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TECHNICAL MEMORANDUM

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TITLE: PCS-1 Testing of March-May 1970

ABSTRACT

PCS-1 testing of March-May 1970 is reported. Testing included many areas of system and component behavior. Specific areas reported are boiler deconditioning, non-condensible gas control, automatic condenser overpressure shutdowns, system degradation, TAA performance, boiler performance, condenser choked-flow phenomena, MPMA head loss, alternator efficiency, speed control performance, and component heat losses. The data are applied to PCS-G design.

KEY WORDS: PCS-1 testing, systems and component evaluations, application to PCS-G

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

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I. SUMMARY

This report discusses the testing performed in PCS-1 during the time period of 12 March through 28 May 1970. Operation consisted of 28 runs with a total running time (based on mercury loop operation) of 1,620 hours 15 minutes. The conclusion of testing brought the accrued operating time of several components into the range of 12,000-14,000 hours. Most significant is the TAA which has now operated for 12,443 hours.

The PCS-1 Test Plan (Reference 1) outlines various tests of both system and component orientation. These tests were all successfully completed. Additional tests were added near the end of the test period to investigate boiler performance and system response to condenser-overpressure shutdowns. Each of the testing phases is summarized below.

A. COMPONENT PERFORMANCE

1. Turbine

The measured turbine efficiency is about 55.0-56.0%. This is about midway between the initial value of 57.5% recorded in March 1968 and the minimum value of 54.8% measured September 1969. The improvement since September 1969 is attributed to cleaning done during the September-March shutdown period.

There is one anomaly in the current turbine performance. The turbine inlet pressure is running about 4% high for a given flow. This phenomenon is presently being attributed to 1st stage nozzle mass transfer deposits, resulting from initial wet operation with a deconditioned boiler.

2. Boiler

Extensive boiler mapping was performed. Mapping was stressed at both the design range and over a second range which simulated (on a per-tube basis) operation at the PCS-G state-point. The performance of the boiler was excellent; the stability (outlet mercury pressure variations) was the best of any boiler tested to date in PCS-1. The only performance weakness of the boiler was a negative slope of pressure drop versus mercury flow, which existed at both the design range and the PCS-G state-point. However, this phenomenon

is readily corrected by a change of inlet restrictor orifice size. The condition exists because there was no requirement to avoid a negative slope when the boiler was designed.

3. Condenser

Condenser mapping was very detailed. The test program was established to evaluate the condenser performance as near as possible to the PCS-G state-point. Particular effort was made to study the effects of choked-flow which occurs at very low condensing-pressure conditions. The testing identified two distinct internal phenomena: loss of temperature potential and choked flow.

The lowest condensing pressure that can be achieved with the condenser at PCS-G conditions is about 5 psia. This means the condenser is adequate for the PCS-G state-point, but only with a small margin. The mercury pressure drop associated with the state-point conditions was also identified. The pressure drop is sufficiently high to warrant further evaluation of the effects on MPMA suction pressure. For steady-state ground operation, there is no problem, but in a zero-g application (particularly during startup) the MPMA suction pressure might be inadequate.

An objective of the test program was to generate and evaluate the apparent condenser outlet restriction experienced in past PCS-1 testing. The phenomenon did not occur during the test program, presumably because of plumbing changes which altered the flow conditions in the area where the apparent restriction used to occur.

4. MPMA

Head loss of the mercury pump was typical of past PCS-1 operation, ranging from 4-11 feet throughout the testing. The pump is satisfactory for use in PCS-G with this amount of head loss.

An attempt to collect a sample of the debris, or gas, causing the head loss was made by taking a sample from the region of the impeller eye. The results were inconclusive. A small amount of gas was collected, but it was insufficient to account for any head loss. The sampling method is not considered sophisticated enough to warrant drawing any conclusions from the test.

During the test, the MPMA developed a leak which was exhibited by mercury in the space seal cavity drain trap. The leak started about

19 April 1970, and continued for the remainder of the testing. The leak rate was about 1 lb/hr. The leakage is tentatively explained as an improperly sealing face seal which allowed liquid mercury leakage under and/or over the visco pump sleeve.

5. Alternator

Tests were conducted to evaluate the effect of speed-control-system harmonics on alternator efficiency. The effects of the harmonics were in the expected direction, but the magnitude was too small to be definitely separated from possible instrumentation effects. The important conclusion is that the effects of harmonics are small enough that the existing alternator efficiency data generated by General Electric Company are adequate. The absence of harmonics when General Electric Company generated the efficiency data has negligible effect on the published results.

The alternator was operated at 80 KVA to find the resulting alternator temperature. The maximum power that could be maintained without exceeding the temperature limit established for the test (bus bar temperature of 520°F was 78 KVA. This is about equal to the required PCS-G KVA. For the existing alternator to meet the SNAP-8 life and reliability requirements, it is recommended that the maximum bus bar and winding temperatures be limited to approximately 470°F and 400°F, respectively. This indicates that additional alternator cooling should be considered for PCS-G.

6. Speed Control

Load transfers to and from the PLR were made to demonstrate the speed control performance with the new boiler and to evaluate repeatability of performance. Transfers of as high as 44 KWE were made, which required operating the PLR at its design limit of 47 KWE. The previous maximum load transfer in PCS-1 was 36 KWE. The testing showed good repeatability, with no change in performance from the previous testing in September 1969.

A second test of the speed control system evaluated the equilibrium saturable reactor temperature when operating the PLR with a 47 KWE load. The 47 KWE condition was maintained for 24 hours. There is some question about the validity of the temperature data. But it can definitely be concluded that the saturable reactor operates at an acceptable temperature. A 10,000-hour life requires the temperature to be no more than 430°F. The recorded PCS-1 data indicated 340°F (or perhaps 380°F if adjusted for the possible error).

B. SYSTEM PERFORMANCE

1. Boiler

The boiler deconditioned about 4 minutes after its initial startup. The most likely explanation for the deconditioning is oil contamination of the mercury loop. It is proposed that prelubrication (prior to rotation) of the TAA and MPMA bearings introduced the oil. It is recommended that PCS-G use greases, or some other method, to eliminate the need of oil-prelubrication.

The boiler performance gradually improved over succeeding runs until fully-conditioned performance was achieved. Full-conditioning was maintained throughout the numerous remaining startups and shutdowns of the test series. Boiler conditioning should not be a PCS-G problem, provided proper consideration is given to the matters of cleanliness and bearing prelubrication.

2. Non-condensible Gas

The first several runs of the test series experienced a continual buildup of non-condensible gas in the condenser. The occurrence was identical to the experience in October 1968. The source of the non-condensible gas is thought to be oil-decomposition products resulting from the oil contamination caused by the bearing prelubrication mentioned above. Once the source of oil was depleted, no further non-condensible gas developed, as evidenced by extensive operation with numerous startups and shutdowns. Just as with the boiler deconditioning, no PCS-G problem is expected, provided the bearing prelubrication method is properly modified.

3. Automatic Shutdowns

A series of condenser-overpressure automatic shutdowns were conducted to evaluate the effects of various mercury loop dump methods. The objective was to find if PCS-G could be properly protected from an excessive condenser overpressure if only the condenser were dumped, as opposed to dumping both the boiler and the condenser. A previous (June 1965) condenser overpressure in RPL-2 had resulted in an excessive condenser overpressure when, presumably, both the boiler and condenser were dumped.

It was found that a condenser-dump only (no boiler dump) was sufficient to protect PCS-1 from an excessive condenser overpressure. The RPL-2 experience is not considered a similar circumstance, presumably due to the different type boiler used (tube in shell), and also because of an uncertainty that the condenser even dumped.

It is concluded that PCS-G would be adequately protected with only a condenser-dump system, provided the effects of other variables such as line sizes and valves are equivalent to those in PCS-1. If the current consideration of 1/2-inch valves in the condenser dump system is pursued, then the safety of PCS-G becomes indecisive. The total PCS-G line and valve resistance with 1/2-inch valves is ten times what it is in PCS-1. A direct application of PCS-1 experience dictates that PCS-G should use 1-inch valves.

4. Heat Loss

The heat load of the L/C system was investigated with a series of tests which varied L/C flow and temperature conditions. While much of the data agreed with earlier component test facility data, other data were very questionable. It is recommended that PCS-G design continue using the L/C heat load data currently available from component test data.

5. System Degradation

The operating time spent in a strict "hands-off" operating condition was insufficient to accurately evaluate any slow system transients, such as might be associated with some specific component degradation. However, general comment can be made on areas of past interest regarding system and component degradation.

a. The typical loss of mercury pump head occurred.

b. The typical loss of mercury pump suction pressure, due to an apparent condenser outlet restriction, did not occur.

c. The boiler pressure drop was notably constant once conditioned performance was achieved.

d. TAA degradation was not detectable.

In all, the system was in a very stable condition throughout the testing, and showed no detectable signs of any significant time-related degradation.

C. OVERALL VALUE OF TESTS

Because of the extensive range of test objectives, and the system-oriented nature of the tests, much insight into PCS-G design requirements has been gained. One cause of boiler conditioning and non-condensible gas buildup has hopefully been identified. The condenser restriction has apparently been eliminated. Automatic shutdowns have been investigated for the first time. Component performance has been identified in sufficient detail to surpass previous PCS-1 accomplishments. No similar time period of PCS-1 operation has contributed so much to understanding the system and its components.

II. INTRODUCTION

PCS-1 testing since October 1968 has been extremely successful. The testing was highlighted by two runs exceeding 2,000 hours, a single-set of components operating 7,320 hours, and the TAA (and several other components) passing the 10,000-hour mark. At the completion of this testing in September 1969, a 6-month major facility and component inspection period followed. During the inspection period, the mercury loop liquid lines and the condenser were cleaned. The TAA, PNPMA, MPMA, and boiler were removed and analyzed. The TAA was in good condition and was reinstalled as Unit 5/5. The PNPMA had failed in the next-to-last run, and had to be replaced. The MPMA required replacement of several critical parts and is considered to be a new unit. The boiler was replaced with a new unit of modified design (shorter overall length and shorter plug inserts). The components comprising the system are listed and identified in Table 1.

This report covers the testing conducted when operation was resumed in March 1970. The time period covered is from 12 March to May 1970. The objective of the testing was to further define component and system behavior with particular emphasis on performance at the new PCS-G state-point. The testing is outlined in the PCS-1 Test Plan (Reference 1).

III. SYSTEM PERFORMANCE

A. OPERATION SUMMARY

Operation during the period of this report (March-May 1970) consisted of 28 individual runs for a total system operating time of 1,620 hours. Table 2 lists the start and stop times of each run, together with the run length, and the reason for each shutdown. The operating time of individual components is listed in Table 3. Particularly noteworthy is the TAA time which now totals 12,442 hours.

B. BOILER CONDITIONING

The first run of the series (D43-6-45) began on 12 March 1970. The mercury flow was brought up to a value of about 6,000 lb/hr, and all appeared normal. Then, the boiler outlet mercury temperature started to decrease, alternator power dropped off, and the turbine speed began to decrease. Various manipulations were made with the mercury flow rate which would temporarily increase the turbine speed, but the speed could not be maintained at 12,000 rpm.

The cause of the erratic performance was a deconditioning of the boiler.

The performance of the boiler is shown in Figure 1. The data clearly show the improving performance during the first 3-4 minutes of the run. The mercury pressure drop is high, the superheat is increasing, the terminal temperature difference is decreasing, and the mercury inventory is normal. Then, a sudden reversal occurs. The superheat and pressure drop begin to decrease, and the terminal temperature difference and mercury inventory begin to increase.

Figure 2 presents boiler NaK-side temperature profiles. One profile is taken just before the peak performance was achieved, and the other represents the performance after the decline had occurred. The shifting of the boiling region in the plots clearly demonstrates the deconditioning that had occurred.

The exact cause of the boiler deconditioning is not known, but there is strong suspicion of the cause. An operational procedure used in PCS-1 requires prelubricating the bearings (before rotation) of any TAA or MPMA that is newly installed or that has been idle for an extended period. It is proposed that this oil injection, without slinger rotation, results in oil passage into the mercury loop. The above procedure was followed in the current operation; both the TAA and MPMA were prelubricated by briefly opening the L/C valves to the two components. The reasons for suspecting the prelubrication as the cause of the boiler conditioning are two-fold. First, the operating time before deconditioning occurred ($\approx$3-4 minutes) is consistent with the time required for mercury (and oil) to flow from the MPMA to the boiler. Secondly, this first run and several subsequent runs were plagued with non-condensible gas in the condenser, exactly as occurred in the fall of 1968. The fall of 1968 was the last time that a MPMA was installed and prelubricated. It is proposed that the non-condensible gas is evidence that oil is in the mercury loop, since the gas is composed of products that could be formed by oil decomposition.

Operating procedures in PCS-1 have now been modified to preclude a recurrence of oil injection. It is recommended that PCS-G use other than oil prelubrication as a bearing preparation method. Consideration should be given to greases, etc.

Presuming the boiler was deconditioned by a single injection of a finite amount of oil, it would be expected to see the boiler eventually condition and remain conditioned. Such was the case. Several hours after the deconditioning occurred, the system was again started. Several short runs followed (shutdowns were required to remove non-condensibles from the condenser). During each of the runs, the boiler performance steadily improved. While the boiler was in the process of conditioning, each of the shutdowns resulted in a partial loss of conditioning. This cyclic conditioning persisted only until the boiler became fully conditioned. From that time on, shutdowns had no effect on conditioning.

Table 4 shows the history of the boiler conditioning. The first few runs of the test series are compared at equivalent time periods (10 hours and 24 hours into the run). The cyclic conditioning on each run is evident, as well as the eventual constant performance. The lower pressure drop shown for Run D43-6-54 is due to a difference of NaK temperature.

C. NON-CONDENSIBLE GAS

Difficulty was experienced with non-condensible gas buildups in the condenser during several of the runs. The history of the non-condensible gas buildup is plotted in Figure 3. The buildup rate is essentially the same on each of the runs until Run D43-6-51, at which time the buildup rate was considerably less. This indicates the source was nearly depleted. On all subsequent runs, there was no buildup of non-condensibles detected.

The whole episode with non-condensibles appears identical to the experience which occurred during October-November of 1968. In both incidents, the buildup rate was about the same, and it finally ceased after about six short runs. In both cases, the gas was identified as being primarily hydrogen. The question naturally arises as to what was the source and what was similar about the system and its operation during these two periods.

Since tantalum has an affinity for hydrogen, the boiler is the natural first suspect. But the boiler is not considered to be the cause, regardless of the fact that the non-condensible gas has been identified as being primarily hydrogen. The reason the boiler is not suspected is that experience has shown that the boiler would give off virtually all its hydrogen in a matter of a day or less. For instance, in 1968 when Boiler No. 2 was first tested, the boiler was only outgassed at full temperature (1300°F) for a few hours prior to startup. When the run began, the non-condensibles only accumulated in the condenser for about a day, after which there was no further problem. The current boiler was even less likely to give off hydrogen subsequent to startup since the boiler was outgassed for a much longer period than in the case of Boiler No. 2. At most, the boiler could not be responsible for supplying hydrogen for more than perhaps one day. Therefore, it is concluded that the boiler is not the source of the present non-condensible gas.

As mentioned earlier, there is one aspect of operation that was the same in 1968 as in the current operation. In both cases, the non-condensible buildup started on the first run, following the installation of a new (or reassembled) mercury pump. Since newly installed units have been prelubricated in place prior to rotation, it is assumed that this operation has supplied oil which ultimately ended up in the mercury loop; oil decomposition could then produce the hydrogen and methane found in the gas samples.

By deleting the current prelubrication procedure, it is hoped that non-condensible gas problems will not be experienced again.

D. AUTOMATIC SHUTDOWNS

An important conclusion regarding the PCS-G design was reached as a result of the PCS-1 testing. Prior to the testing, it was not known if protection against a condenser-overpressure shutdown would necessitate only a condenser mercury dump, or if it would require both a boiler and a condenser dump. During a condenser-overpressure shutdown in SL-1 (1965), both the boiler and condenser were dumped, and there was no significant rise in condensing pressure following the instant the dumping occurred. However, in RPL-2 (1965), a similar shutdown mode resulted in a condenser-overpressure to 180 psia, which is unacceptable. Presumably, the condenser and boiler were both dumped in the RPL-2 case, but a positive statement is not possible from the data. It is known that the boiler dumped, but possibly the condenser did not dump. With the evidence conflicting as it was, and with such an advantage to be gained if PCS-G could use a condenser dump only, it was decided to conduct a series of condenser-overpressure automatic shutdowns in PCS-1.

The testing in PCS-1 was done on 26 and 27 May 1970. Six different shutdown modes were used, as defined below:

Test Number	Conditions
1	Boiler and condenser dump with mercury flow of 6,000 lb/hr.
2	Boiler and condenser dump with mercury flow of 12,000 lb/hr.
3	Boiler dump only with mercury flow of 6,000 lb/hr.
4	Boiler dump only with mercury flow of 12,000 lb/hr.
5	Condenser dump only with mercury flow of 6,000 lb/hr.
6	Condenser dump only with mercury flow of 12,000 lb/hr.

Prior to initiating each shutdown, the condensing pressure was set at 15 psia, and all PMAs, with the exception of the HRPMA, were put on 400 Hz facility power. The HRPMA was put on 60 Hz facility power at shutoff head with HRL flow provided by the HR EM pump. The reason for the EM pump was to protect the HRPMA from the rapid changes in flow that occur during the testing.

Each shutdown was initiated by suddenly stopping HRL flow, thereby simulating the loss of the HRPMA. As the condensing pressure subsequently rose, a condenser-overpressure shutdown automatically occurred when the condensing pressure reached 45 psia. As a precautionary measure, the test engineer stood by to immediately restore HRL flow (with the EM pump) in the event the condensing pressure reached 75 psia.

The results of the testing are shown in Figures 4 through 10. Figures 4 through 8 show condenser mercury inlet and outlet pressures versus time for Test Numbers 3, 4, 5, 6, and 6 (repeat). Test Numbers 1 and 2 are not shown because strip chart data were not available, (DDAS only). However, the tests were simultaneous boiler and condenser dumps, and turned out to be unimportant cases.

The significant features that are evident in Figures 4 through 8 are listed below.

1. Test Nos. 3 and 4 - Boiler Dump Only (Figures 4 and 5)

   a. At 6,000 lb/hr mercury flow, the condensing pressure has no noticeable overshoot beyond the automatic dumping pressure (45 psia).

   b. At 12,000 lb/hr mercury flow, the condensing pressure has about a 10 psi overshoot beyond the automatic dumping pressure.

   c. There is no immediate response of condensing pressure to the boiler dumping. The decline of condensing pressure only results as mercury flow to the condenser decreases. This type of shutdown has the highest peak pressure of any of the tests.

   d. A decrease of condenser mercury inventory (indicated by outlet pressure minus inlet pressure) coincides with the rise of condensing pressure. This is a result of a corresponding rise in mercury flow and transfer of mercury to the boiler.

   e. No visible mercury was found in either the TAA or Hg PMA space seal drains. A sufficiently high condensing pressure could overpower the space seals and force liquid mercury out.

2. Test Nos. 5, 6, and 6 (Repeat) - Condenser Dump Only (Figures 6, 7, and 8)

   a. There is an immediate response of condensing pressure to a condenser dump.

   b. There is very little overshoot of condensing pressure beyond the automatic dump pressure, even at 12,000 lb/hr mercury flow.

   c. The rapid decrease of condensing pressure is partially caused by the increasing amount of cooler heat transfer area exposed as liquid mercury leaves the condenser.

d. A decline in the rate of decrease of the condensing pressure occurs when all the liquid is emptied out of the condenser so that little further exposure to cooler surfaces is possible. At 12,000 lb/hr mercury flow, there is an actual rise in condensing pressure when the last of the liquid leaves the condenser and there is no more cooler surface to be exposed.

e. Fluctuations in the condenser outlet pressure occur as the plumbing to the dump tank is emptied of all liquid and vapor discharges into the dump tank.

f. A 5 psi error in the condenser outlet pressure develops shortly after the condenser empties as the liquid level drops below the location of the outlet pressure transducer. The 5 psi is a head correction programmed into the DDAS output. Therefore, there is a 5 psi discrepancy between the inlet and outlet pressures at the end of the test. The difference between the two pressures is actually zero.

3. <u>Combined Plot of All Condensing Pressures</u> (Figure 9)

The condensing pressure from each shutdown has been plotted on Figure 9 for ease of comparison. The following significant events can be seen.

a. As expected, a much more rapid rise of condensing pressure occurs at a mercury flow of 12,000 lb/hr than at 6,000 lb/hr.

b. A double peak occurs when a condenser-dump-only is used. This phenomenon is the result of the increase of cooling available as the condenser liquid is emptied. When the condenser is empty, the pressure again rises if the boiler is still supplying sufficient mercury. If the boiler is dumped, then there is not a second peak.

c. The maximum pressure reached in the series of shutdowns was with a boiler-dump only.

4. Liquid Mercury Inventory (Figure 10)

Figure 10 presents the condenser liquid mercury inventory for each shutdown. The following significant occurrences are noted.

a. The inventory decreases as the condensing pressure rises. As stated earlier, this is a result of the increased mercury flow and boiler inventory requirement.

b. The rate of inventory decline is greater at 12,000 lb/hr mercury flow than at 6,000 lb/hr because of the more rapid rise of condensing pressure at 12,000 lb/hr.

c. When only the boiler is dumped, there is a subsequent return of condenser inventory.

5. Dumping Rate

Of particular interest to PCS-G is the dumping rate during a condenser dump. From Figure 10, a rough estimate can be made of the dumping rate through the plumbing of PCS-1. The rate appears to be about 60,000 lb/hr.

An hydraulic analyses of the PCS-1 plumbing was made to provide a cross-check on the measured dumping rates. The PCS-1 plumbing consists of the following:

Item	Quantity	Equiv. Length
Straight Section (1-inch tubing)	14 feet	14 feet
Bends	5	3 feet
Tees	2	9 feet
Valve (1-inch)	1	28 feet

The resulting resistance of the PCS-1 plumbing is approximately

$$\Delta P = 7.2 \times 10^{-9} \dot{W}^2 \qquad (1)$$

where ΔP = pressure drop, psi

$\dot{W}$ = mercury flow, lb/hr

For a typical pressure drop as measured in the PCS-1 shutdowns, Equation (1) predicts a mercury flow of about 50,000 lb/hr during a condenser dump. This is in good agreement with the measured dump rate.

6. RPL-2 Condenser Overpressure

The 180 psia condenser pressure that resulted during the 1965 RPL-2 condenser-overpressure shutdown may well have little correlation with possible PCS-1 or PCS-G experience. In the RPL-2 case, the boiler was the original tube-in-shell model. This model had high-pressure-drop restrictors and a higher nominal mercury inventory. Therefore, even though the boiler dumped at the time of the condenser overpressure, the time required to empty the boiler of mercury was greater than with PCS-1 and PCS-G. This means mercury flowed to the condenser for a longer period, which would significantly raise the condensing pressure.

It is not apparent from the RPL-2 data whether the condenser dumped or not. It is possible that it did not, since in the PCS-1 tests it was shown that no high pressures result when the condenser is dumped, whether or not the boiler is dumped. However, the condenser may have dumped, but the greater mercury flow from the tube-in-shell boiler was enough to cause the high overpressure.

Another factor that may have had an effect on the RPL-2 shutdown was the dump tank pressure. More than likely, the dump tanks were pressurized to some level with argon, possibly as much as 50 psia. What effect this may have had is not known.

7. Application to PCS-G Design

The results of the testing show that a condenser-dump-only is sufficient to protect against a condenser overpressure in PCS-1. The same statement could be made about PCS-G provided the plumbing resistance from the condenser to the dump tank (mercury injection reservoir) is equal to, or less than, that in PCS-1. The current PCS-G design has a line pressure drop, exclusive of valves, of about 0.5 psi at rated flow (14,350 lb/hr mercury). Two valves are in the line. It is currently being considered to use 1/2-inch valves because they are available. These 1/2-inch valves have a pressure drop of 7.4 psi each at rated flow. Combining the resistances of the line and valves gives the overall pressure drop as

$$\Delta P = 79 \times 10^{-9} \dot{W}^2 \qquad (2)$$

where ΔP = pressure drop, psi

$\dot{W}$ = mercury flow, lb/hr

By comparison, the PCS-1 pressure drop (Equation (1)) is about one-tenth of what it is in PCS-G. Therefore, if the 1/2-inch valves are used in PCS-G, the PCS-1 data cannot be directly applied to reach the conclusion that PCS-G could likewise be safe with a condenser-dump only. Perhaps PCS-G would be adequately protected even with the higher resistance of the 1/2-inch valves, but it has not been demonstrated by test. Furthermore, PCS-G may use shorter condensing lengths (more mercury inventory) than used in PCS-1 to obtain better response from the inventory control system. This increases the time required to empty the condenser and will increase the maximum condensing pressure reached. If, on the other hand, 1-inch valves are used in PCS-G, the flow resistances of PCS-1 and PCS-G would be almost identical. With identical resistances, it can be concluded on the strength of the PCS-1 tests that PCS-G would be adequately protected against a condenser overpressure having only a condenser-dump system.

E. COMPONENT HEAT LOSS

On several occasions in PCS-1 testing, attempts have been made to evaluate the heat picked up by the L/C system. This heat represents the energy that must be radiated by the L/C radiator of a flight system. Generally, attempts to evaluate the heat load have been inconclusive. This was again the case in the current testing. Although many of the contributions to the total heat input appear correct, others are apparently in error, at least when measured against component loop test data.

Figures 11 through 14 present the data generated during the heat loss mapping. Data are presented for the HRPMA, PNPMA, MPMA, and TAA. For each component, specific parameters, such as L/C flow and temperature, were varied to observe the response of the heat load. The variations of the heat load were small, as expected, and are generally lost in the data scatter. Therefore, the trends of parameters are not entirely obvious since they may have been influenced by system perturbations and data scatter.

In spite of the indecisive nature of some of the trends, the average magnitudes of the various indicated heat loads are clear. Table 5 presents tabulations to compare heat loads as measured in PCS-1 with those currently used in PCS-G design. Some of the comparisons are good; others are not. The TRA and NaK PMAs show good agreement, except for the PNPMA which is reading high, as expected, since it is a MOD III unit. The total TAA heat load agrees well, but the distribution of heat load (between space seal, bearings, and alternator) appears in error. The MPMA and LCPMA do not show good comparisons.

The PCS-1 data can only be considered as an approximation to the actual heat load of the L/C system. It is recommended that PCS-G design continue with the same values which have been obtained on a more laboratory-controlled basis in component test facilities.

IV. COMPONENT PERFORMANCE

A. TURBINE ALTERNATOR ASSEMBLY

From June 1967 to September 1969, the turbine-alternator assembly accrued 10,800 hours of operation. During this operating period, the indicated turbine aerodynamic efficiency decreased from 57.5% to 54.8%. Post-test inspection of the unit disclosed some erosion/corrosion damage and mass-transfer deposition. Based upon the relatively limited extent of the wear, it was concluded that the turbine was capable of at least 20,000 hours of operation. Accordingly, the unit was reassembled after limited cleaning, and was returned to service in PCS-1.

The aerodynamic efficiency to be expected from the reassembled turbine was somewhat vague. The errosion/corrosion damage did not appear sufficient to have caused all the observed efficiency degradation. Therefore, it was anticipated that the efficiency might be somewhat improved because of cleaning (3rd stage nozzle mass-transfer deposits). It was estimated that the efficiency might be about 56%.

TAA performance mapping was performed on 25 March 1970. The data are presented in Figures 15, 16, and 17. Figure 15 presents alternator power versus mercury vapor flow; Figure 16 presents turbine aerodynamic efficiency versus velocity ratio; and Figure 17 presents TAA efficiency versus mercury vapor flow. A comparison of Figure 15 with the same data obtained when the unit was first tested in 1967 indicates the output power at a given vapor flow is about the same. The first reaction to this is that the turbine efficiency has returned to its original value; or if the efficiency is not increased, then the boiler has less carry-over, resulting in higher TAA output. Unfortunately, it appears that neither conclusion is correct.

Although the output power is increased (to original value) for a given flow, the turbine inlet pressure is abnormally high. At nominal flow, the pressure is high by about 5-10 psi. This condition leads to two possible explanations as to the present turbine condition. If it is assumed that the flow meter is in error and that the turbine inlet pressure is a more correct measure of flow, then the turbine efficiency is about the same (55%) as it was when testing was concluded in September 1969. If, alternatively, it is assumed that the flow meter is correct, then the turbine efficiency is improved over what it was September 1969; but something has to have changed within the turbine to cause the high first-stage nozzle inlet pressure. Even with this latter assumption (correct flow meter), the turbine efficiency is still not up to its original value of 57.5-58.0% in spite of the high power output; because of the higher energy availability at the higher inlet temperature, the peak efficiency is still only 55.0-56.0% (Figure 16).

An anomaly of this sort immediately leads to the question of instrumentation accuracy. Although instrumentation error could cause the apparent anomaly, there is good evidence for accepting the instrumentation readings. The turbine inlet pressure readings would be difficult to challenge because of the considerable redundancy. The vapor line has pressure transducers at the boiler outlet, flow-venturi inlet, turbine filter inlet (not reliable), and turbine inlet (2). All these transducers are in agreement. Also, the turbine inlet pressure was confirmed during test with an on-line calibration. The vapor flow meter is the prime suspect for error, but it likewise appears correct. The vapor flow readings have been confirmed by visual-meter data and by an on-line calibration. In addition, heat balance data, while somewhat inaccurate, indicate the vapor flow readings are correct.

The explanation of improved boiler performance has also been proposed. For a given vapor flow, less carry-over certainly results in a higher turbine output power, but less carry-over does not cause an increase in turbine inlet pressure at a given vapor flow. For this reason, the boiler is not considered the cause of the unexpected turbine behavior.

The cause of the turbine anomaly is being investigated by the Rotating Components Group. It is possible that mass-transfer deposits have partially blocked the first-stage nozzle. The boiler was initially deconditioned during the current series of runs (starting 12 March 1970), and deconditioned boiler operation has caused mass-transfer deposits in the past.

The turbine interstage pressure readings give some support to the idea that the first-stage nozzle area has decreased. By means of the interstage pressure readings, the effective area of each nozzle can be calculated. Data on nozzle areas from December 1968 to the present are shown in Figure 18. The calculation of nozzle area is based upon a comparison between the nozzle pressure data and the vapor-flow rate. Thus, an error in vapor flow will cause the calculated nozzle areas to be in error. But conversely, if all calculated nozzle areas were unchanged, then it would be reasonable to conclude that the vapor-flow rate is correct. For the case in point, Figure 18 shows the effective nozzle areas of the second, third, and fourth stages to be basically unchanged. The first stage, however, appears to possibly have a smaller area. These findings lend credance to the postulate that the first stage nozzle area has changed, presumably due to mass-transfer deposits.

An alternative explanation might be some sort of mechanical change within the turbine. But this is only a remote possibility. It is more likely that there is a partial blockage of the first-stage nozzle or even that the vapor-flow meter is in error, in spite of the confirmatory evidence that it is accurate.

B. CONDENSER

1. Heat Transfer and Pressure Drop Characteristics

Condenser performance mapping was conducted on 10-13 April 1970. The testing was far more extensive than any previous mapping of the condenser. The reason for the greater detail was the need to determine the performance of the condenser at the off-design conditions required at the new PCS-G state-point. Recent observations of condenser operation indicated the condenser was subject to considerable deviation from ideal performance because of internal flow and heat transfer characteristics. Specifically, at certain off-design conditions, the condenser loses temperature potential (mercury temperature - NaK temperature) due to mercury pressure drop, and in some cases, a majority of the condensing area is rendered ineffective due to choked-flow (Reference 2).

The test procedure was established to obtain a maximum evaluation of the individual phenomena of pressure drop, temperature-potential loss, and choked-flow. The procedure consisted of establishing a given set of conditions and then lowering the NaK inlet temperature in steps with all other variables held constant. This procedure allowed the condenser to start at a normal operating condition, and then proceed to an ever-increasing loss of temperature potential, and ultimately to choked-flow where the majority of the condenser was ineffective. Associated with each excursion from nominal to choked-flow was a change in total mercury pressure drop. This change is a direct measure of the change in condensing vapor pressure drop. The test sequence was conducted from enough starting points to give an extensive map which could readily be extrapolated to the PCS-G state-point.

The resulting data showed many interesting characteristics. At first, it appeared that the variations in the effective heat transfer coefficient (because of temperature-potential loss and choked-flow) were so varied that it would only be possible to characterize the condenser performance with a number of separate plots. Then, a significant discovery was made. It was found that the product of effective heat transfer coefficient and potential condensing area (UA) was completely independent of condensing area. That is, regardless of the heat transfer variation due to loss of temperature potential or the effective condensing area variation due to choked-flow, the product, UA, remained a constant regardless of how much mercury inventory was in the condenser. This condition was found to hold even when the condenser flow was choked to the extent that only a small fraction of the potentially-available condensing area was actually being used. The above phenomenon is only true when the condenser is operated with a degree of temperature-potential loss or choked-flow; when the condenser is operated at conditions where temperature-potential loss or choked-flow do not occur, the condenser inventory (area) becomes significant. The simplified condition (UA independent of area) introduces some error at the old state-point, but decidedly holds at the new PCS-G state-point.

With UA being independent of area, the data correlation was considerably simplified. It was possible to derive an equation which completely defined the condenser performance over the entire mapping range. The equation accounts for all operating conditions, including loss of temperature-potential and choked-flow. Furthermore, the trends for different parameter combinations are sufficiently smooth to permit a reasonable accuracy in extrapolating from the test data to the new PCS-G state-point. The equation used to define the condenser performance is

$$T_{SAT} = \frac{\dot{W}_L \lambda X}{(C_{PN} \dot{W}_N - C_{PH} \dot{W}_L)} \left[\frac{1}{1 - e^{-\frac{UA}{C_{PN} \dot{W}_N}}} \right] + T_{NI} \qquad (3)$$

where the heat transfer coefficient, UA, has been matched to the test data by

$$UA = (4.26\ \dot{W}_L)\left(1 - \frac{2.81\ \dot{W}_N}{10^5} + \frac{2.89\ \dot{W}_N^{\ 2}}{10^{10}}\right)\left(1 - \frac{7.04\ T_{NI}}{10^3} + \frac{1.76\ T_{NI}^{\ 2}}{10^5}\right)\left(1 + \frac{10^6}{4.17\ T_{NI}^{\ 3}}\right) \quad (4)$$

T_{SAT} = condensing temperature (^{o}F)

T_{NI} = NaK inlet temperature (^{o}F)

$\dot{W}_L$ = liquid mercury flow (lb/hr)

$\dot{W}_N$ = NaK flow (lb/hr)

λ = mercury heat of vaporization (BTU/lb)

X = quality

C_{PN} = NaK specific heat (BTU/lb ^{o}F)

C_{PH} = mercury specific heat (BTU/lb ^{o}F)

UA = heat transfer coefficient (BTU/hr ^{o}F)

Equation (3) is the familiar definition of condenser performance, applicable when no choked-flow or temperature-potential loss occur. The effects of choked-flow and temperature-potential loss are contained in Equation (4). The complexity of Equation (4) is required to properly account for the characteristics of the condenser at low pressures and temperatures.

A plot of Equations (3) and (4) is presented in Figure 19, together with test data to demonstrate the correlation between test and theory. The agreement of the data and the correlating equation is quite good.

The effects of loss of temperature-potential and choked-flow are very evident in Figure 19. Note that at each mercury flow, a minimum condensing pressure is reached as NaK temperature is lowered, regardless of the NaK flow (and, of course, regardless of mercury inventory). Minimum condensing pressures of 3-5 psia are shown; without temperature-potential loss or choked-flow, the condensing pressure could be lowered well below 1 psia.

The most important outcome of the condenser mapping is the ability to predict the performance at the new PCS-G state-point. The mathematical model has been extrapolated to the new state-point as is shown in Figure 19. The far-right block of curves represents a complete description of the condenser performance at the new state-point. The theory predicts that the condenser will operate as low as 5 psia (PCS-G requirement = 8 psia) and is, therefore, satisfactory for use without modification.

The NaK-side temperature profiles generated during the condenser mapping are most interesting. Since the profiles depict the heat transfer conditions within the condenser, they necessarily respond to the condition of choked-flow. A typical set of profiles showing choked-flow is shown in Figure 20. These data show 5 profiles representing 5 different NaK inlet temperatures with all other parameters held constant. Each lower temperature represents a further approach toward choked-flow as the condensing pressure drops and the mercury velocity increases. It is apparent that a point is reached where the entire available condensing length can no longer be used, and the heat transfer regime is confined to a smaller and smaller area of the condenser. In the limiting case shown, the flow is sufficiently choked to move the condensing area up above the NaK-side temperature instrumentation so that the profile is seen as a straight line only. In this condition, the condensing length is some value less than 10 inches (location of top thermocouple), although the available condensing length (to the liquid interface) is 35 inches. This is a vivid demonstration of the marked effect that choked-flow can have on condenser performance.

The mercury vapor pressure drop was also determined from the test data. As explained, the testing sequence was set up to proceed from a non-choked to a choked condition by holding all independent parameters constant, except for NaK inlet temperature. Since mercury inventory was held constant during a given excursion from normal to choked-flow, any change in mercury vapor pressure drop appeared directly as a change in the difference between inlet and outlet pressure. Therefore, changes in vapor pressure drop were readily determined for each set of data, simply by subtracting the outlet pressure from the inlet pressure and correcting for the known inventory liquid head.

Although the changes in vapor pressure drop were readily determined, absolute values of pressure drop could not be obtained from the data. The absolute value of the pressure drop at the start of each temperature series was unknown. To predict the starting pressure drop, use was made of the condenser theoretical model (Reference 2). Using the model, the pressure drop was calculated for the first condition (non-choked) of each temperature series. Since this first condition was always at a high condensing pressure where no choking was occuring, the calculated pressure drop was reasonably accurate. With the calculated pressure drop as a starting point, the changes in pressure drop obtained from the test data were then applied to arrive at absolute pressure drop values for all test conditions.

Another interesting phenomenon became apparent when the absolute values of pressure drop were calculated. It was found that for cases of extreme choked-flow, the absolute values of condenser outlet pressure were coming out negative; an obvious impossibility. The amount by which the pressure was negative was more than could conceivably be attributed to data scatter or error in the calculated starting pressure drop values.

The apparent cause for the negative calculated pressures is a change in liquid holdup on the condenser walls. As the flow becomes very choked, the condensing region of the condenser shortens (Figure 20) to the extent that most of the condenser length is relatively stagnant as far as vapor movement is concerned; the flow in this region consists basically of liquid mercury moving along the tube walls. Under ordinary conditions, there is a high velocity vapor stream in this region, extending down to the liquid-vapor interface. Therefore, the driving force of the mercury vapor, which ordinarily would assist the movement of the liquid mercury, is absent. The end result, then, is that there is more liquid holdup on the tube walls for choked-flow than with normal operation.

The assumption of increased holdup explains the negative pressures that were being calculated. The data were being corrected for an assumed constant liquid inventory head, whereas the liquid head was actually changing as the holdup increased. It is calculated that the amount of holdup, due to the choked-flow operation, is about 0.004 inch if distributed evenly over the tube walls. This quantity of holdup would completely account for the negative pressures originally calculated.

For the data to be useable, it was necessary to correct for the error due to holdup. An assumption had to be made to define the absolute magnitude of the error in indicated pressure drop due to holdup. The assumption was made that the condenser outlet pressure was zero at the most extreme case of choked-flow found during the test program. The holdup correction at this condition was that value which would adjust the data to make the outlet pressure be zero. A second assumption was then necessary to relate the error due to holdup to the degree of choking. By examination of NaK temperature profiles, it was determined at what conditions choked-flow began. The assumption was made that the holdup was proportional to the amount by which the condensing length was shortened due to choking.

With these assumptions regarding holdup effects, it was possible to arrive at a mercury vapor pressure drop for each test condition. Admittedly, the assumptions about pressure drop were extensive. The resulting data are obviously very approximate. But it does provide, for the first time, some information on pressure drop from the PCS-1 data, and it particularly identifies the fact that choked-flow gives rise to large changes in total condenser pressure drop.

The data derived on pressure drop are presented in Figure 21. The data have been arranged as a carpet plot with the ordinate being condenser outlet pressure (or mercury pump suction). These data are corrected for liquid head and, therefore, represent zero-g operation. The data for mercury flows of 8,000, 10,000, and 12,000 lb/hr were generated from the PCS-1 data as described above. The data shown for the PCS-G state-point were obtained by extrapolation and are less accurate. The important feature to be noted is that the condenser outlet pressure rapidly goes to zero (because of choked-flow) at relatively high condensing pressures. It appears that a condensing pressure of about 6 psia is as low as the condenser could be operated at the PCS-G state-point. At the PCS-G state-point condensing pressure of 8 psia, the outlet pressure is 4-5 psia which is satisfactory for mercury pump operation. During startup, however, when the condensing pressure could be very low, there is the possibility of not having ample mercury pump suction pressure (in zero-g operation).

In summary, the condenser performance is now quite well defined. In spite of some assumptions required in the data analysis, the overall accuracy of the data and analysis is considered good. The condenser appears to be satisfactory for the PCS-G state-point. It should have no problem achieving the required 8 psia condensing pressure, but it may be somewhat handicapped due to mercury pressure drop if used in zero-g.

2. Condenser Outlet Restriction

During past years' performance, the condenser has repeatedly formed what appeared to be either gas or deposits at, or near, the mercury outlet. The effect was observed as a loss of outlet pressure of up to 8-10 psi.

Prior to the current test series, the mercury outlet line of the condenser was removed, inspected, and replaced with a new section of pipe. An effort was made to duplicate the location of thermocouples and a pressure tap. In addition, a tube and external bomb were connected to the suspected restriction region in hope of drawing off a sample of whatever was causing the pressure loss.

It appears that the cause of the pressure loss may never be known. Throughout the current test series, there was never any sign of a pressure loss buildup. The operating time was far in excess of the amount that has typically been required to develop the phenomenon.

Most likely, the flow pattern in the vicinity of the condenser outlet has been altered. The section of piping is possibly different, and it is very likely that the pressure tap and extraction tube have affected the flow. It is probable that the problem will never again be experienced.

The most probable explanation of the phenomenon is that gas had always accumulated at the mercury outlet because of the unique geometry that happened to exist there. If so, the problem is apparently gone permanently. If, on the other hand, the pressure loss was due to debris (mass-transfer deposits), then the problem could possibly return. But with the transition from 9-M to a tantalum boiler, this also is unlikely. PCS-G will probably have no problem with restrictions at the condenser outlet.

C. MERCURY PUMP MOTOR ASSEMBLY

1. Head Loss

The mercury pump head was below nominal by 4-11 feet during the period of operation. Data are plotted in Figure 22. The experience was typical in that the head loss both increased and decreased during operation, without any apparent cause.

In an effort to determine when the head loss first occurred, data were traced back to the beginning of the pump's operation (12 March 1970). The first data scan taken (within 12 seconds of pump startup) showed a head loss of 6 feet; the pump was operating at shutoff-head at the time. Because the pump started with a head loss, it is not clear whether the head loss is due to gas (or debris) as has generally been assumed, or whether it is due to some flow instability which is characteristic of the pump. Similar behavior has been noted in LML-5 where gas and debris are less apt to be present. Further analysis of this aspect is being conducted by the Rotating Components Group.

In an attempt to evaluate the cause of the head loss, the pump was fitted with a tube connecting the vicinity of the impeller eye to an external sample bomb. On two occasions, samples were taken during operation when the head loss was significant. The reaction to the sample extraction was negligible. The only effect was a slight decrease of both suction and discharge pressure. This effect would occur simply because mercury was removed from the loop. There was not a recovery of pump head rise.

Analysis of the first sample bomb showed the sample to be almost entirely mercury with a small amount of gas. The constituents were as follows:

Sample size	150 cc
Gas quantity (at STP)	0.08 cc
Gas composition	80% hydrogen, 20% air
Remainder	mercury

The second sample was invalid since air had apparently leaked into the bomb.

The results of the sampling are inconclusive. The lack of gas does not mean that the head loss of the pump is not due to gas. The orientation of the extraction tube may not have been appropriate for extracting gas. Or it may be that the sampling method was too slow; the sample bomb was filled over a relatively long time period ($\sim$5 sec) as opposed to a much more rapid fill which would be more conducive to pulling out a volume of gas, if present.

It is important to note that the mercury pump head loss has a limiting value. Only so much volume of gas can collect without extending into the higher-velocity areas of the flow pattern where gas would be pulled on through the pump. The data indicate this limit is about 11 feet of head loss. This amount of head loss is acceptable to PCS-1 operation since the pump is designed with some excess head. At the new PCS-G state-point, there is even more margin since the general system pressure level is lower. The only requirement placed on the system because of the pump head loss is a possible need for the mercury flow-control valve to make adjustments for changes in the head loss.

2. Space Seal Leakage

A second problem encountered with the mercury pump was mercury leakage into the space seal cavity drain. On about 19 April 1970, the mercury inventory in the condenser began to decrease. Concurrently, mercury was noticed in the mercury pump space seal cavity drain trap. A subsequent evaluation indicated the rate of inventory loss from the condenser was the same as the rate of increase in the drain trap. The rate rose to a value of about 1 lb/hr within two days and remained the same throughout the 37 subsequent days of operation.

Evaluation of the leakage has been inconclusive. At the conclusion of testing, the pump was disassembled and inspected. The only irregularity found was some slight surface damage to the visco pump sleeve where it mates with the Hydrodyne static seal. However, the surface damage was so slight it leaves doubt that this was the cause of the leakage. The Rotating Components Group is continuing analysis of the pump.

D. BOILER

The performance of the boiler was excellent throughout the test series. The only exception was the first few days when the boiler was deconditioned from an apparent accidental contamination with oil.

Analysis of the boiler performance has been divided into three categories: (1) general steady-state mapping, (2) steady-state operation about the PCS-G state-point, and (3) operation over the PCS-G reactor temperature deadband. A fourth area of startup testing was also included in the testing. The startup data are not presented in this report, but will be reported at a later date when data reduction is completed.

1. General Steady-State Mapping

General steady-state mapping of the boiler was performed from 31 March to 5 April 1970. The intent of the testing was to observe the boiler performance over a wide range of off-design conditions. The mapping covered the following ranges of parameters:

Mercury flow	3,000-12,000 lb/hr
NaK flow	25,000-49,000 lb/hr
NaK inlet temperature	1150-1300°F

These ranges of parameters provided data extending from the original design temperature of 1300°F to lower flows and temperatures which simulated operation at the new 1200°F PCS-G state-point.

Data from the general steady-state mapping are shown in Figures 23 through 27.

a. Mercury Pressure Drop

Figure 23 is a carpet plot of the data showing total (boiler plus inlet restrictor) pressure drop versus the independent performance parameters of mercury flow, NaK flow, and NaK inlet temperature. The magnitude of the pressure drop is in accordance with design. The only undesirable feature of the pressure drop characteristics is a negative slope of pressure drop with increasing mercury flow. This negative slope gave rise to some system instability in PCS-1 testing and would be an undesirable condition to have in PCS-G. The negative slope cannot be considered a design weakness of the boiler since there was no specification that there not be a negative slope at the time the boiler was designed. Correction of the negative slope is straightforward (by changing inlet restrictors), and a positive slope has been incorporated into the design of the PCS-G boiler.

Figure 24 shows the same pressure drop data as shown in Figure 23, except the contribution of the inlet restrictors to the total pressure drop has been subtracted out. These data therefore show the actual pressure drop associated with the preheat, boiling, and superheat phases of the boiler operation. Of course, now the negative slope is more pronounced since it is the nature of the boiler to operate with this negative slope. It is the addition of inlet restrictors which corrects the negative slope by adding a significant positive slope.

b. Terminal Temperature Difference

Figure 25 shows terminal temperature difference (NaK inlet-mercury outlet) for the general steady-state mapping, again in the form of a carpet plot. The terminal temperature difference is in accordance with design, at a value of about 40-50°F. It must be added that PCS-1 data are all gathered with surface-reading thermocouples, as opposed to immersion thermocouples. PCS-1 experience has shown that an immersion thermocouple in the mercury vapor stream reads about 30°F higher than the surface thermocouples. Therefore, for a true comparison with design, the PCS-1 data need to be modified by about 30°F which gives a minimum terminal temperature difference of 10-20°F; this agrees with design expectations.

An interesting phenomenon to be observed is that the terminal temperature difference appears to reach a minimum for a given NaK flow and temperature as the mercury flow is increased. Further increases in mercury flow cause an increase in terminal temperature difference. The phenomenon is directly related to the pinch-point temperature differences (minimum difference between NaK and mercury temperatures) at which the boiler was mapped. The data where the terminal temperature difference reverses are all associated with very low pinch-point temperature differences (8-20°F). A low pinch-point temperature difference represents a condition of probable partial plug-insert flooding. This was evident in the testing by a noticeable decrease in boiling stability at the low pinch-point test conditions. The partial loss of plug region performance (less stability, more liquid carryover) could account for the observed increase in terminal temperature difference. This reversal of terminal temperature difference is in accordance with normal boiler performance. The entire phenomenon is only of academic interest since the effect is basically insignificant and the boiler will not be subjected to this low a pinch-point temperature difference at the PCS-G state-point.

c. Pinch-point Temperature Difference

Figure 26 presents pinch-point temperature difference in carpet plot form as a function of mercury flow, NaK flow, and NaK inlet temperature. These data show the pinch-point temperature differences at which the boiler operated for the variety of test conditions run. There is nothing significant to note in the data except that the pinch-point was varied over a wide range, from about 10-400°F.

d. Stability

The stability of the boiler, as measured by the fluctuations of the mercury outlet pressure, was excellent. The instability of the outlet pressure was less than ±1.0% at the 1300°F design condition of the boiler, and less than ±2.0% at the 1200°F simulated PCS-G operating condition. These magnitudes of pressure instability represent a stable boiler. As operating conditions were moved far off design in each direction, instabilities of greater and lesser extent were, of course, obtained. The maximum instability observed in the testing occurred when the mercury flow was 10,830 lb/hr with a NaK flow of 48,500 lb/hr and a NaK inlet temperature of 1194°F (Test Condition No. 36, Figure 27). This set of conditions gave the minimum indicated pinch-point temperature difference of any test ($\approx$8°F), which accounts for the greater instability. At this condition, the instability was about ±4.0%.

Figure 27 shows plots of boiler outlet pressure versus time for the various design and off-design conditions run.

2. Steady-state Operation About the PCS-G State-point

Portions of the boiler mapping were designed to specifically identify the boiler performance at the PCS-G state-point. The PCS-G state-point was simulated with a mercury liquid flow of 8,000 lb/hr, a NaK flow of 32,500 lb/hr, and a NaK inlet temperature of 1200°F. These conditions, on a tube-per-tube basis closely simulate operation at the PCS-G state-point. The performance of the boiler at the PCS-G state-point is presented in Figures 28 through 30. Figure 28 presents the total mercury pressure drop as a function of mercury flow and NaK inlet temperature. The negative pressure drop slope of the boiler is again evident. As discussed earlier, this characteristic is easily remedied with appropriate inlet restrictors. Such a change has been incorporated in the design of the PCS-G boiler.

Figure 29 presents terminal temperature difference as a function of mercury flow and NaK inlet temperature. The general value of the terminal temperature difference at the PCS-G state-point is about 45-55°F. When corrected to the equivalent of an immersion thermocouple reading, this represents about a 20°F difference which is consistent with the PCS-G design.

Figure 30 presents boiler stability data for operation in the vicinity of the PCS-G state-point. The general instability of the outlet pressure is less than about ±2.0%, which is within the design requirements. The total performance of the boiler at the simulated PCS-G condition was excellent.

3. Operation Over the PCS-G Reactor Temperature Deadband

A test was conducted to evaluate the response of the system to the normal variation of the boiler NaK inlet temperature over the reactor temperature deadband. The test was performed by operating the system strictly "hands-off", with the exception of the boiler NaK inlet temperature. The actual PCS-G deadband temperature extremes are 1185°F and 1210°F, but the testing was extended over a wider range (1170-1235°F) to increase the accuracy of the data interpretation.

The responses of various key parameters are shown in Figure 31. All the trends are in accordance with expectations. As an example of the agreement between test and theory, the following comparisons are made:

Effect of Increasing Boiler NaK Inlet Temperature from 1185°F to 1210°F

	Test Results	Analysis*
Mercury flow	1.2% decrease	1.0% decrease
Alternator output power	0.6% decrease	0.7% decrease

*See Reference 3

The testing shows good agreement between actual boiler performance and predicted results. The agreement substantiates the validity of the current mathematical codes being used to analyze the performance of PCS-G.

E. ALTERNATOR

1. Efficiency

The available data on alternator efficiency were generated by General Electric Company. When the test program was conducted to map the alternator efficiency, the alternator was loaded with a passive load bank. In its actual application, the alternator is loaded with a combination of pumps, vehicle load, and the speed control system. It has been considered possible that harmonics generated by the speed control system significantly affect alternator efficiency. If so, then the efficiency data obtained by General Electric Company would not be entirely accurate.

A test was conducted in PCS-1 on 17 April 1970 to evaluate the effects of harmonics on alternator efficiency. The test was performed by maintaining the system at steady-state except for the PLR load, which was run at two separate values. PLR loads of 4 KW and 22 KW were used. The low PLR load essentially represents the nominal operating condition and should result in little harmonic content. The high PLR power is in the range expected to give a maximum of harmonics.

The data from the test are interpreted by calculating the indicated turbine efficiency. Since turbine efficiency calculations are made by working backwards from the alternator output, the calculated turbine efficiency is affected by the particular value of alternator efficiency assumed.

If it is true that the General Electric efficiency data are in error when the harmonic content is high, then the calculated turbine efficiency should be lower when the PLR load is 22 KW than it is when the load is 4 KW.

The results of the PCS-1 tests were significant, but not conclusive. The following comments can be made:

a. The trend of calculated turbine efficiency was in the direction expected. At a 4 KW PLR load (minimum harmonics), the calculated turbine efficiency was 55.77%. At a 22 KW PLR load (maximum harmonics), the calculated turbine efficiency was 55.57%. This would imply that the actual alternator efficiency with a high harmonic content was actually less than indicated by the General Electric Company data. The calculated change in turbine efficiency would represent a loss of about 200 watts due to harmonics.

b. The calculated loss due to harmonics (200 watts) could be instrumentation error. Normal data scatter could account for the indicated change of turbine efficiency. Also, within the small range of the indicated change, harmonics might have had an effect on the PCS-1 electrical instrumentation.

c. The tests have shown that the effect of the harmonics is not large. The indicated effect is not sufficient to require generating new alternator efficiency data. The effect is less than the inherent error in the original alternator efficiency test data. Therefore, use of the General Electric Company data should continue.

2. <u>80 KVA Operation</u>

The new PCS-G state-point requires the alternator to operate at about 80 KVA. Operation in ECTF at about 70 KVA for the last 15,000 hours has indicated marginal conditions which might dictate the need of additional cooling for PCS-G. Since there has been some temperature variation from one alternator to the next, it was decided to conduct an 80 KVA test on the alternator in PCS-1.

The objective of the PCS-1 test was to find the alternator equilibrium temperatures when operating at 80 KVA; or, if the temperature limits were reached, to find the maximum KVA that could be maintained without exceeding the temperature limits. Two temperatures are available: the alternator bus bar temperature and the alternator winding temperature. Limits for these temperatures in the PCS-1 test were arbitrarily set at 520°F and 460°F, respectively.

The test was performed over a 24-hour period beginning on 18 May 1970. The test was conducted by starting at a reduced mercury flow (10,000 lb/hr) and then slowly raising the flow until either (1) an 80 KVA output was reached or (2) either alternator temperature reached the limiting value specified.

The test results are shown in Figure 32. The bus bar temperature limit was reached slightly before the 80 KVA output. After about 6 hours, the mercury flow was up to 13,100 lb/hr. The KVA reached 77.8 and the bus bar temperature reached 520°F. The winding temperature was 445°F. To keep the temperature from rising further, the mercury flow was reduced slightly (to 13,000 lb/hr). The remainder of the 24-hour test was run basically at this condition.

It is concluded that the alternator in PCS-1 reaches a bus bar temperature of 520°F at about 78 KVA; the winding temperature reaches 445°F at this KVA load.

The alternator was designed for 80 KVA with a maximum bus bar temperature of 410°F and a maximum winding temperature of 392°F. The PCS-1 testing shows that PCS-G operation will result in temperatures of slightly over 520°F at the bus bar and slightly over 445°F in the windings. For the existing alternator to meet the SNAP-8 life and reliability requirements, it is recommended that the maximum bus bar and winding temperatures be limited to approximately 470°F and 400°F, respectively (Reference 4).

Therefore, to operate the alternator at a load of 78 KVA in PCS-G, provision for additional cooling should be considered.

F. SPEED CONTROL

1. Load Transfer Tests

The electrical tests comprised two parts. First, load transfer tests were conducted where loads ranging from 36 KW up to 44 KW were transferred from, and back to, the PLR in single steps. The first few transfers were repeats of earlier tests, the purpose being to confirm the capabilities of the speed control system with the new boiler. Subsequent load transfers included loads of increasing magnitude, culminating with 44 KW transfers which required the PLR to be operated at its design limit of 47 KW. The purpose of these latter tests was to see if there were any unexpected limits to the speed control system operation, and if there is a sufficient margin in the vicinity of the design point (36 KW transfers).

The tests were performed on 16 April 1970. Figure 33 presents typical transfers of 36 KW with the PLR operating at 39 KW. All was satsifactory. The results demonstrated the repeatability of previous tests. The design objectives, which were successfully met, were maximum frequency perturbations of less than ±20 Hz and damping times less than 5 oscillations.

Figure 34 shows typical transfers of 44 KW with the PLR at its design limit of 47 KW. The design objectives were again met. The characteristics were as good, or better, at the higher power levels than at the lower levels.

The load transfer tests have shown the performance repeatability of the speed control system, have demonstrated an adequate safety margin at design conditions, and have shown the capability of transferring loads at power levels significantly beyond the design conditions.

2. PLR Test

The PLR test consisted of operating the PLR at its design limit of 47 KW for 24 hours to find the equilibrium temperature of the saturable reactor. The PLR had never been operated at its design limit in PCS-1.

The test was performed on 16-17 April 1970. Unfortunately, the results are inconclusive. The maximum saturable reactor temperature for a 47 KW PLR load was the same (340°F) as was recorded when a similar test was run at 42 KW in September 1969. It is inconsistent for the saturable reactor temperature to be the same at PLR loads of 42 KW and 47 KW. Possibly, some instrumentation error is responsible (such as a loose thermocouple). If it were assumed that the 340°F was correct at 42 KW, then a more likely temperature at 47 KW would be about 380°F.

Regardless of which temperature data is more correct, the important point is that the saturable reactor operates at a very acceptable temperature. The design limit for a 10,000-hour life is a temperature of 430°F, which is considerably above the measured 340°F (or perhaps more correctly 380°F).

REFERENCES

1. PCS-1 Test Plan, SPS-001, Section III, Revision F, dtd 3 March 1970.

2. J. N. Hodgson, Mathematical Correlation of Observed Condenser Heat Transfer Variations, TM 7994:70:621, dtd 21 April 1970.

3. R. G. Geimer, PCS-G State-Point Conditions - Revision Date 26 June 1970, Memo 7992:70:0068, dtd 1 July 1970.

4. ANSC Memo 4968:69:0092 from F. N. Collamore to Distribution, dtd 23 December 1969, Subject: SNAP-8 Alternator Power Capability.

TABLE 1

COMPONENT IDENTIFICATION

Component	P/N	S/N	Unit
TAA	096800-3	A-2	5/5
PNPMA	096647-21	A-3	11/4
HRPMA	096647-23	A-1	4/4
MPMA	098100-15	A-2	6/7
LCPMA	253800-2	481503	3/1
Boiler	1266911	BRDC-4	11/1
Condenser	092500-1	A-2	2/2
Electrical Controls:			
TRA	097760-1	A-1	
LCA	097054-1	A-1	

TABLE 2

SYSTEM OPERATION SUMMARY

Run	Start		Stop		Run Time (Hrs.)	(Mins.)	Reason for Shutdown
D43-6-45	1540	3/12/70	1547	3/12/70		7	Sudden deconditioning of boiler
D43-6-46	2017	3/12/70	0557	3/13/70	9	40	NaK leak near PNPMA filter
D43-6-47	2323	3/19/70	1450	3/20/70	15	27	Remove non-condensible gas
D43-6-48	1516	3/20/70	1937	3/21/70	28	21	Remove non-condensible gas
D43-6-49	2010	3/21/70	2230	3/22/70	26	20	Remove non-condensible gas
D43-6-50	2302	3/22/70	1513	3/24/70	40	11	Remove non-condensible gas
D43-6-51	1540	3/24/70	1516	3/30/70	143	36	Remove non-condensible gas
D43-6-52	1541	3/30/70	0015	4/6/70	152	34	(1) Investigate low MPMA bearing and motor LC flow (2) Place heaters on mercury inlet end of boiler
D43-6-53	1820	4/7/70	1439	4/8/70	20	19	Facility 400 Hz generator clutch malfunction
D43-6-54	1812	4/8/70	0858	5/21/70	1022	46	Evacuate mercury loop, restart, and check repeatability of condenser performance
D43-17-55	0918	5/21/70	1108	5/21/70	1	50	Prepare for startup Test No. 1
D43-9-56	1126	5/21/70	1252	5/21/70	1	26	Prepare for startup Test No. 2
D43-9-57	1304	5/21/70	1334	5/21/70	0	30	Prepare for startup Test No. 3
D43-9-58	1401	5/21/70	1438	5/21/70	0	37	Prepare for startup Test No. 4
D43-9-59	1458	5/21/70	1513	5/21/70	0	15	Prepare for startup Test No. 5
D43-6-60	1536	5/21/70	0859	5/26/70	113	23	Prepare for startup Test No. 6

TABLE 2

SYSTEM OPERATION SUMMARY (Cont.)

Run	Start		Stop		Run Time (Hrs.)	(Mins.)	Reason for Shutdown
D43-9-61	0911	5/26/70	0947	5/26/70	0	36	Prepare for startup Test No. 7
D43-9-62	1014	5/26/70	1040	5/26/70	0	26	Shutdown to put HRL on EM pump for automatic shutdown tests
D43-6-63	1059	5/26/70	1137	5/26/70	0	38	Automatic Shutdown No. 1
D43-6-64	1138	5/26/70	1138	5/26/70	0	0	Accidental 10-sec run because condenser filled with Hg V-7 open and MPMA running. Condenser overpressure shutdown.
D43-6-65	1152	5/26/70	1329	5/26/70	1	37	Automatic Shutdown No. 2
D43-6-66	1346	5/26/70	1404	5/26/70	0	18	Edison power loss
D43-6-67	2224	5/26/70	0914	5/27/70	10	50	Automatic Shutdown No. 3
D43-6-68	0932	5/27/70	1117	5/27/70	1	45	Automatic Shutdown No. 4
D43-6-69	1127	5/27/70	1151	5/27/70	0	24	Automatic Shutdown No. 5
D43-6-70	1204	5/27/70	1314	5/27/70	1	10	Automatic Shutdown No. 6
D43-6-71	1326	5/27/70	1437	5/27/70	1	11	Automatic Shutdown No. 6 (repeat)
D43-6-72	1455	5/27/70	1453	5/28/70	23	58	Termination of test program
				TOTAL	1620	15	

TABLE 3

COMPONENT OPERATION SUMMARY

Component	Hours at Start of Test Series (March 1970)	Hours at End of Test Series (May 1970)
TAA	10,823	12,442
PNPMA	0	1,709
HRPMA	7,911	9,560
MPMA	0	1,628
LCPMA	12,971	14,521
Boiler	0	1,620
Condenser	13,226	14,845
Electrical Controls	11,377	12,996

TABLE 4

EFFECT OF CONDITIONING ON BOILER PRESSURE DROP

Run	Time into Run (hr)	Mercury Vapor Flow (lb/hr)	Pressure Drop (psi)
45	(2 min.)	6,000	165
46	10	6,000	55
47	10	5,600	30
48	10	5,800	50
49	10	5,600	70
49	24	6,200	105
50	10	5,400	75
50	24	10,600	140
51	10	5,800	90
51	24	11,800	125
52	10	12,000	131
52	24	12,000	137
53	10	12,000	138
53	24	12,000	139
54	10	12,000	123
54	24	12,000	128

TABLE 5

COMPONENT L/C HEAT LOAD

Component	PCS-1 Test (KW)		PCS-G Design (KW)	
TAA		8.7		8.95
Space Seal	2.5		2.25	
Bearings and Slingers	3.4		2.50	
Alternator	2.8		4.20	
MPMA		1.8		3.14
Space Seal	1.2		1.30	
Bearings and Slingers	0.3		1.41	
Motor	0.3		0.43	
LCPMA		2.5		1.40
HRPMA		2.3		2.25
PNPMA (MOD III)		3.0		2.12
TRA		0.55		0.59
TOTAL (using 2.12 KW for PNPMA)		18.0 KW		18.45 KW

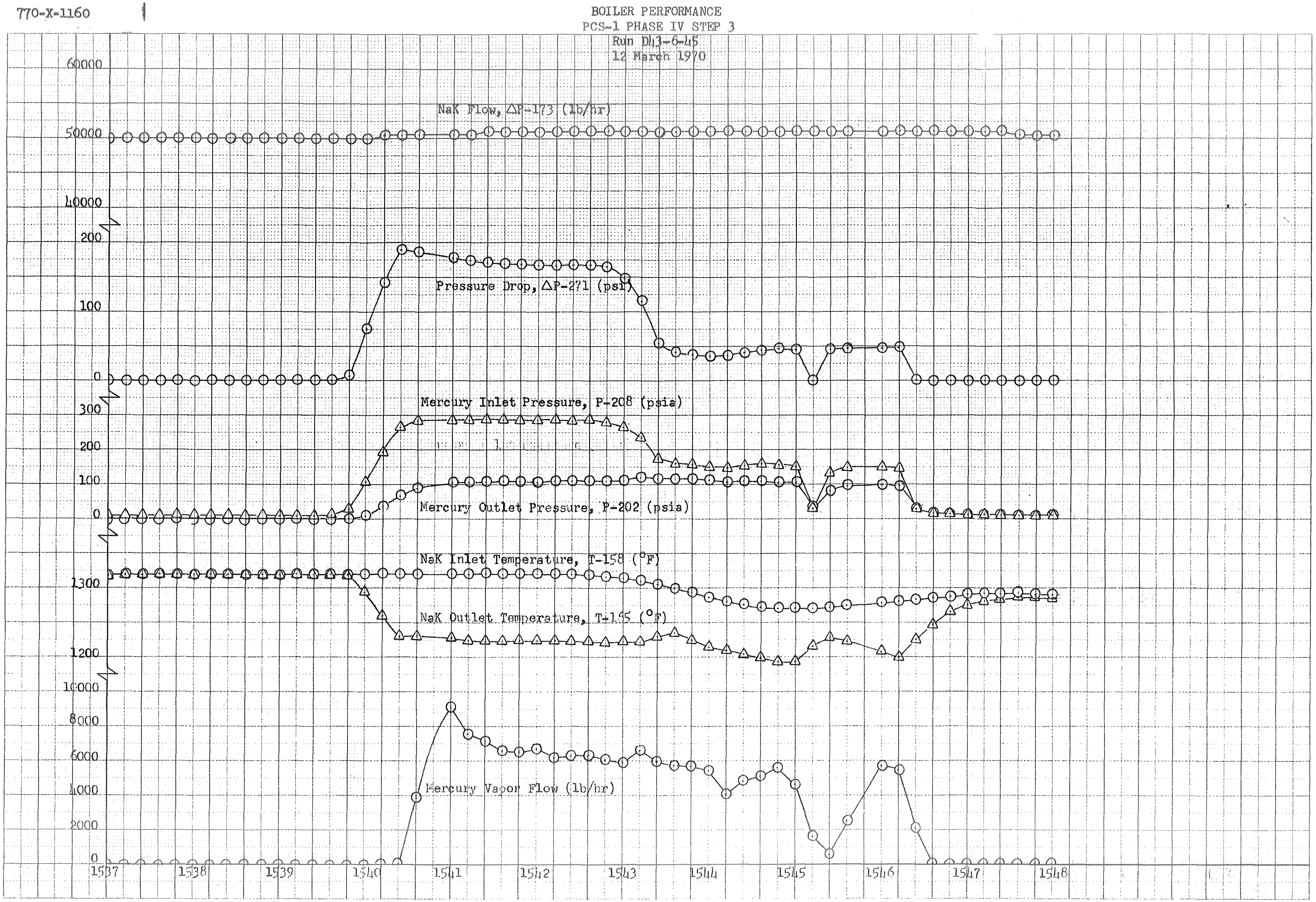

BOILER PERFORMANCE
PCS-1 PHASE IV STEP 3
Run D43-6-45
12 March 1970
60000
50000
40000
NaK Flow, ΔP-173 (lb/hr)
200
100
0
Pressure Drop, ΔP-271 (psi)
300
200
100
0
Mercury Inlet Pressure, P-208 (psia)
Mercury Outlet Pressure, P-202 (psia)
1300
1200
NaK Inlet Temperature, T-158 (°F)
NaK Outlet Temperature, T-155 (°F)
10000
8000
6000
4000
2000
0
Mercury Vapor Flow (lb/hr)
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548

Figure 1

BOILER PERFORMANCE
PCS-1 PHASE IV STEP 3
Run D43-6-45
12 March 1970

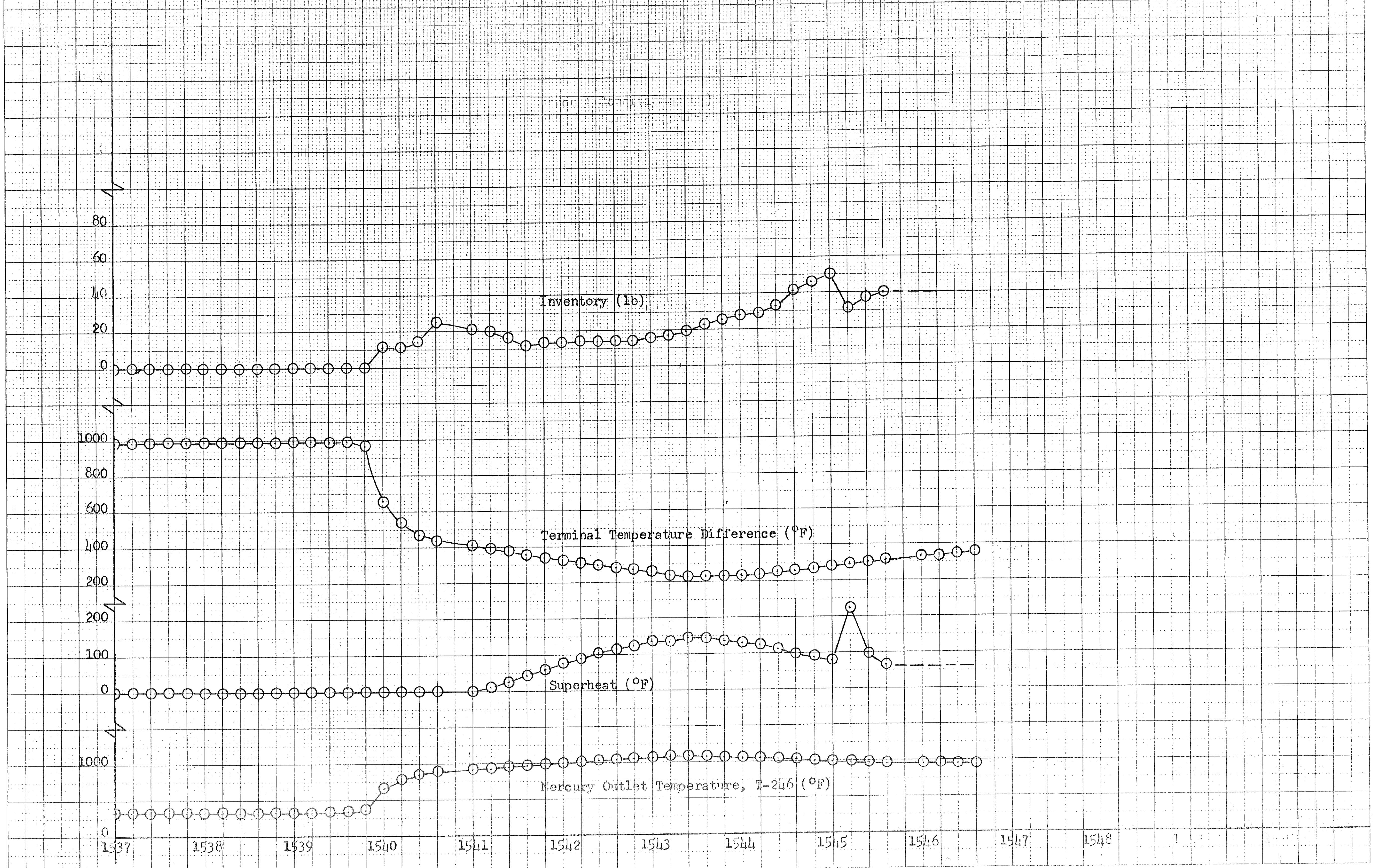
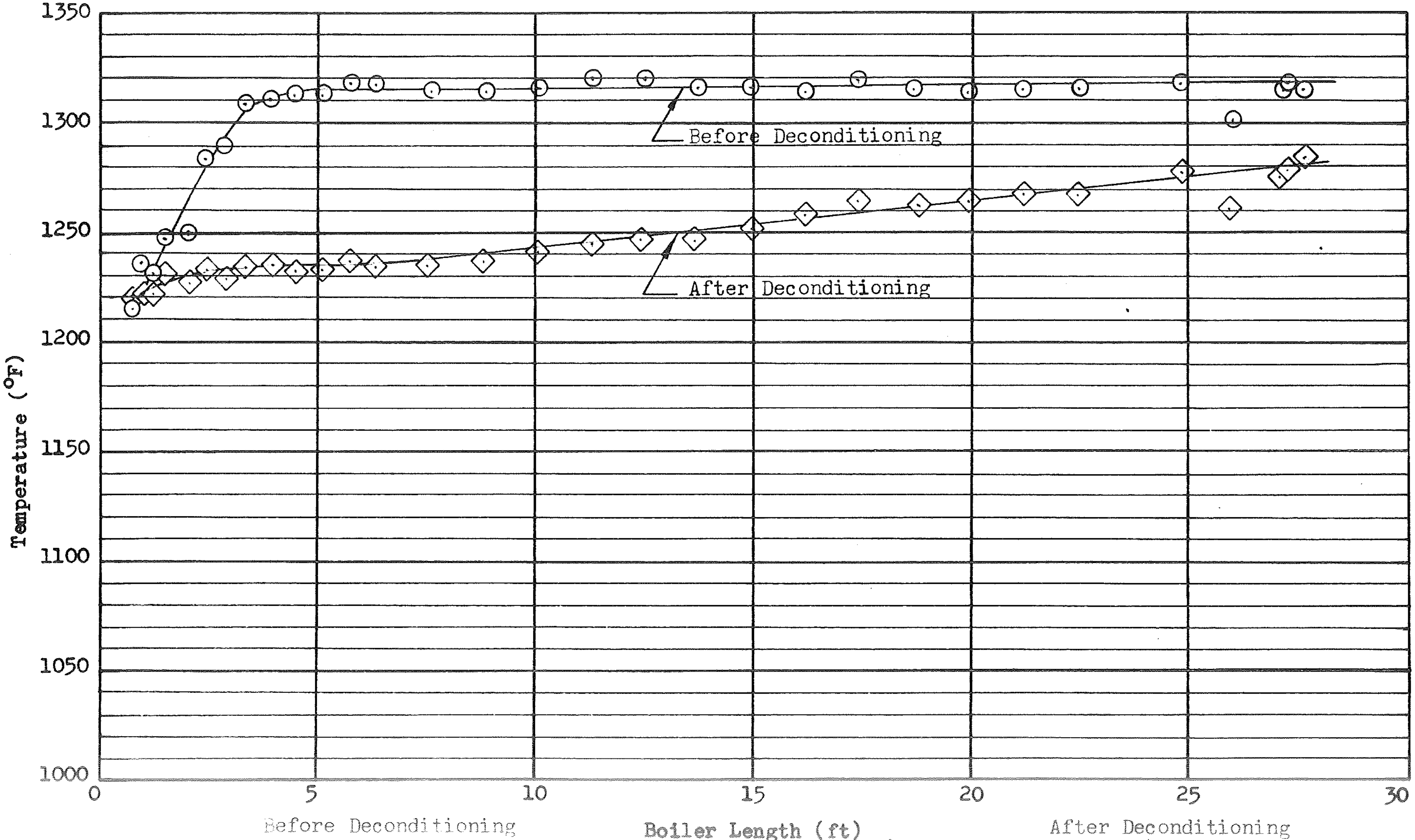


Figure 1

BOILER NAK TEMPERATURE PROFILES
PCS-1 PHASE IV STEP 3
Run D43-6-45
12 March 1970



Before Deconditioning				
$\dot{w}_{Hg}$ = 6685 lb/hr	ΔP_B = 167.4 psi			
$\dot{w}_N$ = 51000 lb/hr	TIME 1542			
T_{NBI} = 1320 °F				

After Deconditioning	
$\dot{w}_{Hg}$ = 5410 lb/hr	ΔP_B = 35.3 psi
$\dot{w}_N$ = 51000 lb/hr	TIME 1544
T_{NBI} = 1286 °F	

Figure 2

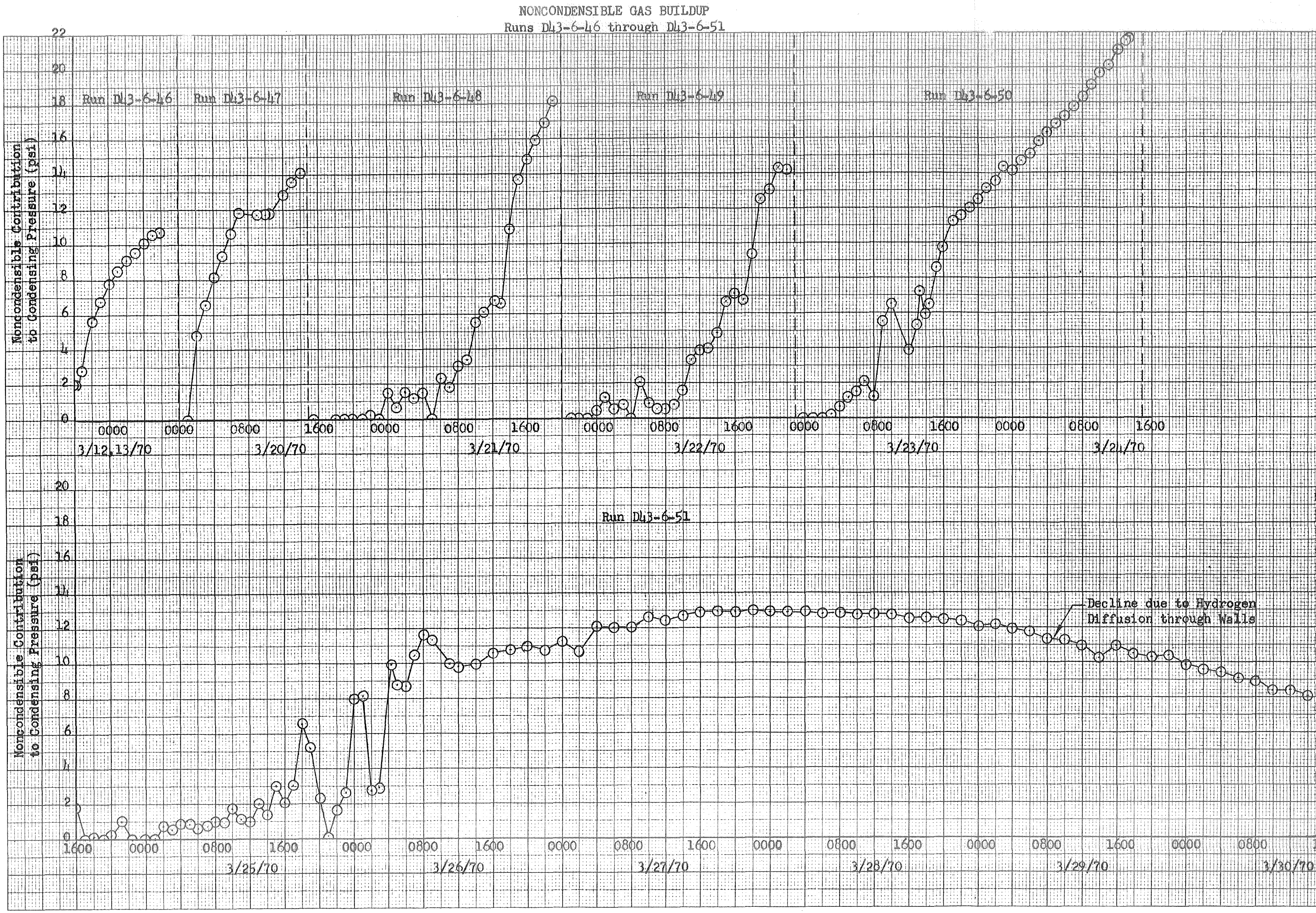

NONCONDENSIBLE GAS BUILDUP
Runs D43-6-46 through D43-6-51
Noncondensible Contribution to Condensing Pressure (psi)
Run D43-6-46
Run D43-6-47
Run D43-6-48
Run D43-6-49
Run D43-6-50
3/12,13/70
3/20/70
3/21/70
3/22/70
3/23/70
3/24/70
Run D43-6-51
Decline due to Hydrogen Diffusion through Walls
3/25/70
3/26/70
3/27/70
3/28/70
3/29/70
3/30/70

Figure 3

AUTOMATIC SHUTDOWN FROM LOSS OF HRL FLOW
BOILER DUMPED, CONDENSER NOT DUMPED
Mercury Flow = 6000 lb/hr
PCS-1 Data of 27 May 1970
Test No. 3

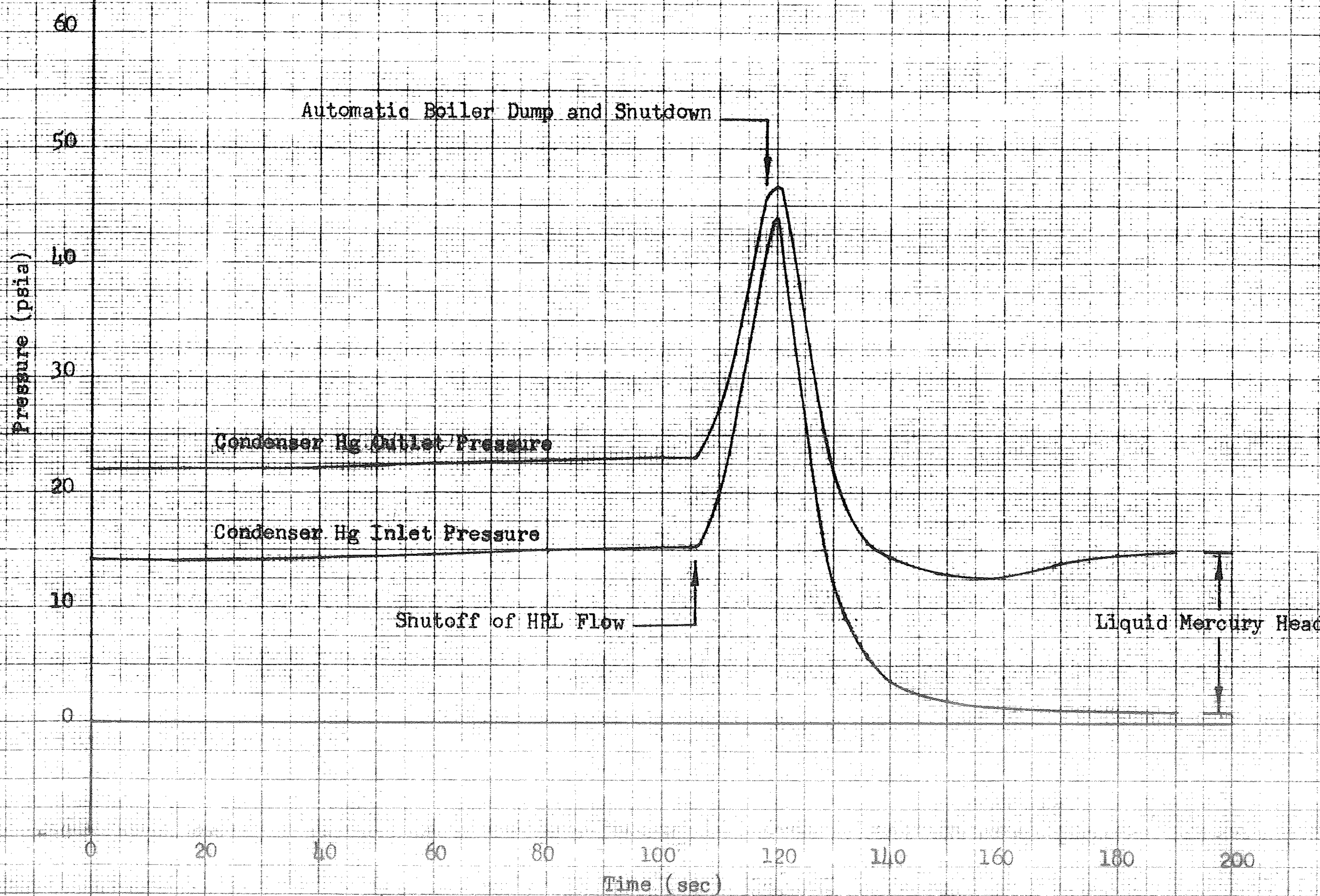


Figure 4

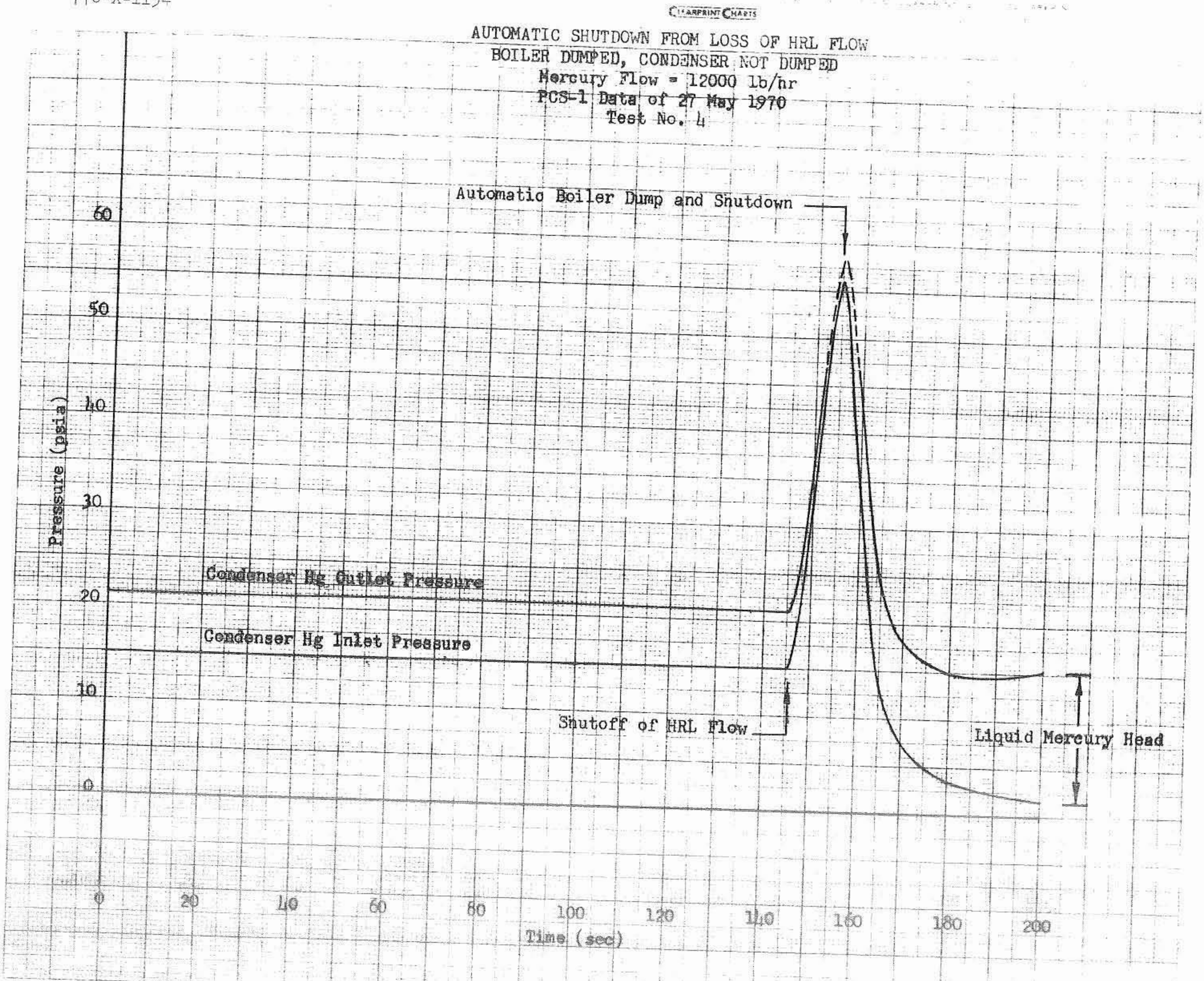

CLEARPRINT CHARTS
AUTOMATIC SHUTDOWN FROM LOSS OF HRL FLOW
BOILER DUMPED, CONDENSER NOT DUMPED
Mercury Flow = 12000 lb/hr
PCS-1 Data of 27 May 1970
Test No. 4
Automatic Boiler Dump and Shutdown
Pressure (psia)
60
50
40
30
20
10
0
Condenser Hg Outlet Pressure
Condenser Hg Inlet Pressure
Shutoff of HRL Flow
Liquid Mercury Head
0
20
40
60
80
100
120
140
160
180
200
Time (sec)

Figure 5

770-X-1155

AUTOMATIC SHUTDOWN FROM LOSS OF HRL FLOW
CONDENSER DUMPED, BOILER NOT DUMPED
Mercury Flow = 6000 lb/hr
PCS-1 Data of 27 May 1970
Test No. 5

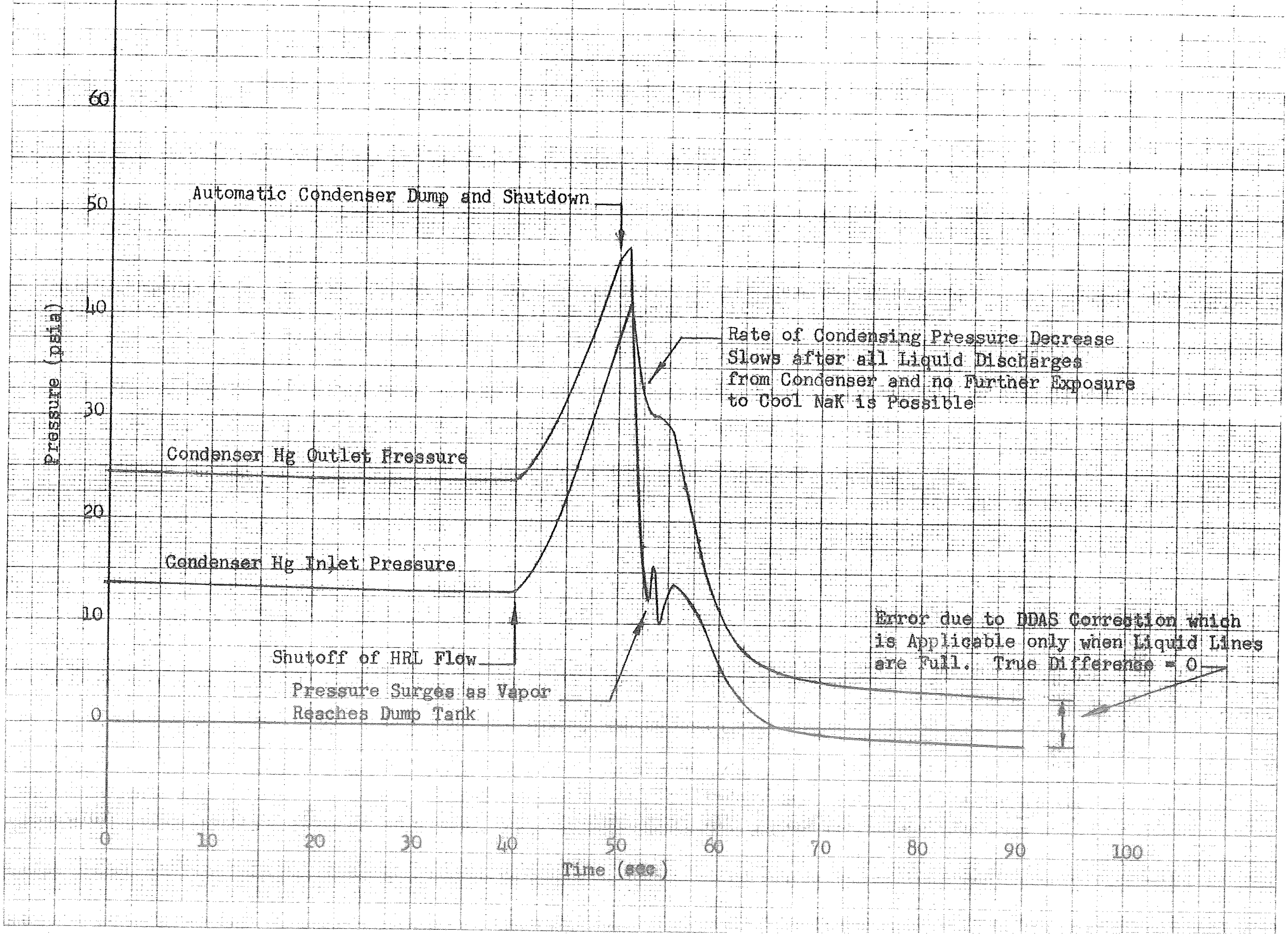


Figure 6

770-X-1163

AUTOMATIC SHUTDOWN FROM LOSS OF HRL FLOW
CONDENSER DUMPED, BOILER NOT DUMPED
Mercury Flow = 12000 lb/hr
PCS-1 Data of 27 May 1970
Test No. 6

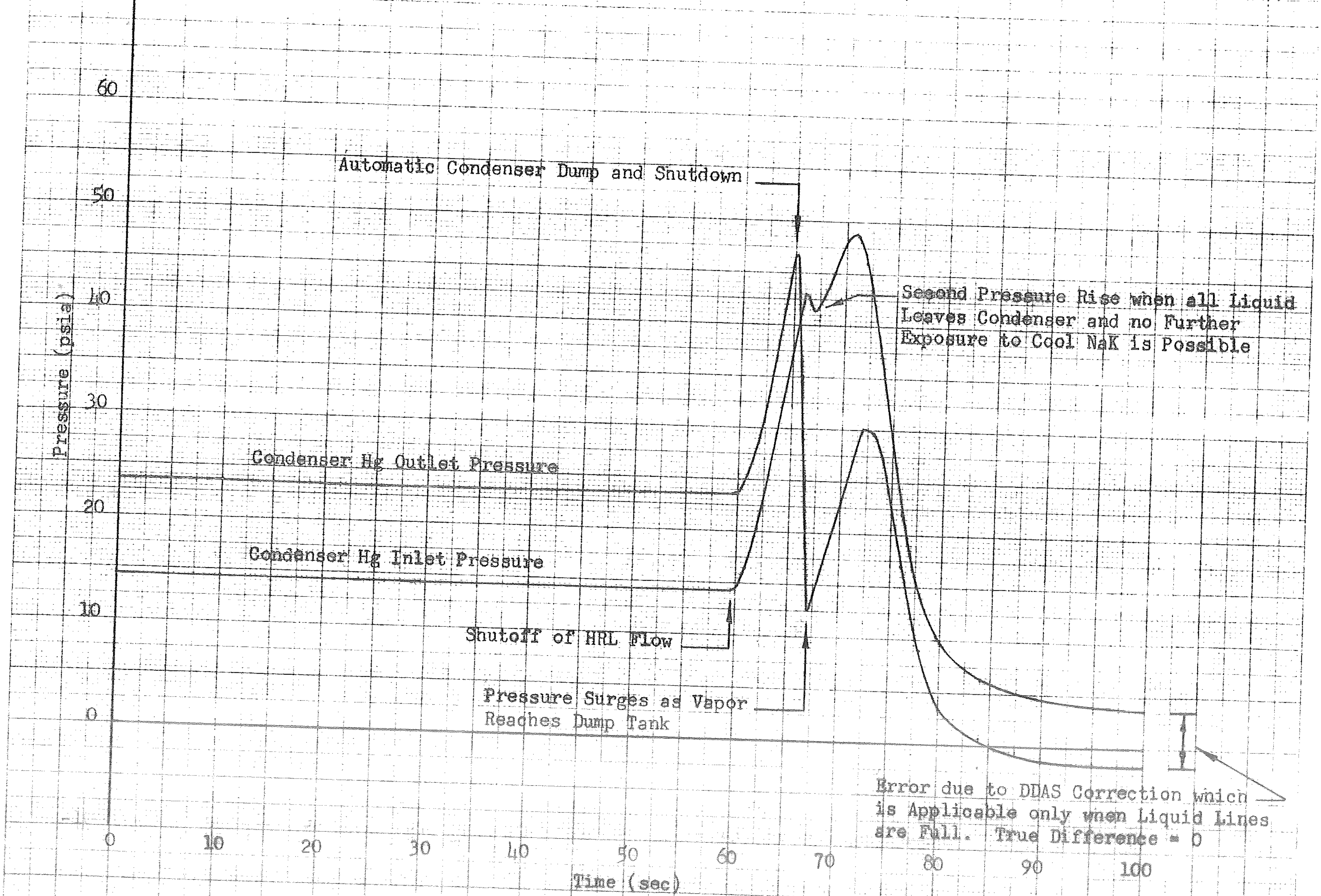


Figure 7

AUTOMATIC SHUTDOWN FROM LOSS OF HRL FLOW
CONDENSER DUMPED, BOILER NOT DUMPED
Mercury Flow = 12000 lb/hr
FCS-1 Data of 27 May 1970
Test No. 6 (Repeat)

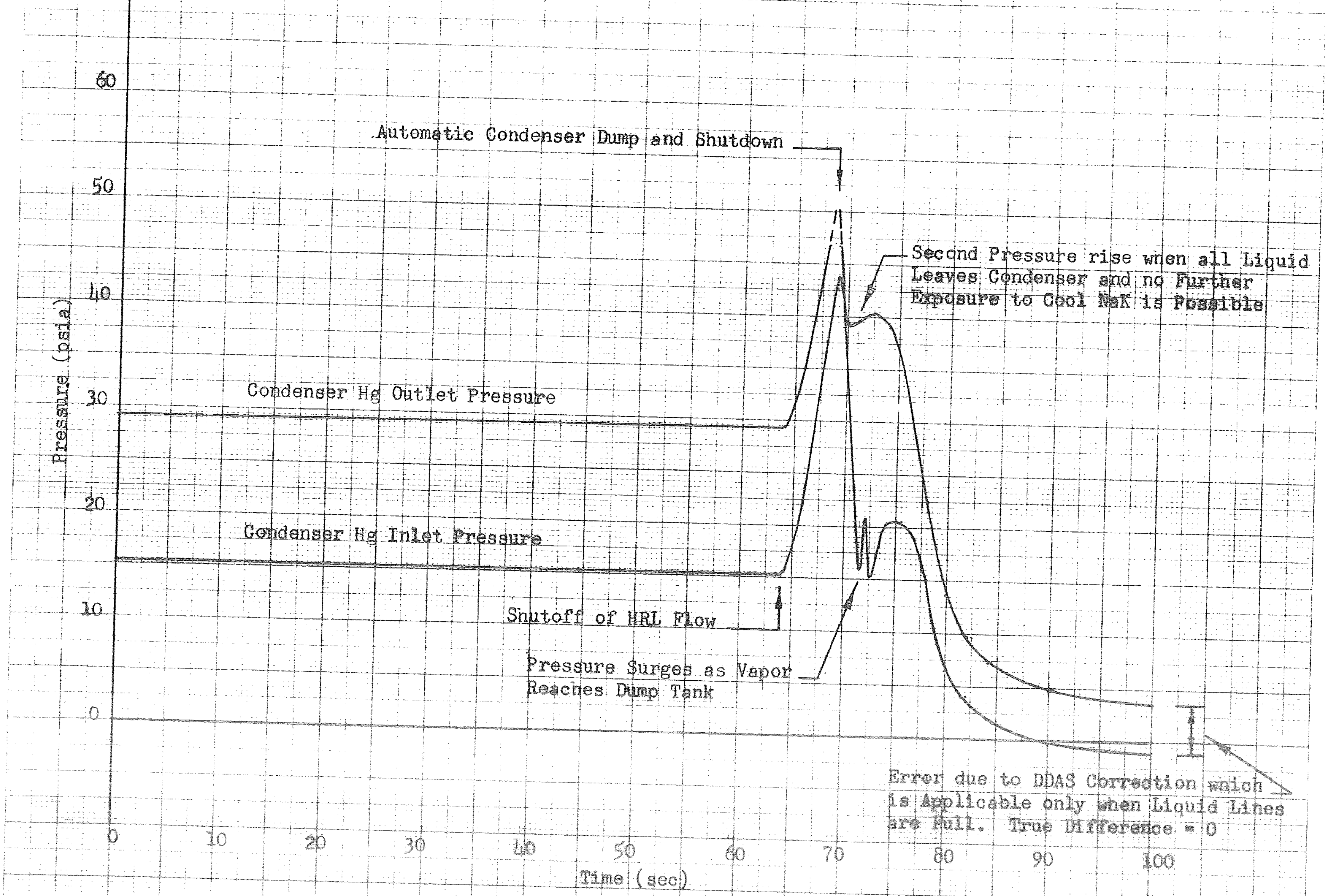


Figure 8

770-X-1157

AUTOMATIC SHUTDOWNS FROM LOSS OF HRL FLOW
CONDENSING PRESSURE VS TIME
PCS-1 Data of 27 May 1970

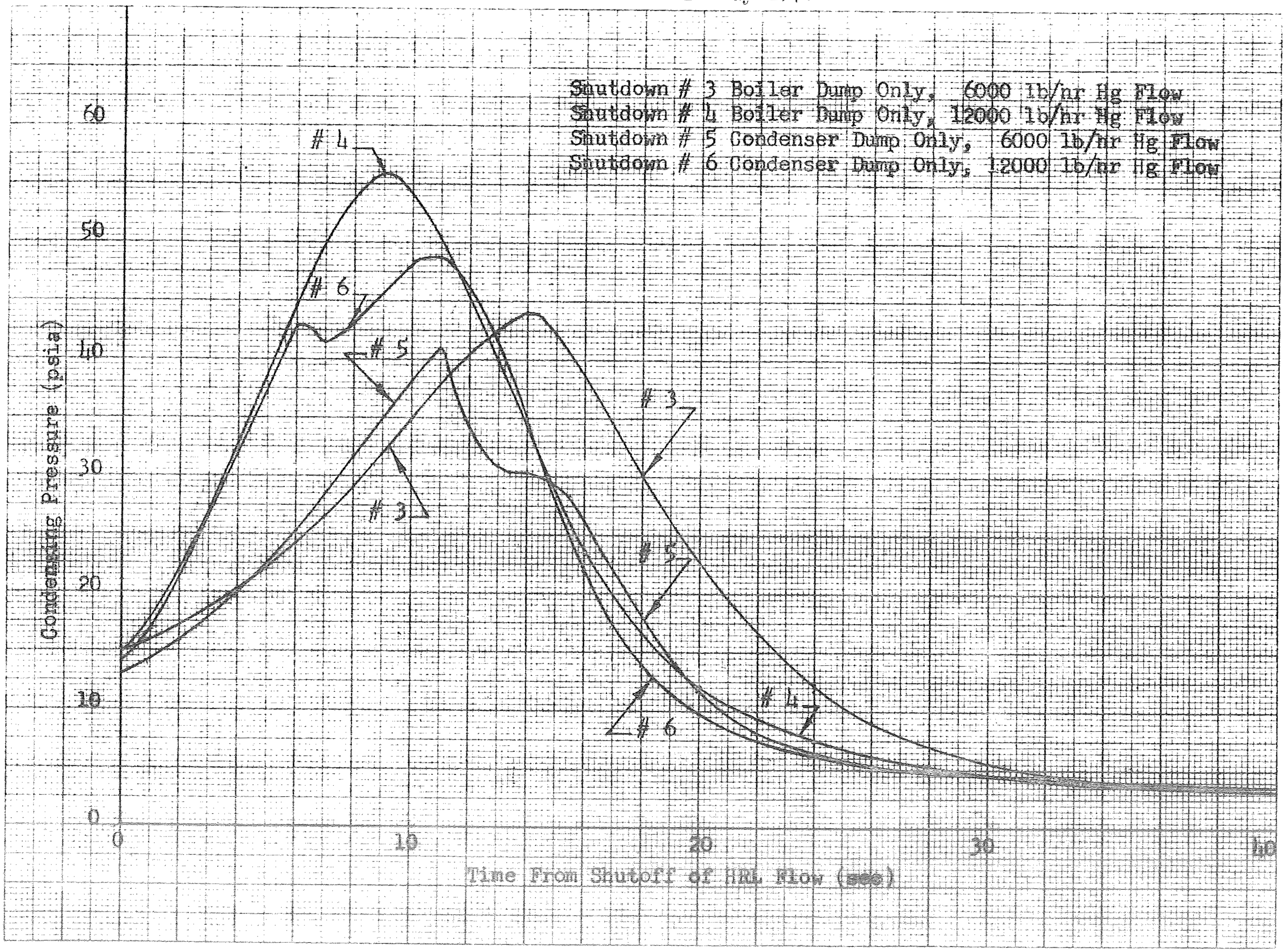


Figure 9

770-X-1158

AUTOMATIC SHUTDOWNS FROM LOSS OF HRL FLOW
CONDENSER MERCURY INVENTORY VS TIME
PCS-1 Data of 27 May 1970

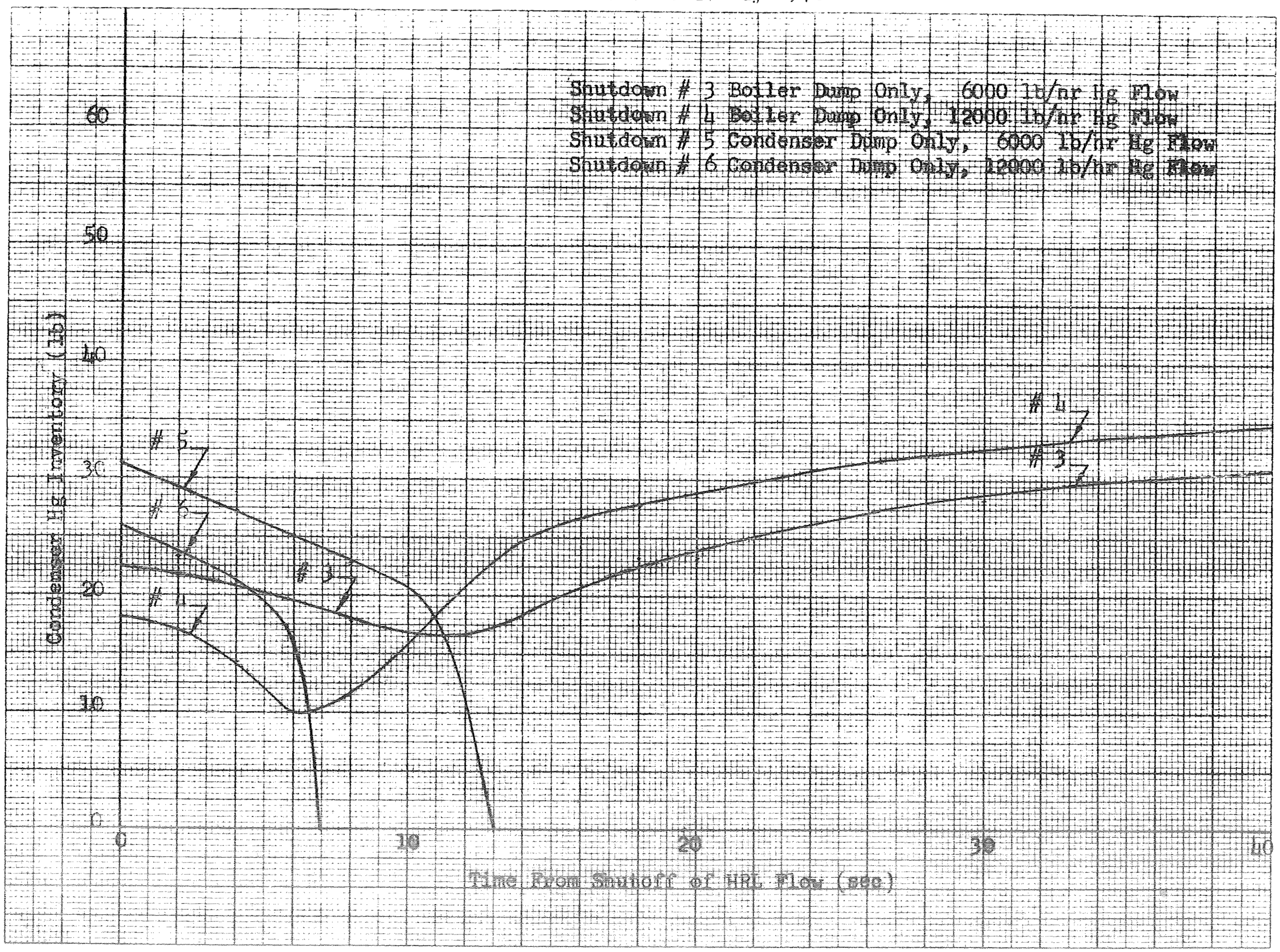


Figure 10

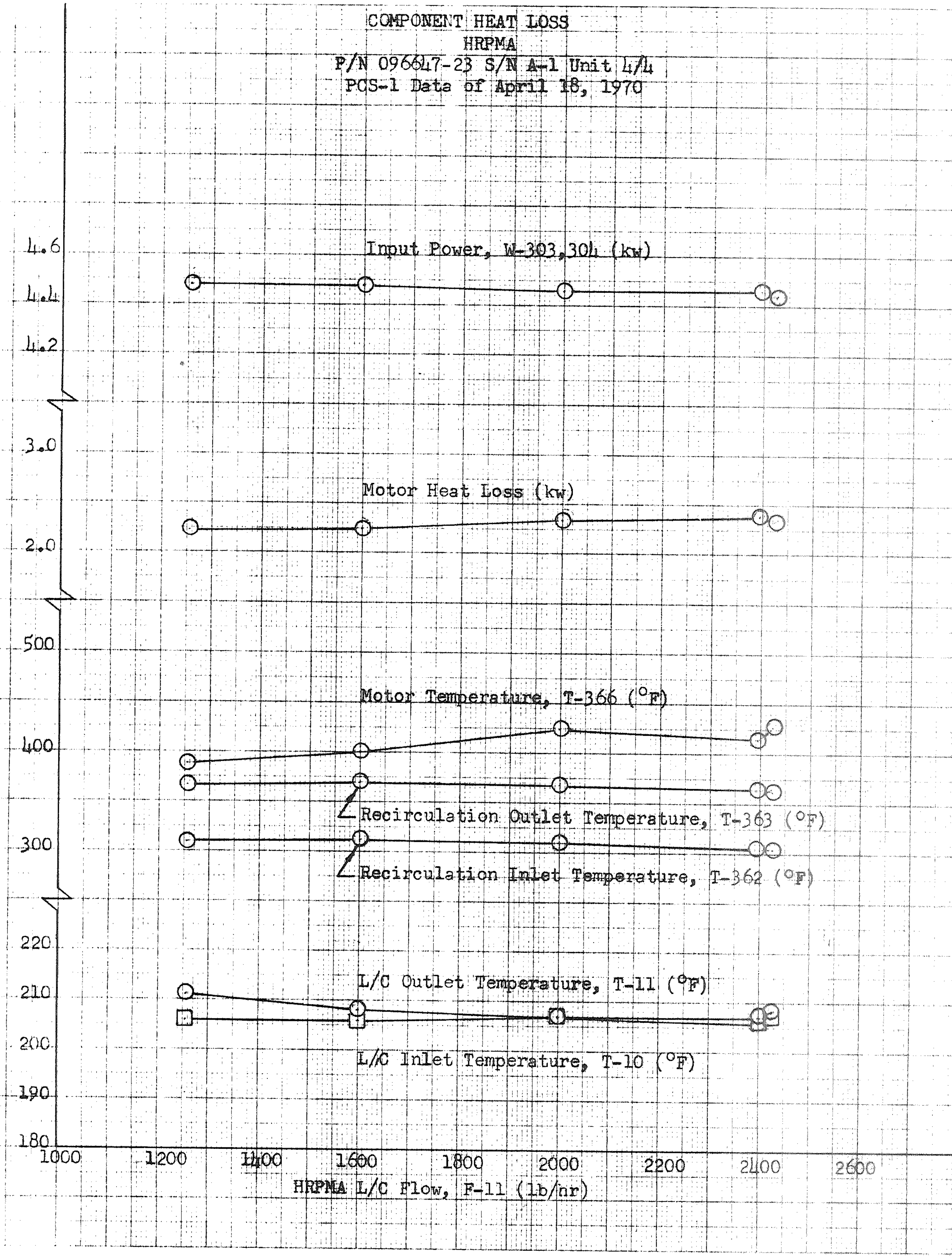
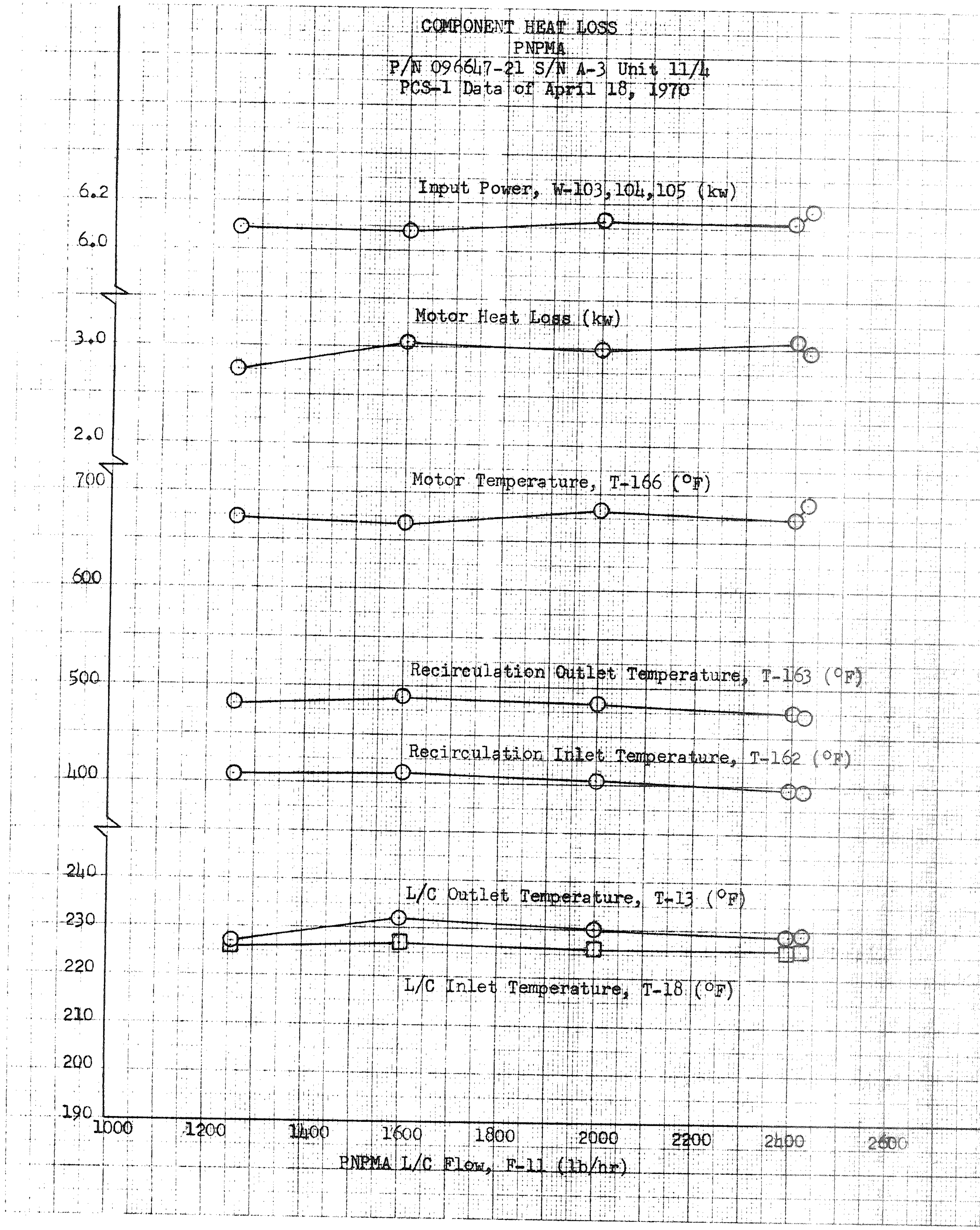

COMPONENT HEAT LOSS
HRPMA
P/N 096647-23 S/N A-1 Unit 4/4
PCS-1 Data of April 18, 1970
Input Power, W-303,304 (kw)
Motor Heat Loss (kw)
Motor Temperature, T-366 (°F)
Recirculation Outlet Temperature, T-363 (°F)
Recirculation Inlet Temperature, T-362 (°F)
L/C Outlet Temperature, T-11 (°F)
L/C Inlet Temperature, T-10 (°F)
4.6
4.4
4.2
3.0
2.0
500
400
300
220
210
200
190
180
1000
1200
1400
1600
1800
2000
2200
2400
2600
HRPMA L/C Flow, F-11 (lb/hr)

Figure 11



COMPONENT HEAT LOSS
PNPMA
P/N 096647-21 S/N A-3 Unit 11/4
PCS-1 Data of April 18, 1970
Input Power, W-103,104,105 (kw)
Motor Heat Loss (kw)
Motor Temperature, T-166 (°F)
Recirculation Outlet Temperature, T-163 (°F)
Recirculation Inlet Temperature, T-162 (°F)
L/C Outlet Temperature, T-13 (°F)
L/C Inlet Temperature, T-18 (°F)
6.2
6.0
3.0
2.0
700
600
500
400
240
230
220
210
200
190
1000
1200
1400
1600
1800
2000
2200
2400
2600
PNPMA L/C Flow, F-11 (lb/hr)

Figure 12

COMPONENT HEAT LOSS
MPMA
P/N 098100-15 S/N A-2 Unit 6/7
PCS-1 Data of April 18, 1970

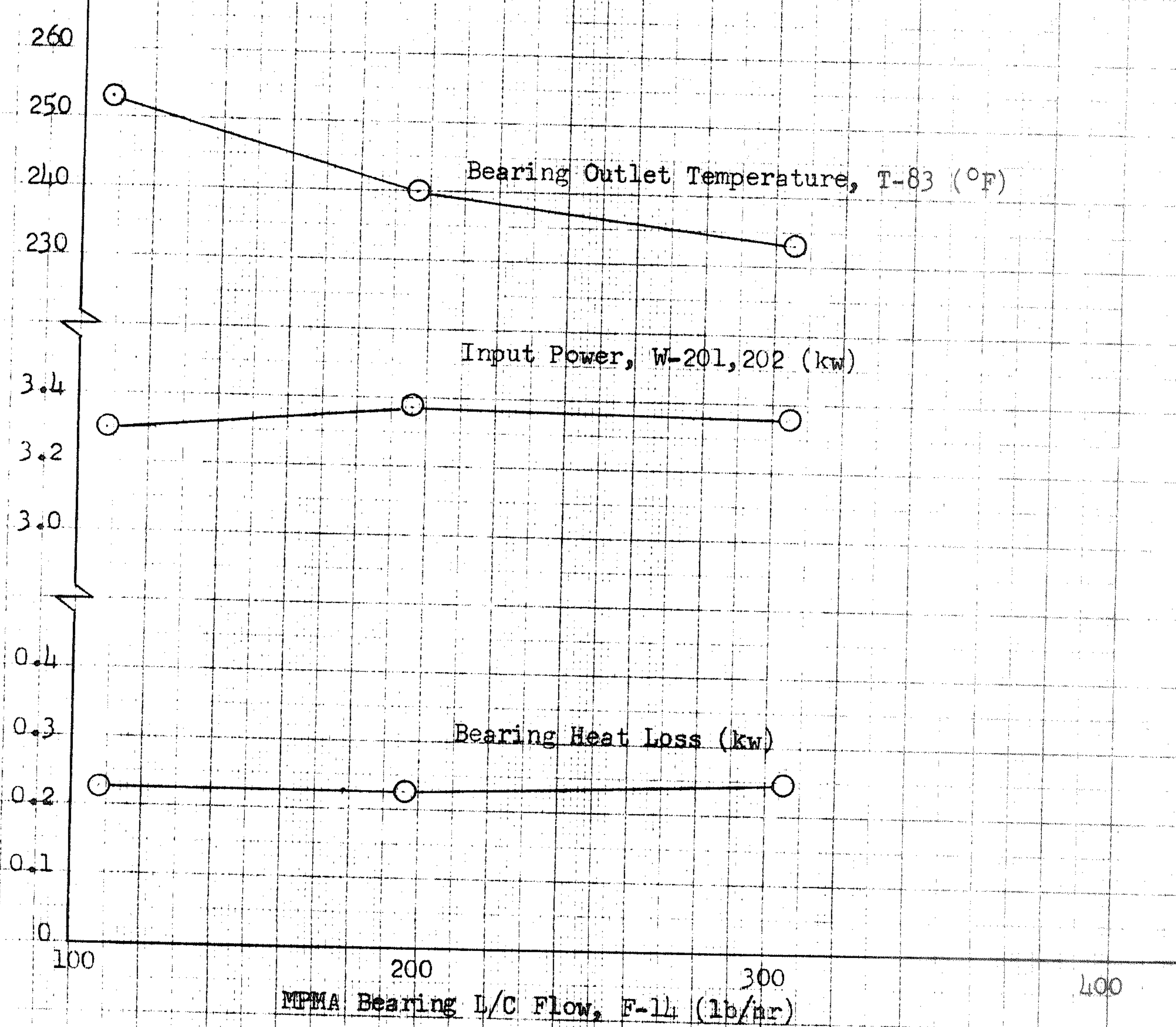


Figure 13

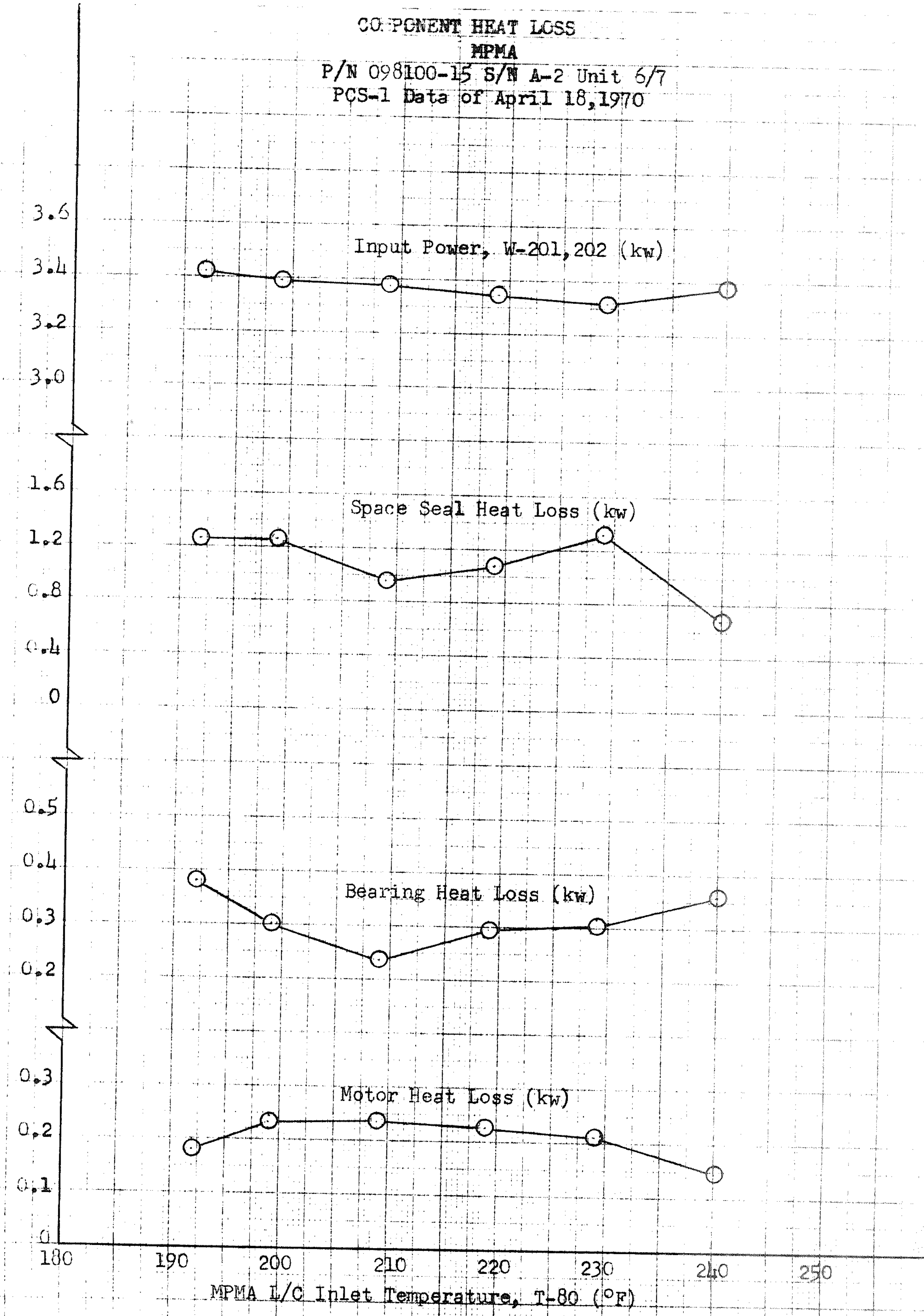

COMPONENT HEAT LOSS
MPMA
P/N 098100-15 S/N A-2 Unit 6/7
PCS-1 Data of April 18, 1970
Input Power, W-201,202 (kw)
Space Seal Heat Loss (kw)
Bearing Heat Loss (kw)
Motor Heat Loss (kw)
3.6
3.4
3.2
3.0
1.6
1.2
0.8
0.4
0
0.5
0.4
0.3
0.2
0.3
0.2
0.1
0
180
190
200
210
220
230
240
250
MPMA L/C Inlet Temperature, T-80 (°F)

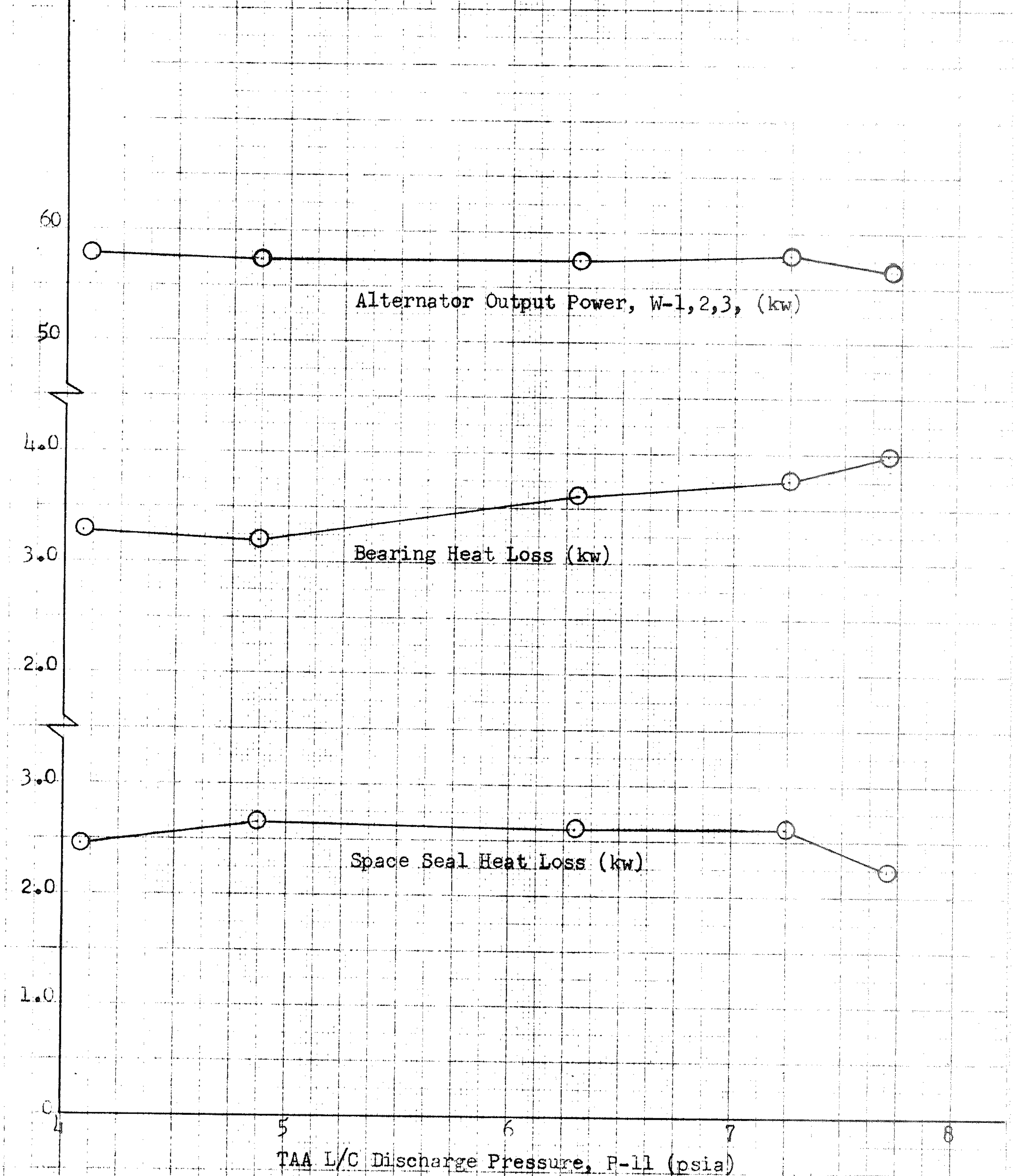
Figure 13

COMPONENT HEAT LOSS

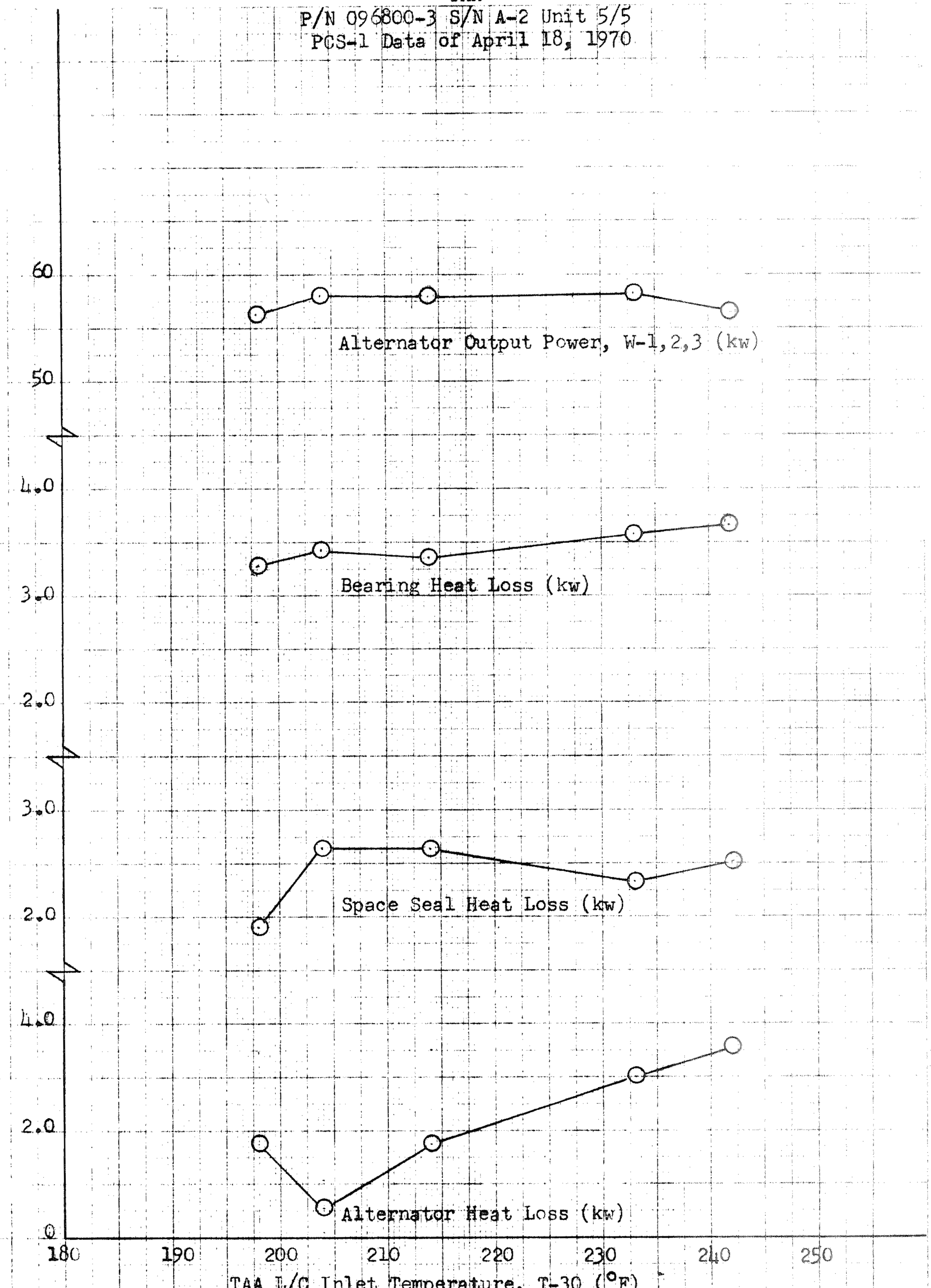
TAA

P/N 096800-3 S/N A-2 Unit 5/5

PCS-1 Data of April 18, 1970



COMPONENT HEAT LOSS
TAA
P/N 096800-3 S/N A-2 Unit 5/5
PCS-1 Data of April 18, 1970



TAA PERFORMANCE
ALTERNATOR POWER VS MERCURY VAPOR FLOW
P/N 096800-3 S/N A-2 Unit 5/5
PCS-1 PHASE IV STEP 3

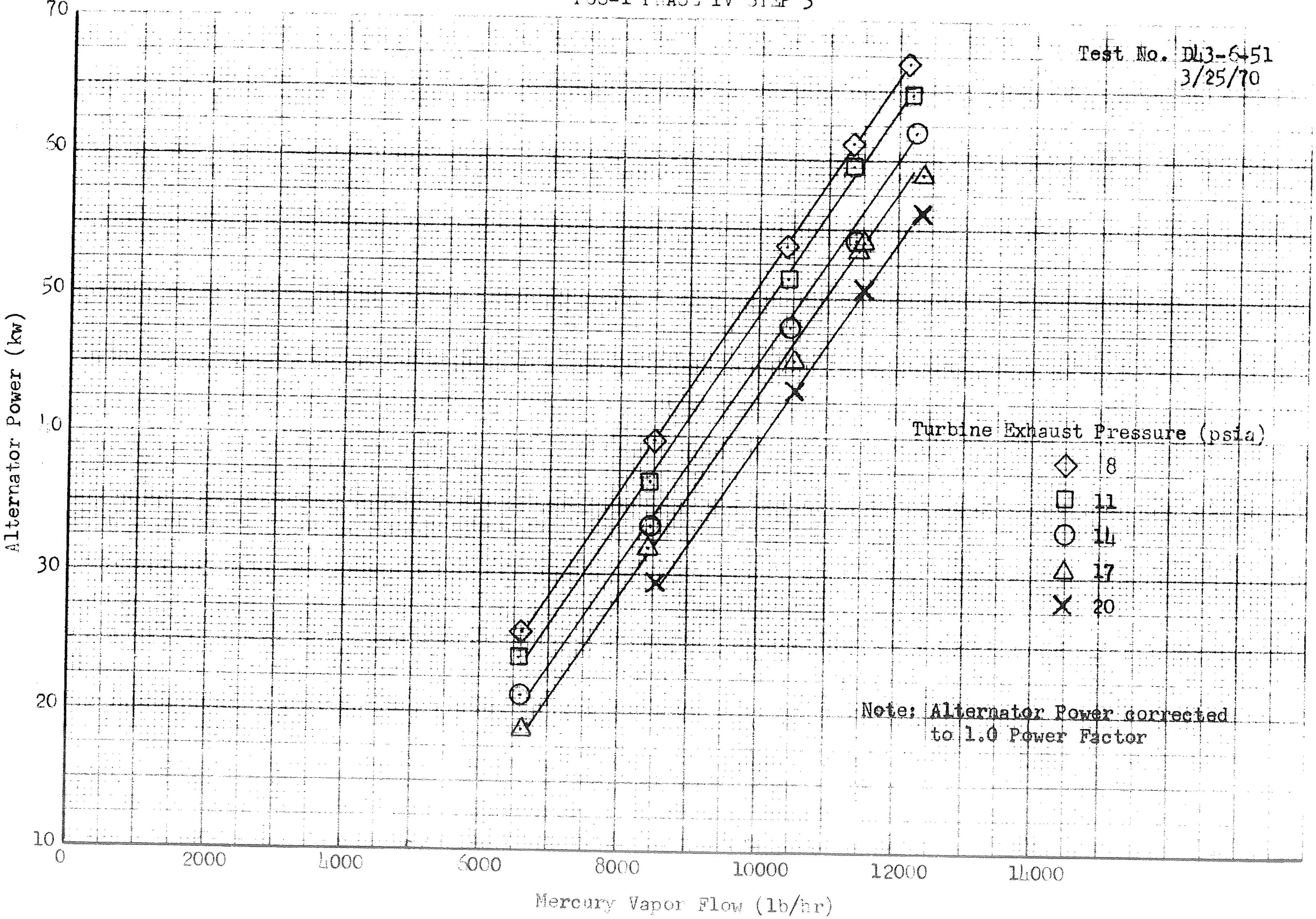


Figure 15

TAA PERFORMANCE
TURBINE EFFICIENCY VS VELOCITY RATIO
P/N 096800-3 S/N A-2 Unit 5/5
PCS-1 PHASE IV STEP 3

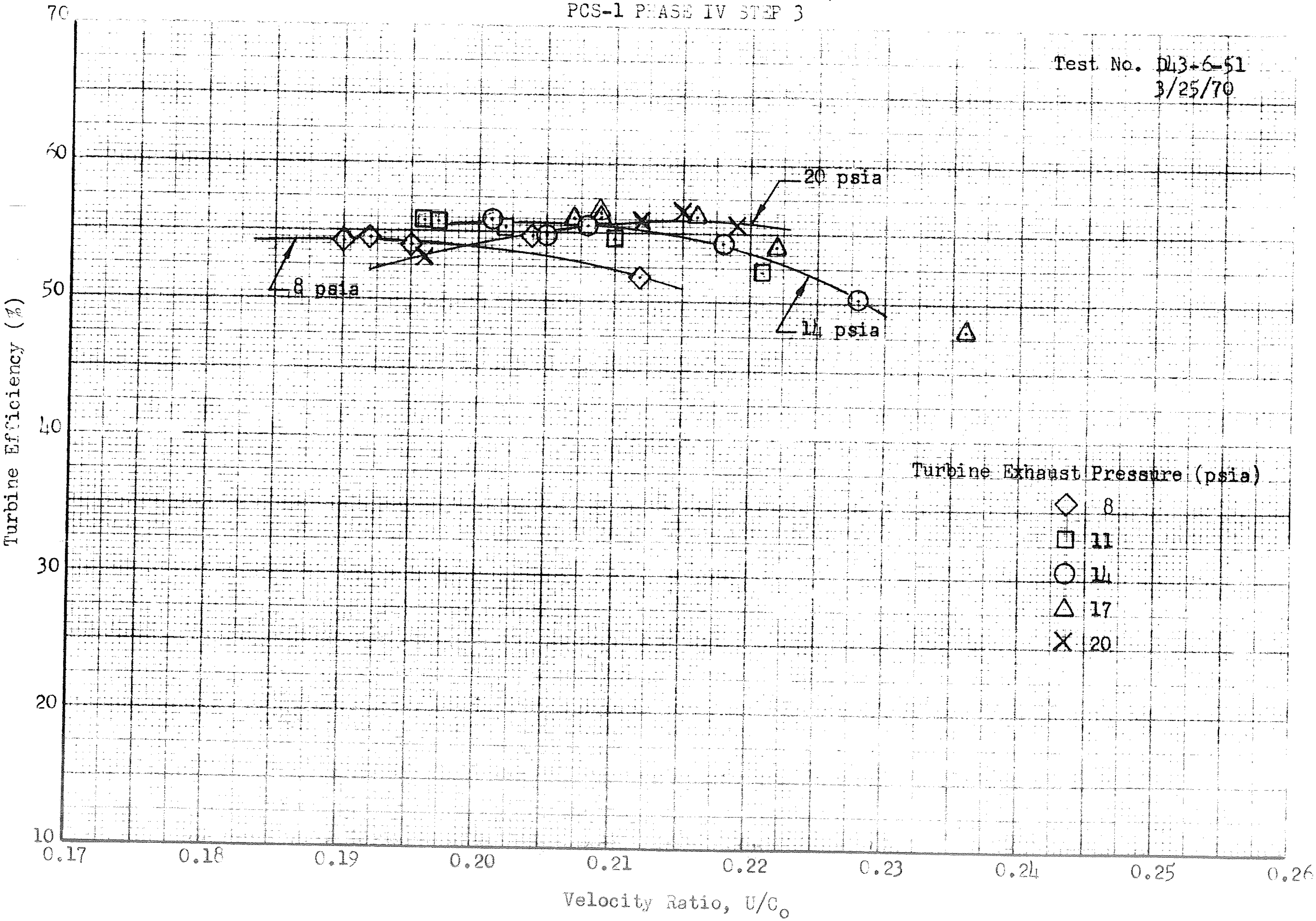


Figure 16

770-X-11--

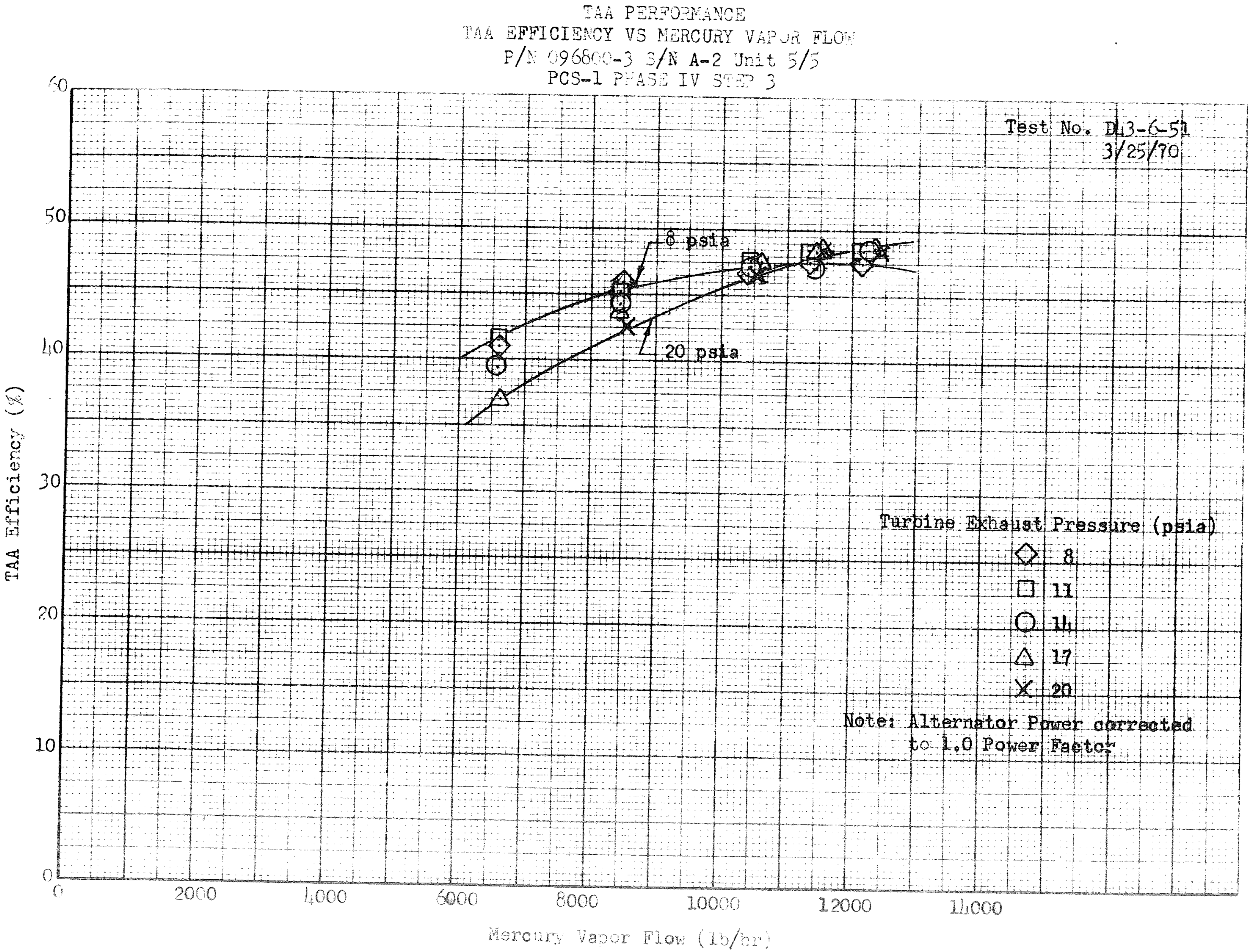
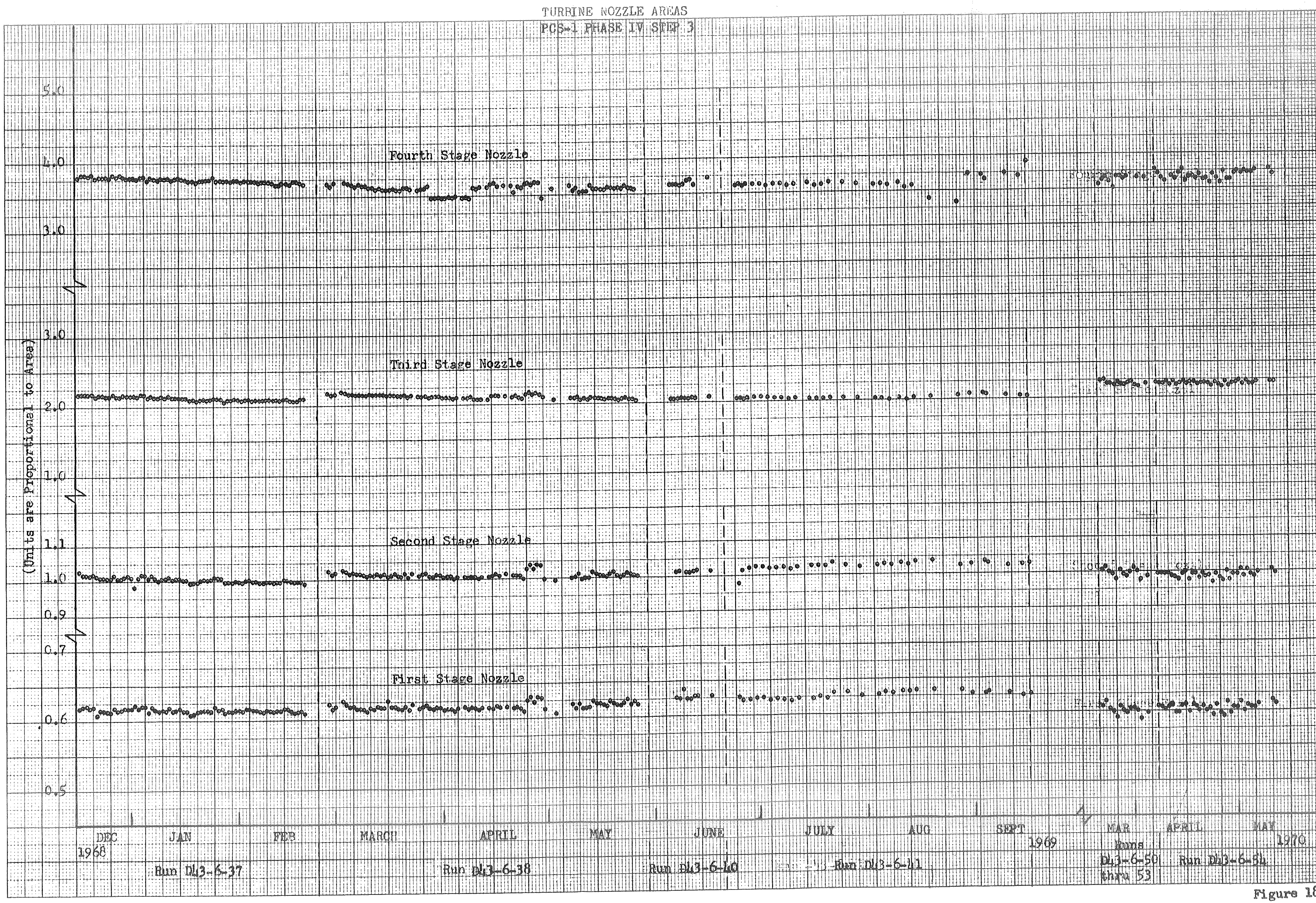
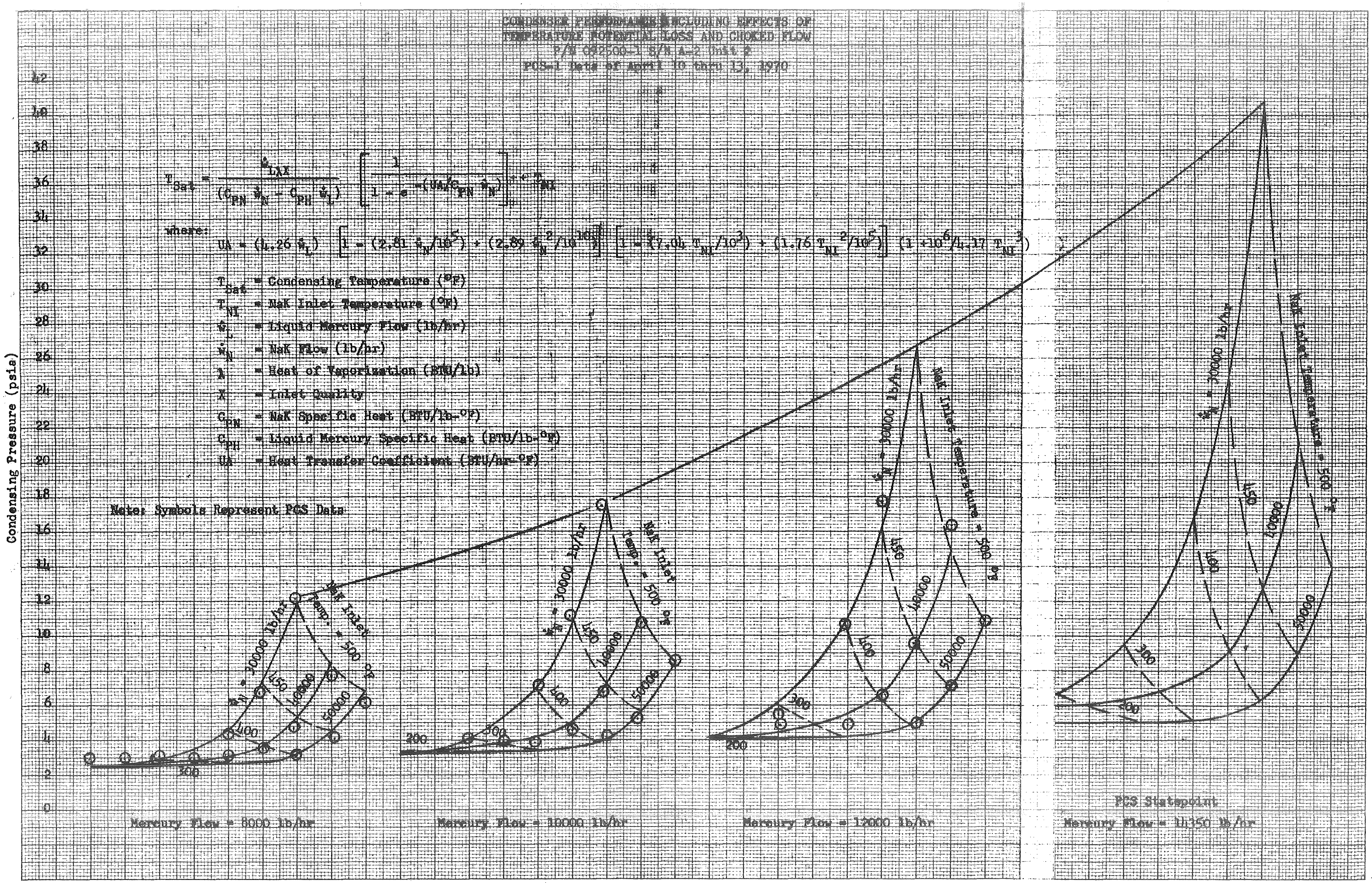


Figure 17



TURBINE NOZZLE AREAS
PCS-1 PHASE IV STEP 3
(Units are Proportional to Area)
Fourth Stage Nozzle
Third Stage Nozzle
Second Stage Nozzle
First Stage Nozzle
5.0
4.0
3.0
3.0
2.0
1.0
1.1
1.0
0.9
0.7
0.6
0.5
DEC
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
AUG
SEPT
MAR
APRIL
MAY
1968
1969
1970
Run D43-6-37
Run D43-6-38
Run D43-6-40
Run D43-6-41
Runs D43-6-50 thru 53
Run D43-6-54

Figure 18



CONDENSER PERFORMANCE INCLUDING EFFECTS OF
TEMPERATURE POTENTIAL LOSS AND CHOKED FLOW
P/N 092500-1 S/N A-2 Unit 2
PCS-1 Data of April 10 thru 13, 1970
$T_{Sat} = \frac{\dot{w}_L \lambda X}{(C_{PN}\dot{w}_N - C_{PH}\dot{w}_L)}\left[\frac{1}{1 - e^{-(UA/C_{PN}\dot{w}_N)}}\right] + T_{NI}$
where:
$UA = (4.26\,\dot{w}_L)\left[1 - (2.81\,\dot{w}_N/10^5) + (2.89\,\dot{w}_N^2/10^{10})\right]\left[1 - (7.04\,T_{NI}/10^3) + (1.76\,T_{NI}^2/10^5)\right](1 + 10^6/4.17\,T_{NI}^3)$
T_{Sat} = Condensing Temperature (°F)
T_{NI} = NaK Inlet Temperature (°F)
$\dot{w}_L$ = Liquid Mercury Flow (lb/hr)
$\dot{w}_N$ = NaK Flow (lb/hr)
λ = Heat of Vaporization (BTU/lb)
X = Inlet Quality
C_{PN} = NaK Specific Heat (BTU/lb-°F)
C_{PH} = Liquid Mercury Specific Heat (BTU/lb-°F)
UA = Heat Transfer Coefficient (BTU/hr-°F)
Note: Symbols Represent PCS Data
Condensing Pressure (psia)
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
$\dot{w}_N$ = 30000 lb/hr
NaK Inlet Temp. = 500 °F
450
400
300
200
40000
50000
NaK Inlet Temperature = 500 °F
Mercury Flow = 8000 lb/hr
Mercury Flow = 10000 lb/hr
Mercury Flow = 12000 lb/hr
PCS Statepoint
Mercury Flow = 14350 lb/hr

Figure 19

CONDENSER NAK TEMPERATURE PROFILES SHOWING EFFECT OF
TEMPERATURE POTENTIAL LOSS AND CHOKED FLOW
P/N 092500-1 S/N A-2 Unit 2
PCS-1 Data of April 11, 1970

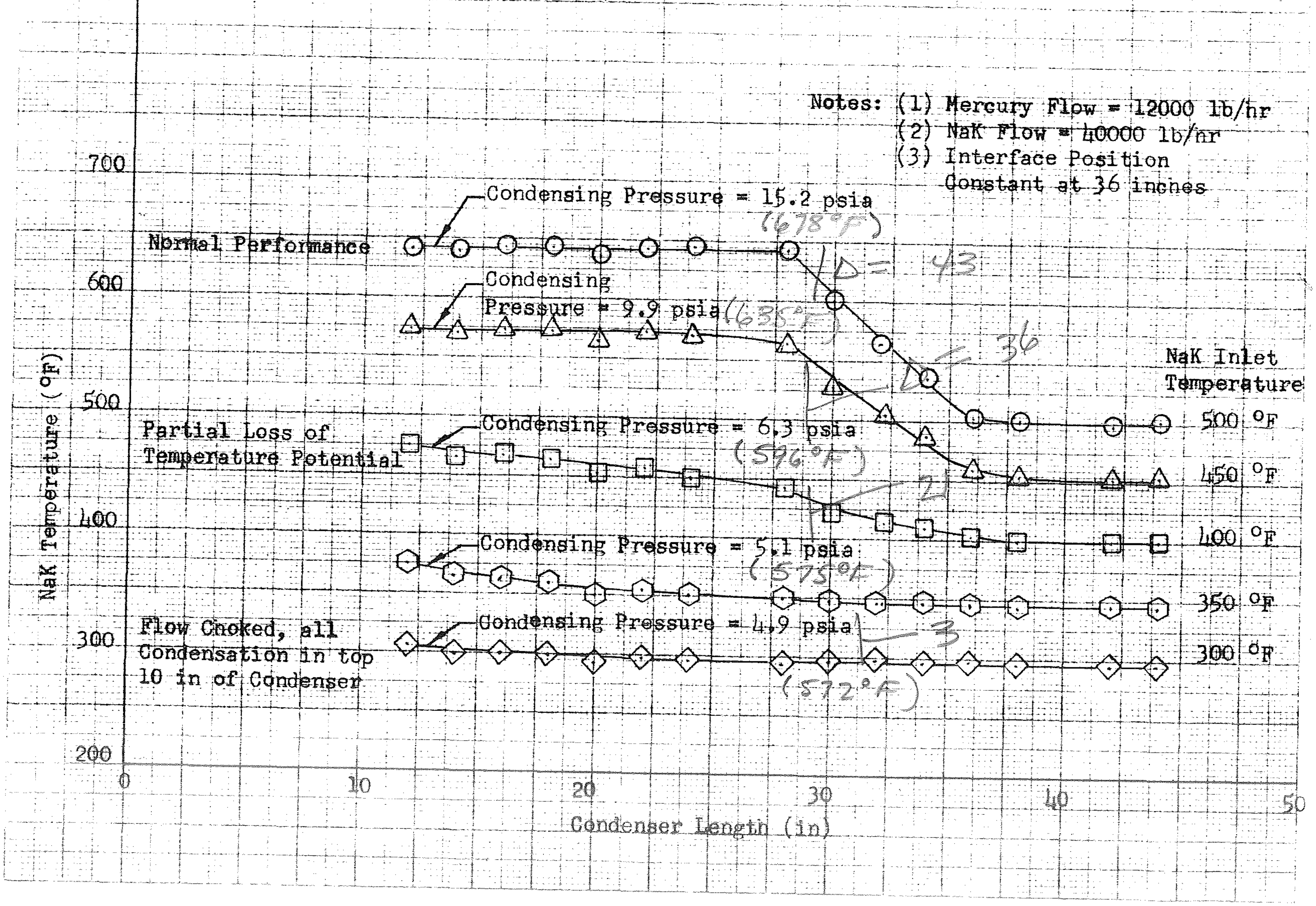
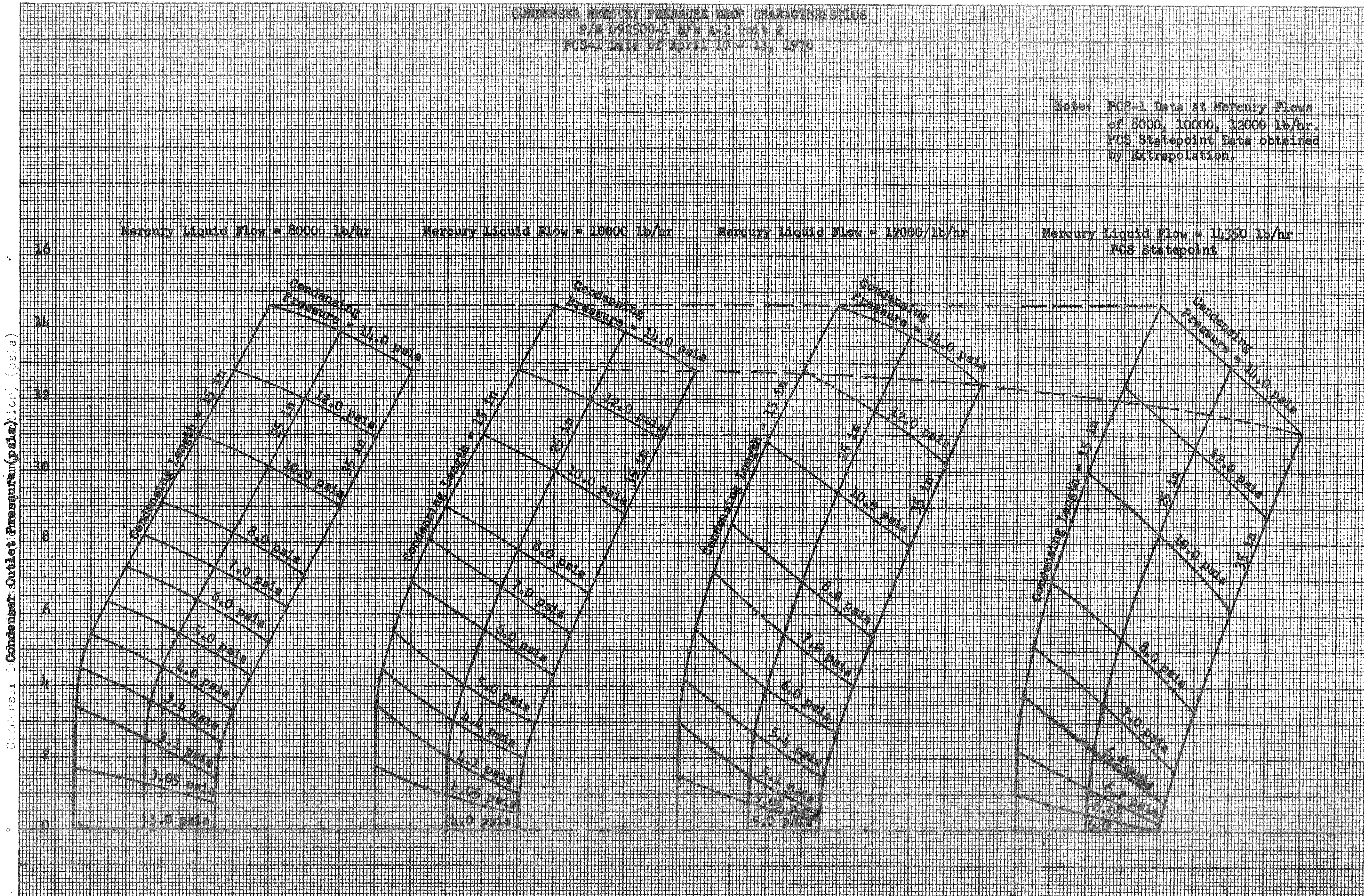


Figure 20



CONDENSER MERCURY PRESSURE DROP CHARACTERISTICS
P/N 092500-1 S/N A-2 Unit 2
PCS-1 Data of April 10 - 13, 1970
Note: PCS-1 Data at Mercury Flows of 8000, 10000, 12000 lb/hr. PCS Statepoint Data obtained by Extrapolation.
Mercury Liquid Flow = 8000 lb/hr
Mercury Liquid Flow = 10000 lb/hr
Mercury Liquid Flow = 12000/lb/hr
Mercury Liquid Flow = 14350 lb/hr
PCS Statepoint
Condenser Outlet Pressure (psia)
Condensing Pressure = 14.0 psia
Condensing Length = 15 in
25 in
35 in
12.0 psia
10.0 psia
8.0 psia
7.0 psia
6.0 psia
5.0 psia
4.0 psia
3.0 psia
16
14
12
10
8
6
4
2
0

Figure 21

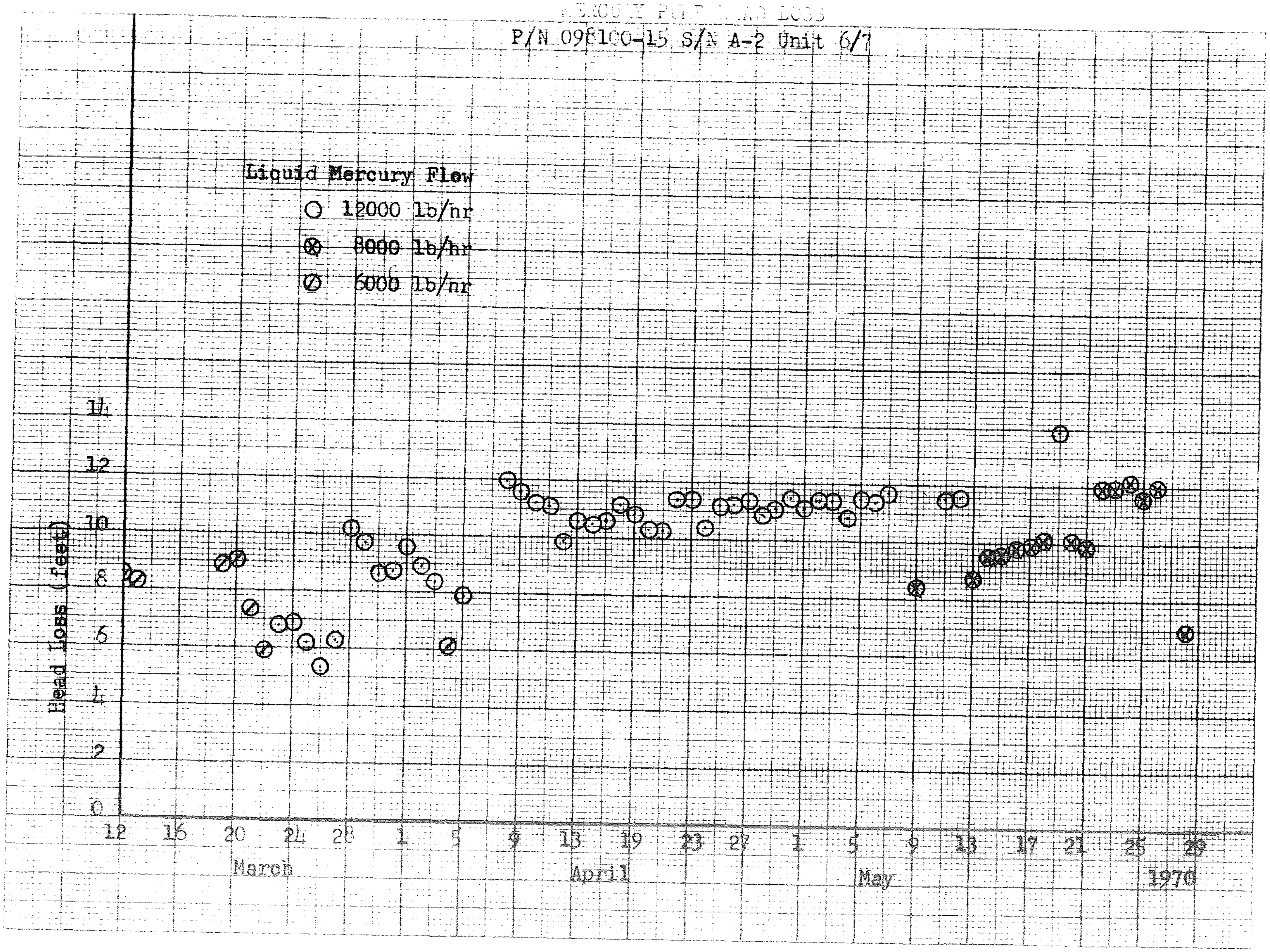

P/N 098100-15 S/N A-2 Unit 6/7
Liquid Mercury Flow
12000 lb/hr
8000 lb/hr
6000 lb/hr
Head loss (feet)
0
2
4
6
8
10
12
14
12
16
20
24
28
1
5
9
13
19
23
27
1
5
9
13
17
21
25
29
March
April
May
1970

Figure 22

BOILER PERFORMANCE
GENERAL STEADY-STATE MAPPING
P/N 1268911 S/N BRDC-4 Unit 11/1
PCS-1 Date of March 31 - April 5, 1970
TOTAL BOILER MERCURY PRESSURE DROP

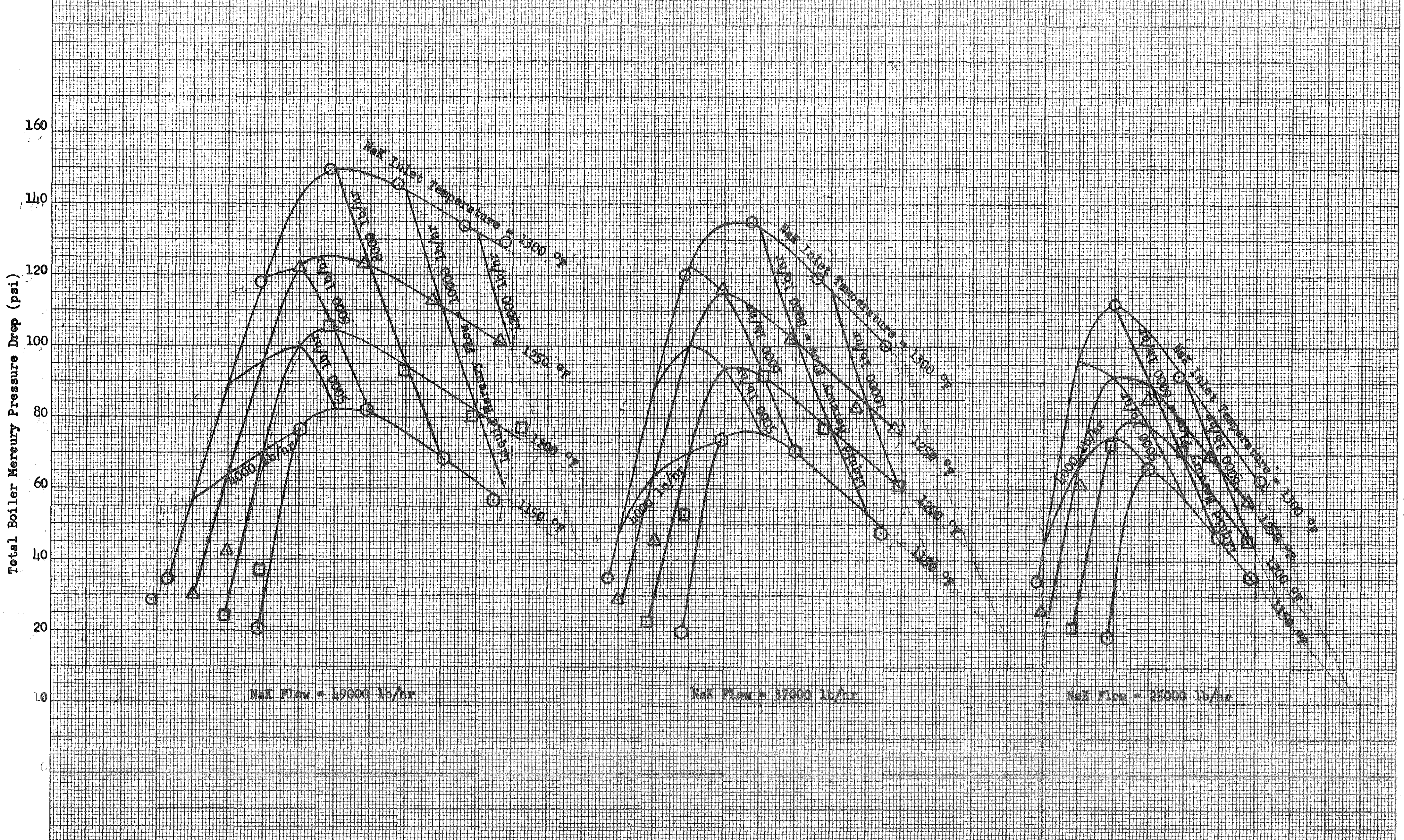


Figure 23

BOILER PERFORMANCE
GENERAL STEADY-STATE MAPPING
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Date of March 31 - April 5, 1970
MERCURY VAPOR PRESSURE DROP

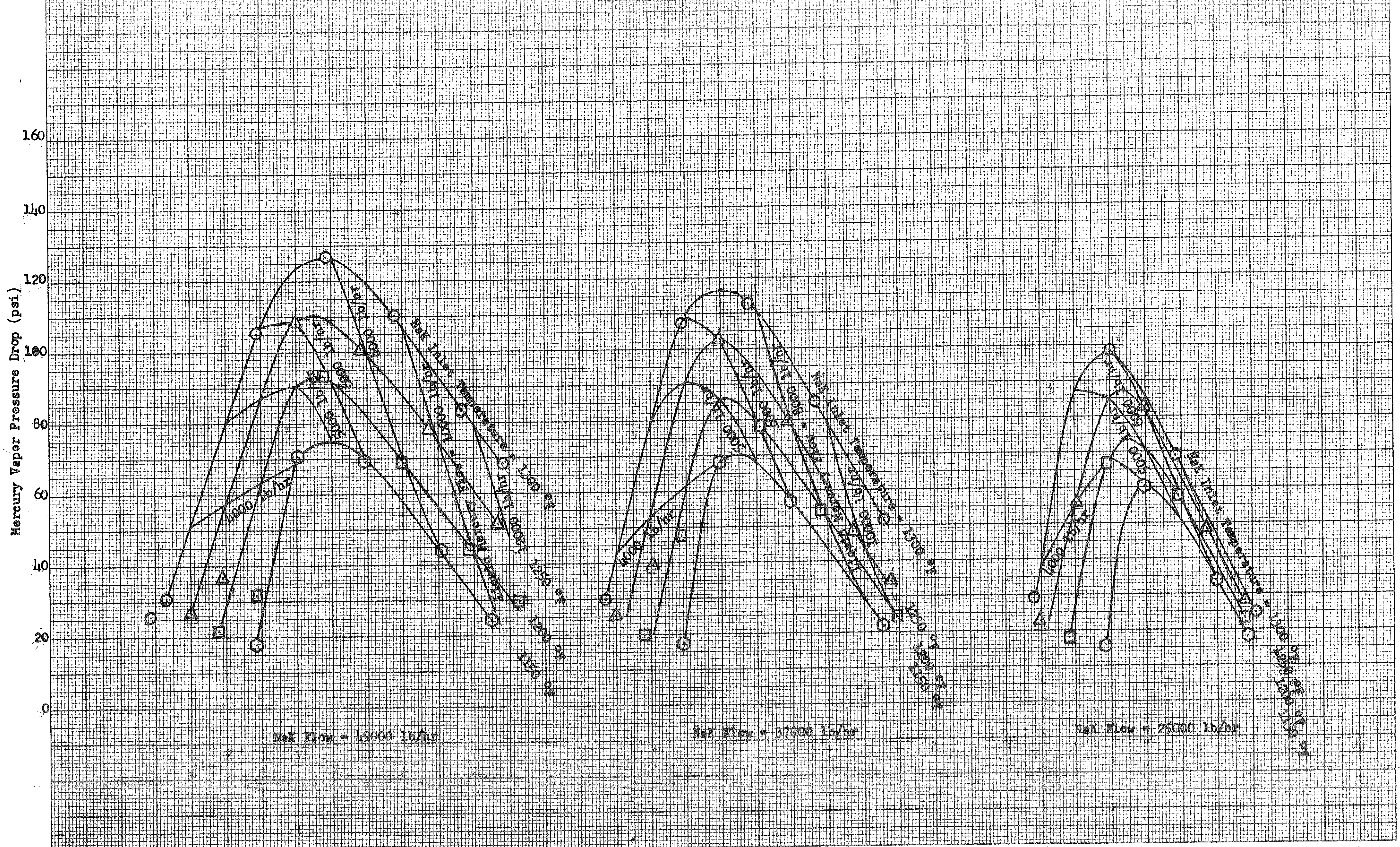


Figure 24

BOILER PERFORMANCE
GENERAL STEADY-STATE MAPPING
P/N 1266911 S/N BRDC-4 Unit 11/A
PCS-1 Data of March 31 - April 5, 1970
TERMINAL TEMPERATURE DIFFERENCE

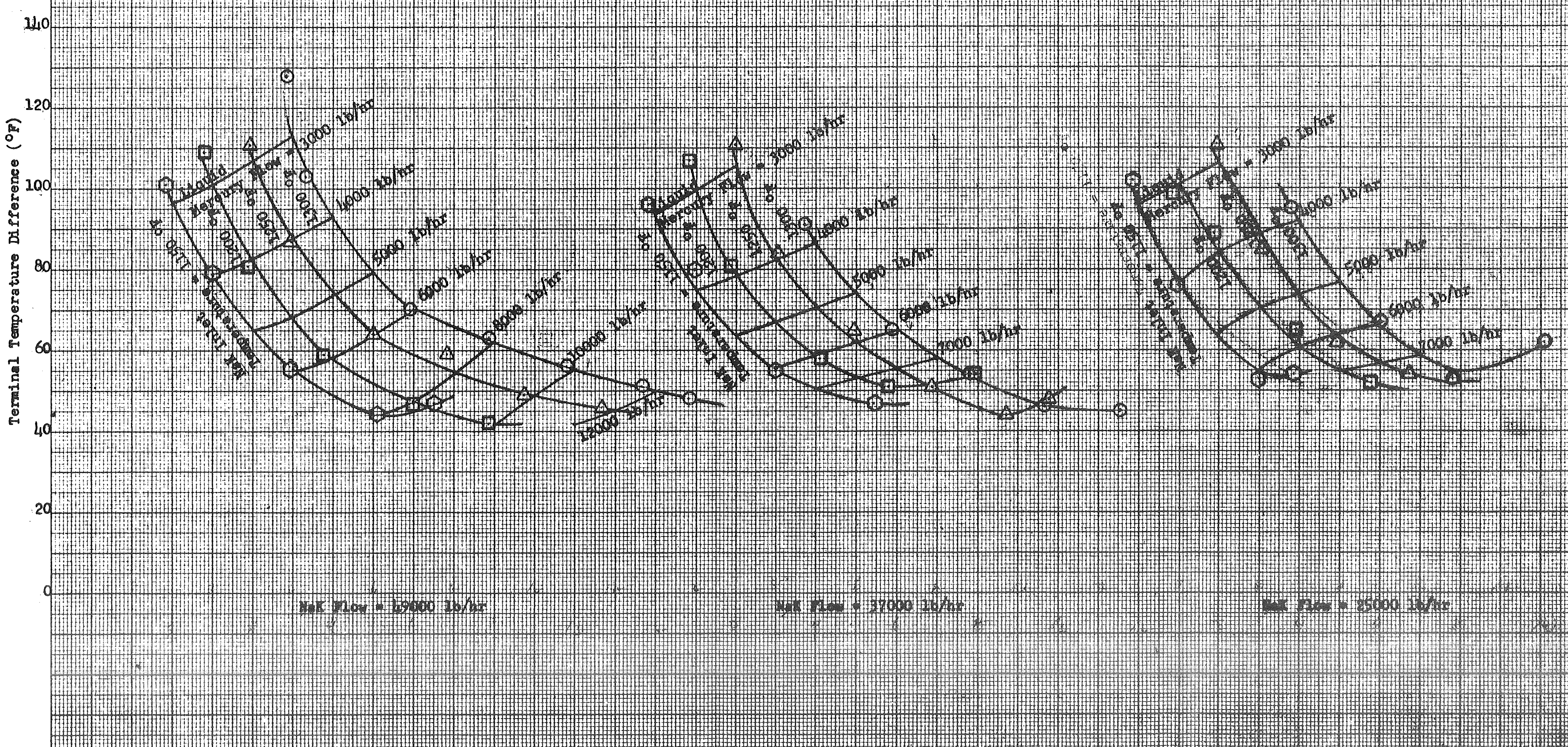


Figure 25

BOILER PERFORMANCE
GENERAL STEADY-STATE MAPPING
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Data of March 31 - April 5, 1970
PINCHPOINT TEMPERATURE DIFFERENCE

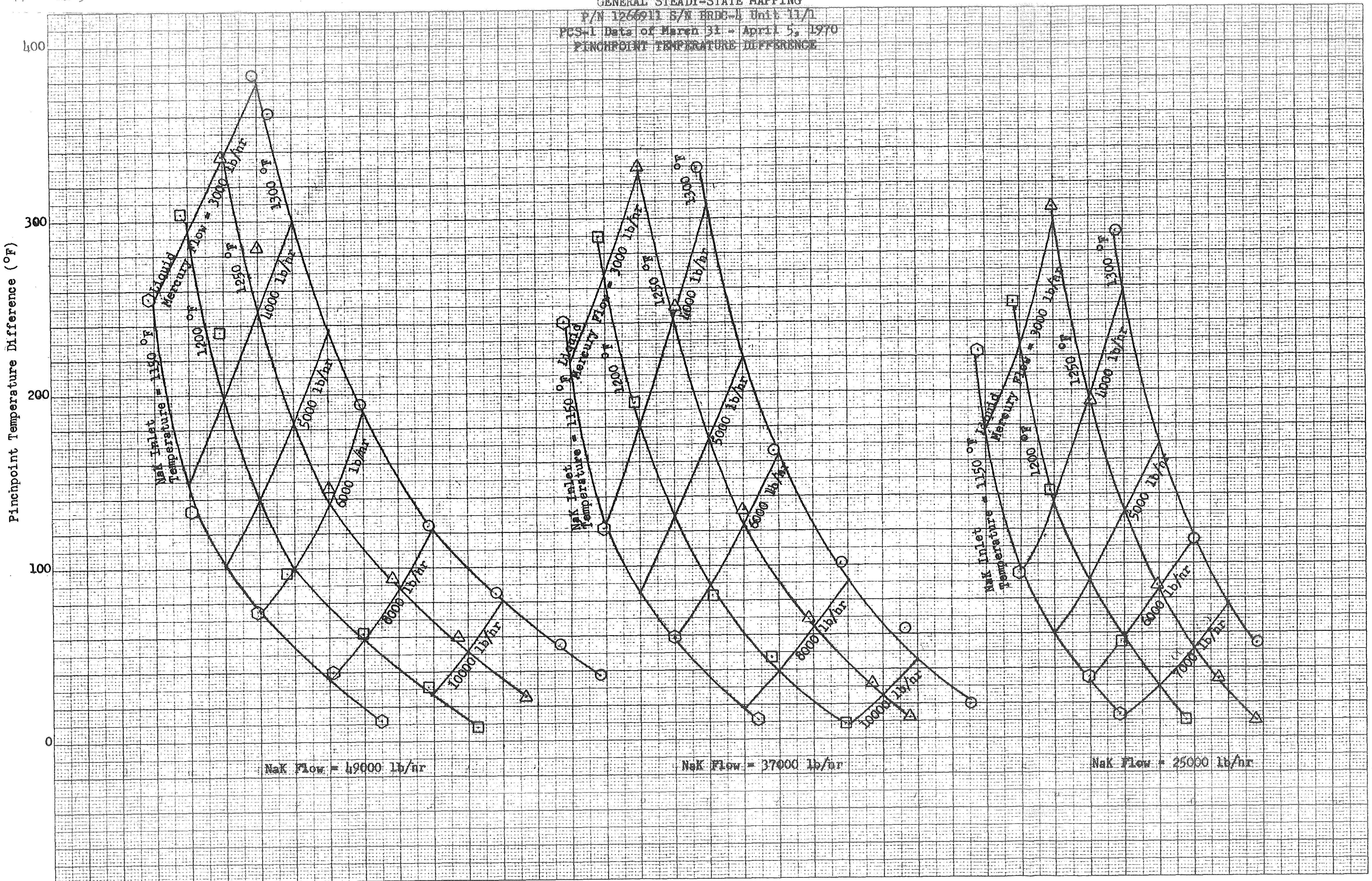


Figure 26

STRIP CHART RECORDING OF BOILER PRESSURE OSCILLATIONS
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Data of March 31 - April 5, 1970
GENERAL STEADY-STATE MAPPING

TEST CONDITION #1
T_{nbi} = 1299 °F
W_v = 12285 lb/hr
W_p = 48700 lb/hr
P_{Hbo} = 261.7 psia

TEST CONDITION #8
T_{nbi} = 1295 °F
W_v = 11070 lb/hr
W_p = 37200 lb/hr
P_{Hbo} = 238.9 psia

TEST CONDITION #14
T_{nbi} = 1289 °F
W_v = 9680 lb/hr
W_p = 26500 lb/hr
P_{Hbo} = 206.4 psia

TEST CONDITION #19
T_{nbi} = 1246 °F
W_v = 11180 lb/hr
W_p = 48500 lb/hr
P_{Hbo} = 235.8 psia

Figure 27

STRIP CHART RECORDING OF BOILER PRESSURE OSCILLATIONS
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Data of March 31 - April 5, 1970
GENERAL STEADY-STATE MAPPING

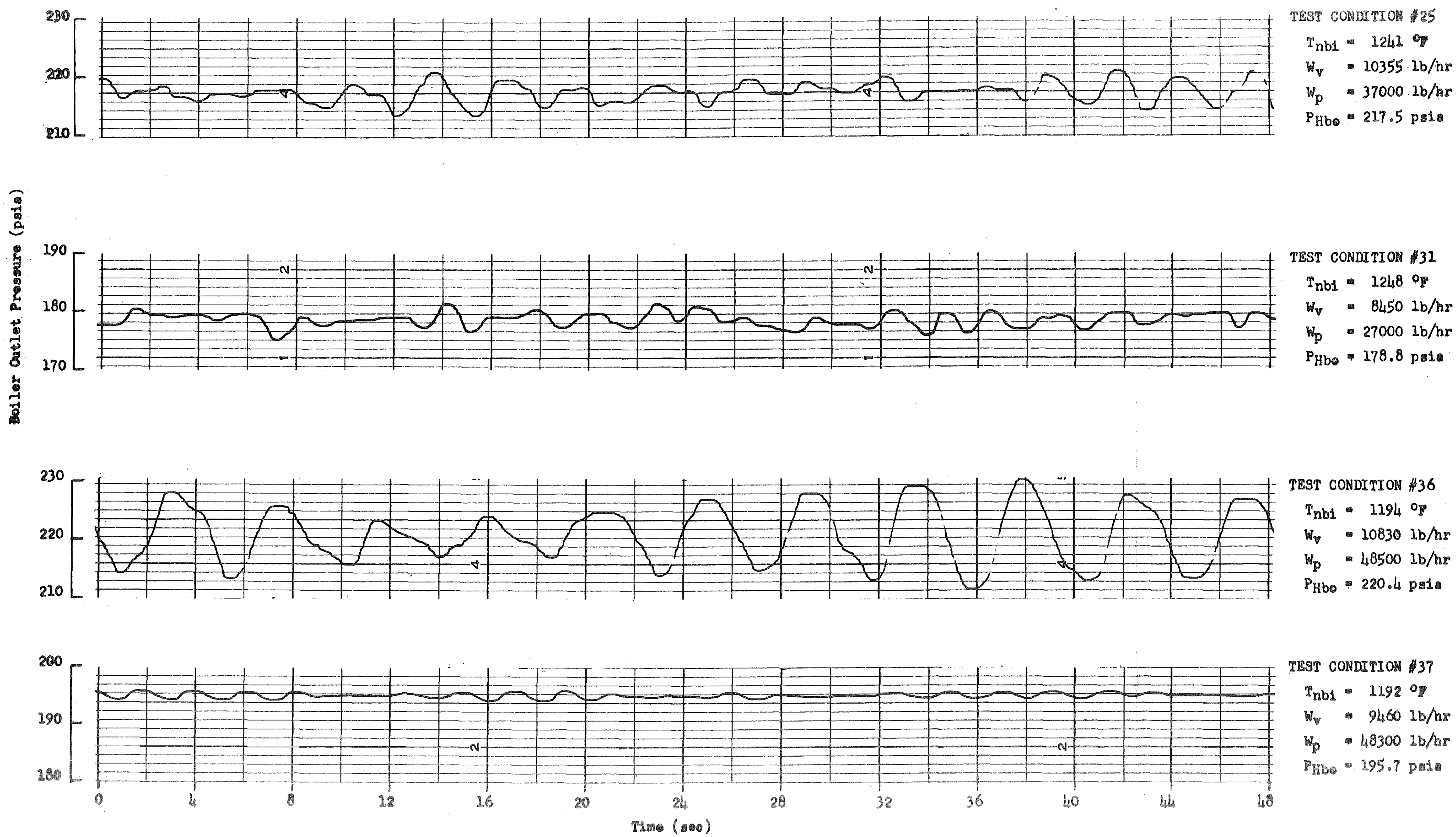
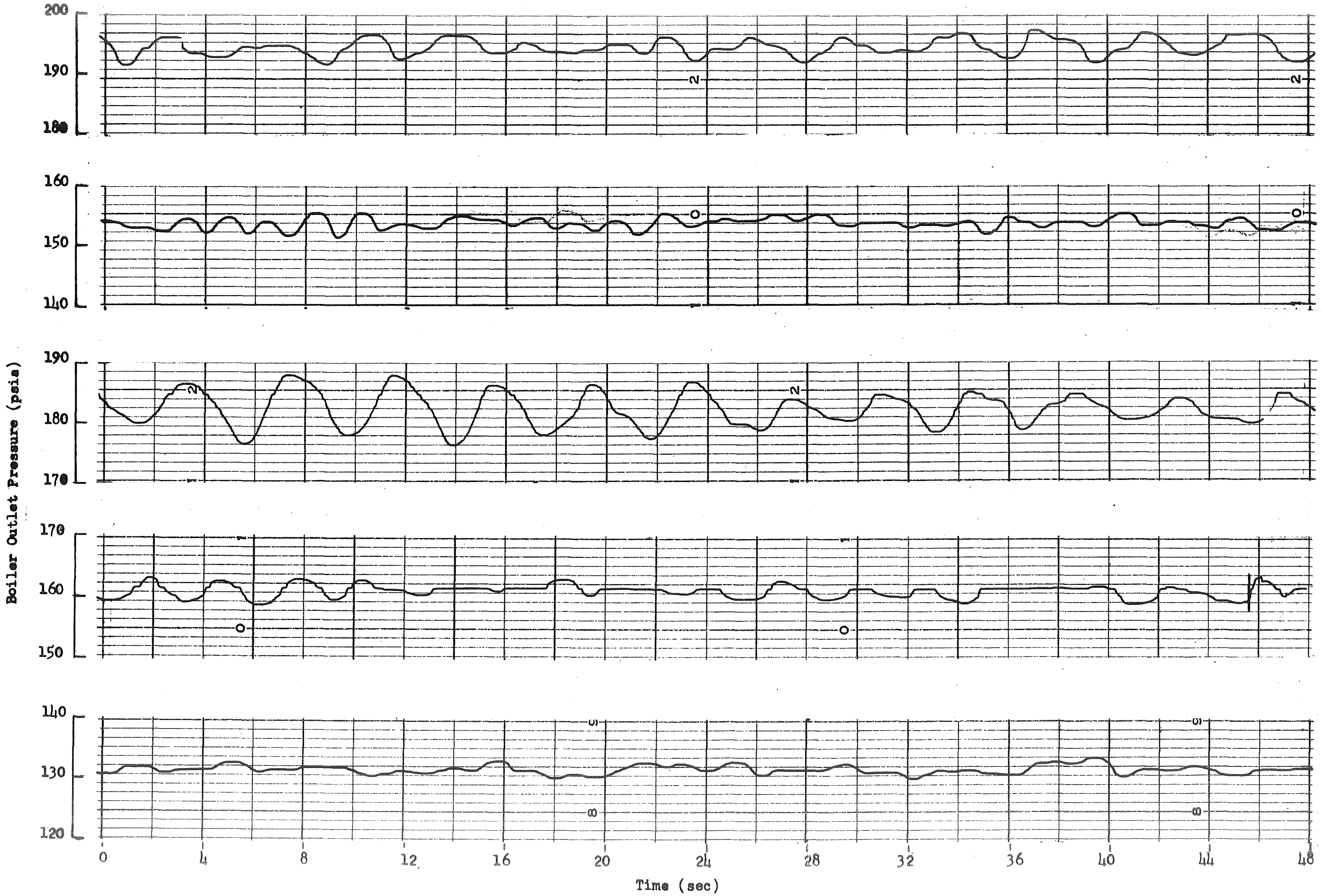


Figure 27

STRIP CHART RECORDING OF BOILER PRESSURE OSCILLATIONS
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Data of March 31 - April 5, 1970
GENERAL STEADY-STATE MAPPING



TEST CONDITION #42
T_{nbi} = 1192 °F
W_v = 9530 lb/hr
W_p = 37600 lb/hr
P_{Hbo} = 194.5 psia

TEST CONDITION #47
T_{nbi} = 1194 °F
W_v = 7470 lb/hr
W_p = 26500 lb/hr
P_{Hbo} = 154.0 psia

TEST CONDITION #51
T_{nbi} = 1139 °F
W_v = 9125 lb/hr
W_p = 48600 lb/hr
P_{Hbo} = 183.1 psia

TEST CONDITION #56
T_{nbi} = 1142 °F
W_v = 8085 lb/hr
W_p = 37400 lb/hr
P_{Hbo} = 161.7 psia

TEST CONDITION #60
T_{nbi} = 1143 °F
W_v = 6590 lb/hr
W_p = 26500 lb/hr
P_{Hbo} = 132.3 psia

Figure 27

OPERATION AT PCS-G STATEPOINT
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Data of March 2, 3, 4, 10 & April 7, 1970
TOTAL MERCURY PRESSURE DROP VS MERCURY LIQUID FLOW
NaK Flow = 33000 lb/hr

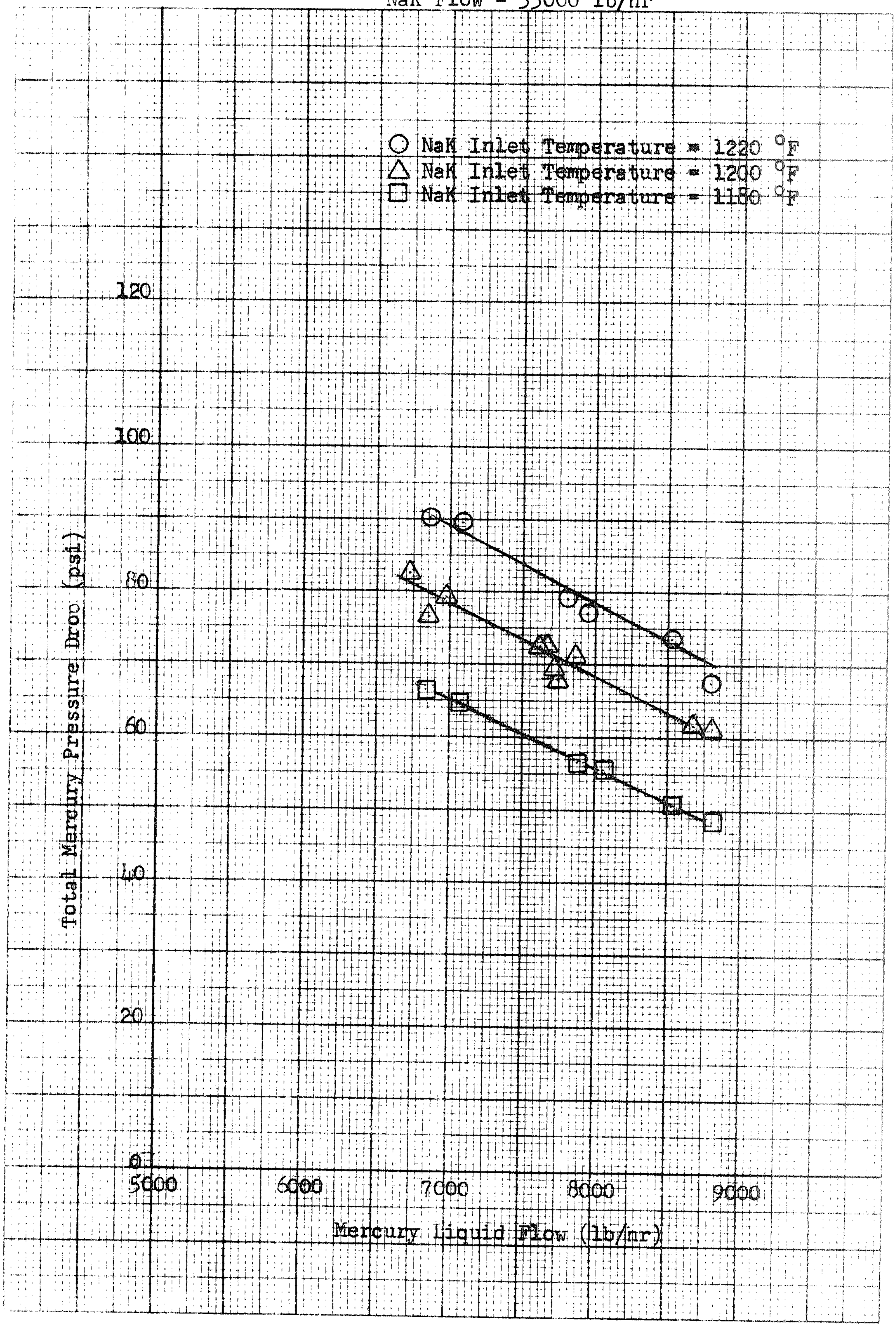
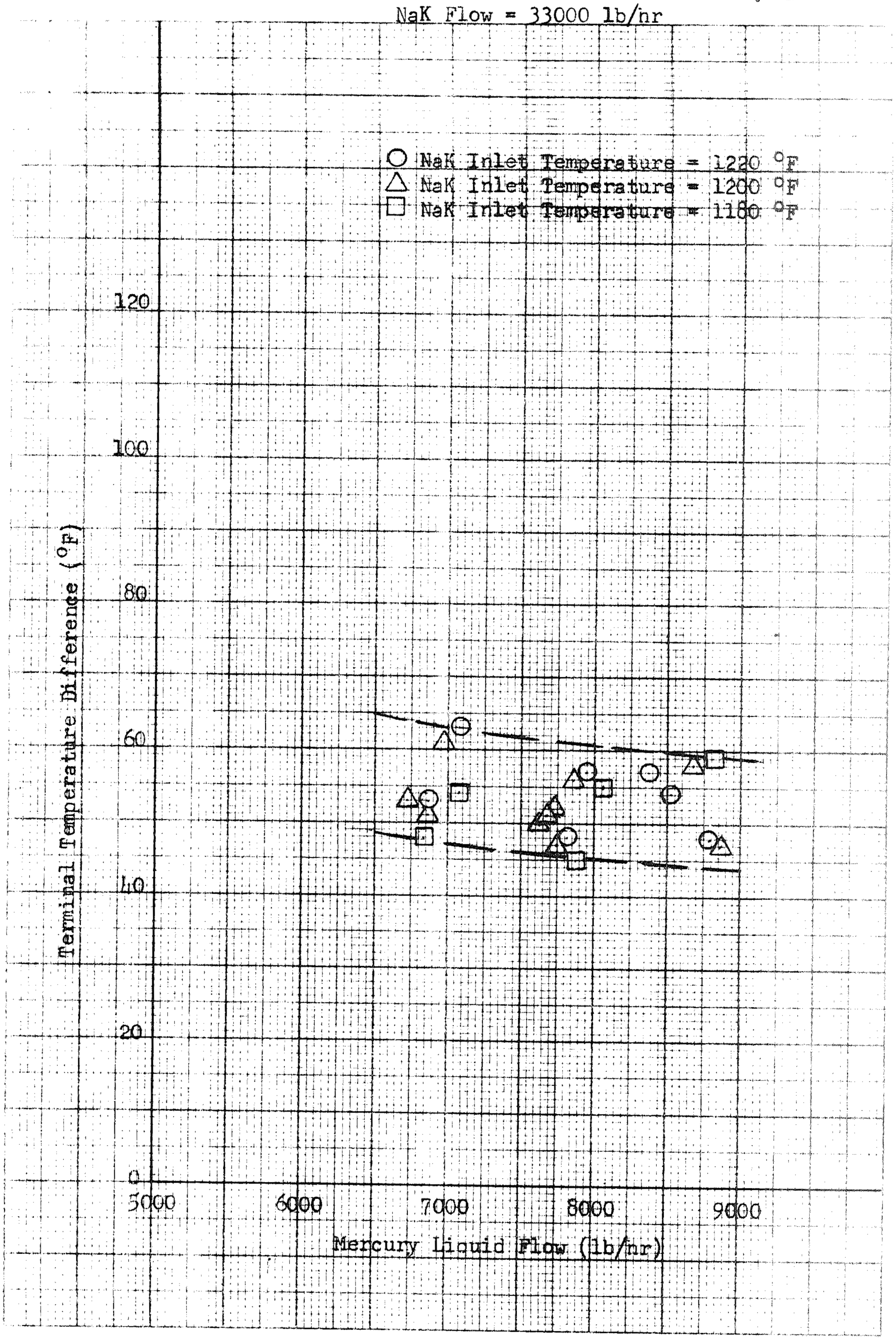
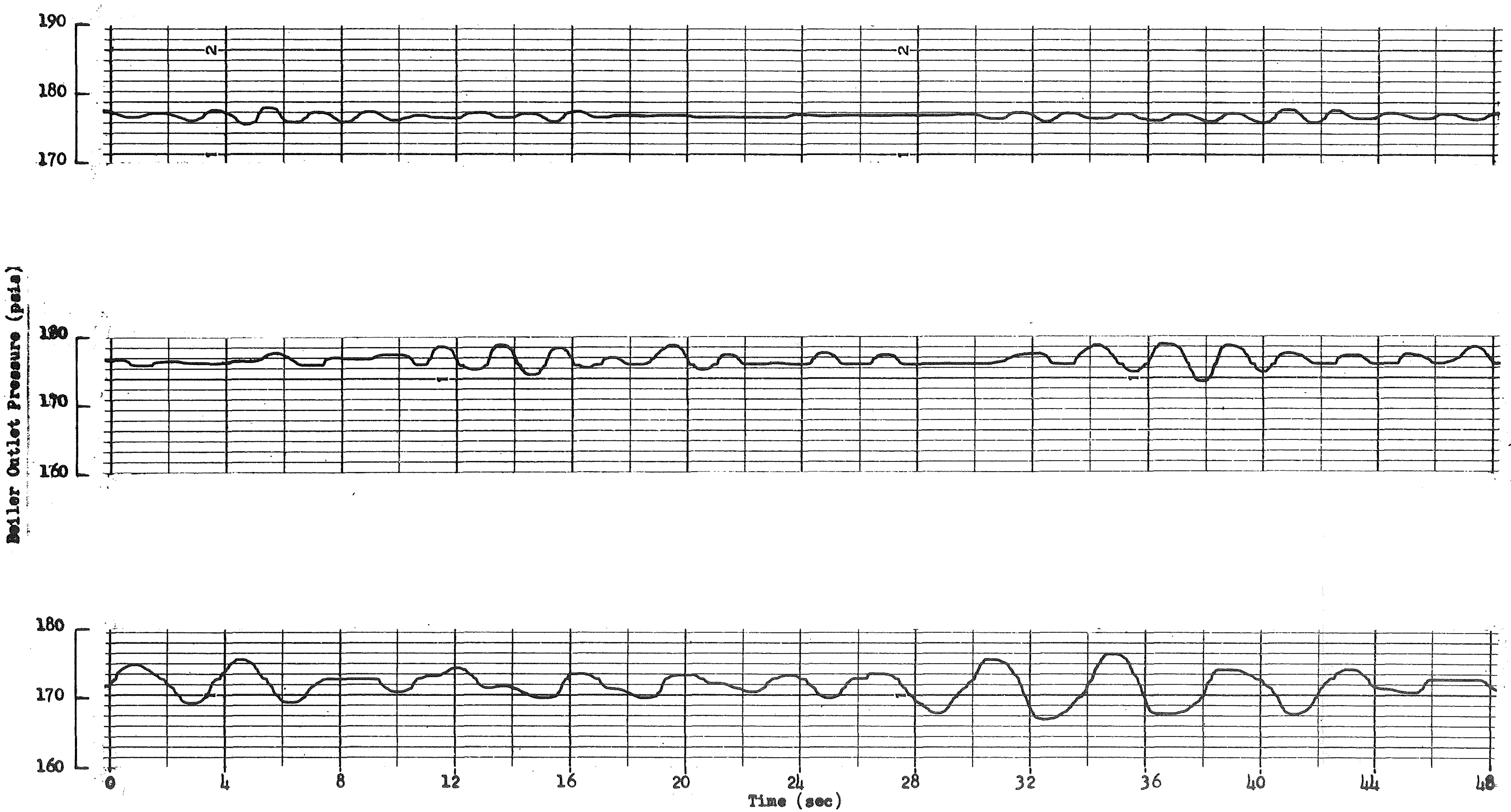


Figure 28

OPERATION AT PCS-G STATEPOINT
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Data of March 2, 3, 4, 10 & April 7, 1970
TERMINAL TEMPERATURE DIFFERENCE VS MERCURY LIQUID FLOW
NaK Flow = 33000 lb/hr



STRIP CHART RECORDING OF BOILER PRESSURE OSCILLATIONS
P/N 1266911 S/N BRDC-4 Unit 11/1
PCS-1 Data of March 31 - April 5, 1970
OPERATION ABOUT PCS-G STATEPOINT



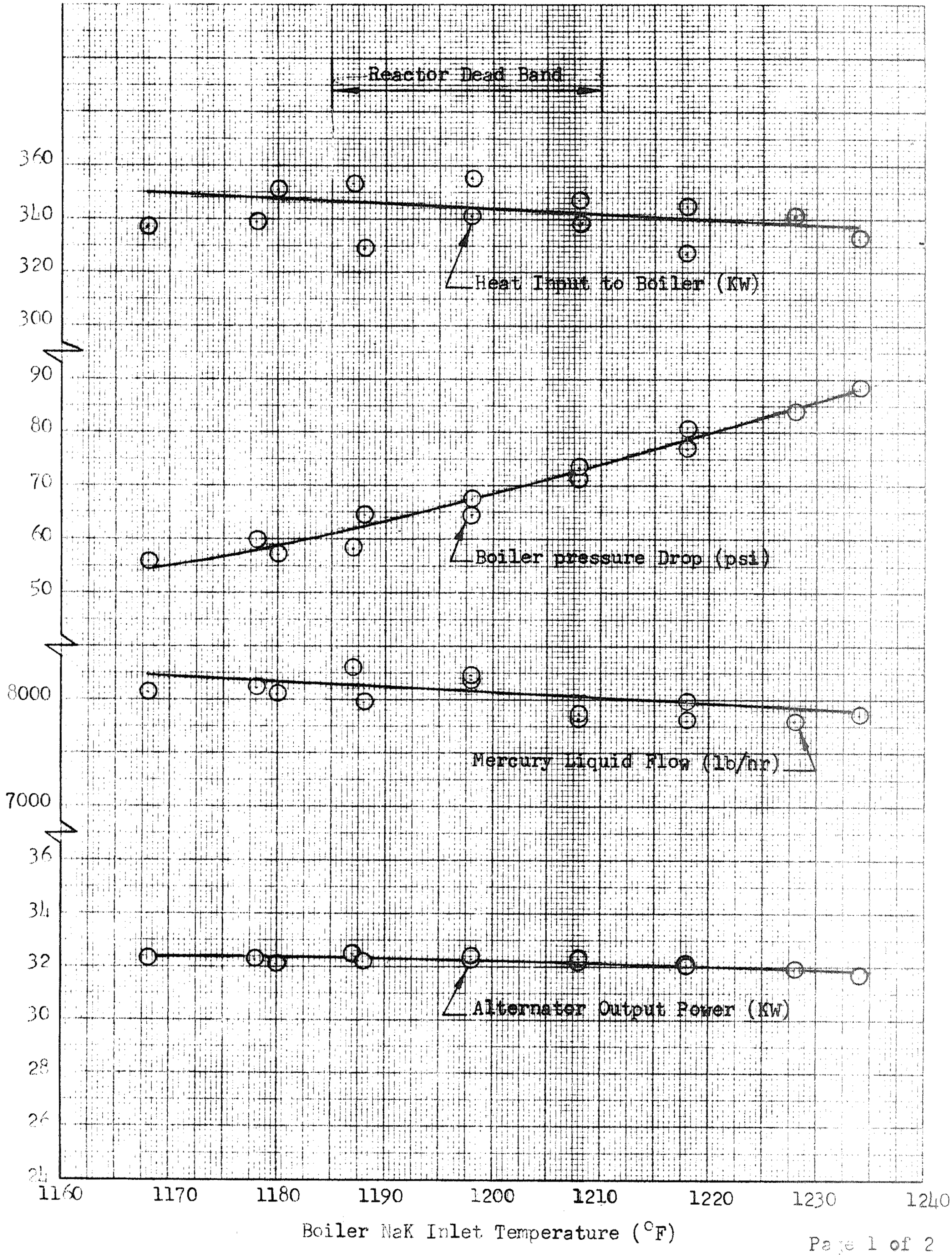
TEST CONDITION #66
T_{nbi} = 1215 °F
W_v = 8440 lb/hr
W_p = 33500 lb/hr
P_{Hbo} = 176.7 psia

TEST CONDITION #69
T_{nbi} = 1198 °F
W_v = 8510 lb/hr
W_p = 34000 lb/hr
P_{Hbo} = 176.8 psia

TEST CONDITION #72
T_{nbi} = 1171 °F
W_v = 8460 lb/hr
W_p = 33500 lb/hr
P_{Hbo} = 172.2 psia

Figure 30

RESPONSE TO REACTOR DEAD BAND TEMPERATURE VARIATIONS
PCS-G STATEPOINT
PCS-1 Data of April 14, 1970



Page 1 of 2
Figure 31

RESPONSE TO REACTOR DEAD BAND TEMPERATURE VARIATIONS
PCS-G STATEPOINT
PCS-1 Data of April 14, 1970

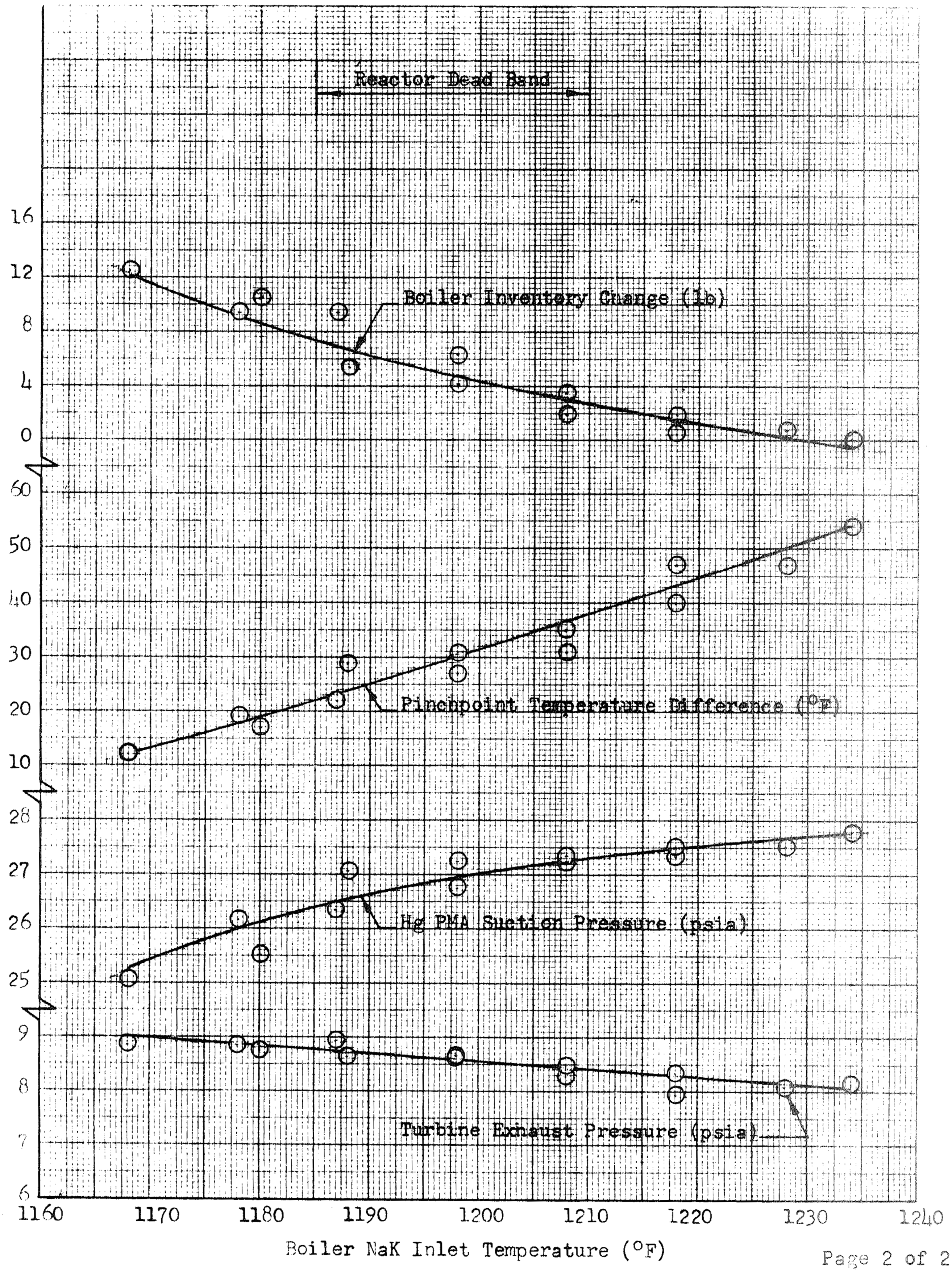
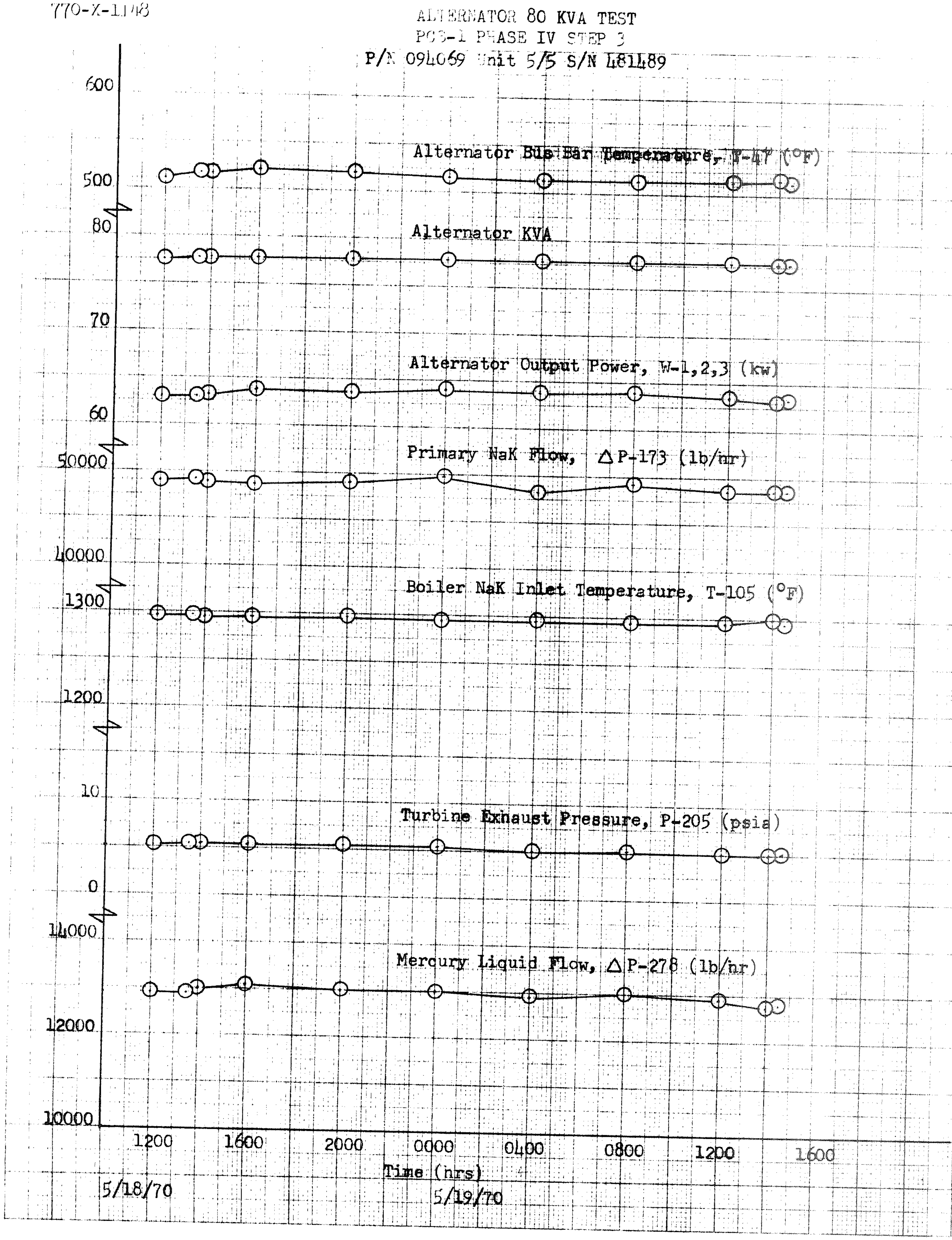


Figure 31



ALTERNATOR 80 KVA TEST
PCS-1 PHASE IV STEP 3
P/N 094069 Unit 5/5 S/N 481489
Alternator Bus Bar Temperature, T-47 (°F)
Alternator KVA
Alternator Output Power, W-1,2,3 (kw)
Primary NaK Flow, ΔP-173 (lb/hr)
Boiler NaK Inlet Temperature, T-105 (°F)
Turbine Exhaust Pressure, P-205 (psia)
Mercury Liquid Flow, ΔP-278 (lb/hr)
600
500
80
70
60
50000
40000
1300
1200
10
0
14000
12000
10000
1200
1600
2000
0000
0400
0800
1200
1600
Time (hrs)
5/18/70
5/19/70

Figure 32

LOAD CHANGE TRANSIENTS - PCS-1 PHASE IV, STEP 3, RUN D43-6-54

TEST CONDITION 1 - 36 kw 1.0 Power Factor Step Vehicle Load Changes
54 kw Nominal Alternator Output Power
39 kw Nominal Parasitic Load Power at Zero Vehicle Load
All PMA Power from TAA

4-16-70

Top Chart - Alternator Frequency, 380 Hz to 420 Hz at 1 Hz/line (0.5 volts/line, zero center) Airpax FDS-30 Frequency to DC Converter
Bottom Chart - Vehicle Load Voltage, Full-Wave Bridge Rectified, 100 volts to 300 volts at 5 volts/line (zero suppressed)
Chart Speed - 5 mm/second
Brush Mark II Recorder - AGC Inventory Number 29754

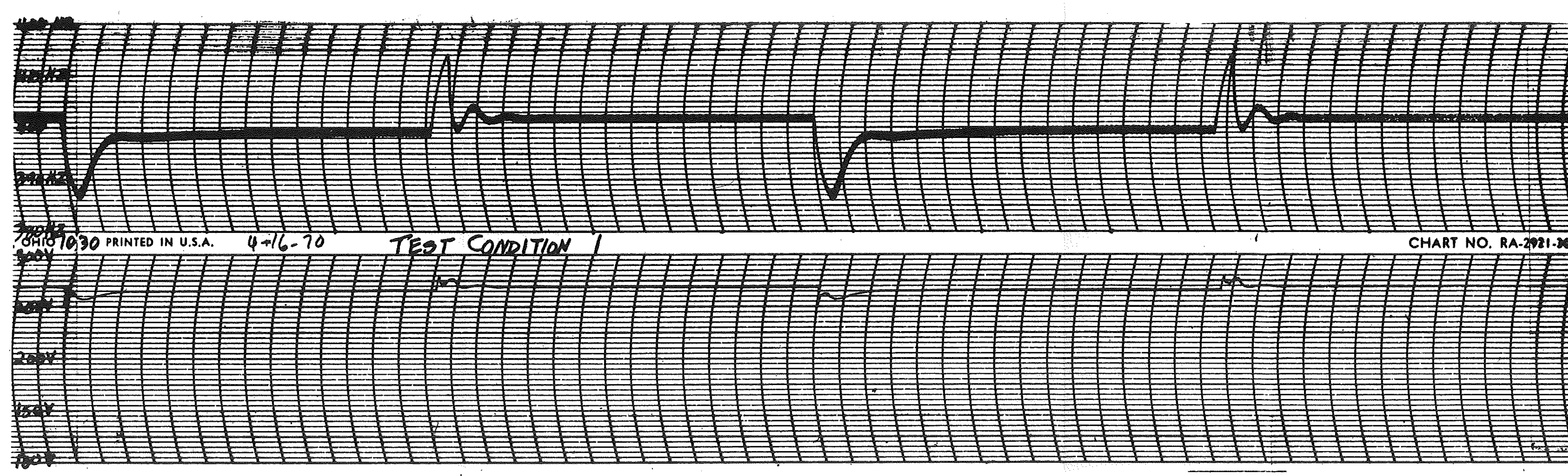


Figure 33

1.6 sec

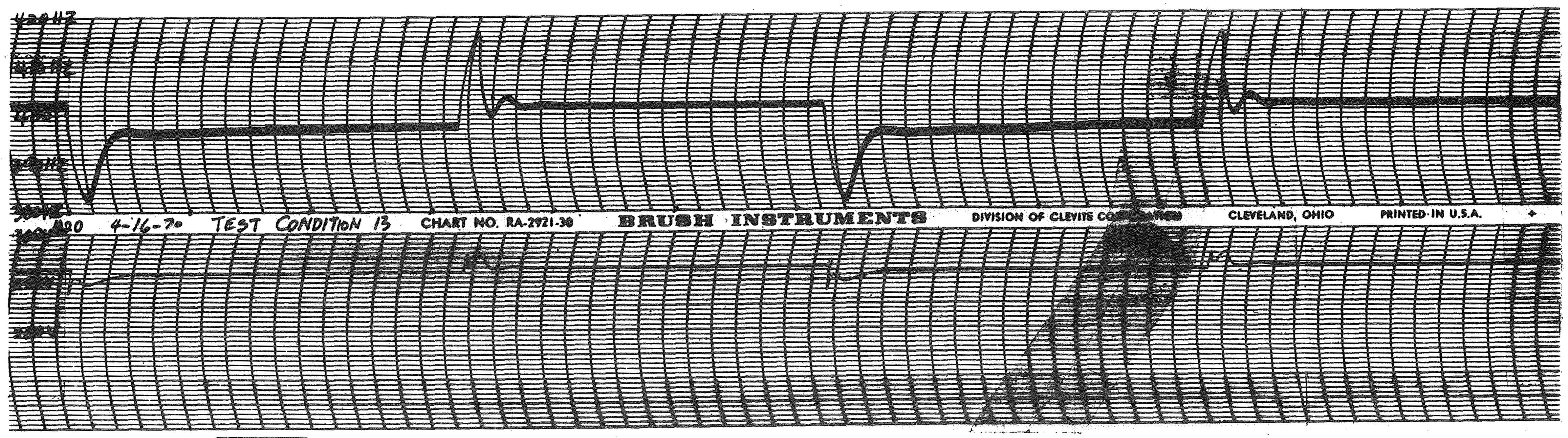
770-X-1151

LOAD CHANGE TRANSIENTS - PCS-1 PHASE IV, STEP 3, RUN D43-6-54

TEST CONDITION 13 - 44 kw 1.0 Power Factor Step Vehicle Load Changes
60 kw Nominal Alternator Output Power
47 kw Nominal Parasitic Load Power at Zero Vehicle Load
LPMA Power from Facility 400 Hz
All other PMA Power from TAA

4-16-70

Top Chart - Alternator Frequency, 380 Hz to 420 Hz at 1 Hz/line (0.5 volts/line, zero center) Airpax FDS-30 Frequency to DC Converter
Bottom Chart - Vehicle Load Voltage, Full-Wave Bridge Rectified, 100 volts to 300 volts at 5 volts/line (zero suppressed)
Chart Speed - 5 mm/second
Brush Mark II Recorder - AGC Inventory Number 29754



Dip 383 Hz 4.7% Rise 417 Hz 3.7%
Recovery 2.0 Sec to 1.5% Recovery 1.0 Sec to 1.5%

Figure 34