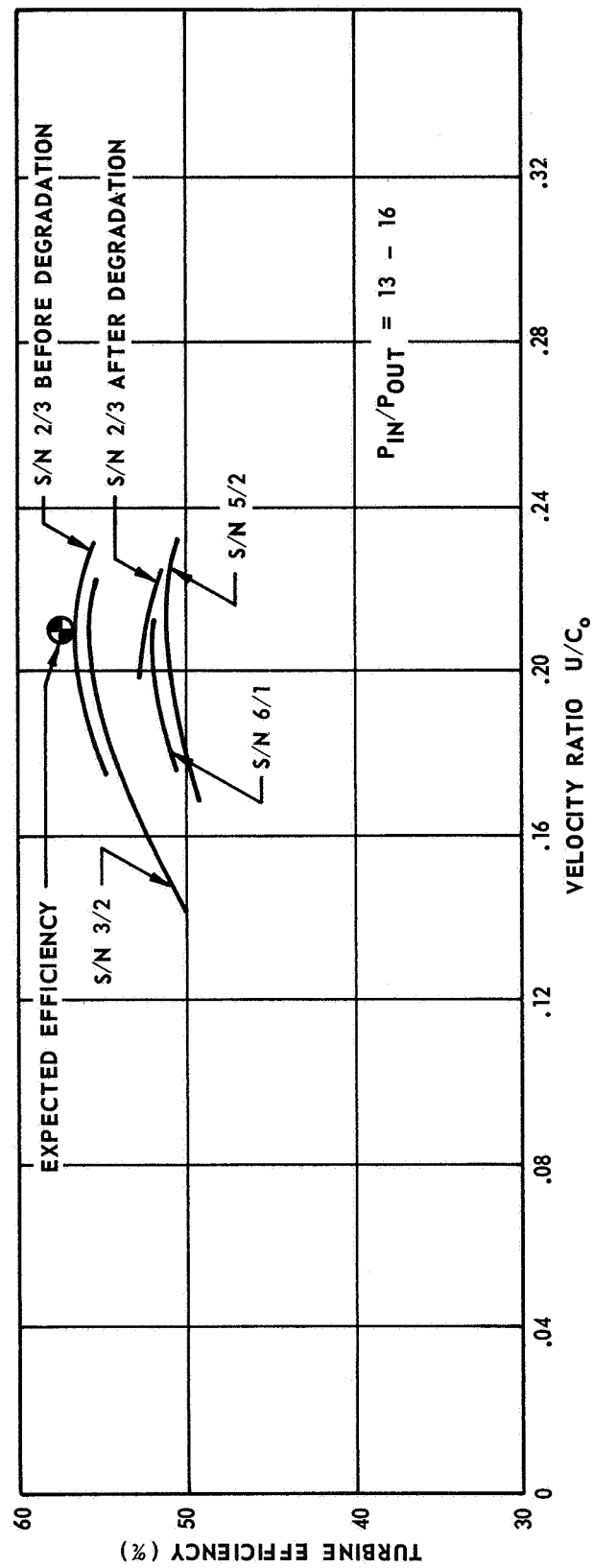
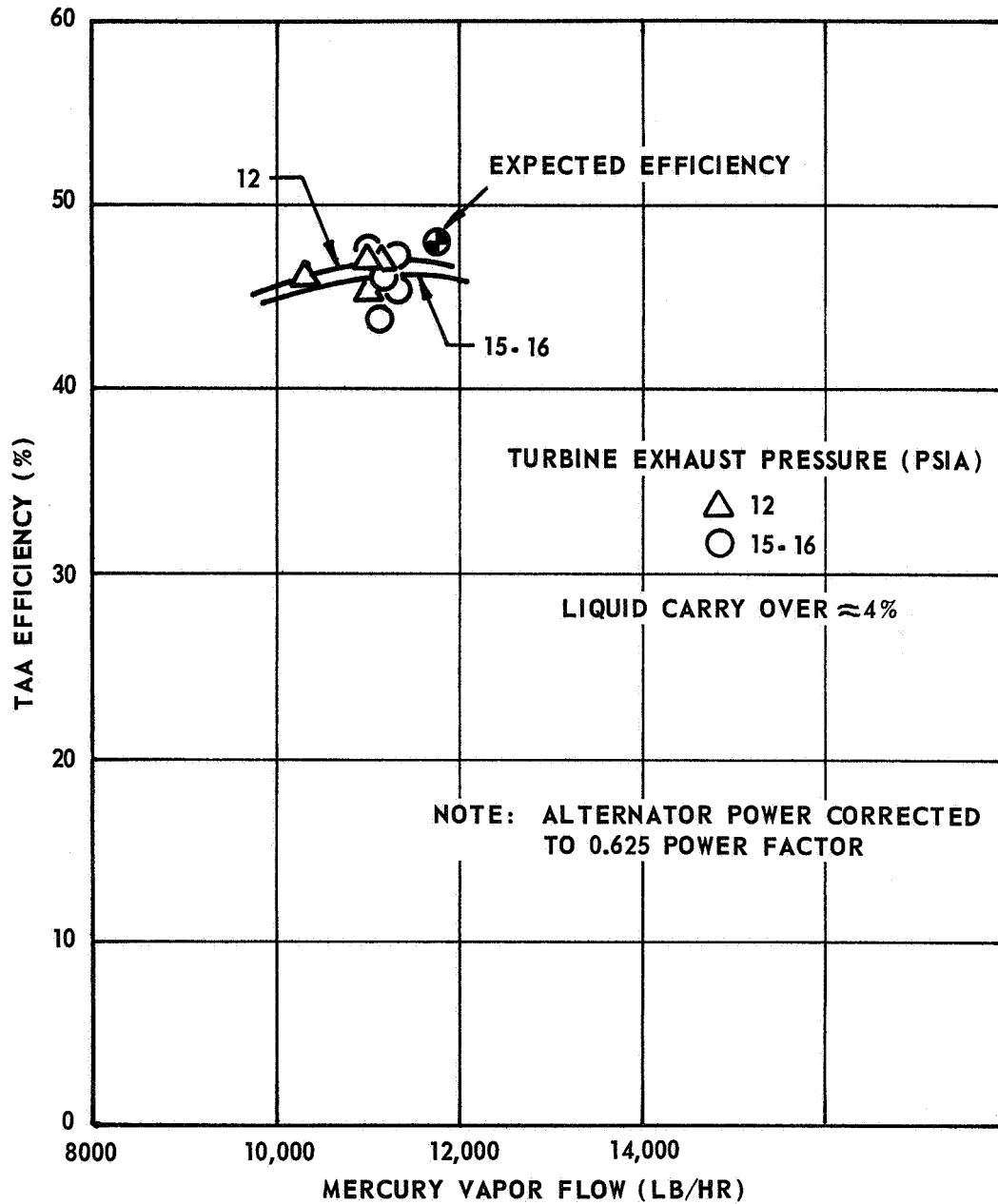


Figure V-7

Turbine Performance Comparison: Turbine
Efficiency vs Velocity Ratio

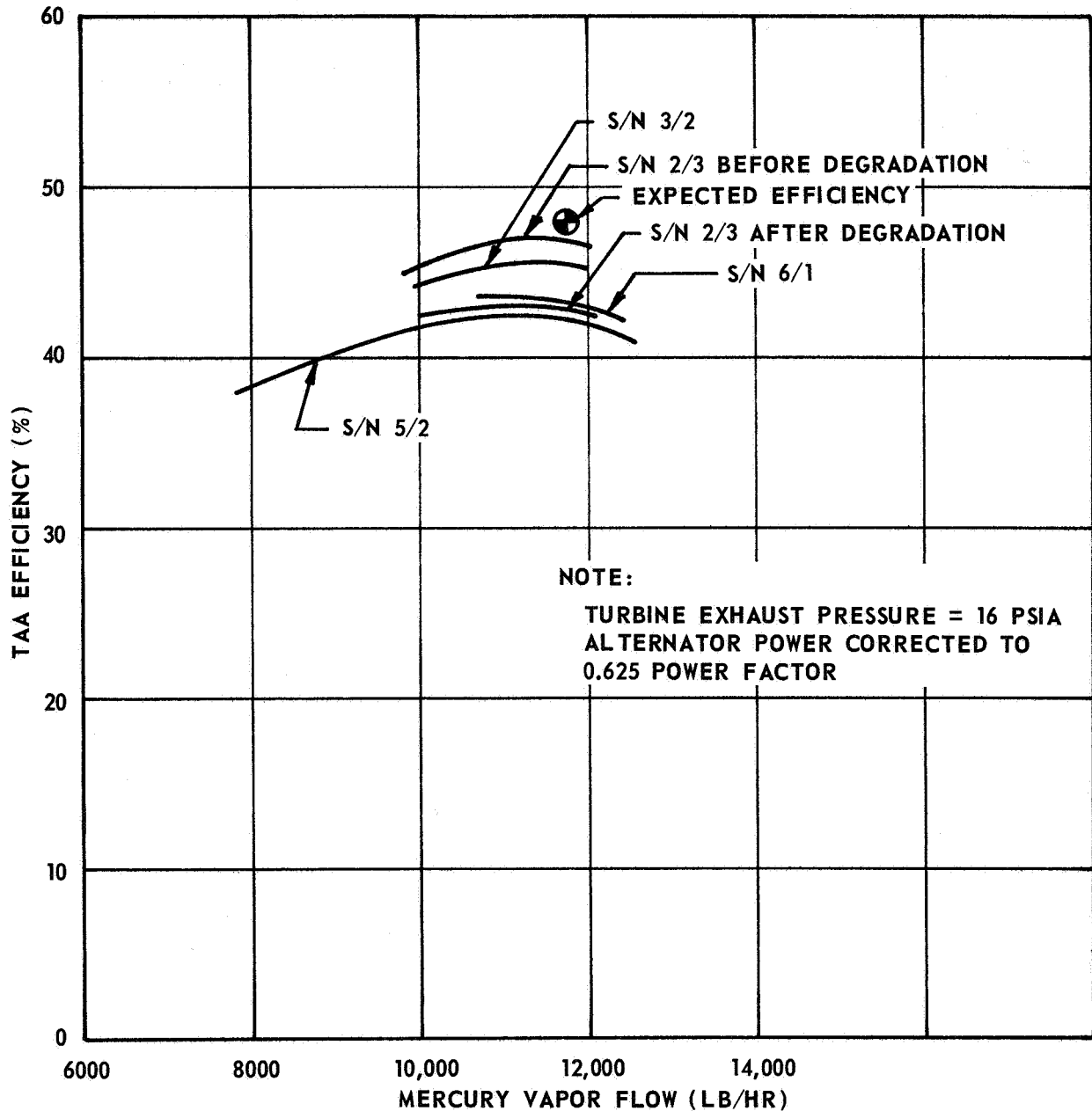
866-NF-1295



TAA(P/N 096800-1, Unit 2/3) Performance Before Degradation:
TAA Efficiency vs Mercury Vapor Flow in PCS-1 Phase IV Step 2

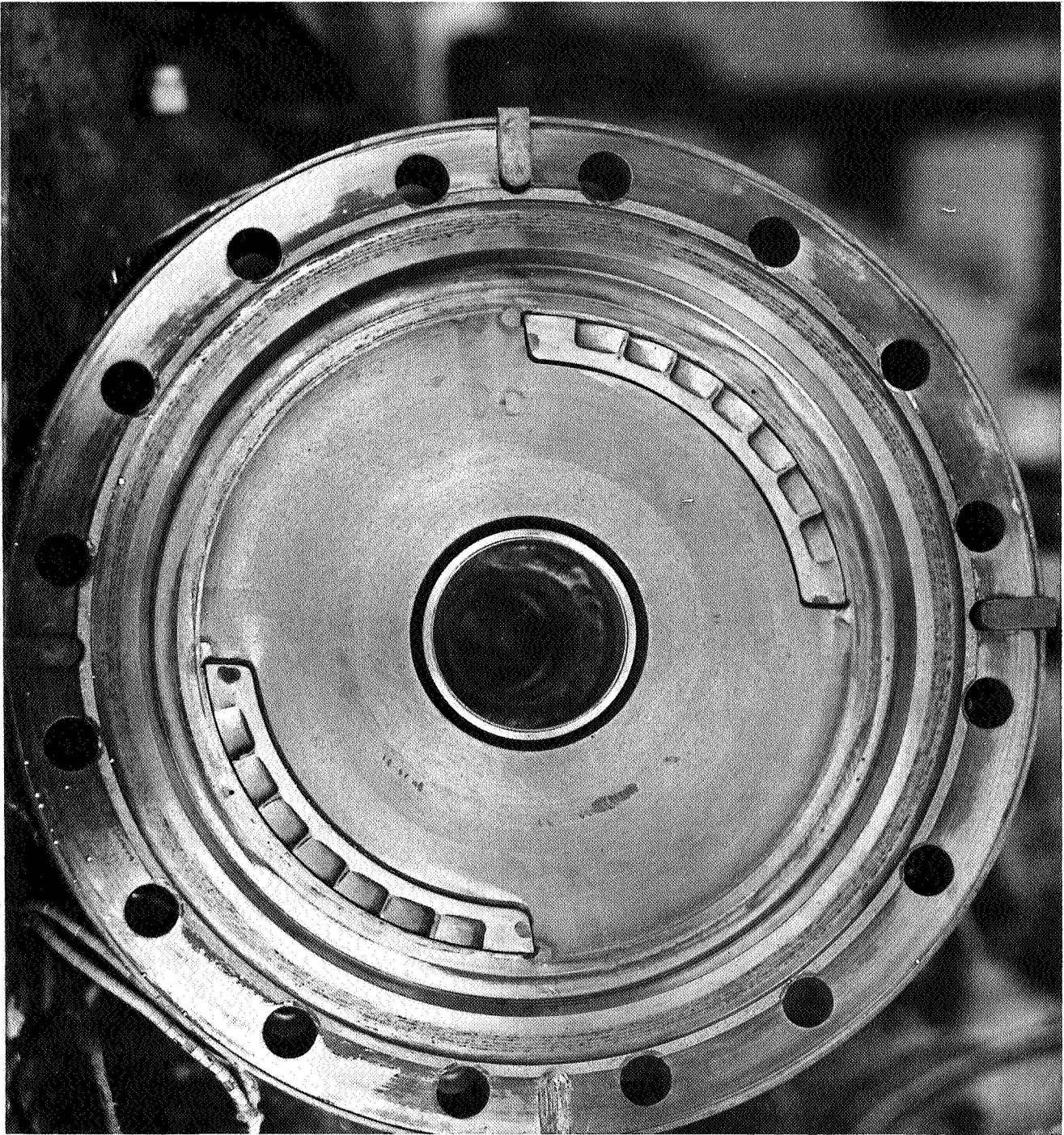
Figure V-8

866-NF-1296



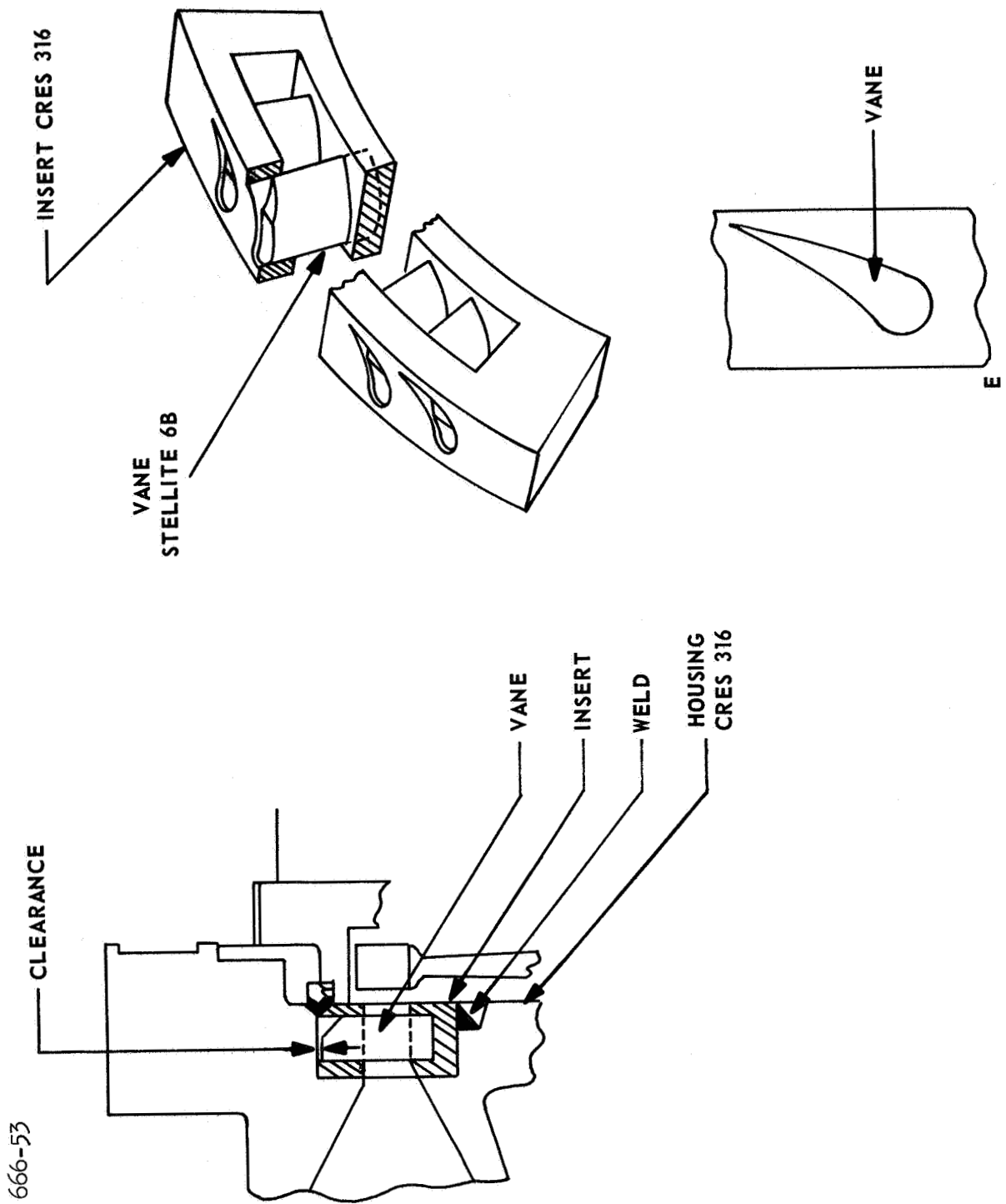
TAA Performance Comparison: TAA Efficiency vs Mercury Vapor Flow in PCS-1 Phase IV Step 2

266-410



Turbine-Alternator Assembly (P/N 096800-1, S/N A-2)
Buildup Removed from PCS-1 Phase 4 Step 2.
Inlet Housing Showing Nozzle Inserts.

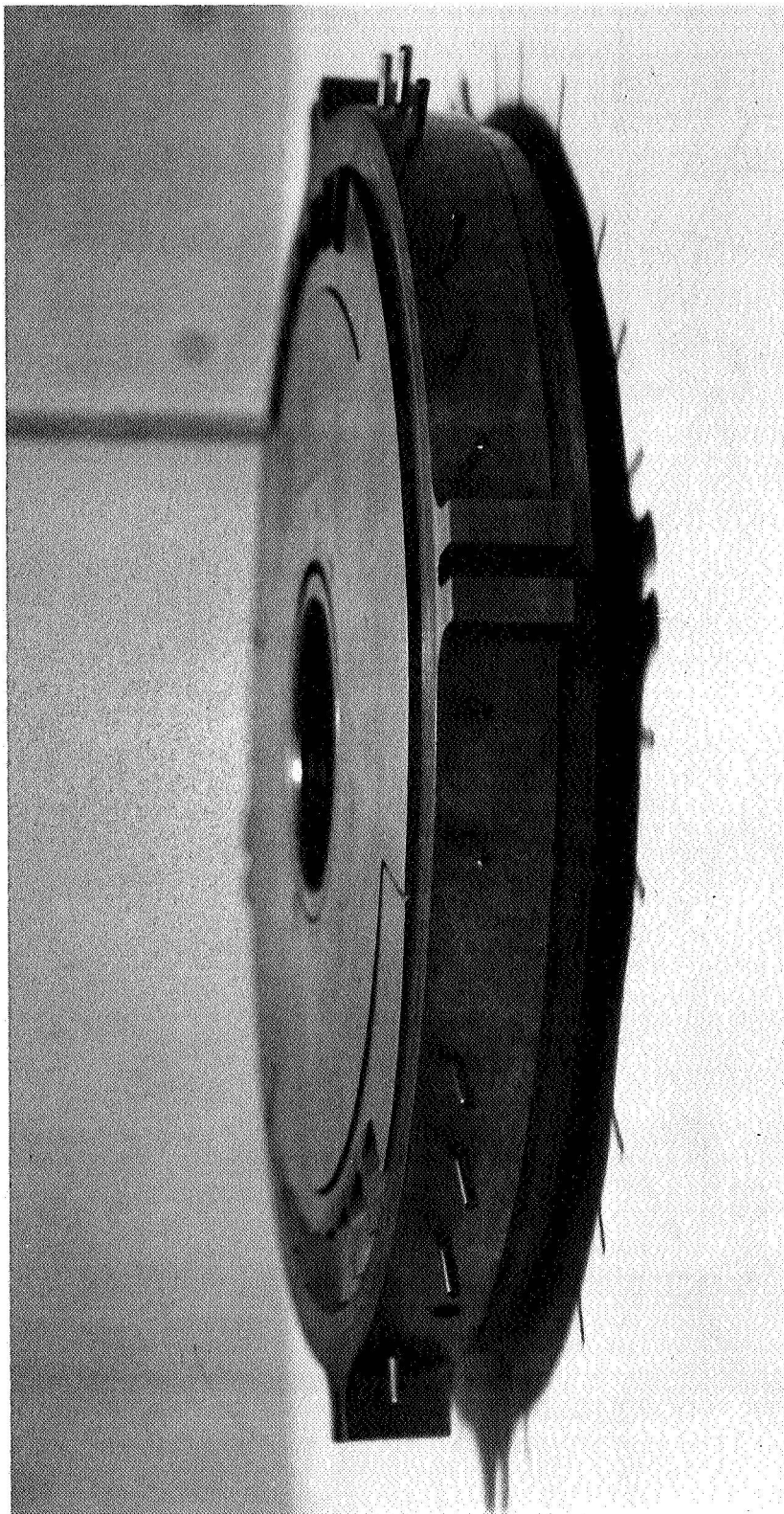
Figure V-10



SNAP-8 Turbine First-Stage Nozzle Insert - Current Design

Figure V-11

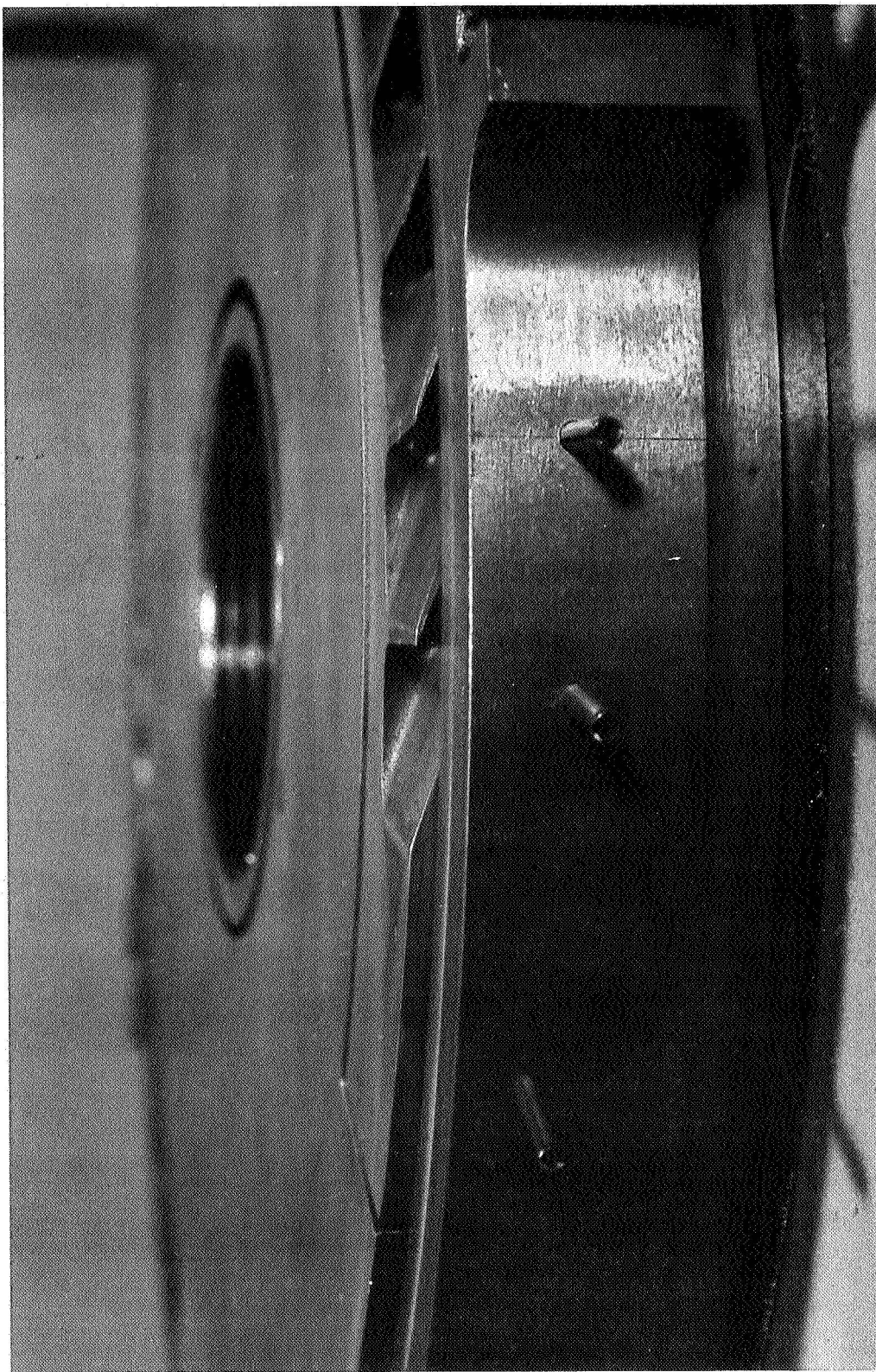
366-59



SNAP-8 Turbine-Alternator Assembly Unit
(P/N 096800-1, S/N A-2) After 141 Hours of
Operation. Second-Stage Nozzle - Note Diaphragm Displacement

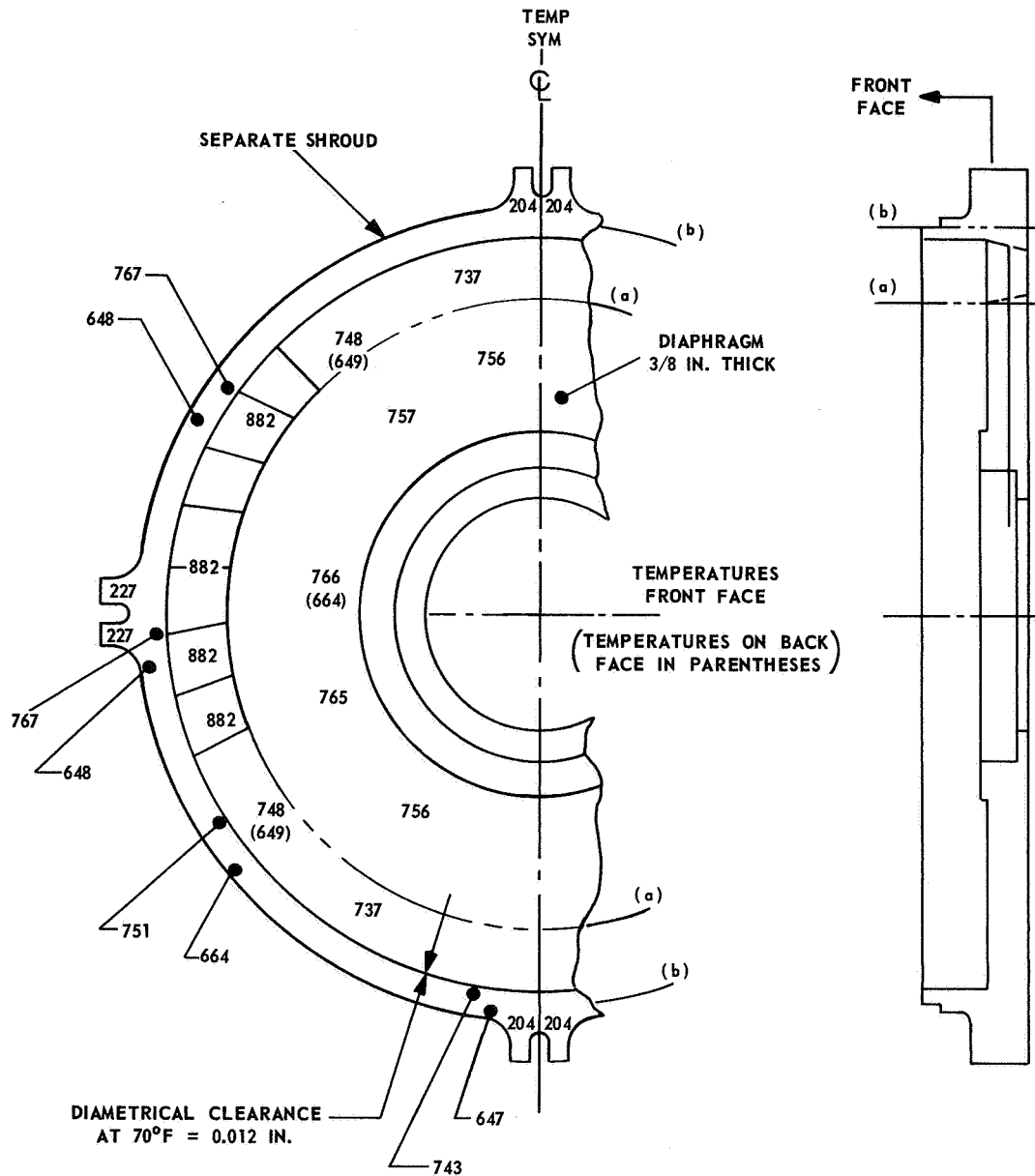
Figure V-12

366-60



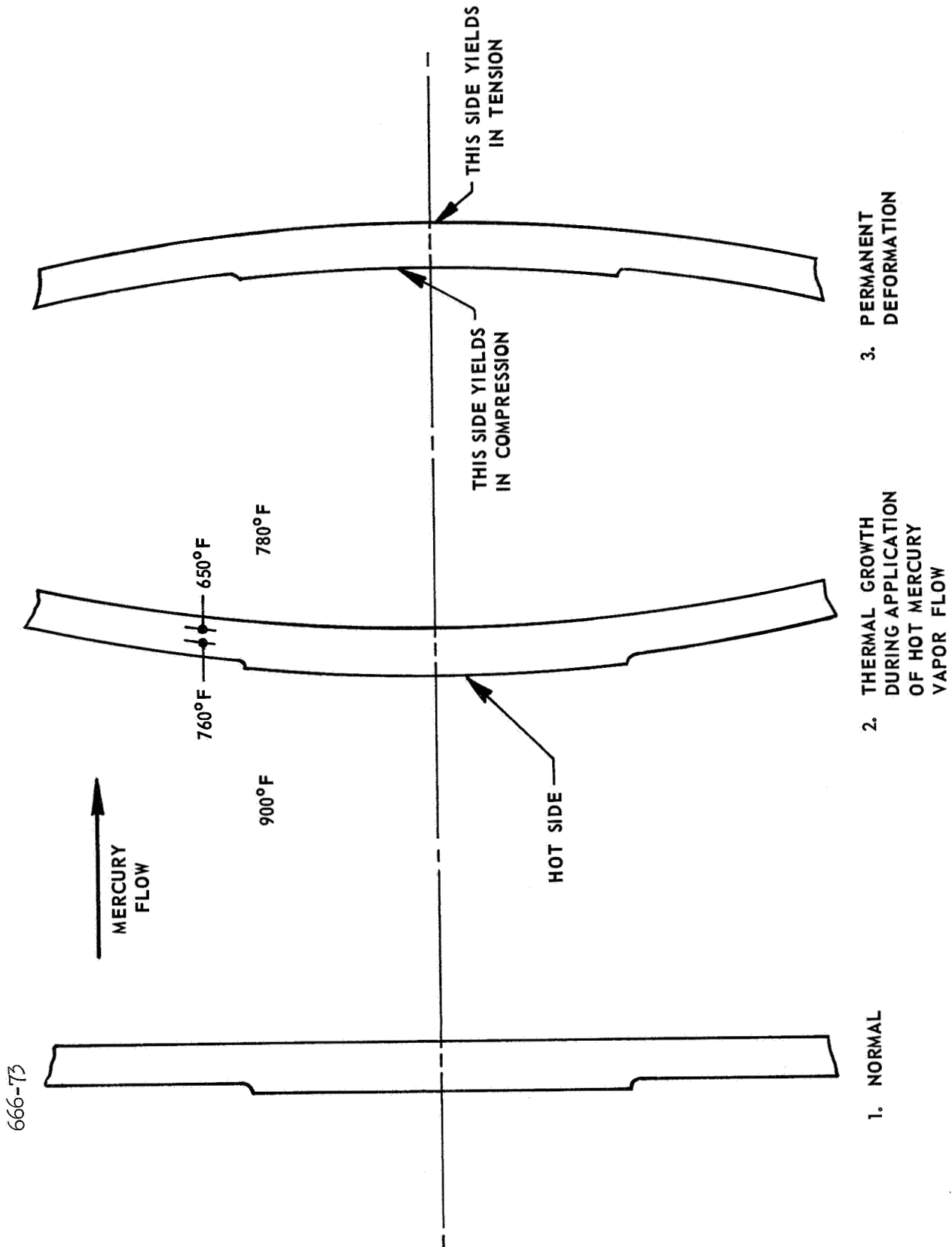
SNAP-8 Turbine-Alternator Assembly Unit 2/3 (P/N 096800-1, S/N A-2)
After 141 Hours of Operation. Second-Stage
Nozzle - Closeup View of Diaphragm Displacement.

Figure V-13



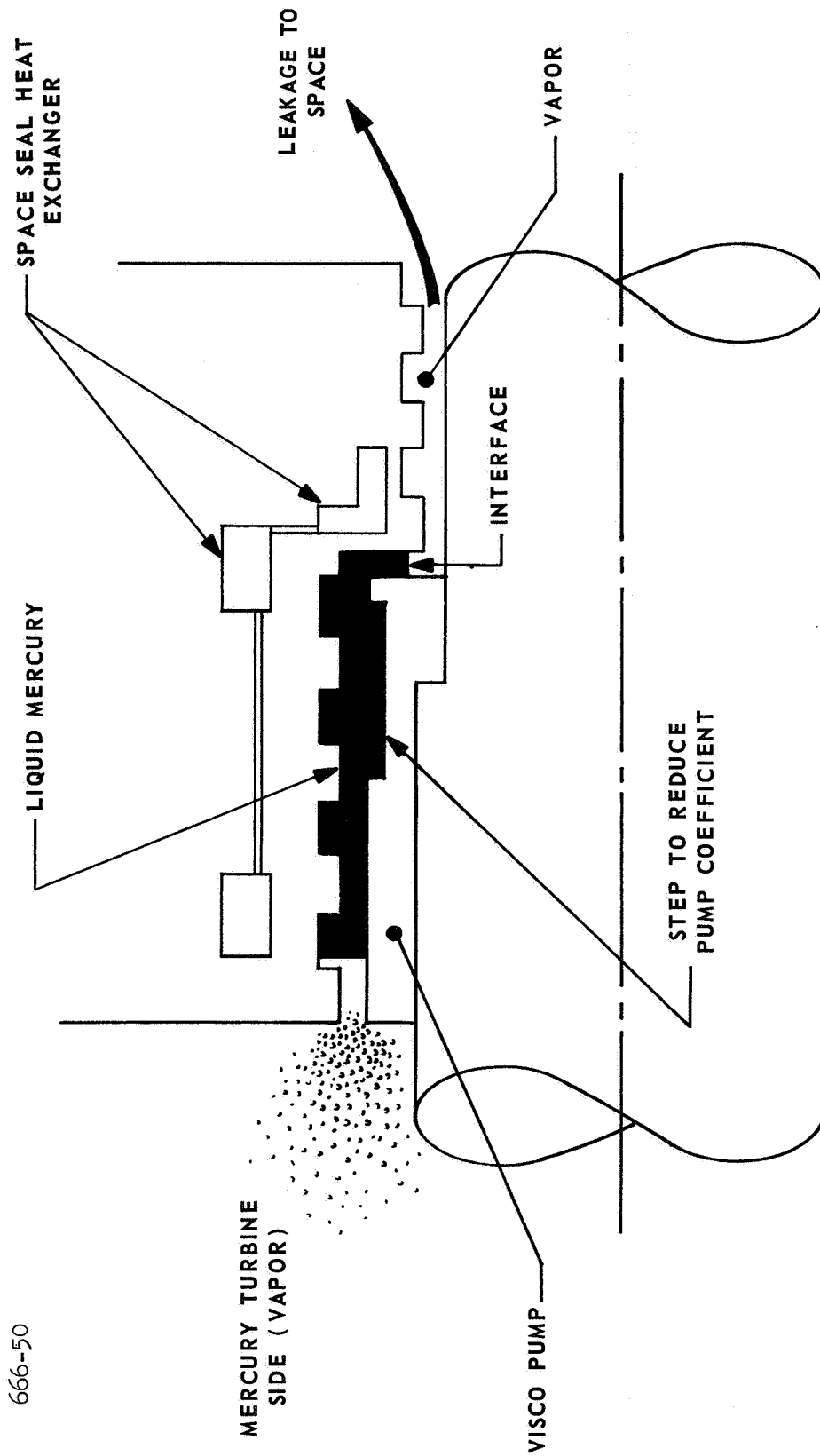
Second-Stage Diaphragm/Nozzle Assembly 21 Seconds
After Mercury Injection - Temperatures in °F

Figure V-14



Possible Mode of Distortion During Start Transients
 SNAP-8 TA Second-Stage Nozzle Diaphragm

Figure V-15



Mercury Visco Seal Showing Step Modification to
Align Interface Position

Figure V-16

566-268



FIGURE A

Greek Ascoloy Mercury Visco Pump runner
after 820 hours operation. Note cavitation
erosion damage on outside diameter.

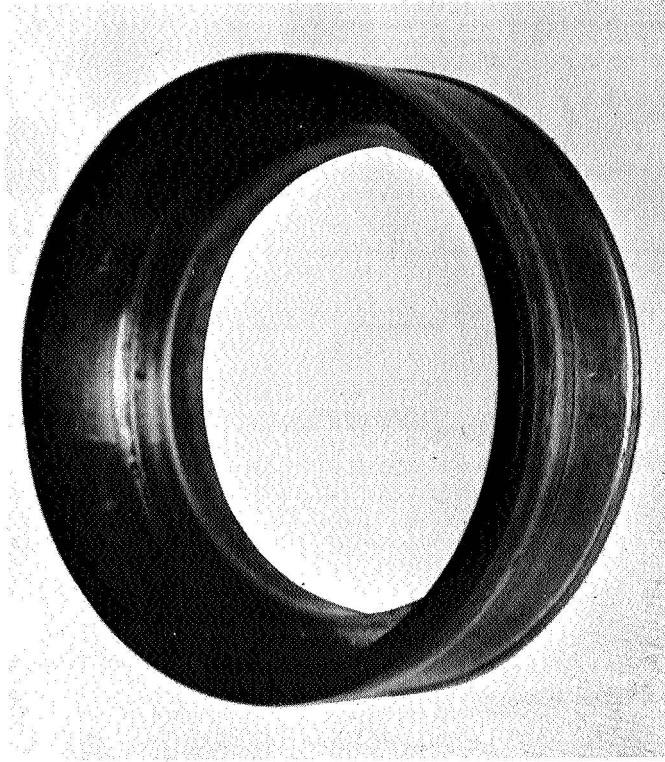
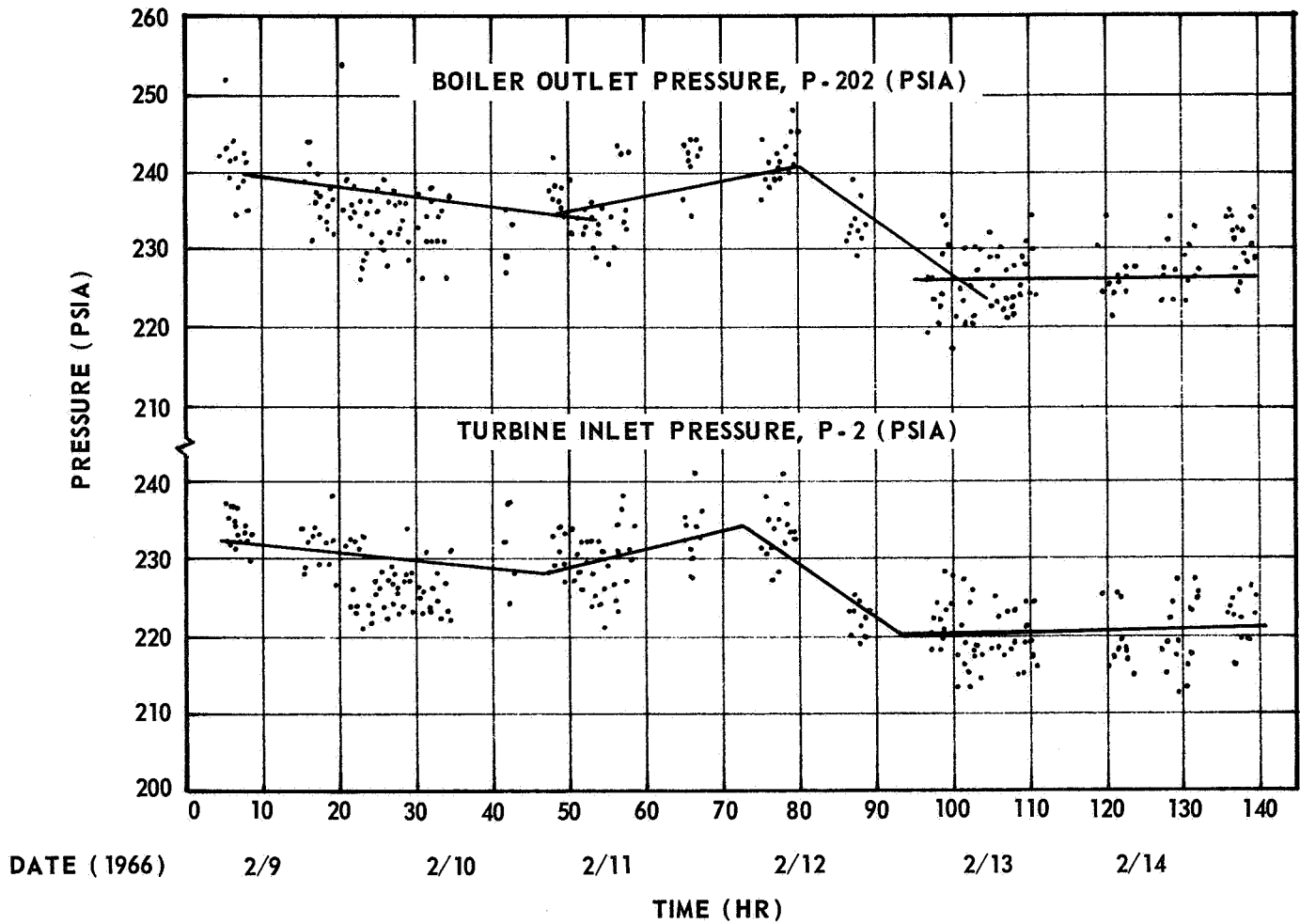


FIGURE B

Stellite 68 Mercury Visco Pump runner after
140 hours operation. Note absence of cavitation
erosion damage on outside diameter.

Mercury Visco Pump Erosion

866-NF-1297



Pressure Level Degradation - Total Run Time

Figure V-18

866-NF-1298

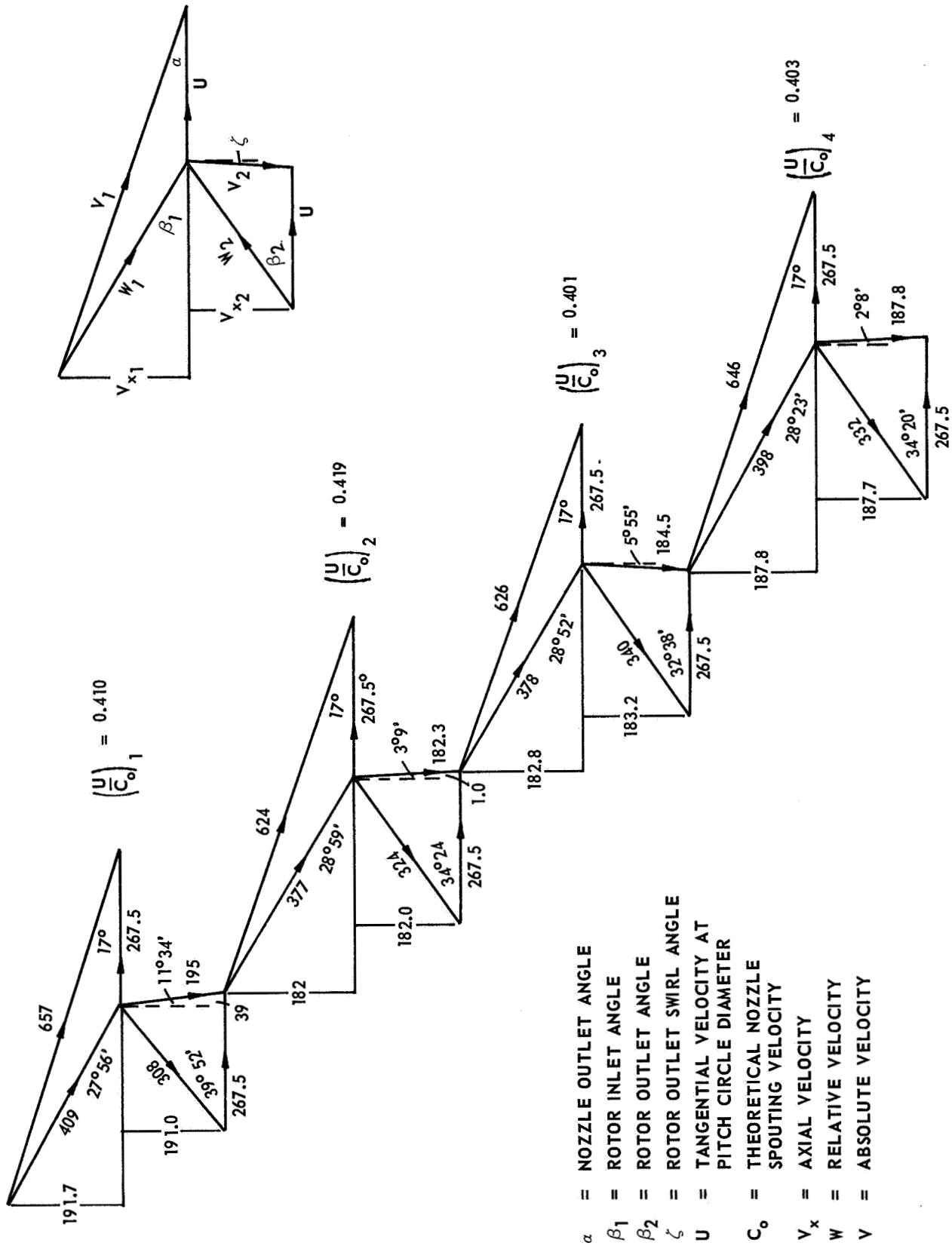
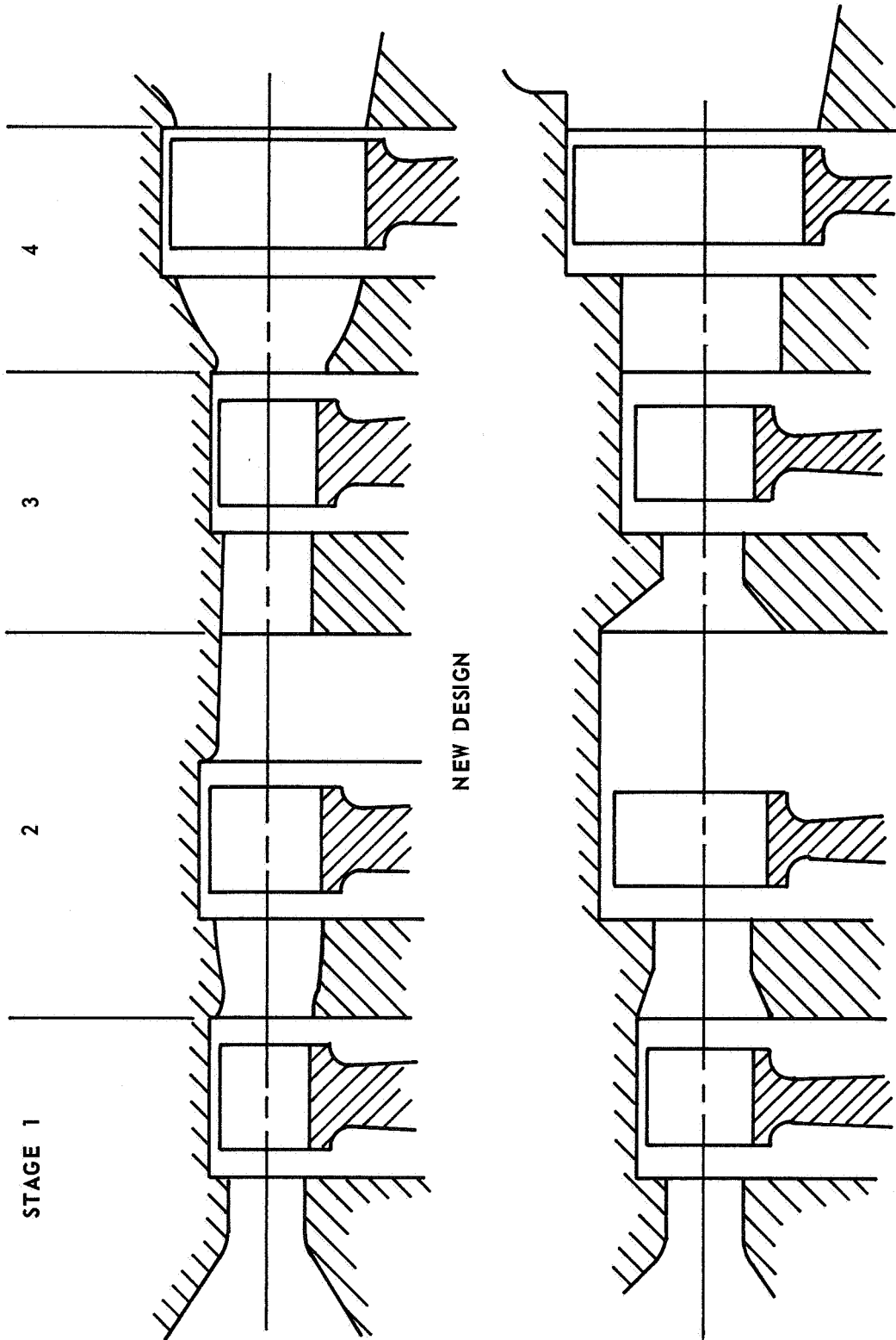


Figure V-19

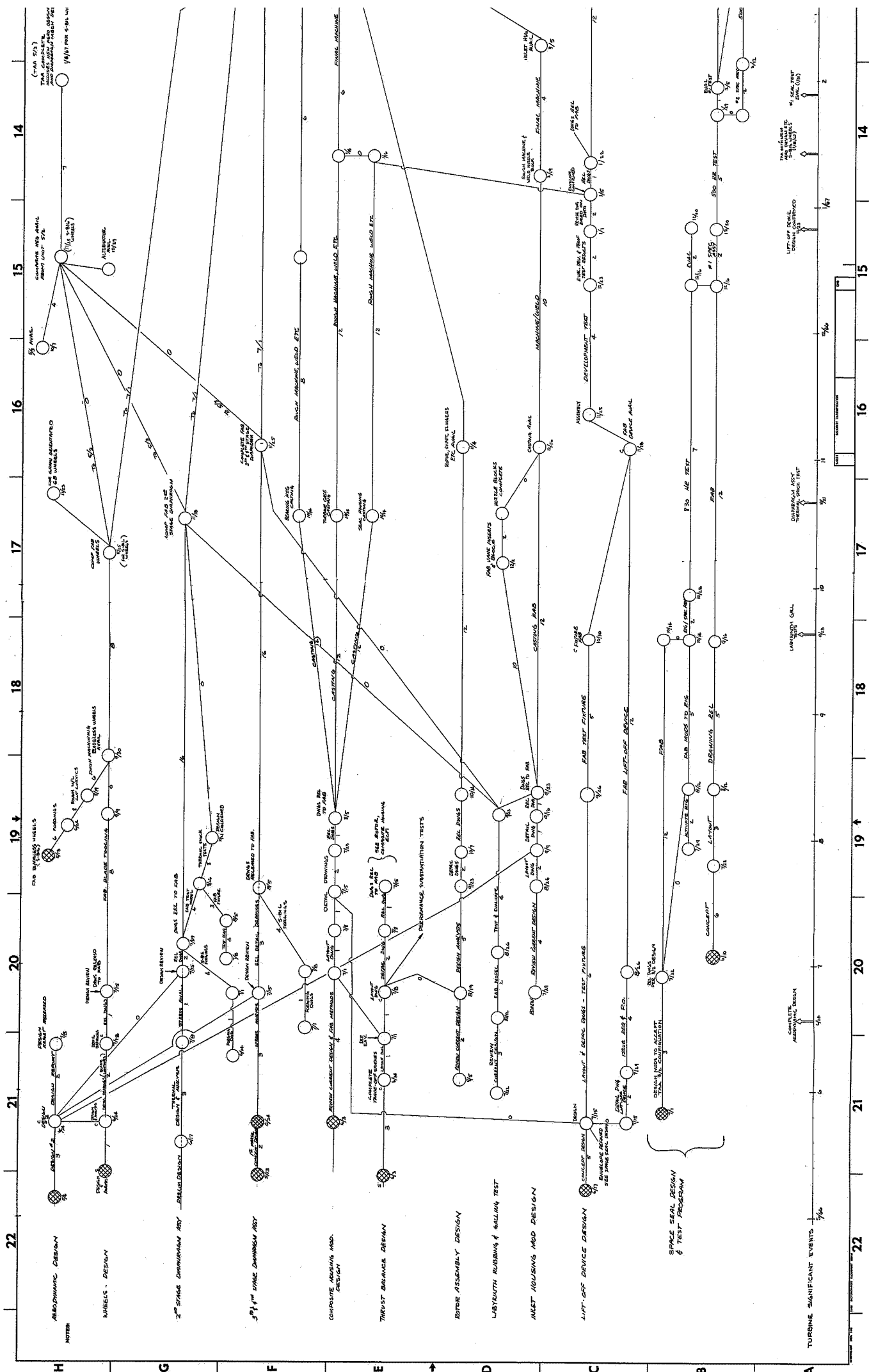
AXIAL PROFILE



PRESENT DESIGN

Axial Profile Comparison

Figure V-20



FOLDOUT FRAME 1

FOLDOUT FRAME 2

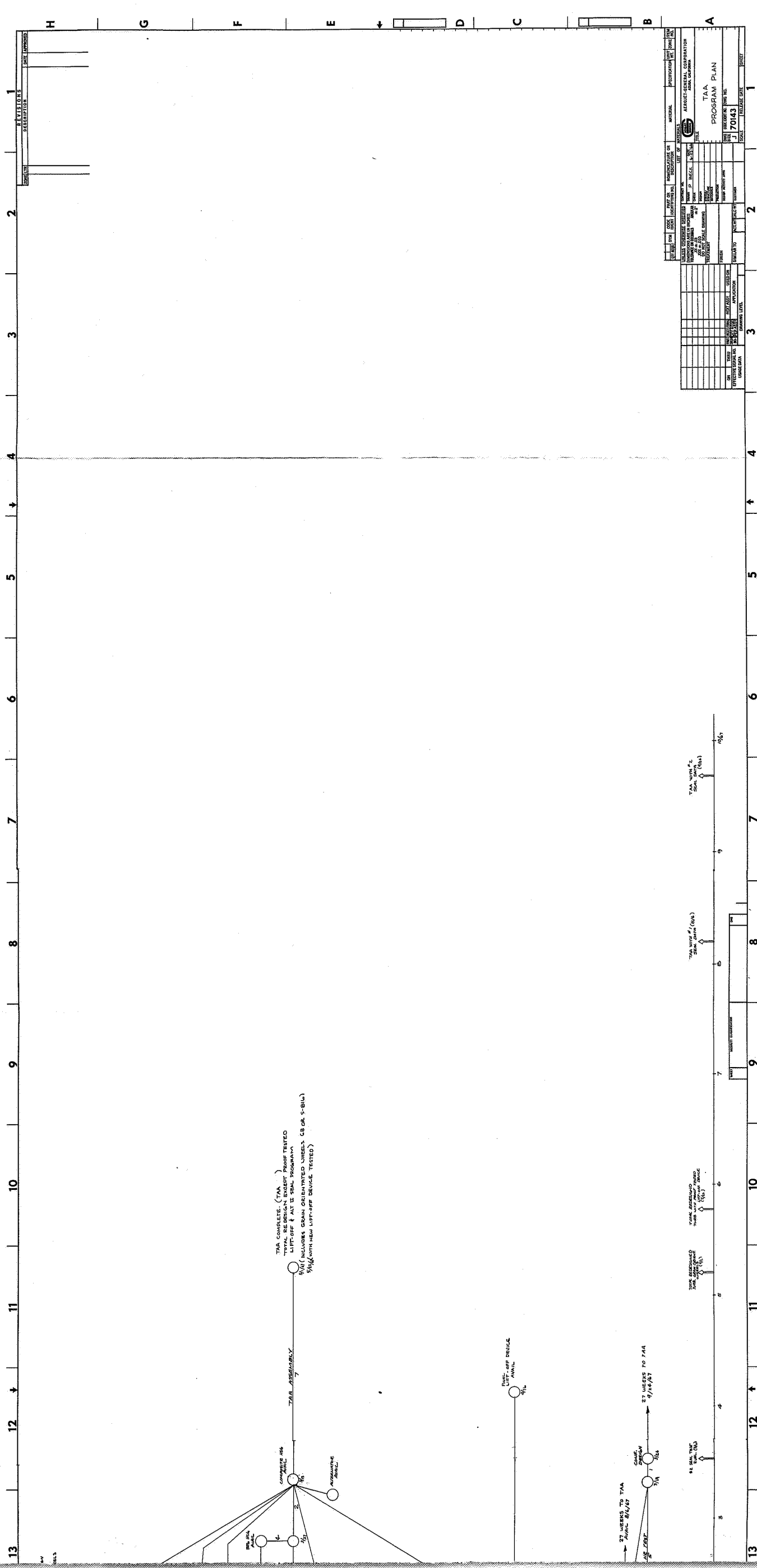


Figure V-21

FOLIOUT FRAME 4

WOLFOUT FRAME 3

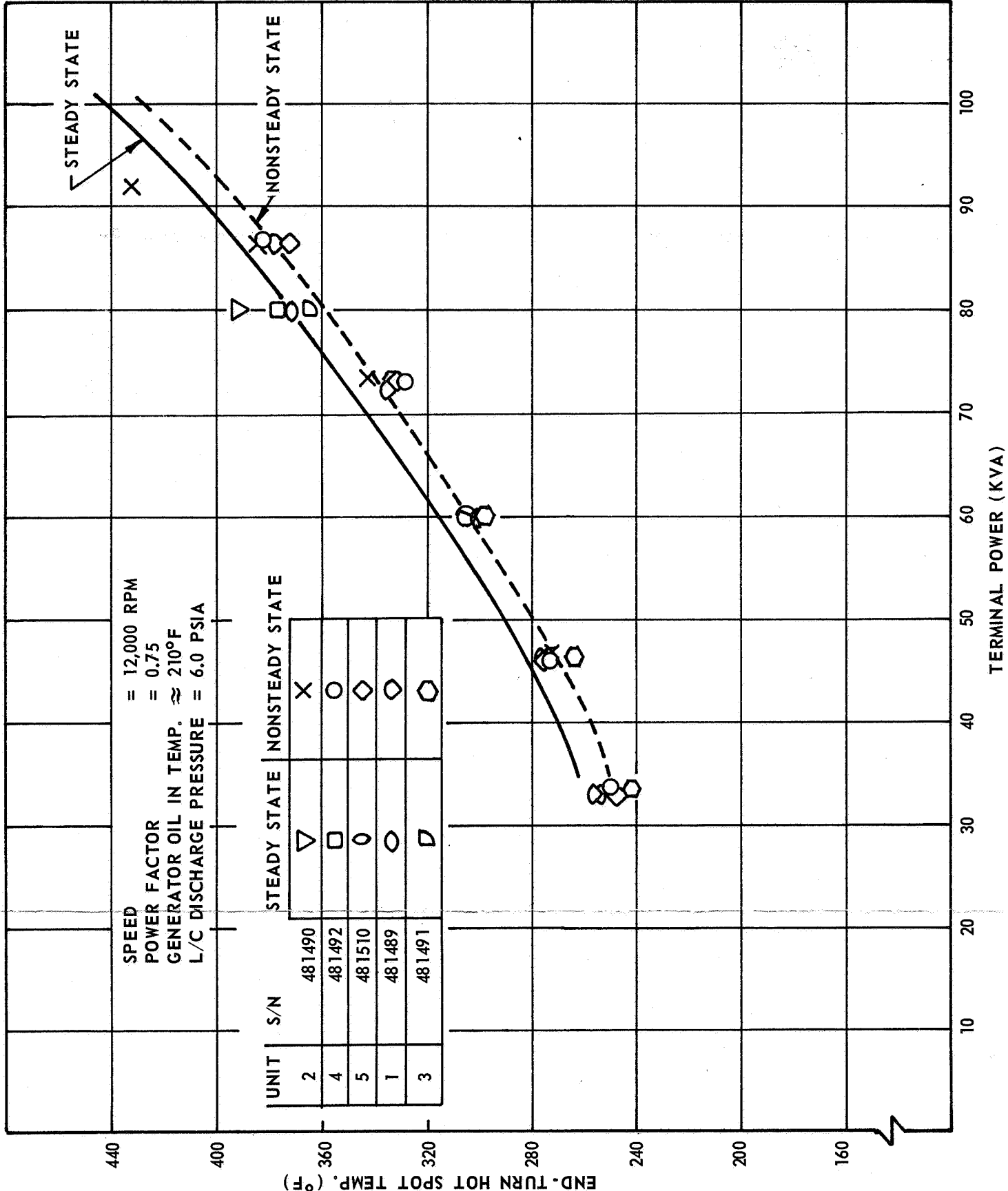
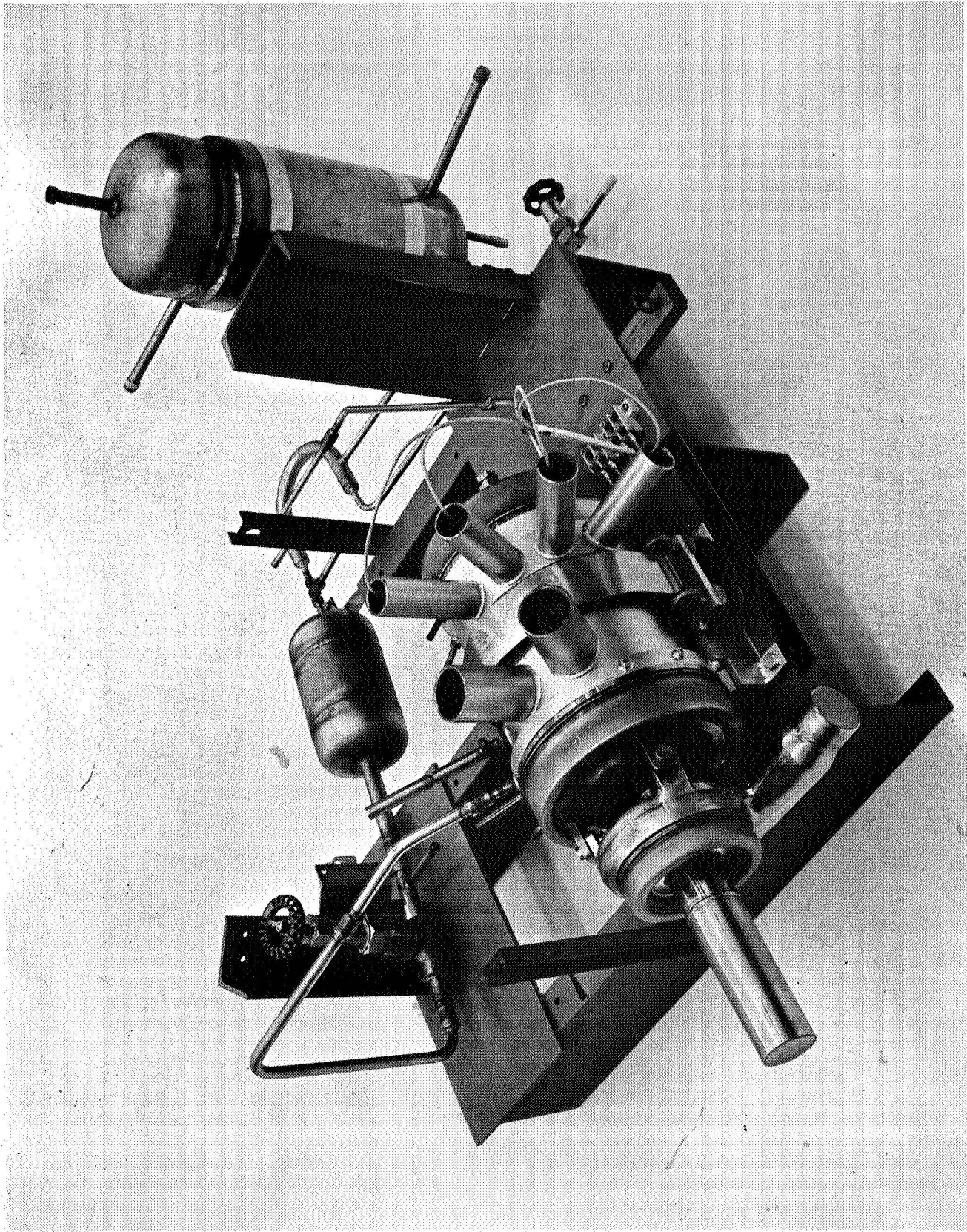


Figure V-22

FOLDOUT FRAME

FOLDOUT FRAME

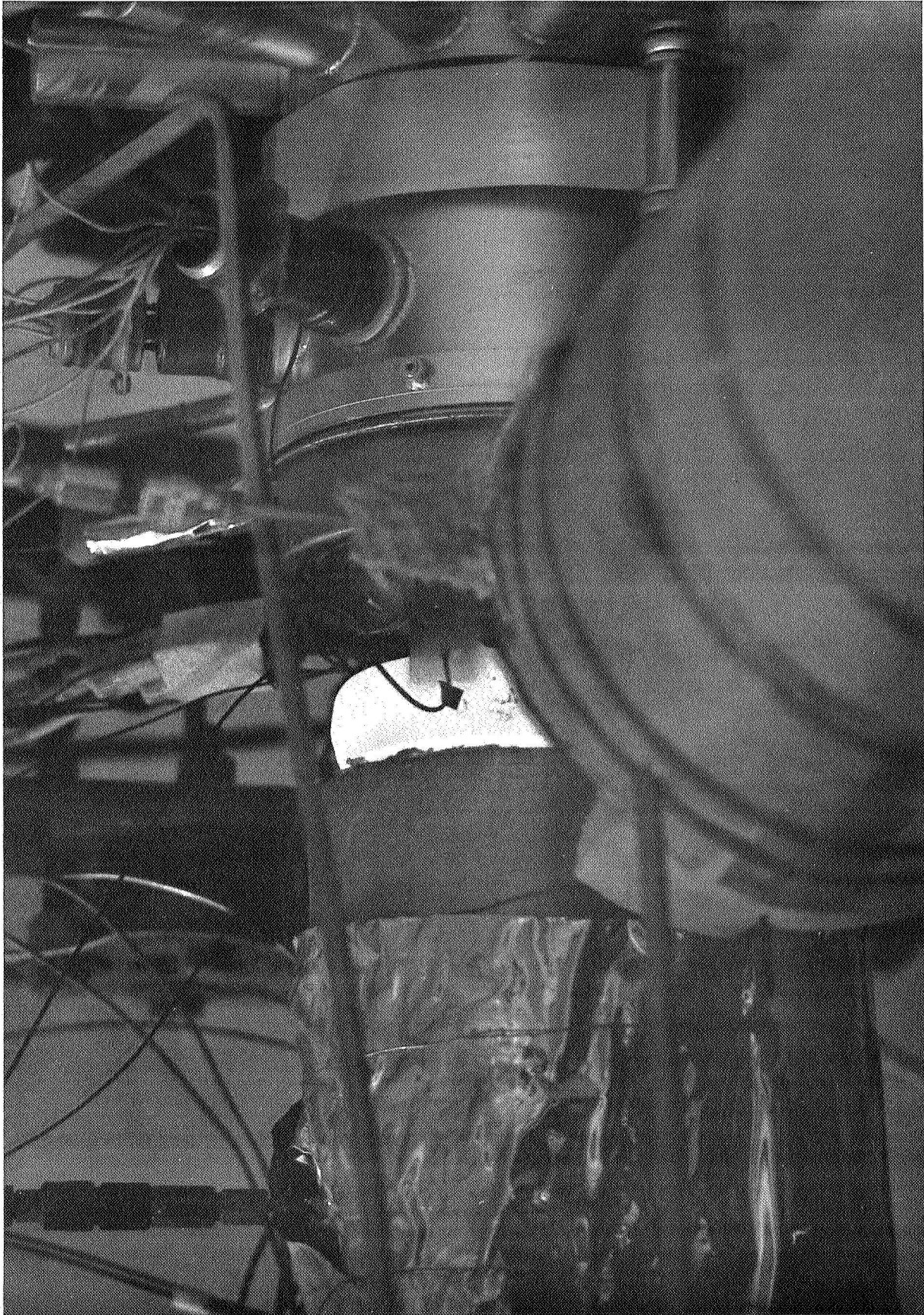
865-293



NaK Pump-Motor Assembly (P/N 093200-13, S/N A-5)

Figure V-23

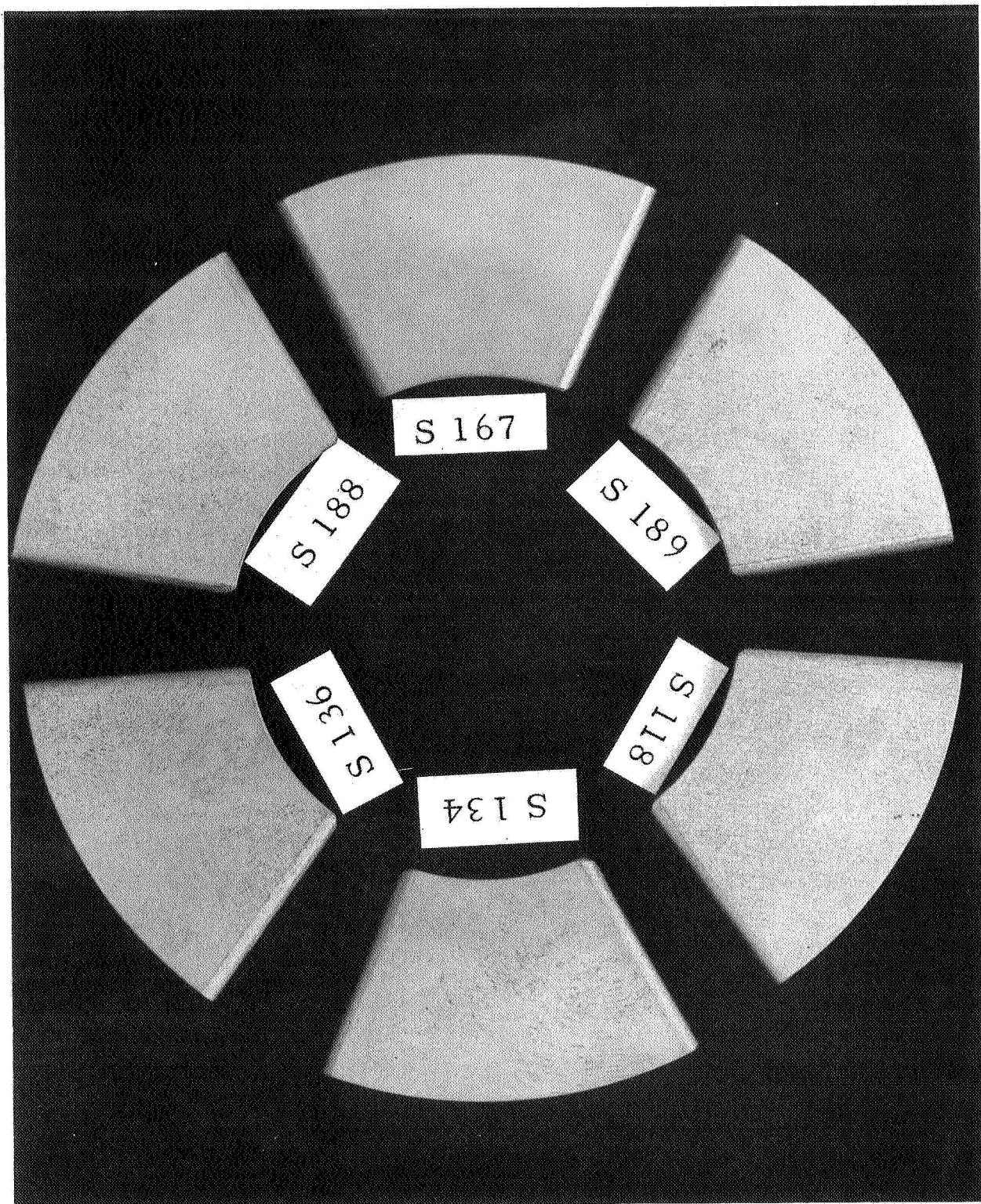
1065-125



NaK Pump-Motor Assembly (P/N 093200-13, S/N A-5)
Glowing at 1225°F During 3000-Hour Run in INL-3

Figure V-24

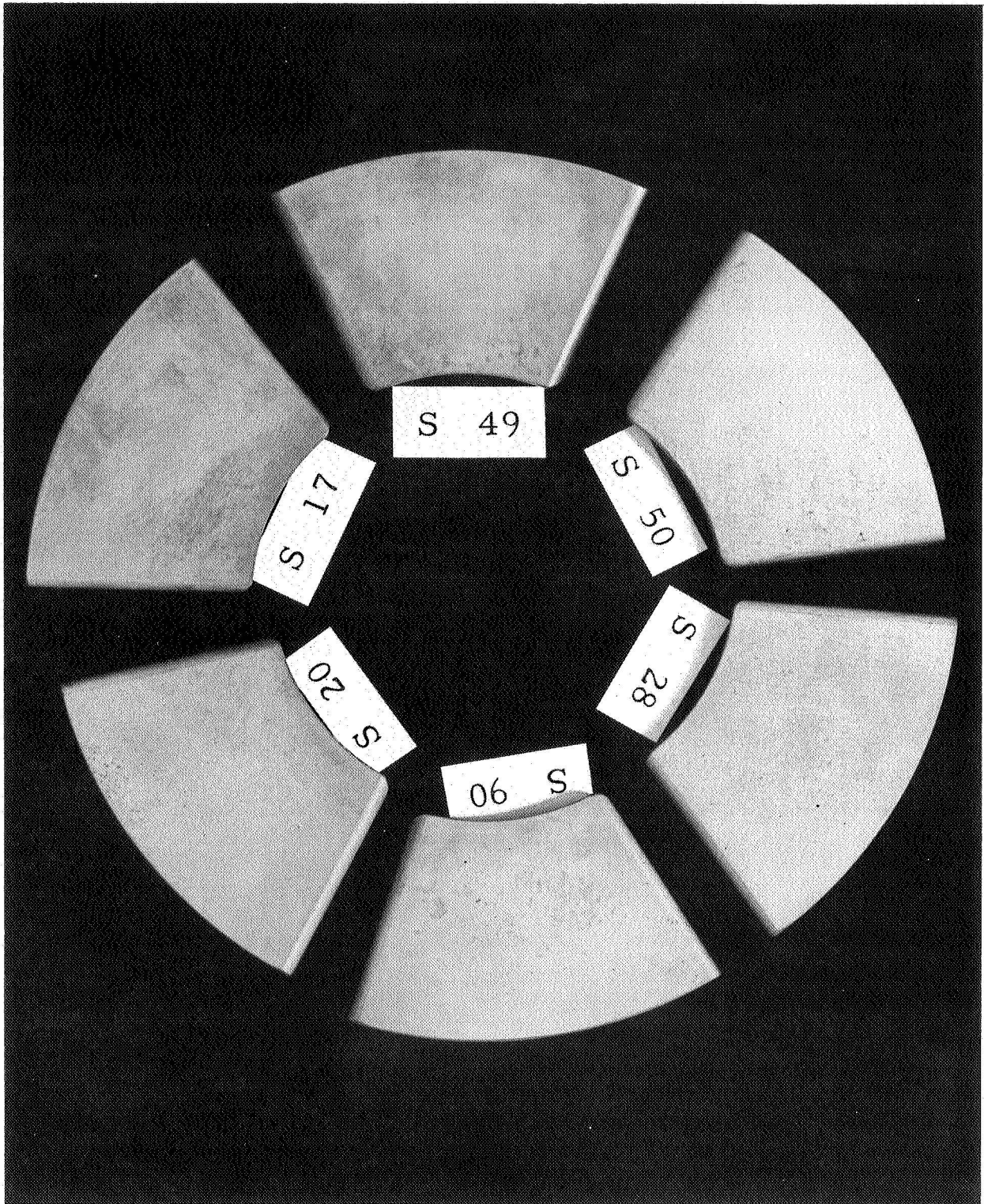
166-670



NaK Pump-Motor Assembly (P/N 093200-13, S/N A-5)
Thrust Bearing Pads From Motor End

Figure V-25

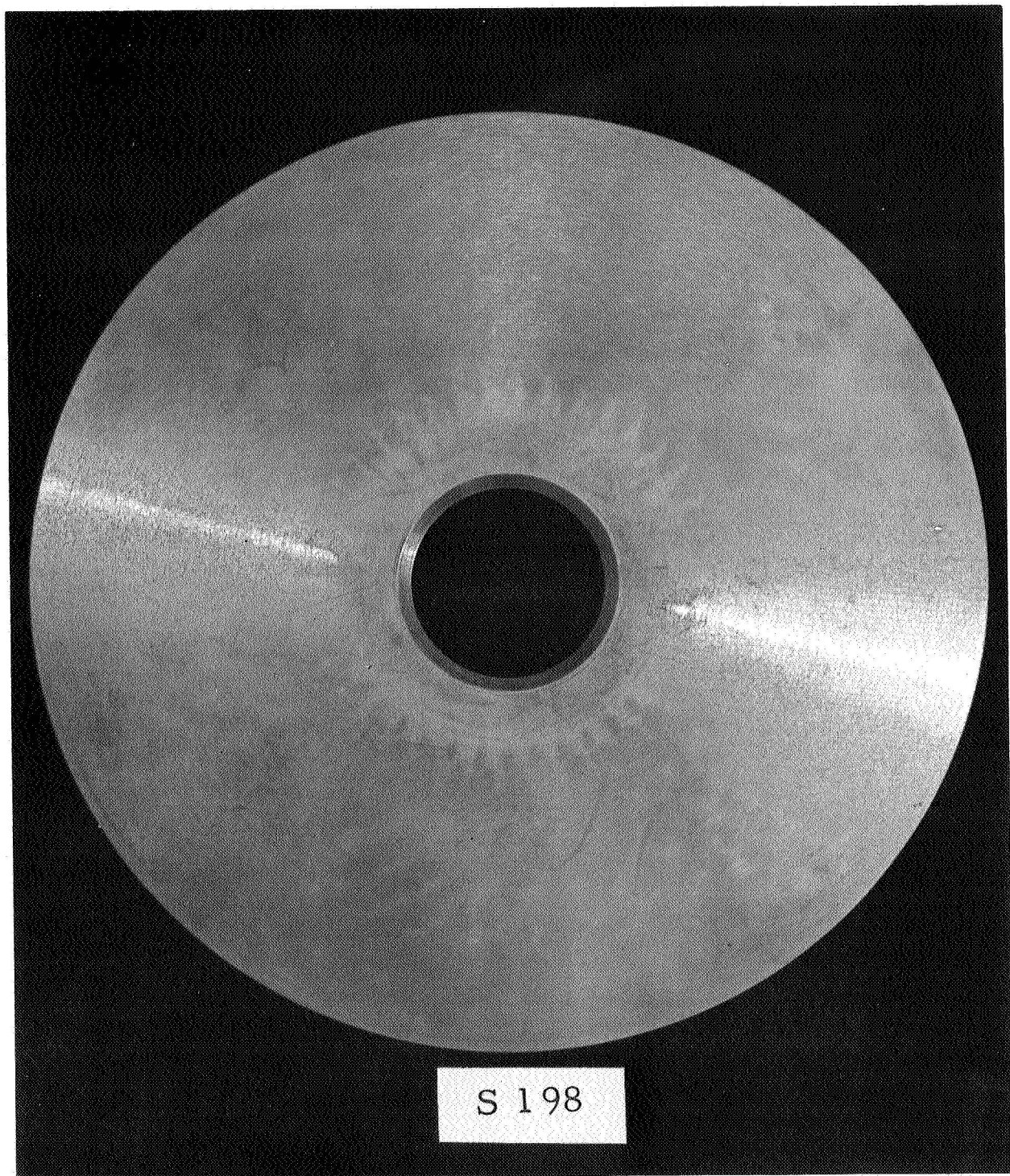
166-671



NaK Pump-Motor Assembly (P/N 093200-13, S/N A-5)
Thrust Bearing Pads From Pump End

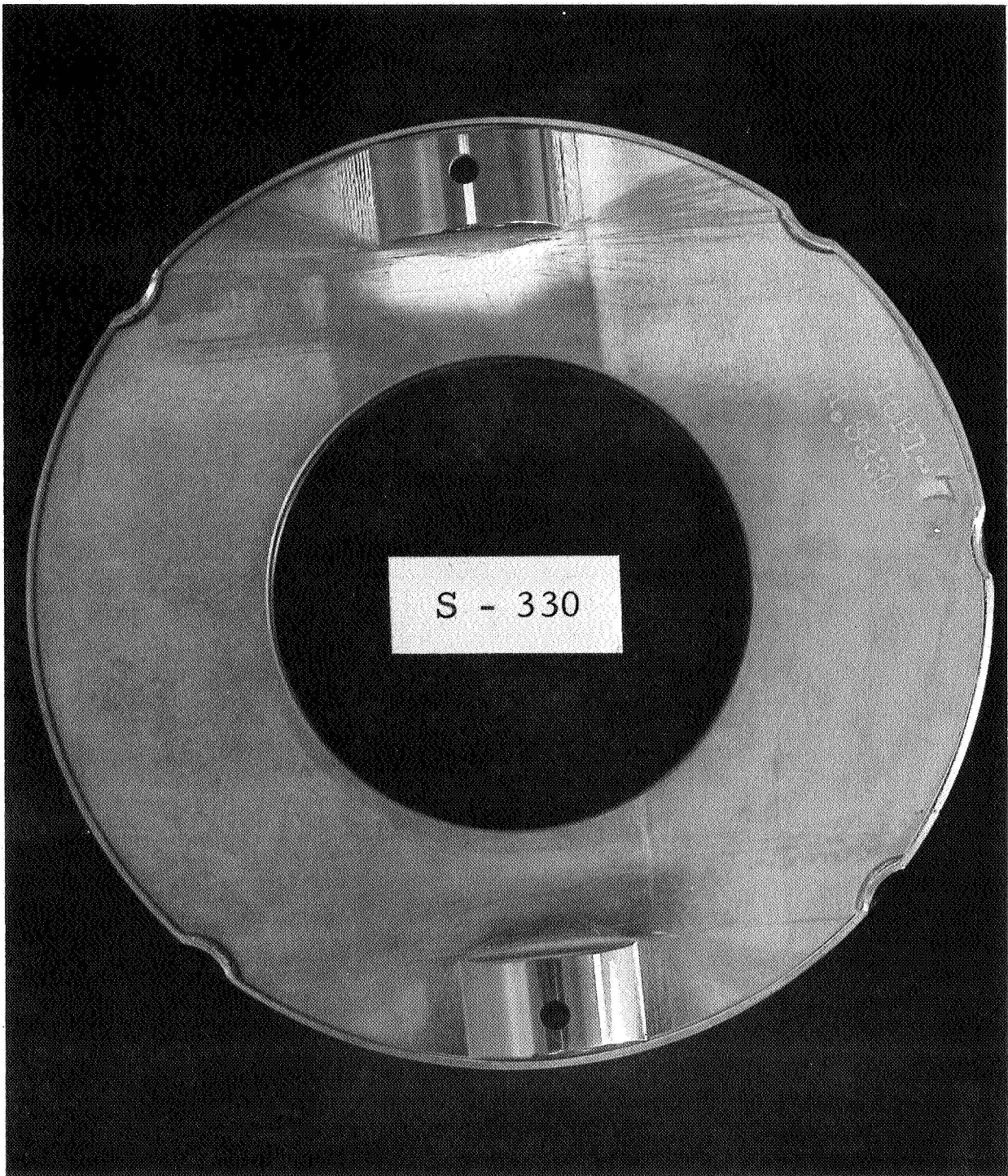
Figure V-26

166-0703



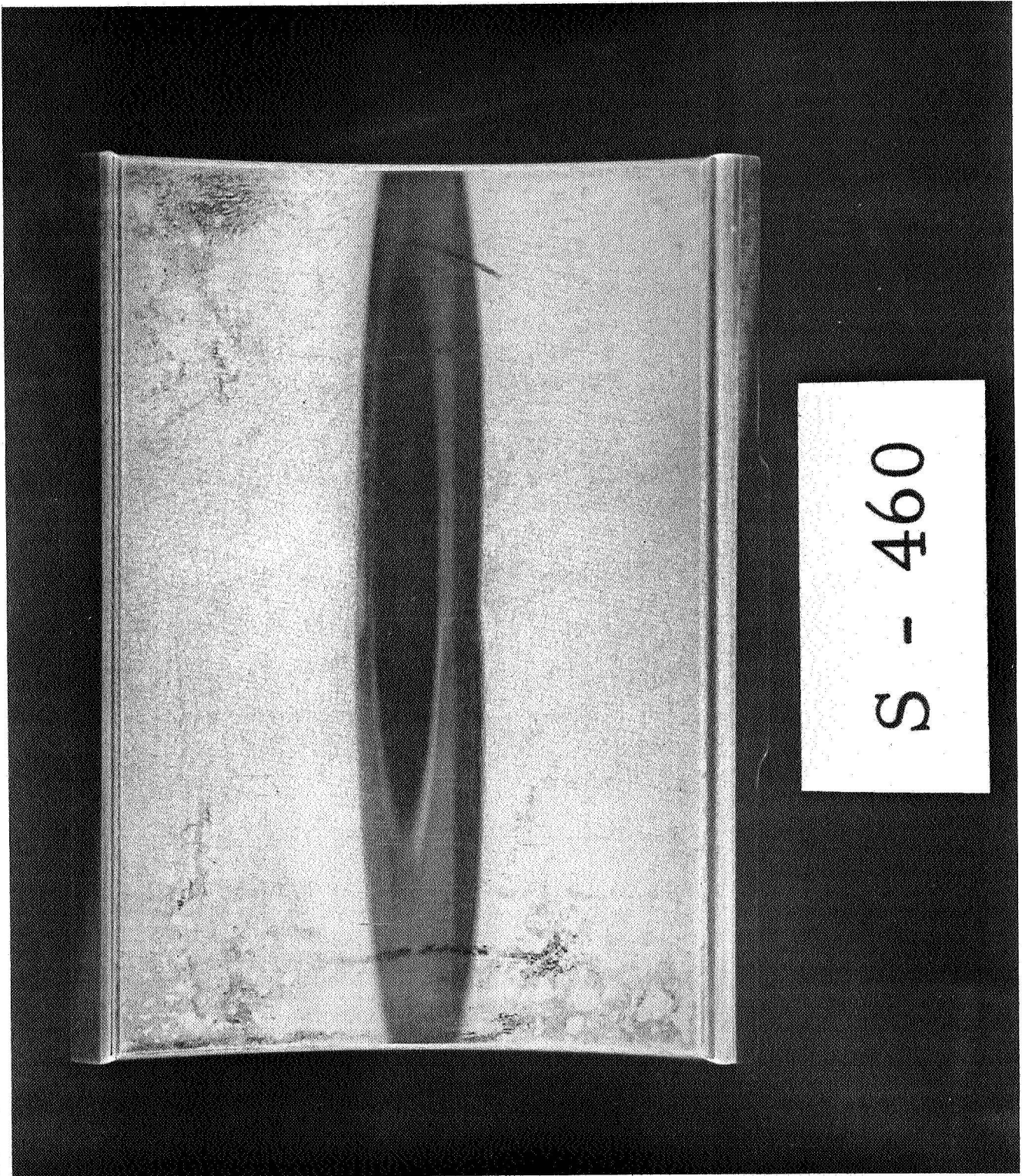
Thrust Runner From NaK Pump-Motor Assembly
(P/N 093200-13, S/N A-5)

166-701



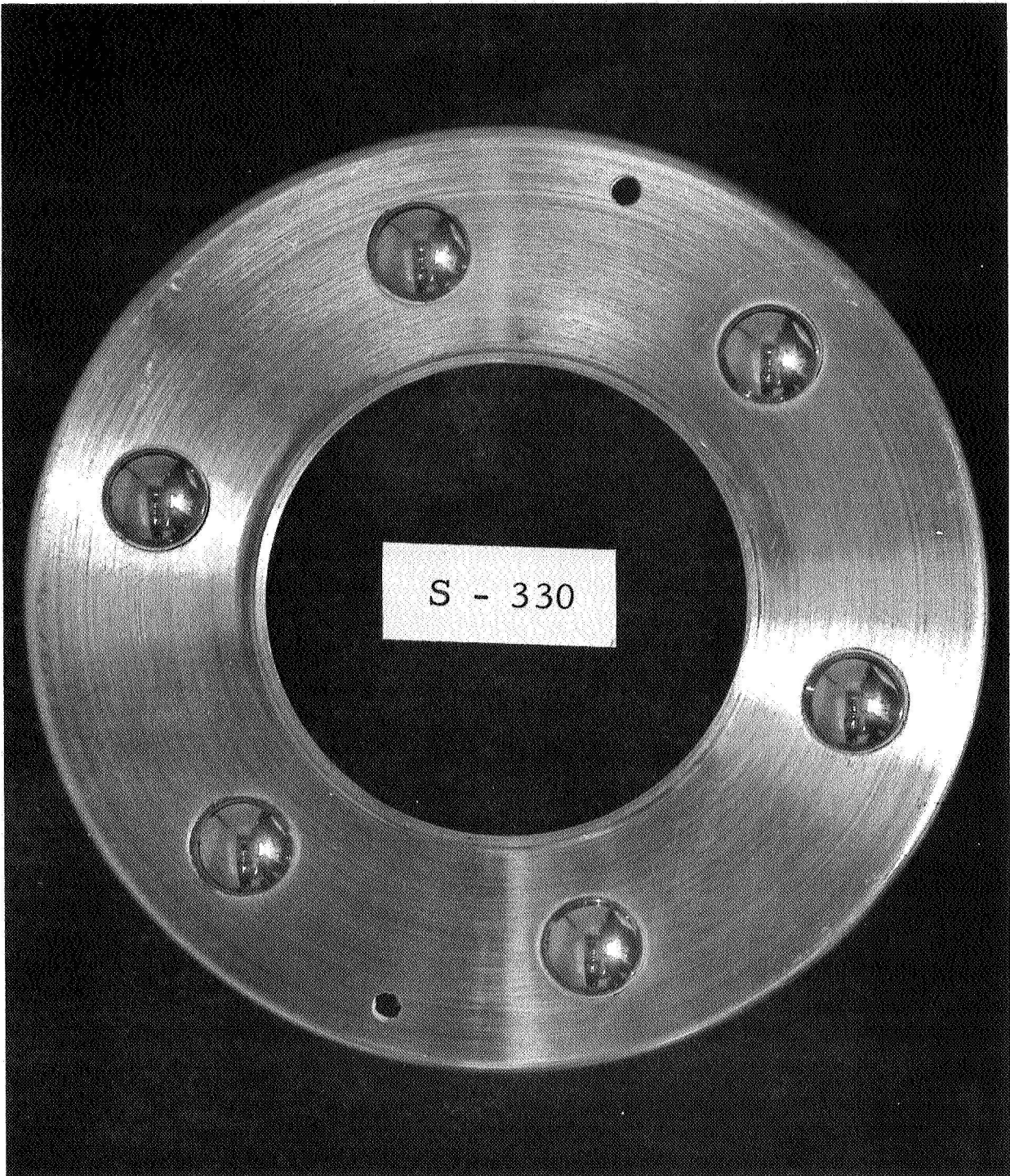
Thrust Bearing Support Ring (Gimbal Side) From
NaK Pump-Motor Assembly (P/N 093200-13, S/N A-5)

166-685



Journal Bearing Pad From NaK Pump-Motor Assembly
(P/N 093200-13, S/N A-5)

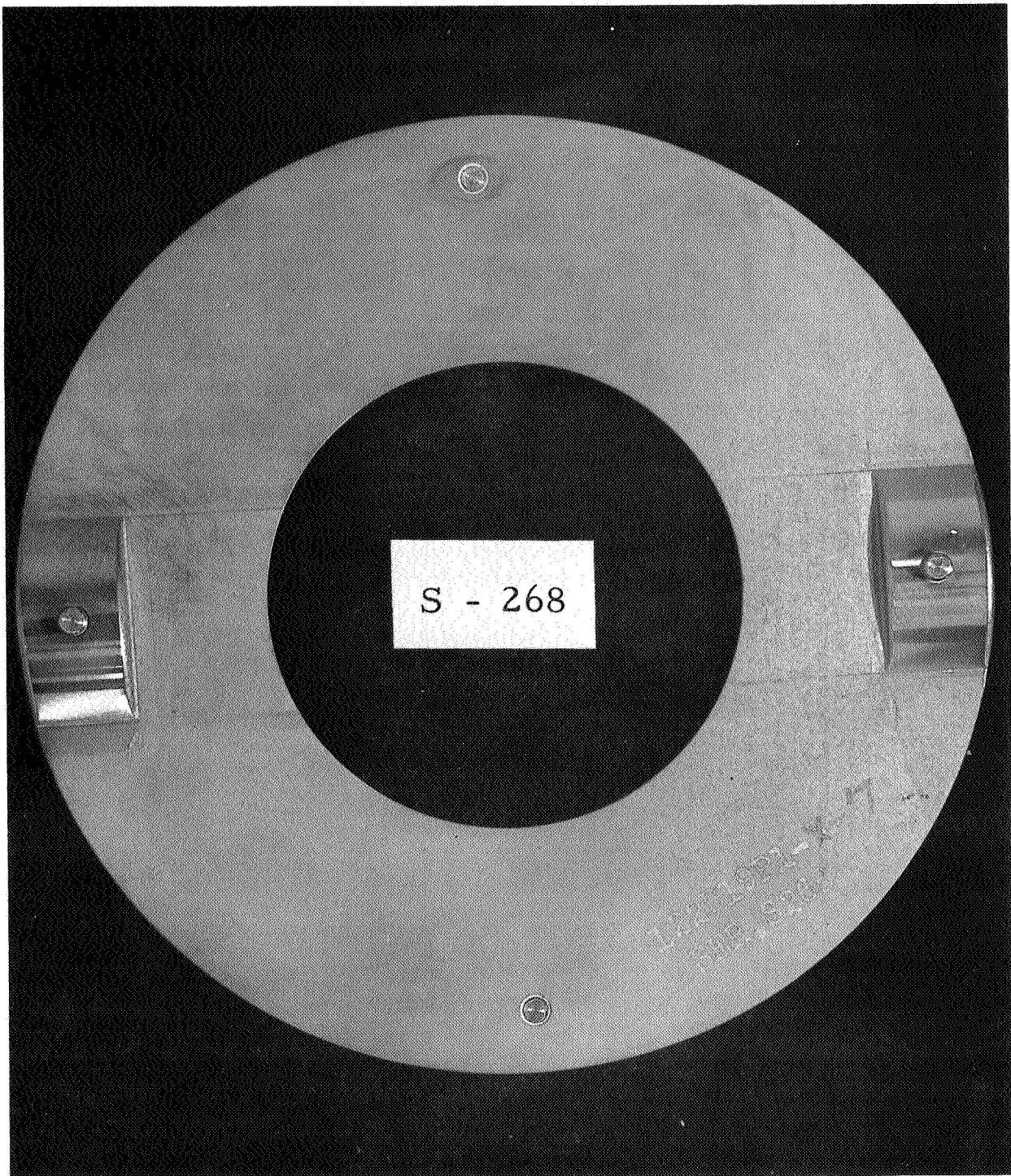
166-691



Thrust Bearing Support Ring (Pivot Side)
From NaK Pump-Motor Assembly
(P/N 093200-13, S/N A-5)

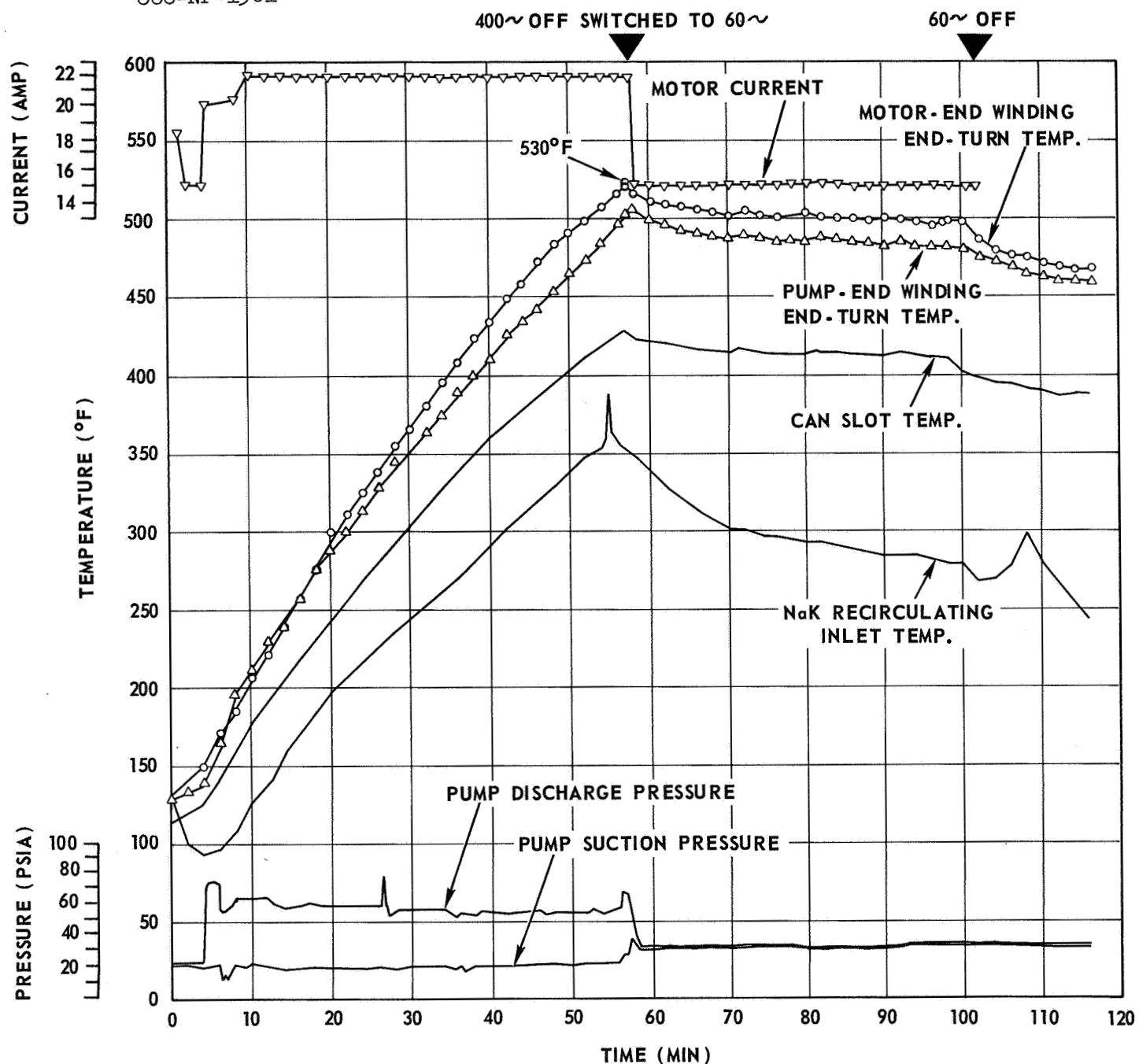
Figure V-30

166-693

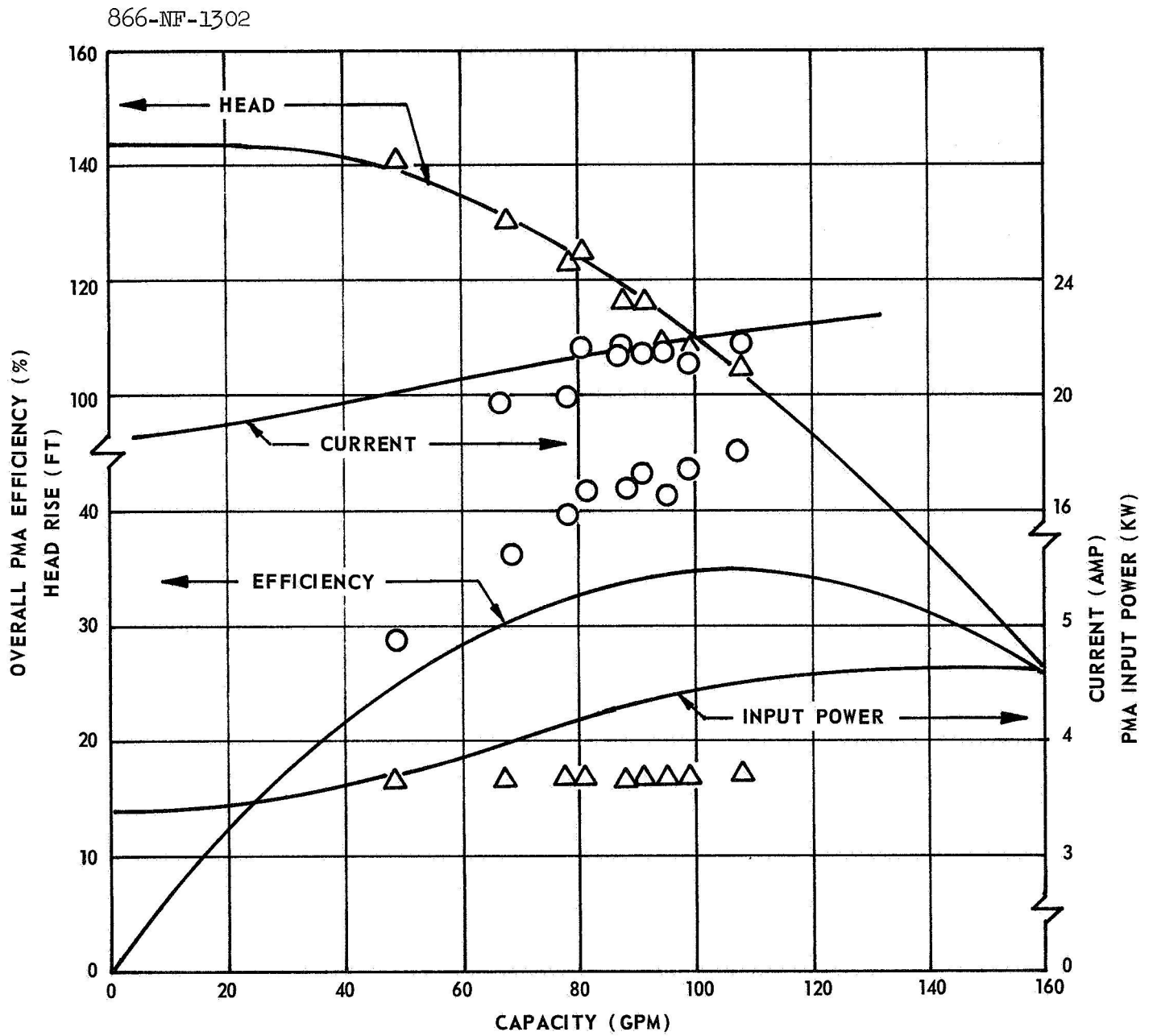


Thrust Bearing Gimbal Ring From NaK Pump-Motor Assembly
(P/N 093200-13, S/N A-5)

866-NF-1301



NaK PMA (S/N A-6) Temperature Test Data From
116 Minutes of Operation in PCS-1 Phase IV Step 2



NaK PMA (S/N A-6) Performance in PCS-1 Phase IV Step 2

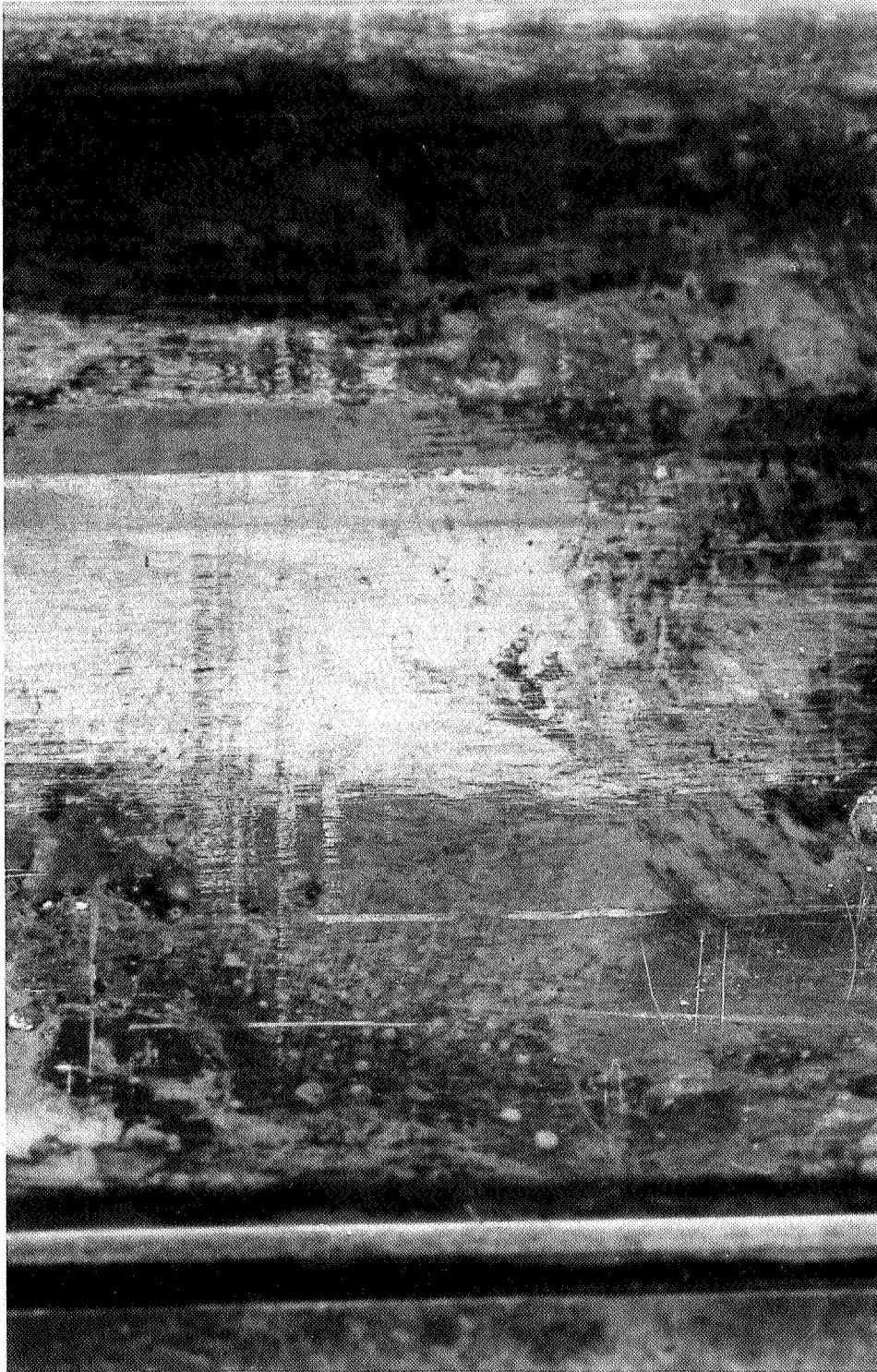
366-303



Pump-End Radial Bearing Pads of NaK Pump-Motor
Assembly (P/N 093200-13, S/N A-6) From Primary
Loop of PCS-1 Phase IV Step 2

Figure V-34

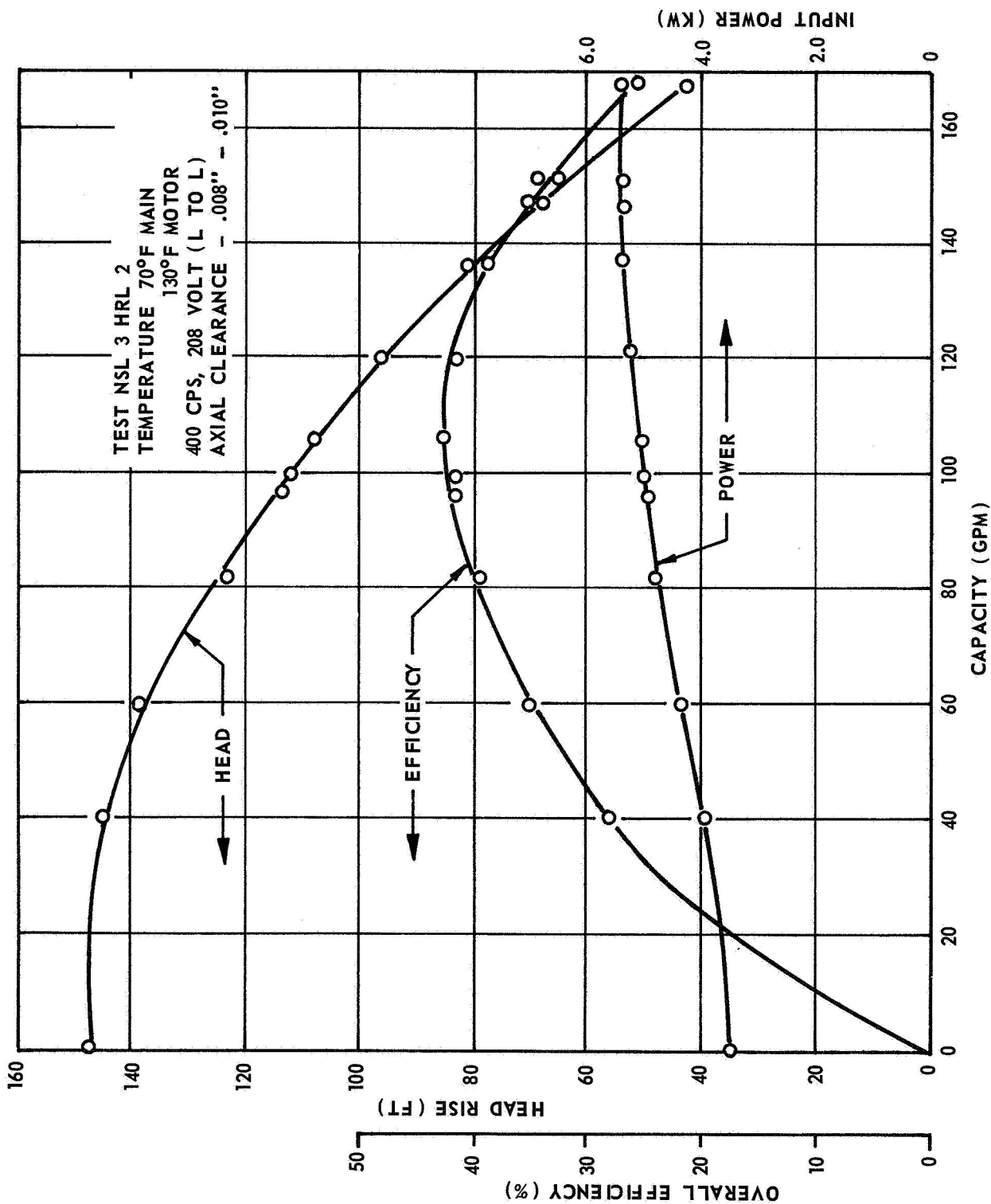
366-503



Motor-End Radial Bearing Pad (S-415), Showing Center Burnishment with Marks Assumed Made During Disassembly From NAK PMA S/N A-6

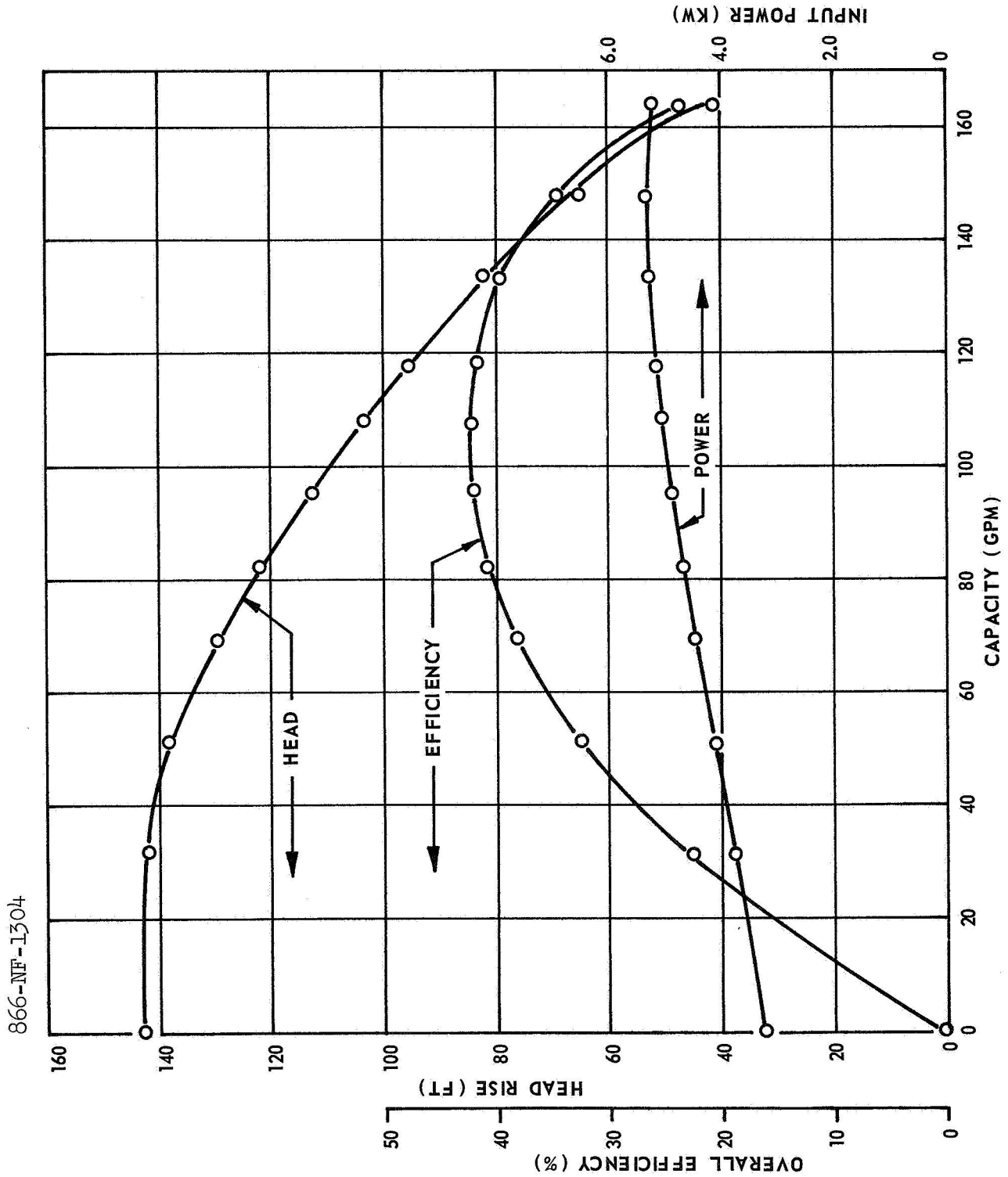
Figure V-35

866-NF-1303



NaK PMA (Unit 5/2) Performance in NSL 3 HRL 2 Water Loop

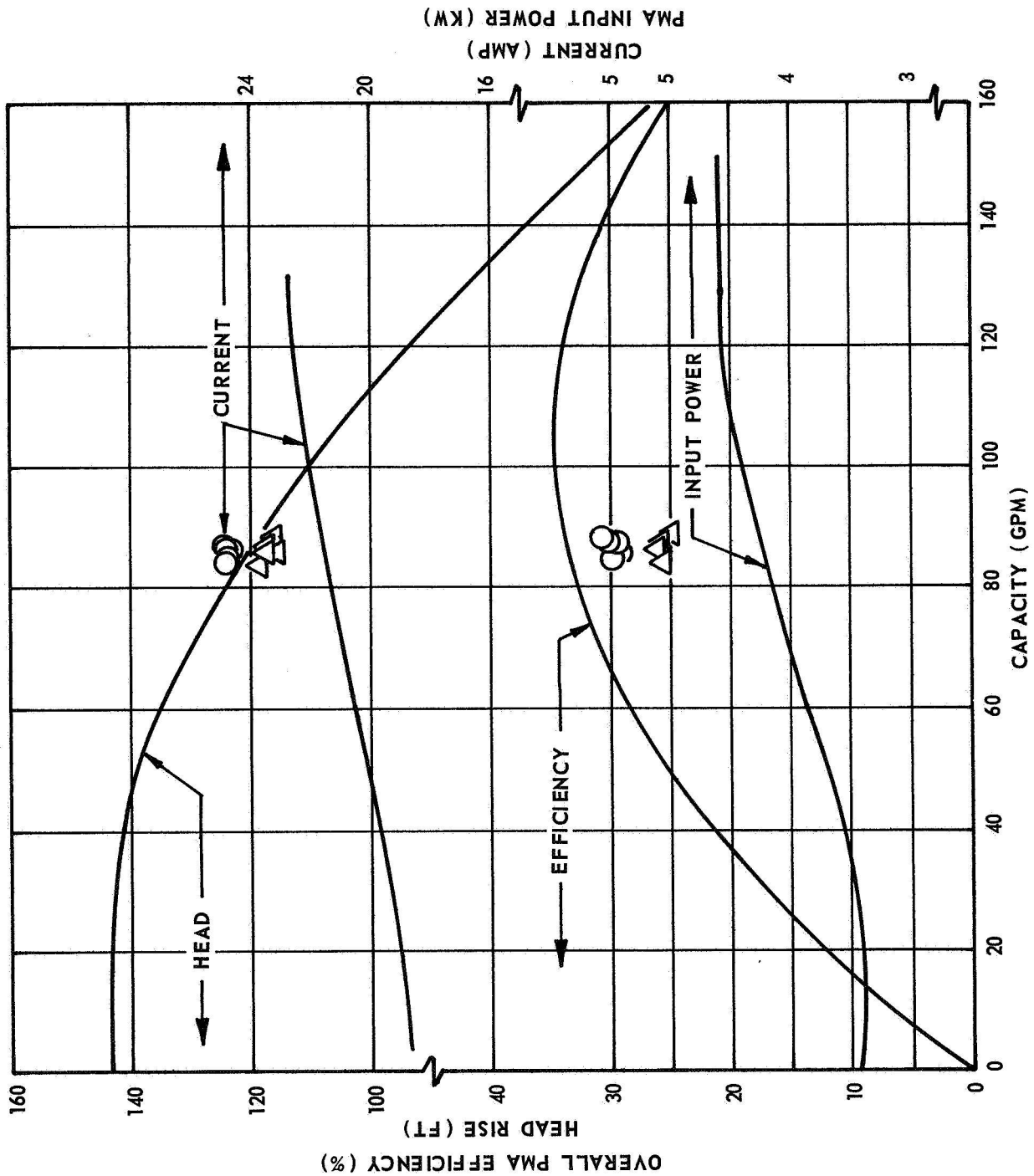
Figure V-36



NaK PMA (P/N 094066-1, S/N A-1) Performance in NSL 2 HRL 2 Water Loop

Figure V-37

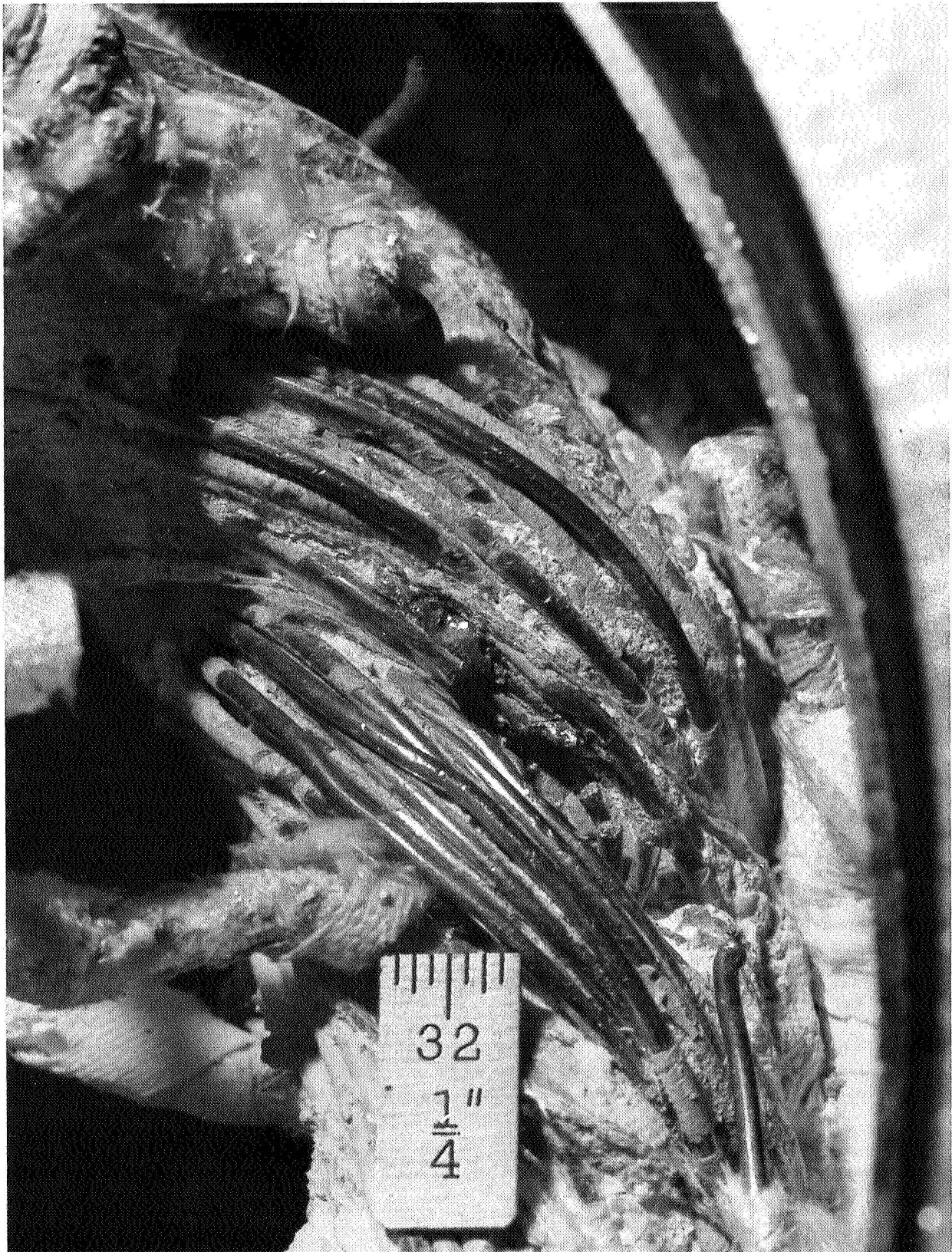
866-NF-1305



NaK PMA (P/N 093200-13, S/N A-2)
Performance in PCS-1 Phase IV Step 2

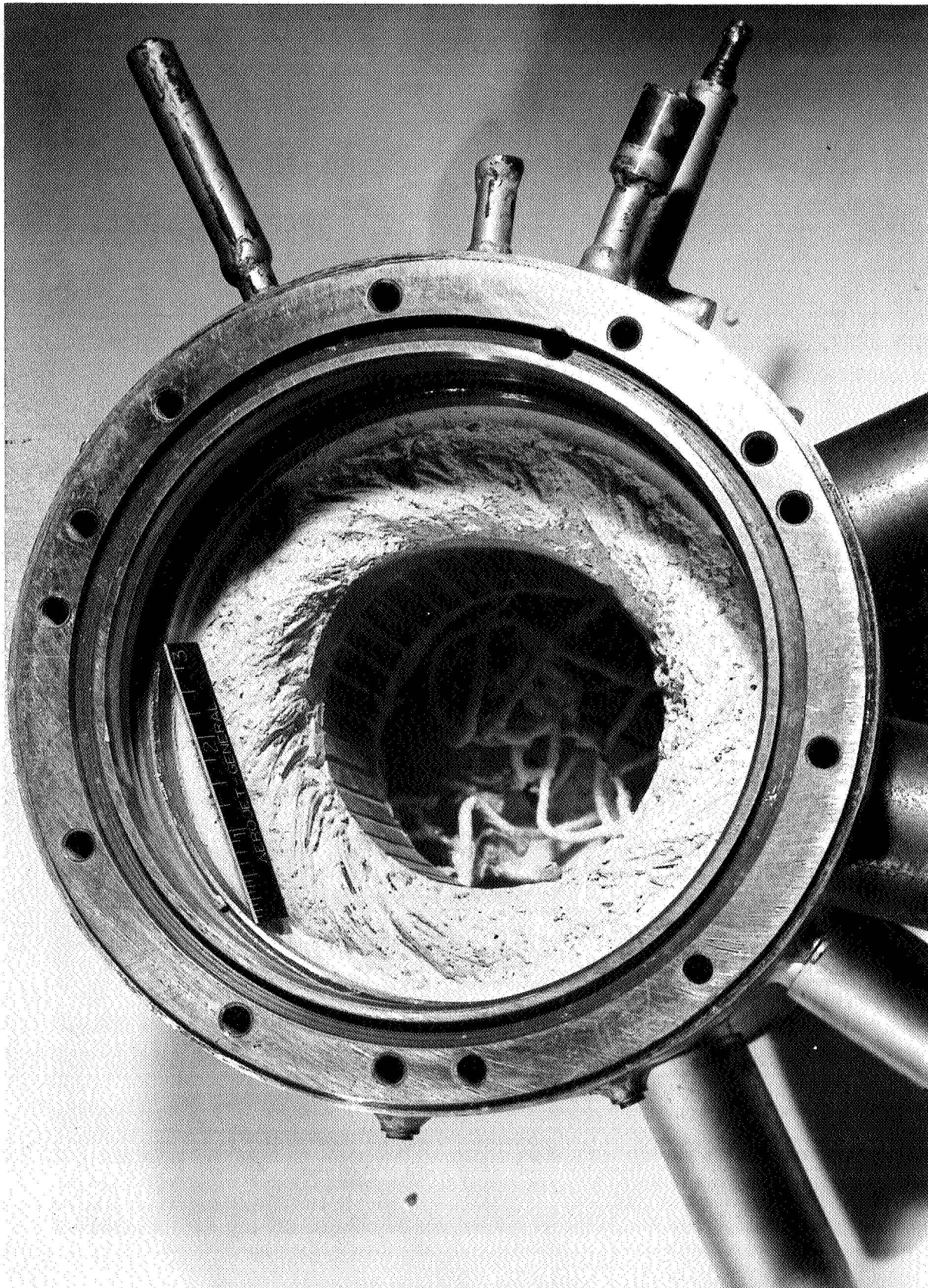
Figure V-38

566-793



Winding Failure of NaK Pump-Motor Assembly S/N A-2

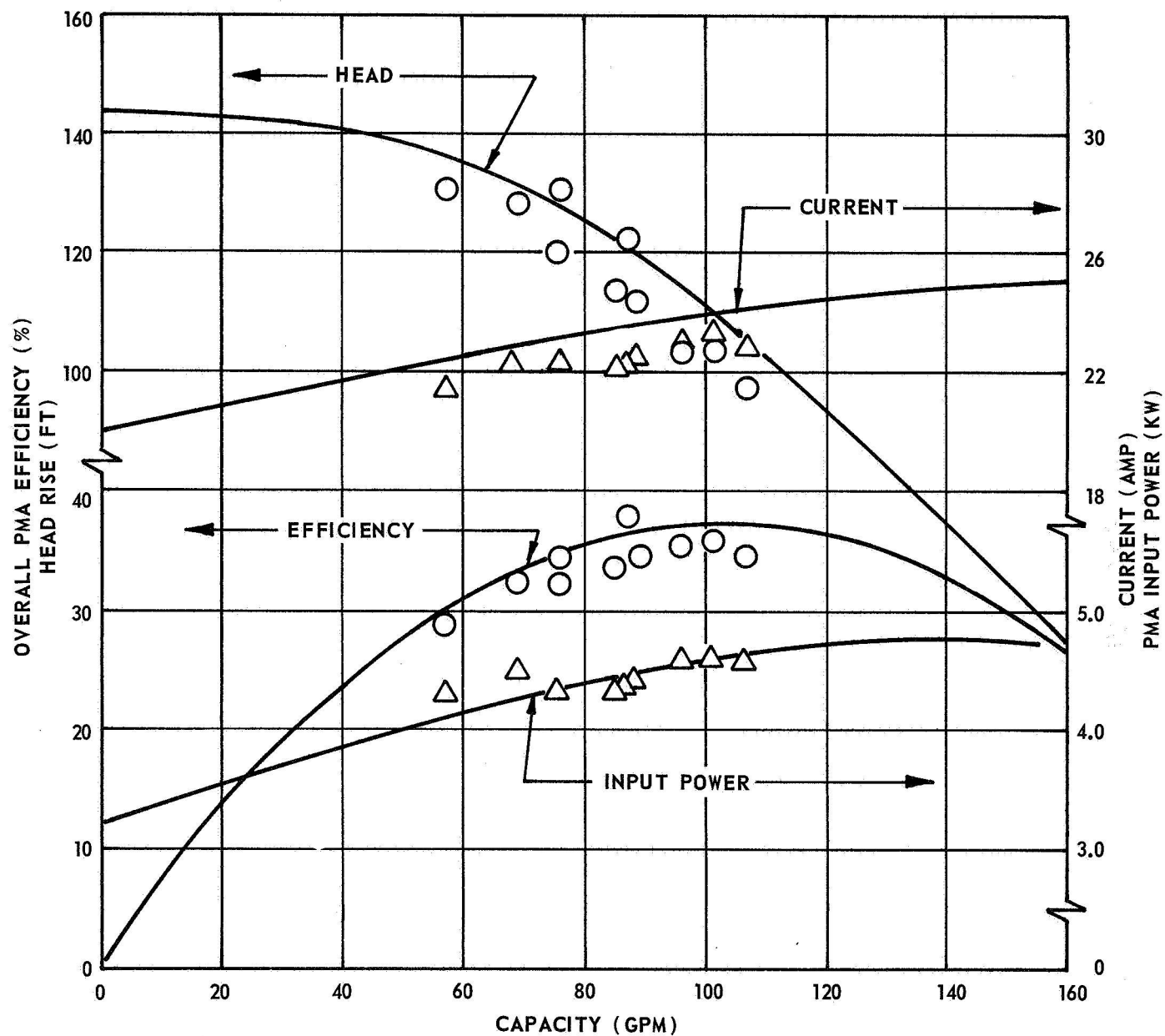
Figure V-39



Potting Compound Used for NaK PMA Motors
Shown Partially Removed During Failure
Investigation of NaK PMA S/N A-2

Figure V-40

866-NF-1306



NaK PMA (P/N 093200-13, S/N A-4)
Performance in PCS-1 Phase IV Step 2

Figure V-41

566-52



Inside Bore of Stator Can From NaK PMA Unit 4/1 (P/N 093200-13C,
S/N A-4), Showing Arc Holes and Copper Splatter at Areas 3 and 4

Figure V-42

566-53



Inside Bore of Stator Can From NaK PMA Unit 4/1(P/N 093200-13C,
S/N A-4), Showing Arc Holes at Area 5

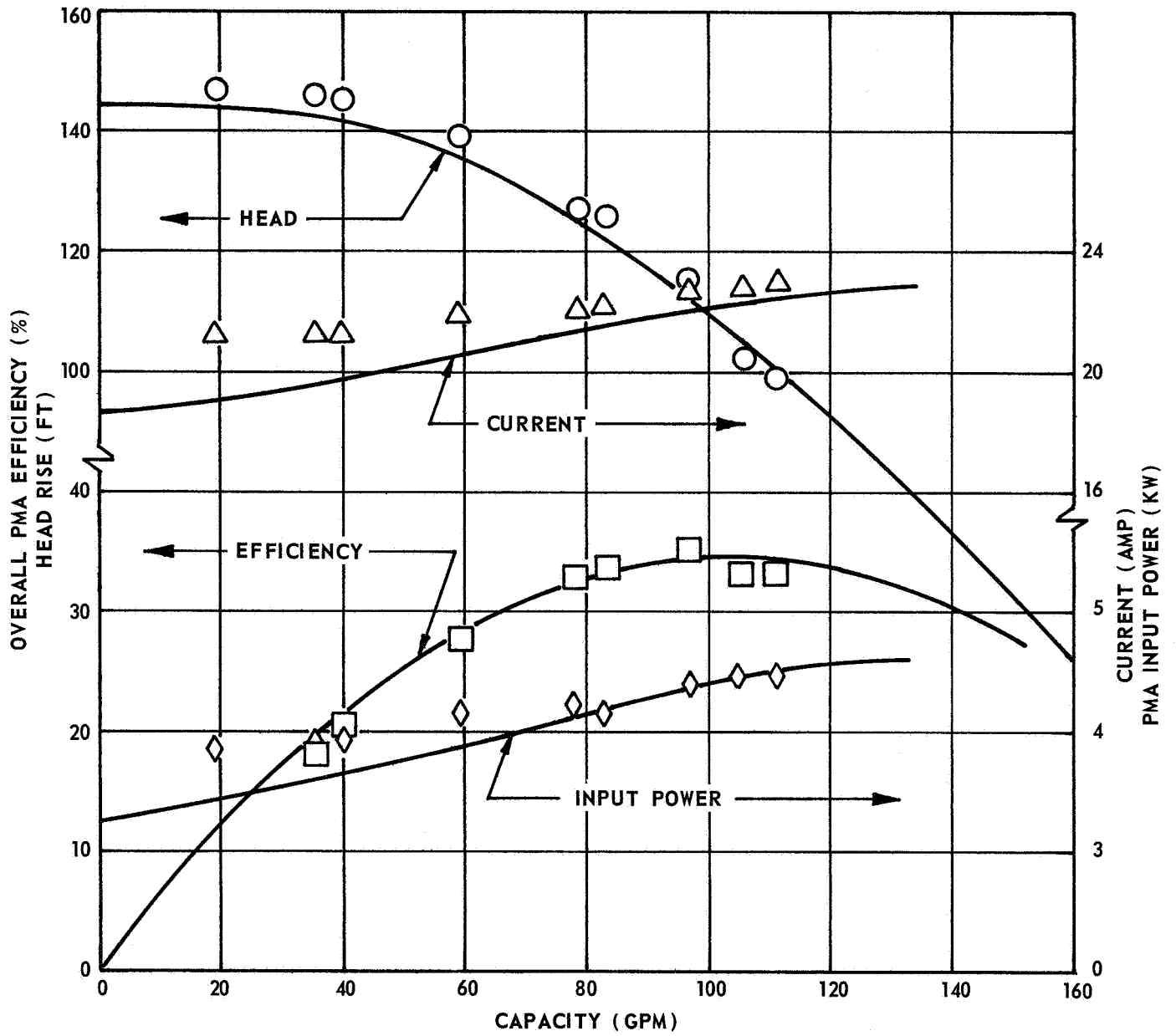
Figure V-43



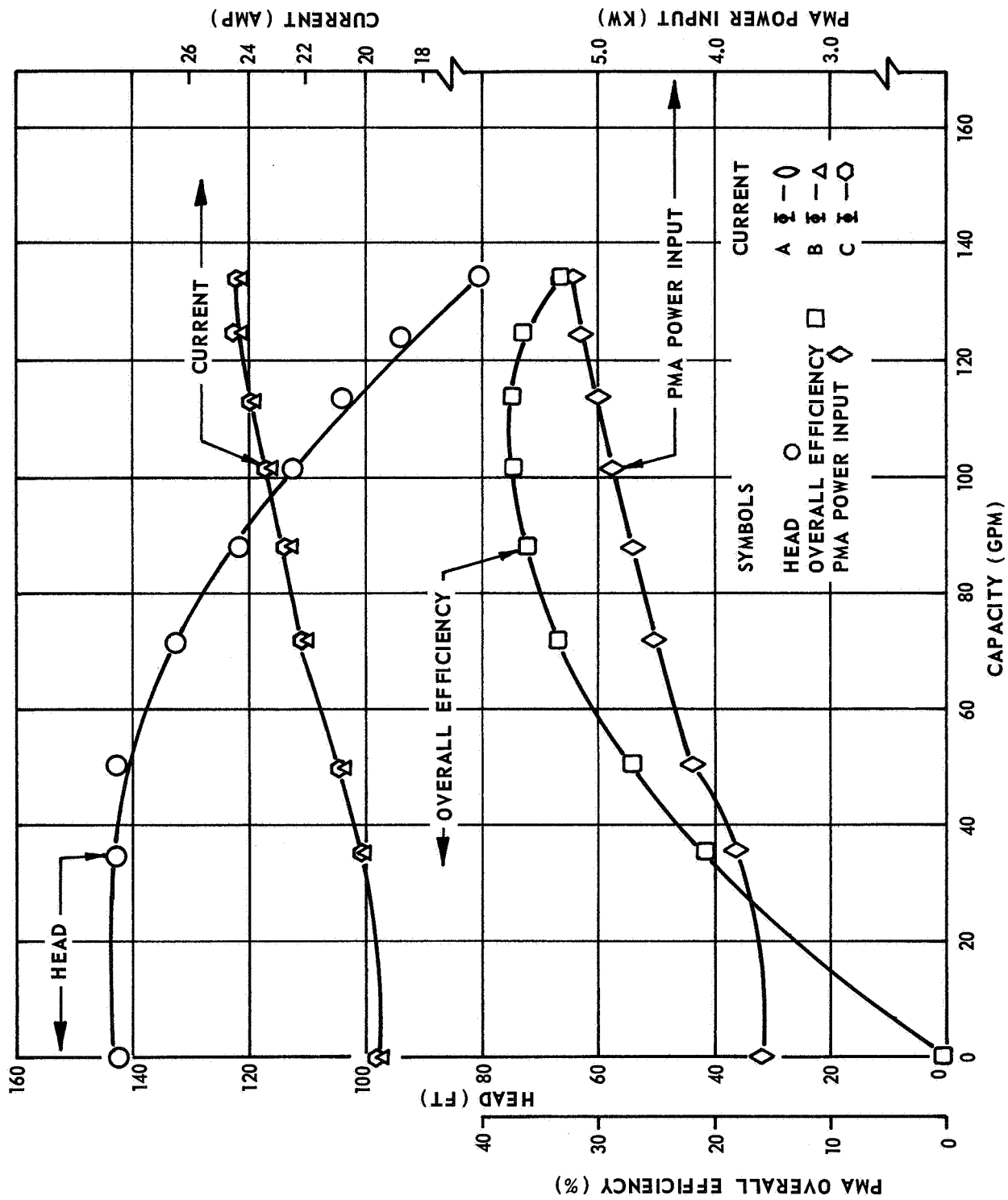
Can Melt on Motor Stator End of NaK PMA Unit
4/1 (P/N 093200-13C, S/N A-4)

Figure V-44

866-NF-1307



NaK PMA (P/N 093200-13, S/N A-7)
Performance in PCS-1 Phase IV Step 2



NaK PMA (P/N 093200-13, S/N A-1)
Performance in PCS-1 Phase IV Step 2

Figure V-46

9

NOTES:
1. THESE ITEMS TO BE FURNISHED WITH 092449-1
2. THESE THERMOCOUPLE WELLS TO BE INSTALLED WITH 092449-1
3. THERMOCOUPLES TO BE INSTALLED AT TEST FACILITY
4. QUICK DISCONNECT MALE TEE/MALE CONNECTORS, CALIBRATE AT 202°F
5. IN SHIELD OR IN THERMOCOUPLE WELLS. THESE THERMOCOUPLES WILL BE
6. USED TO INTERFERE THE PRESENCE OF CRACKS (HOLE). THE INSULATION OF
7. THE SHORTED PINS TO USE SHALL BE 10 MEG OHMS OR GREATER
8. MEASURED AT 50 VDC. INCLUDES T₁₀ TO T₁₉ AND T₁₉ T₁₉.
9. TO BE INSTALLED IN 092449-1.
10. ELECTRICAL INSTRUMENTS TO BE INSTALLED IN TEST FACILITY.
11. INSTRUMENTS TO BE FURNISHED BY FACILITY.
12. HEATER CONTROL REQUIRED TO BE FURNISHED BY TEST FACILITY.
13. CONTROL BY MONITORING IS. CONTROL LIMITATION: 50 OF 100%.
14. COVER GAS PANELS TO BE FURNISHED BY TEST FACILITY.
15. HEATER HAS THERMOSTAT CONTROLLED INCLUDED.
16. BURST DIAPHRAGM ON COVER GAS PANEL ID TO BE TO PSA
17. (99 PSI) ON TANK SIDE.
18. AS AN INTERCHANGEABLE ALTERNATE ITEM, USE THERMOCOUPLE
19. PART NO. 092449-1, CODE IDENT NO. 15460.

PARAMETER LOCATION LEGEND

TEST FACILITY	PARAMETER	TEST FACILITY	PARAMETER	TEST FACILITY	PARAMETER	TEST FACILITY	PARAMETER	TEST FACILITY	PARAMETER
T1	PSIA	T1	PSIA	T1	PSIA	T1	PSIA	T1	PSIA
T2	PSIA	T2	PSIA	T2	PSIA	T2	PSIA	T2	PSIA
T3	PSIA	T3	PSIA	T3	PSIA	T3	PSIA	T3	PSIA
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9

FOLDOUT FRAME 1

FOLDOUT FRAME 2

7

VENT TO SURFACE
LEVEL: 10000
DRAIN
PUMP TANK
LEVEL: 10000
DRAIN
PRESSURE

30

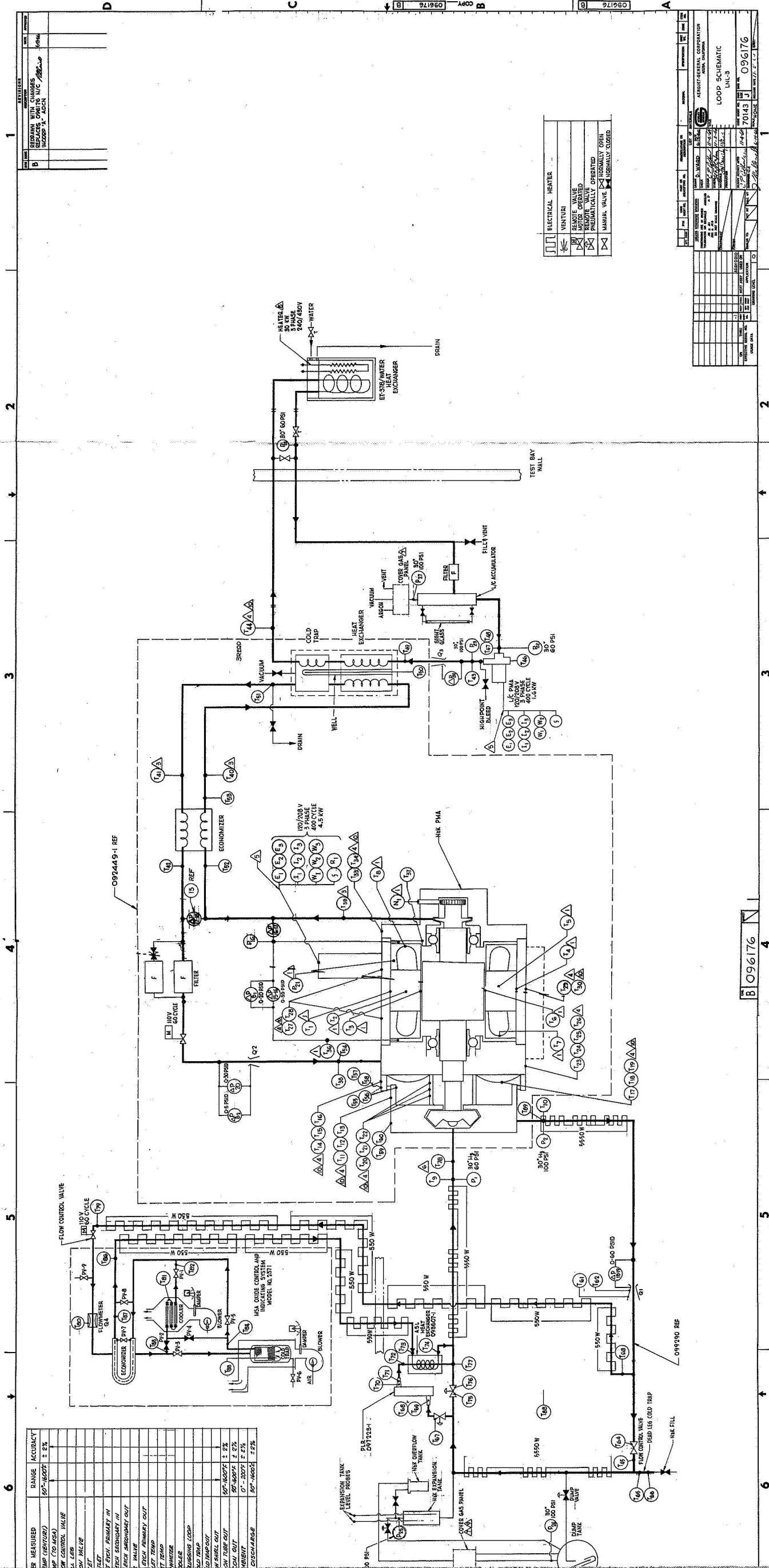


Figure V-47

FOLDOUT FRAME 4

FOLDOUT FRAME 3

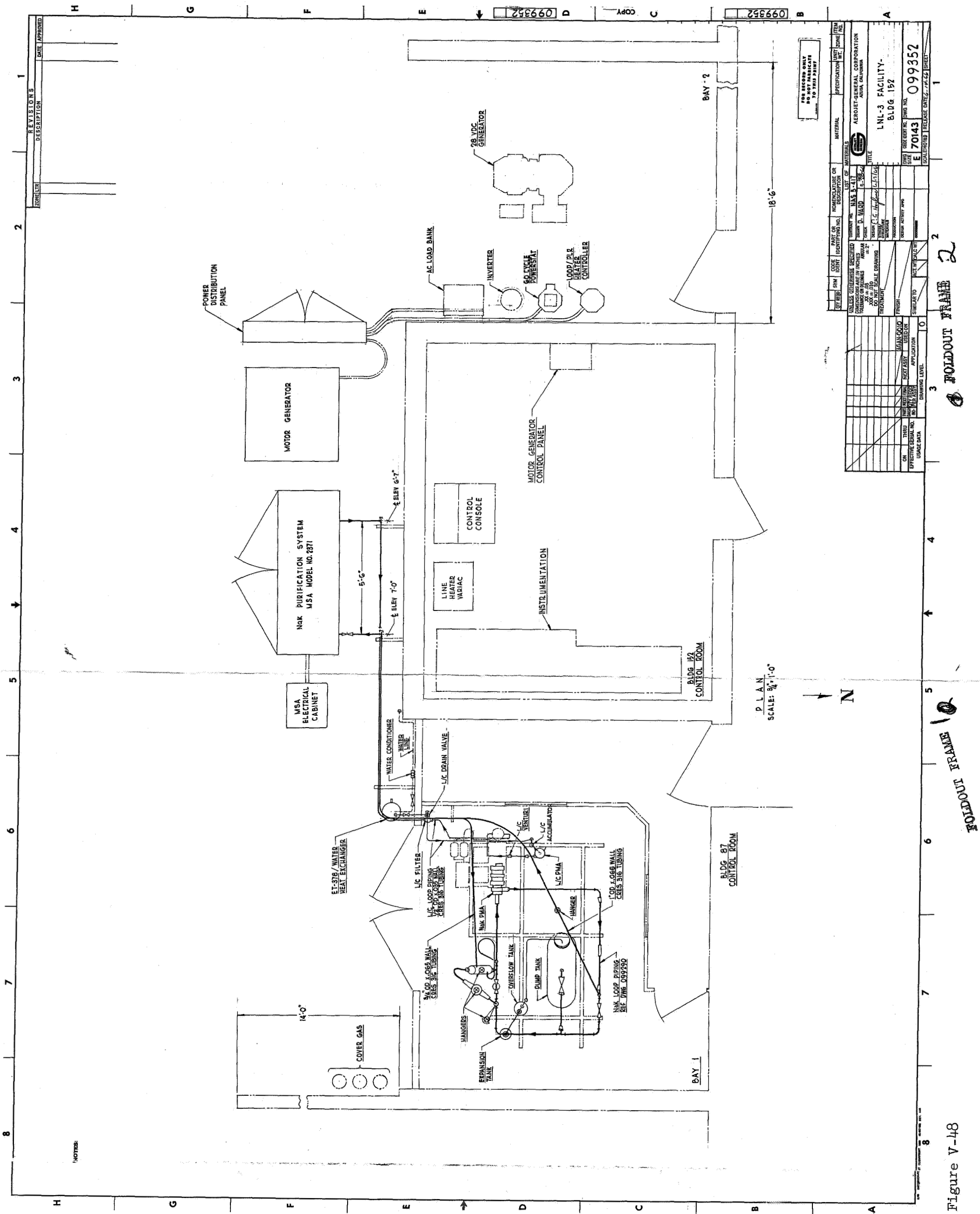
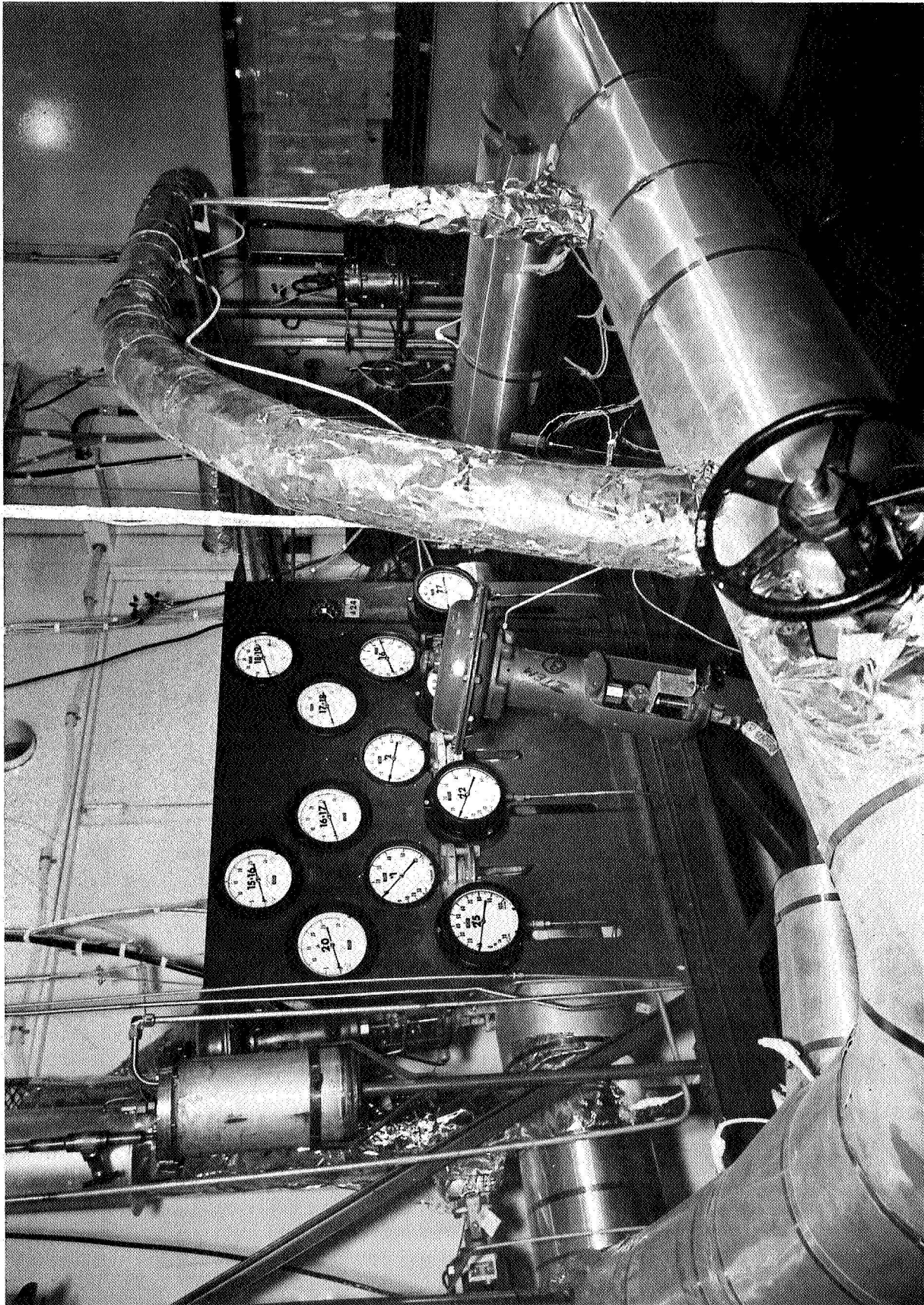


Figure V-48



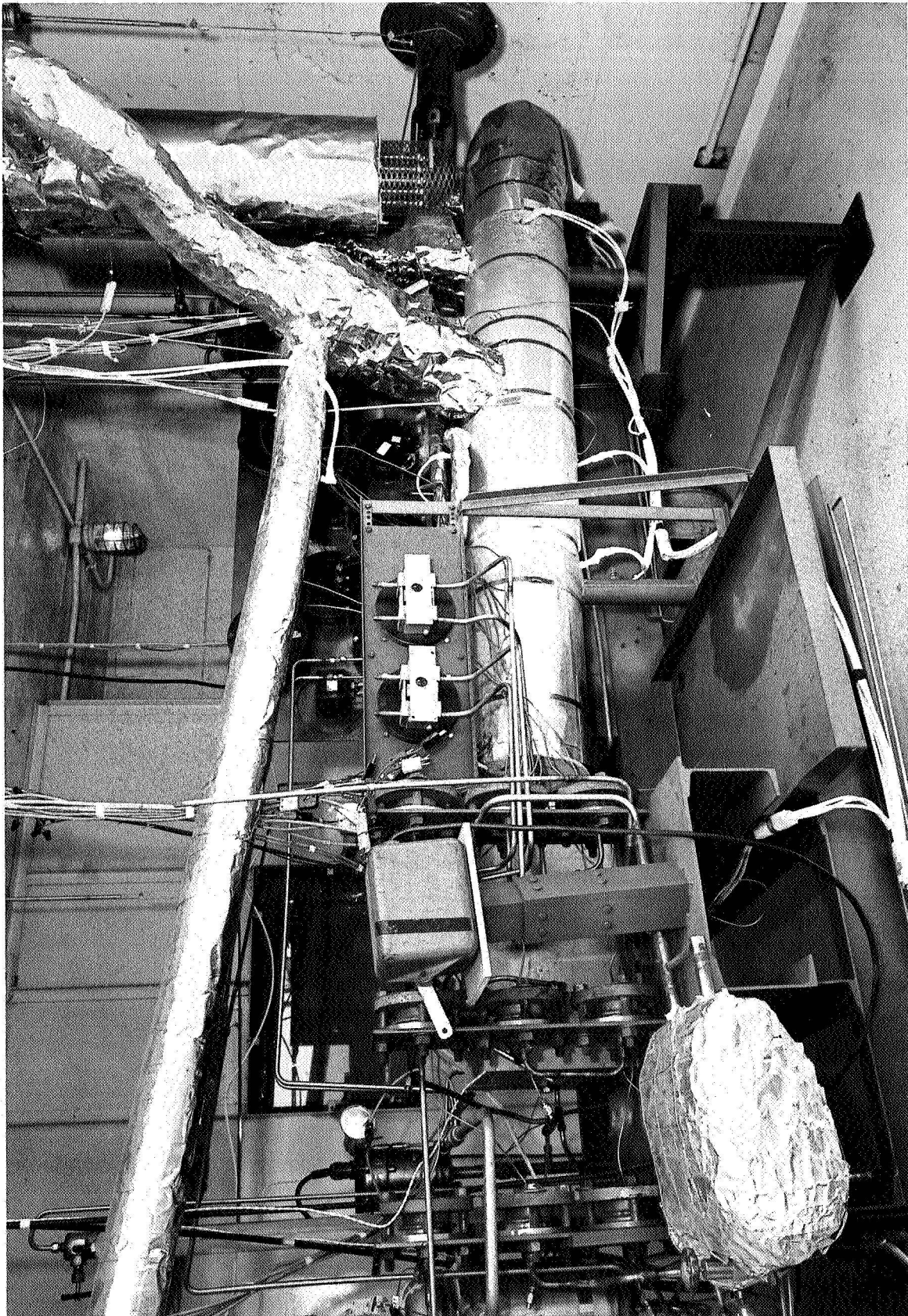
Instrumentation and Controls of INL-3

Figure V-49



INEL-3 Loop, Looking Southwest

Figure V-50

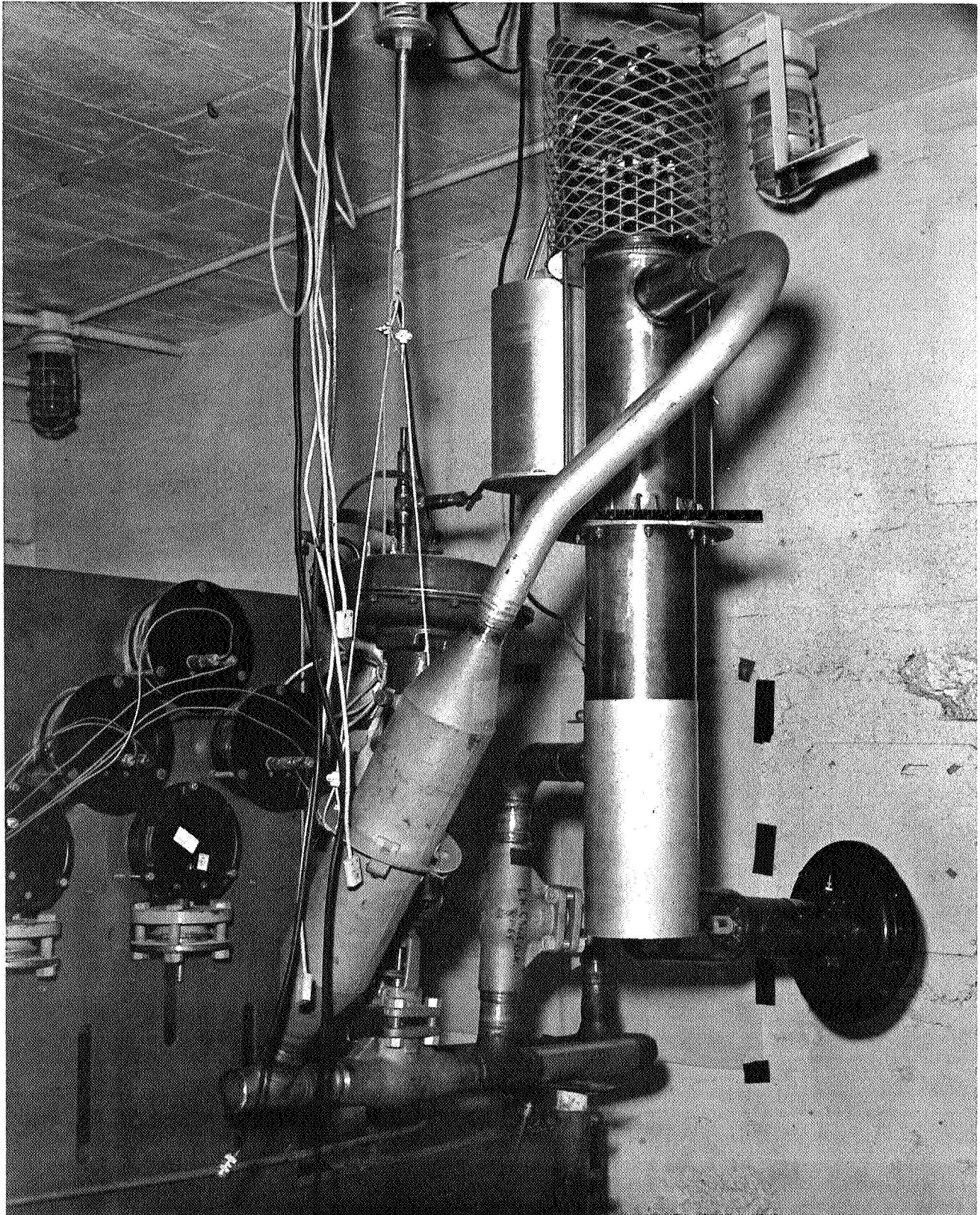


INL-3 Loop, Looking North

Figure V-51

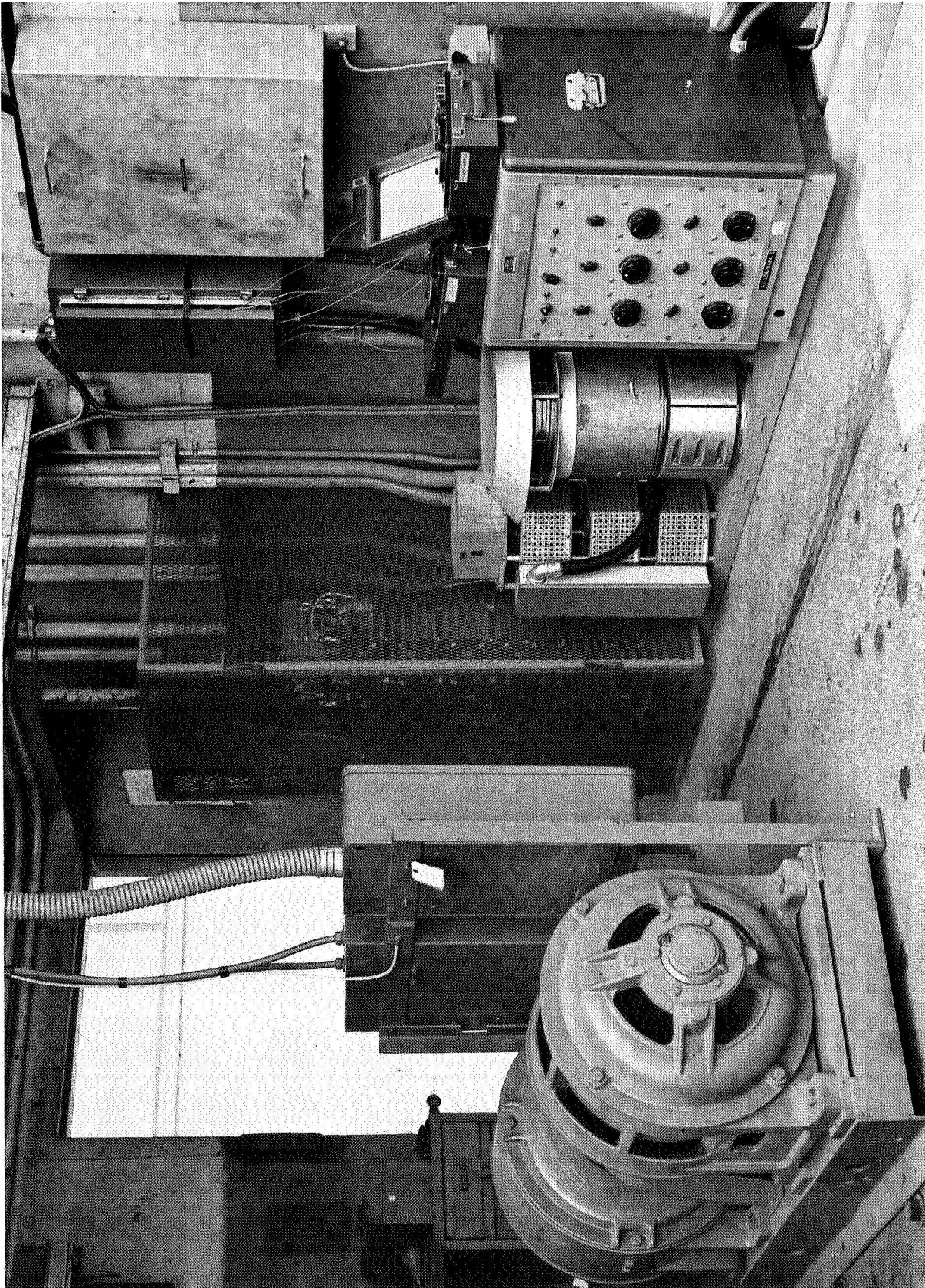
766-465

466-0661



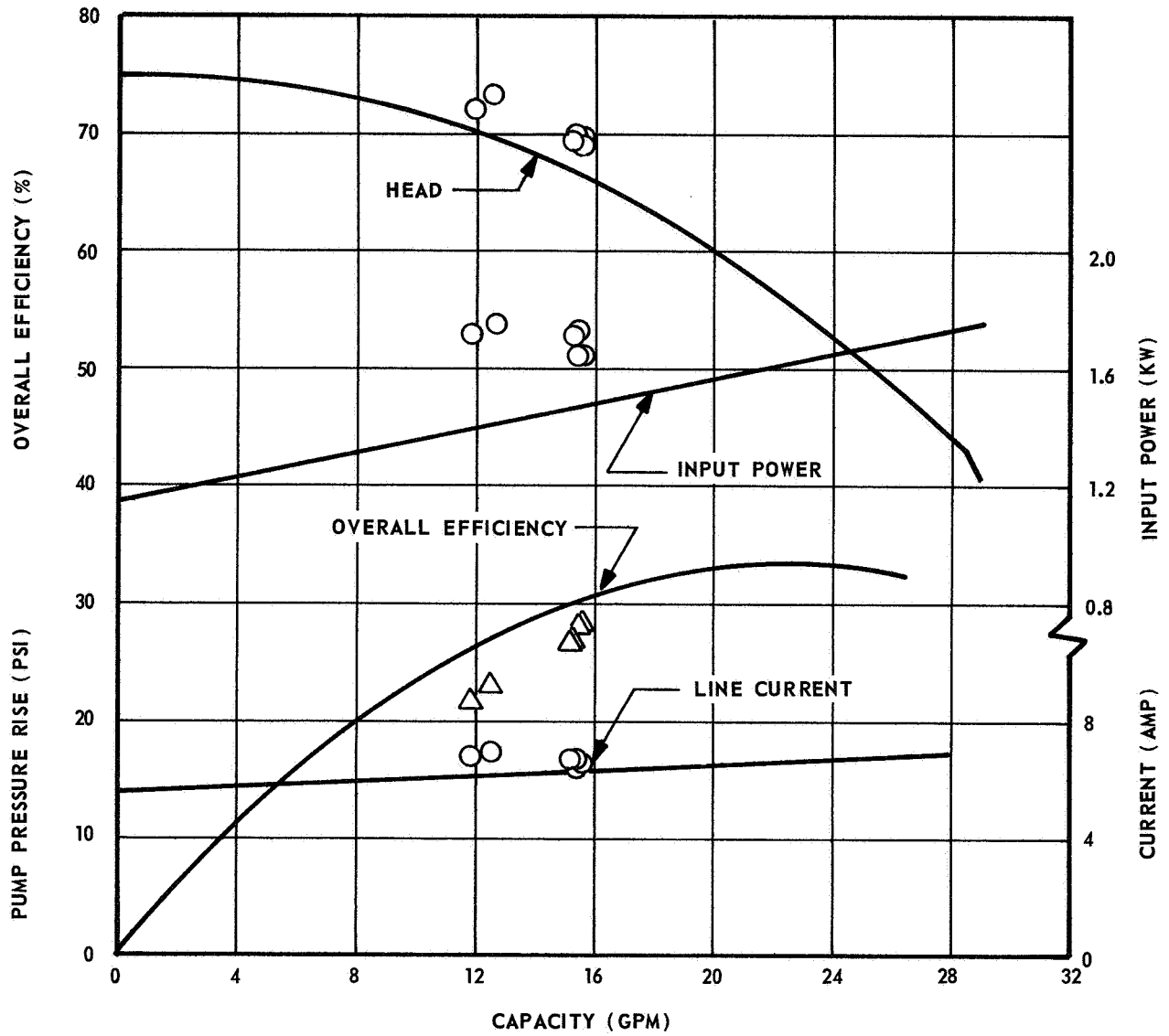
Parasitic Load Resistor and Auxiliary-Start
Heat Exchanger During Construction of LNL-3

Figure V-52



Bay 2, Showing SNAP-8 Inverter,
Load Banks, D.C. Power Supply
and Auto-Transformers

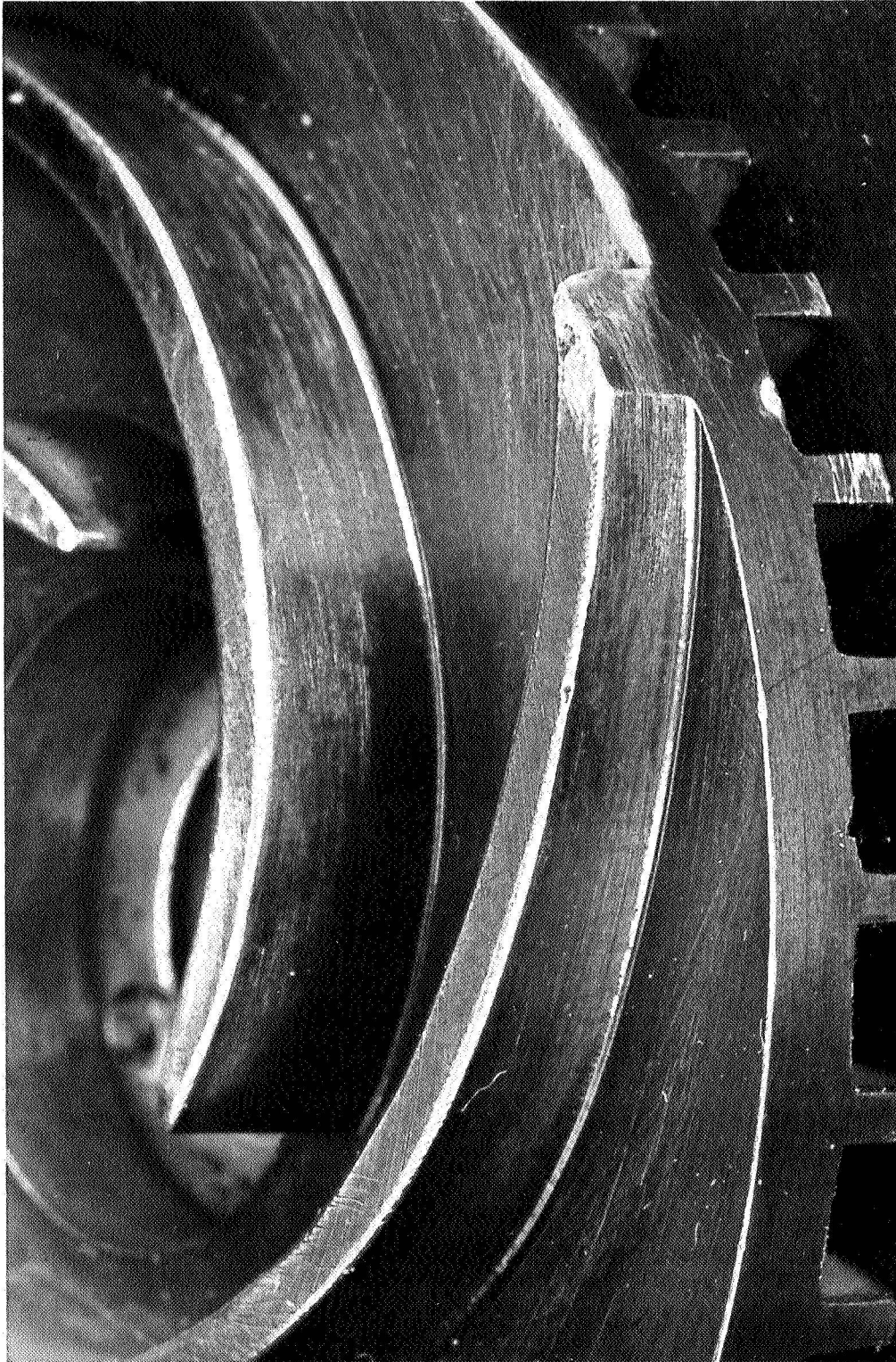
Figure V-53



L/C PMA (P/N 093580, S/N 481504) Performance
in PCS-1 Phase IV Step 2

Figure V-54

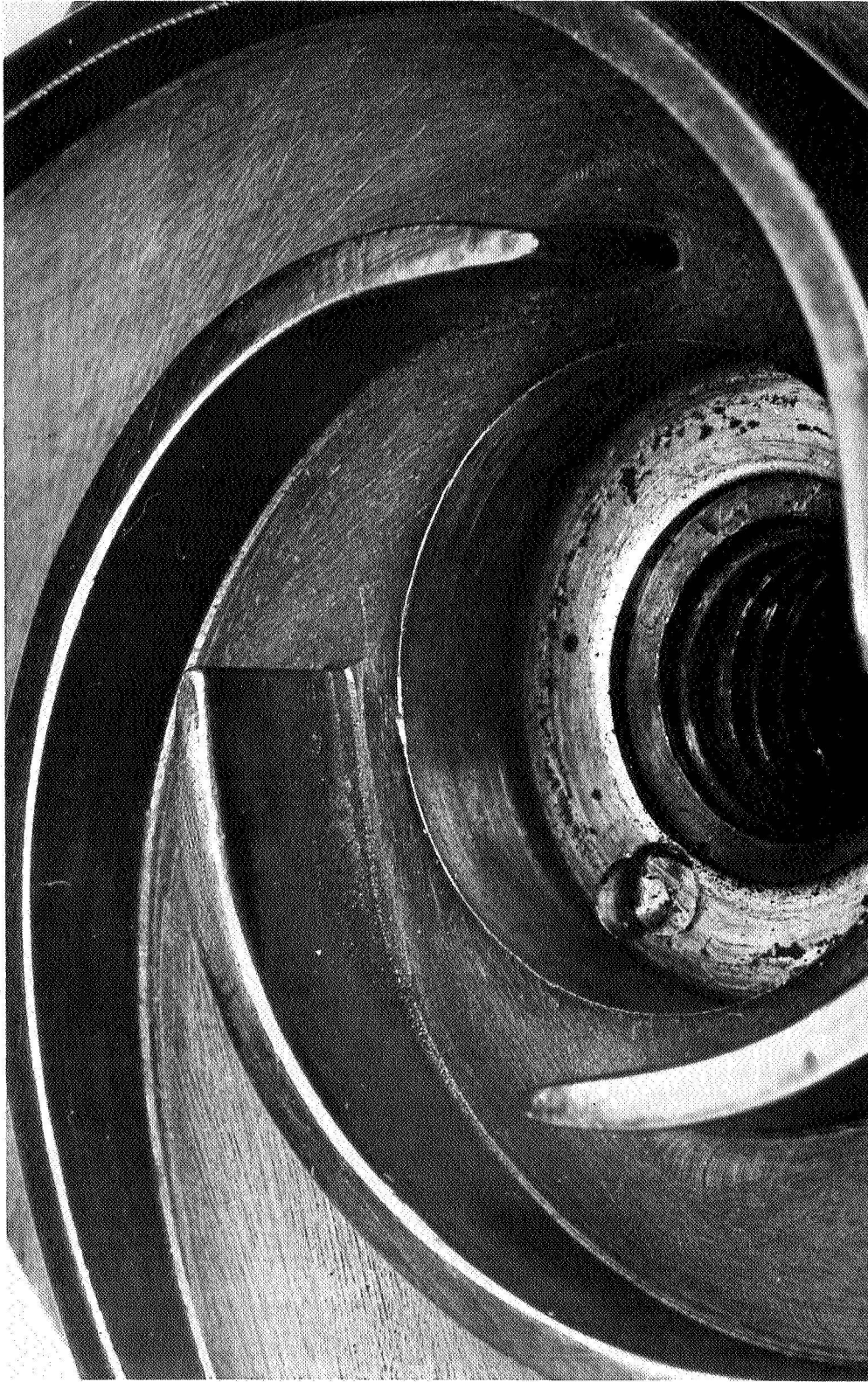
766-364



Impeller From Mercury PMA (P/N 093347-5, S/N A-1),
Showing High-Pressure Side of Front Vane After 806
Hours of Operation

Figure V-55

766-365



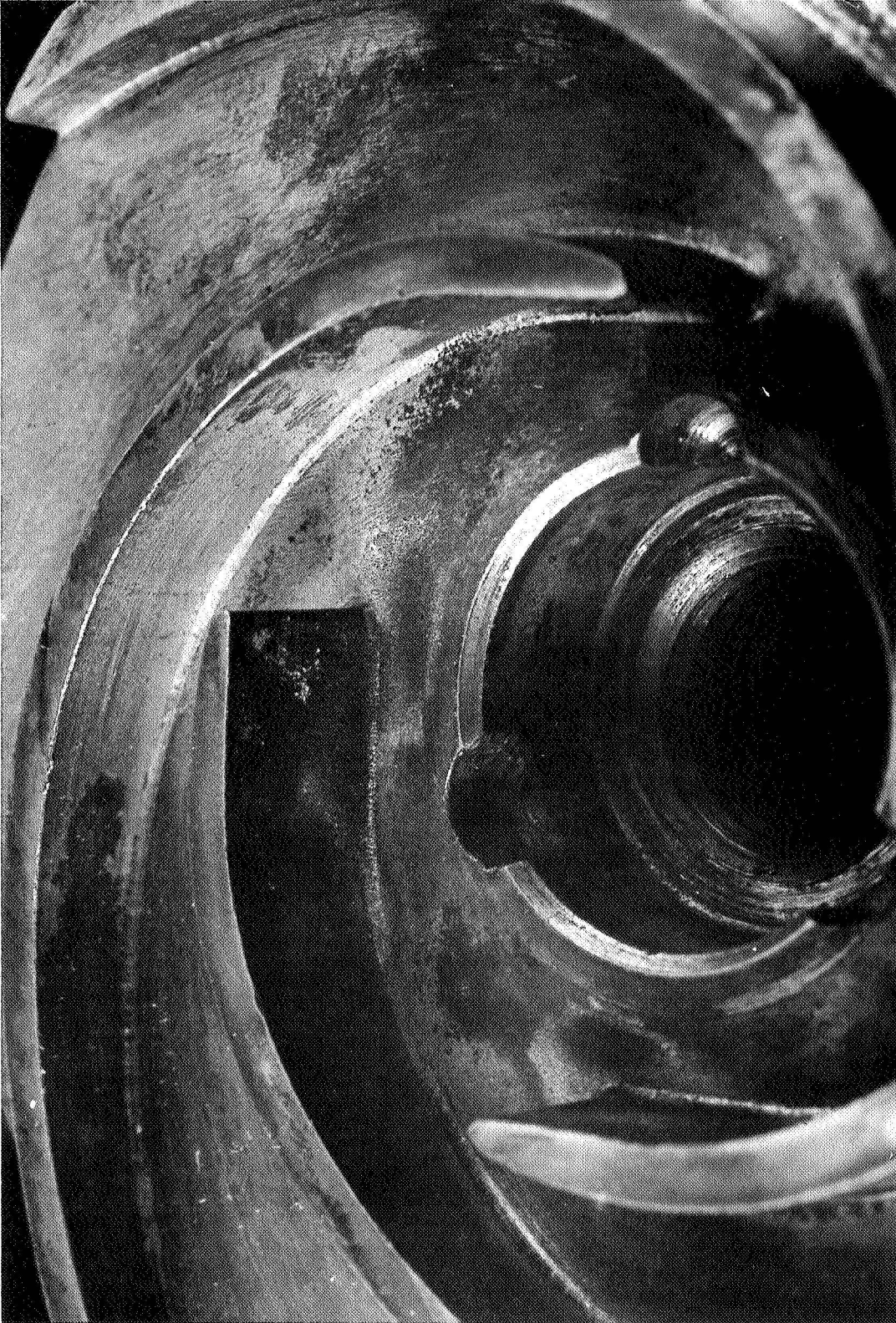
Impeller From Mercury PMA (P/N 093347-5, S/N A-1),
Showing Low-Pressure Side of Front Vane After
806 Hours of Operation

Figure V-56

766-363



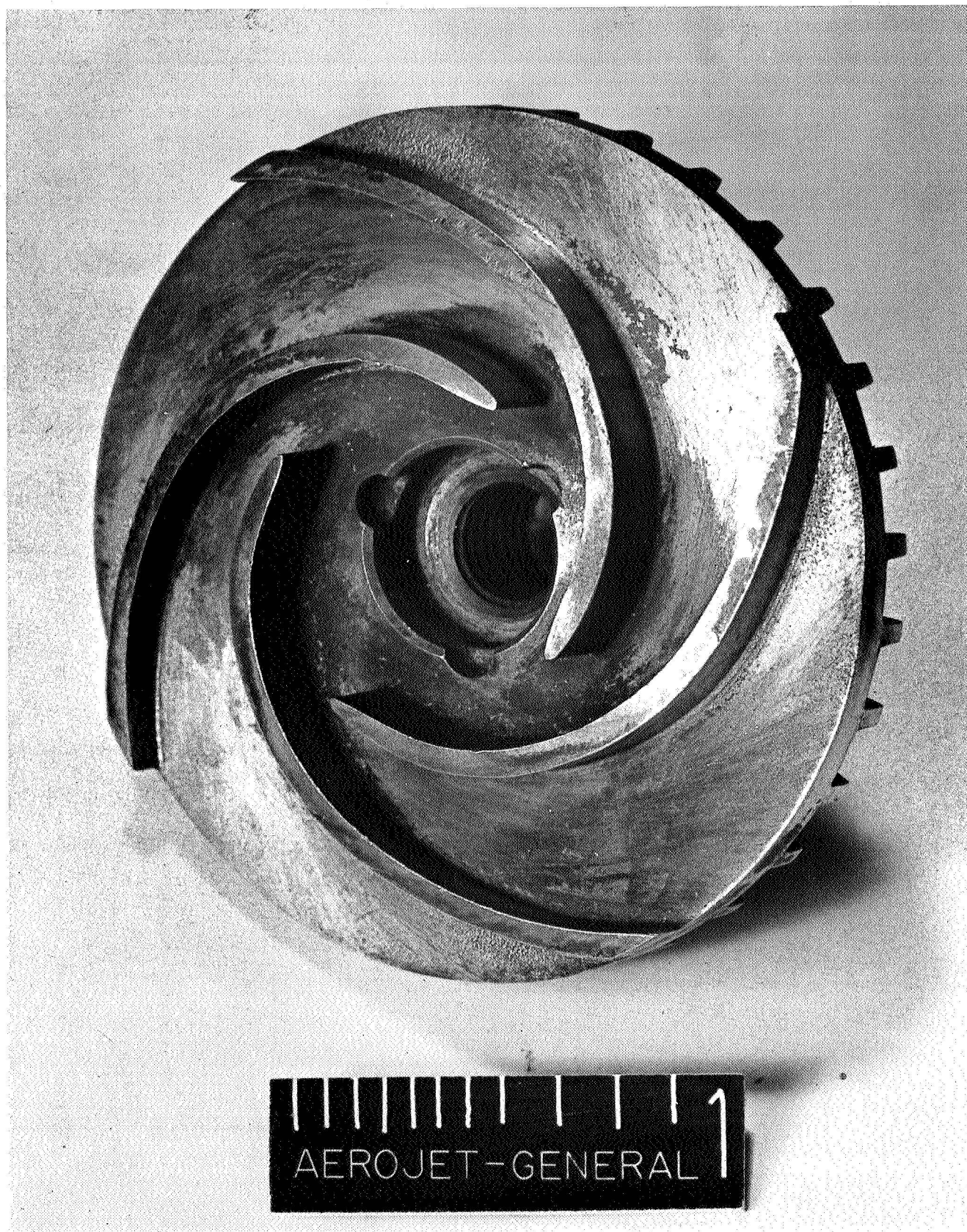
Impeller and Bolt From Mercury PMA (P/N 093347-5, S/N A-1)
After 1099 Hours of Operation in PCS-1



Impeller From Mercury PMA (P/N 093340-1, S/N A-1),
Showing Low-Pressure Side of Front Vane After
756 Hours of Operation in SL-1

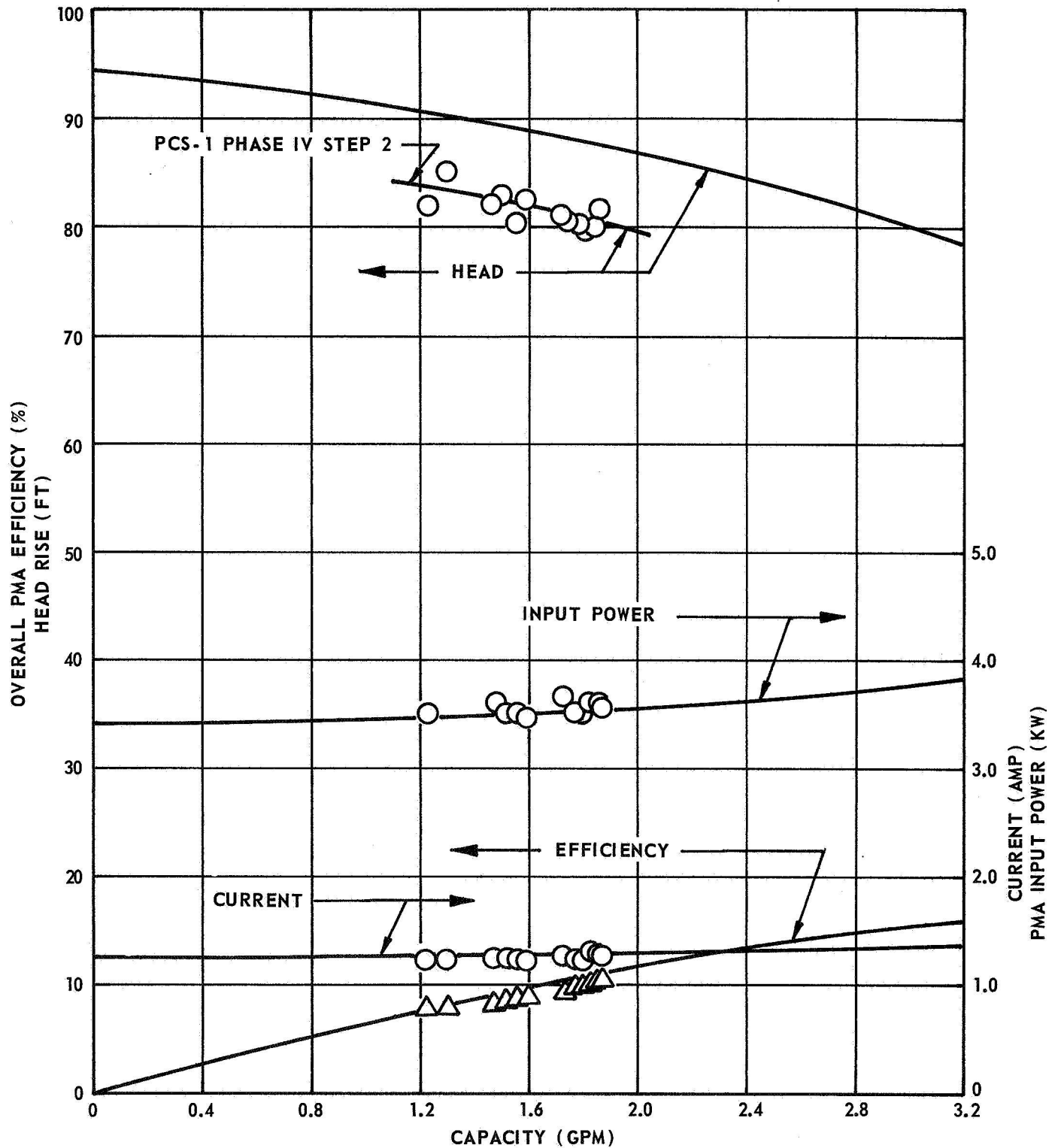
666-646

466-548



Impeller From Mercury PMA (P/N 09340-1, S/N A-1)
After 756 Hours of Operation in SL-1

866-NF-1310



Mercury PMA (P/N 093347-5, S/N A-2)
Performance In PCS-1 Phase IV Step 2

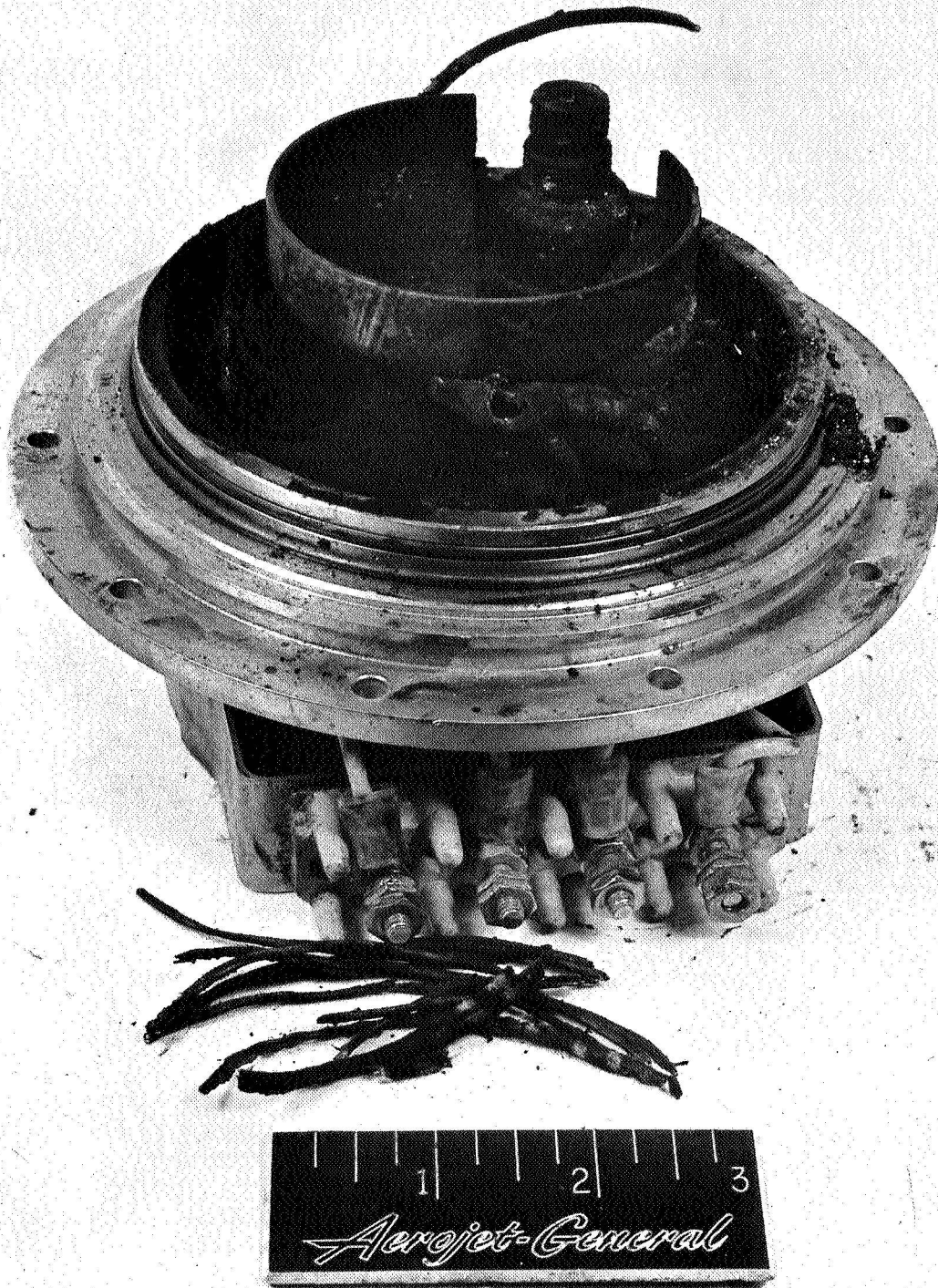
Figure V-60

366-455



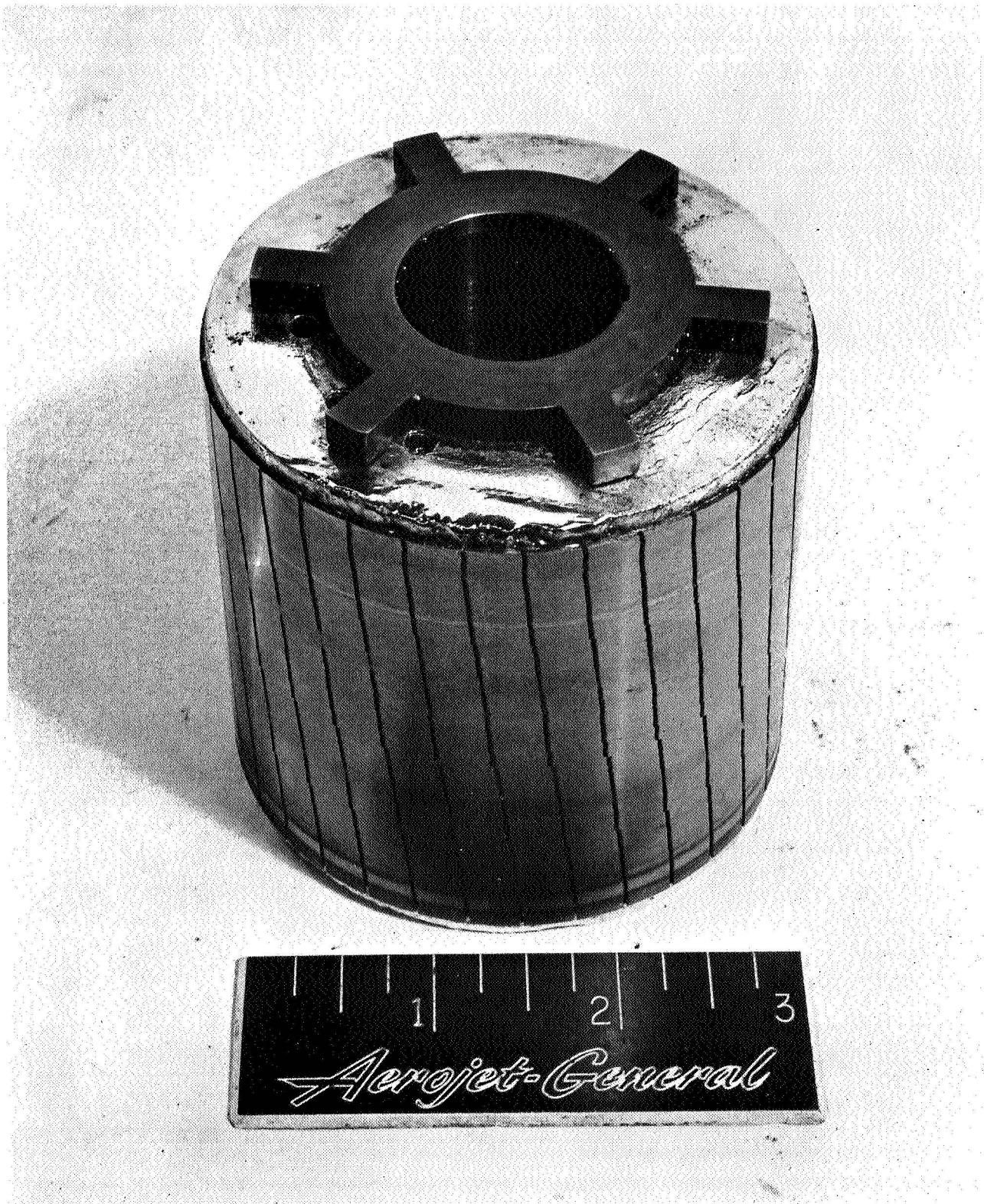
Motor From Mercury PMA, Showing Damage Due to Mercury Contact After 938 Hours of Operation (View 1)

366-456



Motor From Mercury PMA, Showing Damage Due to Mercury Contact After 938 Hours of Operation (View 2)

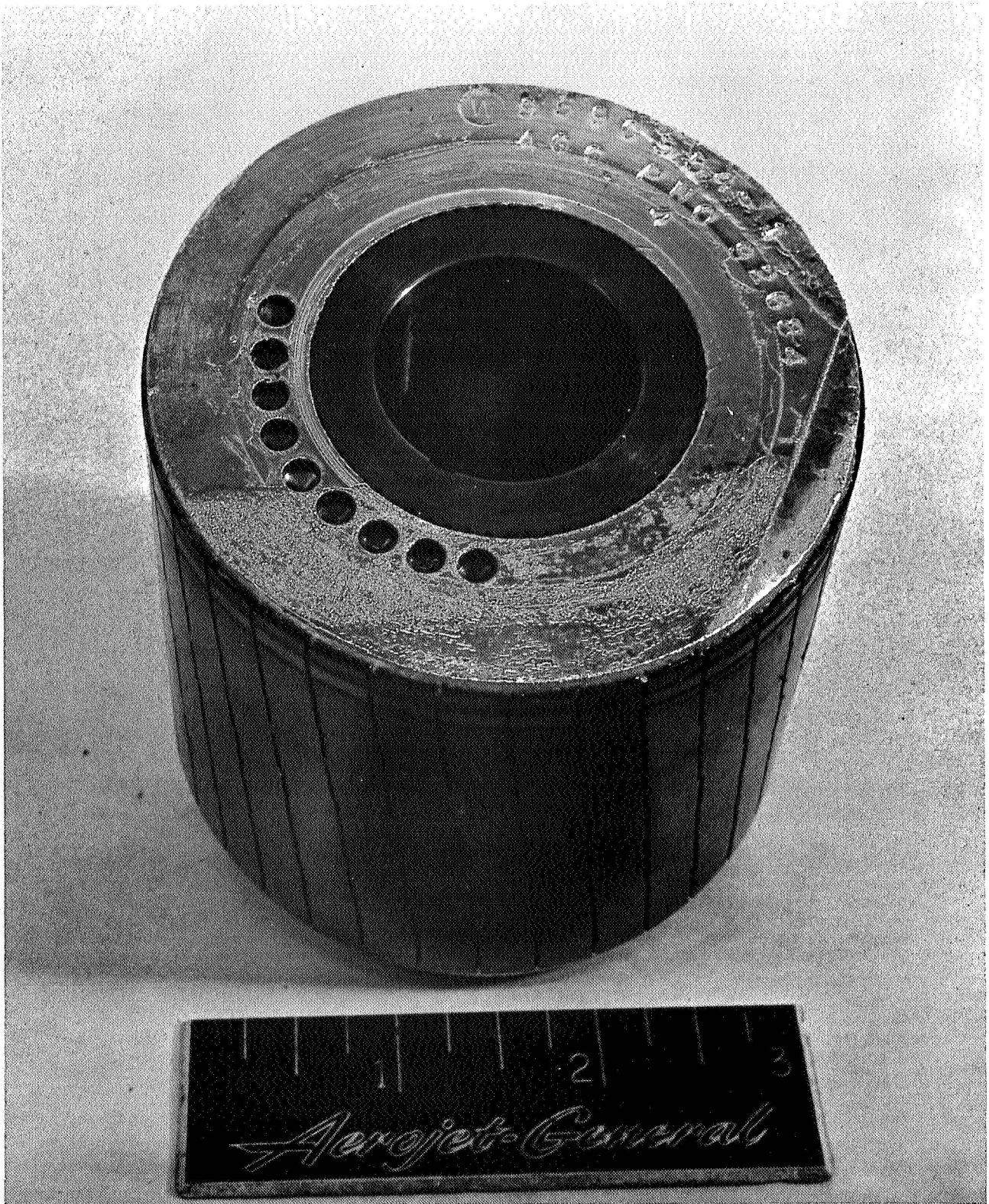
366-457



Motor From Mercury PMA, Showing Damage Due to Mercury Contact After 938 Hours of Operation (View 3)

Figure V-63

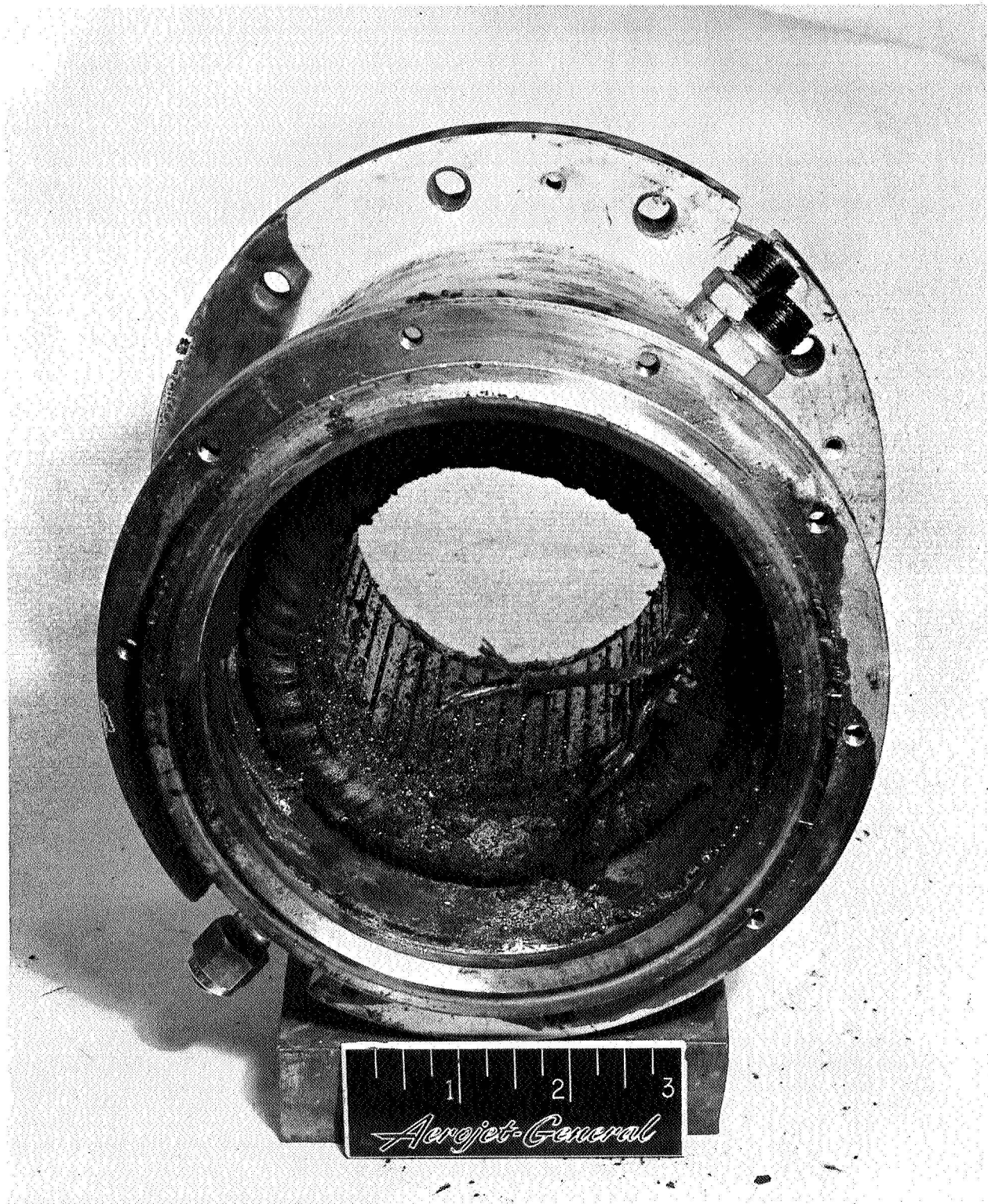
366-458



Motor From Mercury PMA, Showing Damage Due to Mercury Contact After 938 Hours of Operation (View 4)

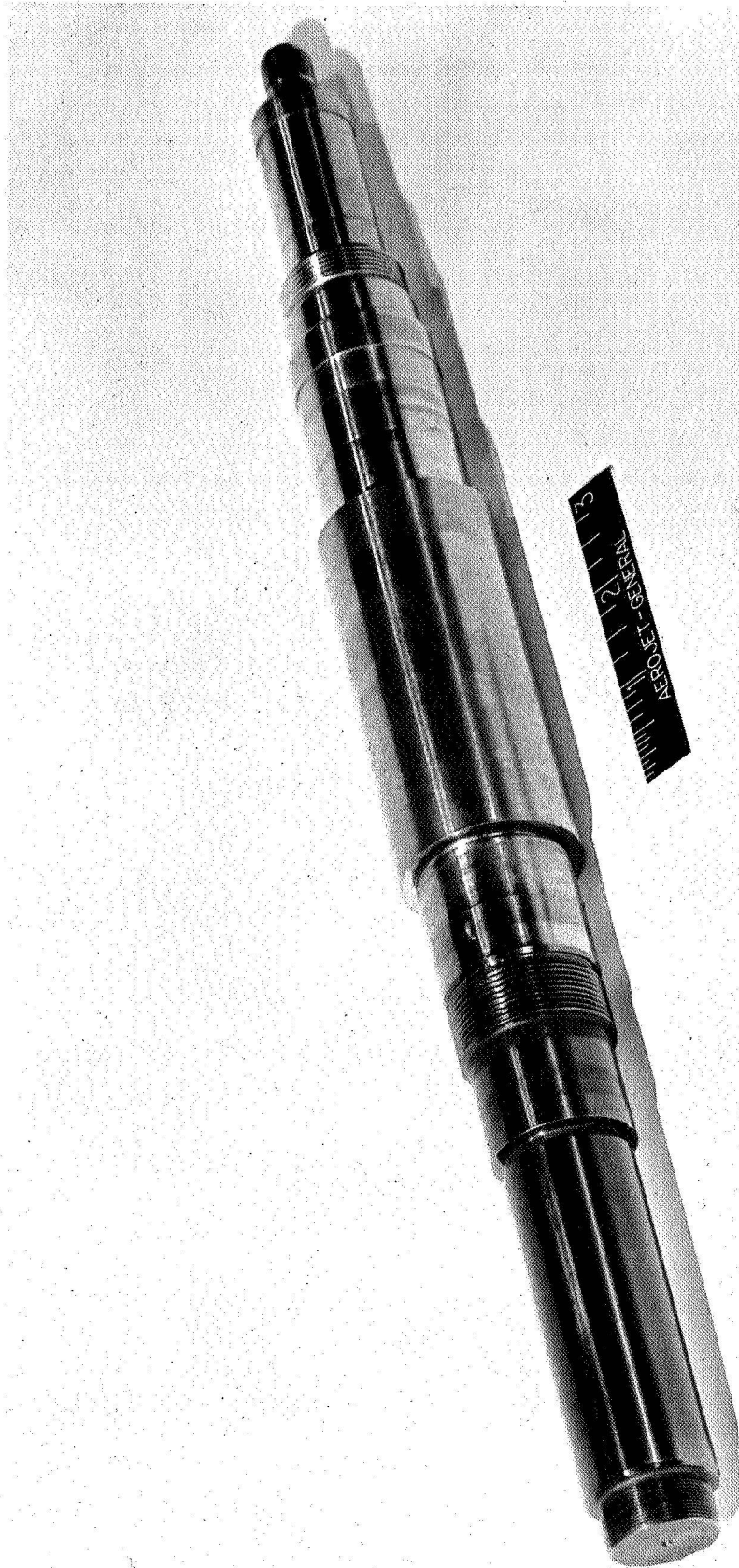
Figure V-64

366-459



Motor From Mercury PMA, Showing Damage Due to Mercury Contact After 938 Hours of Operation (View 5)

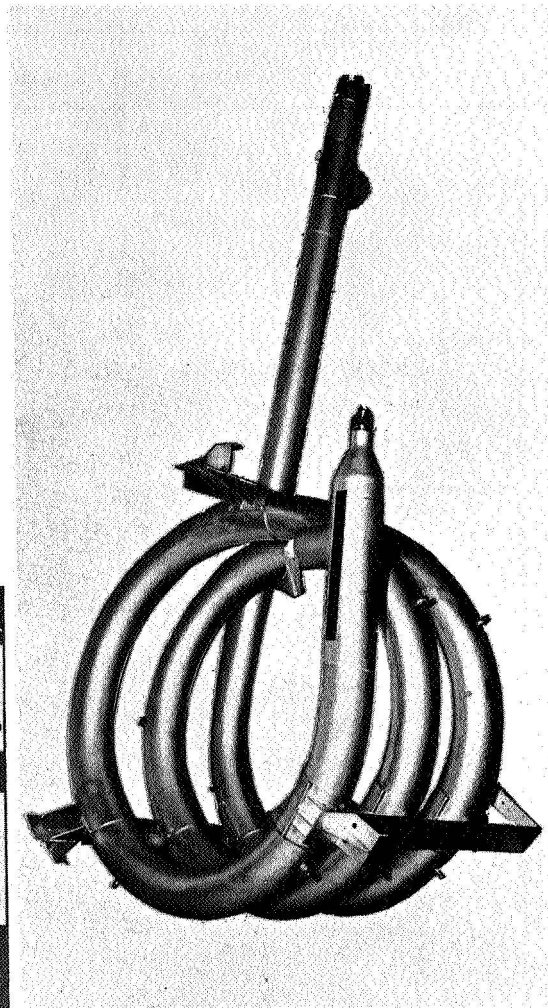
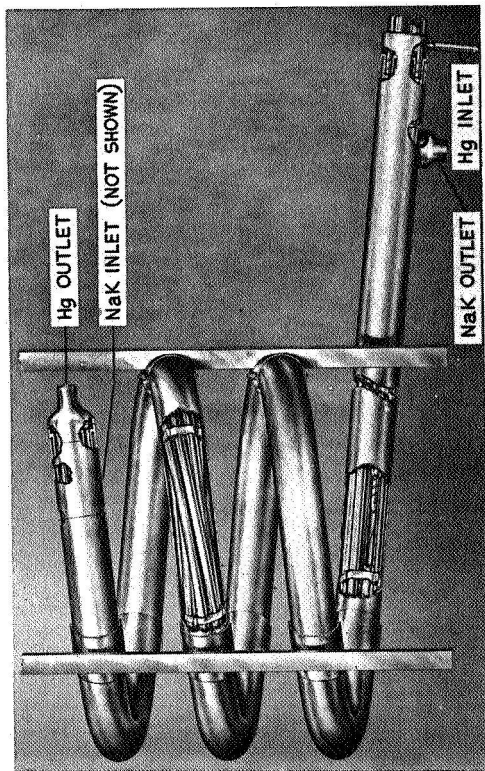
CN466-53



Shaft From Mercury PMA After 756 Hours operation in SL-1,
Showing Heat Discoloration on Motor-End of Shaft

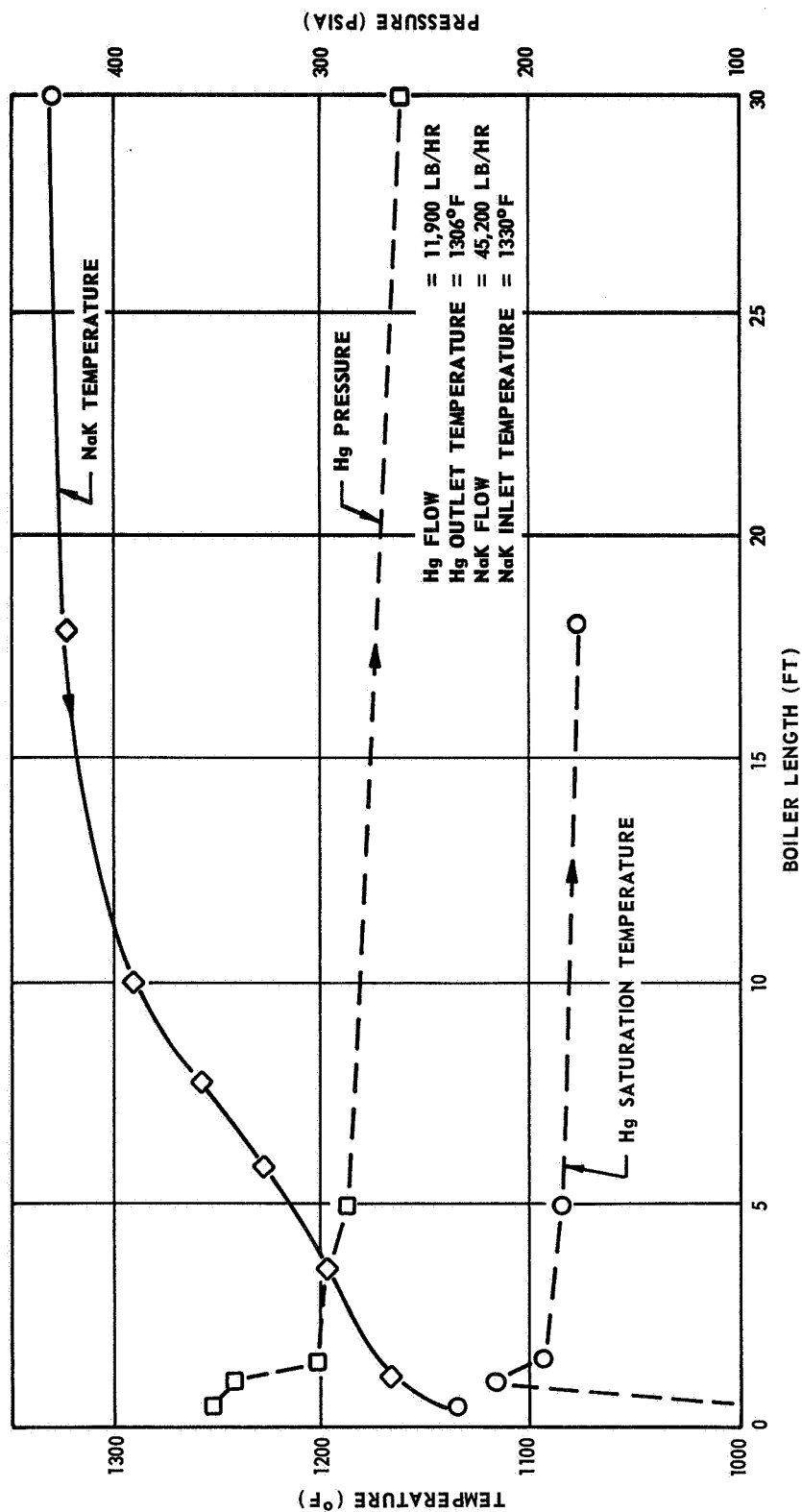
Figure V-66

566-219



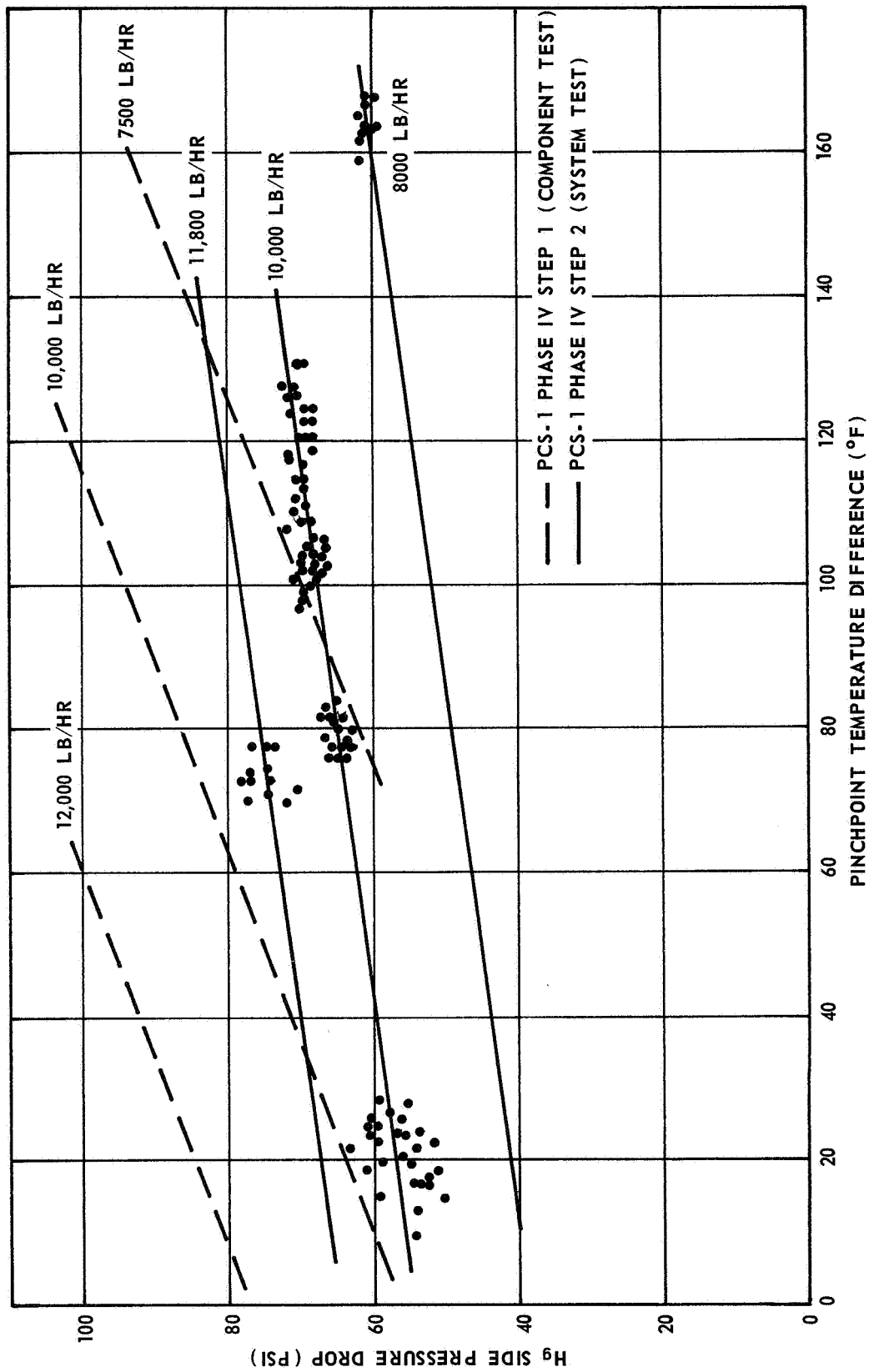
SNAP-8 Tube-in-Tube Boiler

Figure V-67



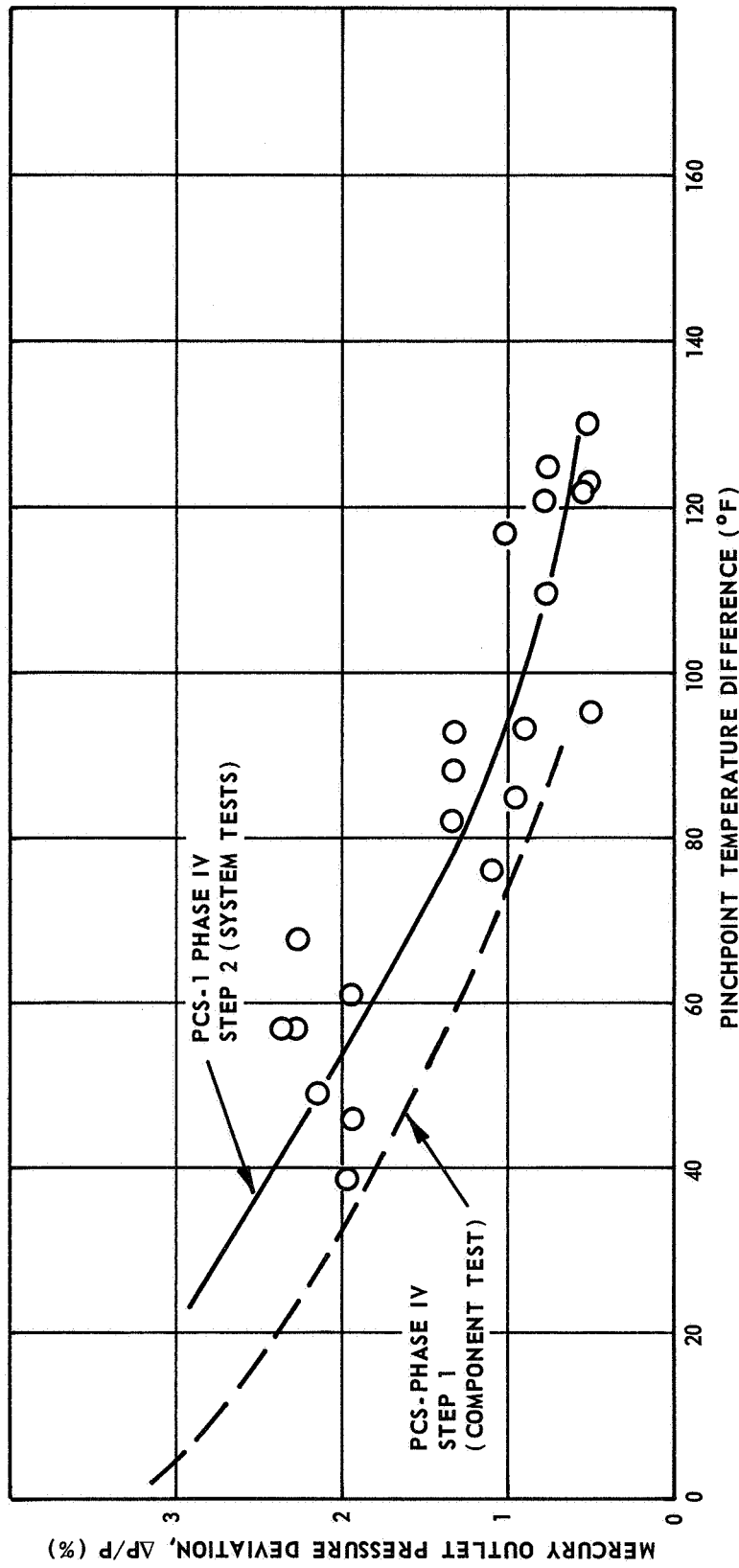
Typical Boiler Temperature Profile From
PCS-1 Phase IV Step 1 Component Testing

Figure V-68



Boiler (P/N 097444-7, S/N A-2) Performance:
 Mercury-Side Pressure Drop vs
 Pinch-Point Temperature Difference

Figure V-69



Boiler (P/N 097444-7, S/N A-2) Performance:
Mercury Outlet Pressure Stability in
PCS-1 Phase IV Step 2

Figure V-70

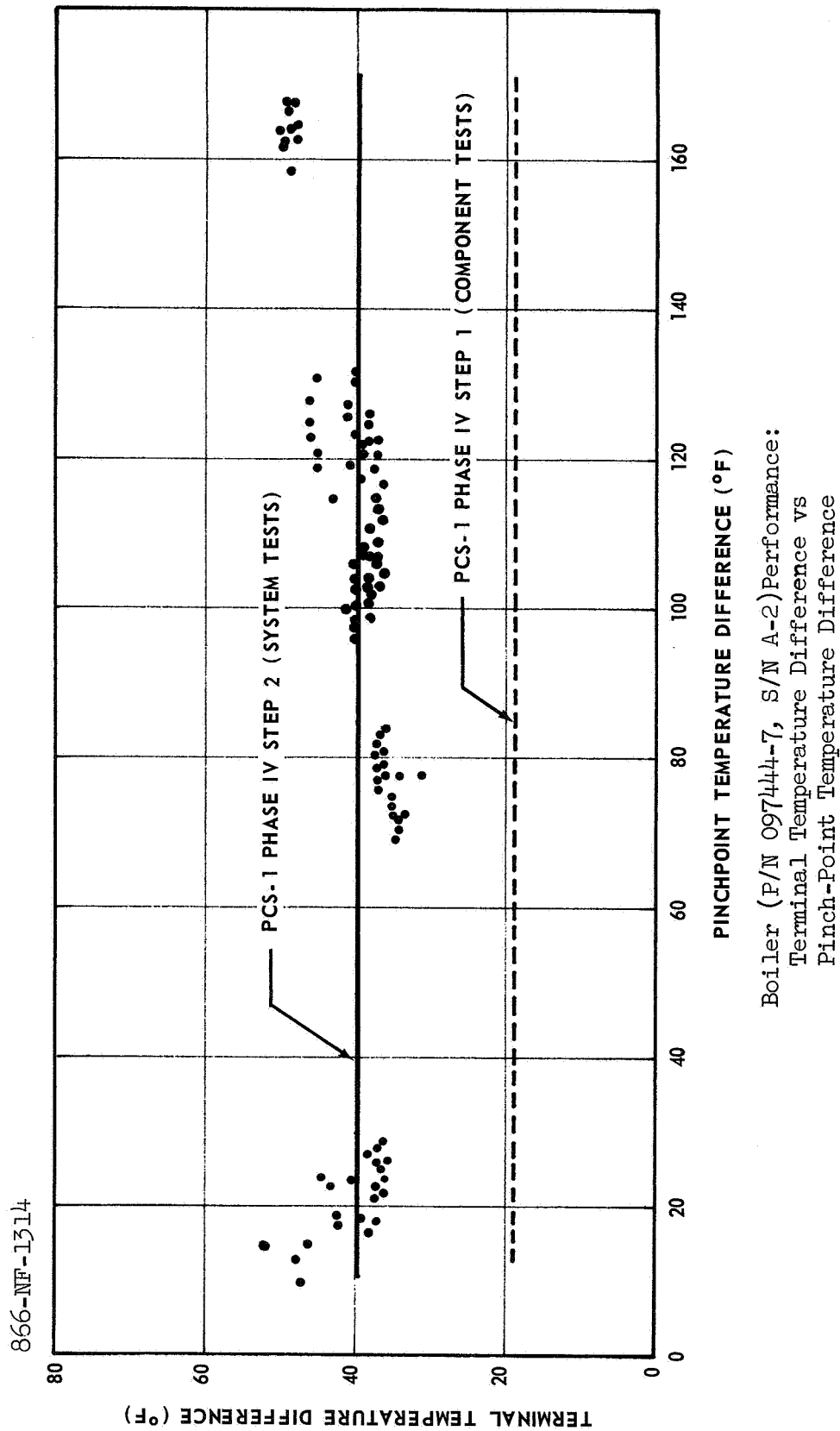
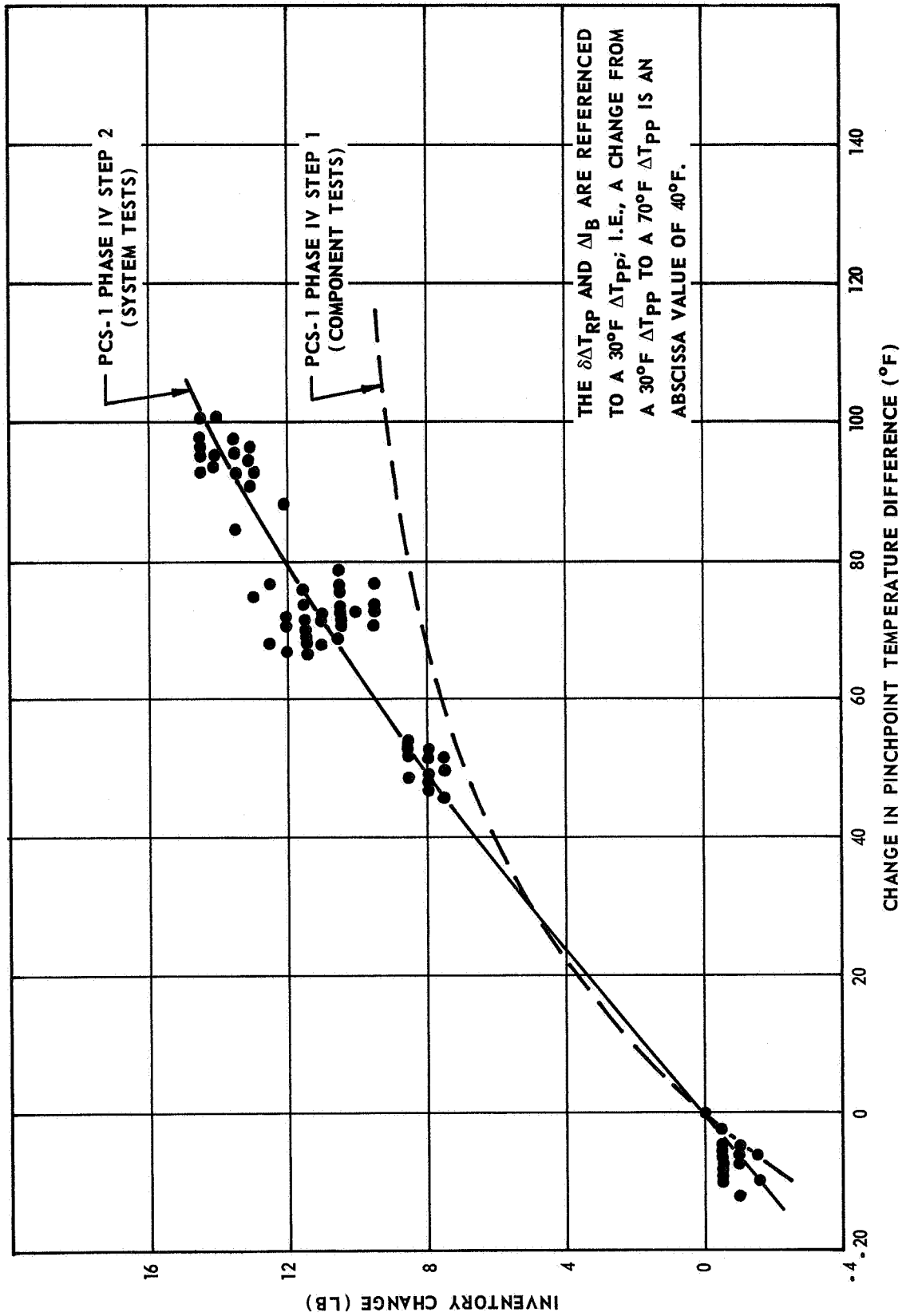


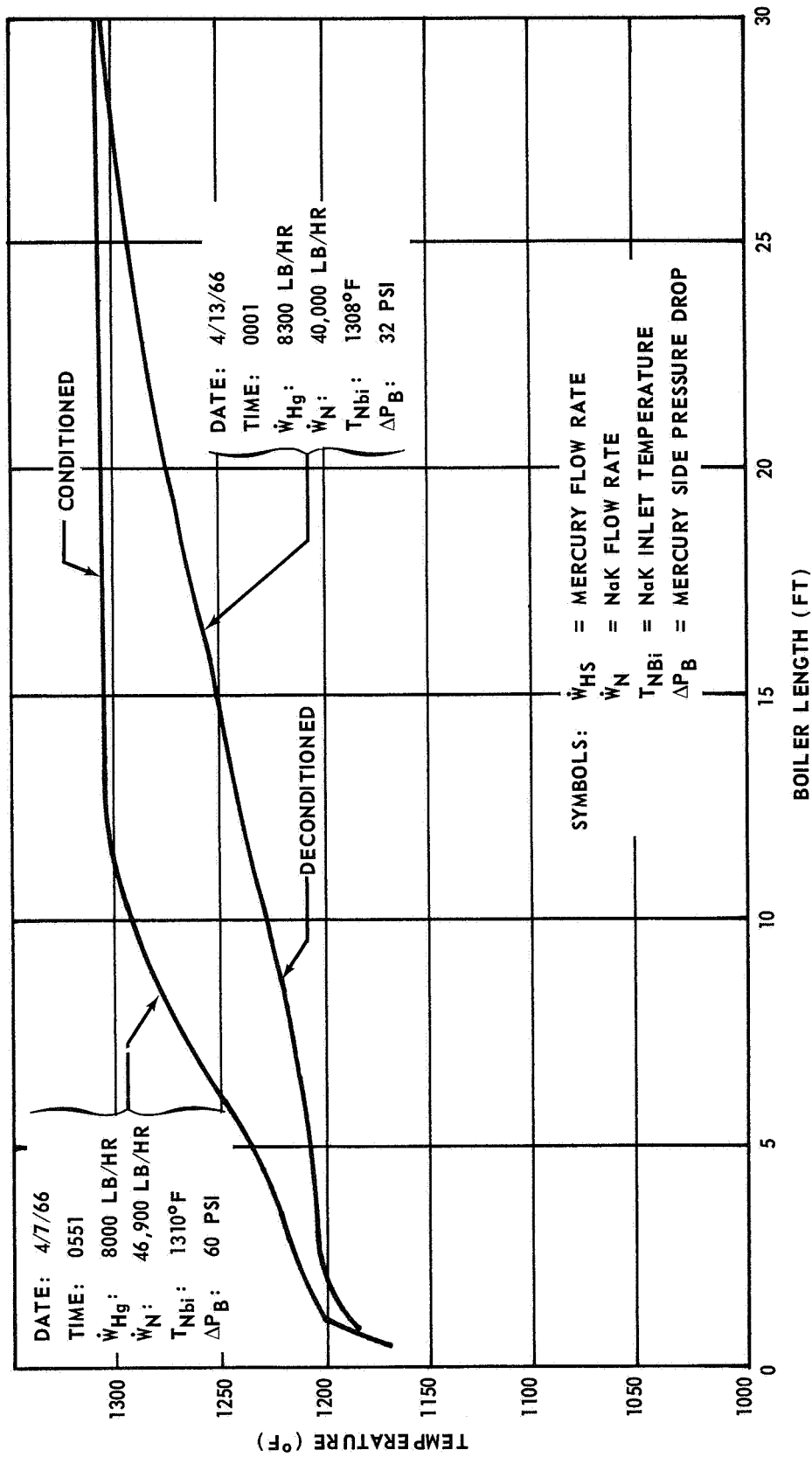
Figure V-71

866-NF-1315



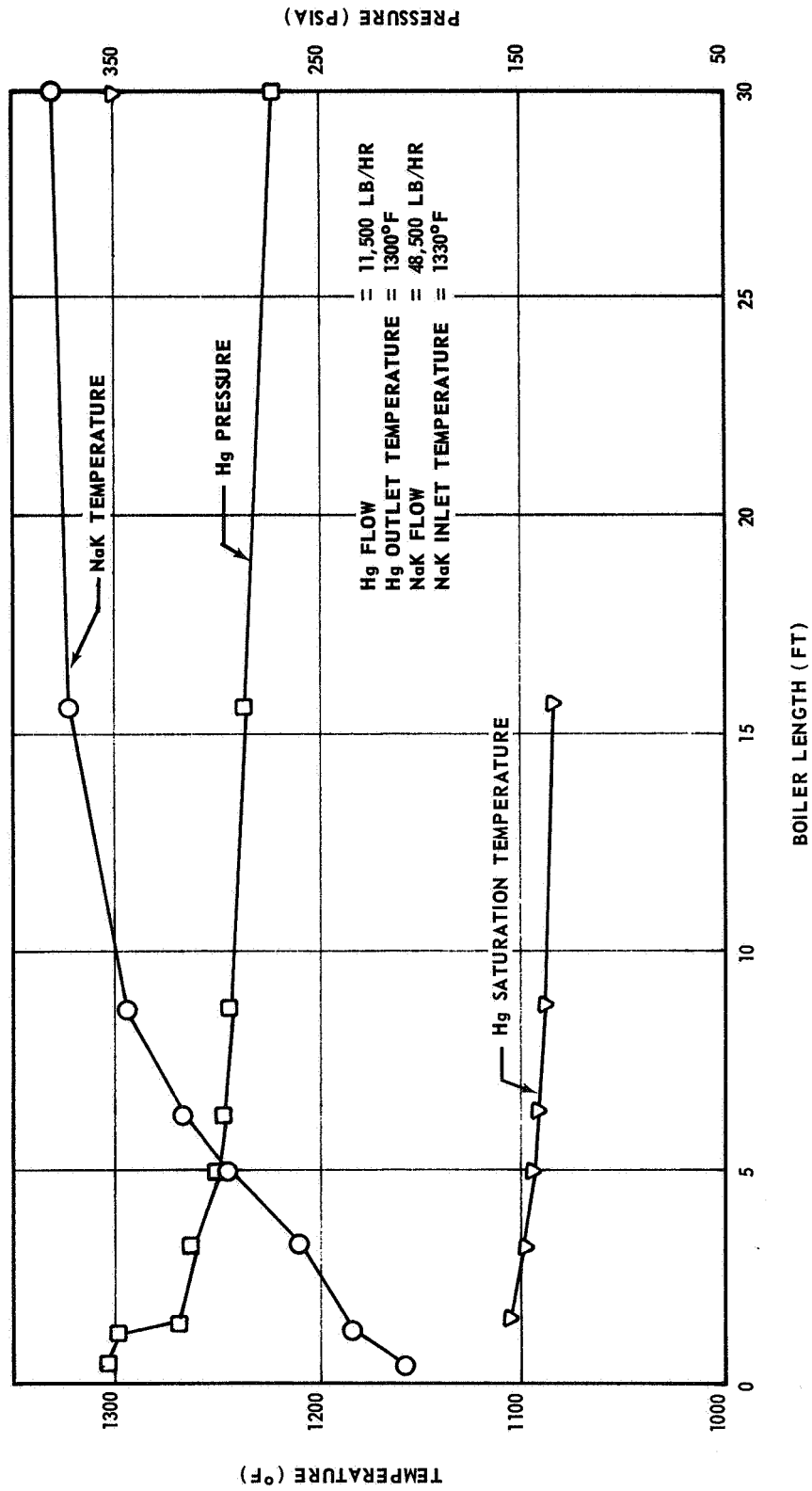
Boiler (P/N 097444-7, S/N A-2) Performance:
Change in Inventory vs Change in
Pinch-Point Temperature Difference

Figure V-72



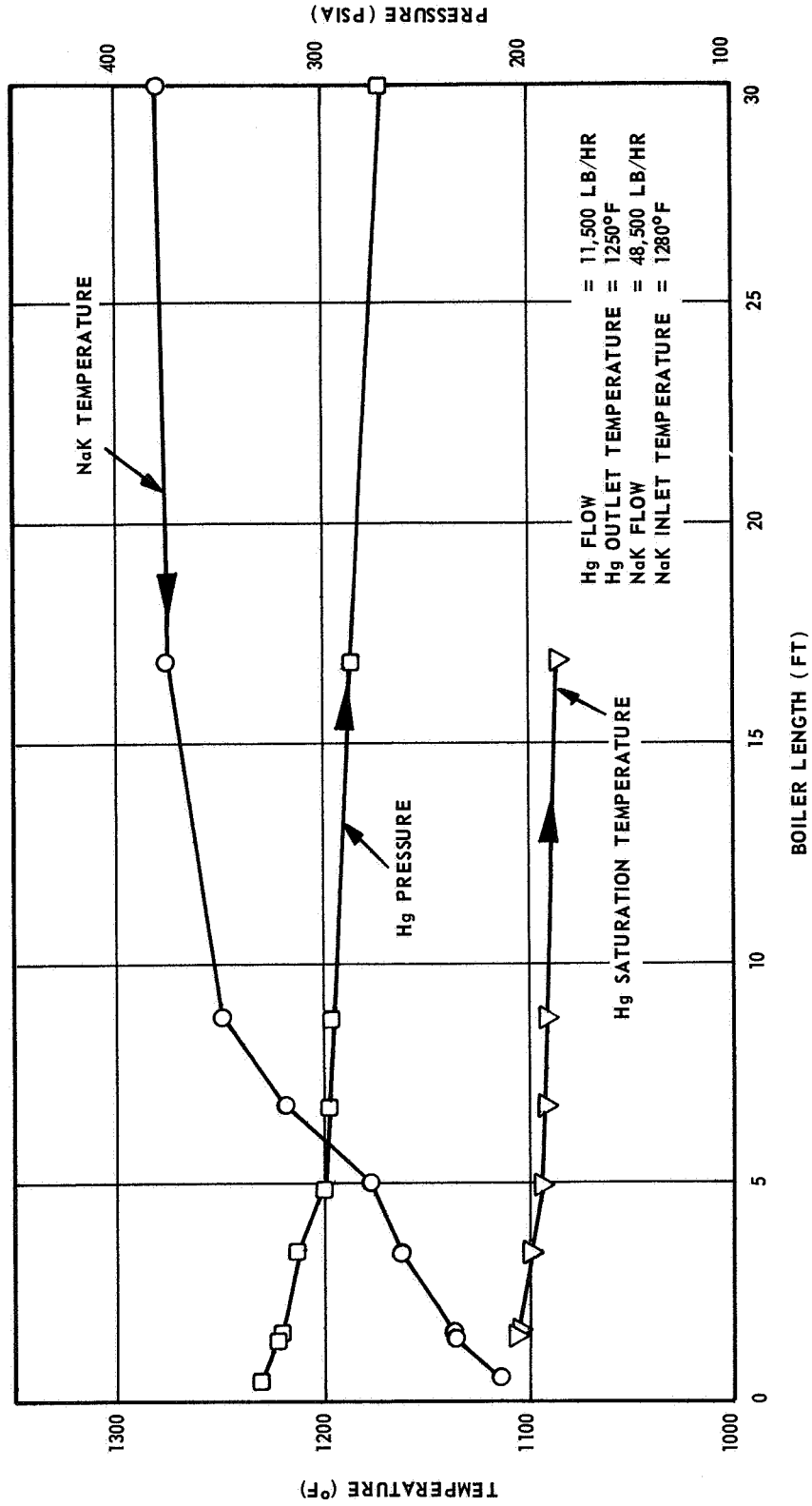
Tube-in-Tube Boiler (P/N 097444-7, S/N A-2) Temperature Profiles During PCS-1 Phase IV Step 2 Testing
Variation in Conditioning

Figure V-73



Probopean (Boiler Computer Code)-High NaK Inlet Temperature

Figure V-74



Probopean (Boiler Computer Code) - Low NaK Inlet Temperature

Figure V-75

866-NF-1319

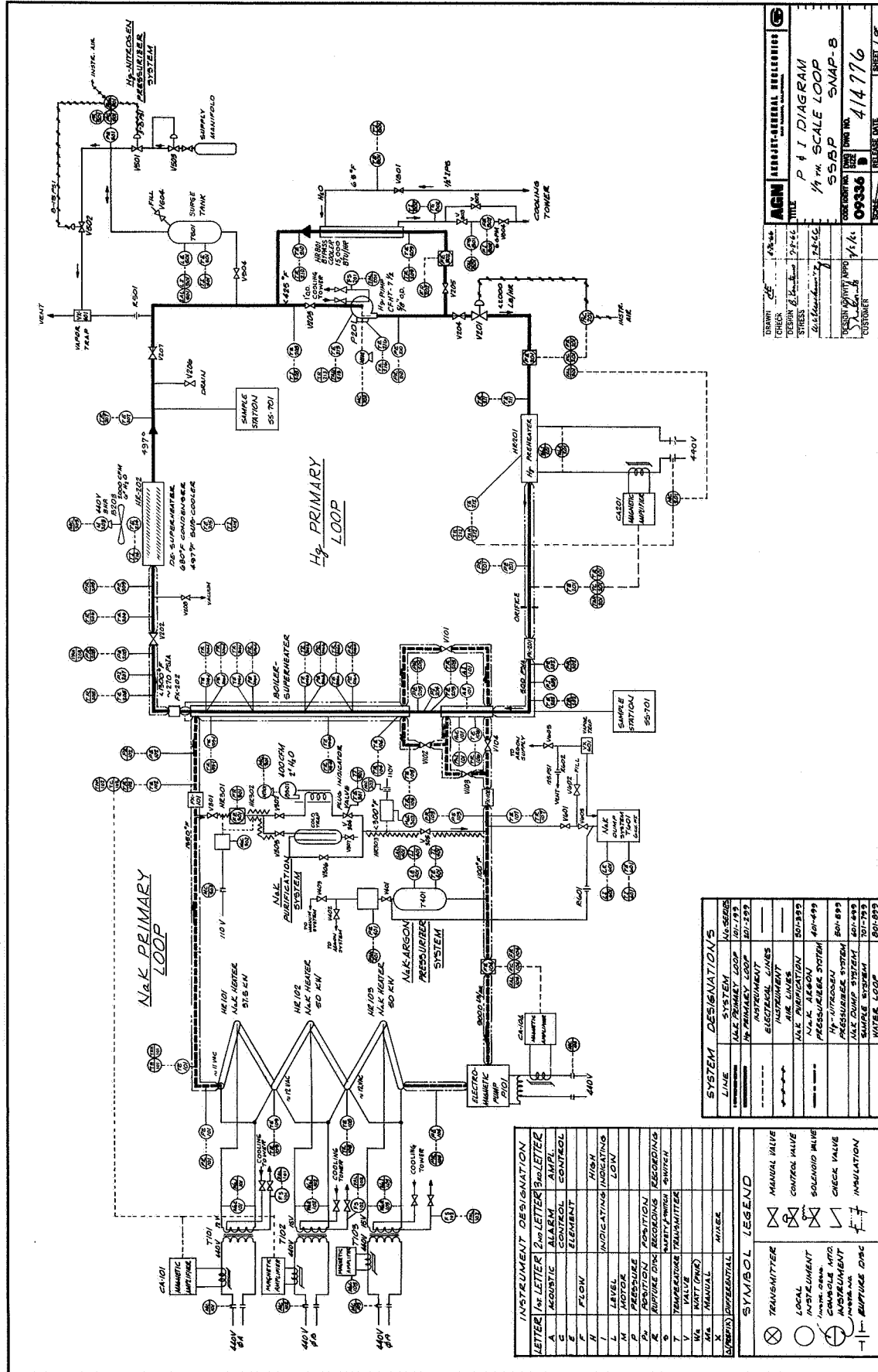
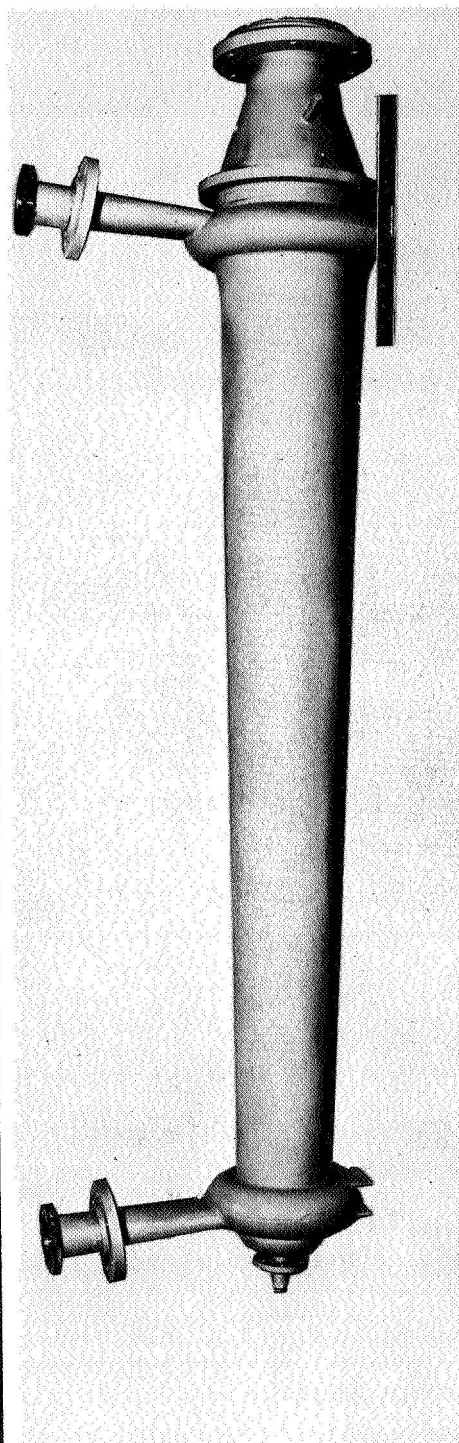
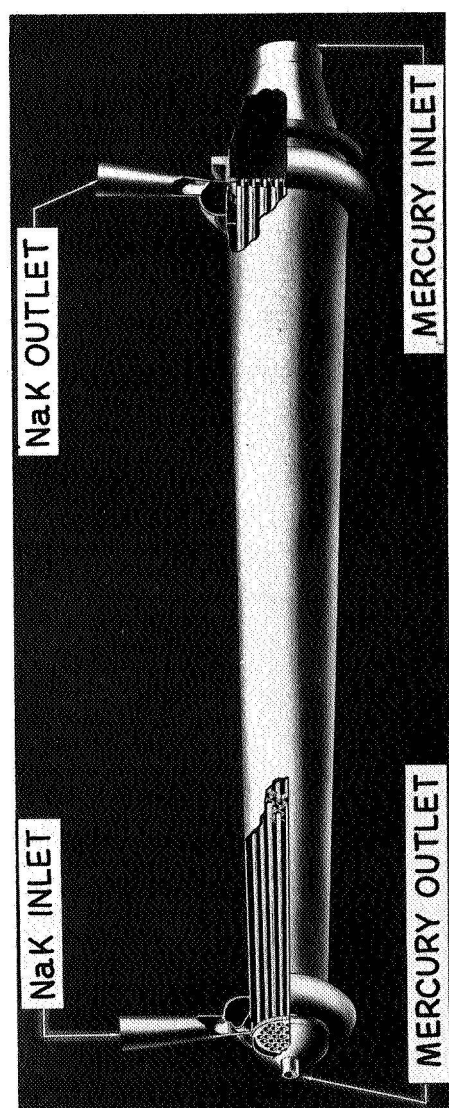


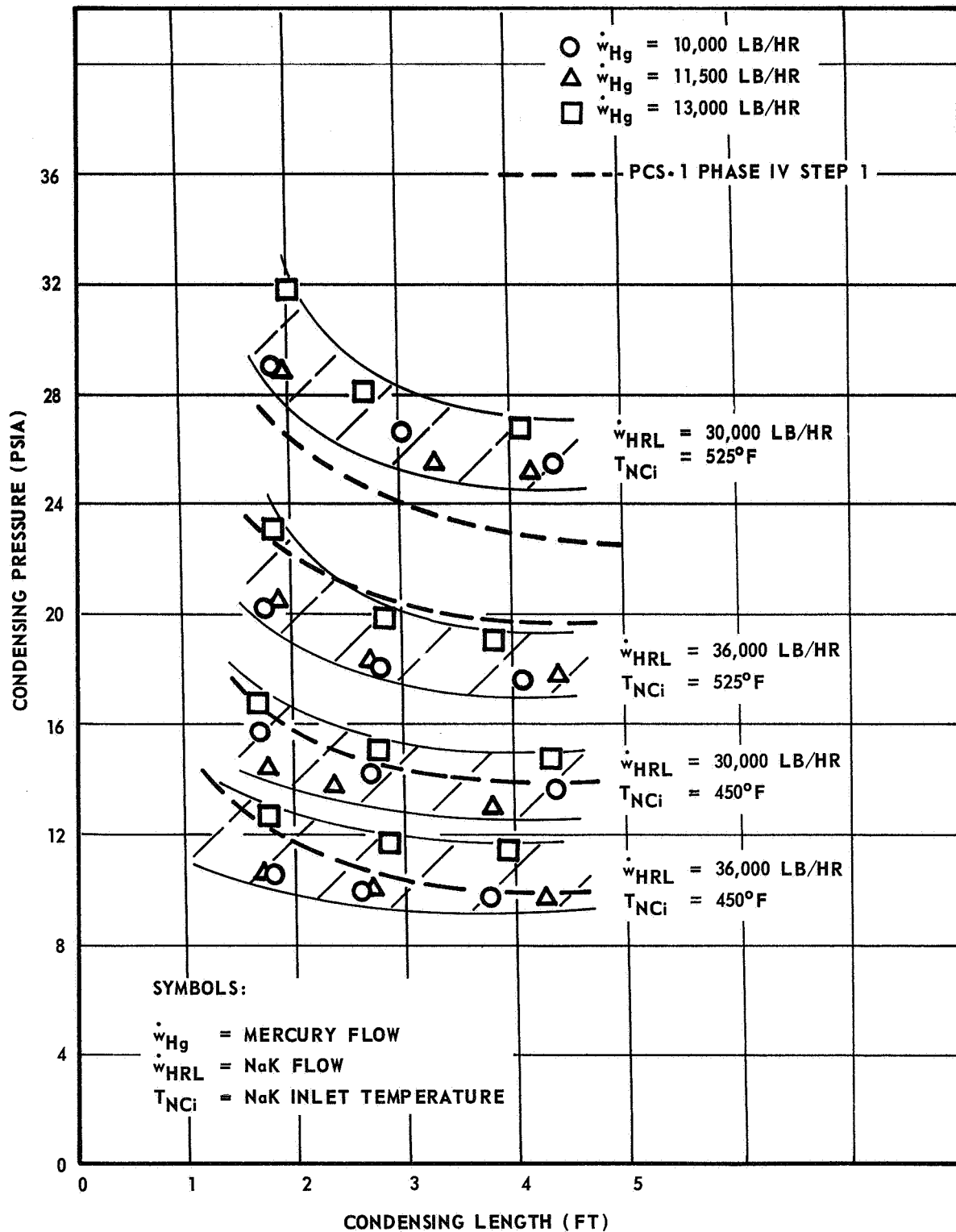
Figure V-76

566-220



SNAP-8 Condenser

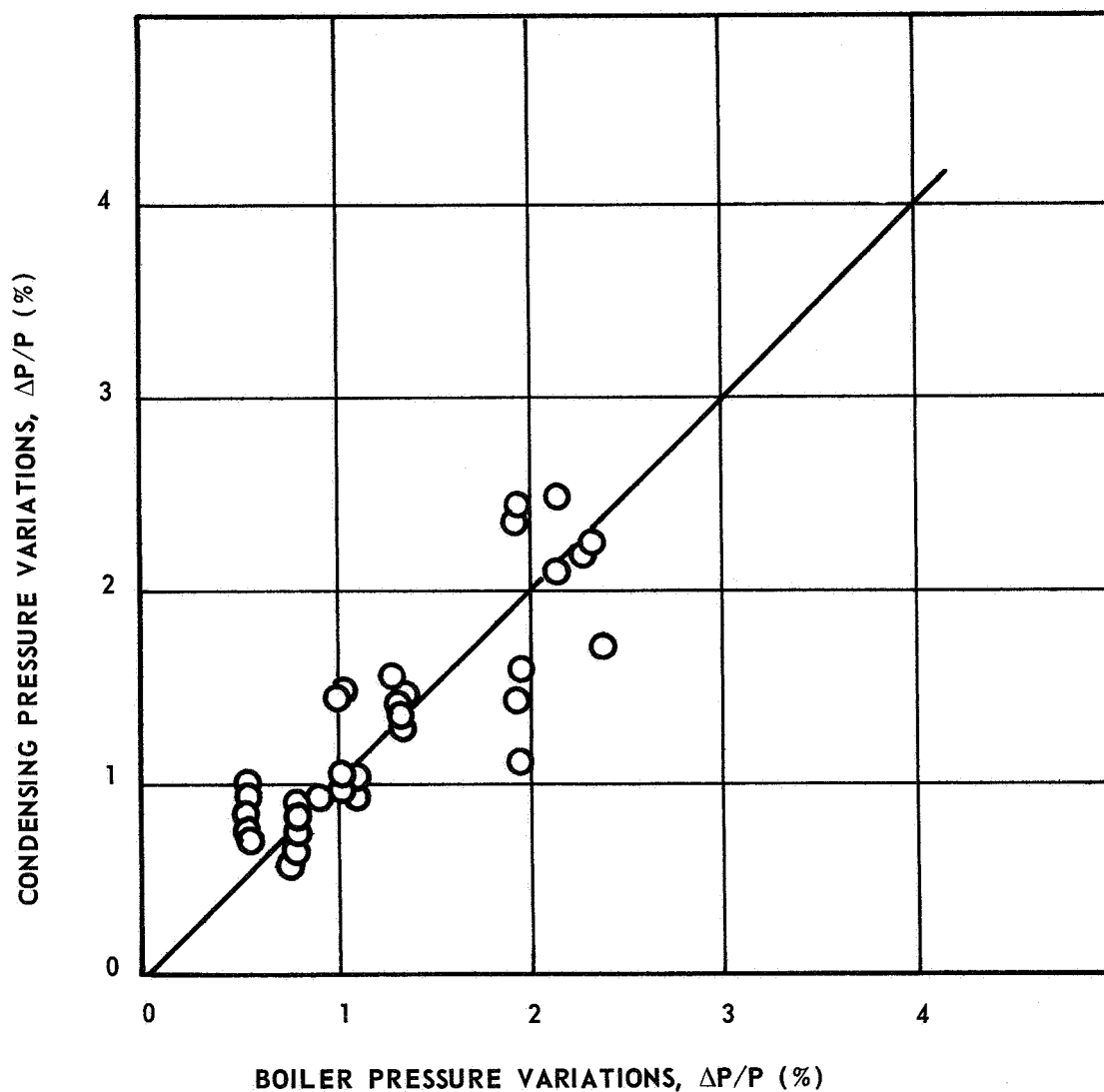
Figure V-77



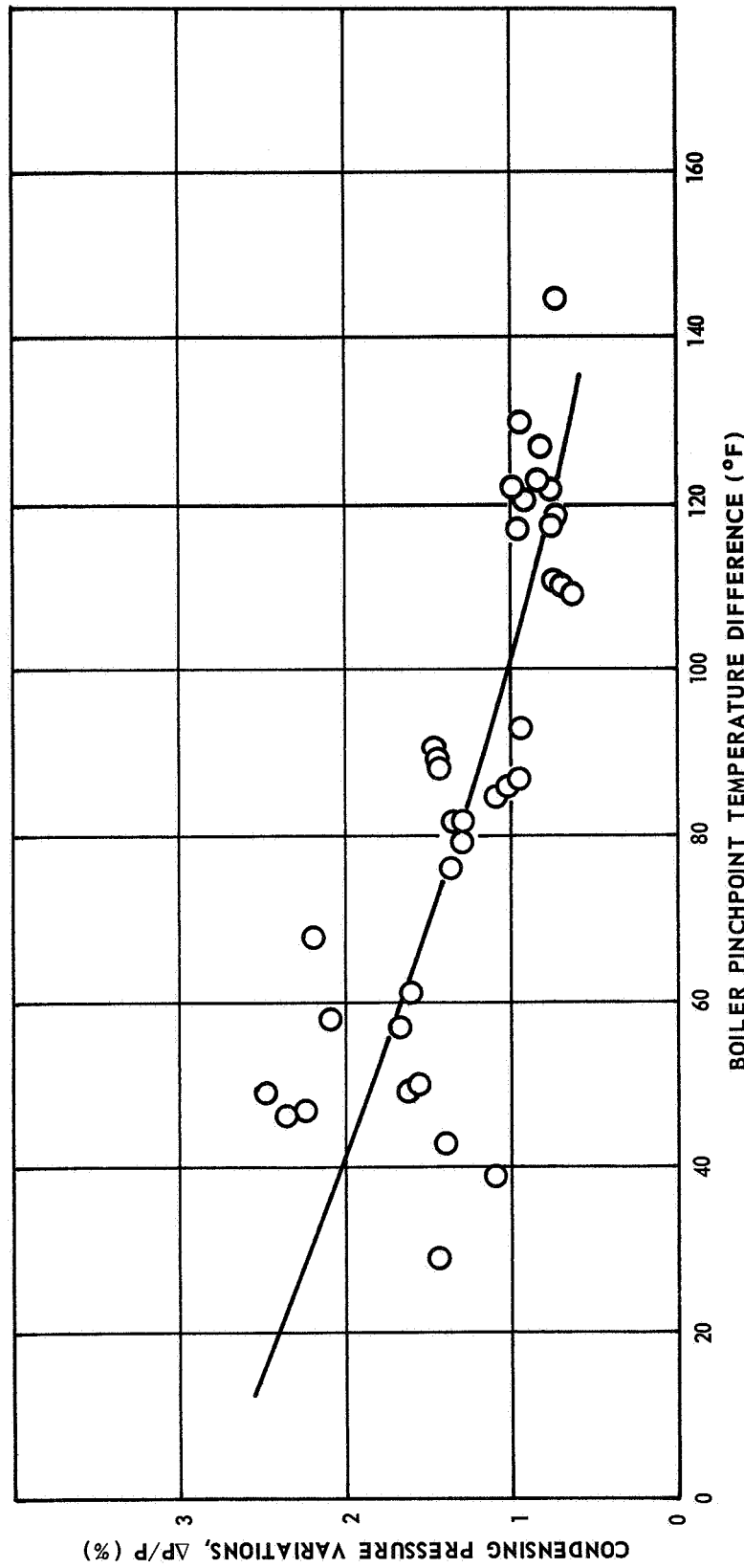
Condenser Performance: Condensing Pressure vs Condensing Length for P/N 092500-1, S/N A-2 During PCS-1 Phase IV Step 2

Figure V-78

866-NF-1321



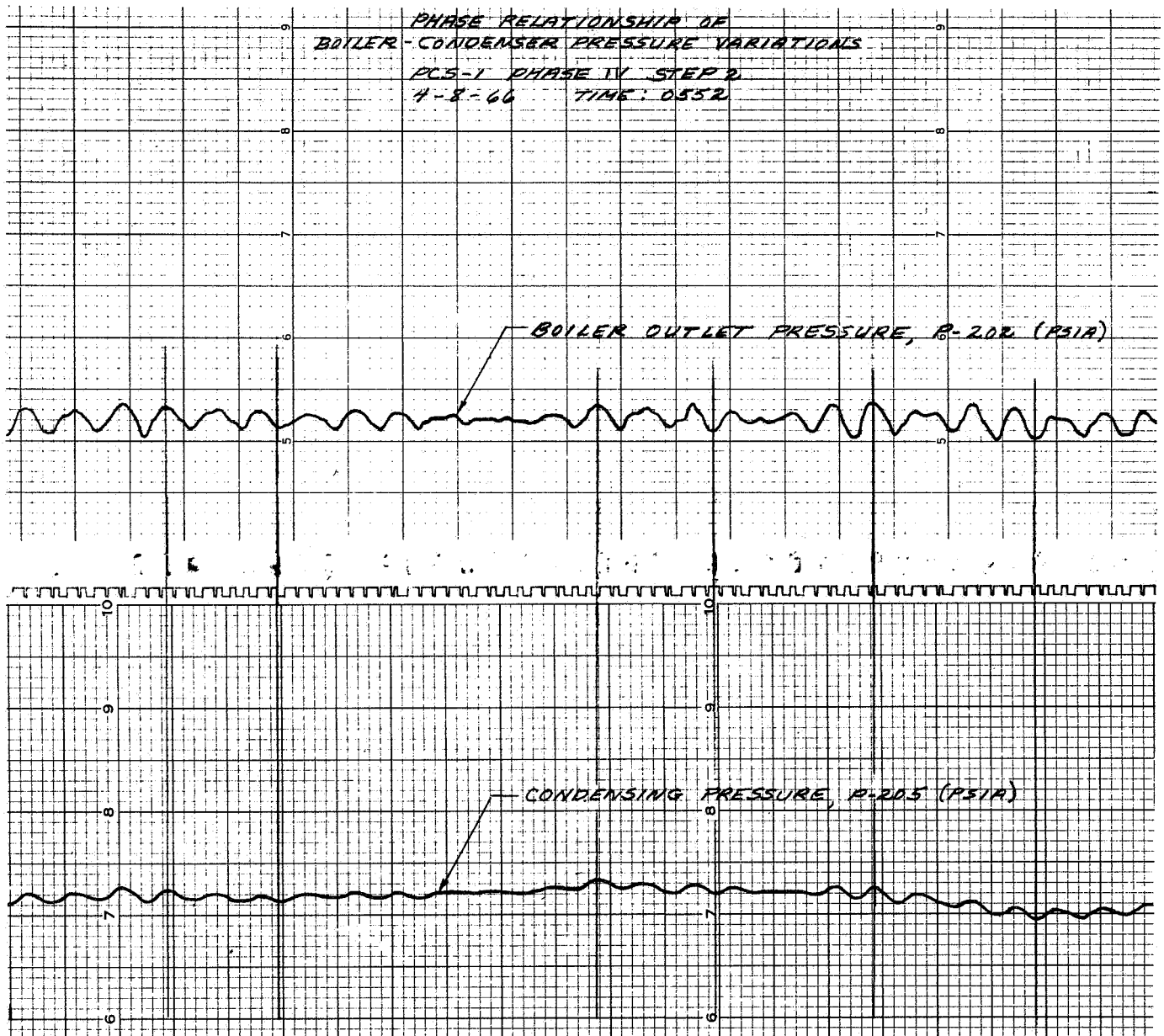
Condenser Performance: Condenser Pressure Variations vs
Boiler Outlet Pressure Variations for P/N 092500-1,
S/N A-2 During PCS-1 Phase IV Step 2



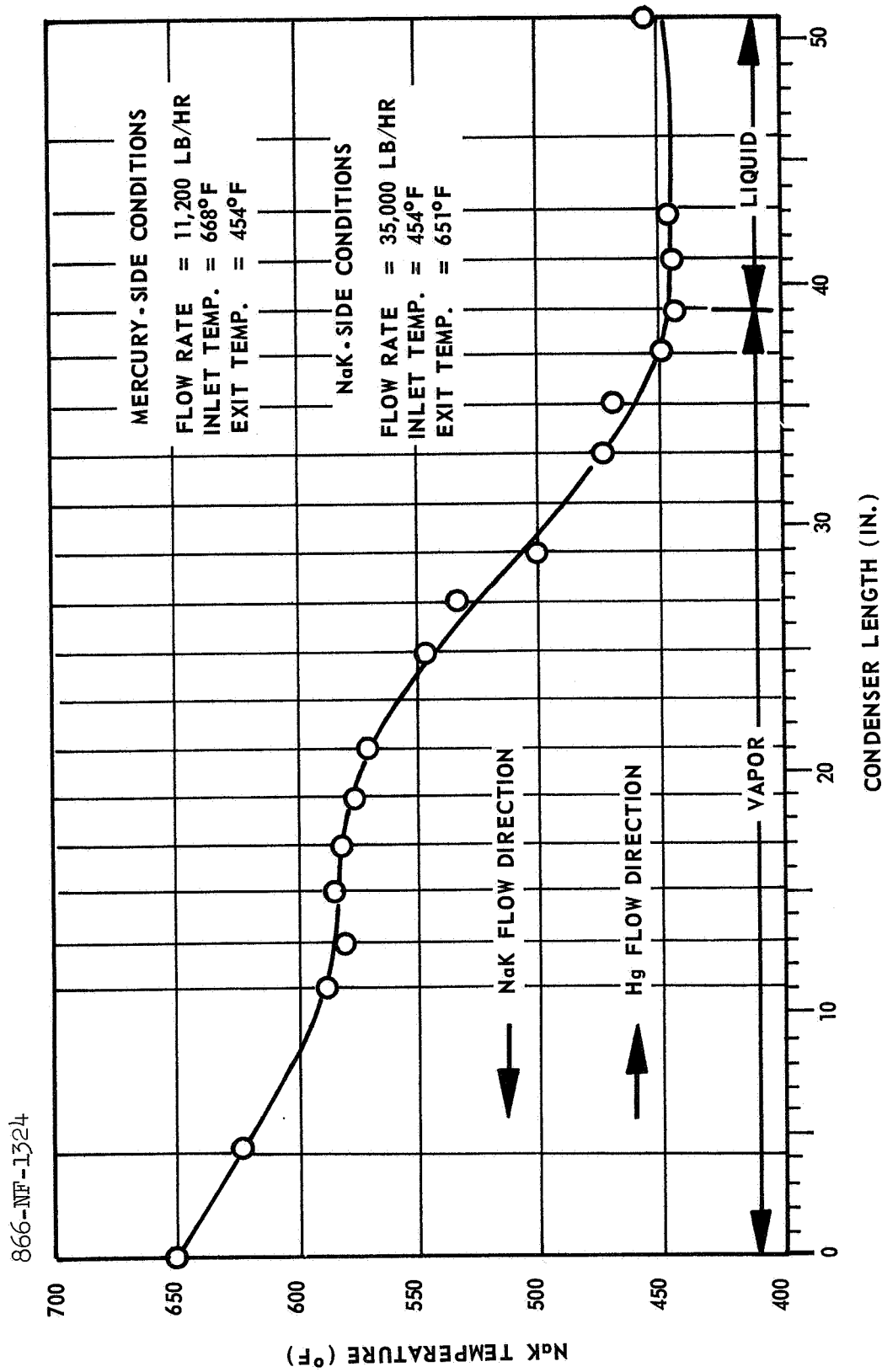
Condenser Performance: Condenser Pressure Variations vs
Boiler Pinch-Point Temperature Difference
for P/N 092500-1, S/N A-2 During PCS-1 Phase IV
Step 2

Figure V-80

866-NF-1323

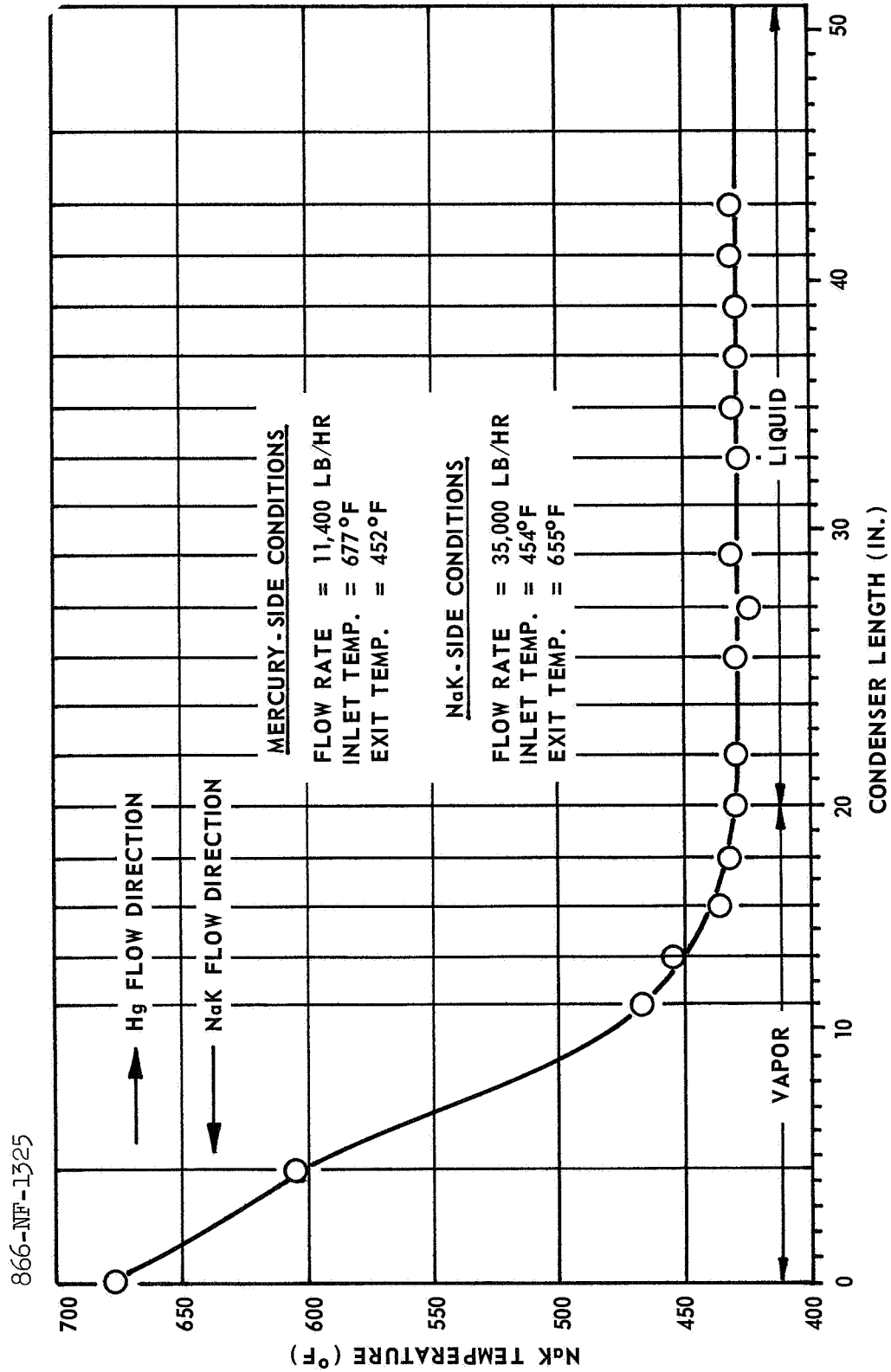


Phase Relationship of Boiler-Condenser Pressure
Variations During PCS-1 Phase IV Step 2

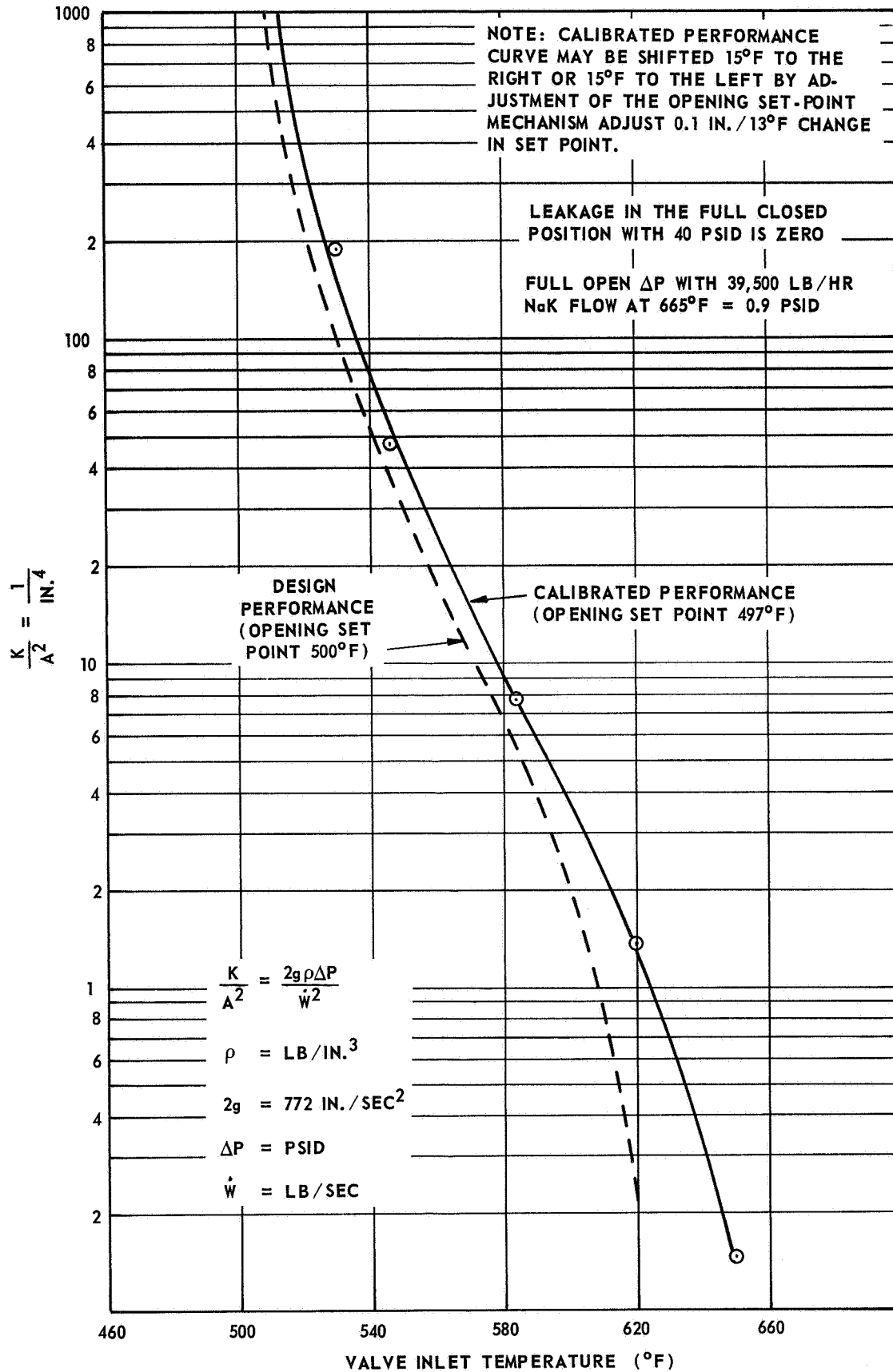


Condenser Temperature Profile in PCS-1
 Phase IV Step 2 - "Long" Condensing Length

Figure V-82

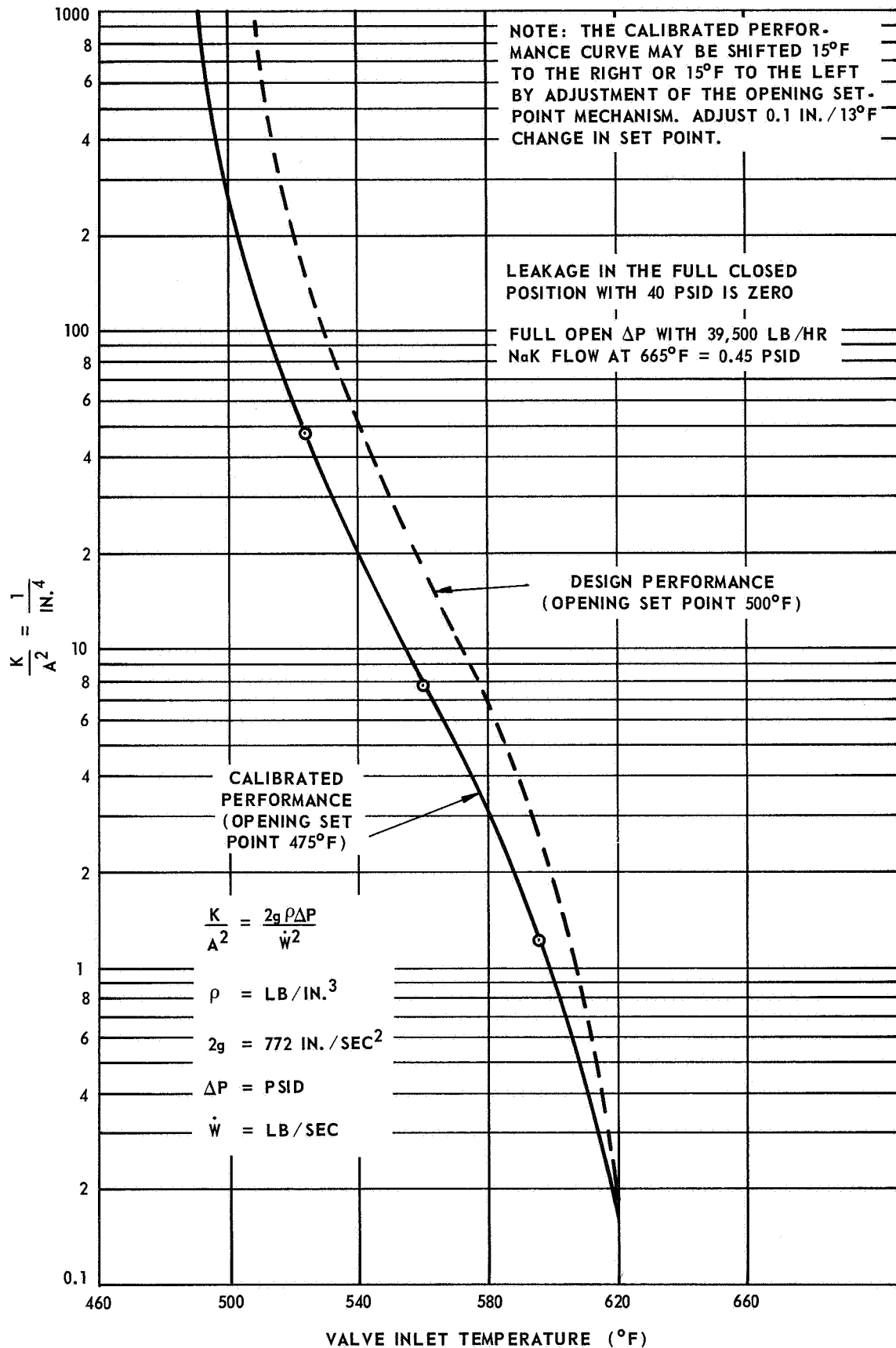


Condenser Temperature Profile in PCS-1 Phase IV
 Step 2 - "Short" Condensing Length



Total Performance with Vinson TCV, S/N 100G

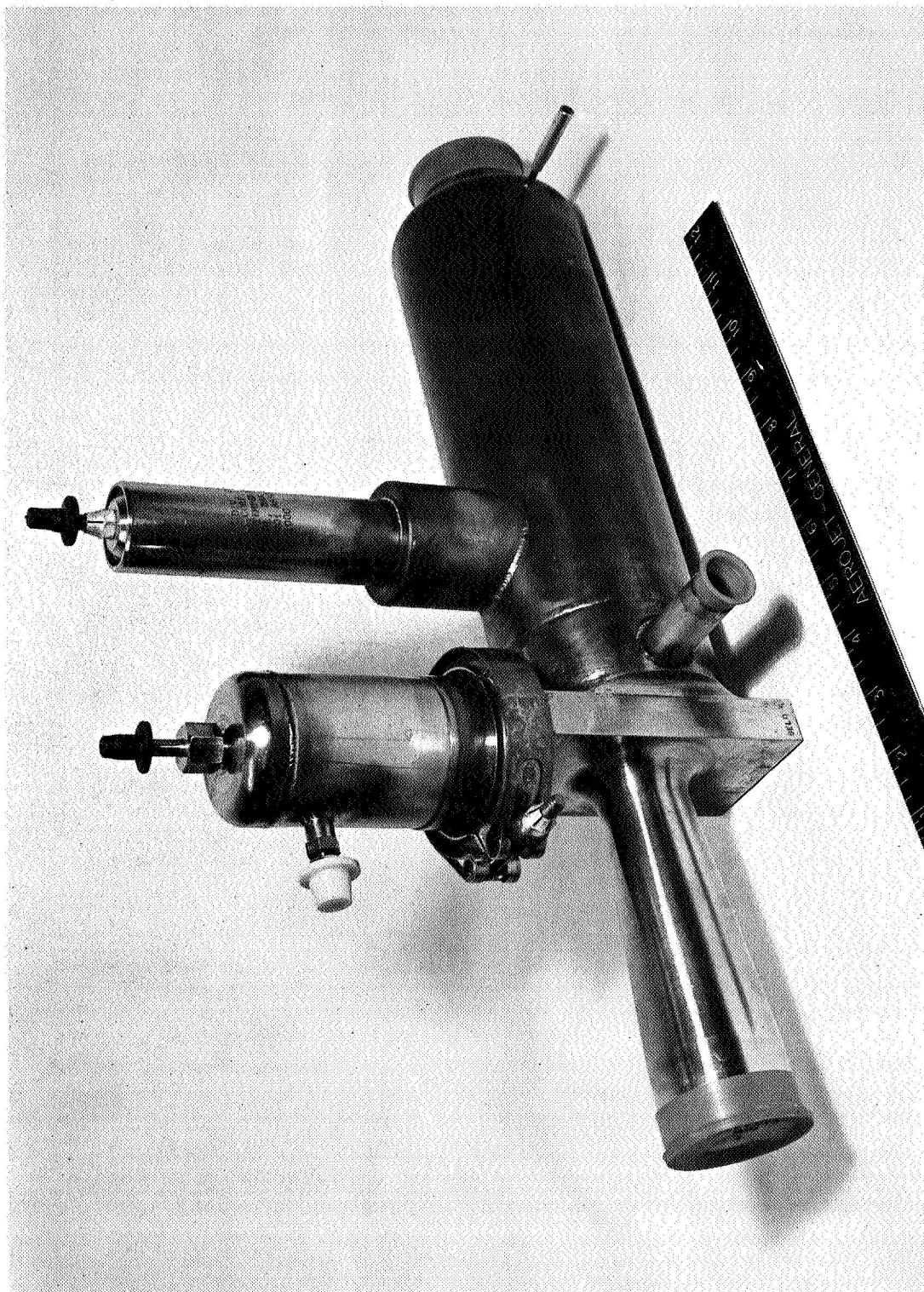
Figure V-84



Total Performance with Vinson TCV, S/N 101G

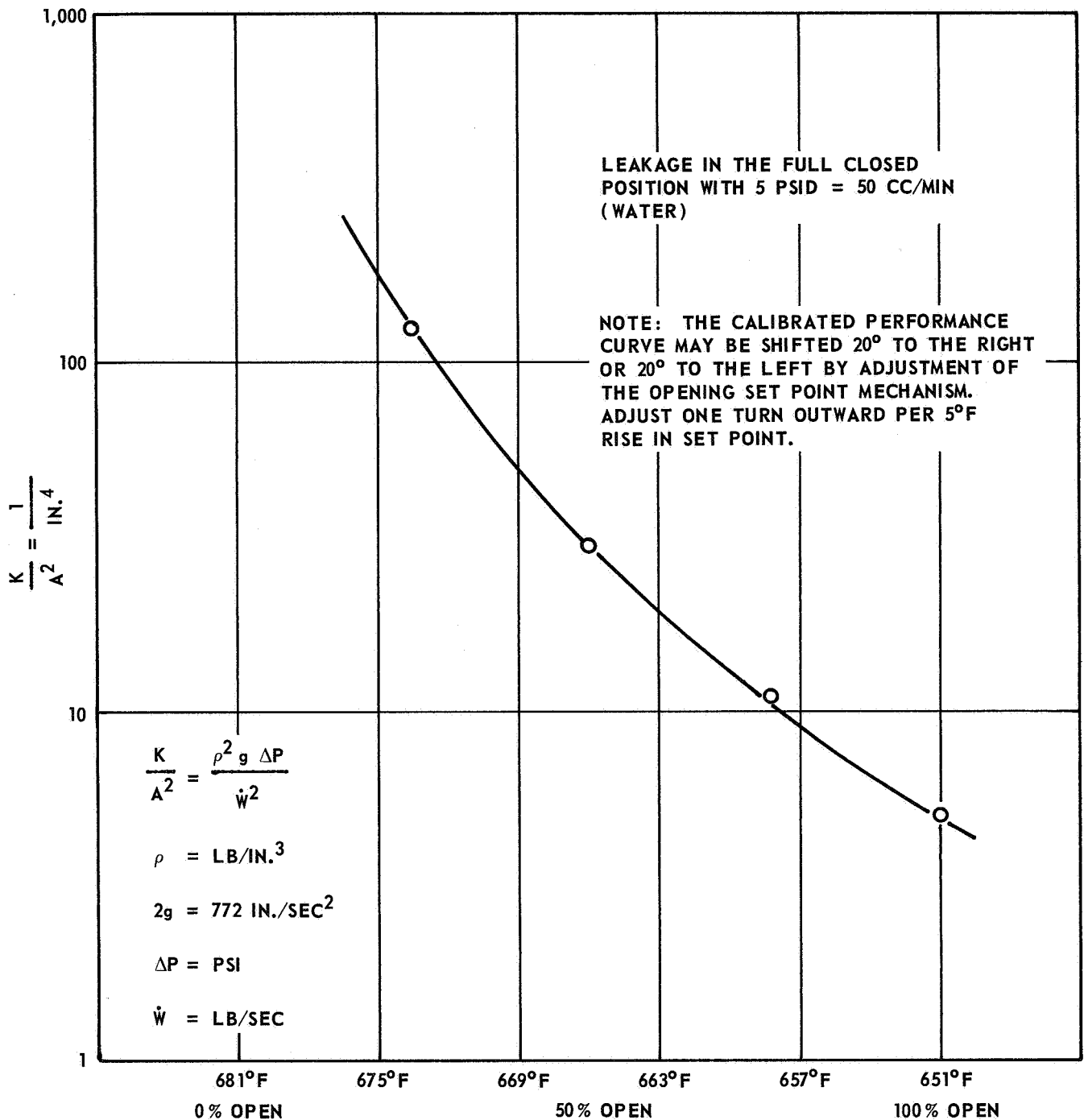
Figure V-85

466-098

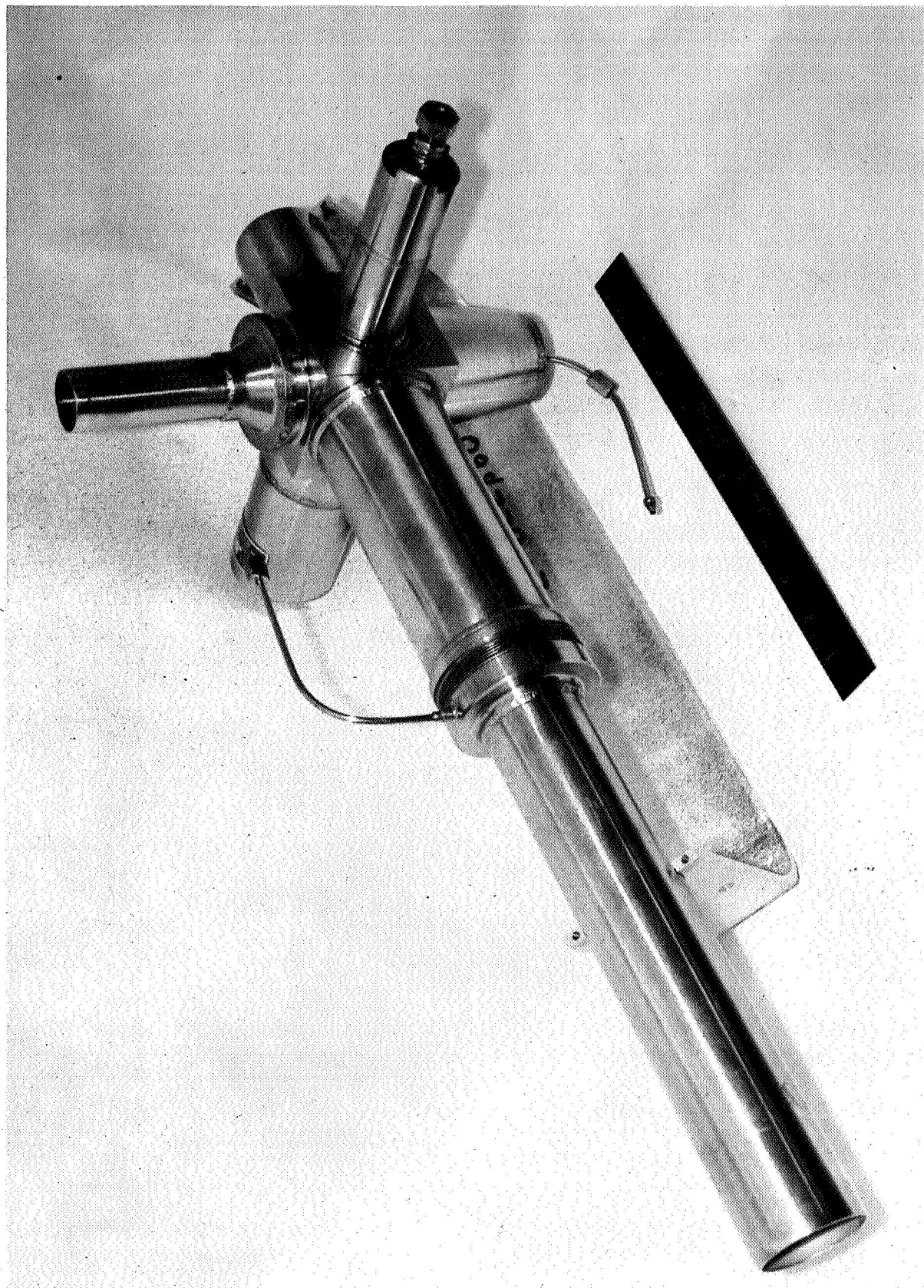


Vinson Temperature Control Valve

Figure V-86



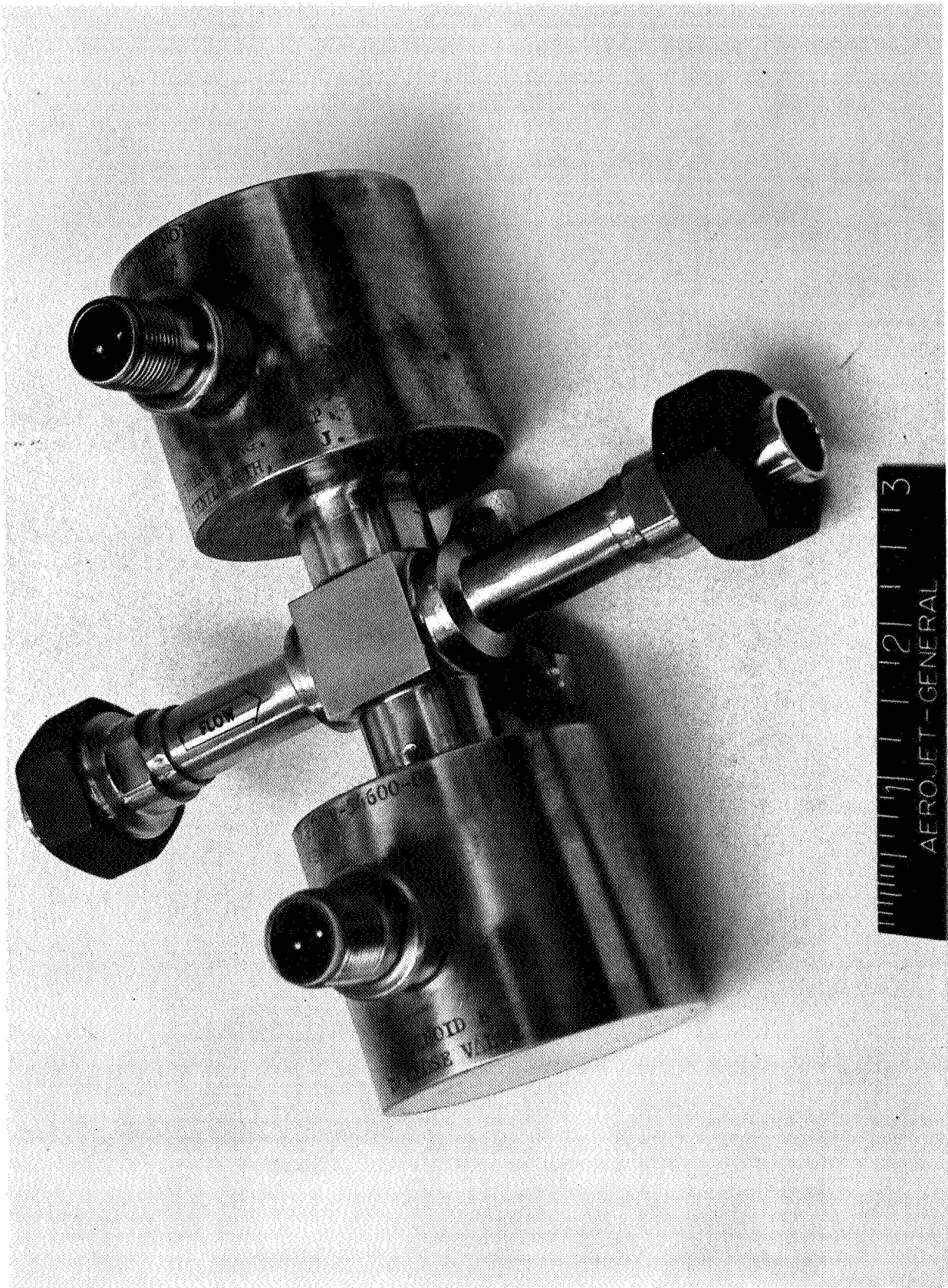
Total Performance - Condenser By-Pass Valve (P/N 097347)



SNAP-8 Condenser By-Pass Valve

Figure V-88

765-539



Double-Solenoid Latch Valve

Figure V-89

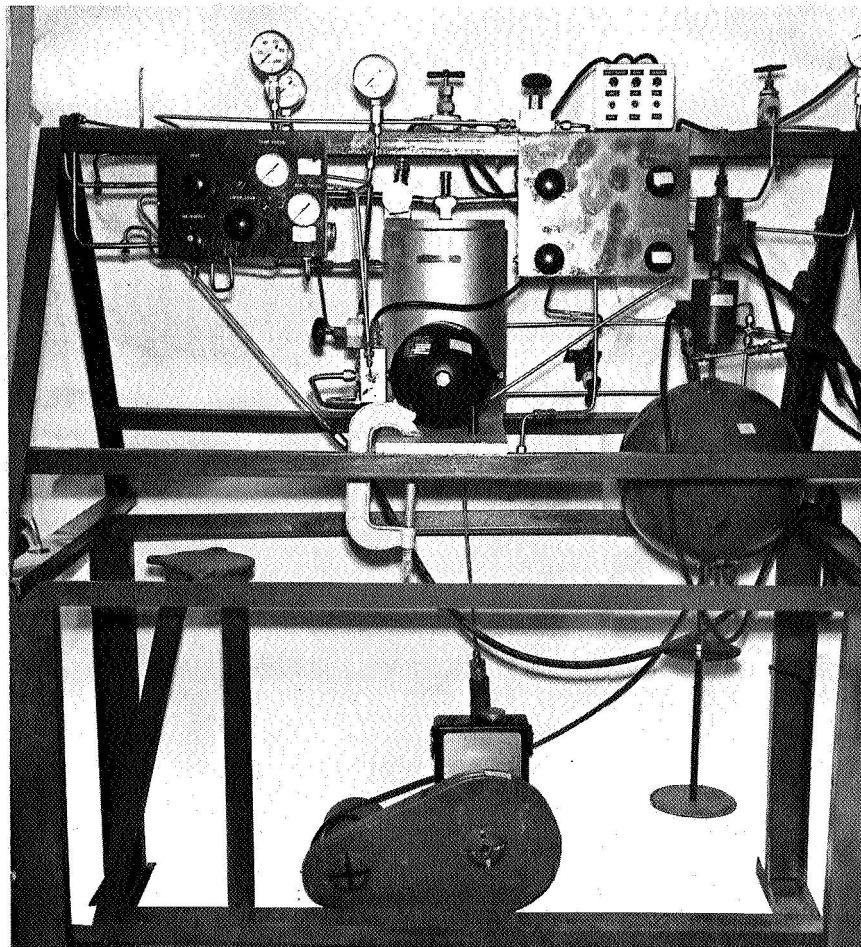
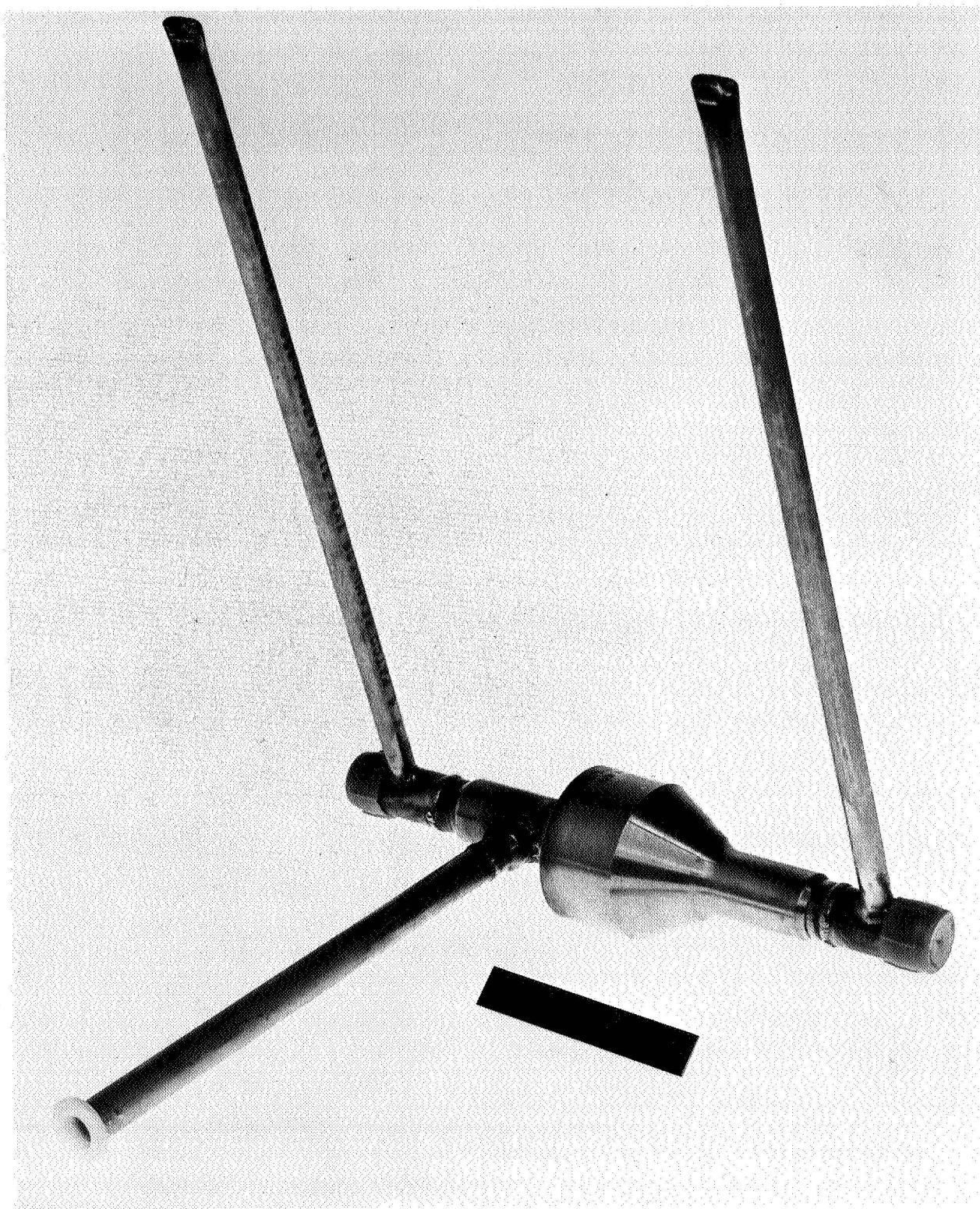


Figure V-90

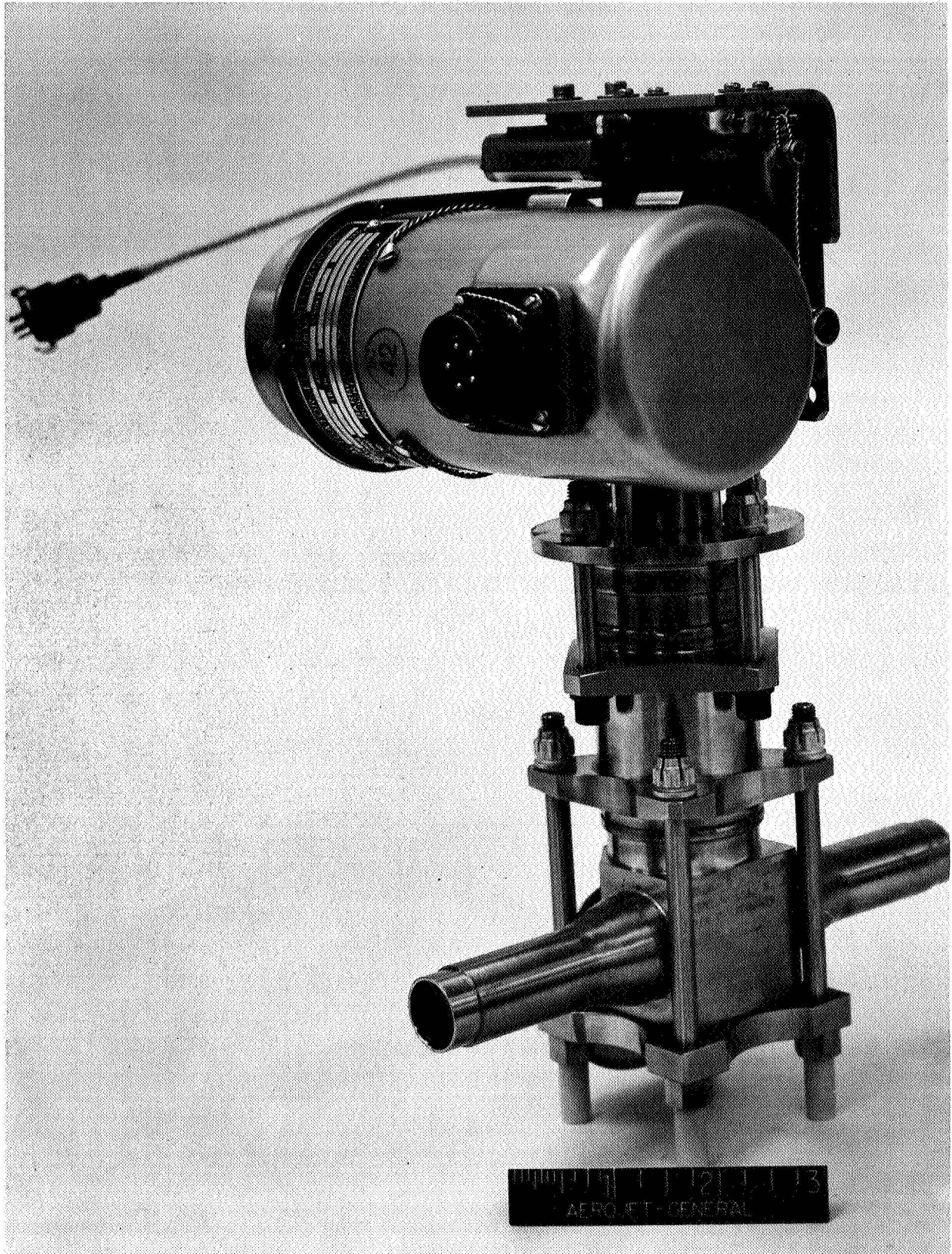
466-095



Isolation Check Valve

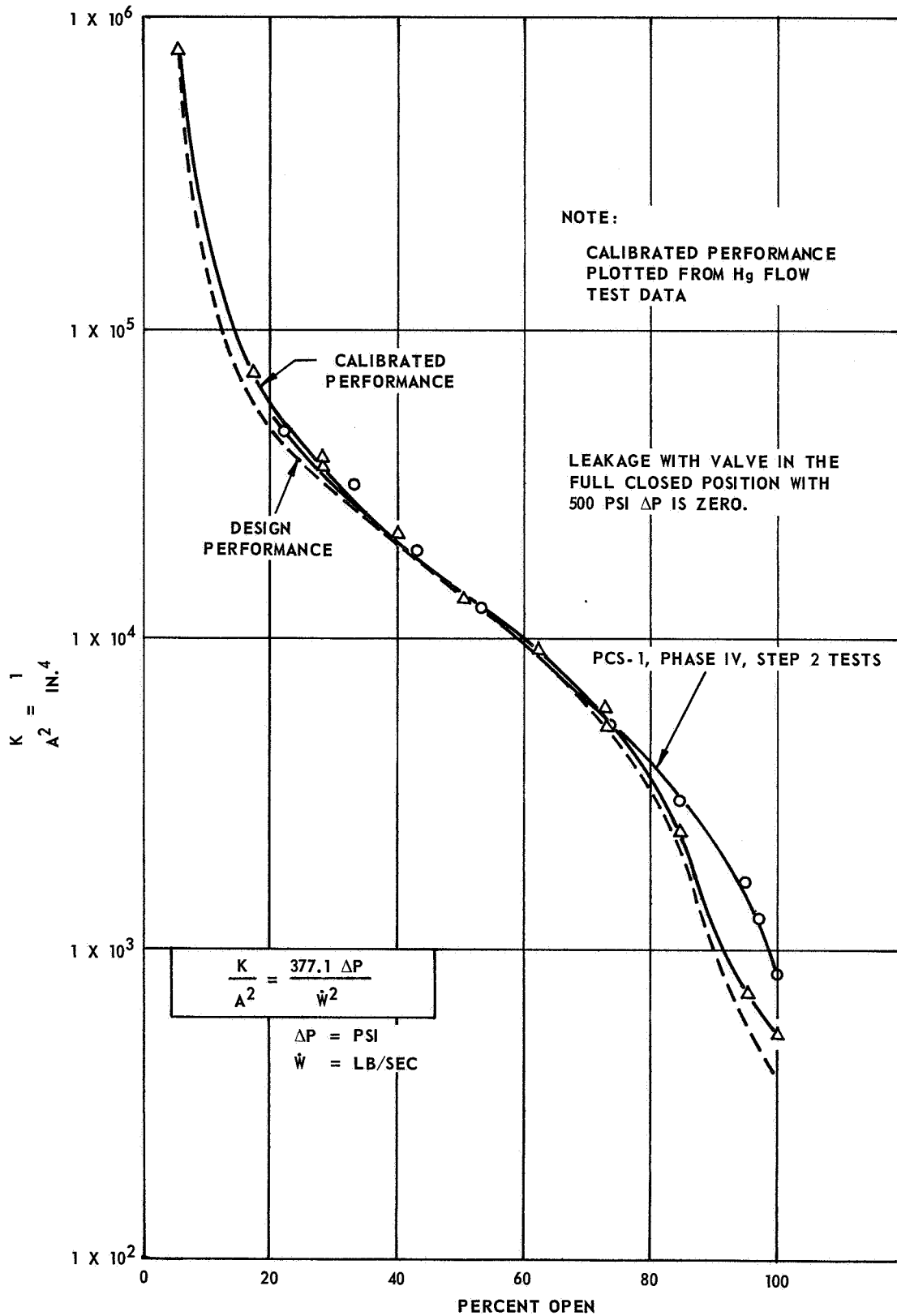
Figure V-91

765-540



Mercury Flow-Control Valve

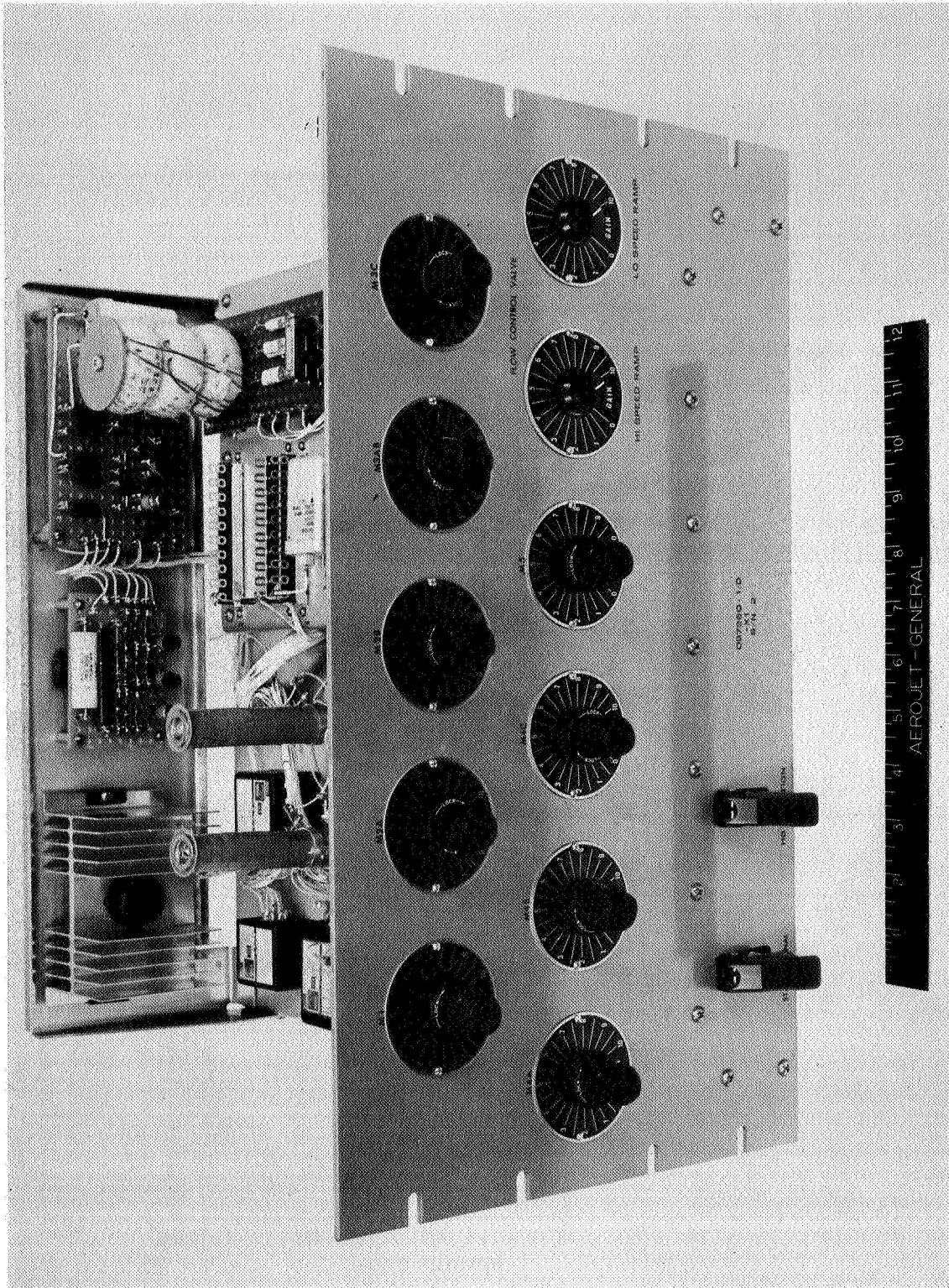
Figure V-92



Flow Characteristics - Mercury Flow-Control Valve (P/N 097330)

Figure V-93

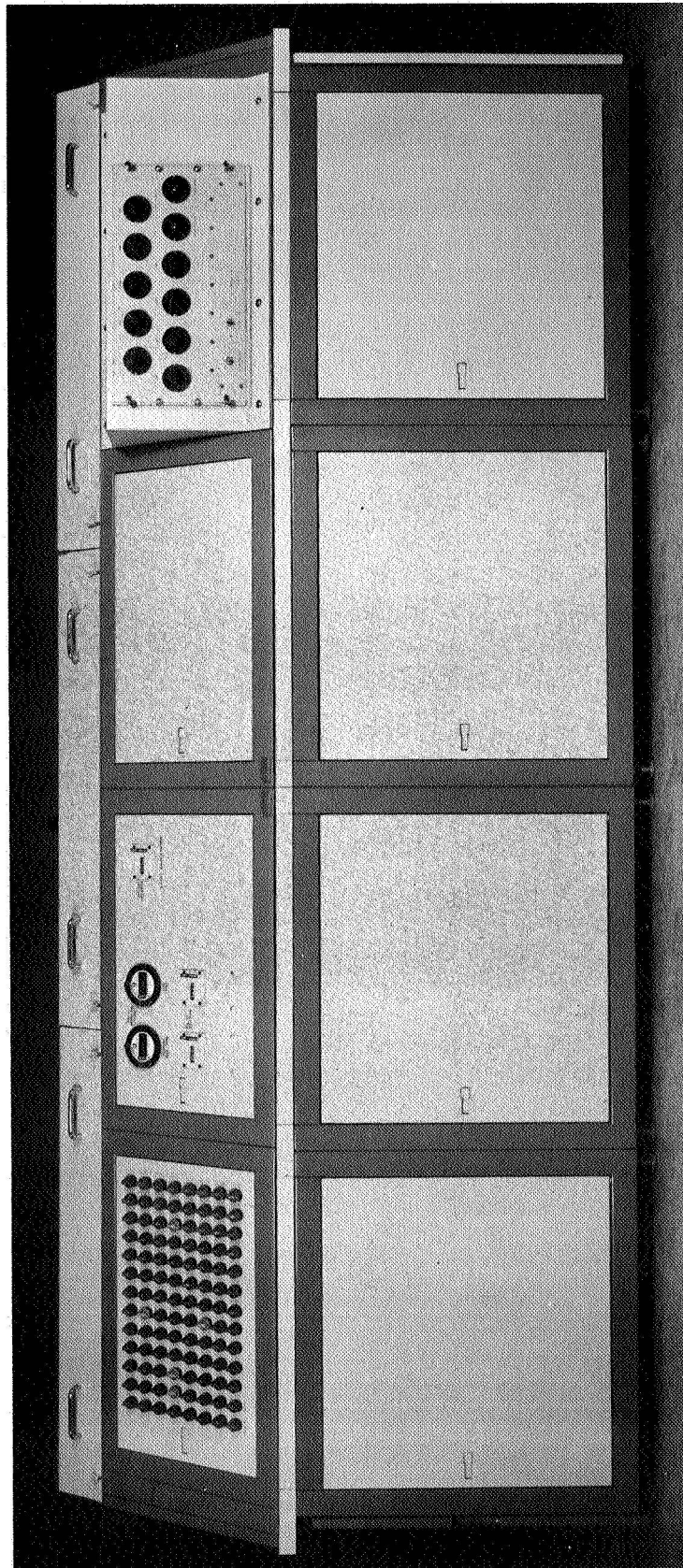
586-148



Start Programmer

Figure V-94

466-589



Building 180 Main Control Console - Rear View

Figure V-95

VI. TECHNICAL SUPPORT

A. SYSTEMS ANALYSIS

1. SCAN - Steady-State System Performance Computer Program

a. Initial Utilization

The SCAN digital computer program was first utilized in studies to determine the effects of component performance variations on system performance. These studies are part of the work being performed under a separate contract (Contract NASw 1296) referred to as the Performance Potential Program. The results of the studies have been reported in Reference 20.

Experience gained in applying the SCAN computer code to problems for the Performance Potential Program was useful when the program was later applied to more direct SNAP-8 system studies and also indicated areas where changes were made to improve the utility of the computer code.

b. PCS-1 Phase IV Operating Conditions

The SCAN computer code was used to determine possible operating conditions for the PCS-1 Phase IV system. Computer runs were made to determine the effects on overall system performance that were caused by variations in the amount of liquid carryover from the boiler and variations in the NaK temperature at the boiler inlet. The results of these computer runs, shown in Figures VI-1 and -2, indicate the increase in mercury flow rate that is required in order to obtain a net electrical output of 35 kw when the amount of liquid carryover varies from 0 to 10%. The required primary and heat-rejection-loop flow rates also are shown as a function of liquid carryover. The primary-loop flow rate was based on the assumption that a 75°F boiler pinch-point temperature difference would provide satisfactory boiler operation when the NaK temperature at the boiler inlet is 1330°F. Figure VI-1 also shows the change in mercury flow rate resulting from a NaK temperature change (at the boiler inlet) from 1330°F to 1280°F. An increase of approximately 400 lb/hr is indicated for all values of liquid carryover when the NaK temperature changes

from 1300°F to 1280°F. Figure VI-2 shows the heat transferred to the mercury loop as a function of liquid carryover and the effect of liquid carryover on the minimum boiler pinch-point temperature difference. The minimum boiler pinch-point temperature difference of approximately 30°F occurs when the NaK inlet temperature to the boiler is at 1280°F.

Additional computer runs were made to determine the effect of vehicle load changes and sun-to-shade variations on overall system performance and operating conditions. A comparison of pertinent system conditions resulting from these variations is presented in Table VI-1. Tests of this type will be conducted during Step 3 test operations and the computer results for the heat-rejection-loop temperature changes occurring during a sun-to-shade variation will be used as test condition inputs.

c. PCS-1 Phase IV Step 2 Test Data Evaluation

Minor modifications were made to the SCAN computer code to include the effects of liquid elevation head characteristics of the PCS-1 Phase IV Step 2 test-loop configuration. Computer runs were made at conditions similar to actual Step 2 test conditions in order to determine the effects on system performance that were caused by variations in condenser inventory and variations in NaK temperature at the inlet to the boiler. A comparison of computer run results and test results indicated that, in general, the computer results were within 2% of the actual test results for a large number of system parameters. A graphical comparison of the results of the Step 2 tests and the comparison with the SCAN computer results will be presented in the forthcoming PCS-1 Phase IV Step 2 Test Report.

d. PCS-G Performance Studies

Approximately fifty computer runs were made, using the SCAN computer program, to assist the PCS-G project group in the selection of PCS-G steady-state operating conditions and component performance requirements. Computer runs were made to provide a map of system operating conditions from which values of flow rates, reactor power, and reactor temperature difference can be determined for various values of net electrical output power.

Computer runs also were made to determine the effects on system operating conditions when parameters such as the following were varied:

- (1) NaK temperature at boiler inlet
- (2) Mercury flow rate
- (3) Turbine efficiency
- (4) Liquid carryover
- (5) Turbine back pressure

The results of the computer runs in this series were transmitted to the PCS-G project for evaluation.

e. Analysis of System Performance with 1200°F Reactor Outlet Temperature.

A study was conducted to determine what the effects would be if the nominal NaK temperature was reduced to 1200°F at the reactor outlet; the SCAN computer code was used. The study included the determination of the net electrical output for a system using -1 component performance characteristics that have been demonstrated to date. Further analysis was conducted to determine the component design changes required to obtain a net power output of at least 35 kwe. The results of the analysis were evaluated on the basis of reactor power, temperature and coolant flow-rate limitations obtained from Atomics International. A technical memorandum, Reference 21, was prepared which describes the assumptions and general method of analysis, and summarizes the results. In general, the results indicate that the net power output of the current SNAP-8 system would be reduced to approximately 18 kwe if the reactor outlet temperature was reduced to 1200°F; however, the net output power values in excess of 35 kwe can be obtained by redesigning the turbine and the boiler and by providing power factor correction to the alternator.

2. Hybrid Computer Simulation of PCS-1 Phase IV

A hybrid computer simulation of the PCS-1 Phase IV test system arrangement was prepared and checked out. The computer simulation

contains dynamic representations for all significant PCS components in the primary, mercury, heat rejection, and auxiliary start loops. Design and off-design characteristics of the following components are contained in the simulation: primary loop NaK heaters; tube-in-tube boiler; condenser; heat rejection loop NaK cooler; all pump motor assemblies, including the L/C PMA; turbine; alternator; auxiliary-start heat exchanger; heat-rejection-loop temperature control valve; parasitic load resistor; and speed-control system. Thermal capacities of all major components are represented and fluid transport delays in the primary, mercury, and heat rejection loops are simulated.

Several typical system start-up runs were made by programming the mercury flow-rate into the boiler. For these runs, the time of the initial flow ramp from 0 to 5000 lb/hr was varied and the effect on turbine acceleration was noted. Two additional runs were made in which the time delay between the NaK temperature at the condenser outlet and the NaK temperature at the heat-rejection-loop temperature control valve was varied. The results of the two runs revealed that with the temperature control valve located considerably downstream of the condenser NaK outlet, the mercury temperature and pressure in the condenser would reach extreme values before the temperature control valve started to open. The purpose of the temperature control valve is to regulate heat-rejection-loop flow rate in a manner which will prevent condenser temperature and pressure from reaching extreme values during start-up. Therefore, as a result of the information obtained from these runs, a recommendation was made to the PCS-1 Phase IV project group that the temperature control valve should be located within 5 ft. of the condenser outlet. A technical memorandum, Reference 22, was prepared in which the computer simulation and the results of the preliminary start-up runs are discussed in more detail.

Revisions and improvements to the computer simulation of PCS-1 Phase IV were made in preparation for a series of start-up runs. The improvements to the simulation included:

- a. Relationships describing the mercury flow-control valve and injection system characteristics.
- b. An expression for alternator efficiency as a function of load and speed.
- c. Turbine power relationships adjusted to agree more closely with actual turbine test results.
- d. Temperature relationships in the boiler and auxiliary heat exchanger were made compatible with component performance.

The improved simulation of the PCS-1 Phase IV system was used to conduct a series of start-up runs similar to those which will be made during the Step 3 start-up development test period. Approximately 20 computer runs were made to investigate the effects of variations in mercury flow-control valve operation, temperature control-valve operation, and heat-rejection-loop cooler temperature feedback on overall system start-up transients. The results of the computer runs are being analyzed and will be used for defining tests and conditions for Step 3 operations.

3. Turbine and Mercury Vapor Line Condensation Effects

The study to determine the effects on start-up of mercury condensation in the turbine vapor feedline was continued after a limited amount of T-T boiler off-design performance data was obtained from tests conducted in RPL-2. The data was extrapolated to mercury flow rate and pressure values that are expected to occur during the early stages of PCS startup. A boiler off-design performance map and mercury flow-control valve characteristics were incorporated into the computer code for determining condensation in the turbine and mercury vapor line.

Computer runs were made to determine the amount of mercury which could condense in the vapor line between the boiler and the turbine for various initial line temperatures and line sizes. The vapor line in the PCS-1 Phase IV system is a 2.5 in. Schedule-10 pipe approximately 30 ft long. The

results of runs made for this line size were compared with the amount of mercury which could condense in a representative close-coupled reference system. The vapor line for the close-coupled system was assumed to be a 1.75 in. OD tube approximately 9 ft long and to have an initial temperature of 100°F. The overall results of the study are presented in Figure VI-3 which shows that approximately 29 lb of mercury would condense in the representative close-coupled system. The amount of mercury condensed in the PCS-1 Phase IV vapor line is shown as a function of initial line temperature in Figure VI-3. The results shown in Figure VI-3 also indicate that the PCS-1 Phase IV system vapor line should be preheated to approximately 550°F in order to produce the same amount of condensation that would occur in a close-coupled system. It should be noted that the results obtained from the mercury condensation computer program are conservative in that the calculated amount of mercury condensed is considered to be a maximum value.

An additional study was conducted to determine the turbine acceleration transient that would occur for the representative close-coupled system when condensation effects are taken into account. The digital computer program for determining condensation in the mercury vapor line was expanded to include the determination of turbine acceleration transients. A conservative relationship for alternator efficiency as a function of load, and relationships for system electrical loads as functions of speed, were used in the program. The results of a computer run for the representative close-coupled system with an initial line temperature of 100°F are presented in Figure VI-4. As shown in Figure VI-4 the turbine does not start to accelerate until 57 seconds after mercury enters the boiler, and reaches rated speed approximately 53 seconds later. This result can be compared with the results of a similar hybrid computer run in which it was assumed that vapor line condensation did not occur. For the hybrid computer run, the turbine started to accelerate 16 seconds after mercury entered the boiler and reached rated speed approximately 64 seconds later. Thus, the acceleration transients are very similar and the major difference lies in the time when acceleration starts.

The results of the digital computer runs which were conducted to determine the effects of condensation in the vapor line, were used to formulate a simplified analytical model for use on the hybrid computer. This analytical model will be incorporated into the hybrid computer simulation of the PCS-1 Phase IV system for use in future start-up studies for Step 3 tests.

4. Condenser Pressure-Drop Correlation Investigation

A digital computer program was completed for calculating two-phase pressure drop by the Baroczy method. The program was used to calculate condenser pressure drop at conditions similar to those of the MECA tests which utilized a single SNAP-8 tapered condenser tube. Results were obtained for a curve of pressure drop as a function of condensing length and compared with the results of the MECA tests. A plot of the calculated values and data prints from MECA tests are shown in Figure VI-5. The calculated pressure drop values agree closely with the MECA test data; however, closer agreement could be obtained if the assumption was made that actual condensation does not occur over the total available condensing length. The MECA test data indicates that this situation does occur.

Further work on condensing pressure drop correlation is anticipated and alternate methods of calculating two-phase pressure drop will be investigated.

5. Modification of ADP and SEDAN Computer Programs

Modifications are being made to the ADP (Automatic Data Processing) and SEDAN (SNAP-8 Data Analysis) computer programs to facilitate the data reduction and data analysis tasks of the PCS-1 Phase IV project for the Step 3 test phase.

The ADP program has been modified to provide a new printout format which displays more data per page than previous versions and displays the data in a more convenient form for performing periodic data checks. Sub-routines also have been coded and checked out for making plots of various

system parameters as functions of time, using either IBM computer on-line plotting or off-line plotting with the CAL-COMP plotter. Subroutines also are being coded which will permit plotting of selected system parameters as functions of one another, such as boiler and condenser NaK temperature profiles.

The SEDAN program has been modified so that corrected data from the ADP program can be used directly as input to SEDAN or further corrections to data from the ADP program can be made by specifying the appropriate correction factors. A subroutine has been written which will provide for simple arithmetic averaging of data for which redundant instrumentation is available. This subroutine replaces the more sophisticated statistical averaging technique employed in previous versions of SEDAN. Subroutines also have been written which will permit:

- a. The selection of specific instrument readings to be used in component and system performance analysis subroutines.

- b. Definition of specific limits for readings of individual instruments. If readings fall outside the specified limits, a computer printout is obtained and appropriate corrections can then be made to the data.

The subroutines within SEDAN which provide for calculation of individual component performance values and overall system performance and heat balances presently are being checked out. Satisfactory checkout of all PMA performance subroutines has been obtained.

6. Restart Capability

The Electrical Generating System (EGS) concept is being examined to determine the modifications or changes to the EGS and to its operation that may be necessary to provide controlled shutdown and restart capability. Work emphasis has been on the problems associated with mercury inventory handling and control for the EGS during system shutdown and start-up. In this connection, a number of concepts for a restart system have been developed and their desired operating characteristics defined.

Several basic prerequisites for such restart systems have been determined to include (1) the capability for operation at zero gravity and in a gravity field up to 1 g, (2) an environment assuring EGS working fluids remain fluid during shutdown, (3) integration of all restart equipment with the PCS, and (4) the availability of vehicle or station auxiliary power for start-up and restart, as required.

Of the concepts examined for applicability to the EGS, the restart system selected for further definition, incorporates the following major features:

- a. Mercury injection is at mercury pump inlet.
- b. Injection pressure is obtained internally from operation of the L/C or Hg pumps.
- c. Restarts utilize mercury extraneous to normal mercury loop inventory needs.
- d. The excess mercury is withdrawn from the mercury loop as rated conditions are achieved.
- e. The inverter drives the mercury PMA during the initial stages of start-up as well as the other PMA's.

For the special circumstance of EGS operation solely under a gravitational field (e.g., a lunar base application), an alternate restart system concept also is being considered. This concept would take advantage of the presence of gravity to reduce the mercury condensing pressure of the EGS and, thereby, obtain system operation at a higher cycle efficiency.

At the close of the report period, recommendations of a restart concept for the SNAP-8 EGS were being documented. Evaluation to date has been limited to qualitative assessment of the several concepts. Further qualitative and quantitative studies will be performed in support of the recommendations.

B. MATERIALS^{*}

Materials work during the first half of the 1966 calendar year provided data to guide the selection of materials for SNAP-8 system components. Metallurgical assistance also was provided in the design, development, fabrication and testing of the system.

1. Power Conversion System 1 (PCS-1) Phase IV Step 2

The wall thickness of the NaK containment pipes in the two gas-fired NaK heaters of the PCS-1 Phase IV test loop was determined by ultrasonic pulse-echo technique. It was estimated that the remaining heater life ranged from 6,200 to 12,600 hours. General wall thinning occurred since the previous inspection in June, 1965 (heaters had operated 970 hours between inspections). The continued use of the heaters for Step 3 (of the PCS-1 Phase IV sequence) testing with reinspection after an additional 1000 hours of operation, was recommended for SNAP-8 testing.

Failure of a liquid-level probe from the PCS-1 Phase IV primary NaK expansion tank, during Step 1 operation, occurred because the probe was stressed to its ultimate strength probably during insertion and/or an unsuccessful attempt to remove it from the tank. The failure occurred in a ductile manner and no indications of material deficiencies were detected. It appears that metallic fragments did not separate from the probe during failure. However, it is estimated that 0.0007 cubic inch of the magnesium oxide insulation from the probe was introduced into the expansion tank. No adverse effects on loop operation should result from the separation of the insulation.

*

Under the terms of the SNAP-8 contract a Semiannual Materials Report (Reference 23) is prepared, covering the same time period covered in this Semiannual Progress Report. The Semiannual Materials Report is summarized in this section. For specific details, the reader is referred to the complete report.

Report No. 3233

NaK contamination of the Hg loop inventory was apparently caused by external sources, probably by the use of previously contaminated NaK-exposed TSE components. There was no apparent cross-loop leakage and the NaK quantity was detrimental to continued use of the Hg inventory.

Arcing of an electrical line heater during a start-up produced two holes in the 316 SS Hg vapor line. The section of the line including the holes, was removed from the loop and examined visually and metallographically. Visual examination revealed that the influx of air into the hot line when the holes were produced, had oxidized the inside surface of the line to varying degrees; the amount of oxidation was apparently dependent on the varying temperature of the metal along its length. Some areas contained a loose flaky oxide scale while others had a tenacious oxide coating. Metallographic examination of a hot-spot area, remote from the arcing location and in a cooler area of the loop, indicated that the material was satisfactory for continued use. No indications of grain growth, incipient melting, or sub-surface or intergranular oxidation were evident.

Examination of several 316 SS pressure taps that had operated in the Hg-vapor section of the PCS-1 Phase IV Hg loop revealed some corrosion. The corrosion rate is estimated at 10.6 to 14.2 mils per 1000 hr. Extrapolated anticipated total life is 2500 to 3350 hr. The material appears to be insufficiently resistant to Hg corrosion in this application where some degree of Hg condensing reflux action occurs. A change to 9Cr-1Mo steel is recommended.

After Step 2 operations, an evaluation of 316 SS thermowells from PCS-1 Phase IV indicated that indium, a heat-transfer medium used inside the well, and 316 SS, the well material, are incompatible under the system operating conditions. The failure of two of the wells in the Hg vapor line was attributed to the incompatibility which led to localized ID wall thinning and eventual wall penetration. It was recommended that the use of indium in 316 SS thermowells be discontinued and that other materials or methods should be investigated in order to provide the required sensitivity and response in temperature measurement.

Analysis of mix-4P3E samples, removed from the L/C loop of PCS-1 Phase IV after the 14 February shutdown, indicated that the fluid was acceptable for continued use. The spectrogram, isomer distribution, specific gravity, refractive index and viscosity of a dump-tank sample were within the tolerances specified for new material in the mix-4P3E procurement specification (AGC-10320).

2. LNL-3 Post-Test Evaluation

No metallic mass-transfer deposits were found after this NaK system had operated isothermally for 2655 hours at temperatures between 1125 and 1175°F; oxygen content was less than 30 ppm. Carbon migration occurred from the mild steel (0.020 in. maximum decarburization depth) to the 316 SS (0.010 in. maximum carburization depth) in the system. The amount of transfer was not sufficient to deleteriously affect loop operation should it be used for additional NaK PMA tests.

3. General Test Operations Support

A filtration procedure and system was developed and successfully used to process approximately 1800 lb of previously-used NaK removed periodically from various SNAP-8 systems. The processing produced NaK that conforms to the SNAP-8 procurement specification (AGC 10340).

4. Turbine-Alternator Assembly

Examination of the seal welds between the HY-80 (low alloy steel) trunnion ring and the mild steel case on five GE-fabricated prototype alternators (P/N 094069) revealed that variations exist in the weld configuration from unit to unit. There also is a variation in the type and amount of weld filler metal used for this joint. Chemical analyses of filings from the alternator seal weld that cracked in service (S/N 481489) indicated that alloying due to melting of the parent metals produced a weld composition which is hardenable. Weld hardening appears to be accentuated by the chilling effect on the massive HY-80 trunnion boss. A probable major factor contributing

to the failure of this unit was this hardened, and consequently less ductile, metal structure. Chemical spot tests of the other four alternators, which have not been tested at AGC, indicate that the seal welds in these units also may be subject to seal-weld cracking. The potential for cracking varies according to the weld configuration and weld filler metal used in each unit. Since stress relieving (a weld-tempering heat treatment) of these units is not practical, it is recommended that a multiple-pass overlay weld be deposited on the present seal weld, using Inco A filler which is a metal that is nonhardenable and ductile. Any units that are operated without this overlay, and that crack in the weld, should be repaired with this same Inco A weld filler metal. For future units, the seal-weld design, materials selection, and fabrication procedure should be reviewed to avoid nonductile welds.

Using the previously established standard thermal treatment (1650°F for 4 hours, followed by 1250°F for 48 hours), the transformation of Stellite 6B tension and impact test specimens from FCC to HCP crystalline structure for the determination of mechanical properties was unsuccessful. While 80% HCP structure and R_C 48.5 hardness were minimum requirements, only 30% HCP and R_C 49 resulted; the "as-received" condition was 6.7% HCP and R_C 37. Preliminary tests indicated that a soak temperature of 1450°F produces the most rapid transformation. After exposure of up to 1100 hours, all of the impact specimens were satisfactorily transformed and final specimen machining was started. The tensile specimens have been exposed for as long as 800 hours without acceptable results. Exposure is continuing.

Exposure of Stellite 6B and S-816 Specimens (at 1065 and 1200°F , respectively) continued in order to evaluate the metallurgical stability of these two turbine aerodynamic cobalt-base materials. The Stellite 6B was treated by salt-bath quenching, reducing the temperature from 2250°F , the solution annealing temperature, to 1000°F in order to stabilize the FCC structure. The two materials have proven stable after 3955 hours (Stellite 6B) and 4275 hours (S-816) exposure. A Stellite 6B specimen exposed at 1200°F was

found to be transformed to the HCP structure when examined after 1710 hours. This test was discontinued and indicates that, with the currently established metallurgical knowledge, Stellite 6B transformation from FCC to HCP cannot be prevented at 1200°F.

PH 15-7 Mo, a precipitation hardenable stainless steel used for the TAA second-stage shroud, in the TH 1050 condition, was found to be metallurgically unstable at 1065°F. The material is not recommended for use in the SNAP-8 turbine. Although stable alloys should be substituted for the PH 15-7 Mo, this material must be used in the interim. Therefore, a preassembly thermal treatment was developed to produce metallurgical stability at the turbine operating temperature (1065°F). This treatment incorporates a 50-hour soak at 1065°F of the material after it has been heat treated to the TH 1050 condition, but before final machining has been performed.

An Inconel (nickel base alloy) TA retainer spring was evaluated for Hg corrosion effects after 117 hours of operation in the S/N 6/1 turbine. A plated surface layer (pure nickel over iron, directly on the spring) metallurgically appeared unaffected by the Hg exposure. It appears that nickel components may be usable in the 1st and 2nd stages of the turbine without catastrophic Hg corrosion occurring.

A brazed joint which was developed to connect the TA inter-stage pressure taps, was found to be metallurgically stable after exposure of samples in air at 1000°F (the maximum operating temperature) for approximately 2000 hours. No detrimental reaction occurred between the Easy-Flo braze alloy and either the mild steel pressure tap or the 9Cr-1Mo steel turbine case which represents the S/N 5/2 turbine configuration; the joint is considered acceptable for turbine tests of at least 2000 hours duration.

The remelt temperature of a brazed joint, consisting of Easy Flo braze alloy, 316 SS pressure tap and 9Cr-1Mo steel turbine case (representing the S/N 2/3 turbine configuration), was established at 1145°F; rupture of the joint required 47 psi (lap shear strength). As a result, it appears that removal of the taps is practical should it prove necessary during S/N 2/3 TA testing.

5. Boiler Evaluation

The Hg inlet plug from the -1 boiler (P/N 092020-1F, S/N A-1) was examined, as part of the continued evaluation, after the boiler had operated for 1425 hours in RPL-2. Both the mild steel rod and mild steel wire which comprise the plug, had been attacked. The maximum depth was 4.2 mils, measured 16 inches from the Hg inlet. Both elements were attacked at the rod-wire interface, indicating Hg by-pass flow in the axial direction rather than the helical path formed by the wire.

The twisted ribbon turbulator, located downstream of the plug in order to maintain vapor vortex flow, had been stress relieved of the cold work strains imposed during twisting. The boiler operating temperature, between 1100 and 1300°F, produced the effect. The stress relieving caused local buckling of the ribbon. The distorted areas acted as corrosion product traps, containing large accumulations of porous, dendritic mass-transfer buildup. The maximum buildup was 3.3 mils at 46 ft 8 inches from the Hg inlet.

The available analysis data which was used to extrapolate the expected total available operating life of this boiler was based on the premise that penetration attack is the life limiting mechanism. It is estimated that the boiler would have operated approximately 11,000 hours. This estimate is based on the conservative assumptions of a 0.200-inch thick wall in the area of maximum attack rather than the current 0.090-inch wall thickness; and the limit of penetration defining boiler life is through the added thickness (0.110 inches) only.

6. Corrosion Loop Program

A parametric analysis of the corrosion in the preheat section of the boiler was performed in an attempt to determine the design parameters that can be modified to reduce the boiler corrosion rate.

Mercury wetting capsule tests were started to provide a procedure that would assure complete local wetting of the mercury containment tube in the boiler.

The original mercury boiler in Corrosion Loop 4 (CL-4) was removed and a modified boiler, designated 4A, was installed. This boiler was designed so that the straight section of the boiler inlet plug can be removed and readily replaced. The first of four boiler inlet-plug test sections was installed in the CL-4A boiler and operated to obtain mass and heat-transfer data.

Work was initiated on a single-phase liquid mercury loop designated Corrosion Mechanism Loop-1 (CML-1). The objective of this loop is to determine the mechanism that controls the corrosion of 9Cr-1Mo in mercury.

C. RELIABILITY

1. Management and Control

Reliability and Quality Assurance coordinated the preparation of Aerojet's proposed revision to EGS Specification 417-4, "Specifications for SNAP-8 Reliability and Quality Program Implementation".

SNAP-8 Reliability Program Plan (Reference 24) was updated (Reference 25) but its release was deferred pending disposition of the proposed EGS Specification 417-4A. Before the SNAP-8 reliability program plan was updated, a reliability charter was established which covered the mission, organization, function and staff of the reliability department. It was used as a governing management policy document for making changes to the SNAP-8 reliability program plan (AGC Report 2406).

Reliability characteristics of the SNAP-8 system were discussed with members of the Presidential Scientific Advisory Committee (PSAC).

SNAP-8 Division Procedure VI-B5, "SNAP-8 Test and Data-Point Identification Control" and a "Test Number Assignment Record and Guide" were prepared and issued.

2. Reliability Statistics

A target reliability growth curve was developed to establish reliability goals for the SNAP-8 PCS throughout its projected development period.

An initial evaluation was completed of the expected life of SNAP-8 TSE for spares estimation purposes.

A formal assessment of the reliability of the major SNAP-8 PCS components was completed. Estimates verify earlier evaluations which indicated that the NaK PMA and the TAA are the two PCS components most susceptible to failure.

3. Operations Evaluation and Failure Analysis

Reliability personnel continued to monitor SNAP-8 testing activities at the Von Karman Center and to participate in the reporting, analysis, and corrective action of equipment failures. General information on the failures reported during this report period are summarized in Table VI-2, SNAP-8 Active Failure Report Status. A procedure requiring the formal scheduling of failure corrective actions in the SNAP-8 Milestone Chart Review System was developed and implemented. Under this system, progress on failure corrective actions is reviewed weekly by the SNAP-8 Program Management review team.

Audits were conducted to evaluate performance in two documentation areas: recording of significant test events in test operations of PCS-1 Phase IV (Steps 1 and 2) during the period 19 November 1965 to 30 April 1966, and the documentation of PCS-1 Phase IV test operations hardware and equipment failures. Problem areas were documented and cognizant persons notified for corrective action.

Cumulative operating times for major PCS components were compiled and reported on a monthly basis. The detailed summary provided in Table VI-3 gives operating times by component unit and cover the period of January through June 1966.

A zero defects (ZD) chart for monitoring performance in PCS-1 Phase IV test operations was developed and maintained.

Test equipment drawings, test specifications and test requests were reviewed for compatibility with SNAP-8 test reliability requirements. Areas of incompatibility were reviewed with cognizant personnel, and the required corrective action initiated.

D. QUALITY ASSURANCE

1. General

During the period, the Quality Assurance support of the SNAP-8 technical program has been expanded beyond the scope of the SNAP-8 Quality Program Plan (Reference 26). The increased QA activities apply in the following functional areas; review and sign-off of all drawings, monitoring of all test equipment fabrication and installation, and uniform QA controls for electrical equipment. The latter responsibilities provide guidelines for basic QA controls, drawing requirement, shop order requirements, and electrical workmanship characteristics. The previously issued policy direction for QA control of mechanical TSE continued in force.

All of the above improvements were incorporated in a coordination draft of the SNAP-8 Quality Program Plan (QPP). Although the revised QPP could not be finalized, all of the intended improvements were implemented.

2. QA Review of Drawings and Specifications

The QA review of drawings and specifications was increased in scope and depth in accordance with the policy directions referenced under para. 1; particular emphasis was placed on electrical drawing requirements in accordance with the guidelines listed in Table VI-4.

The need for improved controls of special processes, electrical workmanship standards, and technician training/certification was evident from the analysis of test event reports which identified installation error or workmanship as the largest single cause of problem events. As suggested by QA,

two workmanship standards (AGC-20030 and AGC-STD-2019) were added to drawings, beginning in March 1966, which then formed the basis for the improvements listed above.

The general scope of the QA document review effort is shown on Figure VI-6. It is noteworthy that QA recommendations for updating drawings reached significant proportions during this period.

In addition to recommendations for updating, suggestions were made to improve drawing call-outs. An example is the improvement in acceptance check requirements for curvic couplings on turbine wheels; changed dimensioning and added inspection parameters will result in better controls.

A significant increase in QA efforts was experienced in the review of specifications and book standards. This was partly due to increased volume and partly due to an improvement in contents. Examples for the latter were the acceptance standard for boilers (AGC-STD-1289), the clean room operating procedure (AGC-10336), and the basic cleaning specification (AGC-10319), each of which received intensive QA attention before release or revision.

3. Control of Procured Materials

Supplier inspection system requirements per NPC 200-3 (implemented by AGC QC Standard H 1-6) were invoked for less than 2% of procurements initiated during the period. This low level of application was caused by a combination of factors, the most important being the high ratio of TSE versus PCS equipment procured (Figure VI-7). Since most of the procured TSE consisted of commercial, off-the-shelf items, the selective application of product quality requirements was considered more appropriate than the imposition of a general quality specification.

At the same time, SNAP-8 QA initiated a revision of QC Standard H 1-6 to eliminate problems encountered with its application. The revised edition is considerably simplified and actually corresponds more closely to NPC 200-3 than the previous issue.

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The quality requirements for major PCS components were summarized in Quality Engineering Instructions, of which ten were prepared during the period. These are narrative QA documents written for use by the subcontractor's management, and consist of three major sections: inspection system requirements (such as QCS H 1-6), quality documentation to be furnished, and scope of supplier QA program desired in qualitative terms.

A significant part of the QA procured-materials control effort is to ascertain that the drawings are up to date in accordance with working agreements; QA prepared over 150 recommendations to update drawings during the second half of the period.

Significant QA source surveillance activities covered the following products: LeRC boiler, pressure transducers, NaK liquid level probes, dual solenoid valves, turbine wheels, and nozzle diaphragm assemblies. QA efforts pertaining to the LeRC boiler included the witnessing of final tests per AGC-STD-1289; the standard was released after QA verification. The QA objective for pressure transducer monitoring was to assure that supplier final tests and calibrations were performed under controlled conditions in order to minimize the need for costly repeat tests at AGC. Most of the transducers procured during the report period were processed without retest or recalibration.

Receiving inspection of incoming materials was performed in accordance with quality engineering instructions entered or referenced on purchase orders. Figure VI-8 shows the average monthly inspection acceptance rate and the quantity of articles inspected each month.

Laboratory testing, as part of receiving inspection, was primarily concerned with the calibration of measuring and test equipment, such as temperature sensors, meters, thermocouples, flow meters. Valves were leak tested and X-ray inspected.

4. Control of AGC Fabricated Materials

The review and integration of inspection requirements into shop orders for electrical and test support equipment received increased emphasis during the reporting period (Figure VI-9). Typical requirements included the following: prior acceptance and traceability of components; workmanship of wiring and cabling; workmanship of soldered and mechanical joints; and inspection for handling damage. An Inspection Instruction (QE 851-5056) was provided to list the various workmanship characteristics.

Another field of QA concentration was helium leak testing of test loops, predicated on the frequent recurrence of leakage problem events. A detailed Inspection Instruction (QE 851-5057) was prepared and the shop order instructions to technicians were upgraded. Typical inspection points included verification of adequate vacuum; determination of leak detector sensitivity and response time; application of helium to joint; and recording of test results.

A new area of control was introduced by the use of shop orders for functional calibration and reconditioning of instrumentation.

Improvements were made in the traceability of SNAP-8 parts and materials. At the present time, SNAP-8 QA has a record of all serialized SNAP-8 parts made during the last four years, including cross references to the work initiation documents.

Several PCS components were delivered to NASA during this reporting period. In all cases, Aerojet and Government inspection was accomplished in accordance with Quality Engineering Instructions without significant nonconformances. Specific shipping instructions were generated for each deliverable item as follows: NaK Pump Motor Assembly (QE 851-1228), Temperature Control Valve (QE 851-1204), Turbine Exhaust Bellows (QE 851-1206), Tube-in-Tube Boiler (QE 851-1188), and the Voltage Regulator and exciter (QE 851-1227).

Inspections in fabrication and assembly shops, including the SNAP-8 clean room, were accomplished with integrated shop orders and/or separate inspection instructions. The results of these inspections are shown on Figure VI-10.

The quality of weldments made remained very high. From a total of over 2000 inches of weld joint inspected by radiographic and dye-penetrant inspection methods, only about 1% were found to be nonconforming (Figure VI-11).

5. Nonconforming Materials

A total of 158 nonconformance reports (IR's) were written and subsequently dispositioned by the Engineering Review Board during the reporting period. Of these, 53 nonconformances (or about 32%) were considered of sufficient magnitude to require rework or repair of the article.

Table VI-5 shows the causes of nonconformances and the number of occurrences in each category.

Table VI-6 is a summary review of the significant nonconformances and corrective action taken.

The nature of discrepancies was so diversified that no trend or pattern suitable for analysis could be established. Primarily, this is due to the fact that SNAP-8 fabrication and inspection is normally dealing with dissimilar pieces of custom made equipment.

6. Control of Measuring and Test Equipment

AGC source surveillance of supplier calibrations of pressure transducers, as well as subsequent audit checks after receiving, indicated that supplier and AGC interpretations of calibration requirements may be different enough to result in acceptance by one laboratory and rejection by another.

As a result of this finding, AGC-STD-1283 was scheduled to define the technical requirements in operative terms. A parallel effort is being made for electrical transducers (ref. AGC-STD-1287).

As a corollary to the above, in-plant controls were improved. Agreements were reached with Instrumentation Engineering to (a) use a shop order work initiation system for all instrumentation, (b) establish controlled calibration procedures for various types of instrumentation and instrumentation systems, (c) qualify instrumentation technicians as certified solderers, and (d) establish traceability for instrumentation subject to repeat use.

7. Certification Control Center Activities

a. Three SNAP-8 fusion welders were qualified in accordance with AGC-14067 and were continually monitored to assure a high level of workmanship (Ref. Figure VI-11). This requirement is supplementary to and exceeds the general aerospace practice of certifying welder capabilities to MIL-T-5021C; the SNAP-8 welders are required to demonstrate proficiency in accordance with the Military Specification before admittance to the more stringent SNAP-8 qualification tests.

b. Ten SNAP-8 technicians were trained and certified for soldering electrical connections in compliance with AGC-STD-2019. This action was initiated by QA in an effort to upgrade the workmanship of electrical-electronic components.

c. A program was started to train and certify SNAP-8 inspectors and technicians in helium-leak detection techniques as applicable to test loops and special SNAP-8 equipment. This program is in parallel with the effort to provide a SNAP-8 book standard for helium-leak test methods.

d. Facilities located in Building 185 and Building 56 were surveyed and certified as to their capability and conformance to cleaning requirements per AGC-10319. The certification covered seven different processes and eleven methods of cleaning.

e. The SNAP-8 clean room was surveyed and certified for its capability to meet the requirements of AGC-10336. The specification itself was revised at the request of QA as a result of the survey.

8. Data Reporting and Corrective Action

QA continued to assemble "Build-up and Assembly Logs" for each major PCS component fabricated; all major PCS-1 components included in Phase IV Step 3 were documented in this manner.

The effectiveness of cause, responsibility, and intended corrective action determinations associated with nonconformances reported by Inspection, was continually monitored by QA. As shown in Figure VI-12, the effectiveness of these efforts has significantly improved during the reporting period.

QA also issued monthly reports of overall SNAP-8 product quality and detailed summaries of all nonconformances.

9. Quality Audits Performed

No regularly scheduled quality audits were performed during the reporting period. However, a special audit of PCS-1 Step 3 TSE fabrication was completed during May. The Audit Report (AR 303) showed that improvements have been achieved in most areas of performance, and that the controls have been effectively implemented. Findings of minor deficiencies were brought to the attention of the responsible individuals.

E. SPECIFICATIONS AND STANDARDS

1. Documentation control

Implementation of the Documentation Control Plan has been progressing satisfactorily for the PCS-1 Phase IV Project. An index of SNAP-8 Division Specifications and Standards was issued to show the latest status of each document and indicate the standard numbering system for the SNAP-8 controlled documents. The test plans and operating procedures for PCS-1 (SPS-001, Sections III and IV) and LNL-3 (SPS-004, Sections I and II) have been issued as controlled documents.

2. Released specifications and standards

Since December 1965, 15 process and assembly procedures, 3 acceptance test procedures, 6 component specifications, 2 material specifications, 2 part standards, 2 instrumentation lists, 9 calibration procedures, and 2 test plans were released.

3. Documentation in process

Work is continuing on the generation of the PCS-G System Specification, AGC-10512. Completion is expected before the end of August. Work also is continuing on the following PCS-1 documents:

<u>Number</u>	<u>Title</u>
AGC-STD-1259	Pump-Motor Assembly, 093340-5, Assembly and Inspection Procedure for
AGC-STD-1283	Leak Testing, Helium
AGC-STD-1283/M1	Leak Testing, Helium, Loop
AGC-STD-1283/M2	Leak Testing, TAA, 096800
AGC-STD-1287	Transducers Electrical, Quality Conformance Inspection for
AGC-STD-1287/M10	Transducer, Voltage Sine Wave Form, QCI
AGC-STD-1288	Transducers, Pressure, Strain Gage, QCI
AGC-STD-1288/M10	Transducer, Differential Pressure, AS8016
AGC-STD-1310	Recorder, Tape, Concertone 804, Operation of
AGC-STD-1403	Pump-Motor, NaK, 093200, Assembly and Inspection Procedure for
AGC-STD-1408	Alternator, 80 KVA, 094069, Reassembly and Inspection Procedure for
AGC-10331A	Welding of Electrical Connections, Inert-Arc

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<u>Number</u>	<u>Title</u>
AGC-10414	Valve, Motor Driven, Flow-Control, Mercury
AGC-10468A	TAA, 096800
AGC-10546	Valve, Motor Driven, Flow-Control, Mercury, Liquid-Cooled
AS8029	Transducer, Differential Pressure, Strain Gage, High Overpressure Performance Sensitivity 3.0 mv/v MIN
AS8031	Thermocouple, Immersion

4. PCS-1 Phase IV Engineering Parts List progress on the IBM key punched engineering parts list has been steadily increasing. The uncorrected key-punched cards are available for the electrical subsystem and this list will be distributed with the next release of the PCS-1 parts list. Until the IBM parts list is completed, a first tier parts list of the PCS-1 System shall continue to be distributed periodically, as required.

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TABLE VI-1

CHANGES IN SYSTEM CONDITIONS RESULTING FROM CHANGES IN OPERATING CONDITIONS
(Typical PCS-1 Phase IV System Operation)

	<u>Base Conditions</u>	<u>Vehicle Load Change</u>	<u>Sun-Shade Variation</u>	<u>NaK Temp. Variation</u>
Boiler Inlet NaK Temp., °F	1280	1280	1280	1330
Primary Loop Input Power, kwt	522	486	522	512
Hg Flow Rate, lb/hr	12400	12400	12350	12040
Turbine Inlet Press., psia	243	243	242	239
Condensing Press., psia	17.0	17.0	14.8	15.6
HRL Cooler Inlet Temp., °F	679	679	665	670
HRL Cooler Outlet Temp., °F	505	505	492	500
HRL Cooler Heat Rej., kwt	451	451	448	441
Alternator Gross Output, kwe	54.7	55.8	56.3	54.8
Net Elec. Output, kwe*	35	0	35	35

* Assumed vehicle power demand.

TABLE VI-2

SNAP-8 FAILURE STATUS REPORT

Report Period: 3-1-66 to 7-1-66
Date of Last Report: 3-1-66

		F.R. Held Over		PCS	TSE	Total
		Added		7	3	10
		Completed		13	25	38
		Pending		5	15	20
				15	13	28

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
1-6-65	1211	Mounting Clamp P/N MAC 605220 L/C PMA, P/N 253801, S/N 48595 (TRW)	During L/C PMA environmental test, resonance frequency scan, the motor end mounting clamp broke.	Minor (PCS)	Yes	Rerun of vibration test required to verify corrective action and close case.
1-7-66	0427	Prim. NaK Expansion Tank Level Probe P/N 098403	On first wet checkout probe indicated as shorted. Found probe broken.	Incident (TSE)	Yes	Failure analysis corrective action report required to close case.
1-20-66	0445	Press. Xducer (P28) CEC P/N 170119-0104 S/N 1126	L/C Pump Press. Xducer showed large zero shift during instr. checkout	Incident (TSE)	Yes	Instr. Final Report No. 4937-66-0077 dated 27 April 1966. Close-out Report No. 4922R-66-0052.
1-28-66	0433	NaK PMA (PNL) P/N 093200-13C S/N A-6	On 2nd startup attempt pump would not rotate. Over 50 restart attempts were unsuccessful.	Major (PCS)	Yes	See Memo No. 4931-66-0073 dated 3-15-66 for failure analysis and corrective action report. Close-out Report No. 4922R-66-0048 dated 28 June 1966. Case closed.

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TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
2-1-66	0153	TAA Turbine Interstage Instr. P/N 096800-1 S/N A-2	Excessive vacuum decay rate on Hg Loop. The leak check showed leaks in 6 instr. pressure taps at turbine casing.	Minor (PCS)	No	Interim corrective action on existing units. Future units will have weld type fitting design and fitting material change. Final report required.
2-1-66	0434	Hg Loop Vacuum Pump Duoseal Model No. 1397 S/N 10379	Pump motor failed to operate when energized. Pump appeared frozen.	Incident (TSE)	Yes	Investigation and corrective action complete. See Memo No. 4932-66-0042 dated 4-12-66. Case closed.
2-6-66	0177	TAA Alternator G.E. P/N 2CM-291B1 S/N 481489 TAA S/N A-2	Lube Coolant leak from alternator coolant passage. Cracked weld at trunion boss to alternator shroud. Ref. AGC Dwg 096800 Zone 5B and GE Dwg 194F728 Zone J12.	Major (PCS)	Yes	Unit repaired in place by rewelding. Problem became major upon second failure on 2-14-66. Ref. FR 0182. Final report on analysis and corrective action required to close case.
2-9-66	0178	TAA Face Seal Bellows. Belfab Corp. P/N 104840 AGC P/N 092848 TAA S/N A-2	Excessive vacuum decay rate in space seal system when TAA face seal system pressurized indicated possible bellows leak.	Minor (PCS)	No	Bench leak test of bellows showed bellows OK. FR cancelled. Case closed.
2-14-66	0181	L/C Valve (LCV-15) Valcor P/N 54600-06 S/N-7	Valve failed to close on demand when TAA was shut down.	Minor (PCS)	Yes	Failed part returned to vendor for analysis and repair. Report required to close case.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
2-14-66	0182	TAA Alternator G.E. P/N 2CM-391B1 S/N 481489 AGC P/N 094069 TAA S/N A-2	TAA shutdown required when L/C System vacuum decayed and L/C leak noted from TAA. Cracked weld found in alternator shroud seal weld.	Major (PCS)	Yes	Failure investigation, analysis, and corrective action complete. Materials Report No. 4923:66:6032. See FR 0379. Final report required to close case.
3-2-66	0183	L/C Vacuum Pump Duoseal Mod. No. 1397 S/N 10838	Failed to obtain required vacuum on L/C Loop. Dead headed pump checks showed unsatisfactory operation.	Incident (TSE)	No	Investigation and repair completed. See Memo No. 4953:66:0104. Case complete.
3-4-66	0186	LN ₂ Controller TAA Vacuum Syst. P/N 106-000 Sulfrian Cryogen.	LN ₂ Controller for TAA Space Seal vacuum system failed to reset automatically.	Incident (TSE)	Yes	Failure investigated, analyzed, and corrective action implemented. Final report required to close case. See FR 0189 and FR 0195.
3-7-66	0184	TAA Alternator G.E. P/N 2CM-391B1 S/N 481491 TAA S/N A-1	L/C leak noted from alternator shroud seal weld during L/C system pretest checkout.	Major (PCS)	Yes	Unit repaired in place. See FRs 0177, 0182, and 0191. Final report required to close case.
3-7-66	0195	Pri. NaK PMA 093200-13 S/N A-2	Pump motor current became erratic during testing and caused a high current alarm. Normal restart attempt unsuccessful.	Major (PCS)	Yes	Failure analysis and corrective action determination in progress. See interim report No. 4932:66-0043.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
3-9-66	0189	LN ₂ Controller P/N 106-000 Sulfrian Cryogen.	Cryopump overfilled when LN ₂ Controller failed to reset automatically.	Incident (TSE)	Yes	Unit removed, replaced, and returned to AGC instr. shop for repair. See FR 0186 and FR 0195. Final report required to close case.
3-11-66	0190	Press. Xducer (P-33) CEC P/N 170119-0104. S/N 1046	L/C PMA discharge press. Xducer indicated open bridge on post test checks.	Incident (TSE)	No	Instr. Eng. Report No. 4937:66-0079 dtd 27 April 1966. Close-out report No. 4922R-66-0052.
3-14-66	0191	TAA Alternator G.E. P/N 2CM391B1 S/N 481491 TAA S/N A-1	L/C leak noted from alternator shroud seal weld approx. 1/4" repair made on 3-7-66.	Major (PCS)	Yes	Unit repaired in place. FRs 0184, 0182, and 0177. Final report required to close case
3-14-66	0192	Hg PMA P/N 093347-5 S/N A-1	On attempted startup PMA power supply circuit breaker blew. Investigation showed motor windings open.	Major (PCS)	Yes	Investigation, analysis, and repair completed. Final report 4922R-66-0053 issued. Case complete.
3-16-66	0193	P-270 Visual ΔP gage. ΔP-0-25 PSI S/N 20019272 Barton	Gage started leaking from body during test shutting down test.	Incident (TSE)	No	Investigation, corrective action completed. Final report No. 4922R-66-0054 issued. Case complete.
3-16-66	0194	ΔP-276 Data Sensor P/N PB415B-17 S/N 273	Hg noted to be leaking from Xducer body just prior to test start. Unit valved out of syst. and testing continued.	Incident (TSE)	No	Investigation showed transducer had not failed. Failure Report cancelled by final report No. 4922R-66-0055. Case closed.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
3-17-66	0196	Hg Vapor Line Heaters (4) Arcover Cal-Rod Heaters	Lost Hg Loop vacuum just prior to Hg injection. Found Hg vapor line heaters (4) had failed, burning a hole thru piping.	Incid (TSE)	No	Investigation and corrective action complete. See Memo No. 4953:66:0120 dtd 4-26-66. Case completed.
3-18-66	0197	EM Pump MSA P/N 501014 S/N 564	Primary NaK Loop flow rate too low to meet system requirements. Pressure drop across pump found to be excessive.	Incid (TSE)	Yes	Unit removed and replaced. AGC investigation complete. MSA report dtd 15 June 1965 received. Tube section being returned to AGC for materials analysis.
3-21-66	0198	Pri. NaK PMA P/N 093200-13 S/N A-7	PMA recirculation line cracked approx. 1/4" from motor outlet by accident during PCS-1 down period.	Minor (PCS)	No	Line repaired per VEO 0531. See Memo 4953:66:0115 dated 20 April 1966. Case closed.
3-21-66	0199	Hg T.C. Well T-213 P/N 094111-13	Thermocouple well for T-213 in Hg vapor line leaking.	Incid (TSE)	Yes	Well capped off to complete testing. Post test materials analysis completed. Final report required to close case. See FR 0383 dtd 5-17-66.
3-25-66	0195	LN ₂ Controller TAA Space Seal Vac. Syst. Mod. No. 106-000 Sulfrian	Erratic operation, frequently overfilling cryopump.	Incid (TSE)	Yes	Failure investigation and analysis complete. Final report required to close case.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
3-26-66	0155	DDAS Buss Driver P/N 64182 S/N 1157L. Beckman	Erroneous readouts from DDAS. Arithmetic unit found to be malfunctioning due to buss driver component failure.	Incident (TSE)	No	Failed unit replaced and repaired. Case closed. Ref FR 0364 dtd 4-10-66.
3-26-66	0160	Thermo. Elect. Temp. Controller S/N M5970-12 10 Channel	Hg Vapor line heater controller called for heat intermittently on all channels though control signals were not demanding heat.	Incident (TSE)	Yes	Unit removed and replaced. Instr. Eng. investigation and analysis complete. Final report required to close case.
3-29-66	0154	NaK Purification Syst. Piping	NaK leak noted during purification operation, in piping just downstream of flowmeter.	Incident (TSE)	No	Leaked section of pipe removed and new spool piece installed using swagelok fittings. Case closed.
3-31-66	0157	TAA P/N 096800-1 S/N A-1	Attempt to operate system failed when TAA indicated no rotation on startup.	Major (PCS)	Yes	Disassembly inspection showed alternator frozen (see FR -358), and turbine thrust balance labyrinth seal severely rubbed. Final analysis report required to close case.
4-4-66	0358	Alternator P/N 094069-1 S/N 481491 (GE) TAA S/N A-1	Alternator seizure discovered during TAA failure investigation (ref FR 0157).	Major (PCS)	Yes	Failure investigation, analysis, and corrective action recommendations complete. See TM 4932: 66-413 dtd 23 May 1966. Final report required to close case.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
4-4-66	0158	Vacuum Pump P/N 1397 S/N 11683 Duo Seal	Pump seized up after servicing. During I/C loop operation the alternator cavity vacuum pump was flooded with 4P3E.	Incid	No	Failure investigation and corrective action complete. See Memo No. 4953:66:0104 dtd 11 April 1966. Final report required to close case.
4-10-66	0359	HR NEMA P/N 093200-13 S/N A-4	Failure of HRL NaK PMA caused automatic shut-down. Motor found shorted to case and phase to phase.	Major (PCS)	Yes	Failure analysis complete. Corrective action determination in progress. See materials investigation report No. 4923:66-6091 dtd 6-22-66.
4-10-66	0364	DDAS Buss Driver, P/N 64182 S/N 1237L Beckman Instr.	DDAS started providing erratic readouts during testing. Found circuit No. 4 slow switching true to false.	Incid (TSE)	Yes	Vendors failure investigation and analysis report received. See Report No. 4937-66-0109. Final report required to close case.
4-10-66	0361	DDAS Alpha Beta Driver 501456 Beckman S/N 440G	Investigating failure of DDAS (FR 0364). Circuits Nos. 2 and 4 failed. Board placed in wrong slot by error.	Incid (TSE)	No	Removed and replaced failed board. Personnel error. Case considered closed. See FR Nos. 0362 and 0363.
4-10-66	0362	DDAS Digital Amp. Beckman P/N 63889 S/N 2186F	Circuit No. 2 found to have weak output. Probably caused by Alpha Beta Driver board in wrong slot.	Incid (TSE)	No	Removed and replaced failed board. See FR 0361. Case considered closed.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
4-10-66	0363	DDAS Relay HGSM. Beckman P/N 514340 S/N 101	Relay No. 4 not working. Probably caused by placing Alpha Beta Driver board in wrong slot.	Incid (TSE)	No	Removed and replaced relay board. See FR 0361. Case considered closed.
4-11-66	0172	Vacuum Gage P17. (TAA) CVC No. GMA-001 S/N 39625-2	During Hg Loop vacuum leak check found P17 vacuum gage leaking at gage body, electrical connector end seam weld.	Incid (TSE)	Yes	Investigation, analysis, and corrective action complete. See Memo 4937:66-0107 dtd 21 June 1966. Case closed. See FR 0173
4-11-66	0173	Vacuum Gage P16 (TAA) CVC No. GMA- 001 S/N 396- 25-1	During Hg Loop vacuum leak check found D-16 vacuum gage leaking at gage body electrical connector end seam weld.	Incid (TSE)	Yes	Investigation, analysis, and corrective action complete. See Memo No. 4937:66-0107. Ref FR 0172. Case closed.
4-11-66	0368	Solenoid Valve LN ₂ (L/C Vac.) G.I.A. P/N V5L- 16280M S/N 51	LN ₂ valve to L/C Loop cryopump failed to close when energized.	Incid (TSE)	No	Removed and replaced failed valve. Case considered closed.
4-12-66	0369	Pri. NaK PMA 093200-13D S/N A-7	Changes in flow rate or suction head pressure caused pump motor amps to increase and speed decrease. Switching from 400 ~ to 60 ~ pump stopped. No rotation on restart attempt.	Major (PCS)	Yes	Failure investigation and analysis complete. Correction action im- plemented to be tested. See Memo No. 4932-66-0056 dtd 9 May 1966. Final report required to close case.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
4-19-66	0380	TRA Contactor P/N BHL38AKH S/N AL65325 Hartman Elect.	During electrical check-out open circuit traced to motor transfer contactor in TRA.	Minor (PCS)	No	Commercial part used in PCS equipment for ground testing only. Failed part removed and replaced. Case closed.
2-15-66 (4-21-66)	0379	TAA P/N 096800-1 S/N A-2	Unit removed from loop on 2-15-66 to investigate indicated turbine performance degradation noted after approx. 90 hrs of operation.	Major (PCS)	Yes	Investigation determined 1st and 2nd stage nozzles cocked and thrust balance labyrinth rubbed on 1st stage wheel hub. FR issued 4-21-66. Failure analysis in progress.
4-22-66	0385	DDAS Buffer Amplif. (2) P/N 61201 S/N 208S and 218L.	DDAS visual display showed erratic values. See FR 0386 also.	Incident (TSE)	No	Vendor repaired short and loose transistor. Checked OK. Case closed.
4-22-66	0386	DDAS-H.S. Buffer Amplif. (2) P/N 6120Z S/N 203J and 209M.	DDAS visual display erratic values. See FR 0385	Incident (TSE)	No	Vendor repaired shorts. Checked OK. Case closed.
5-16-66	0384	TAA 2nd Stage Diaphragm P/N 095241-1 S/N A-1 TAA Unit 6/1	Post test engineering inspection revealed 2 hair line cracks at root of vane. Diaphragm had also taken a permanent bowing type set.	Major (PCS)	Yes	Investigation and analysis complete. See Interim Report No. 4932-66-0075 dtd 21 June 1966. Implementation of corrective action in progress.

TABLE VI-2 (cont.)

Date of Failure	Failure Report No.	Failed Part Name and Number	Description of Failure	Failure Classif.	Failure Analysis Required	Status/Remarks
5-17-66	0383	Thermowell T-212 P/N 094111	Hg vapor line thermowell for T-212 T/C found to have pinhole leak during post test checks. Ref FR 0199 on T-213 T/C.	Minor (TSE)	Yes	Failure analysis complete. Corrective action implemented. See TM No. 4923:66-425. Final report required to close case.
6-23-66	0406	Space Seal Valve No. 11 ASCO - 4 way solenoid	SSV-11 failed to open on demand. Found defective solenoid coil.	Incident (TSE)	No	Random failure. Replaced with new part. FR to be closed out.
6-25-66	0405	HGV-1 Hg Valve Aveco Valve S/N 1252 MXU	Pneumatic driven Hg V-1 valve failed to operate during pre-test leak checks. Found valve plug lifting washer sheared and bent pintle.	Incident (TSE)	No	Wearout type failure - valve removed and replaced. Close out report required.
6-27-66	0388	Hg Inj. Syst. 094583 S/N 3	During bench test, safety valve Part No. 097921-11 did not move freely. Valve identified for AGC use only.	Minor (PCS)	Yes	Design analysis and correction action report. to close case.

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TABLE VI-3

SNAP-8 MAJOR PCS COMPONENT MONTHLY OPERATING TIMES THROUGH 6-30-66

Component Name	Unit No.	Ser. No.	Part No.	Facility and Loop	Total Hrs 1964-65	Total Hrs.	Jan	Feb	Mar	Apr	May	Jun	Total Hrs	Remarks
1. Aux. Start Heat Exchanger	1	A-1	093607-1	RPL-2 (HRL)	--	Mthly	-	-	-	-	-	-	--	Removed and sectioned for eng. evaluation 2-11-65
					1243	Cum	-	-	-	-	-	-	1243	
	2	A-3	093607-1	LNL-3	--	Mthly	-	-	-	-	-	20	--	LNL-3 testing
						Cum	-	-	-	-	-	20		
	3	A-1	093607-11	PCS-1 Ph IV Steps 2 and 3	--	Mthly	-	-	-	-	-	0	--	New installation for Step 3 PCS-1 Ph IV
						Cum	-	-	-	-	-	0		
	Total all aux. start heat exchangers				1243								1263	Total hrs all aux. start heat exchangers
2. Boiler (Tube in Shell)	1	A-1	092020-1F	RPL-2 (HGL)	--	Mthly	-	-	-	-	-	-	--	Removed and sectioned for eng. evaluation 7-65
					1429	Cum	-	-	-	-	-	-	1429	
	2	A-1	092952-3	SL-1 (HGL)	--	Mthly	-	-	-	-	-	-	--	Removed and held in storage 8-65
					226	Cum	-	-	-	-	-	-	226	
Tube in Shell Total					1655								1655	
Tube in Tube	1	A-1	097444-5	SL-1 (HGL)	--	Mthly	-	-	-	-	-	-	--	SL-1 loop mothballed 11-65
					530	Cum	-	-	-	-	-	-	530	
	2	A-1	097444-7	PCS-IV (HGL)	--	Mthly	-	143	42	117	-	-	--	Used in Steps 2 and 3 Phase IV
					120	Cum	120	263	305	422	422	422	422	
Tube in Tube Total					650								952	
Total all boilers					2305								2607	Total hrs. all boilers
3. Condenser	1	A-1	093043-3	SL-1 (HGL)	--	Mthly	-	-	-	-	-	-	--	SL-1 loop mothballed 11-65
					756	Cum	-	-	-	-	-	-	756	
	2	A-2	092500-1	RPL-2 (HGL)	--	Mthly	-	143	42	117	-	-	--	RPL-2/PCS-1 Phase IV Step 2
					1549	Cum	1549	1692	1734	1851	1851	1851	1851	
Total all condensers					2305								2607	Total hrs all condensers
4. Lube Coolant PMA	1	481501	TRW253800	LNL-3 (LC Loop)	--	Mthly	-	-	-	-	-	-	--	Removed from LNL-3, 12-65 test complete
					*4552	Cum	-	-	-	-	-	-	*4552	*Includes 1018 hr test at TRW (max. single unit time)
	2	481502	TRW253801	LNL-3 (LC Loop)	--	Mthly	-	-	-	-	-	-	--	Unit held in LNL-3
					273	Cum	-	-	-	-	-	-	273	
	3	481503	TRW253801	SL-1 (LC Loop)	--	Mthly	-	-	-	-	-	-	--	Loop mothballed 11-65
					1023	Cum	-	-	-	-	-	-	1023	
	4	481504	TRW253801	RPL-2 (LC Loop)	--	Mthly	123	163	249	153	-	-	--	RPL-2 loop redesignated PCS-1 Ph IV Step 2
					1154	Cum	1277	1440	1689	1842	-	-	1842	Removed for eng evaluation at completion of Step 2 testing
	1/2	481501	TRW253801-1	LNL-3 (LC Loop)	--	Mthly	-	-	-	-	-	36	--	LNL-3 testing
						Cum	-	-	-	-	-	36		
	7/1	481507	TRW253801-3	PCS-1 Ph IV (LC Loop)	--	Mthly	-	-	-	-	-	0	--	Step 3 testing Phase IV
						Cum	-	-	-	-	-	0		
Total all L/C PMAs					7002								7726	Total hrs all L/C PMAs

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TABLE VI-3 (cont.)

Component Name	Unit No.	Ser. No.	Part No.	Facility and Loop	Total Hrs 1964-65	Total Hrs.	Jan	Feb	Mar	Apr	May	Jun	Total Hrs	Remarks
5. Mercury FMA	1	A-1	093347-1	LML-3 (Hg Loop)	--	Mthly Cum	--	--	--	--	--	--	120	Removed - disassembled - evaluated
	2	A-2	093347-5	RPL-2 (Hg Loop)	--	Mthly Cum	1	143	43	118	--	--	1099	Removed from PCS-1 Ph IV Step 2 for eng evaluation. (Motor failure 3-14-66 (FR 0192) used motor from LML-3 for replacement)
	3	A-1	093340-1	SL-1 (Hg Loop)	--	Mthly Cum	--	--	--	--	--	--	756	Unit removed and disassembled for possible rework
	6/1	A-1	098100-1	PCS-1 Ph IV (Hg Loop)	--	Mthly Cum	--	--	--	--	--	0	--	New installation for PCS-1 Ph IV Step 3
	Total all Hg FMAs				1670								1975	Total hrs all Hg FMAs
6. NaK FMA	1	A-1	093200-1	LNL-3 (NaK)	--	Mthly Cum	--	--	--	--	--	--	52	Modified to -13 Ser No. A-5
	2/1	A-1	093200-13	LNL-3 (NaK)	--	Mthly Cum	--	--	--	--	--	--	31	Modified to Ser. No. 1/2
	1/2	A-5	093200-13	LNL-3 (NaK)	--	Mthly Cum	--	--	--	--	--	--	3028	Removed from loop. 3000 hr. test complete 12/65.
	2/2	A-1/2	093200-13	LNL-3 (NaK)	--	Mthly Cum	--	--	--	--	--	--	247	Plated housing. Disassembled/unusable.
	3/2	A-2	093200-13	LNL-3 (NaK)	--	Mthly Cum	--	0.2	49	--	--	--	243	Removed from LNL-3 and modified for use in PCS-1.
	5/3	A-6	093200-13-C	PCS-1 (NaK)	--	Mthly Cum	1	--	139	131	--	--	270	PCS-1 Ph IV Step 2. Rubbing condition occurred (FR 0369). Removed from loop.
	2/3	A-1	093200-13	LNL-3 (NaK)	--	Mthly Cum	--	--	--	--	--	20	20	LNL-3 testing
	4/1	A-4	093200-13	PCS-1 (NaK)	--	Mthly Cum	--	81	66	117	--	--	--	Motor shorted out (FR 0359). Removed for repair.
	Total all NaK FMAs				3552								4155	Total hrs all NaK FMAs.
7. Turbine Alternator Assembly	1/2	A-1	093000-5	GN2S-1 (No Loop)	--	Mthly Cum	--	--	--	--	--	--	36	Unit failed. Disassembled/turbine unusable.
	3/2	A-3	093000-5	RPL-2 (Hg Loop)	--	Mthly Cum	--	--	--	--	--	--	820	Unit failed. Disassembled/turbine unusable.
	2/4	A-2	096800-1	PCS-1 (Hg Loop)	--	Mthly Cum	--	--	--	--	--	0	0	PCS-1 Phase IV Step 3
	2/3	A-2	096800-1	PCS-1 (Hg Loop)	--	Mthly Cum	0.4	143	--	--	--	--	143	Phase IV Step 2. Removed from loop on 2-15-66. Performance degradation (FR 0379)
	6/1	A-3	096800-1	PCS-1 (Hg Loop)	--	Mthly Cum	--	--	--	115	--	--	115	Installed 3-31-66 PCS-1 Phase IV Step 2. Removed for inspection 4-13-66.
	5/3	A-1	096800-1	PCS-1 (Hg Loop)	--	Mthly Cum	--	--	41	--	--	--	41	Unit removed from loop 3-31-66 (FR 0157)
	Total all TAAs				856								1155	Total hrs. all TAAs

TABLE VI-4

GUIDELINES FOR QUALITY ASSURANCE REVIEW OF DRAWINGS FOR
SNAP-8 PCS ELECTRICAL COMPONENTS, ELECTRICAL TEST SUPPORT EQUIPMENT AND INSTRUMENTATION

DRAWING CHARACTERISTICS	DRAWINGS FOR PCS ELECTRICAL COMPONENTS	DRAWINGS FOR ELECTRICAL TSE	DRAWINGS FOR INSTRUMENTATION
Title block, drawing level, signatures	All major PCS electrical components will utilize -1 level drawings, released specifications, sign-off by QA.	Depending on item's importance for the success of test, commercial level drawings may be acceptable. "0" level drawings will be signed by QA when requested by the responsible engineer.	
List of materials	Functionally significant materials (e.g., wires) and operative electrical components (e.g., resistors, diodes) will be identified with an applicable Government or AGC specification.	For non-critical use, commercial designation of materials is acceptable.	
Material and component traceability (Note 1)	Drawings to include delta note showing traceability requirement for functionally significant materials and components. Sensors used in data-gathering applications are to be traceable. (Note 2)		
Identification of completed article	Identification by P/N, S/N, and C/L is required for each PCS electrical sub-system and when electrical or non-destructive testing is involved.	Identification and serialization is required when inspection testing of the article is required. Design option on others.	
Special process specification	Special manufacturing processes, such as cleaning, soldering, resistance welding, and special inspection processes, such as non-destructive testing inspection shall be identified with an applicable Government or AGC specification, including workmanship/acceptance standards.	Depending on item's importance for the success of test, commercial manufacturing processes may be acceptable.	
Operator certification	Drawing will reference the applicable specifications for the qualification of welders (fusion, resistance, etc.) and solderers.		
Fabrication/assy. instructions, in-process checks, workmanship standards	When special fabrication or assy. techniques and standards (e.g., coil winding, wire routing and dressing), or in-process checks (e.g., continuity or insulation resistance) are required, a process specification will be referenced or direct drawing notes will be provided for control.	Design Option	
Final acceptance specification	A final acceptance test specification will be referenced for major PCS components.	Design Option	
Preservation	Drawing to include appropriate note.	Preservation, packaging, handling, storing, etc. of sensitive items (e.g., transducers) will be specified.	

Note (1): Traceability is defined as the identification of materials and parts by a serialized inspection Acceptance Tag which will provide an uninterrupted chain of information traceable to records at Receiving Inspection.

Note (2): Sensors procured prior to the effective date of this document must be traceable, as a minimum, to records of a recent functional testing or calibration.

TABLE VI-5

CAUSES OF NONCONFORMANCES REPORTED BY INSPECTION

Month	Categories of Nonconformances*											Total
	A	B	C	D	E	F	G	H	I	J	K	
January	5	3	1	0	1	4	8	8	1	0	0	31
February	0	0	0	0	1	5	10	3	4	0	0	23
March	3	2	2	0	1	1	8	6	3	1	2	29
April	1	0	1	0	0	4	10	4	0	0	5	25
May	2	3	1	0	1	3	5	6	5	0	4	30
June	<u>2</u>	<u>2</u>	<u>3</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>6</u>	<u>5</u>	<u>5</u>	<u>4</u>	<u>4</u>	<u>40</u>
	13	10	8	2	7	21	47	32	18	5	15	178

* CODING FOR CATEGORIES OF NONCONFORMANCE

Code	Description
A	<u>Operator Errors, Workmanship Defects</u> Examples: Operator misunderstood instructions, made errors, didn't meet workmanship standards.
B	<u>Weld Defects - Workmanship</u> Defects found in weld areas when the principal cause of the deficiency is inadequate workmanship.
C	<u>Defects Caused by Tooling or Equipment</u> Defects caused by inadequate, insufficient or lacking tooling/equipment.
D	<u>Handling/Environmental Damage, Inadequate Process Controls</u> Examples: Physical damage, corrosion, failure in leak/proof testing.
E	<u>Planning Errors, Production/Change Control Errors</u> Examples: Inadequate/incorrect planning, out-of-date instructions spec's.; B/P's.
F	<u>Engineering Design and Specification Deficiencies</u> Examples: Design errors, poor selection of materials or processes, defects inherent to design or process prescribed.

TABLE VI-5 (cont.)

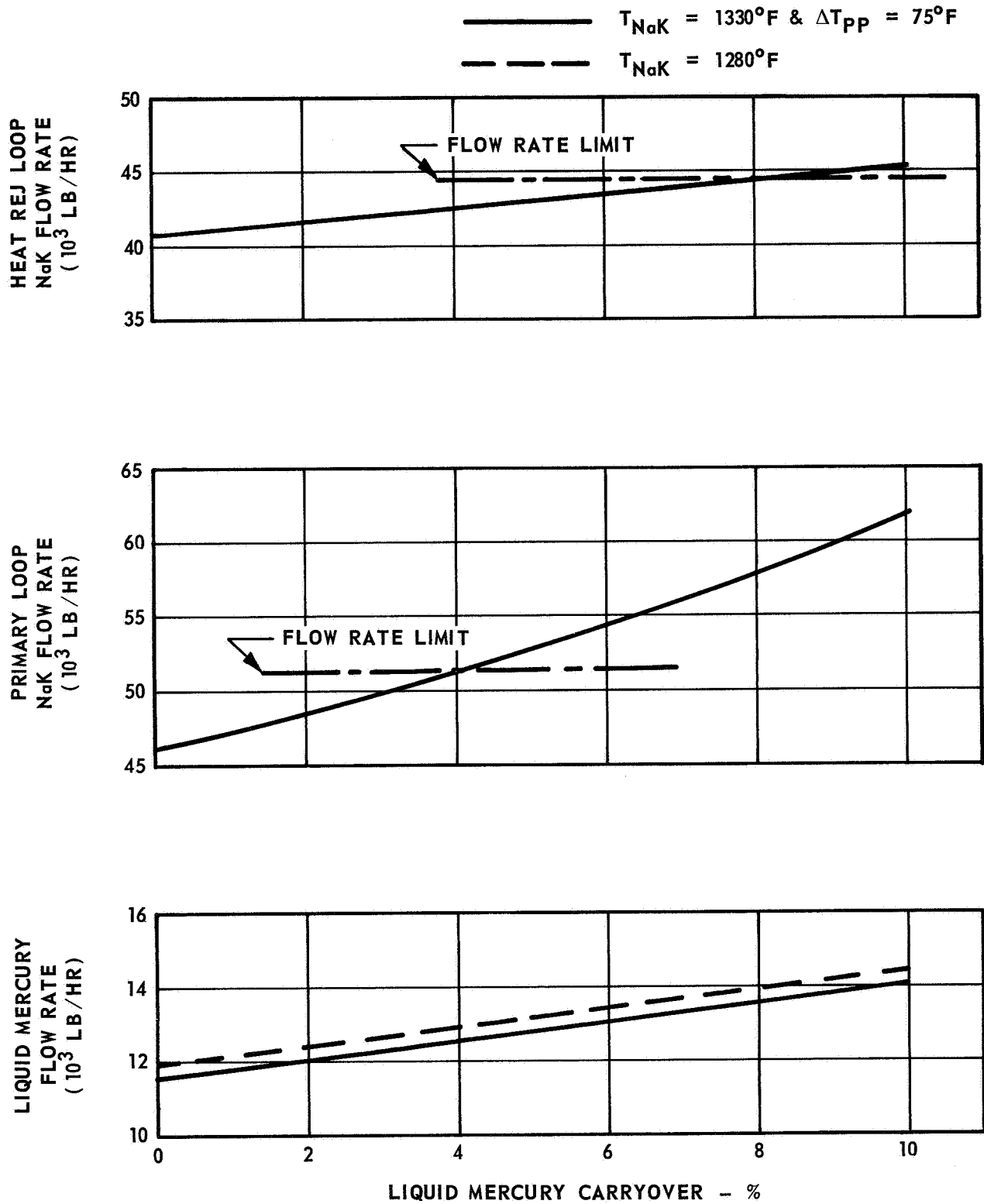
<u>Code</u>	<u>Description</u>
G	<u>Nonconformance of Supplier Furnished Material</u> The deficiency originated outside VKC, regardless of responsibility (AGC, Supplier, damage).
H	<u>Procedural, Paper Defects (non-hardware)</u> Examples: Certifications missing, inspection not called, no evidence of prior acceptance, unauthorized work performed.
I	<u>Miscellaneous Causes of Defects</u> The cause of defect was determined and it is other than Categories A through H.
J	<u>Cause of Defect not Determined</u> The cause of defect was not determined or the determination is still pending.
K	<u>Defects Caused by Operational Degradation</u> Defects noted at disassembly inspection after operational testing.

TABLE VI-6SUMMARY REVIEW OF SIGNIFICANT NONCONFORMANCES
AND CORRECTIVE ACTION TAKEN

<u>Inspection Report No. Part Name and No.</u>	<u>Interpretation of Insp. Results Reported</u>	<u>Review of Corrective Action Taken</u>
IR No. 152909 Vinson Temp. Cont. Valve P/N A65078	Gasket material disintegrated at elevated temperature and contaminated internal areas of valve.	Investigation revealed that gasket material was unsatisfactory for high temperatures. Changed gasket material to unimpregnated asbestos.
IR No. 155577 Aux. Start Loop Heat Exch. P/N 093607-11	Welds show burn through and excessive penetration over entire welded area.	Welding machine had faulty starting mechanism. Welding machine has been replaced.
IR No. 152914 Alternator P/N 094069-1	Threads are mis-located to true dimensional tolerances in two places.	Drill drifted while performing hand drill operation. Planning has been changed to incorporate the use of a drilling aid on future units.
IR No. 156070 Expansion Tank P/N 099009-1	Girth welds show intermittent areas of incomplete joint penetration and excessive scattered porosity.	This is an inherent problem due to spherical heads distorting under welding heat. Design will be reviewed prior to future fabrication.
IR No. 152455 LC Loop Installation P/N 098622-1	One weld was only tack welded in position. Helium leak test did not disclose discrepancy.	Corrective Action Report No. 4056 indicates that helium was not injected into this section of line. New leak detection procedure will prevent recurrence of this type of discrepancy.

TABLE VI-6 (cont.)

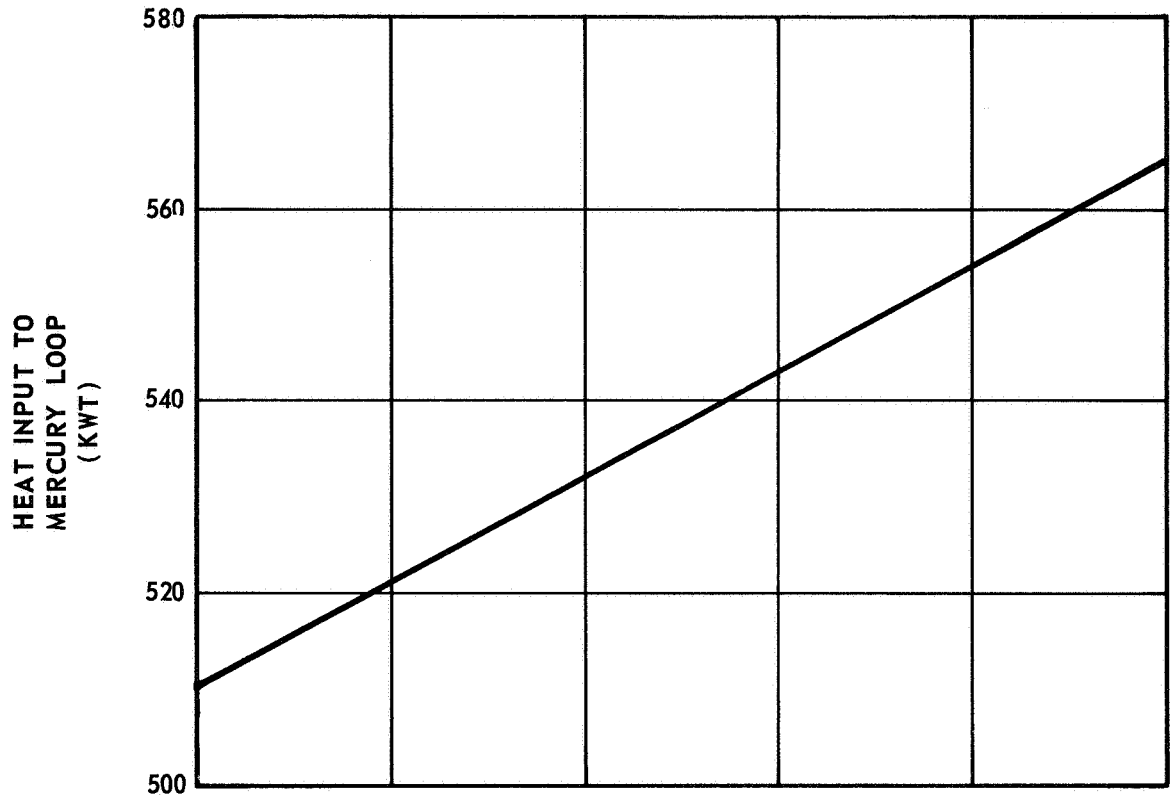
<u>Inspection Report No. Part Name and No.</u>	<u>Interpretation of Insp. Results Reported</u>	<u>Review of Corrective Action Taken</u>
IR No. 152970 Primary NaK Loop PCS-1 Phase IV	Leak test was performed with insufficient vacuum on loop per specification.	The large volume of the loop prohibits low vacuum pressure without excessive pump down time. AGC Spec. has been written to permit valid leak test with higher vacuum pressure.
IR No. 152974 Saturable Reactor -1 Model P/N 094680-3	Seal pinch-off tube broken during potting operation.	Corrective Action Report No. 4100 verifies that planning will be changed to install seal pinch-off tube after potting operation.
IR No. 152976 Valve Temp. Control Condenser P/N 097347-1	Temperature calibration readings were taken by mechanical measurement instead of by electrical measurement as required by specification.	Method used was more accurate than specification requirements. Spec. is being revised to include the mechanical measurement method.
IR No. 152866 Alternator P/N 094069-1	Cap screws holding out-board screw seals required excessive torque to remove and several heads broke off during removal operation.	Supplier Corrective Action Report No. 6122 revealed that the plating on the screws is being scraped off and binding in the threads. Screws were also bottoming in tapped holes. Supplier is investigating the use of a different type of screw for future units and inspection planning strengthened to emphasize hole-depth requirements.
IR No. 158405 Nozzle 4th-Stage TA P/N 098056-1	The roll pins are broken in 15 out of 22 places.	Roll pin material was not adequate for use. New type roll pins now in use.



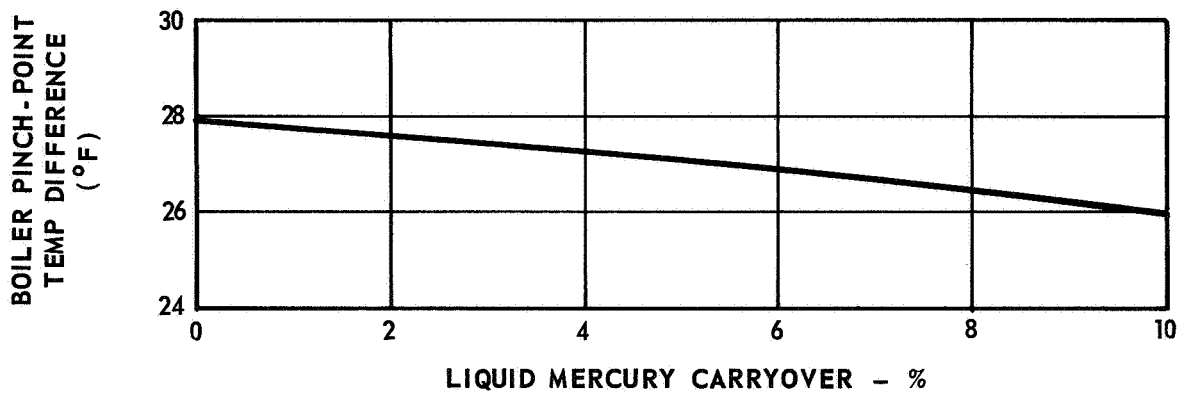
Effect of Liquid Mercury Carryover in System
Flow-Rate Requirements for 35 KWE Output (PCS-1 Phase IV System)

Figure VI-1

A466-NF-1124

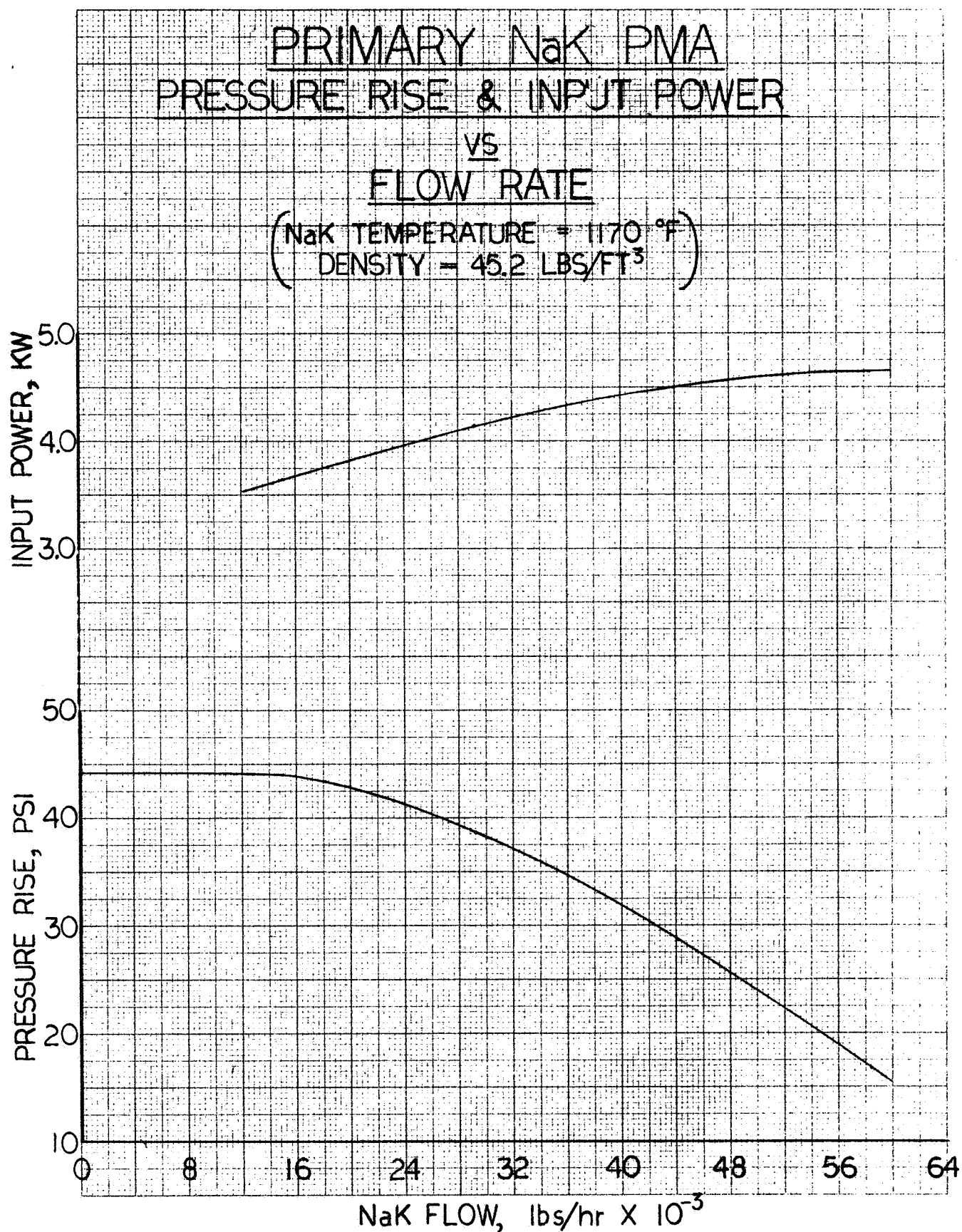


$T_{NaK} = 1280^{\circ}\text{F}$



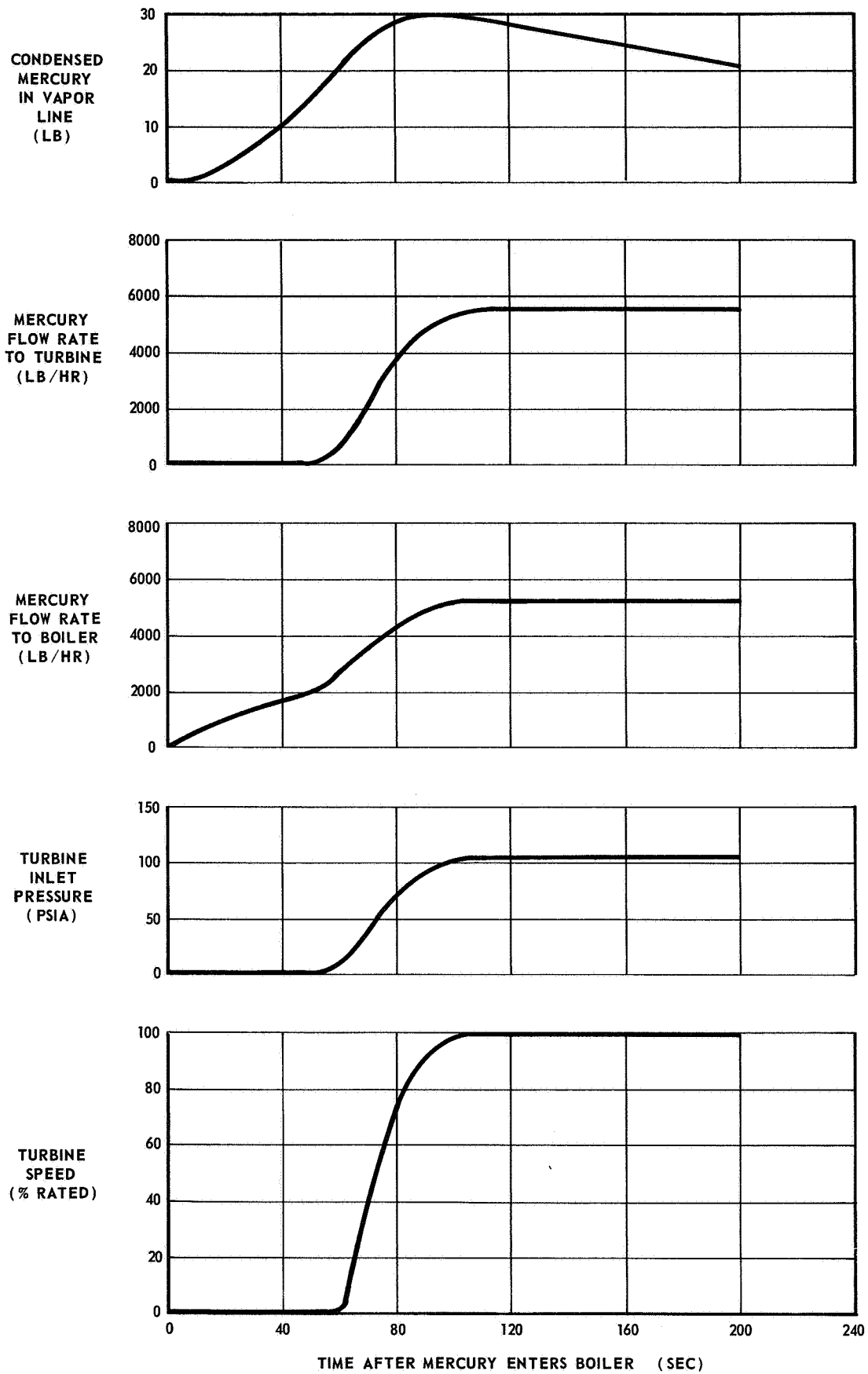
Effect of Liquid Mercury Carryover on
Heat Input to Mercury Loop and Boiler Pinch-
Point Temperature Difference (PCS-1 Phase IV System)

Figure VI-2



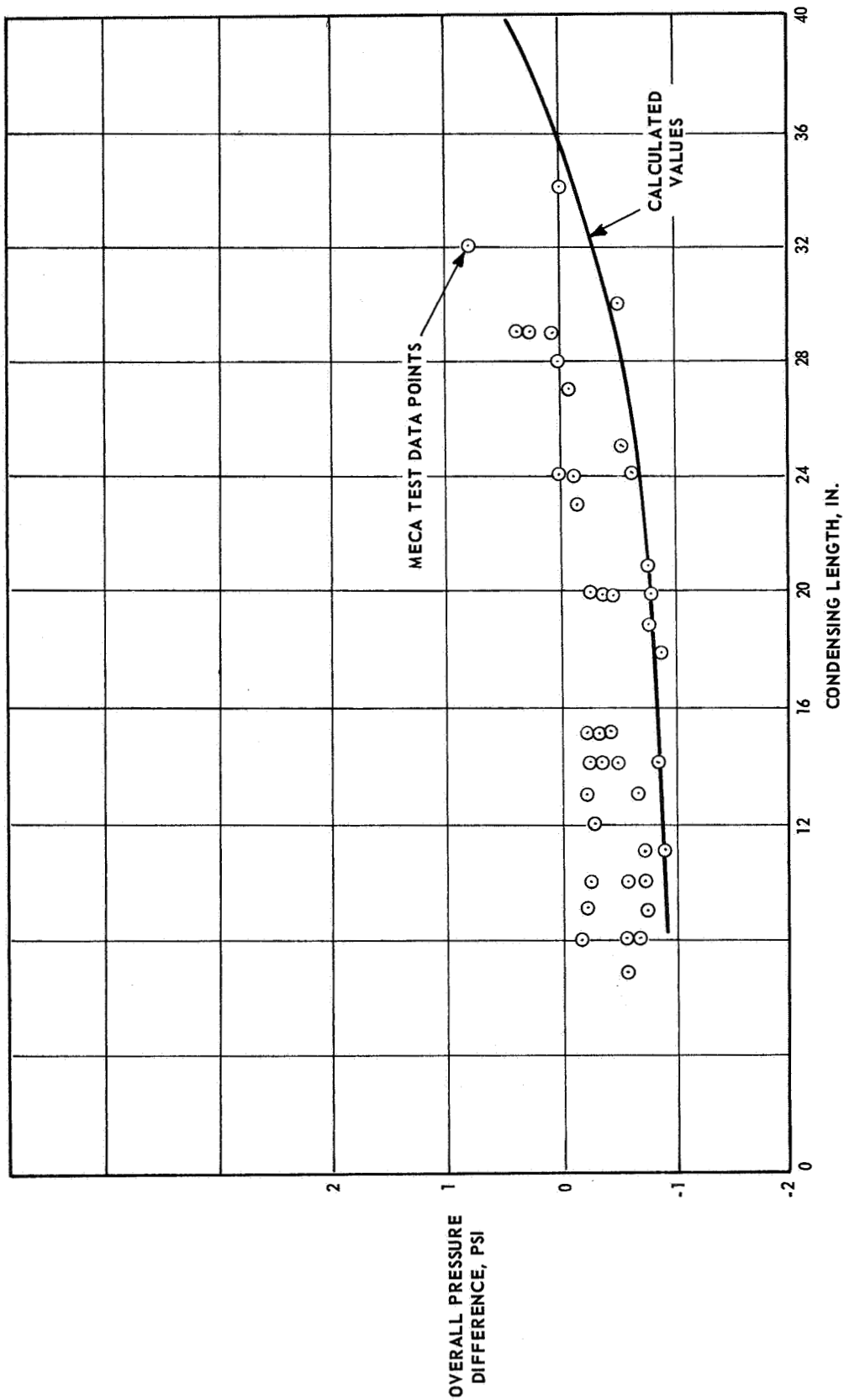
Effect of Initial Vapor-Line Temperature on Total
Amount of Mercury Condensed (PCS-1 Phase IV System)

Figure VI-3



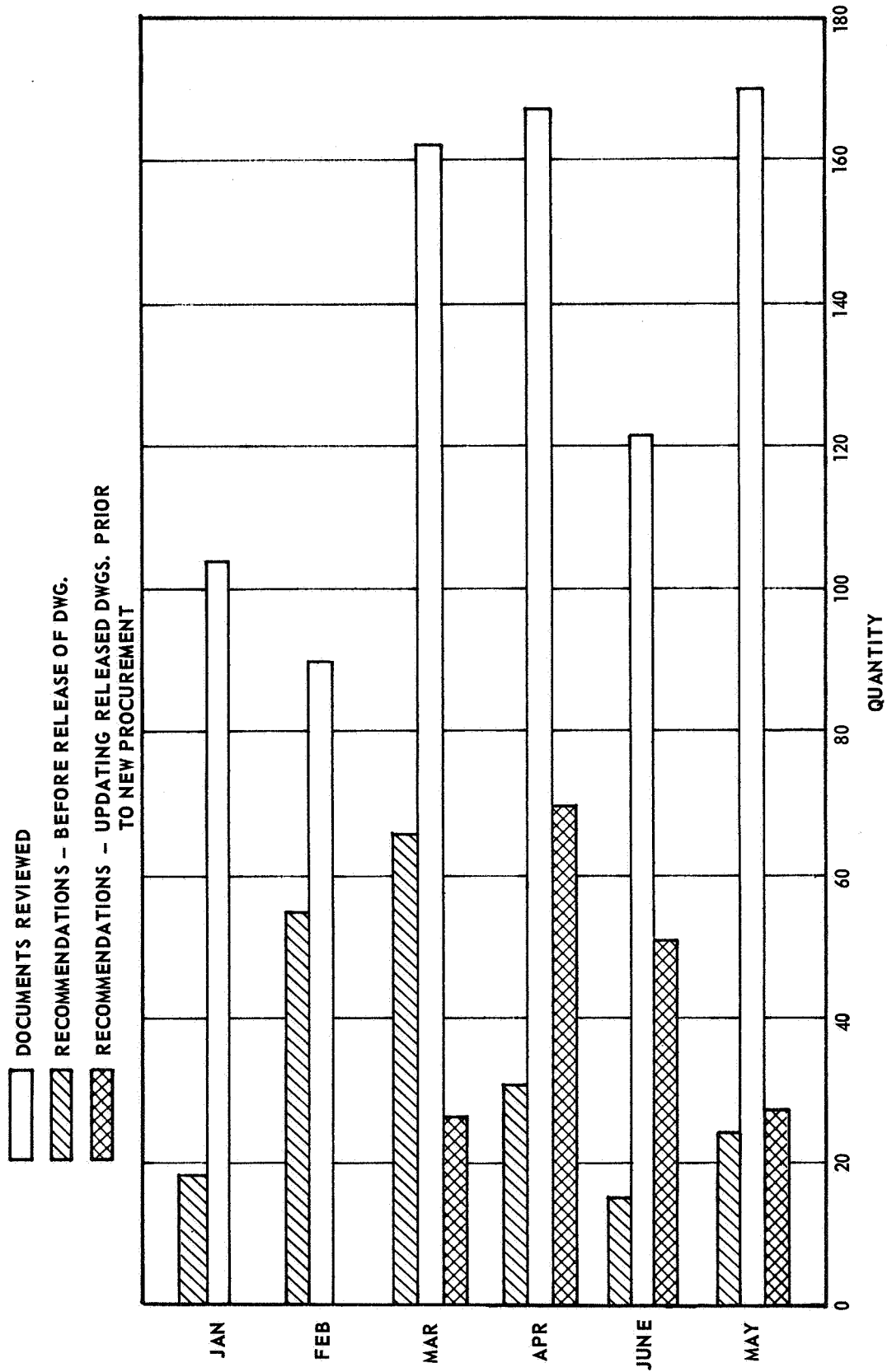
Turbine Acceleration and Mercury-Loop Startup
Transients for a Close-Coupled System with an Initial
Vapor-Line Temperature of 100°F

Figure VI-4



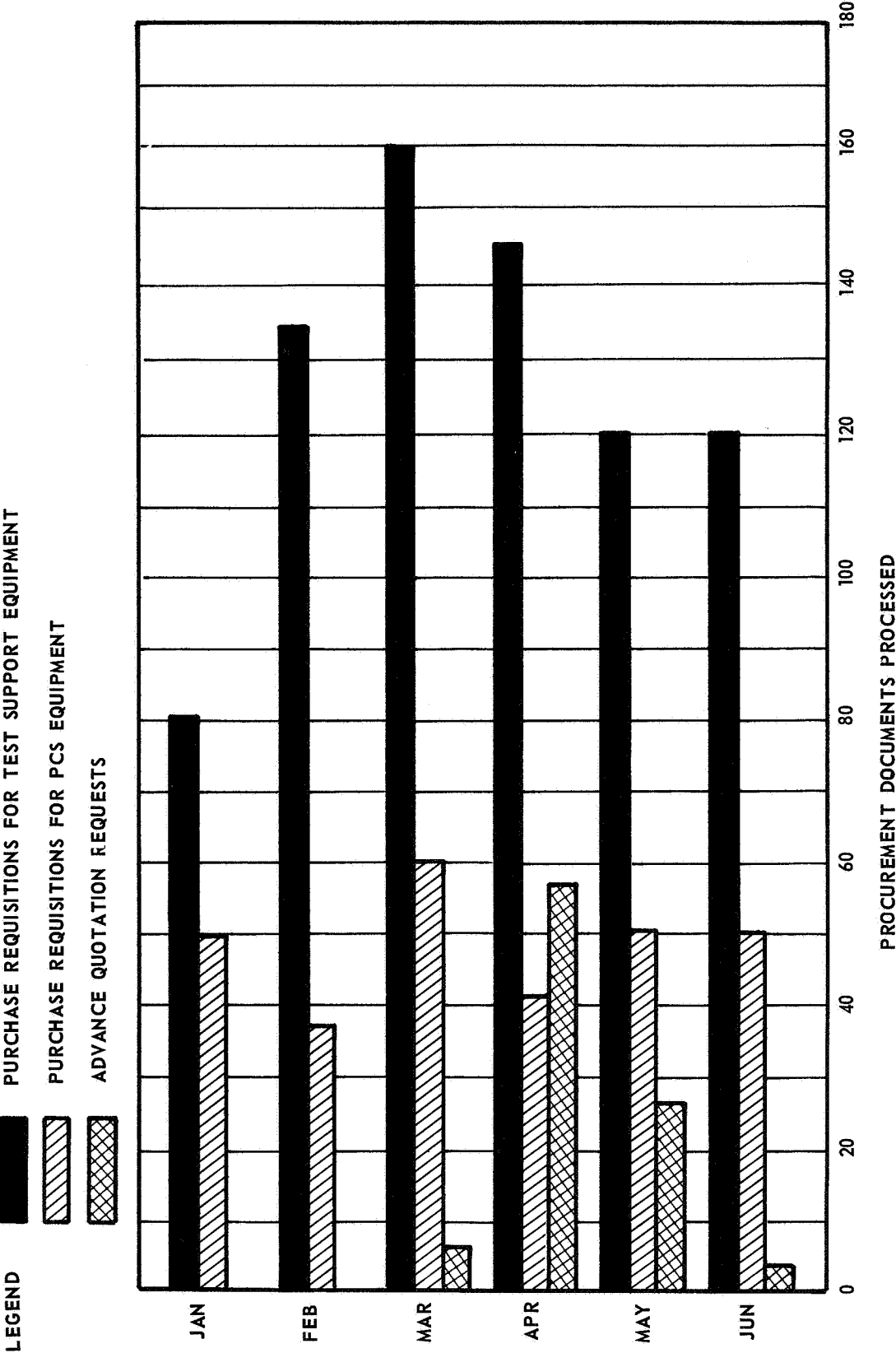
SNAP-8 Tapered Tube Condenser. Overall Pressure Difference as a Function of Condensing Length

Figure VI-5



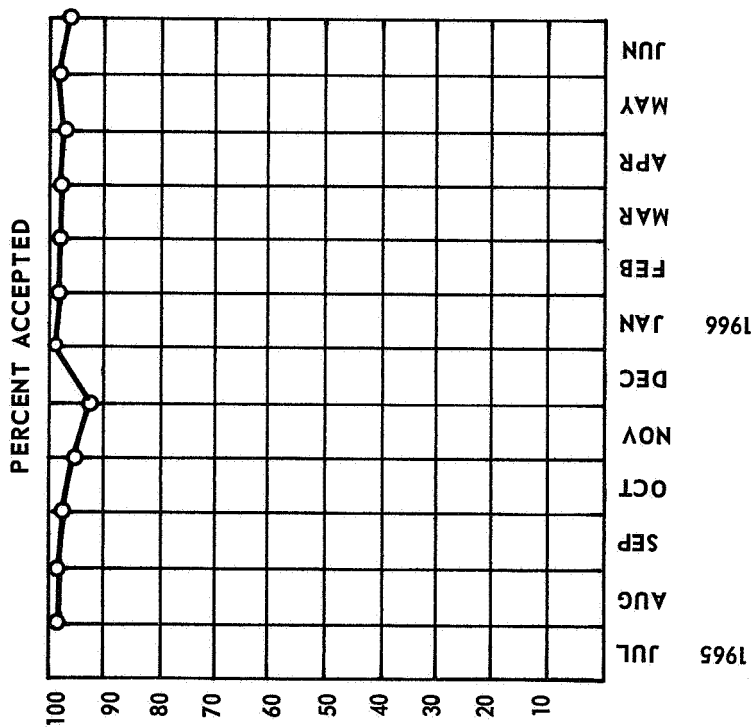
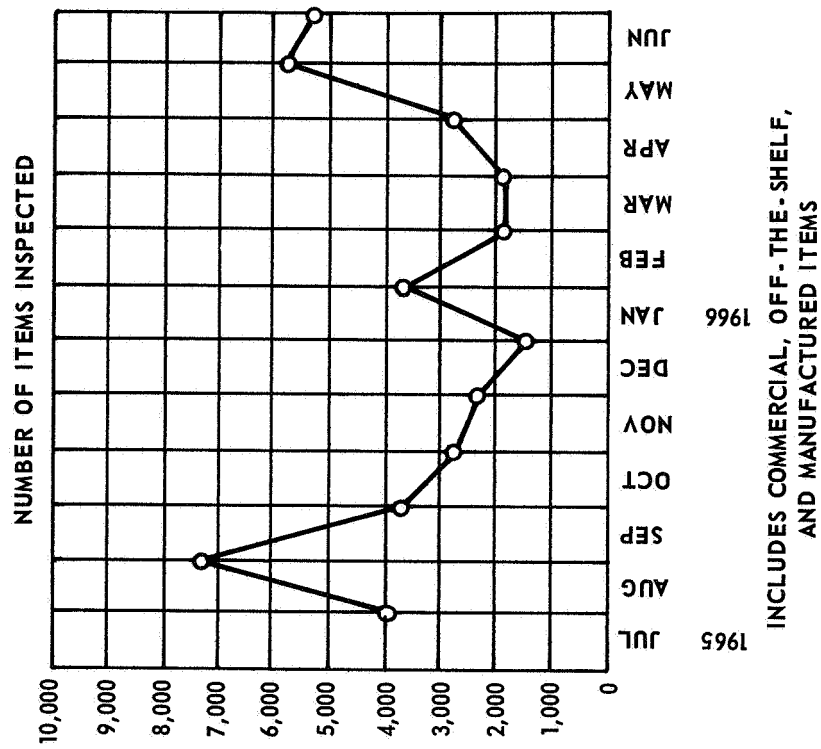
Summary of Drawing Specification Review by Quality Assurance

Figure VI-6



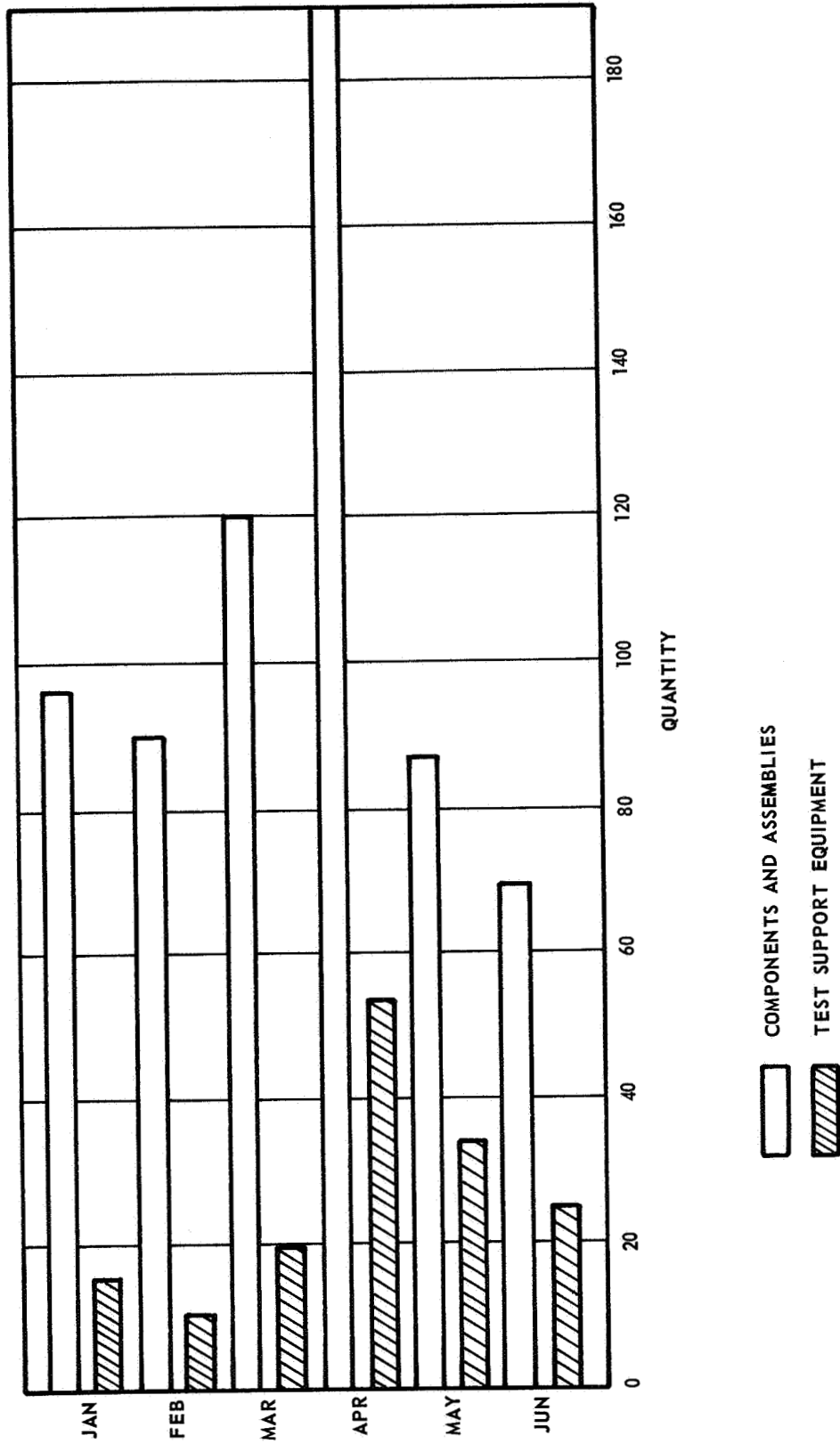
Quality Assurance Requirements Integrated into Procurement Documents

Figure VI-7



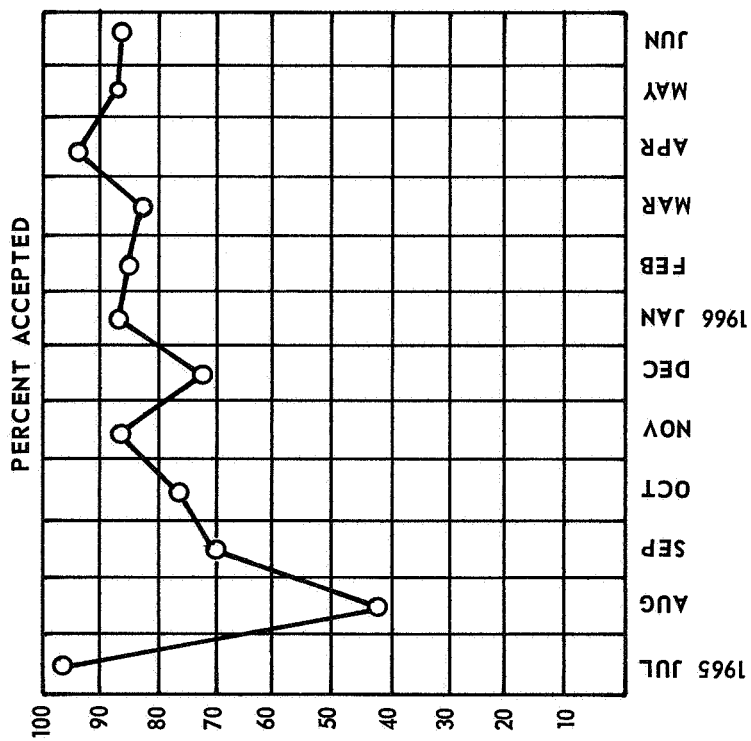
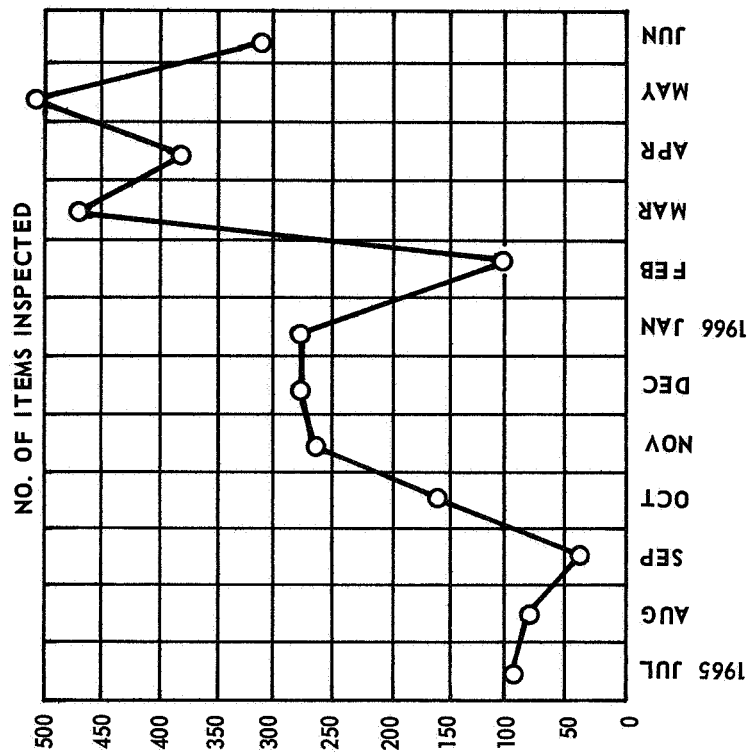
Summary of Items Inspected and Receiving Inspection Acceptance

Figure VI-8



Shop Orders Reviewed and Inspection Requirements Incorporated

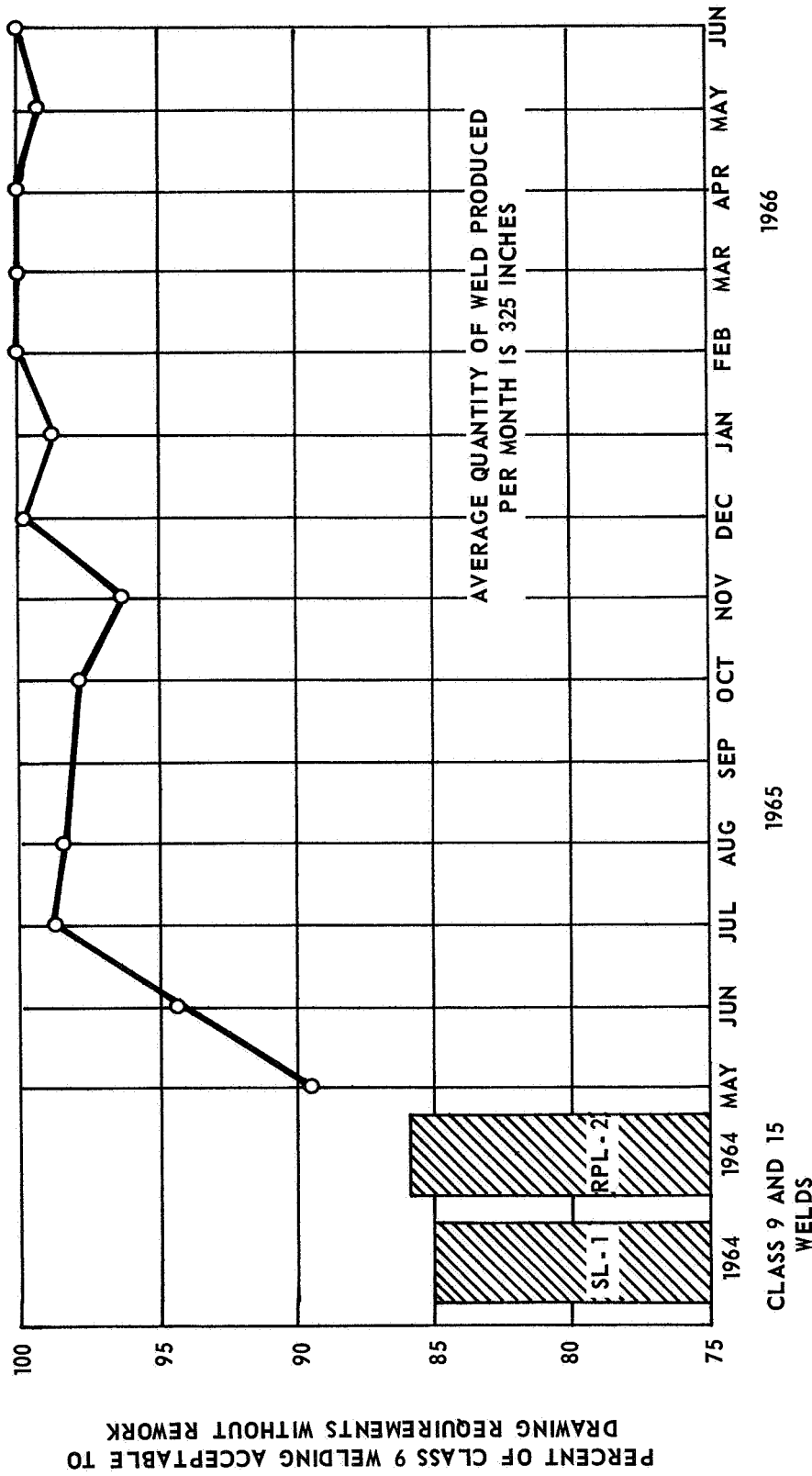
Figure VI-9



Quality Summary of In-Plant Items Inspected and Accepted

Figure VI-10

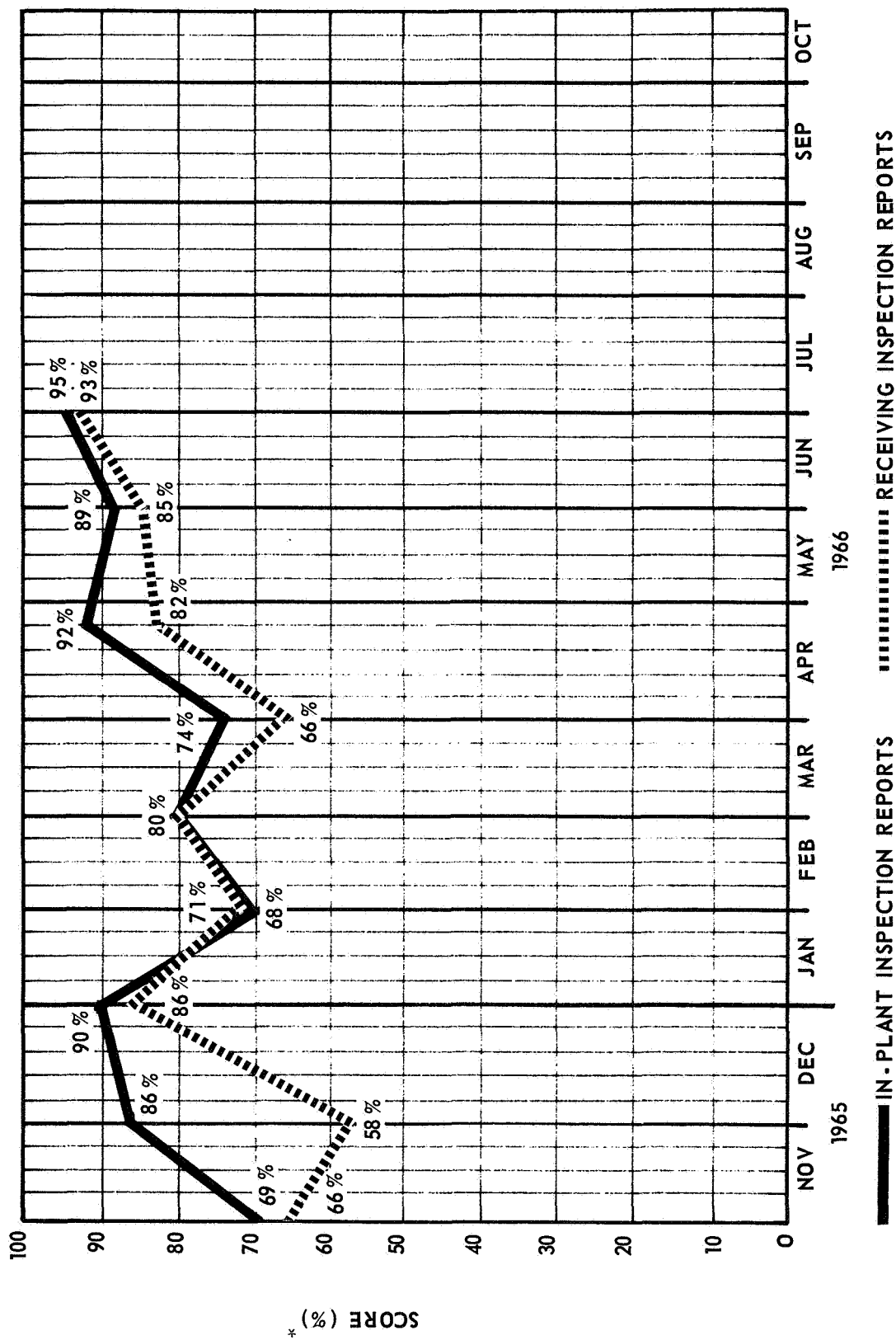
866-NF-1334



LEGEND: THIS GRAPH SHOWS THAT TSE WELDMENTS ACCEPTABLE AS WELDED PER DRAWING REQUIREMENTS HAVE SIGNIFICANTLY INCREASED DURING THE LAST 12 MONTH PERIOD. THE REMAINING SMALL PERCENTAGE OF NONCONFORMING WELDING IS USUALLY ACCEPTABLE WITHOUT REPAIR.

SNAP-8 Weld Quality Test Facility Buildup

Figure VI-11



* CAUSE, RESPONSIBILITY, CORRECTIVE ACTION ACTUALLY REPORTED - MAXIMUM POSSIBLE DETERMINATIONS.

Effectiveness of Cause and Corrective Action Determinations for Nonconforming Materials

Figure VI-12

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