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STEADY-STATE PERFORMANCE OF A SNAP-8 DOUBLE-CONTAINMENT TANTALUM-STAINLESS STEEL MERCURY BOILER

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ABSTRACT

Boiler performance mapping was performed between SNAP-8 system startup tests. The mercury boiler was a counterflow heat exchanger with double-containment, tantalum and stainless steel construction. Boiler performance data obtained between early startup tests (3 through 21) indicated a boiler deconditioning (mercury-side surface contamination) problem. The boiler did condition (mercury-side surface contamination removed) for later startups (34 through 135) resulting in an overall pressure drop of 183 psi for a mercury flow rate of 6600 lbm/hr and a boiler inventory of 26 pounds. At the design mercury flow rate of 12,300 lbm/hr the boiler overall pressure drop was 129 psi with a boiler inventory of 34 pounds. The boiler NaK flow rate and inlet temperature for both of the above mercury flow rates were approximately 46,000 lbm/hr and 1280° F and 45,700 lbm/hr and 1300° F, respectively.

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SUMMARY

An experimental investigation of SNAP-8 startup and shutdown characteristics was conducted at the Lewis Research Center. During stabilized system operation following startup tests, a limited amount of steady-state boiler performance mapping was accomplished. The pertinent boiler parameters varied were mercury flow rate, NaK flow rate, and NaK inlet temperature. The variation of overall boiler mercury-side pressure drop for a range of mercury flow rates from 6100 to 12,300 lbm/hr was examined. In addition, the changes in overall pressure drop for a range of NaK flow rates from 39,800 to 46,500 lbm/hr and a range of NaK inlet temperatures from 1260° to 1300° F were examined.

The results showed the boiler underwent periods of deconditioning (mercury-side surface contamination) and conditioning (removal of mercury-side surface contamination) during the early startup tests (numbers 3 through 21) before attaining a conditioned state. The early deconditioned state of the boiler caused lower mercury-side overall pressure drops than would have been obtained if the boiler had been conditioned. However, two important boiler operating points were defined when the boiler was conditioned, one at the self-sustaining mercury flow rate (6600 lbm/hr) and the other at the design flow rate (12,300 lbm/hr). For the self-sustaining mercury flow rate (6600 lbm/hr) the boiler overall pressure drop was 183 psi. The mercury liquid inventory was 26 pounds and the NaK flow rate and inlet temperature were 46,000 lbm/hr and 1280° F, respectively. For the design flow rate the overall pressure drop was 129 psi. For this pressure drop the boiler liquid inventory was 34 pounds and the NaK flow rate and inlet temperature were 45,700 lbm/hr and 1300° F, respectively.

The boiler shell temperature profiles obtained during early (startups 3 through 21) mapping showed that a mercury flow maldistribution occurred for some boiler operating points. This flow maldistribution was not observed when the boiler was conditioned, but the amount of steady-state conditioned boiler data obtained during this investigation was too limited to exclude the possibility of its occurrence.

INTRODUCTION

A system that will produce a continuous electrical power supply and also have the capability of numerous startups and shutdowns upon command without performance degradation is required for long-term space mission applications. One such system, presently under development, is the SNAP-8 nuclear-Rankine, turboelectric power system (ref. 1). The basic SNAP-8 system is designed to produce a minimum of 35 kilowatts of usable electrical energy. In this liquid metal system an eutectic mixture of sodium and potassium (NaK-78) is used in both the reactor primary loop and heat rejection loop, while mercury is used in the power conversion loop.

In order to determine the startup and shutdown procedure for the SNAP-8 system, a series of 135 startups were performed at NASA Lewis Research Center. A breadboard SNAP-8 system using flight-type components with an electric heat source and air-cooled heat exchangers, simulating a nuclear reactor and a space radiator, respectively, was tested.

The boiler component has undergone several design changes prior to the current double-containment, tantalum and stainless steel concept (ref. 2). A boiler similar in design was used during earlier component and system endurance testing in the Lewis SNAP-8 test facility. The major difference between that boiler and the one used in the startup tests was the size of the inlet orifice restrictions. The earlier boiler had an orifice diameter of 0.070 inch as compared to an orifice diameter of 0.080 inch in the startup-test boiler. The results of the endurance boiler performance are covered in reference 3.

During the startup-test program some steady-state boiler performance data were acquired for a range of mercury flow rates, NaK flow rates and NaK inlet temperatures. Basic SNAP-8 mercury loop startup requirements call for a mercury flow ramp from zero to the system self-sustaining flow rate (6600 lbm/hr). After system transients settle out, a mercury flow ramp from the self-sustaining flow to the design flow (12,300 lbm/hr), concludes the power conversion loop startup. To define the boiler mercury-side overall pressure drop during system startup, mercury flow rates from 6100 lbm/hr to 12,300 lbm/hr were tested, while NaK flow rate and NaK inlet temperature ranges from 39,800 to 47,500 lbm/hr and 1260 to 1340° F, respectively, were tested. These data are presented and discussed in this report.

SNAP-8 TEST SYSTEM

General Description

A schematic diagram of the three major loops in the SNAP-8 test system are shown in figure 1. The primary (heating) loop contained a pump-motor assembly, an electric heater, electromagnetic flowmeter, the tube-in-shell boiler, and an auxiliary start heat exchanger. The electric heater, ignitron power controller, and analog computer simulated the operation of a nuclear reactor (refs. 4 and 5). The variation of primary loop flow was accomplished by altering the position of the valve (V-115) at the primary pump outlet. The primary loop piping consisted of AISI type 304 stainless steel from the boiler NaK outlet to approximately 5 feet beyond the pump-motor assembly outlet. The remainder of the loop piping consisted of AISI type 316 stainless steel.

The power loop (mercury loop) used AISI type 316 stainless steel for all piping from the boiler outlet to the condenser inlet and for all three venturi meters. AISI type 304 stainless steel was used for the remaining piping. The components in the mercury loop included a pump-motor assembly, the tube-in-shell boiler, a four-stage axial-flow turbine-alternator assembly, a condenser and three venturi meters. Mercury in the power loop flowed through the pump, a gas operated valve (V-247), an electro-hydraulic flow-control valve (V-230) controlled by an analog computer signal and a hydraulic backup valve (V-206). It then flowed through a venturi meter, a gas operated valve (V-260) and through the boiler. The vapor flowed through the turbine and into the condenser where it was condensed and subcooled. The mercury then passed through a gas operated valve (V-210), a venturi meter and V-207, a gas operated valve at the pump inlet. A gas operated valve (V-217) was in a line connecting the mercury standpipe with the power loop. V-204 is a variable position gas controlled valve in the mercury bypass line. The following valves in the mercury loop were used in a fully open or closed position: V-207, V-247, V-210 and V-217.

The feedback control circuit, shown schematically in figure 2, was used for automatic control of the electro-hydraulic flow control valve (V-230). The control circuit utilized a combination of open loop and integral-plus-proportional control. A detailed description of the operation of valve (V-230) is discussed in reference 6.

The heat rejection loop utilized AISI 304 stainless steel for all the piping between components. The loop consisted of a pump-motor assembly, an electromagnetic flowmeter, a condenser, two-finned NaK-to-air heat exchangers and a second electromagnetic flowmeter positioned at the outlet of one of the heat exchangers. Butterfly valves controlled by an analog computer signal varied the air flow to the NaK-to-air heat exchangers, to simulate operation of a space radiator. The pressure at the mercury inlet side of the condenser was sensed and converted into a command signal to actuate valve (V-314) at the pump outlet. This valve movement in turn varied the heat rejection loop flow.

Expansion tanks were used with both NaK loops to provide for changes in volume of the NaK fluid due to temperature variations and to maintain sufficient pressure at the inlet of the pumps. An oxide control system, common to both NaK loops was used to precipitate out oxides from the NaK fluid during periods when the mercury loop was not in operation. An increase in concentration of oxides in the NaK fluid is undesirable since these oxides cause plugging of system valves and piping. A lubricant-coolant loop containing polyphenol ether (4P3E) was used to lubricate the turbine-alternator assembly and mercury pump-motor assembly bearings. The 4P3E was also used to cool the remaining system pumps and certain parts of the turbine-alternator assembly and mercury pump-motor assembly. Vacuum, argon, and nitrogen systems were also used for proper operation of the three main loops.

Double Containment Boiler

The double-containment boiler was a tube-in-shell counterflow heat exchanger as shown in figure 3. A single inlet tube led into a plenum where the liquid-mercury flow was distributed into orifices at the entrance to each of seven boiler tubes. The tantalum orifices had an upstream diameter of 0.590 inch, a throat diameter of 0.080 inch and a metering length of 1.81 inches. The tantalum tubes had a 0.75-inch outside diameter, 0.040-inch wall thickness and an approximate length of 37 feet. Each of these tubes was placed into a 316 stainless-steel tube with an outside diameter of 1 inch, 0.035-inch wall thickness and an approximate length of 36.7 feet. These seven 1-inch diameter tubes were swaged into an oval shape prior to insertion of the 0.75-inch diameter tubes (fig. 4(a)). The oval shape of the containment tubes was to allow for radial movement of the inner tantalum tube which compensates for the difference in thermal expansion between the tantalum and the 316 stainless steel. The void between the outside surface of the 0.75-inch diameter tube and the inside surface of the oval tube was filled with static NaK, which served as a heat transfer medium between the flowing NaK and the mercury loop. An additional function of the static NaK passage is to provide a containment region for flowing NaK or mercury in the event of internal boiler failure. The double-containment boiler construction thus prevents contamination of the mercury loop with primary loop NaK and vice-versa.

The next sequence in the boiler assembly was to insert the seven double containment tubes into a 316 stainless-steel shell with a 5-inch outside diameter, 0.095-inch wall thickness and approximately 38.9 feet in length (fig. 4(a)). The completed boiler assembly consisted of straight inlet and outlet sections 74.3 and 15.5 inches long, respectively. The center section of the boiler comprised a $2\frac{1}{2}$ turn helix with a pitch of 10.5 inches and a pitch diameter of 48 inches. The double-containment tube bundle was supported within the outer shell by support brackets placed at 15-inch increments throughout the first full turn of the helical section of the boiler, beginning at the plug-section exit. The remaining support brackets were placed at 31-inch increments.

A spiralled-passage, multi-fluted "plug" at the tantalum tube inlet, approximately 55 inches in length, was used to restrict mercury flow and thus to increase liquid velocity. The plug, a 0.662-inch diameter grooved tantalum rod (fig. 4(b)) was fixed at the inlet end by a threaded shaft which was part of the orifice assembly. The downstream end of the plug coincided with the end of the straight inlet section (boiler station 12, fig. 3).

At the plug outlet was another swirl inducer which extended to within 1 inch of the tantalum tube outlet. The swirl inducer consisted of 0.062-inch diameter tantalum wire with a pitch diameter of 0.608 inch and a pitch of 2 inches. This wire was intended to centrifuge liquid from the vapor to the inner wall of the tantalum tube thus increasing heat transfer rates and reducing the amount of liquid carryover to the turbine. The seven-tube outlet manifold led into a plenum which formed a single mercury outlet passage.

Boiler Cleaning

The mercury boiler was cleaned as an individual component before installation into the system. An argon purge was imposed on the mercury, flowing NaK and static NaK passages of the boiler to prevent contamination of the tantalum tubes by the surrounding atmosphere. The mercury passage of the boiler was then evacuated to 0.02 torr and then filled with trichloroethane. After a soaking period of ½ hour the mercury passage was gravity drained. A chemical analysis of the solvent indicated the same composition as the original solvent. The flowing NaK passage of the boiler was then filled with trichloroethane and drained after a soaking period of ½ hour. The chemical analysis of the solvent indicated no contamination of the original solvent.

Mercury and flowing NaK passages of the boiler were leaked checked by injecting helium into the static NaK passage. A vacuum was then imposed on the mercury passage of the boiler. The vacuum was allowed to decay over an 8-hour period and it was determined that the rate of decay was 0.004 torr/hour, an acceptable value for component testing.

Finally the static NaK passage of the boiler was filled with trichloroethane and allowed to soak for a period of ½ hour, before the passage was drained. The procedure was performed twice due to the deposition of minute metal chips on filter paper used to screen the efflux of trichloroethane from the static NaK passage during the first drain. The analysis of the trichloroethane after a second ½ hour soaking period and subsequent drain indicated no change in the original solvent.

INSTRUMENTATION

A discussion of instrumentation used in the SNAP-8 facility is found in references 7 and 8. A description of boiler instrumentation follows.

Temperature

Boiler temperature-measuring instrumentation consisted of shell thermocouples, immersion thermocouples in the mercury outlet tube, and surface thermocouples on the inlet and outlet piping for both mercury and NaK. The three surface thermocouples on the mercury inlet piping were constructed of Instrument Society of America (ISA) standard calibration J (Iron-Constantan) wires which were located 8 inches upstream of the boiler inlet. All other thermocouples were constructed of ISA standard calibration K (Chromel-Alumel) wires. Three thermocouples were welded on the mercury outlet piping, 120 degrees apart (section B-B in fig. 3). Four immersion thermocouples were located in a 11-inch section welded to the mercury boiler outlet. Immersion thermocouples A and B were inserted at a 45 degree angle in a direction opposite to the vapor flow direction. Thermocouple A was also located at the top of the outlet piping, while thermocouple B was located at an angle of 30 degrees (clockwise) with respect to thermocouple A (view C-C in figure 3). The direction of mercury flow in view C-C is out of the paper. Immersion thermocouples C and D were inserted at a 45 degree angle pointing in the same direction as mercury vapor flow. These thermocouples were also located at the bottom of the outlet piping (view C-C in fig. 3). The NaK inlet thermocouples were placed on the surface of the NaK inlet transition section and were located 4.75 inches from the NaK shell-flow-direction centerline. The thermocouples at the NaK outlet were placed on the transition section at a location 4 inches from the NaK shell-flow-direction centerline.

Both the top and bottom surfaces of the boiler shell were instrumented with thermocouples to give an indication of the NaK temperature distribution. Thermocouples were placed at location A (section A-A fig. 3) for all station numbers except number 4. The circumferential location of thermocouples at station 12 (section A-A fig. 3) defines the location positions used at any station along the boiler, see table I. All thermocouple stations were located with respect to the vertical centerline through the boiler NaK outlet transition section. Table I lists all the boiler shell thermocouples and their respective locations for each station number.

Pressure and Flow

The boiler pressure instrumentation consisted of one absolute pressure transducer at the mercury boiler inlet and two absolute pressure transducers at the mercury boiler outlet passage. A differential pressure transducer was also used to measure pressure drop across the NaK side of the boiler. The absolute and differential pressure transducers were of the slack diaphragm and capillary tube type. A detailed description of the internal mechanism associated with each type of transducer can be found in reference 9. Each pressure transducer was calibrated over its design range. The boiler inlet pressure transducer had a design range of zero to 500 pounds per square inch absolute and the outlet pressure transducers had design ranges of zero to 300 and zero to 400 pounds per square inch absolute. The accuracy of each absolute pressure transducer measurement was within 1 percent of its range. The differential pressure transducer had a design range of zero to 10 pounds per square inch and its accuracy was 1 percent of its range. The locations of the pressure taps for the three absolute and one differential pressure transducer are shown in figure 3.

The primary loop NaK flow into the boiler was measured by an electromagnetic flowmeter. Mercury liquid and vapor flow were measured by calibrated venturi flowmeters upstream and downstream of the boiler (fig. 1). The pressure drop across each venturi flowmeter from the inlet to the throat was measured by a differential pressure transducer. Each transducer was calibrated over its entire range of zero to 20 pounds per square inch and the accuracy of a given reading was 1 percent of its range.

Data Recording

All pressures and temperatures used for analysis were recorded using a computerized digital data recording system. This system was used to record both steady-state and transient test system conditions. The recording system scanned and recorded a cycle of data, containing 400 different instrument outputs, in 11.43 seconds. During steady-state tests a data run consisted of taking the average of three cycles of the 400 different instrument outputs during an interval of 34.3 seconds. A computer program was used to calculate the test parameters during steady-state runs. The results were stored on magnetic tape and used to produce the computer plots of steady-state boiler shell temperature profiles shown in the report.

RESULTS AND DISCUSSION

Performance History

The following discussion is focused on boiler steady-state data acquired integrally with startup tests. In general, each data point presented in table II was obtained after a unique mercury-loop startup from zero flow to the self-sustaining mercury flow rate of approximately 6600 lbm/hr. The data in table III were obtained after mercury flow ramps from the self-sustaining level to the rated flow rate of approximately 12,300 lbm/hr.

The boiler mercury overall pressure drops, recorded between 5 and 8 minutes after startup to the self-sustaining flow level, are shown as a function of startup number in figure 5. During mercury-loop startups an automatic-digital data-recording system was cycled continuously for 8 to 9 minutes through 400 words of information. A time of 11.43 seconds was required to record each cycle of information. An average of 48 to 49 cycles of data were acquired per startup. Near the end of the data acquisition time the boiler parameters, flow rates, temperatures and pressures, appeared to have reached a steady-state level. Consequently, the boiler overall pressure drops shown in figure 5 represent steady-state data. During some startups the digital data-recording system did not function properly; thus, the digital-startup data was lost. In figure 5 this problem is indicated by the absence of a data point for these startups. All of the data points were connected consecutively with a straight line. Therefore, for a startup number having no data point, the overall pressure drop may be misrepresented by the intersection of the startup number and with the straight line connecting preceding and following data points.

For the early startups (3 through 21) in figure 5, the boiler overall pressure drop experienced numerous significant changes. Overall pressure drops from 55 to 205 psi were obtained during this period. The large changes in boiler overall pressure drop did not affect turbine inlet conditions (to be shown later) because in the SNAP-8 test facility a constant mercury flow rate was maintained by using a closed-loop feedback signal for the mercury flow control valve. However, for simplicity, the flight system mercury flow control valve will have open-loop control. If in the flight system the boiler mercury overall pressure drop varied as it did during the early startups (3 through 21) the mercury flow rate would vary considerably with the possible consequence being large liquid mercury carryover into the turbine.

The reason for the large boiler overall pressure drop changes during the early startups (3 through 21) is not explicitly known, but a possible cause could be varying boiler deconditioning and conditioning. Boiler deconditioning will be defined as the reduction of clean tantalum surface area on the mercury side due to a surface contamination, while conditioning means the surface contamination is being removed. A contaminated tantalum surface (boiler deconditioned) will impede the mercury boiling, while a clean tantalum surface (boiler conditioned) will enhance mercury boiling. In addition to the condition of the boiler, the physical makeup of the boiler affects the overall pressure drop. In the SNAP-8 test facility boiler, the mercury flow area in the plug region was considerably smaller than the mercury flow area downstream of the plug; therefore, fluid velocities were higher in the plug region. As long as the boiler remained conditioned, all or most, depending upon the mercury flow rate, of the boiling occurred in the plug region where the frictional pressure losses were high. Once the boiler became deconditioned, more of the high quality boiling occurred downstream of the plug where the frictional pressure losses were lower than in the plug. Thus, deconditioning would cause the boiler mercury side overall pressure drop to decrease.

Possible sources of tantalum surface contamination in the test system were vacuum-pump oil and lubricant-coolant loop oil. Post-test analysis of the mercury in the dump tank did show the presence of some vacuum-pump oil and lubricant-coolant loop oil.

After startup 21 the boiler apparently underwent a conditioning process until the overall pressure drop obtained a level of approximately 195 $\pm$ 15 psi (fig. 5). It remained at this level until startup 109, when the boiler apparently underwent a slight deconditioning. The overall pressure drop history from this point shows a gradual upward trend in level (fig. 5).

Boiler performance data were taken after startup numbers 8 and 10. As can be seen in figure 5, there were large changes in pressure drop after these startups and before the following startup. The total time of boiler operation after startup number 8 was 47 hours, while the boiler was in operation approximately 2 hours after startup number 10. The additional boiler data presented in this report were acquired after startup numbers 20, 93, and 122. After these startups the boiler data were obtained while the boiler was operating with constant flow rates and temperatures. Over the time period of 135 startups there were loop downtime periods of approximately two weeks in length. Loop downtime resulted from making necessary loop repairs and to accomplish recalibration of instrumentation. The loop downtimes occurred after startup numbers 4, 10, 15, 50 and 108.

Boiler Performance With Variable Conditioning

The boiler data obtained after startups 8 and 10 are presented in tables IV and V, respectively. The results of these data are also shown in figures 6 through 11. In figure 6(a) the mercury overall pressure drop is shown as a function of time after startup for constant mercury and NaK flow rates, and constant NaK inlet temperature. The overall pressure drop falls rapidly from a value of 180 psi to 157 psi in a time interval of 2 hours and then falls gradually from 157 psi to 148 psi in 11.5 hours. At 14.5 hours after startup number 8 the primary NaK flow rate was increased and preparations were made to map the boiler overall pressure drop as a function of mercury flow rate. These results are presented later.

Boiler NaK shell temperature profiles for the first and last data points shown in figure 6(a) are shown in figures 7(a) and 7(b), respectively. In these figures as in following boiler shell temperature profile plots, the end of the mercury tube plug insert occurs at a distance of 4 feet from station 3. Station 3 is located at the NaK outlet of the boiler. In figure 7(a) boiling has essentially stopped by the end of the plug, while in figure 7(b) boiling is still occurring downstream of the end of the plug; indicating the boiler has deconditioned.

The affect of the SNAP-8 test facility boiler deconditioning on turbine inlet conditions or boiler outlet conditions can be seen in table IV (CADDE readings 290-297). These readings represent the data presented in figure 6(a). Data in the table shows that the boiler outlet conditions remained approximately constant during the boiler deconditioning.

Further comparison of the profiles in figures 7(a) and 7(b) showed that the amount of required boiling heat transfer area increased with time and a different heat flux distribution developed between the top and bottom of the boiler. The heat transfer area increase was caused by the boiler deconditioning problem mentioned earlier and the latter by an apparent mercury flow maldistribution. The boiler deconditioning would cause an increase in liquid mercury inventory. This was verified by examination of the mercury condenser inlet and outlet pressure transducer readings for these same data points, which showed that the condenser inventory did decrease with time. Since all of the valves not in the mercury flow loop were closed, the loss of condenser inventory had to be caused by an increase in boiler inventory.

In figure 6(b) the affect of NaK inlet temperature on boiler overall pressure drop is shown for three different NaK flow rates. These data are a continuation of the boiler mapping data obtained after startup number 8. As expected, the boiler overall pressure drop decreased with a decrease in NaK inlet temperature for NaK flow rates of 46,500 and 39,800 lbm/hr. However, for a NaK flow rate of 42,800 lbm/hr the overall pressure drop decreased with an increase in NaK inlet temperature. At this time it might be important to digress for a moment and point out the sequence in which the data were obtained. Starting with a NaK flow rate of 46,500 lbm/hr and holding it constant, the NaK inlet temperature was decreased. Then the NaK flow rate was decreased to 42,800 lbm/hr and held constant, while the NaK inlet temperature was increased. Finally, the NaK flow rate was reduced to 39,800 lbm/hr and held constant, while the NaK inlet temperature was decreased. This sequence of data acquisition should not have influenced the results obtained, but it does represent increasing boiler operating time. Therefore, it was surmised that the boiler deconditioning with time had more of an influence on the results shown in figure 6(b) than the variation of the NaK inlet temperature.

Boiler shell temperature profiles at the highest and lowest NaK inlet temperature for each NaK flow rate curve in figure 6(b) are shown in figures 8(a) through 8(f). Included in these are the elapsed times after startup number 8. Comparison of figures 8(a), 8(d), and 8(e) with figures 8(b), 8(c), and 8(f) shows a different heat flux distribution developed between the top and bottom tubes of the boiler, when the boiler NaK inlet temperature was reduced from 1320 to 1262° F. A reexamination of figures 7(a) and 7(b) shows a similar situation occurred when the NaK inlet temperature dropped only 3 to 4° F. For both cases it was assumed that a mercury flow maldistribution was responsible for the variance in heat transfer between the top and bottom of the boiler.

In figure 9 the boiler mercury-side overall pressure drop is shown as a function of mercury flow rate for data obtained after startup numbers 8 and 10. In general, the boiler overall pressure drop for the same mercury flow rate was 6 to 13 psi higher after startup number 8 than after startup number 10. Earlier it was pointed out that the boiler appeared to be deconditioning after startup 8 as shown in figure 5. Also, figure 5 shows that the boiler was in the process of becoming conditioned after startup 10. Since the boiler was apparently deconditioned after startups 8 and 10 the overall pressure drop curve for a fully conditioned boiler would be different that those shown in figure 9.

Boiler shell temperature profiles for the data shown in figures 9(a) and 9(b) are shown in figures 10 and 11, respectively. The data presented in these figures are presented in an order of increasing mercury flow rate. Again, the separation of the top and bottom temperature profiles was evident as observed in figures 10(b), 10(c), 10(f), 11(b), 11(e) and 11(f).

After startup number 20 a mercury flow rate plateau of 7500 lbm/hr was reached. At this flow rate the mercury loop was operated for a continuous time period of 19 hours and 40 minutes, while the NaK flow rate and NaK inlet temperature to the boiler were held constant. During the above time period the boiler mercury overall pressure drop decreased from a value of 121 psi to 66 psi as shown in figure 12. Boiler data for this time period are shown in table VI. Boiler shell temperature profiles for the first and last data points in figure 12 are shown in figures 13(a) and 13(b), respectively. Comparison of these latter figures shows a change in boiler heat transfer conditions with time; indicating boiler deconditioning. There was also a large change in boiler overall pressure drop for the self-sustaining mercury flow rate between startup numbers 20 and 21 as shown in figure 5. This shows the boiler was deconditioning between startup numbers 20 and 21. Again, notice the constant boiler outlet conditions in table VI.

Performance of Conditioned Boiler

Between mercury loop startup 93 and 94 condenser inventory mapping was performed at the mercury self-sustaining flow rate of 6600 lbm/hr. The boiler inventory was calculated and found to be 26 pounds. This boiler inventory remained constant during the condenser mapping as indicated by the boiler data in table VII and the boiler shell temperature profiles for the first and last data points, figures 14(a) and 14(b). Examination of table VII and figures 14(a) and 14(b) show negligible change in boiler overall pressure drop from the 183 psi level, and that essentially all of the boiling occurred within the mercury tube plug length. During this period the boiler NaK flow rate and inlet temperature were held constant at 46,000 lbm/hr and 1280° F, respectively.

After startup 122 condenser inventory mapping was accomplished at the design mercury flow rate of 12,300 lbm/hr. Based on the condenser inventory determined from this mapping, the boiler inventory was found to be 34 pounds. Boiler data taken during this period are shown in table VIII. As shown in table VIII, the boiler mercury flow rate, 12,300 lbm/hr, NaK flow rate, 45,700 lbm/hr, and NaK inlet temperature, 1300° F, remained constant for approximately five hours during the condenser mapping. Furthermore, the boiler overall pressure drop remained constant at approximately 129 psi; showing the boiler condition remained constant. Boiler shell temperature profiles for the first and last data points in table VIII are shown in figures 15(a) and 15(b), respectively. Scrutinization of figures 15(a) and 15(b) shows the boiling heat transfer characteristics did not change in the boiler over the five-hour period.

The boiler shell temperature profiles in figures 14 and 15 did not show any significant separation of top and bottom profiles as experienced during some of the early boiler mapping tests. However, when the boiler was conditioned, steady-state boiler data were obtained only during the condenser mapping. Consequently, it is not known whether the flow maldistribution problem would have occurred if the earlier steady-state boiler flow and temperature ranges had been repeated.

SUMMARY OF RESULTS

The results of the steady-state boiler data obtained between SNAP-8 system startup tests can be summarized as follows:

(1) During early startup tests (numbers 3 to 21) the boiler apparently underwent various degrees of deconditioning and conditioning. The overall boiler mercury-side pressure drop varied between 55 to 205 psi during this period. With each successive startup between numbers 21 and 34 the boiler pressure drop increased; indicating that the boiler was conditioning. From startup number 34 to startup number

135 the boiler overall pressure drop was approximately constant.

(2) The variation in the SNAP-8 test facility boiler overall pressure drop obtained during the early startups (3 through 21) did not affect turbine inlet (boiler outlet) conditions, because the mercury flow rate was held constant by utilizing a feedback signal to the mercury flow control valve. However, in the flight system for simplification reasons, the mercury flow control valve will have open loop control. Any boiler overall pressure drop changes of the magnitude experienced during SNAP-8 test facility boiler deconditioning, will cause large changes in mercury flow rate; resulting in the possibility of large liquid mercury carryover into the turbine.

(3) A mercury flow maldistribution problem was indicated by some boiler shell temperature profiles obtained during early boiler operation (startups 3 through 21). However, when the boiler was conditioned, steady-state boiler data were obtained only during the condenser mapping. Consequently, it is not known whether the flow maldistribution problem would have occurred if the early steady-state boiler flow and temperature ranges had been repeated.

(4) When the boiler was conditioned, the overall pressure drop at the system self-sustaining mercury flow rate (6600 lbm/hr) was 183 psi. For this pressure drop the NaK flow rate was 46,000 lbm/hr, the NaK inlet temperature was 1280° F and the boiler liquid mercury inventory was 26 pounds.

(5) The conditioned boiler overall pressure drop at the design mercury flow rate (12,300 lbm/hr) was 129 psi. For this pressure drop the NaK flow rate was 45,700 lbm/hr, the NaK inlet temperature was 1300° F and the boiler liquid mercury inventory was 34 pounds.

Lewis Research Center
National Aeronautics and Space Administration
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6. Soeder, Ronald H.; and Lottig, Roy A.: Investigation of Pump Transfer Frequencies from Auxiliary Power to Alternator Power During Startup of the SNAP-8 System. NASA TM X-52712, 1969.

7. Deyo, James N.; and Wintucky, William T.: Instrumentation of a SNAP-8 Simulator Facility. NASA TM X-1525, 1968.

8. Macosko, Robert P.; Hanna, William T.; Gorland, Sol H.; and Jefferies, Kent S.: Performance Evaluation of an Experimental SNAP-8 Power Conversion System. NASA TM X-1732, 1969.

9. Lottig, Roy A.; and Soeder, Ronald H.: Investigation of Mercury-Flow Ramp Rates for Startup of the SNAP-8 System. NASA TM X-52689, 1969.

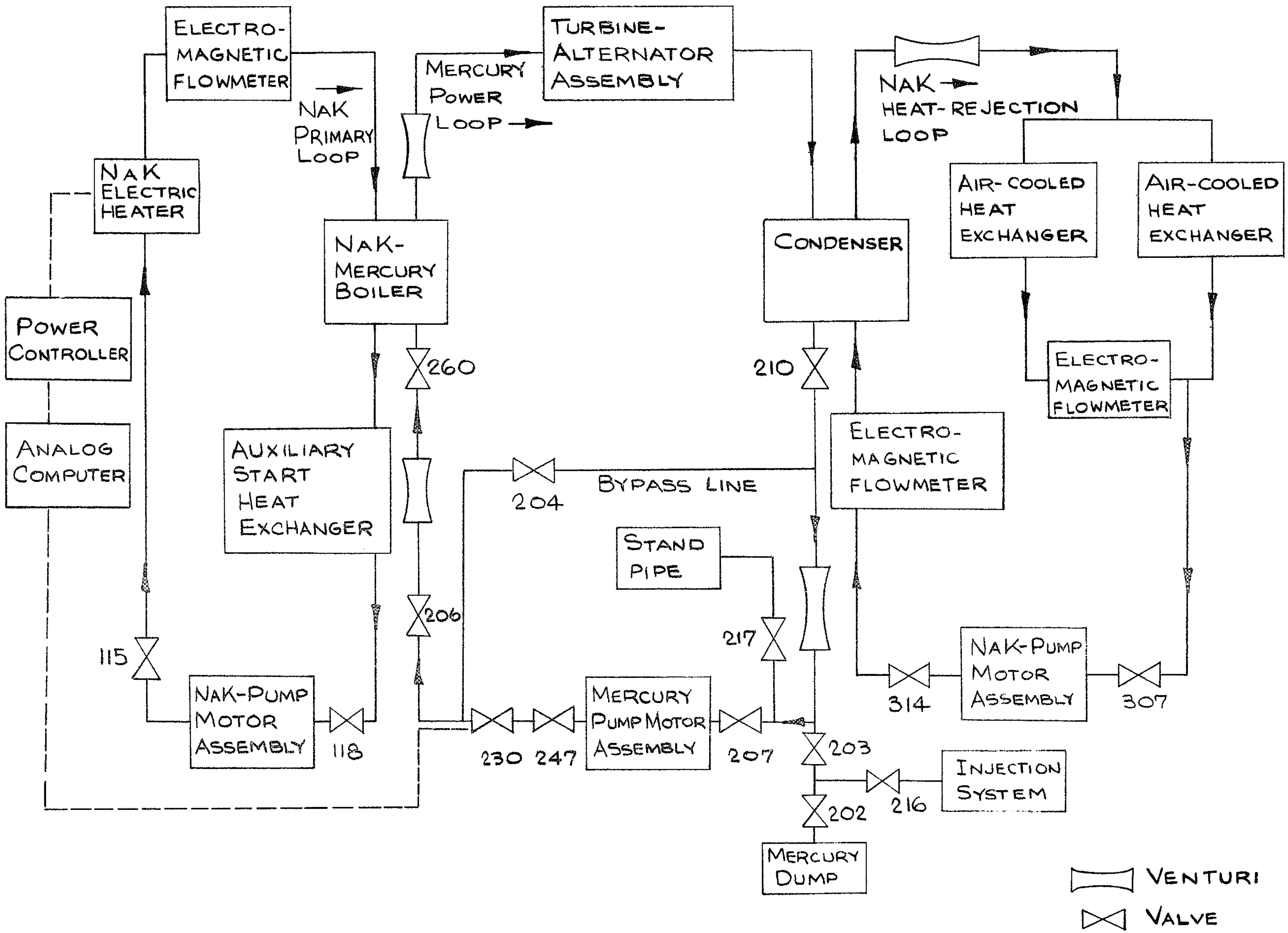


FIGURE 1.- SCHEMATIC OF SNAP-8 TEST SYSTEM

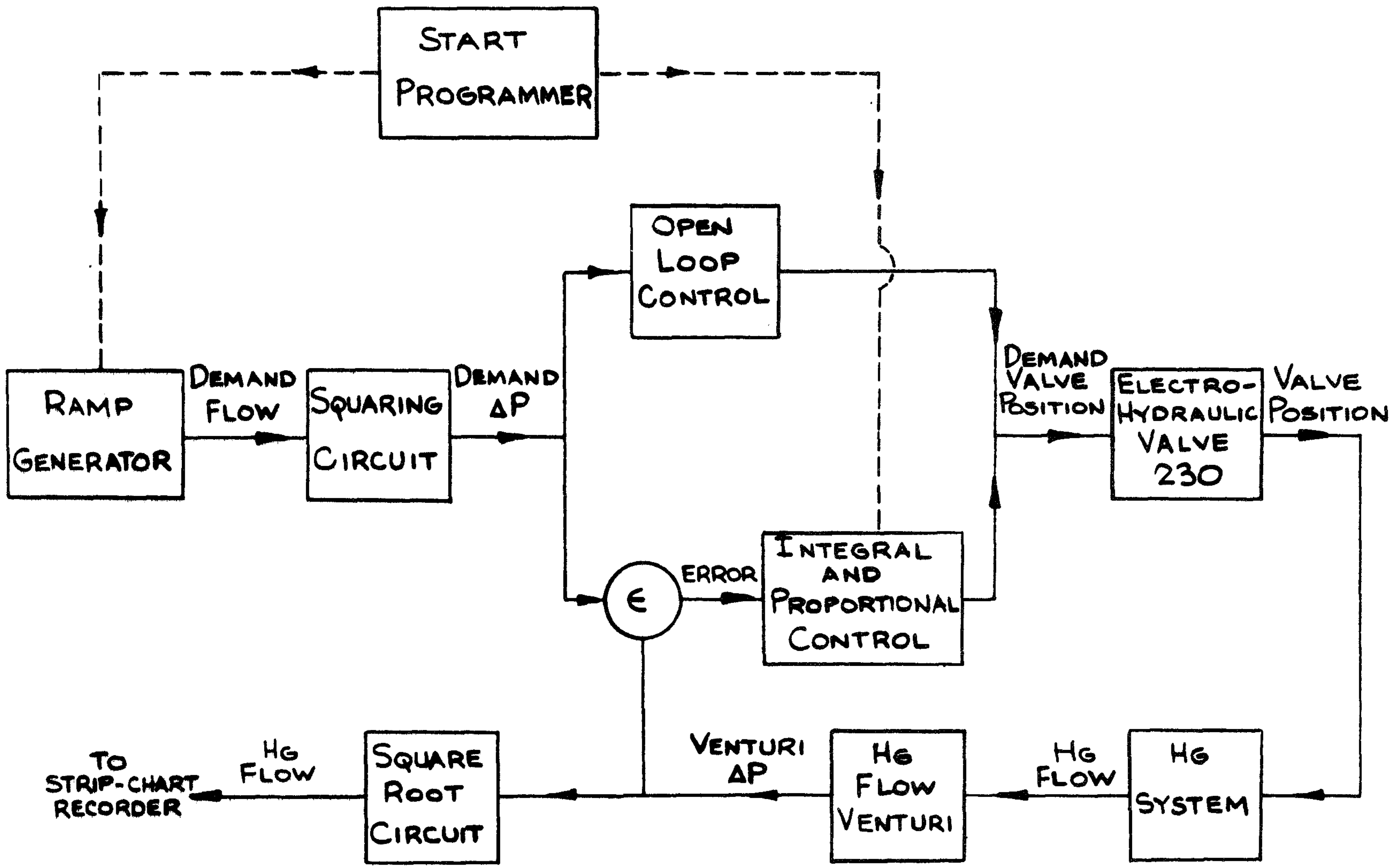


FIGURE 2. - ELECTRO-HYDRAULIC VALVE 230 FEEDBACK CONTROL CIRCUIT

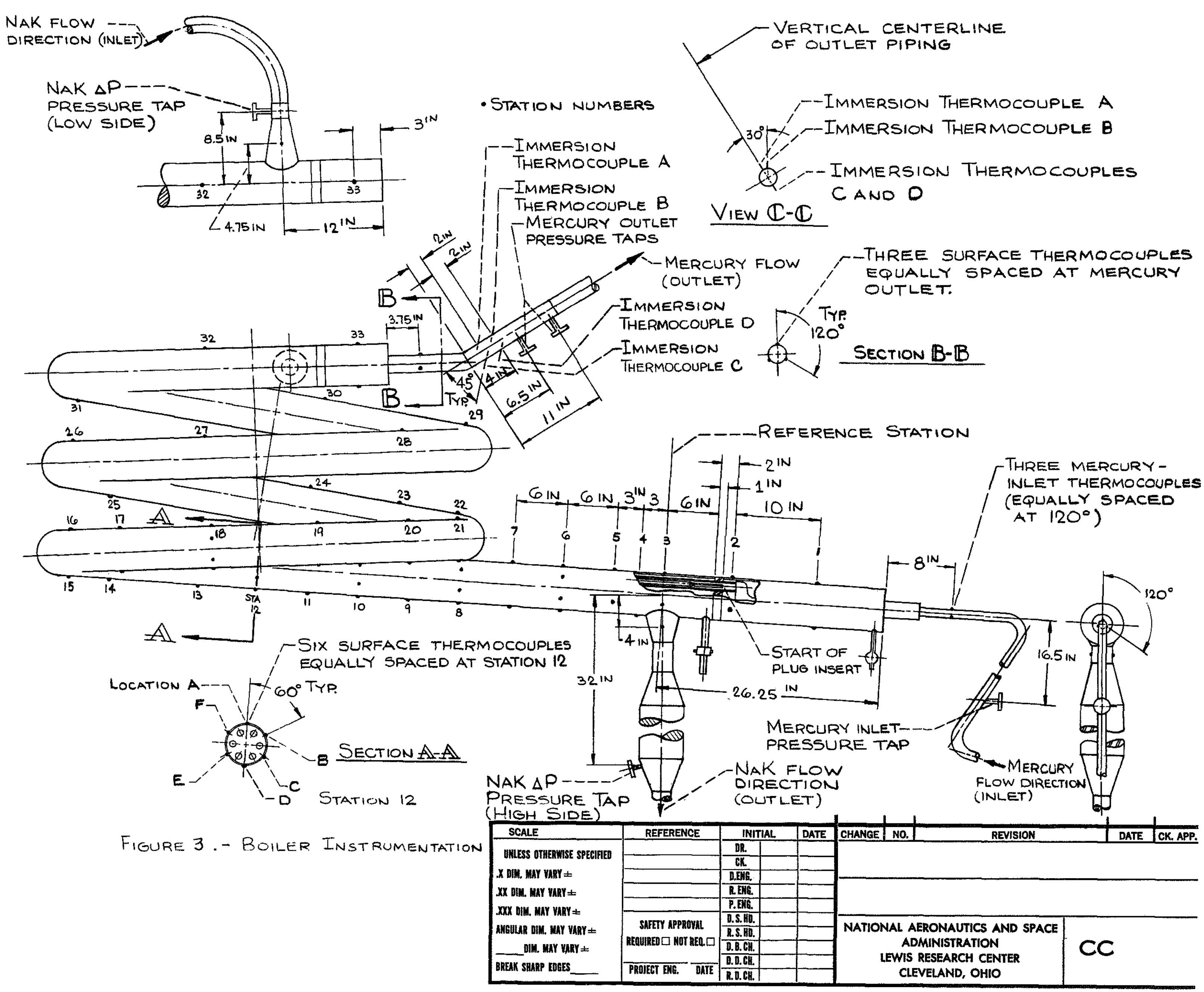
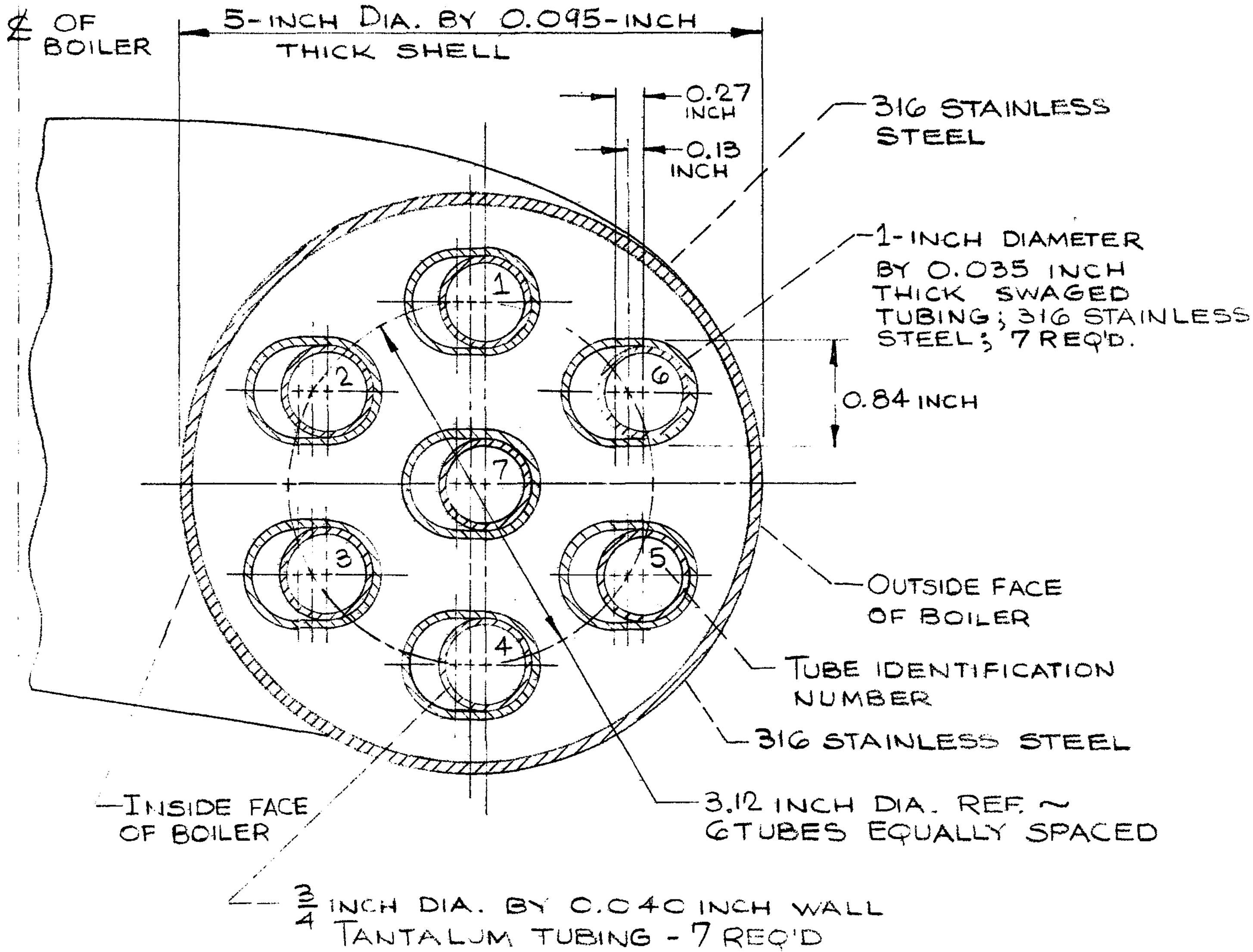
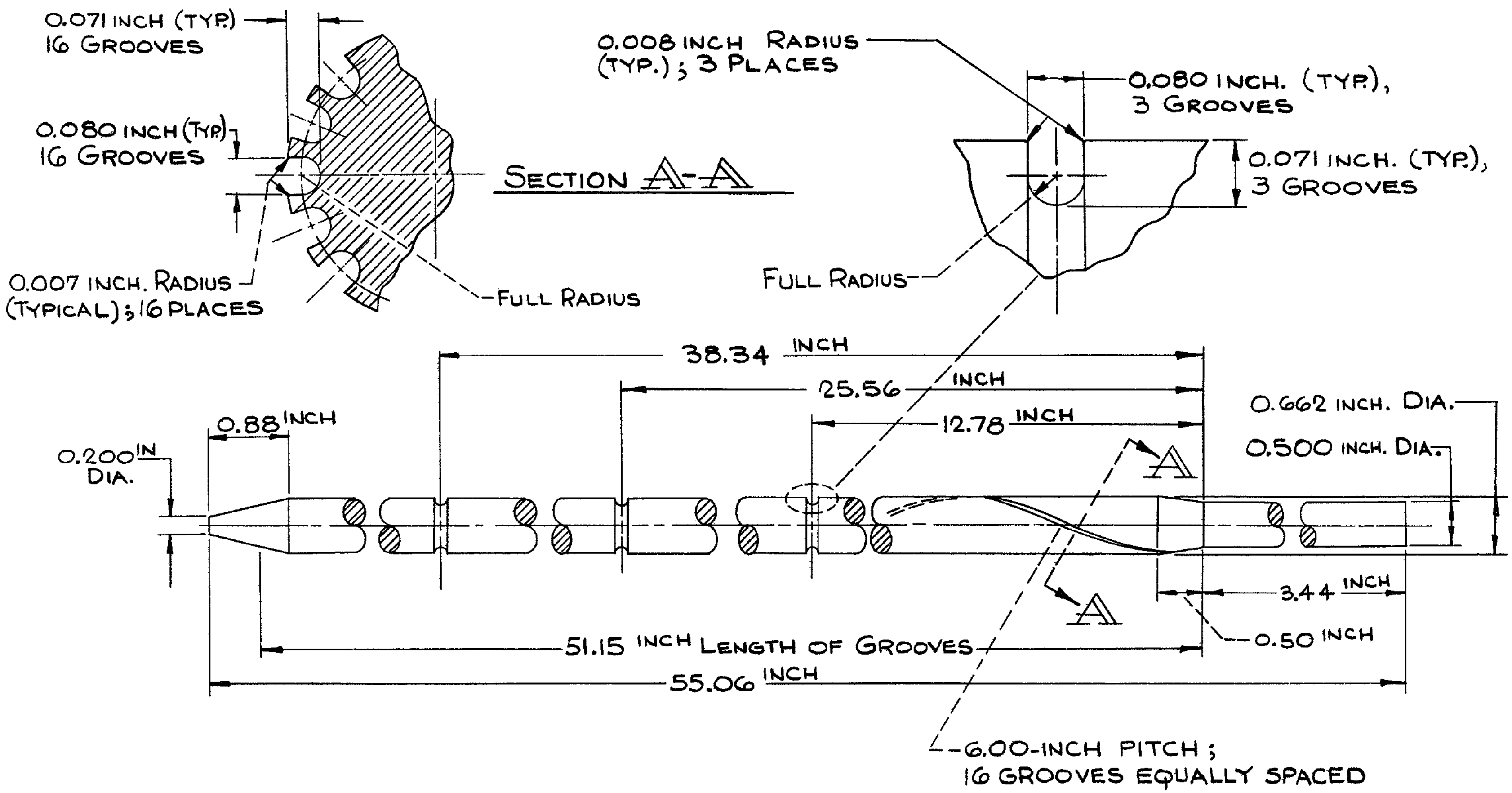


Figure 3. - Boiler Instrumentation



(a) CROSS SECTION OF BOILER TUBE BUNDLE CONFIGURATION TAKEN IN DIRETION OF MERCURY FLOW AT PLUG EXIT.

FIGURE 4.- SNAP-8 BOILER DETAILS.



(b) MULTIFLUTED BOILER PLUG. PLUG MATERIAL, TANTALUM

FIGURE 4 - CONCLUDED

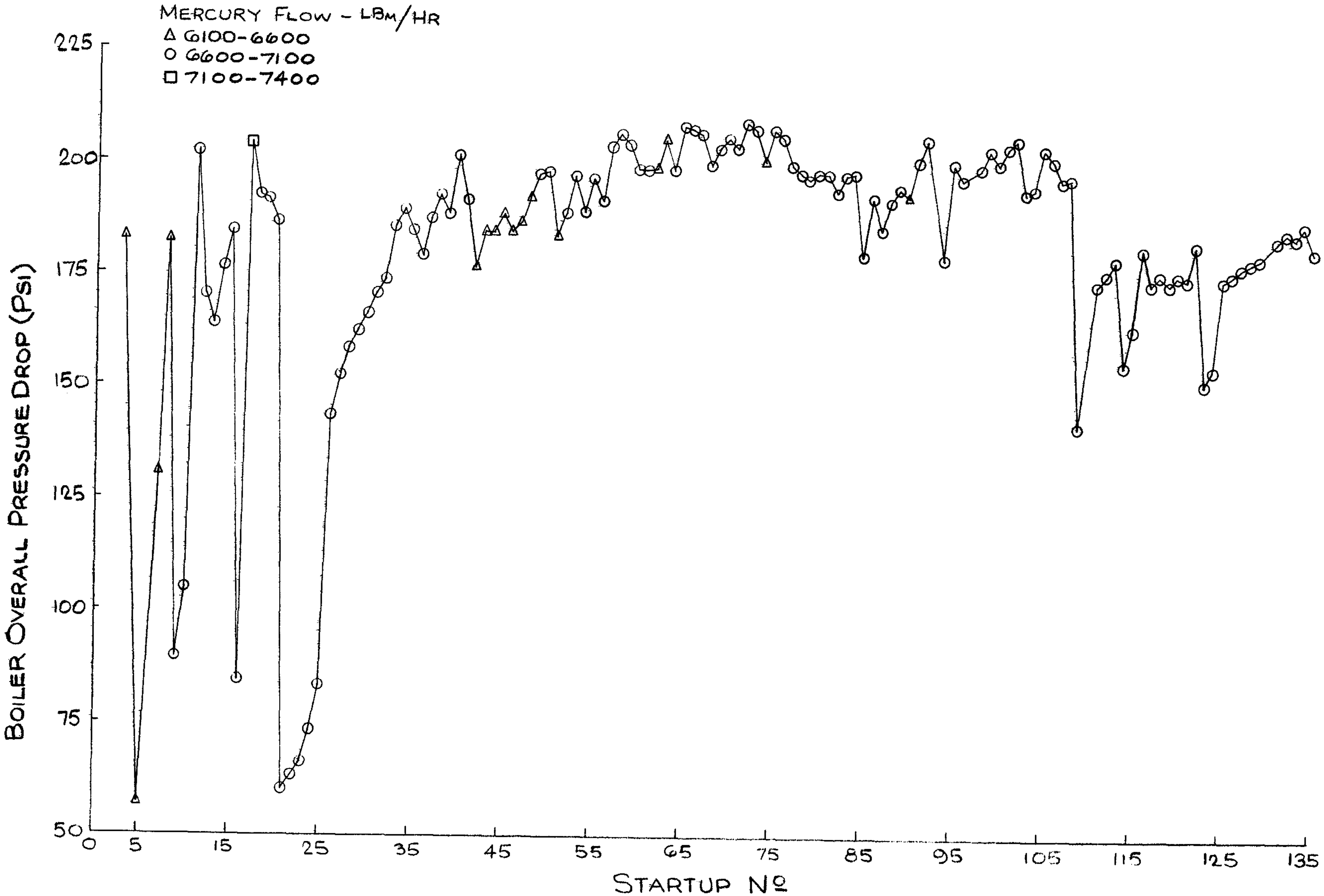
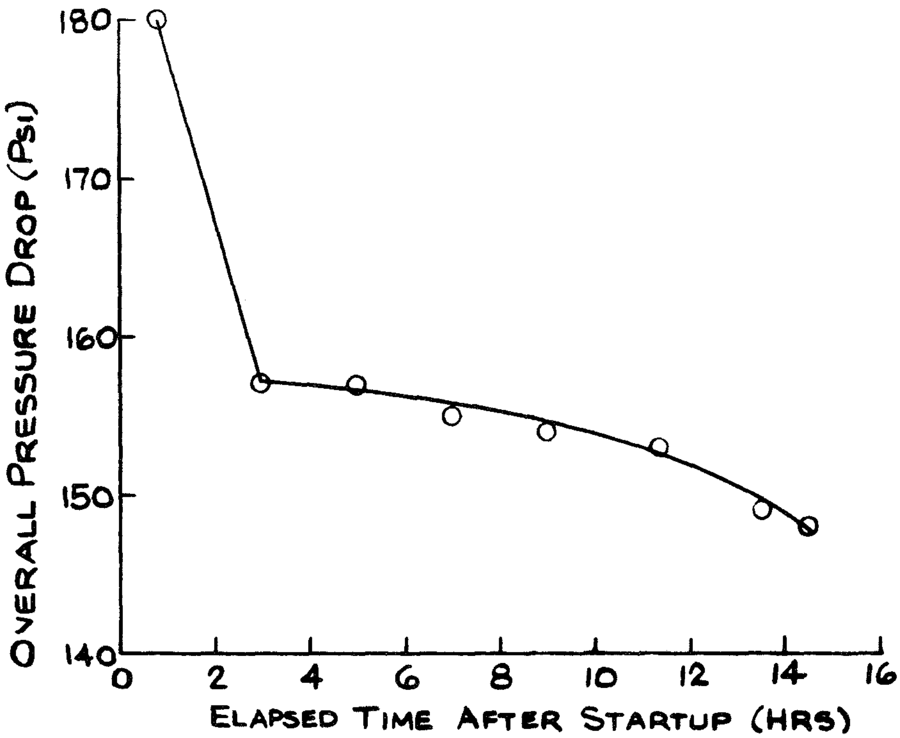
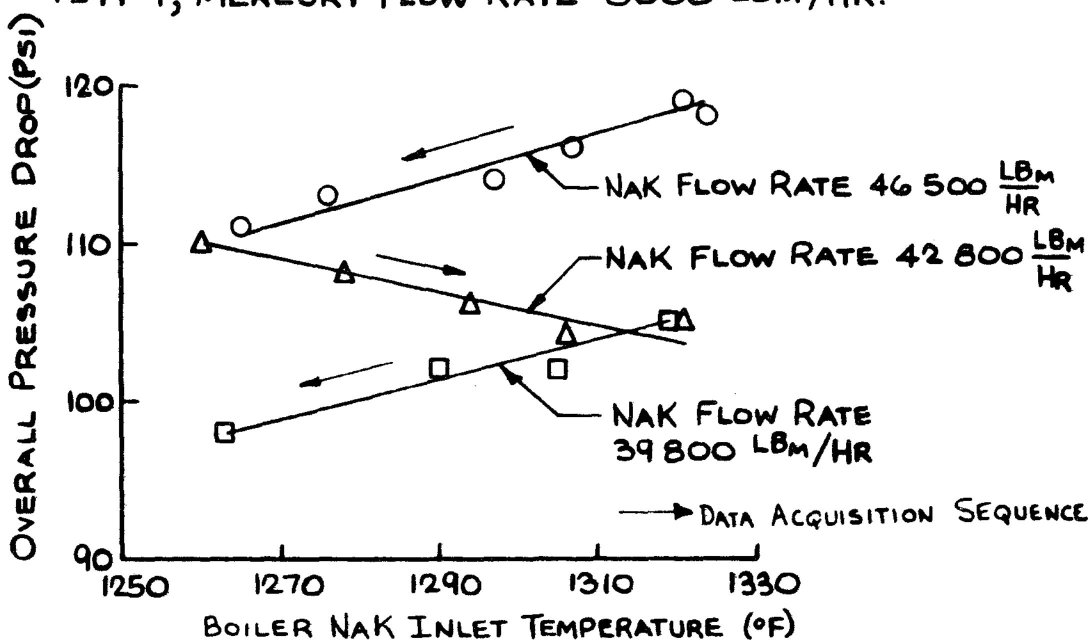


FIGURE 5.- BOILER MERCURY OVERALL PRESSURE DROP HISTORY AS A FUNCTION OF STARTUP NUMBER FOR THE SELF-SUSTAINING MERCURY FLOW RATE.

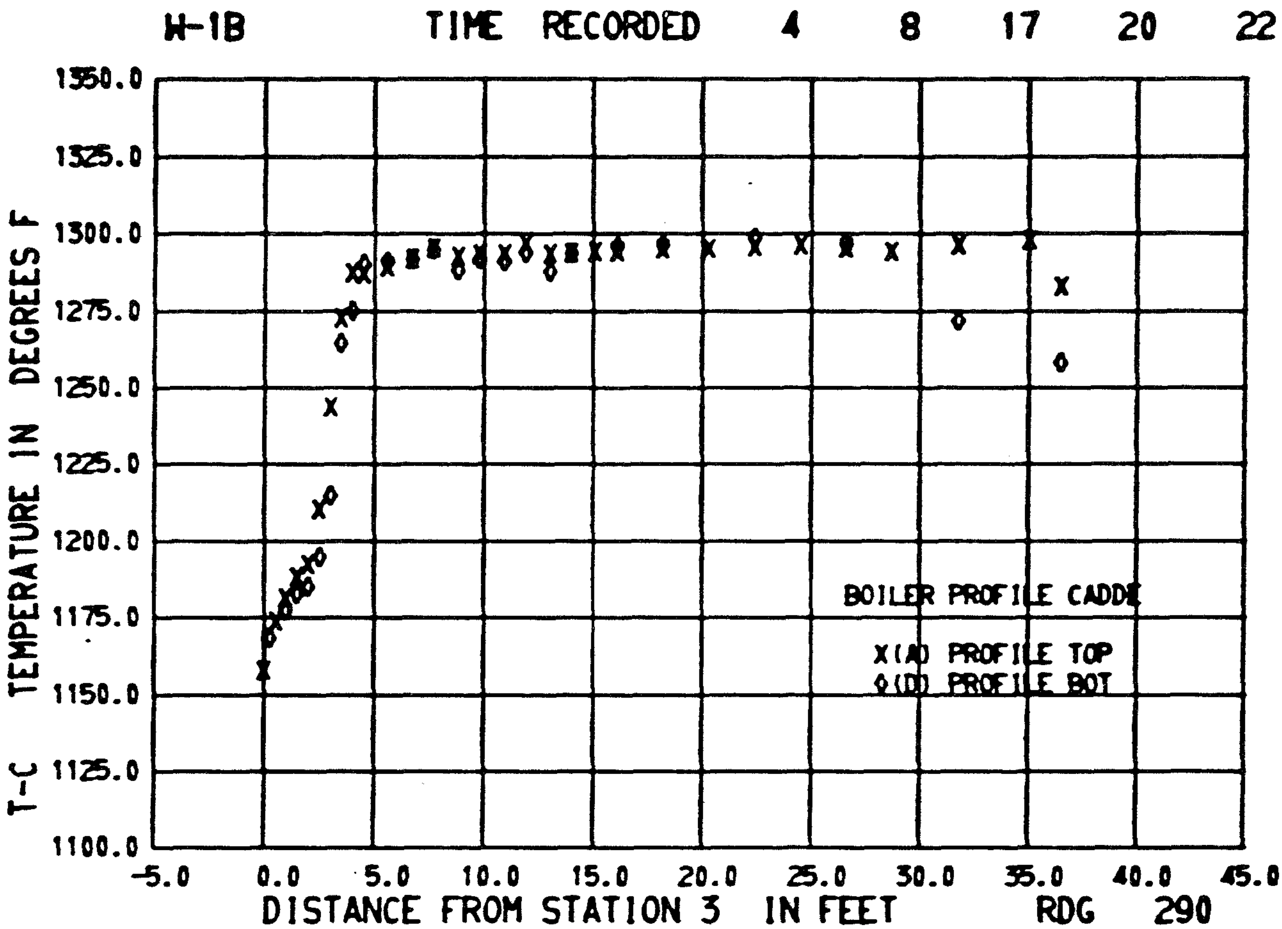


(a) NaK Flow Rate 40600 Lbm/Hr, NaK Inlet Temperature 1294 °F, Mercury Flow Rate 8000 Lbm/Hr.



(b) Mercury Flow Rate 8060 Lbm/Hr. Data taken between 31 hours and 30 minutes, and 47 hours and 5 minutes after Startup #8.

Figure 6.- Boiler Data Taken Between Startup #8 and #9.



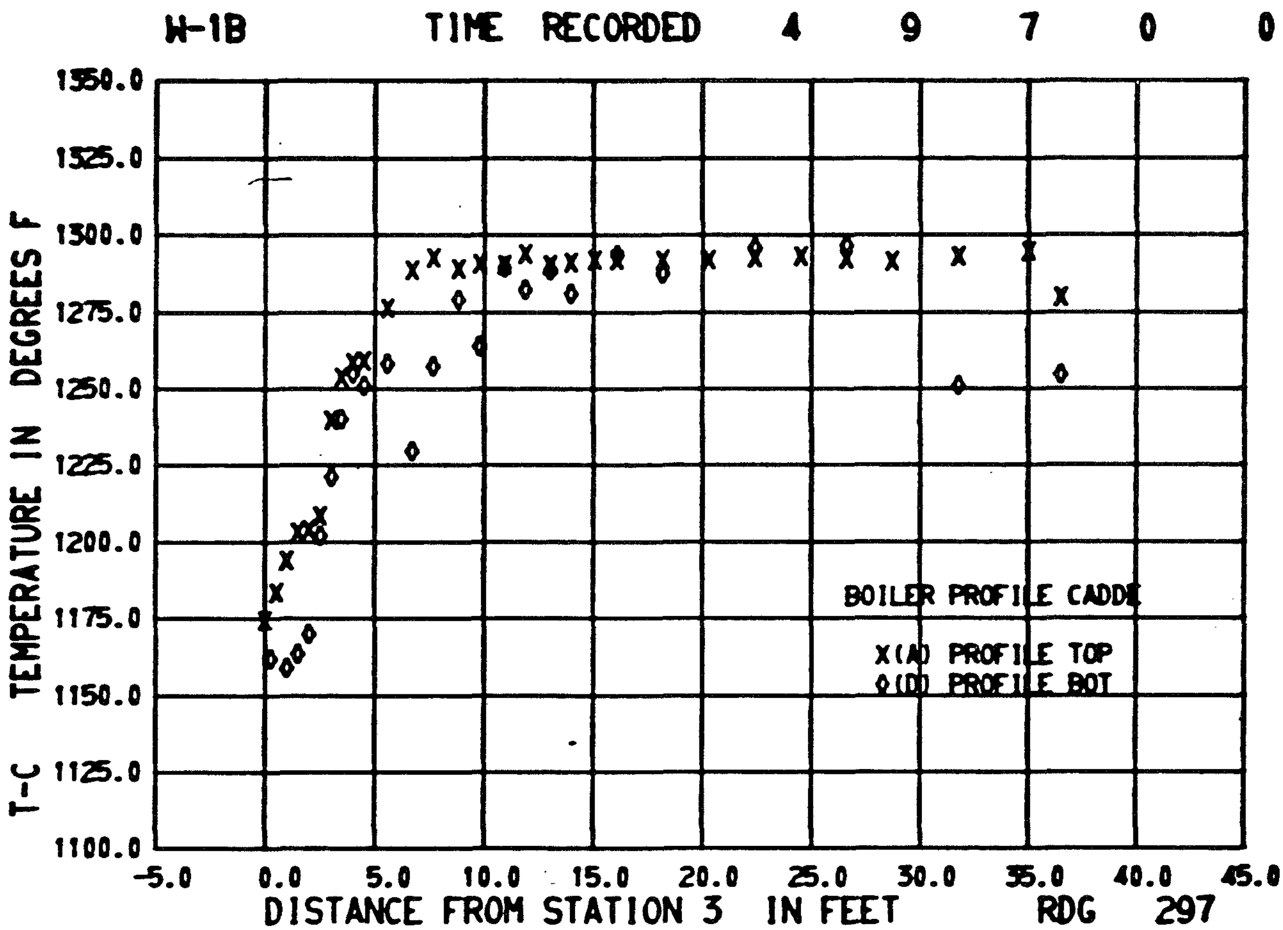
NAK SIDE DATA

FLOW RATE	40650.722 LB/HR
PRESS DROP	1.472 PSI
THERMAL POWER	335.246 KW
AVG INLET TEMP	1293.190 F
AVE OUTLET TEMP	1159.131 F

MERCURY SIDE DATA

LIQUID FLOW RATE	8133.100 LB/HR
VAPOR FLOW RATE	8385.782 LB/HR
QUALITY(HT. BAL.)	0.909 0/0
AVG ENTHALPY OUT	150.551 BTU/LB
INLET PRESS	340.903 PSIA
OUTLET PRESS	160.959 PSIA
SAT TEMP OUT	980.983 F
TEMP OUT	1283.747 F
AVG TEMP IN	435.852 F
THERMAL POWER	363.545 KW

FIGURE 7(a).- BOILER SHELL TEMPERATURE PROFILES. 49 MINUTES AFTER STARTUP #8.



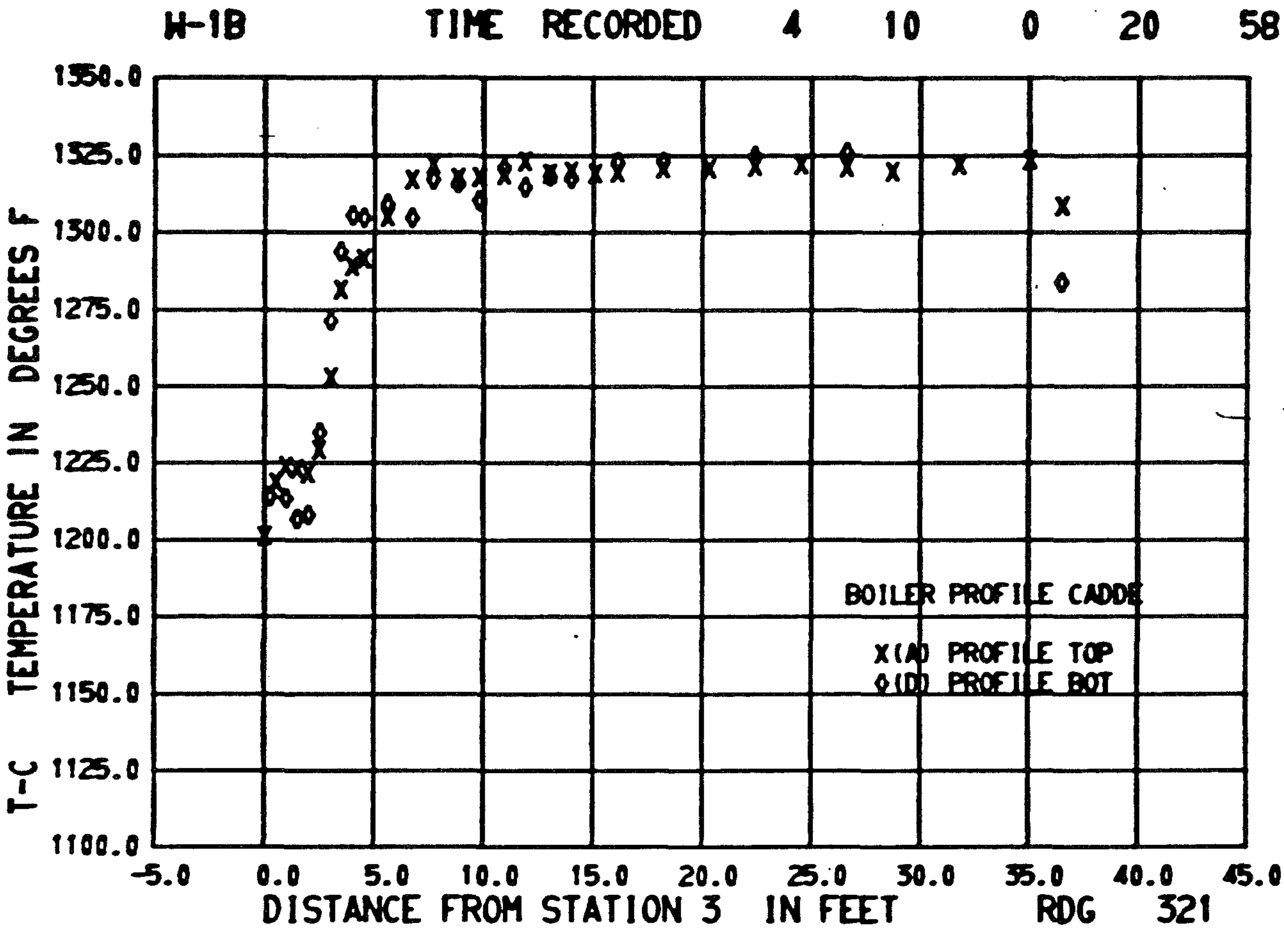
NAK SIDE DATA

FLOW RATE	40611.706 LB/HR
PRESS DROP	1.256 PSI
THERMAL POWER	330.267 KW
AVG INLET TEMP	1289.688 F
AVE OUTLET TEMP	1157.479 F

MERCURY SIDE DATA

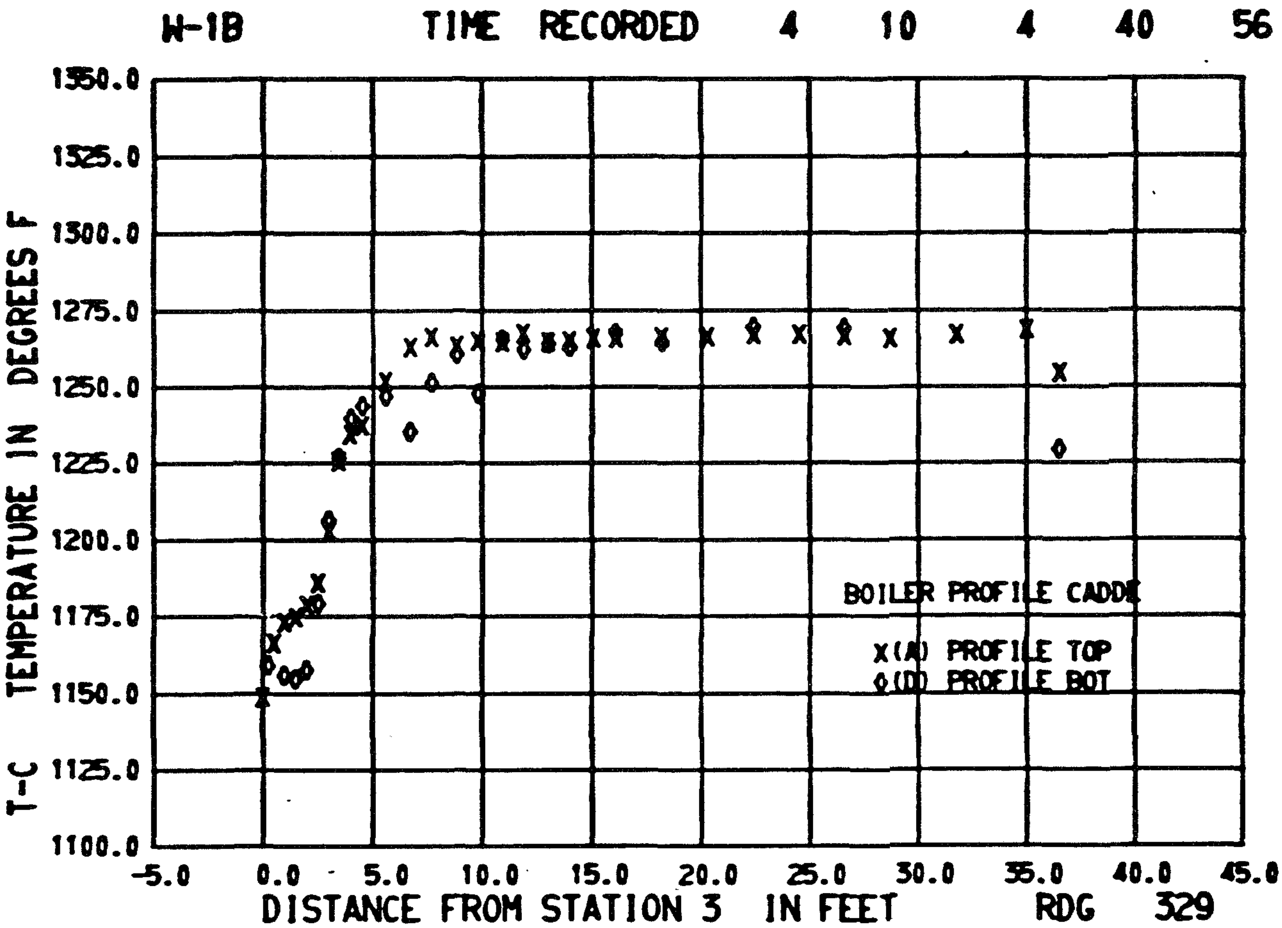
LIQUID FLOW RATE	7908.769 LB/HR
VAPOR FLOW RATE	8174.247 LB/HR
QUALITY(HT. BAL.)	0.928 0/0
AVG ENTHALPY OUT	152.953 BTU/LB
INLET PRESS	305.002 PSIA
OUTLET PRESS	156.602 PSIA
SAT TEMP OUT	976.716 F
TEMP OUT	1279.222 F
AVG TEMP IN	436.430 F
THERMAL POWER	352.007 KW

FIGURE 7(b).- BOILER SHELL TEMPERATURE PROFILES. 14 HOURS AND 29 MINUTES AFTER STARTUP #8.



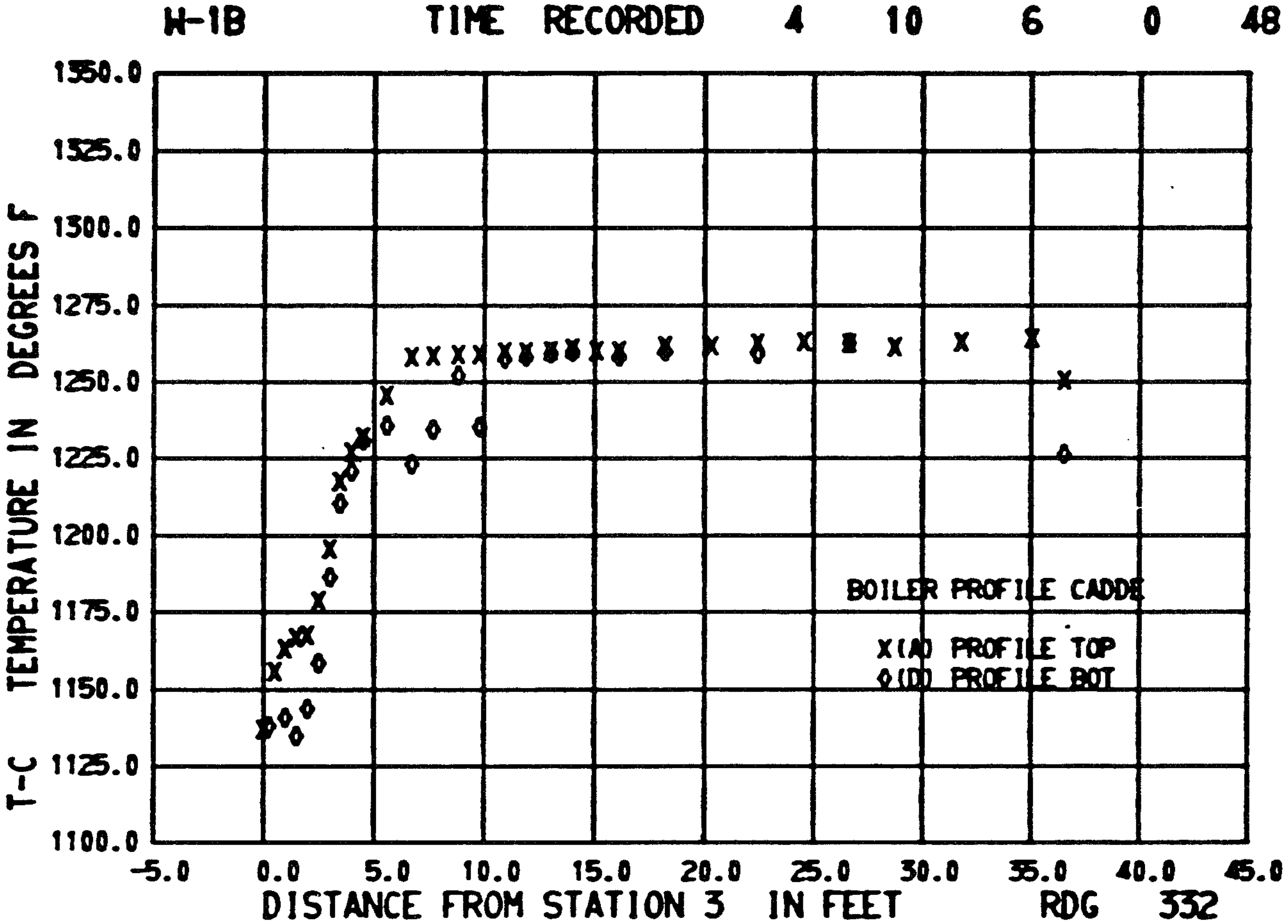
NAK SIDE DATA		MERCURY SIDE DATA	
FLOW RATE	46470.542 LB/HR	LIQUID FLOW RATE	8107.241 LB/HR
PRESS DROP	1.631 PSI	VAPOR FLOW RATE	8342.467 LB/HR
THERMAL POWER	347.948 KW	QUALITY(HT. BAL.)	0.958 0/0
AVG INLET TEMP	1320.692 F	AVG ENTHALPY OUT	157.476 BTU/LB
AVE OUTLET TEMP	1199.167 F	INLET PRESS	281.165 PSIA
		OUTLET PRESS	162.439 PSIA
		SAT TEMP OUT	982.409 F
		TEMP OUT	1307.095 F
		AVG TEMP IN	433.124 F
		THERMAL POWER	361.189 KW

Figure 8(a).- Boiler Shell Temperature Profiles. 31 Hours and 50 Minutes After Startup #8.



NAK SIDE DATA		MERCURY SIDE DATA	
FLOW RATE	46982.942 LB/HR	LIQUID FLOW RATE	8088.057 LB/HR
PRESS DROP	1.645 PSI	VAPOR FLOW RATE	8577.819 LB/HR
THERMAL POWER	332.994 KW	QUALITY(HT. BAL.)	0.922 0/0
AVG INLET TEMP	1264.946 F	AVG ENTHALPY OUT	151.604 BTU/LB
AVE OUTLET TEMP	1149.643 F	INLET PRESS	270.728 PSIA
		OUTLET PRESS	159.611 PSIA
		SAT TEMP OUT	979.675 F
		TEMP OUT	1253.857 F
		AVG TEMP IN	432.546 F
		THERMAL POWER	356.952 KW

FIGURE 8(b).- BOILER SHELL TEMPERATURE PROFILES. 36 HOURS AND 10 MINUTES AFTER STARTUP #8.



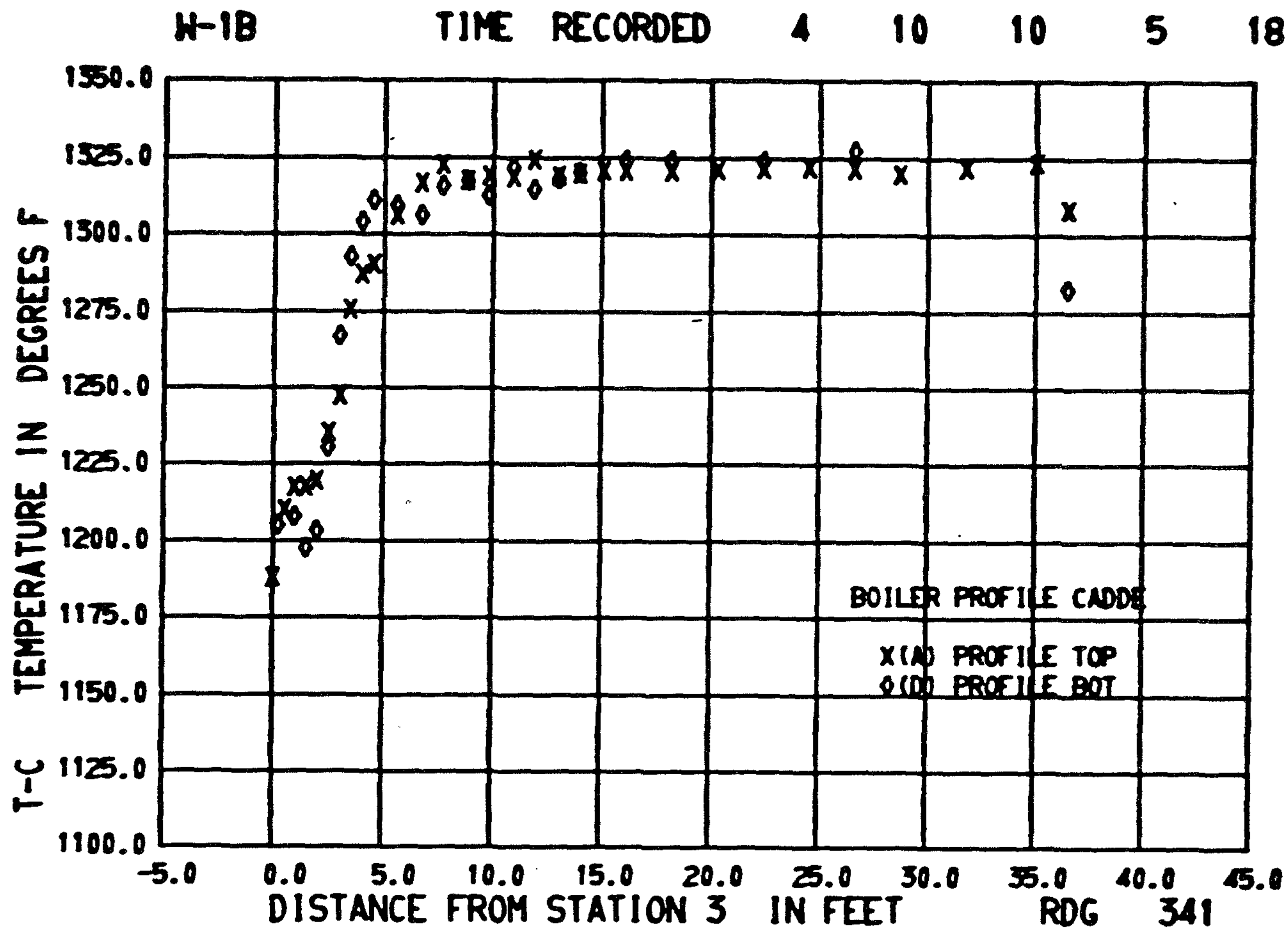
NAK SIDE DATA

FLOW RATE	43219.914 LB/HR
PRESS DROP	1.394 PSI
THERMAL POWER	336.252 KW
AVG INLET TEMP	1260.319 F
AVE OUTLET TEMP	1133.699 F

MERCURY SIDE DATA

LIQUID FLOW RATE	8122.061 LB/HR
VAPOR FLOW RATE	8389.258 LB/HR
QUALITY(HT. BAL.)	0.928 0/0
AVG ENTHALPY OUT	152.245 BTU/LB
INLET PRESS	269.575 PSIA
OUTLET PRESS	159.769 PSIA
SAT TEMP OUT	979.828 F
TEMP OUT	1249.338 F
AVG TEMP IN	427.162 F
THERMAL POWER	558.504 KW

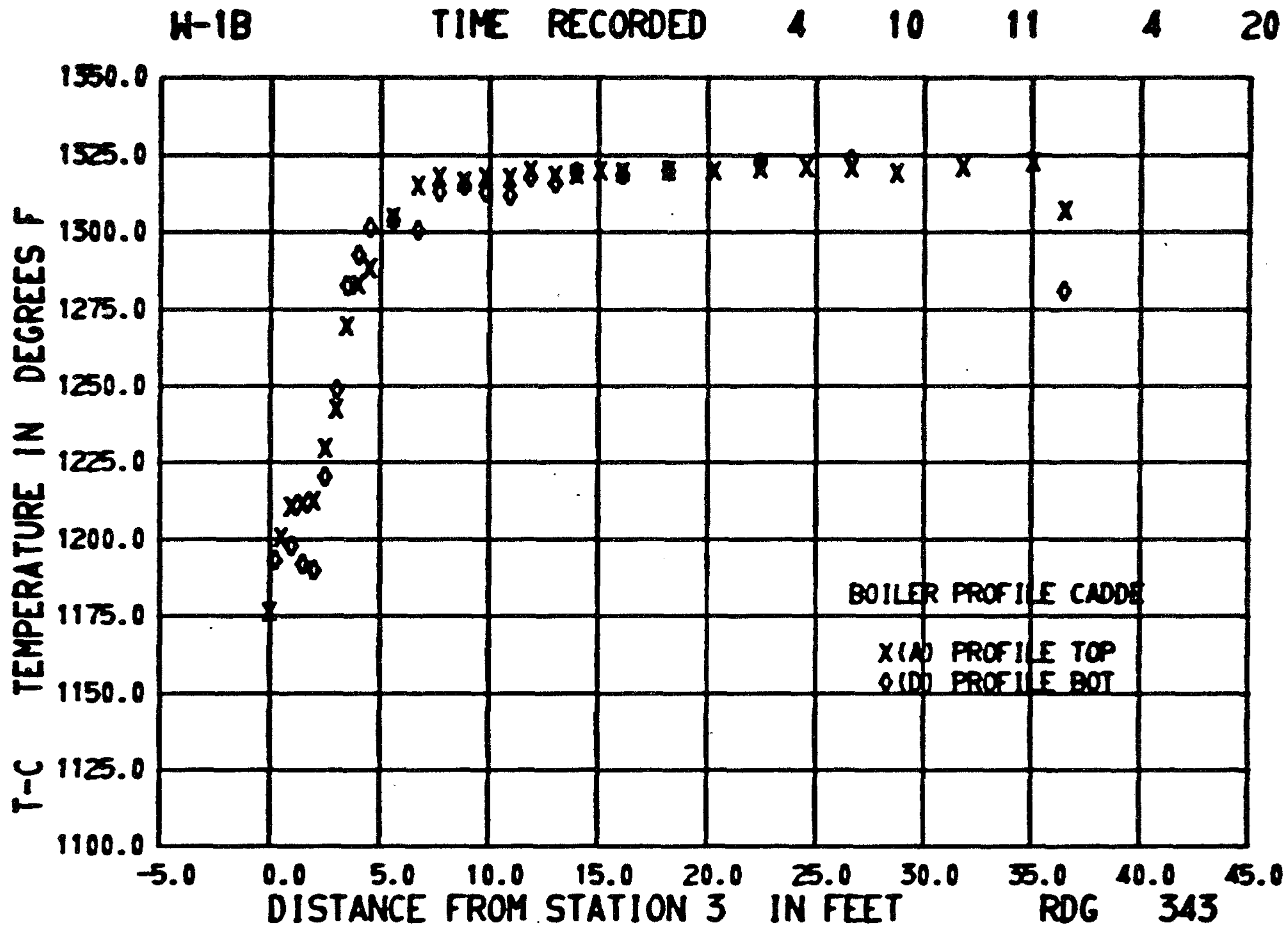
FIGURE 8(c).- BOILER SHELL TEMPERATURE PROFILES. 37 HOURS AND 30 MINUTES AFTER STARTUP #8.



NAK SIDE DATA	
FLOW RATE	42510.879 LB/HR
PRESS DROP	1.302 PSI
THERMAL POWER	336.130 KW
AVG INLET TEMP	1320.515 F
AVE OUTLET TEMP	1192.161 F

MERCURY SIDE DATA	
LIQUID FLOW RATE	8054.488 LB/HR
VAPOR FLOW RATE	8299.898 LB/HR
QUALITY(HT. BAL.)	0.927 0/0
AVG ENTHALPY OUT	153.492 BTU/LB
INLET PRESS	267.372 PSIA
OUTLET PRESS	161.808 PSIA
SAT TEMP OUT	981.802 F
TEMP OUT	1308.440 F
AVG TEMP IN	427.253 F
THERMAL POWER	358.757 KW

Figure 8(d).- Boiler Shell Temperature Profiles. 41 Hours and 34 Minutes After Startup #8.



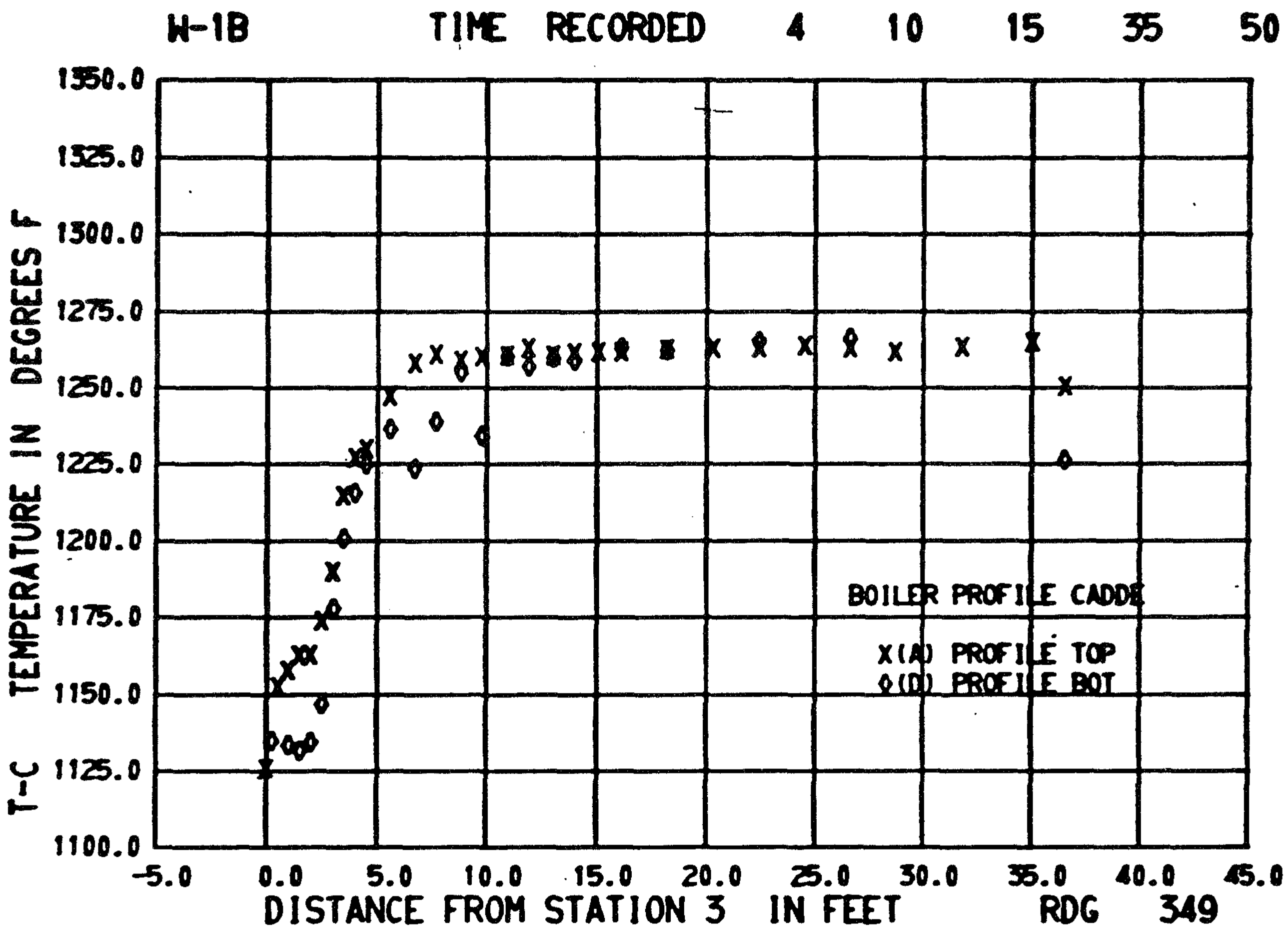
NAK SIDE DATA

FLOW RATE	39584.830 LB/HR
PRESS DROP	1.110 PSI
THERMAL POWER	336.115 KW
AVG INLET TEMP	1318.567 F
AVE OUTLET TEMP	1180.688 F

MERCURY SIDE DATA

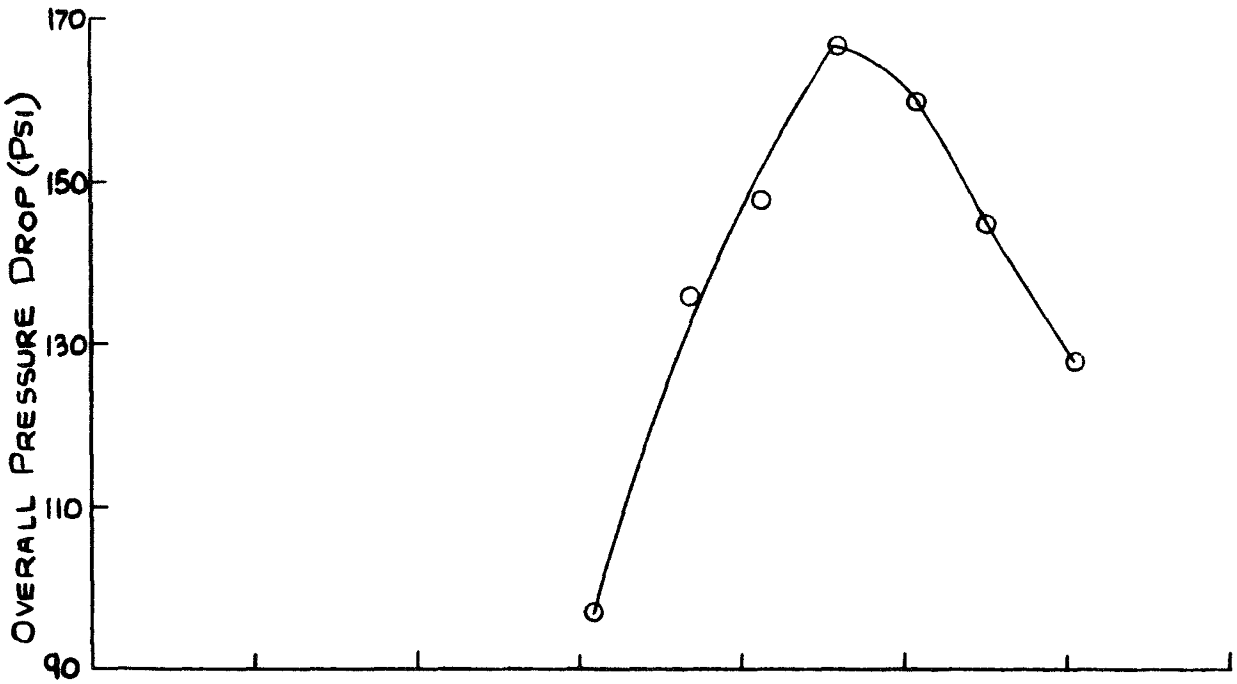
LIQUID FLOW RATE	8053.697 LB/HR
VAPOR FLOW RATE	8323.938 LB/HR
QUALITY(HT. BAL.)	0.928 0/0
AVG ENTHALPY OUT	153.555 BTU/LB
INLET PRESS	266.837 PSIA
OUTLET PRESS	161.760 PSIA
SAT TEMP OUT	981.755 F
TEMP OUT	1307.520 F
AVG TEMP IN	428.662 F
THERMAL POWER	358.518 KW

FIGURE 8(e).- BOILER SHELL TEMPERATURE PROFILES. 42 HOURS AND 33 MINUTES AFTER STARTUP #8.

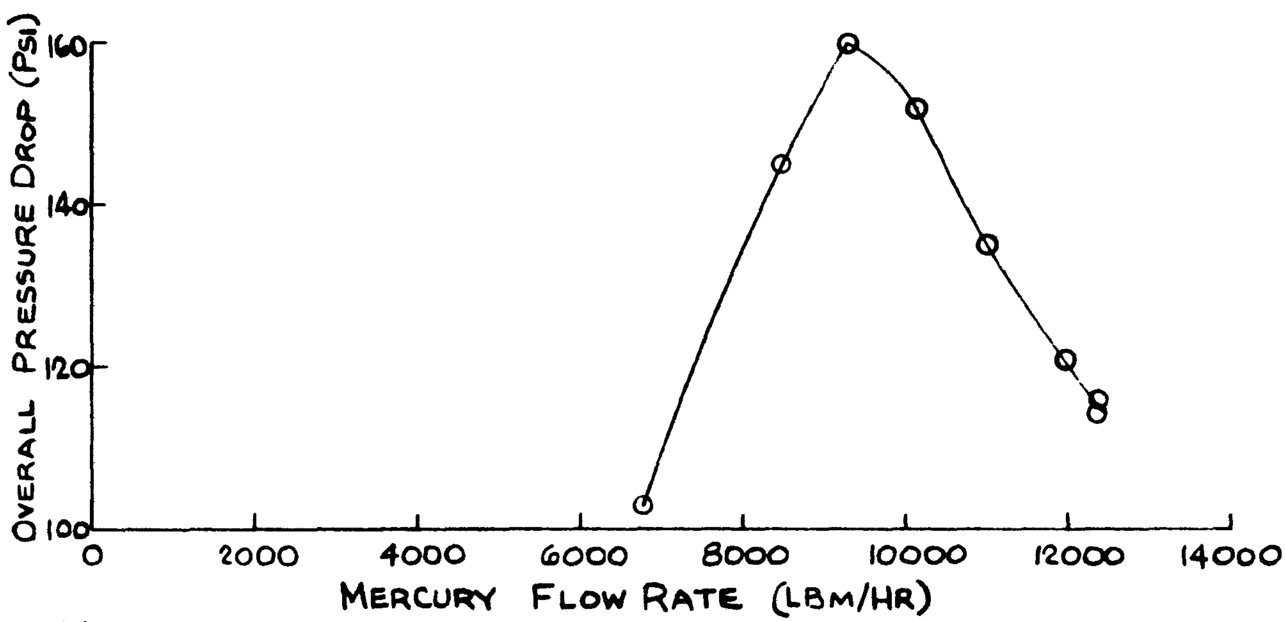


NAK SIDE DATA		MERCURY SIDE DATA	
FLOW RATE	39820.546 LB/HR	LIQUID FLOW RATE	8065.656 LB/HR
PRESS DROP	1.156 PSI	VAPOR FLOW RATE	8359.774 LB/HR
THERMAL POWER	339.591 KW	QUALITY(HT. BAL.)	0.946 0/0
AVG INLET TEMP	1262.756 F	AVG ENTHALPY OUT	154.572 BTU/LB
AVE OUTLET TEMP	1123.943 F	INLET PRESS	258.212 PSIA
		OUTLET PRESS	159.575 PSIA
		SAT TEMP OUT	979.639 F
		TEMP OUT	1251.032 F
		AVG TEMP IN	417.299 F
		THERMAL POWER	356.313 KW

FIGURE 8(f).- BOILER SHELL TEMPERATURE PROFILES. 47 HOURS AND 5 MINUTES AFTER STARTUP #8.

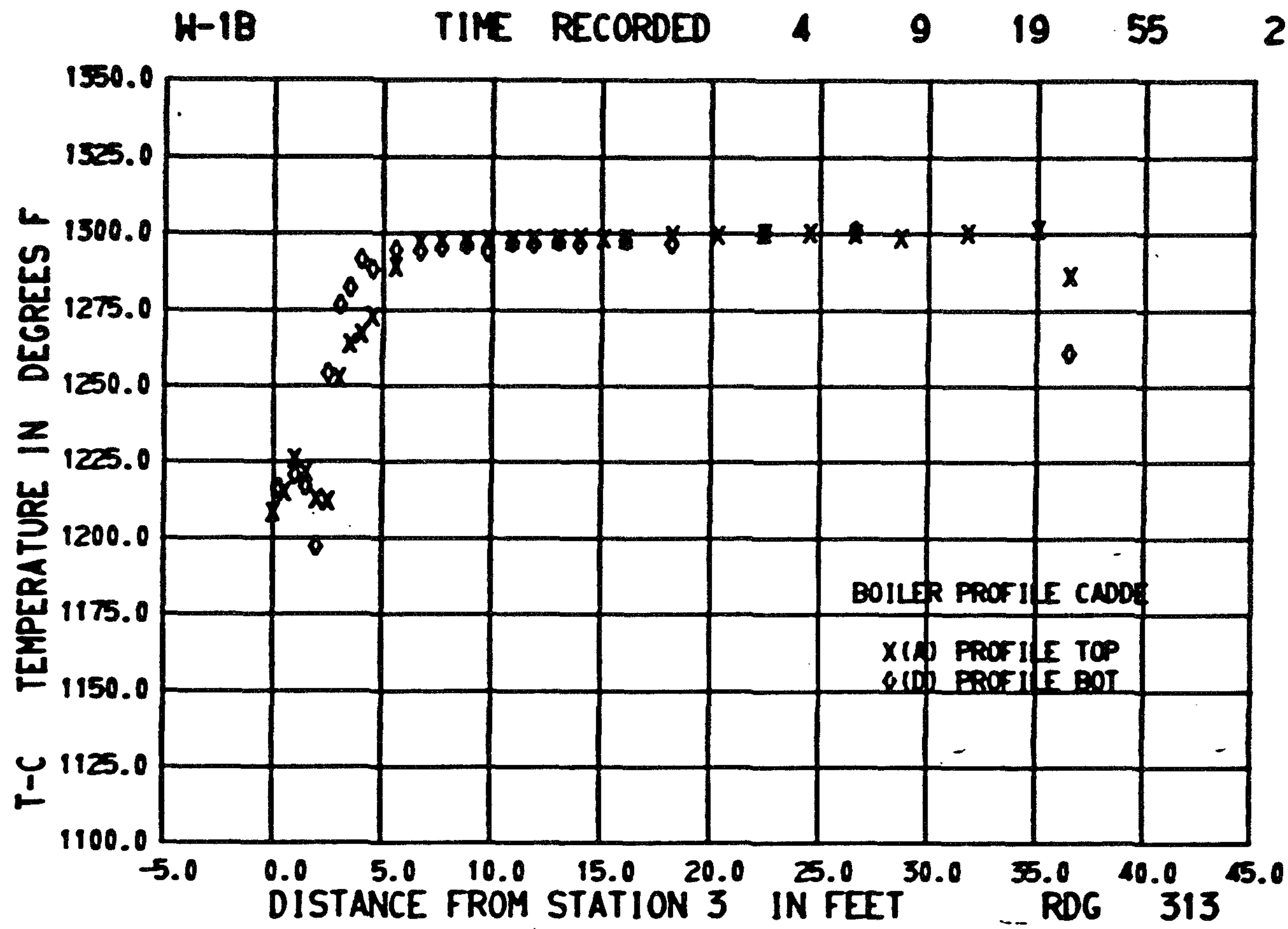


(a) DATA ACQUIRED BETWEEN 19 HOURS AND 10 MINUTES, AND 27 HOURS AND 25 MINUTES AFTER STARTUP #8. NAK FLOW RATE 46500 LBM/HR, NAK INLET TEMPERATURE 1291 °F.



(b) DATA ACQUIRED BETWEEN 15 MINUTES, AND 1 HOUR AND 29 MINUTES AFTER STARTUP #10. NAK FLOW RATE 47000 LBM/HR, NAK INLET TEMPERATURE 1286 °F.

FIGURE 9. - VARIATION OF BOILER OVERALL PRESSURE DROP AS A FUNCTION OF LIQUID MERCURY FLOW RATE.



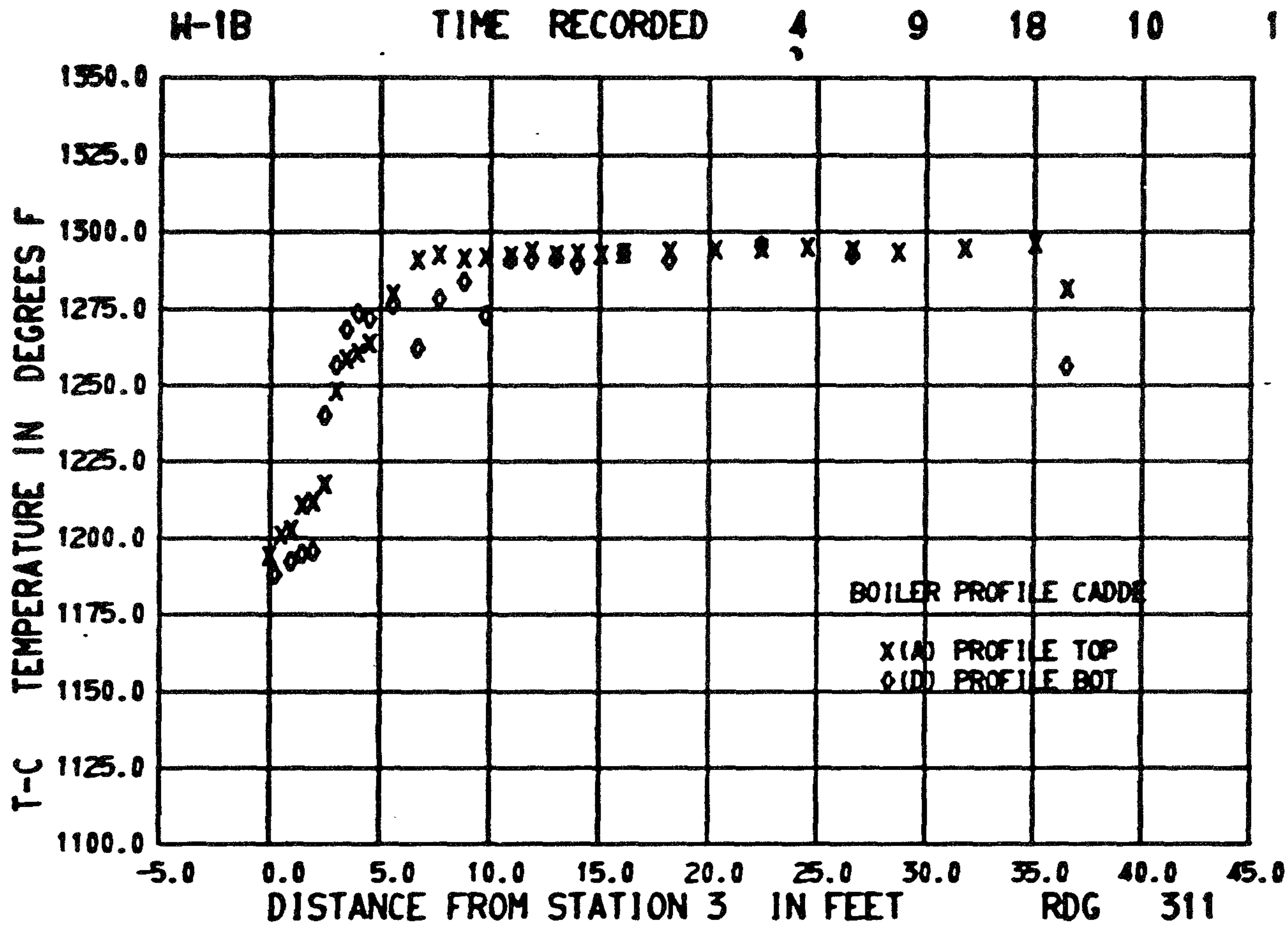
NAK SIDE DATA

FLOW RATE	46247.900 LB/HR
PRESS DROP	1.662 PSI
THERMAL POWER	255.024 KW
AVG INLET TEMP	1297.152 F
AVE OUTLET TEMP	1207.621 F

MERCURY SIDE DATA

LIQUID FLOW RATE	6151.905 LB/HR
VAPOR FLOW RATE	6295.878 LB/HR
QUALITY(HT. BAL.)	0.922 0/0
AVG ENTHALPY OUT	152.178 BTU/LB
INLET PRESS	216.506 PSIA
OUTLET PRESS	119.792 PSIA
SAT TEMP OUT	935.655 F
TEMP OUT	1283.535 F
AVG TEMP IN	425.554 F
THERMAL POWER	275.572 KW

FIGURE 10(a).- BOILER SHELL TEMPERATURE PROFILES. 27 HOURS AND 25 MINUTES AFTER STARTUP #8.



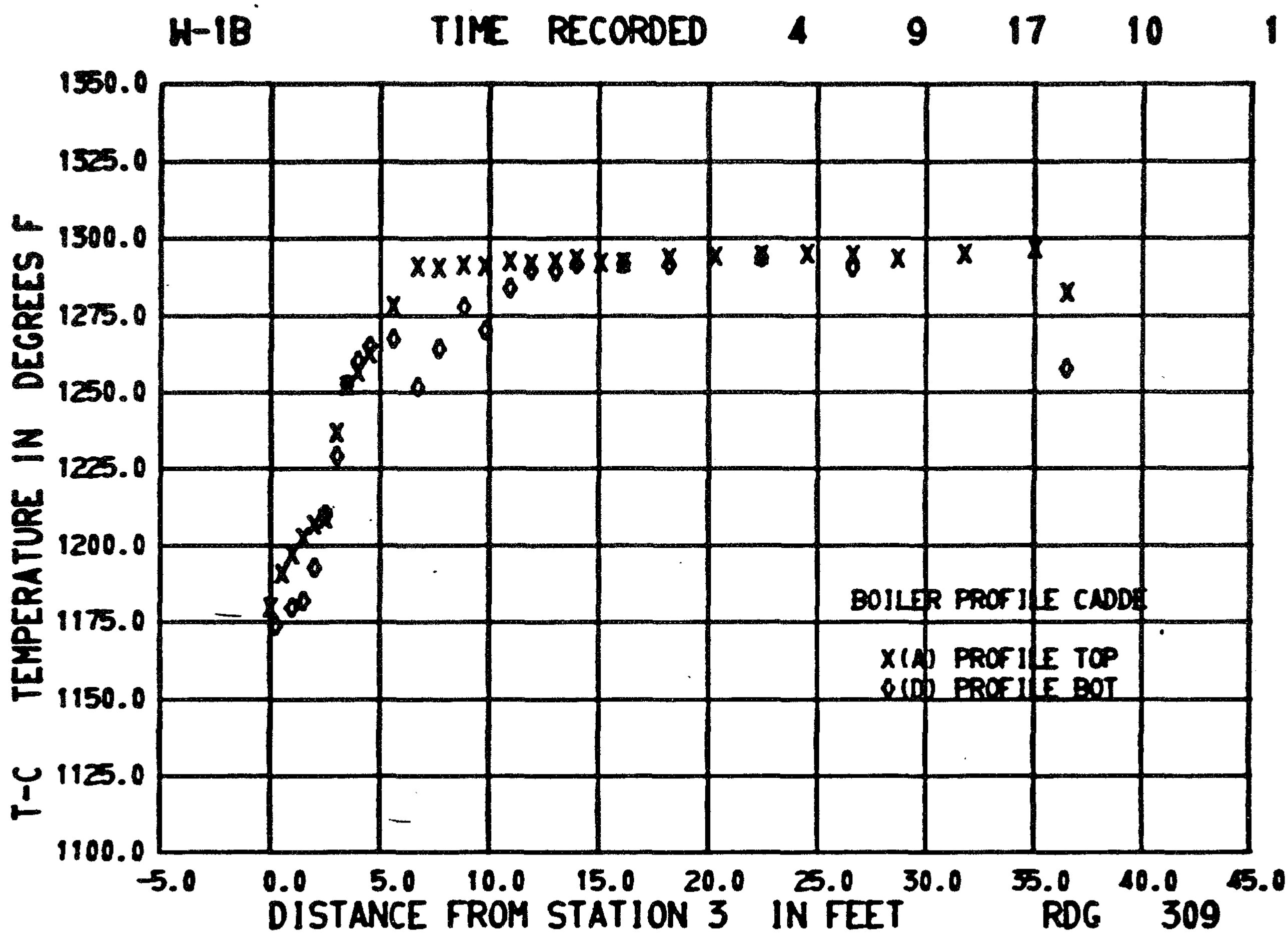
NAK SIDE DATA

FLOW RATE	46215.507 LB/HR
PRESS DROP	1.658 PSI
THERMAL POWER	310.209 KW
AVG INLET TEMP	1292.836 F
AVE OUTLET TEMP	1183.784 F

MERCURY SIDE DATA

LIQUID FLOW RATE	7327.213 LB/HR
VAPOR FLOW RATE	7569.147 LB/HR
QUALITY(HT. BAL.)	0.942 0/0
AVG ENTHALPY OUT	154.736 BTU/LB
INLET PRESS	281.206 PSIA
OUTLET PRESS	144.478 PSIA
SAT TEMP OUT	964.254 F
TEMP OUT	1279.788 F
AVG TEMP IN	427.813 F
THERMAL POWER	326.585 KW

FIGURE 10(b).- BOILER SHELL TEMPERATURE PROFILES. 25 HOURS AND 40 MINUTES AFTER STARTUP #8.



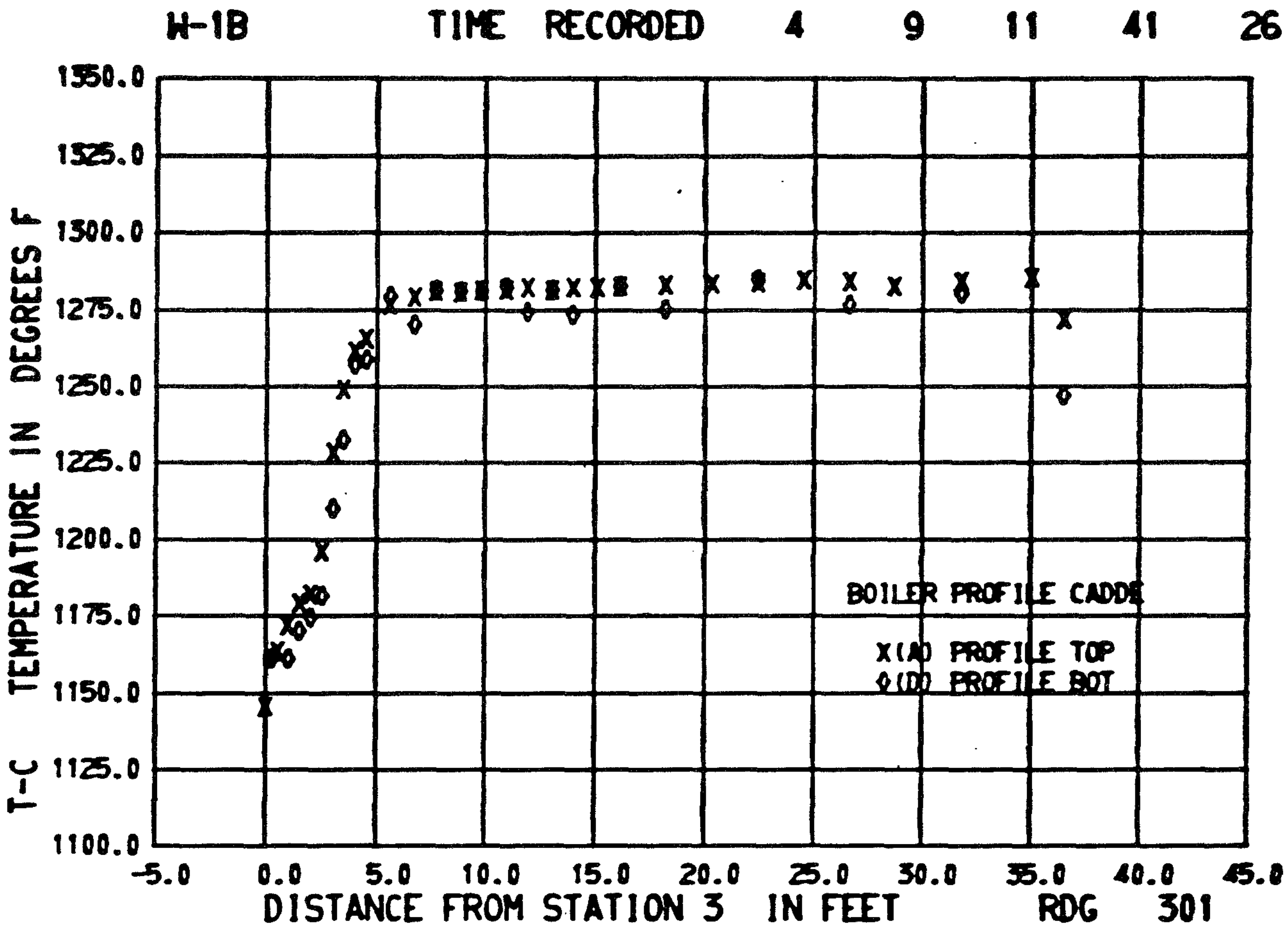
NAK SIDE DATA

FLOW RATE	46648.782	LB/HR
PRESS DROP	1.693	PSI
THERMAL POWER	345.623	KW
AVG INLET TEMP	1291.775	F
AVE OUTLET TEMP	1171.366	F

MERCURY SIDE DATA

LIQUID FLOW RATE	8214.817	LB/HR
VAPOR FLOW RATE	8499.852	LB/HR
QUALITY(HT. BAL.)	0.934	0/0
AVG ENTHALPY OUT	153.765	BTU/LB
INLET PRESS	311.055	PSIA
OUTLET PRESS	162.730	PSIA
SAT TEMP OUT	982.688	F
TEMP OUT	1280.565	F
AVG TEMP IN	425.988	F
THERMAL POWER	366.332	KW

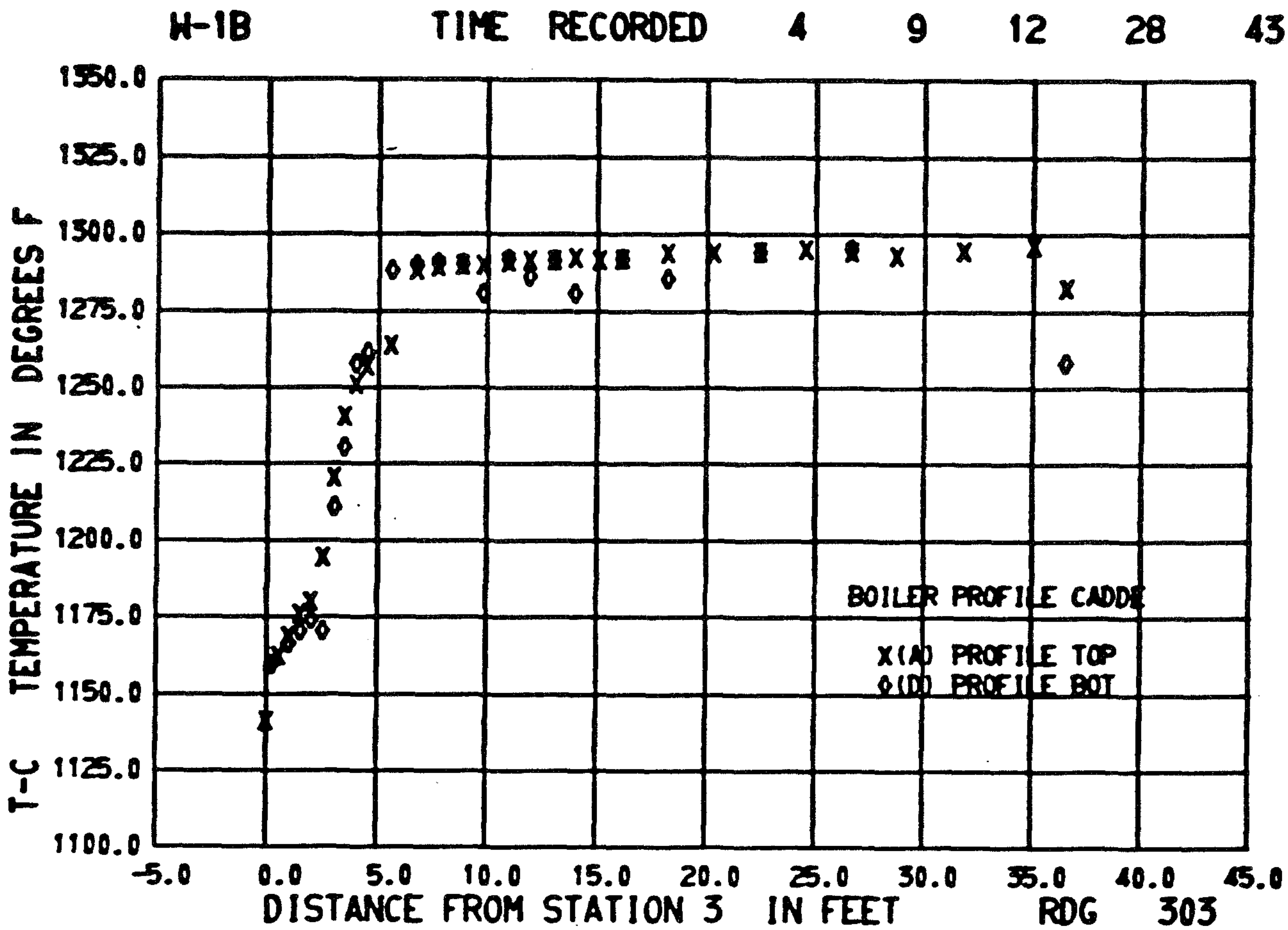
FIGURE 10 (c). - BOILER SHELL TEMPERATURE PROFILES. 24 HOURS AND 40 MINUTES AFTER STARTUP #8.



NAK SIDE DATA	
FLOW RATE	46815.350 LB/HR
PRESS DROP	1.696 PSI
THERMAL POWER	377.108 KW
AVG INLET TEMP	1281.485 F
AVE OUTLET TEMP	1150.486 F

MERCURY SIDE DATA	
LIQUID FLOW RATE	9166.829 LB/HR
VAPOR FLOW RATE	9508.047 LB/HR
QUALITY(HT. BAL.)	0.909 0/0
AVG ENTHALPY OUT	150.383 BTU/LB
INLET PRESS	348.582 PSIA
OUTLET PRESS	181.978 PSIA
SAT TEMP OUT	1000.203 F
TEMP OUT	1272.578 F
AVG TEMP IN	424.272 F
THERMAL POWER	408.704 KW

FIGURE 10(d).- BOILER SHELL TEMPERATURE PROFILES.
19 HOURS AND 10 MINUTES AFTER STARTUP #8.



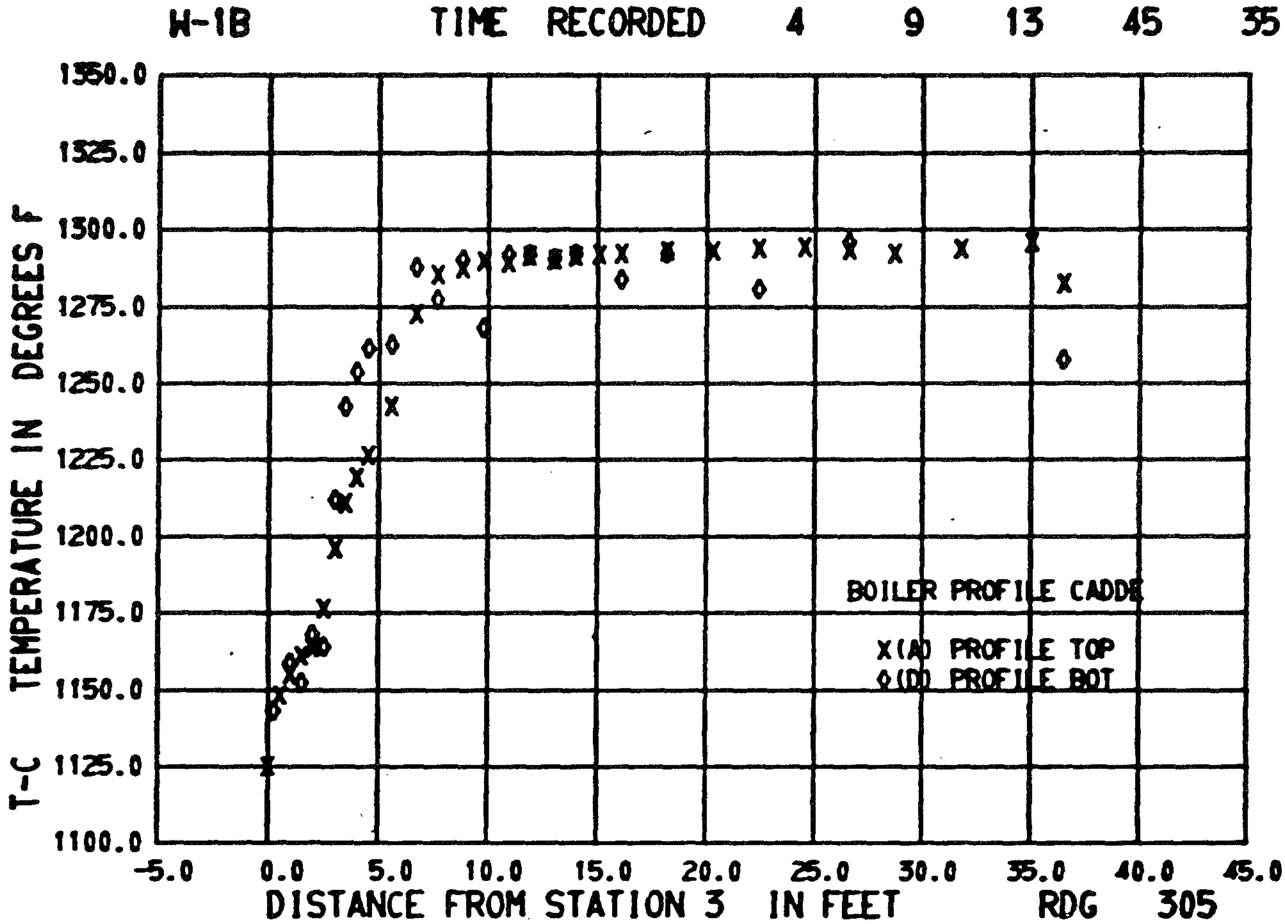
NAK SIDE DATA

FLOW RATE	46955.593 LB/HR
PRESS DROP	1.741 PSI
THERMAL POWER	420.687 KW
AVG INLET TEMP	1291.952 F
AVE OUTLET TEMP	1146.271 F

MERCURY SIDE DATA

LIQUID FLOW RATE	10131.005 LB/HR
VAPOR FLOW RATE	10537.269 LB/HR
QUALITY(HT. BAL.)	0.919 0/0
AVG ENTHALPY OUT	151.875 BTU/LB
INLET PRESS	362.703 PSIA
OUTLET PRESS	203.399 PSIA
SAT TEMP OUT	1017.939 F
TEMP OUT	1281.485 F
AVG TEMP IN	419.087 F
THERMAL POWER	451.846 KW

Figure 10(e).- Boiler Shell Temperature Profiles. 19 Hours and 58 Minutes After Startup #8.



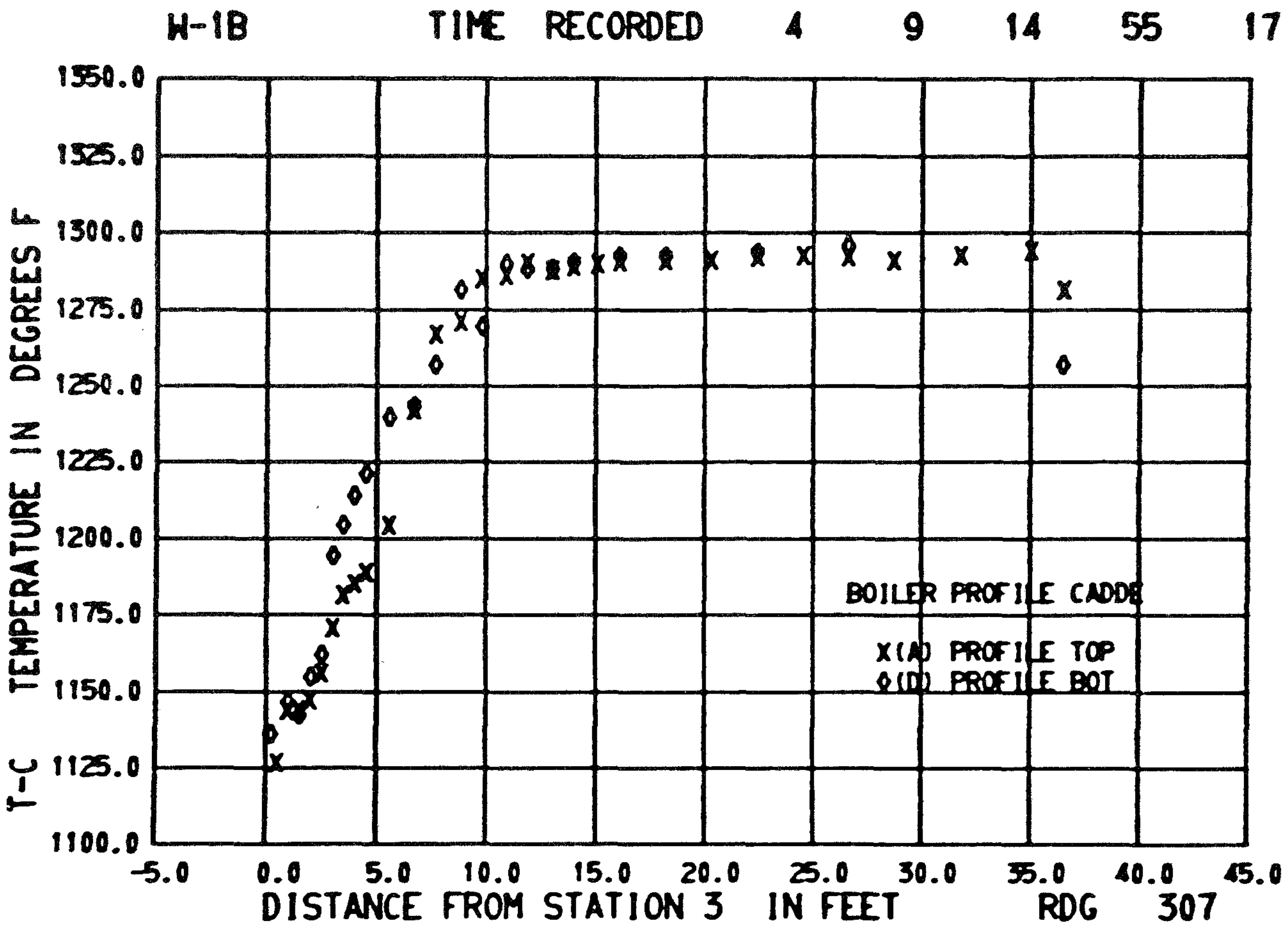
NAK SIDE DATA

FLOW RATE	47220.992 LB/HR
PRESS DROP	1.727 PSI
THERMAL POWER	457.264 KW
AVG INLET TEMP	1290.608 F
AVE OUTLET TEMP	1133.103 F

MERCURY SIDE DATA

LIQUID FLOW RATE	11012.212 LB/HR
VAPOR FLOW RATE	11495.727 LB/HR
QUALITY(HT. BAL.)	0.920 0/0
AVG ENTHALPY OUT	152.101 BTU/LB
INLET PRESS	367.150 PSIA
OUTLET PRESS	221.749 PSIA
SAT TEMP OUT	1033.025 F
TEMP OUT	1282.899 F
AVG TEMP IN	413.126 F
THERMAL POWER	490.522 KW

FIGURE 10(f).- BOILER SHELL TEMPERATURE PROFILES. 21 HOURS AND 15 MINUTES AFTER STARTUP #8.



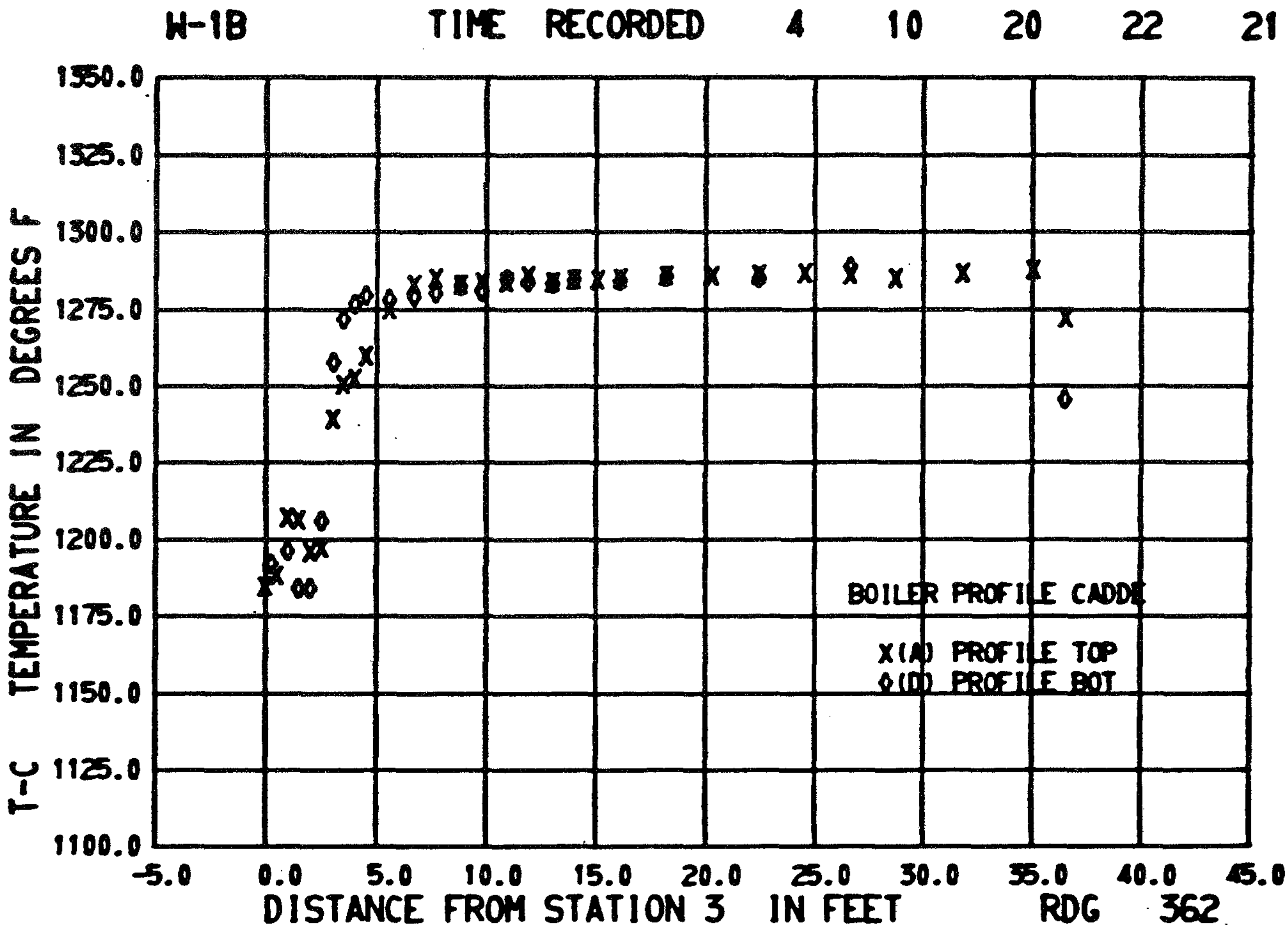
NAK SIDE DATA

FLOW RATE	47039.679	LB/HR
PRESS DROP	1.700	PSI
THERMAL POWER	509.690	KW
AVG INLET TEMP	1290.254	F
AVE OUTLET TEMP	1113.945	F

MERCURY SIDE DATA

LIQUID FLOW RATE	12097.185	LB/HR
VAPOR FLOW RATE	12714.079	LB/HR
QUALITY(HT. BAL.)	0.939	0/0
AVG ENTHALPY OUT	154.516	BTU/LB
INLET PRESS	373.181	PSIA
OUTLET PRESS	245.111	PSIA
SAT TEMP OUT	1051.191	F
TEMP OUT	1281.555	F
AVG TEMP IN	407.670	F
THERMAL POWER	537.576	KW

FIGURE 10(g).- BOILER SHELL TEMPERATURE PROFILES. 22 HOURS AND 25 MINUTES AFTER STARTUP #8.



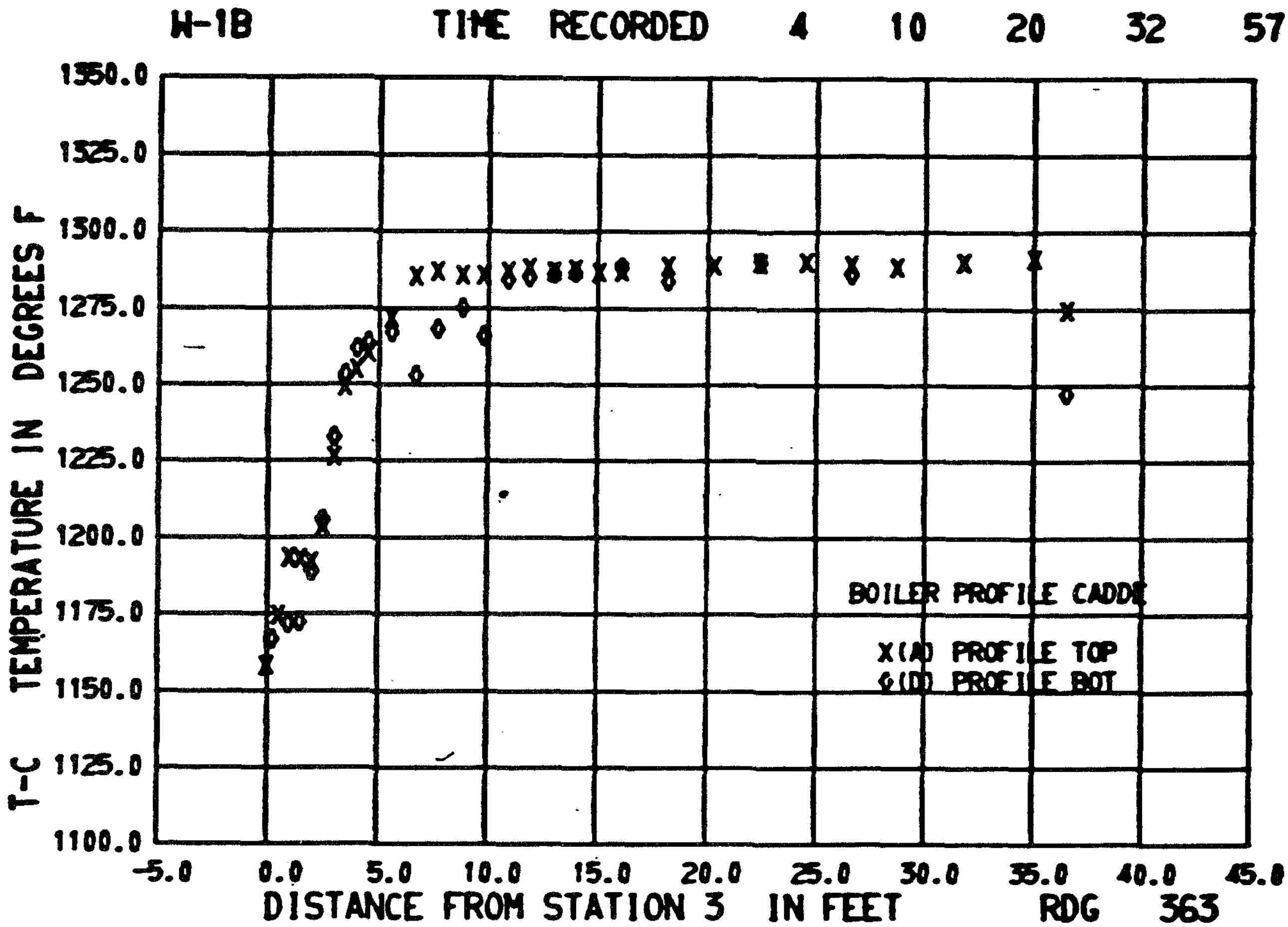
NAK SIDE DATA

FLOW RATE	46613.977 LB/HR
PRESS DROP	2.067 PSI
THERMAL POWER	299.365 KW
AVG INLET TEMP	1284.843 F
AVE OUTLET TEMP	1180.477 F

MERCURY SIDE DATA

LIQUID FLOW RATE	6750.139 LB/HR
VAPOR FLOW RATE	6965.239 LB/HR
QUALITY(HT. BAL.)	0.953 0/0
AVG ENTHALPY OUT	155.901 BTU/LB
INLET PRESS	234.806 PSIA
OUTLET PRESS	131.7 ~~76.147~~ PSIA
SAT TEMP OUT	950.090 F
TEMP OUT	1270.245 F
AVG TEMP IN	232.716 F
THERMAL POWER	311.710 KW

FIGURE 11(a).- BOILER SHELL TEMPERATURE PROFILES. 15 MINUTES AFTER STARTUP #10.



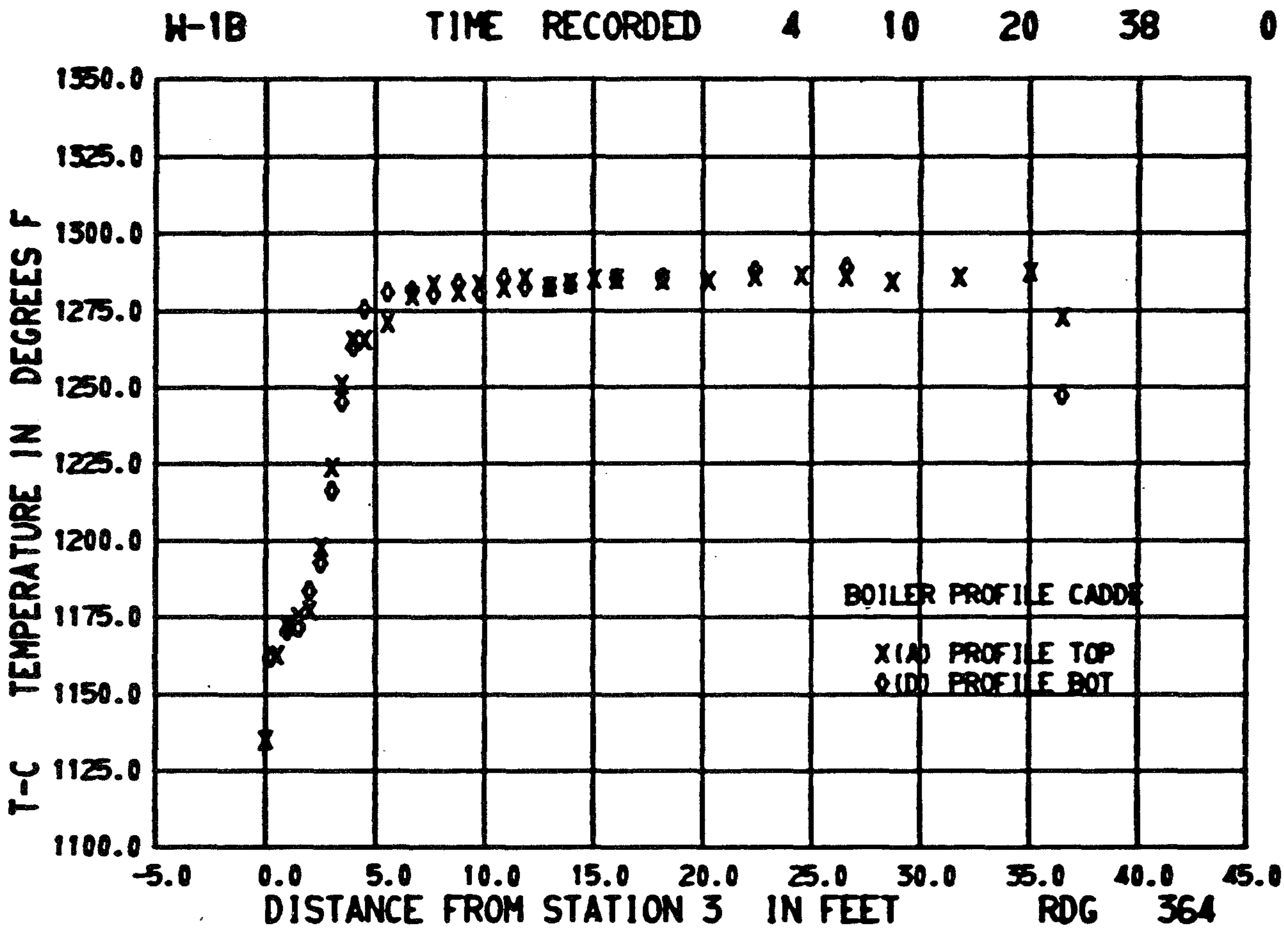
NAK SIDE DATA

FLOW RATE	46769.159 LB/HR
PRESS DROP	2.160 PSI
THERMAL POWER	370.012 KW
AVG INLET TEMP	1288.415 F
AVE OUTLET TEMP	1159.799 F

MERCURY SIDE DATA

LIQUID FLOW RATE	8474.754 LB/HR
VAPOR FLOW RATE	8721.424 LB/HR
QUALITY(HT. BAL.)	0.938 0/0
AVG ENTHALPY OUT	154.062 BTU/LB
INLET PRESS	310.828 PSIA
OUTLET PRESS	166.0 ~~75.249~~ PSIA
SAT TEMP OUT	985.792 F
TEMP OUT	1274.344 F
AVG TEMP IN	262.740 F
THERMAL POWER	390.260 KW

FIGURE 11(b).- BOILER SHELL TEMPERATURE PROFILES. 26 MINUTES AFTER STARTUP #10.



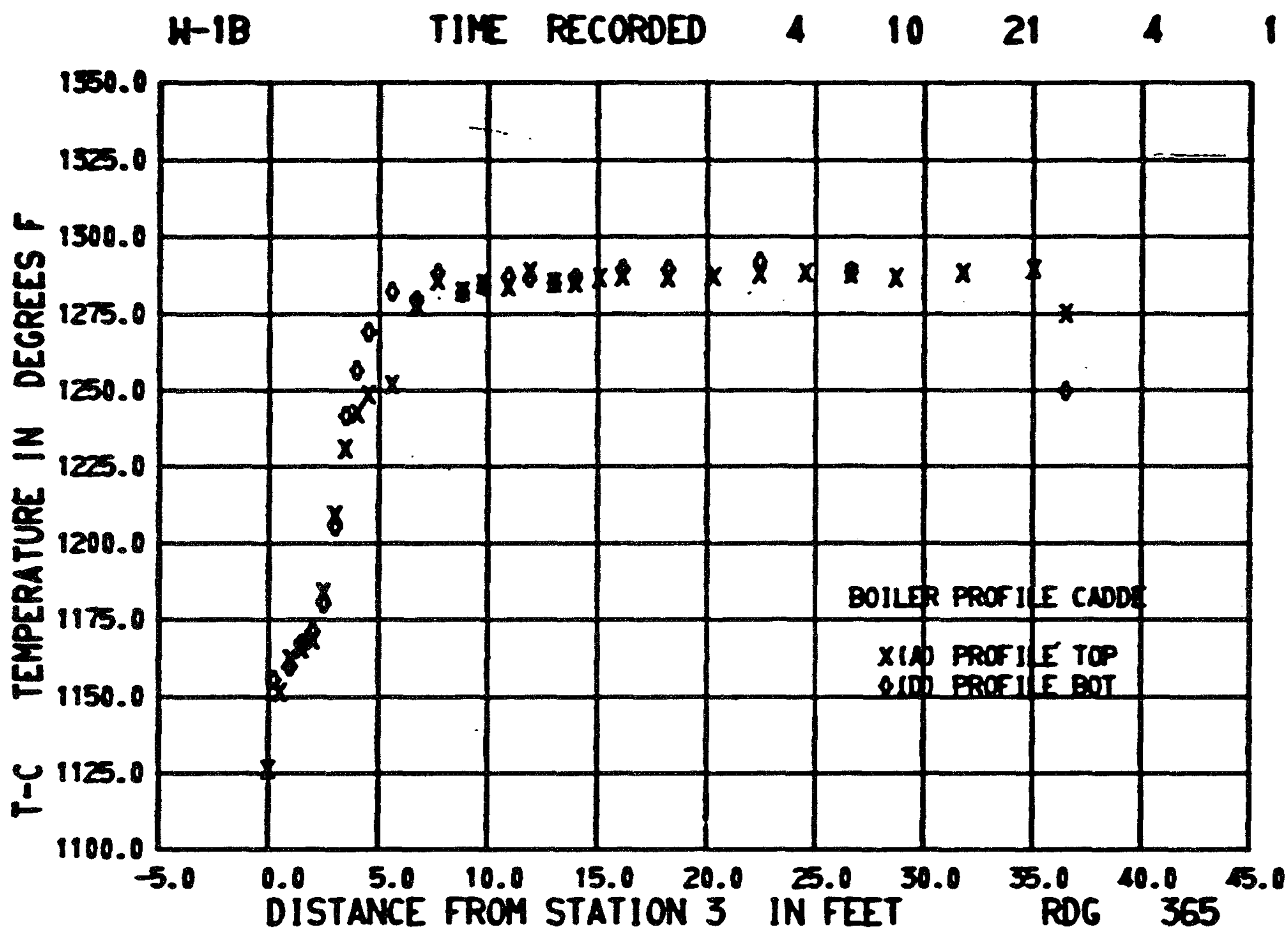
NAK SIDE DATA

FLOW RATE	47045.933	LB/HR
PRESS DROP	2.152	PSI
THERMAL POWER	399.822	KW
AVG INLET TEMP	1283.853	F
AVE OUTLET TEMP	1145.639	F

MERCURY SIDE DATA

LIQUID FLOW RATE	9282.001	LB/HR
VAPOR FLOW RATE	9593.135	LB/HR
QUALITY(HT. BAL.)	0.924	0/0
AVG ENTHALPY OUT	152.317	BTU/LB
INLET PRESS	343.147	PSIA
OUTLET PRESS	183.0 ~~75.953~~	PSIA
SAT TEMP OUT	1001.106	F
TEMP OUT	1275.263	F
AVG TEMP IN	274.034	F
THERMAL POWER	426.762	KW

FIGURE 11(c).- BOILER SHELL TEMPERATURE PROFILES.
31 MINUTES AFTER STARTUP #10.



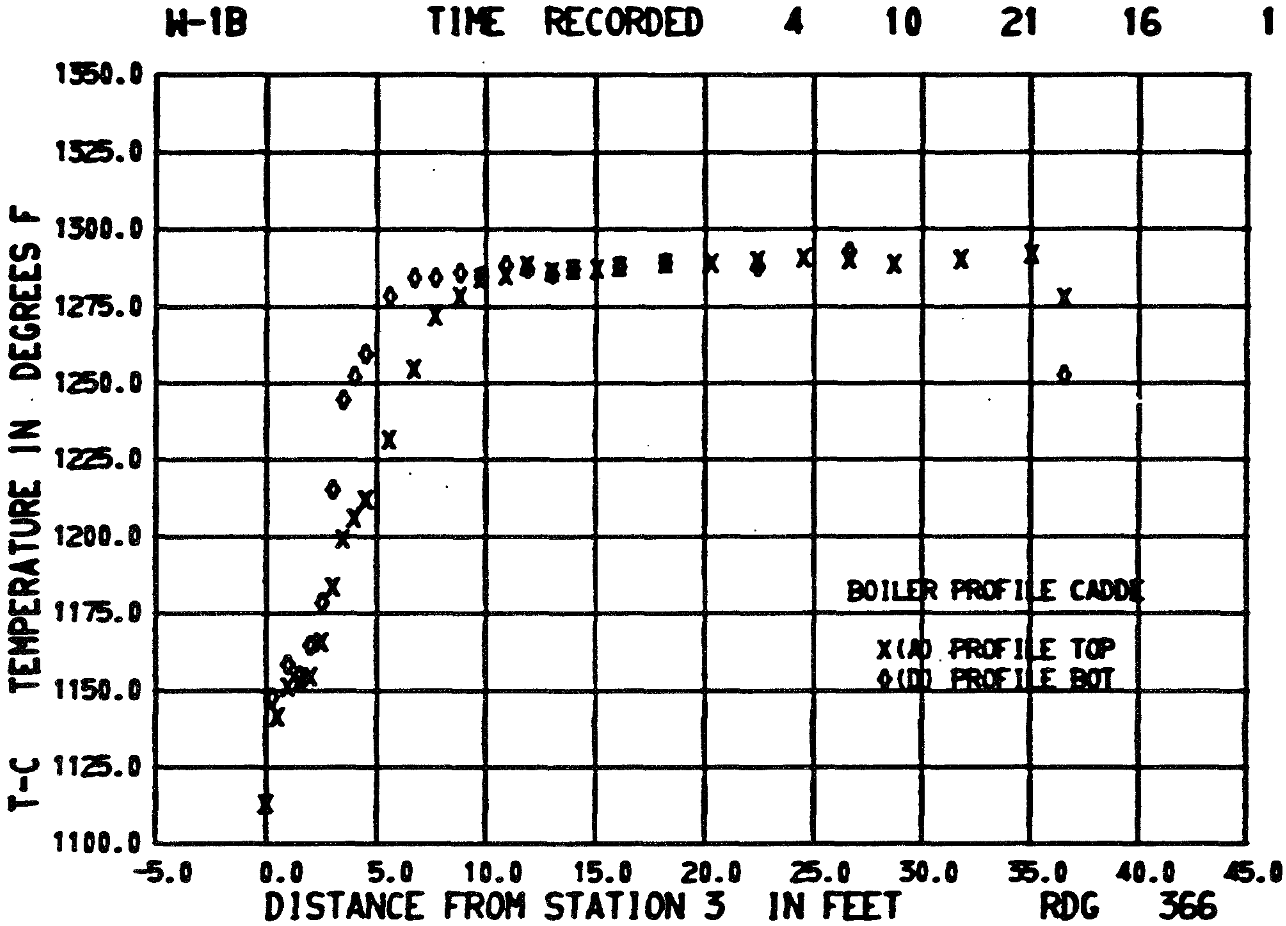
NAK SIDE DATA

FLOW RATE	47067.111	LB/HR
PRESS DROP	2.119	PSI
THERMAL POWER	429.270	KW
AVG INLET TEMP	1286.187	F
AVE OUTLET TEMP	1137.842	F

MERCURY SIDE DATA

LIQUID FLOW RATE	10148.239	LB/HR
VAPOR FLOW RATE	10436.025	LB/HR
QUALITY(HT. BAL.)	0.919	0/0
AVG ENTHALPY OUT	151.775	BTU/LB
INLET PRESS	351.958	PSIA
OUTLET PRESS	200.3 ~~232.698~~	PSIA
SAT TEMP OUT	1015.280	F
TEMP OUT	1277.031	F
AVG TEMP IN	329.986	F
THERMAL POWER	460.456	KW

FIGURE 11(d).- BOILER SHELL TEMPERATURE PROFILES. 57 MINUTES AFTER STARTUP # 10.



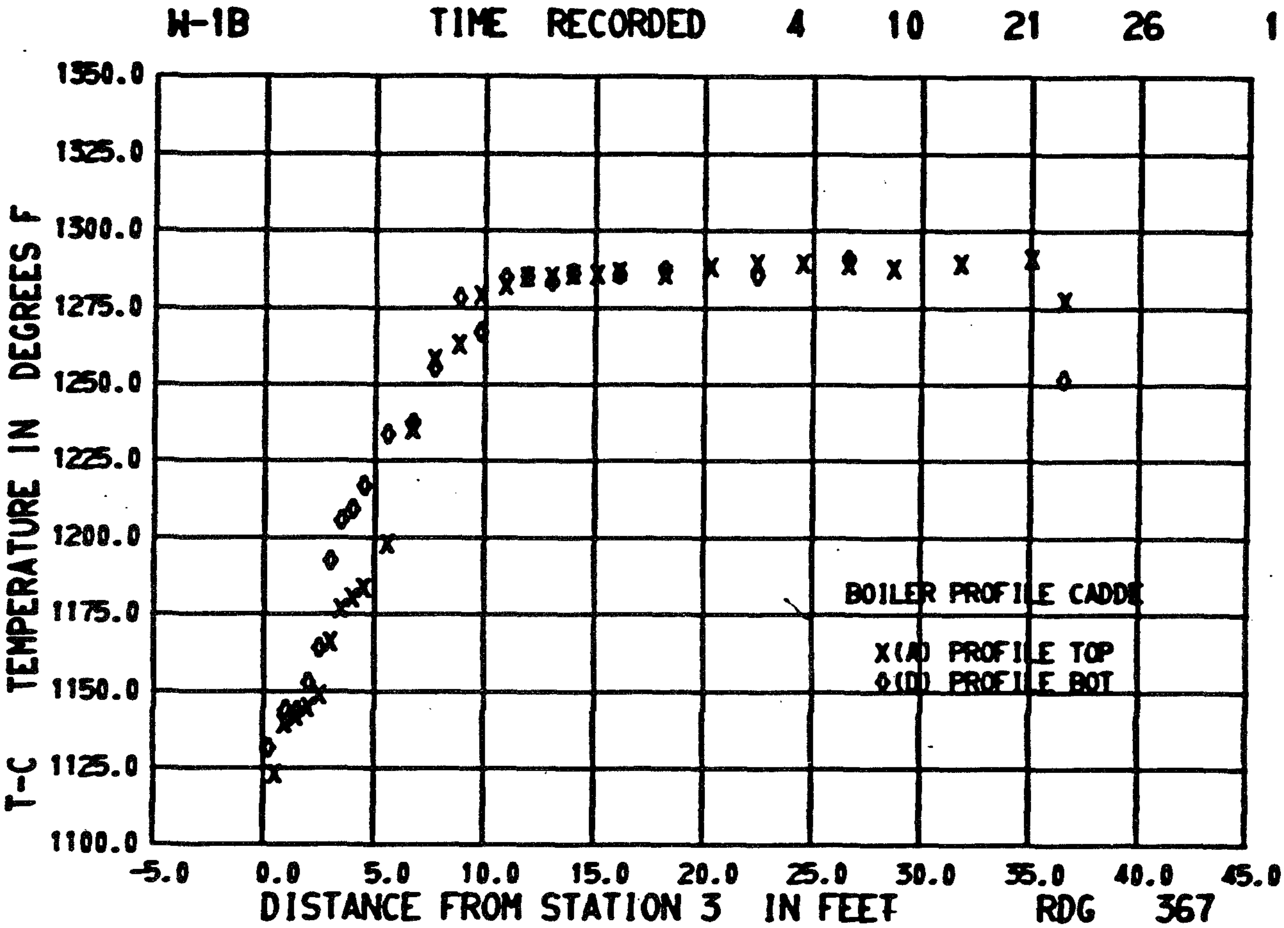
NAK SIDE DATA

FLOW RATE	47378.857 LB/HR
PRESS DROP	2.073 PSI
THERMAL POWER	468.857 KW
AVG INLET TEMP	1287.531 F
AVE OUTLET TEMP	1126.539 F

MERCURY SIDE DATA

LIQUID FLOW RATE	11014.595 LB/HR
VAPOR FLOW RATE	11518.826 LB/HR
QUALITY(HT. BAL.)	0.958 0/0
AVG ENTHALPY OUT	154.344 BTU/LB
INLET PRESS	357.619 PSIA
OUTLET PRESS	222.829 PSIA
SAT TEMP OUT	1033.889 F
TEMP OUT	1278.091 F
AVG TEMP IN	365.867 F
THERMAL POWER	494.528 KW

FIGURE 11 (e).- BOILER SHELL TEMPERATURE PROFILES.
1 HOUR AND 9 MINUTES AFTER STARTUP #10.



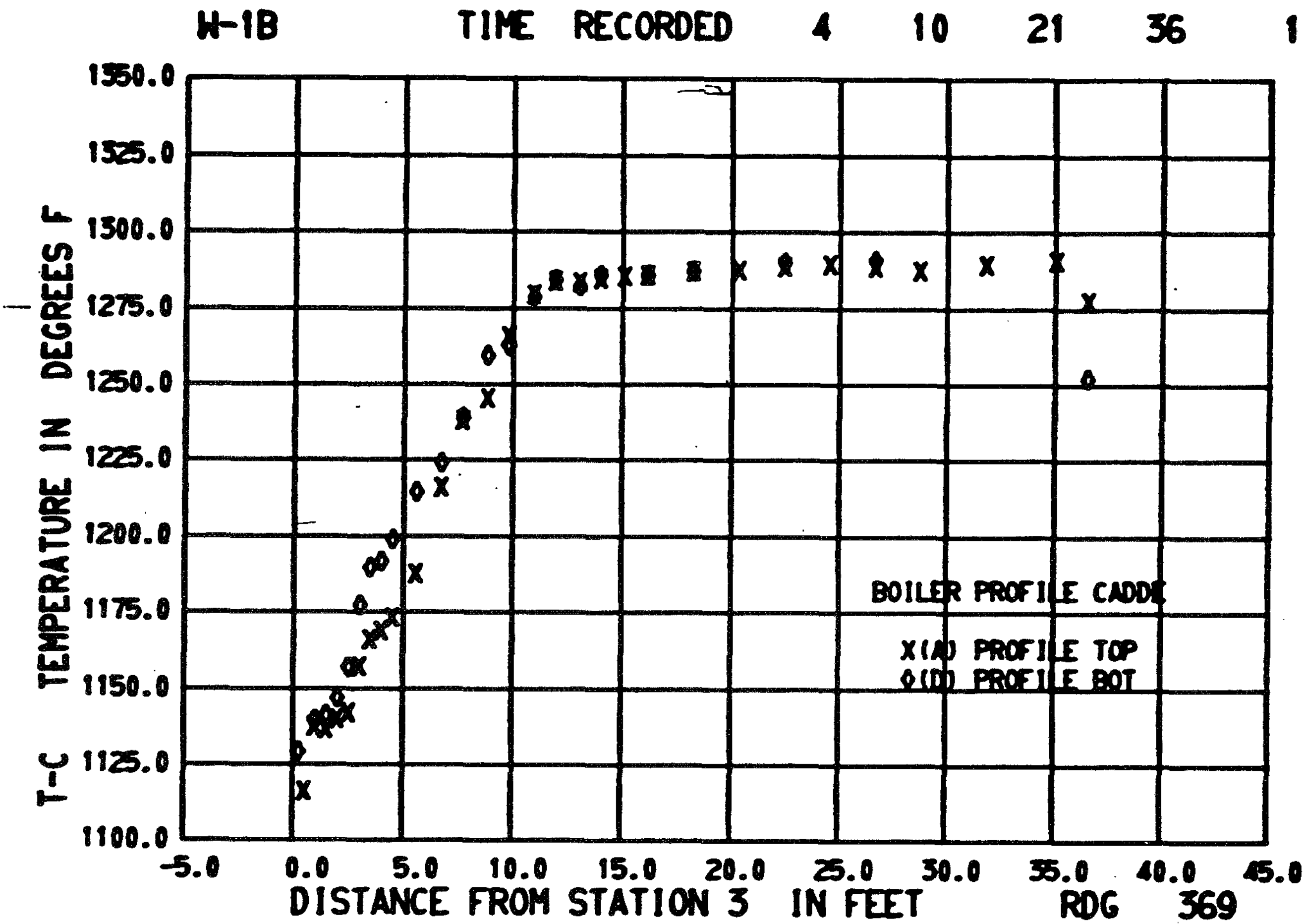
NAK SIDE DATA

FLOW RATE	47437.125 LB/HR
PRESS DROP	2.054 PSI
THERMAL POWER	510.916 KW
AVG INLET TEMP	1287.425 F
AVE OUTLET TEMP	1112.156 F

MERCURY SIDE DATA

LIQUID FLOW RATE	11988.906 LB/HR
VAPOR FLOW RATE	12578.274 LB/HR
QUALITY(HT. BAL.)	0.950 0/0
AVG ENTHALPY OUT	155.915 BTU/LB
INLET PRESS	363.506 PSIA
OUTLET PRESS	243.096 PSIA
SAT TEMP OUT	1049.667 F
TEMP OUT	1277.667 F
AVG TEMP IN	396.289 F
THERMAL POWER	533.319 KW

FIGURE 11(*f*).– BOILER SHELL TEMPERATURE PROFILES. 1 HOUR AND 19 MINUTES AFTER STARTUP #10.



NAK SIDE DATA

FLOW RATE	47548.477 LB/HR
PRESS DROP	2.020 PSI
THERMAL POWER	524.505 KW
AVG INLET TEMP	1285.975 F
AVE OUTLET TEMP	1106.441 F

MERCURY SIDE DATA

LIQUID FLOW RATE	12382.391 LB/HR
VAPOR FLOW RATE	13055.154 LB/HR
QUALITY(HT. BAL.)	0.940 0/0
AVG ENTHALPY OUT	154.622 BTU/LB
INLET PRESS	367.129 PSIA
OUTLET PRESS	251.385 PSIA
SAT TEMP OUT	1055.890 F
TEMP OUT	1277.455 F
AVG TEMP IN	378.766 F
THERMAL POWER	552.302 KW

Figure 11(g). - Boiler Shell Temperature Profiles 1 Hour and 29 Minutes After Startup #10.

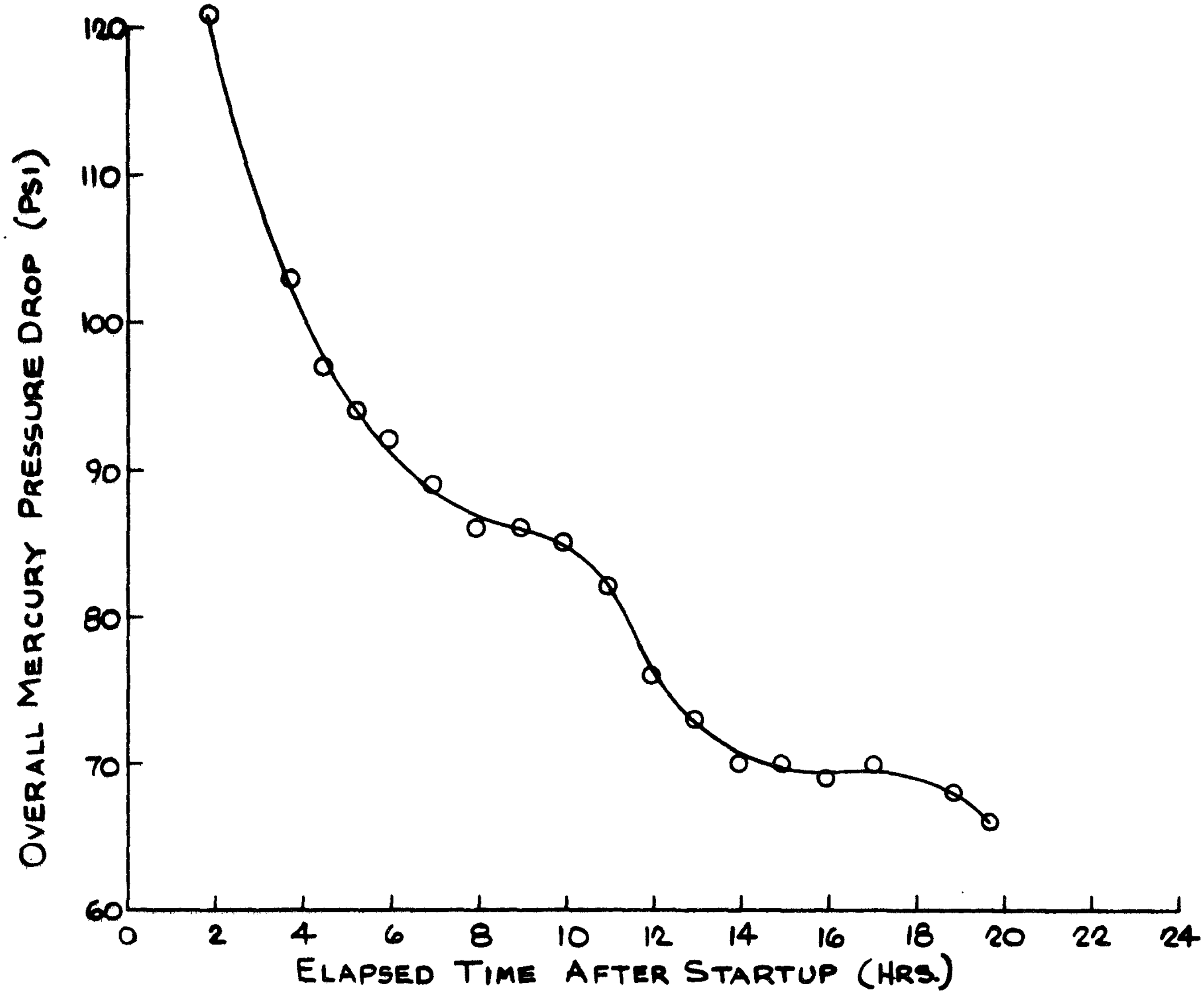
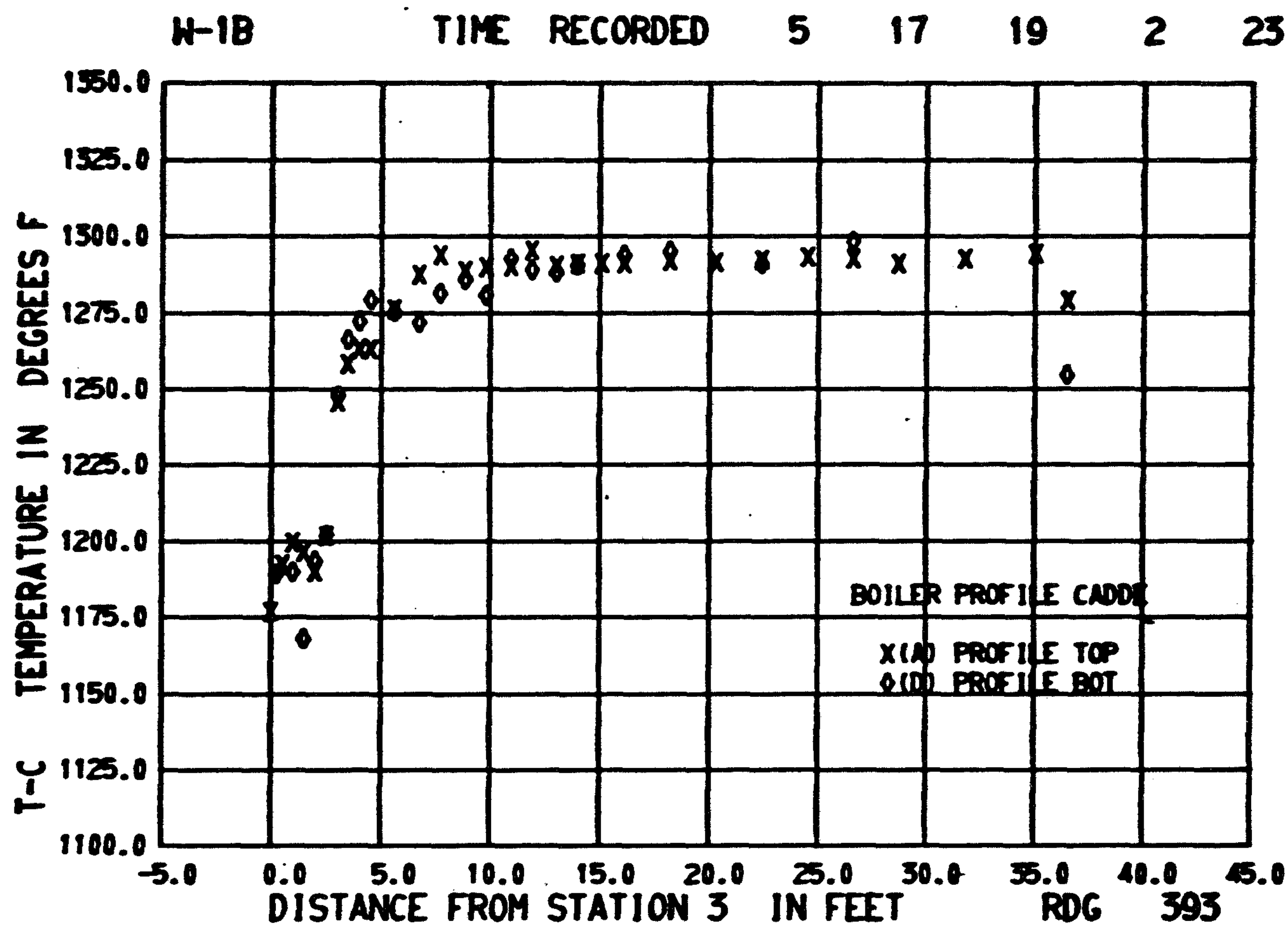


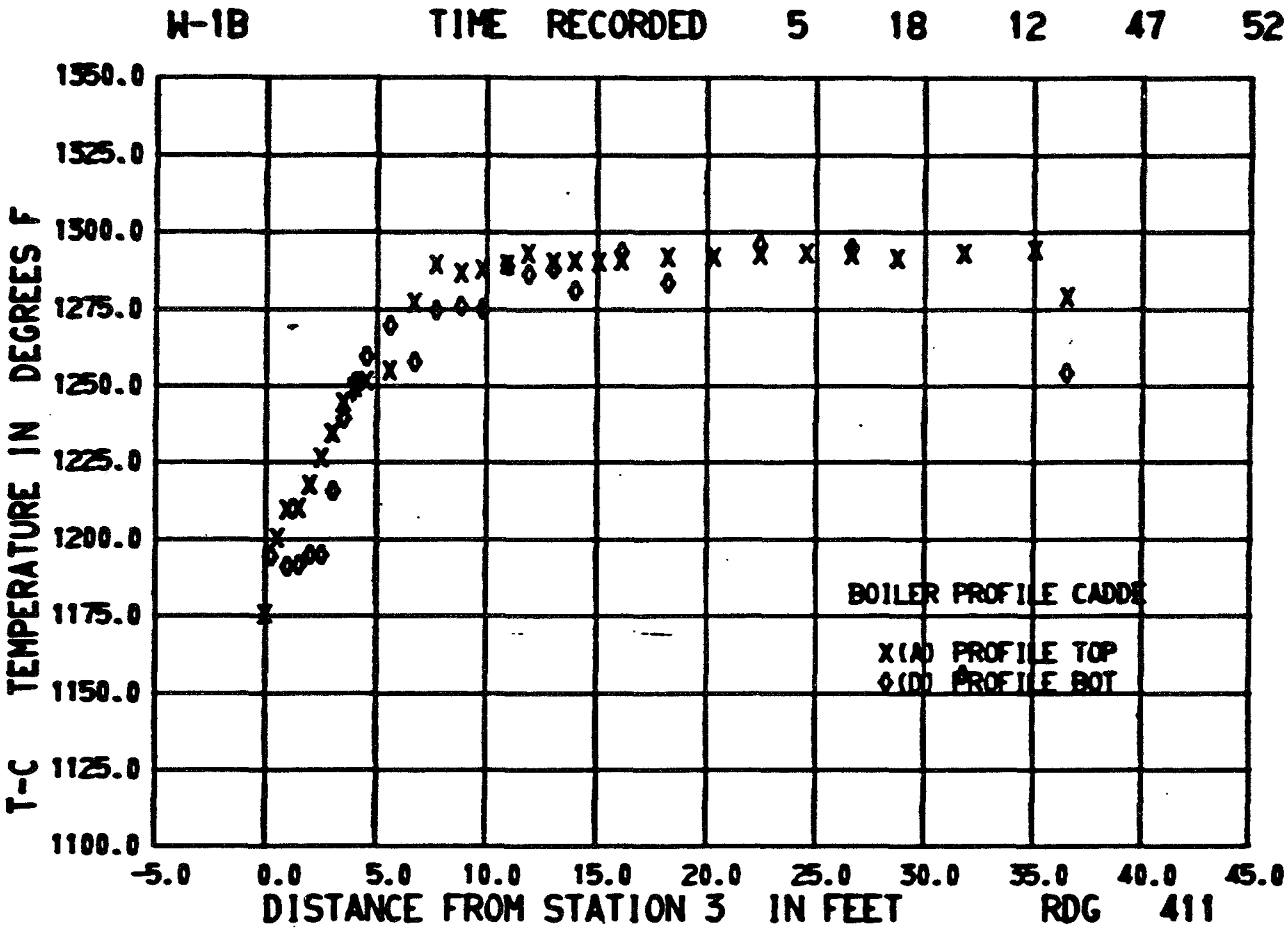
FIGURE 12. VARIATION OF BOILER OVERALL MERCURY PRESSURE DROP WITH ELAPSED TIME AFTER STARTUP #20. NAK FLOW RATE 45,400 LBM/HR, NAK INLET TEMPERATURE 1290 °F, MERCURY FLOW RATE 7500 LBM/HR.



NAK SIDE DATA	
FLOW RATE	45489.123 LB/HR
PRESS DROP	1.596 PSI
THERMAL POWER	310.073 KW
AVG INLET TEMP	1290.183 F
AVE OUTLET TEMP	1179.421 F

MERCURY SIDE DATA	
LIQUID FLOW RATE	7491.103 LB/HR
VAPOR FLOW RATE	7702.056 LB/HR
QUALITY(HT. BAL.)	0.924 0/0
AVG ENTHALPY OUT	152.321 BTU/LB
INLET PRESS	269.431 PSIA
OUTLET PRESS	148.470 PSIA
SAT TEMP OUT	968.460 F
TEMP OUT	1279.151 F
AVG TEMP IN	441.651 F
THERMAL POWER	332.061 KW

FIGURE 13(a).- BOILER SHELL TEMPERATURE PROFILES.
1 HOUR AND 54 MINUTES AFTER STARTUP #20.



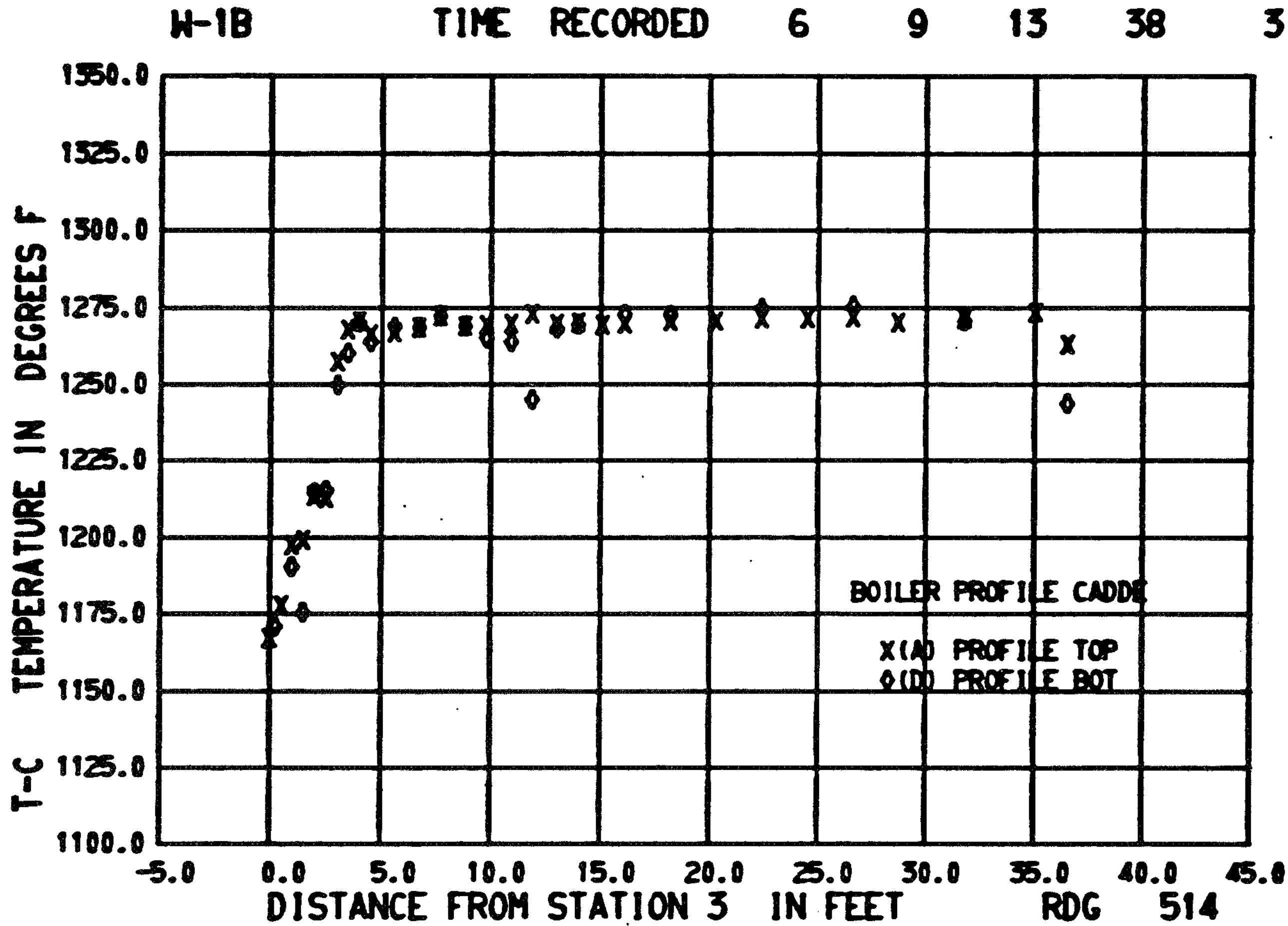
NAK SIDE DATA

FLOW RATE	45544.723 LB/HR
PRESS DROP	1.370 PSI
THERMAL POWER	304.759 KW
AVG INLET TEMP	1290.608 F
AVE OUTLET TEMP	1181.884 F

MERCURY SIDE DATA

LIQUID FLOW RATE	7460.257 LB/HR
VAPOR FLOW RATE	7608.099 LB/HR
QUALITY(HT. BAL.)	0.918 0/0
AVG ENTHALPY OUT	151.488 BTU/LB
INLET PRESS	213.809 PSIA
OUTLET PRESS	148.228 PSIA
SAT TEMP OUT	968.207 F
TEMP OUT	1278.091 F
AVG TEMP IN	434.388 F
THERMAL POWER	328.447 KW

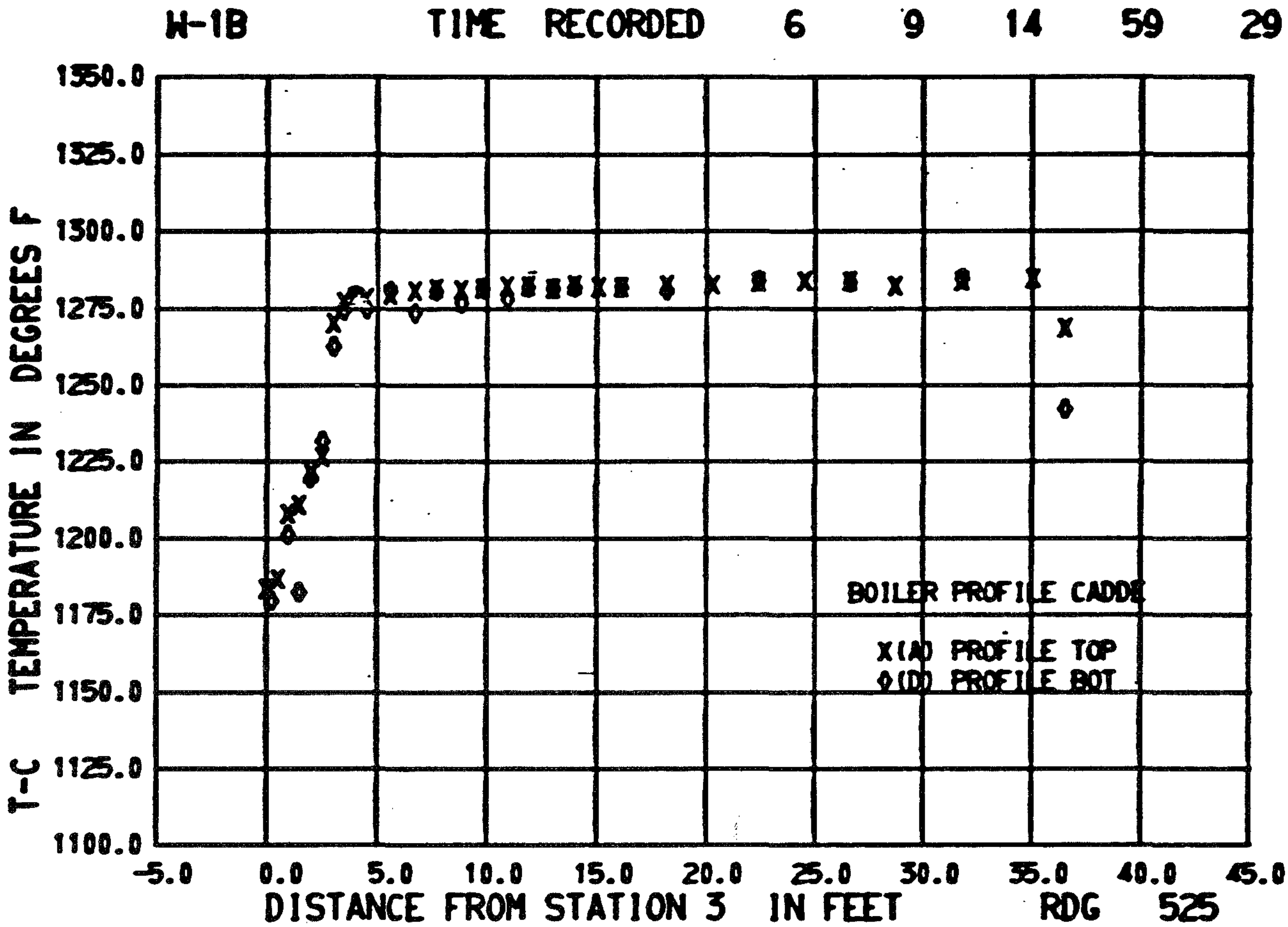
FIGURE 13(b).- BOILER SHELL TEMPERATURE PROFILES. 19 HOURS AND 40 MINUTES AFTER STARTUP #20.



NAK SIDE DATA	
FLOW RATE	45682.662 LB/HR
PRESS DROP	1.889 PSI
THERMAL POWER	293.519 KW
AVG INLET TEMP	1271.341 F
AVE OUTLET TEMP	1166.865 F

MERCURY SIDE DATA	
LIQUID FLOW RATE	6742.598 LB/HR
VAPOR FLOW RATE	6886.761 LB/HR
QUALITY(HT. BAL.)	0.925 0/0
AVG ENTHALPY OUT	151.963 BTU/LB
INLET PRESS	310.725 PSIA
OUTLET PRESS	131.637 PSIA
SAT TEMP OUT	949.982 F
TEMP OUT	1257.882 F
AVG TEMP IN	246.527 F
THERMAL POWER	312.958 KW

FIGURE 14(a).- BOILER SHELL TEMPERATURE PROFILES. 22 MINUTES AFTER STARTUP #93.



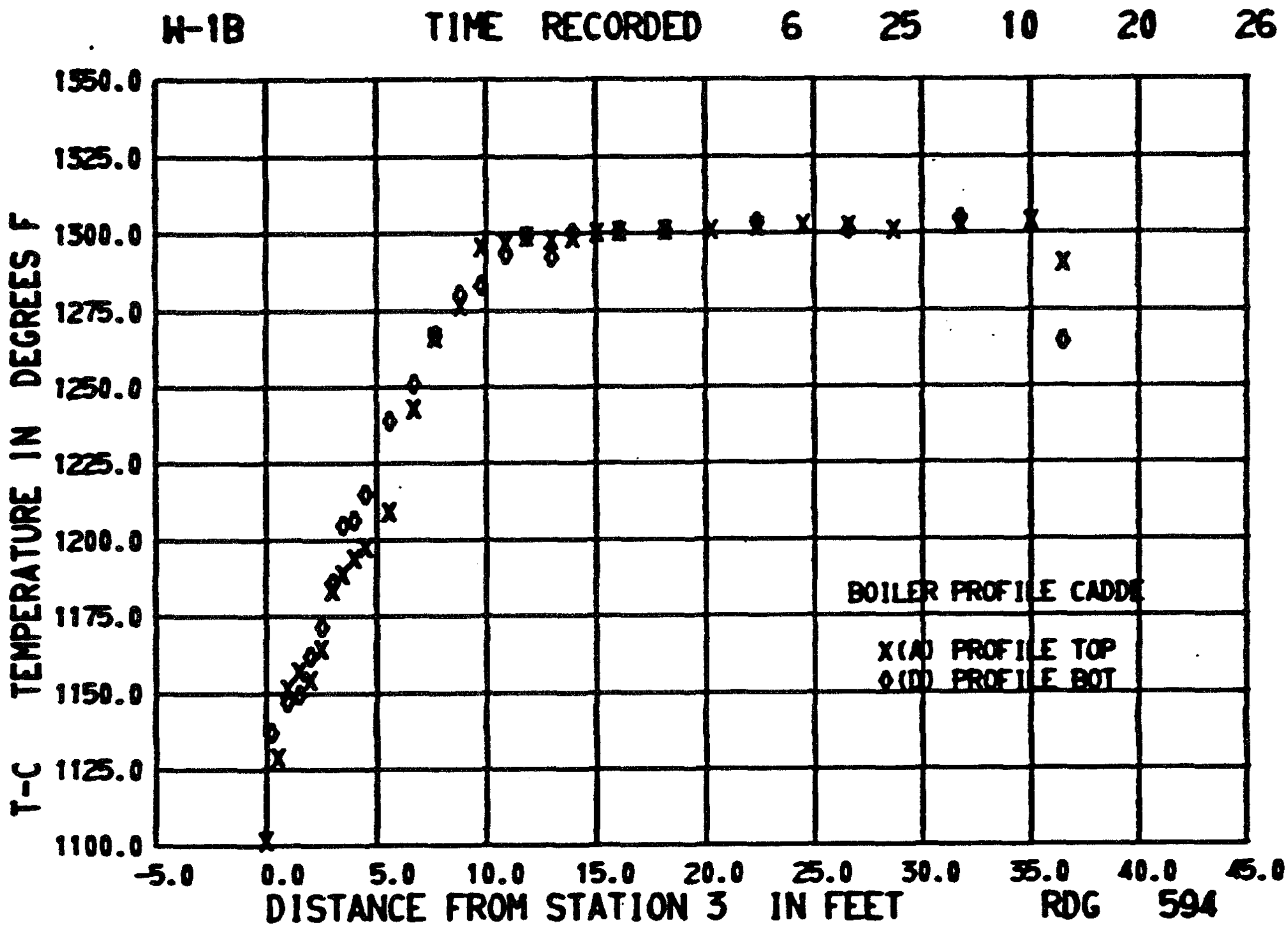
NAK SIDE DATA

FLOW RATE	46274.317 LB/HR
PRESS DROP	1.823 PSI
THERMAL POWER	286.143 KW
AVG INLET TEMP	1279.293 F
AVE OUTLET TEMP	1178.788 F

MERCURY SIDE DATA

LIQUID FLOW RATE	6759.557 LB/HR
VAPOR FLOW RATE	6858.222 LB/HR
QUALITY(HT. BAL.)	0.897 0/0
AVG ENTHALPY OUT	148.535 BTU/LB
INLET PRESS	316.345 PSIA
OUTLET PRESS	132.548 PSIA
SAT TEMP OUT	951.034 F
TEMP OUT	1266.995 F
AVG TEMP IN	270.323 F
THERMAL POWER	312.826 KW

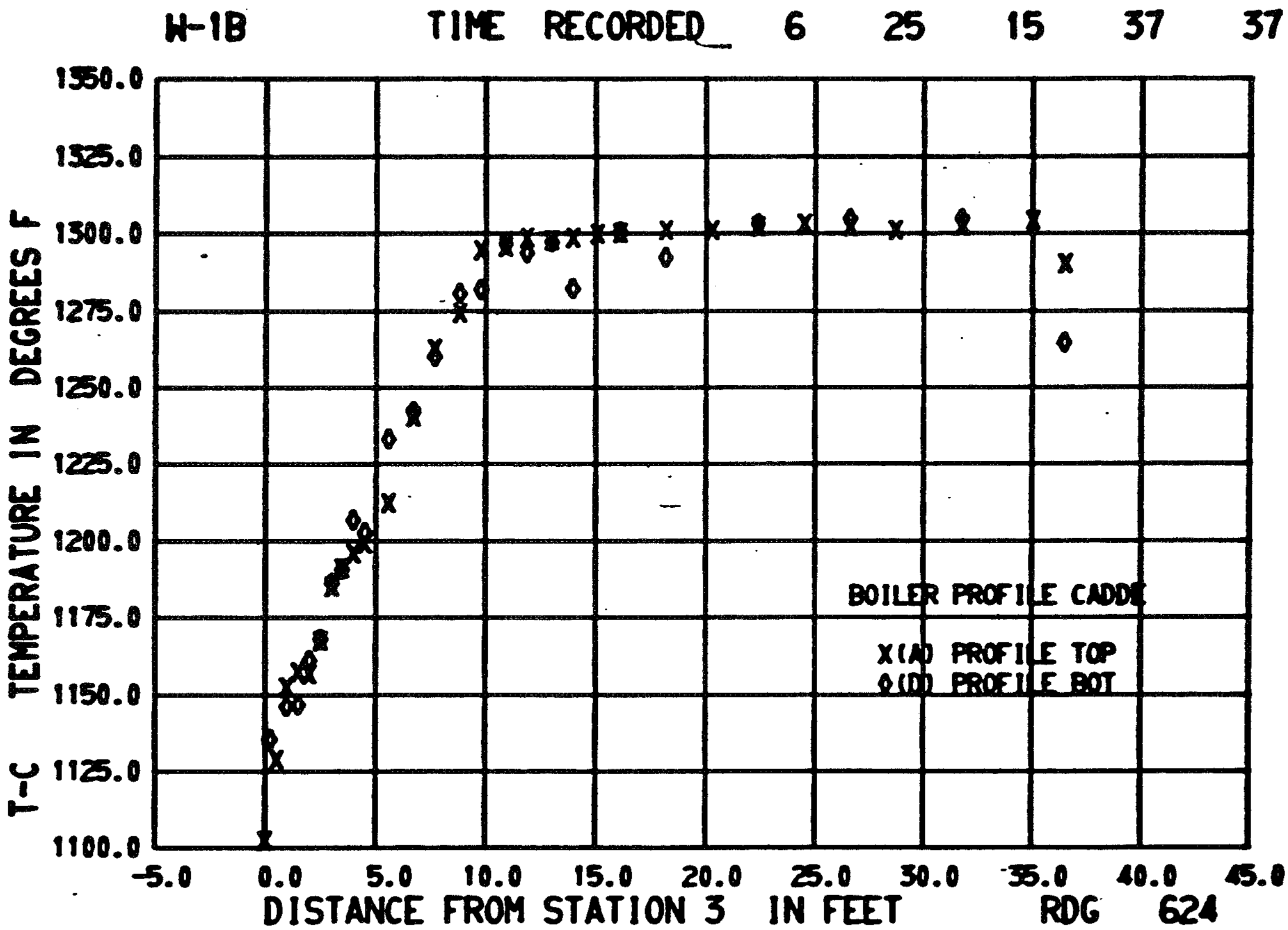
FIGURE 14(b).- BOILER SHELL TEMPERATURE PROFILES.
1 HOUR AND 43 MINUTES AFTER STARTUP #93.



NAK SIDE DATA	
FLOW RATE	45707.387 LB/HR
PRESS DROP	1.525 PSI
THERMAL POWER	516.706 KW
AVG INLET TEMP	1300.265 F
AVE OUTLET TEMP	1116.365 F

MERCURY SIDE DATA	
LIQUID FLOW RATE	12206.508 LB/HR
VAPOR FLOW RATE	12847.818 LB/HR
QUALITY(HT. BAL.)	0.948 0/0
AVG ENTHALPY OUT	155.943 BTU/LB
INLET PRESS	376.249 PSIA
OUTLET PRESS	247.684 PSIA
SAT TEMP OUT	1053.298 F
TEMP OUT	1291.810 F
AVG TEMP IN	430.450 F
THERMAL POWER	540.671 KW

FIGURE 15(a).- BOILER SHELL TEMPERATURE PROFILES. 48 MINUTES AFTER STARTUP #122.



NAK SIDE DATA		MERCURY SIDE DATA	
FLOW RATE	45776.946 LB/HR	LIQUID FLOW RATE	12232.239 LB/HR
PRESS DROP	1.365 PSI	VAPOR FLOW RATE	12715.557 LB/HR
THERMAL POWER	510.467 KW	QUALITY(HT. BAL.)	0.933 0/0
AVG INLET TEMP	1299.310 F	AVG ENTHALPY OUT	153.965 BTU/LB
AVE OUTLET TEMP	1117.909 F	INLET PRESS	376.063 PSIA
		OUTLET PRESS	247.927 PSIA
		SAT TEMP OUT	1052.700 F
		TEMP OUT	1291.456 F
		AVG TEMP IN	433.124 F
		THERMAL POWER	541.518 KW

FIGURE 15(b).- BOILER SHELL TEMPERATURE PROFILES. 6 HOURS AND 5 MINUTES AFTER STARTUP #122.

Table I. - Thermocouple Locations Along Boiler Shell

Station Number	Location positions for thermocouples at given station number[a]	Length, Inches[b]
1	A,D	-18.0
2	A,C,D,E	-8.0
3	A,B,C,E,F	0
4	D	3.0
5	A,C,E	6.0
6	A,B,C,D,E,F	12.0
7	A,D	18.0
8	A,B,C,D,E,F	24.0
9	A,D	30.0
10	A,B,C,D,E,F	36.0
11	A,D	42.0
12	A,B,C,D,E,F	48.0
13	A,D	54.0
14	A,D	67.2
15	A,B,C,D,E,F	80.4
16	A,D	92.4
17	A,D	105.6
18	A,B,C,D	117.6
19	A,D	130.8
20	A,D	142.8
21	A,D	156.0
22	A,D	168.0
23	A	181.2
24	A,D	193.2
25	A,D	218.4
26	A	243.6
27	A,D	268.8
28	A	294.0
29	A,D	319.2
30	A	344.4
31	A,D	381.6
32	A	420.0
33	A,D	436.3

[a] See Fig. 3. Section A-A.

[b] See Fig. 3. Reference station at centerline of NaK outlet passage. Dimensions shown are based on thermocouple positions A and D.

TABLE II. - BOILER DATA AT THE SELF-SUSTAINING MERCURY FLOW RATE

R.O. ____________

DATE ____________

START No.	TIME OF START HR:MIN	CADDE RDG. No.	TIME OF CADDE RDG. HR:MIN	NAK FLOW RATE LB/HR	NAK INLET TEMP. °F	NAK OUTLET TEMP. °F	NAK PRESS. DROP PSI	HG FLOW RATE LB/HR	HG INLET TEMP. °F	HG OUTLET TEMP. °F	HG INLET PRESS. PSIA	HG OUTLET PRESS. PSIA	HG PRESS. DROP PSI	PINCH POINT TEMP. DIFF. °F	SUPER HEAT °F	OUTLET QUAL. (HEAT BAL.) %
3	15:23	137	15:40	44082	1297	1194	—	6468	365	1279	232	125	107	175	337	95
4	14:11	242	15:46	46377	1289	1199	2.05	6100	409	1276	308	121	187	124	339	92
4	14:11	243	15:53	46697	1295	1186	2.01	7248	414	1280	345	144	201	92	316	95
8	16:31	289	16:47	40575	1291	1184	1.63	6245	330	1278	291	122	169	124	340	92
10	20:07	362	20:22	46614	1285	1180	2.07	6750	233	1270	235	132	103	163	320	95
15	19:56	380	20:16	46384	1285	1177	2.00	6961	214	1271	279	136	143	129	316	94
20	17:08	392	17:52	45157	1288	1186	1.82	7051	426	1278	300	139	161	119	320	88
49	17:26	442	17:47	46376	1292	1191	2.18	6696	229	1280	318	130	188	115	332	90
50	13:42	447	14:38	46185	1260	1163	1.87	6617	240	1251	297	128	169	100	306	88
57	12:01	463	12:27	45354	1337	1234	1.86	6726	243	1323	334	135	199	149	369	89
64	12:01	471	12:35	46073	1292	1188	1.83	6748	242	1278	319	133	186	111	327	92
81	13:10	490	13:29	45879	1294	1192	2.01	6737	235	1280	322	132	190	114	330	89
84	11:00	498	11:18	46143	1296	1193	1.91	6807	229	1283	325	133	192	113	332	90
93	13:16	514	13:38	45683	1271	1169	1.89	6743	247	1258	311	132	179	96	307	93
97	11:06	530	11:31	45536	1289	1193	2.01	6549	254	1279	314	128	186	118	333	87
98	12:30	537	12:50	45644	1293	1189	1.88	6747	234	1280	321	132	189	112	329	91
107*	13:31	560	14:00	45953	1293	1191	1.86	6491	245	1276	310	127	183	119	332	94
113	15:31	571	15:50	45875	1290	1181	2.20	6928	160	1276	313	135	178	111	322	92
121	16:46	590	17:10	46062	1283	1176	1.84	6847	246	1268	314	134	180	104	320	94
122	09:32	593	09:50	45372	1292	1186	1.74	6840	242	1278	316	135	181	112	319	92
124	17:46	628	18:05	45726	1286	1187	1.85	6810	244	1278	294	134	160	127	322	86
129	15:36	634	16:00	45596	1306	1197	2.08	6836	179	1291	313	135	178	126	340	93
132	12:01	638	12:20	46227	1290	1187	1.94	6805	170	1277	315	135	180	115	321	88
133	13:01	640	13:22	45392	1286	1177	1.80	6748	174	1270	309	133	176	109	316	95
135	15:46	646	16:06	45723	1286	1183	1.65	6831	242	1277	307	134	173	115	324	89

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*DATA FOR START NUMBERS 107 THROUGH 135 WERE OBTAINED FROM THE FIRST CYCLE OF DATA ACQUIRED DURING A MERCURY FLOW RAMP FROM THE SELF-SUSTAINING LEVEL TO THE RATED FLOW LEVEL.

TABLE III .- BOILER DATA AT RATED MERCURY FLOW AFTER A FLOW RAMP FROM THE SELF-SUSTAINING FLOW

R.O. ____________

DATE ____________

START No.	TIME OF START HR:MIN	CADDE RDG. No.	TIME OF CADDE RDG. HR:MIN	NAK FLOW RATE LB/HR	NAK INLET TEMP. °F	NAK OUTLET TEMP. °F	NAK PRESS. DROP PSI	HG FLOW RATE LB/HR	HG INLET TEMP. °F	HG OUTLET TEMP. °F	HG INLET PRESS. PSIA	HG OUTLET PRESS. PSIA	HG PRESS. DROP PSI	PINCH POINT TEMP. DIFF. °F	SUPER HEAT °F	OUTLET QUAL. (HEAT BAL.) %
50	13:42	452	15:51	47247	1287	1109	1.85	12071	416	1276	363	243	120	24	226	96
81	13:10	493	14:46	46879	1289	1119	1.88	11608	411	1280	366	233	133	32	238	94
84	11:00	500	11:54	47049	1295	1123	1.92	11938	478	1286	374	240	134	30	239	94
98	12:30	539	13:36	46594	1296	1119	1.84	12137	494	1287	373	246	127	27	236	95
98		542	16:06	46393	1295	1118	1.66	11981	490	1284	367	242	125	29	236	95
98		543	16:14	46721	1293	1119	1.68	12078	485	1285	371	244	127	28	235	94
99	09:46	548	10:42	46816	1295	1112	1.83	12295	414	1285	372	249	123	24	231	96
99	09:46	549	10:44	46786	1298	1116	1.83	12144	415	1287	373	246	127	27	235	96
107	13:31	561	14:24	46751	1301	1124	1.86	12103	420	1292	379	245	134	31	241	94
107	13:31	562	14:31	46896	1298	1121	1.79	12062	419	1289	374	243	131	30	239	95
113	15:31	572	16.17	46525	1320	1131	2.20	12221	292	1308	393	248	145	37	258	96
113		573	16:20	46462	1321	1130	2.14	12251	297	1308	391	248	143	37	258	97
113		574	16:23	46817	1318	1133	2.13	12291	300	1308	393	247	146	39	258	93
113		575	16:30	46840	1320	1131	2.06	12216	319	1309	393	248	145	35	259	97
113		576	16:35	46751	1318	1136	2.03	12181	409	1309	393	247	146	37	259	95
113		579	17:50	46633	1317	1132	1.71	12187	339	1309	393	248	145	36	259	95
113		580	17:55	46252	1317	1135	1.73	12202	343	1309	393	249	144	38	260	93
122	09:32	594	10:20	45707	1300	1116	1.53	12207	431	1292	376	248	128	26	239	95

TABLE IV. - BOILER DATA TAKEN BETWEEN STARTUP #8 AND #9.

DATE AND TIME OF STARTUP #8 ARE 4/8/69 AND 16:31, RESPECTIVELY.

CADDE RDG. No.	DATE OF CADDE RDG. (MO/DAY/YR)	TIME OF CADDE RDG. (HR:MIN)	NAK FLOW RATE (LB/HR)	NAK INLET TEMP. (°F)	NAK OUTLET TEMP. (°F)	NAK PRESS. DROP (PSI)	HG FLOW RATE (LB/HR)	HG INLET TEMP. (°F)	HG OUTLET TEMP. (°F)	HG INLET PRESS. (PSIA)	HG OUTLET PRESS. (PSIA)	HG PRESS. DROP (PSI)	PINCH POINT TEMP. DIFF. (°F)	SUPER HEAT (°F)	OUTLET QUAL. (HEAT BAL.) (%)
289	4/8/69	16:47	40575	1291	1184	1.63	6245	330	1278	291	122	169	124	340	92
290		17:20	40651	1293	1159	1.47	8133	436	1284	341	161	180	73	303	91
291		19:30	40409	1295	1154	1.25	8190	435	1282	320	163	157	80	300	95
292		21:30	40788	1295	1159	1.27	8012	436	1282	316	159	157	88	304	94
293		23:30	40771	1294	1159	1.19	8050	442	1284	315	160	155	88	304	93
294	4/9/69	01:30	40643	1296	1162	1.22	7905	436	1283	311	157	154	93	307	94
295		03:51	40473	1301	1167	1.16	7852	434	1286	309	156	153	99	310	95
296		06:01	40470	1291	1157	1.21	7995	439	1279	307	158	149	91	301	93
297		07:00	40612	1290	1158	1.26	7909	436	1279	305	157	148	93	303	93
298		09:30	46663	1281	1163	1.69	8147	437	1271	314	162	152	91	289	92
299		10:45	46714	1283	1165	1.70	8141	425	1270	311	161	150	95	290	92
301		11:41	46815	1282	1151	1.70	9167	424	1273	349	182	167	62	272	91
303		12:29	46956	1292	1146	1.74	10131	419	1282	363	203	160	54	264	92
305		13:46	47221	1291	1133	1.73	11012	413	1283	367	222	145	42	250	92
307		14:55	47040	1290	1114	1.70	12097	408	1282	373	245	128	25	230	94
309		17:10	46649	1292	1171	1.69	8215	426	1281	311	163	148	102	298	93
311		18:10	46216	1293	1184	1.66	7327	428	1280	281	145	136	131	316	94
313		19:55	46248	1298	1208	1.66	6152	426	1284	217	120	97	198	348	92
315		21:20	45990	1293	1219	1.72	5190	417	1277	147	98	49	269	371	90
317		21:52	45613	1290	1229	1.70	4528	402	1275	126	85	41	300	391	84
320	4/10/69	00:01	46306	1324	1205	1.60	8087	432	1312	281	163	118	155	330	93
321		00:21	46470	1321	1199	1.63	8107	433	1307	281	162	119	149	325	96
323		01:40	46371	1307	1187	1.67	8114	431	1296	278	162	116	139	314	94
325		02:45	46450	1297	1179	1.65	8075	433	1285	275	161	114	133	304	93
327		03:46	46645	1276	1159	1.65	8072	432	1266	273	160	113	114	286	93

NASA-C-801C (10-24-51)

R.O.

DATE

TABLE IV. - CONTINUED.

R.O. ______

DATE ______

CADDE RDG. No.	DATE OF CADDE RDG.	TIME OF CADDE RDG.	NAK FLOW RATE	NAK INLET TEMP.	NAK OUTLET TEMP.	NAK PRESS. DROP	HG FLOW RATE	HG INLET TEMP.	HG OUTLET TEMP.	HG INLET PRESS.	HG OUTLET PRESS.	HG PRESS. DROP	PINCH POINT TEMP. DIFF.	SUPER HEAT	OUTLET QUAL. (HEAT BAL.)
	MO/DAY/YR	HR:MIN	LB/HR	°F	°F	PSI	LB/HR	°F	°F	PSIA	PSIA	PSI	°F	°F	%
329	4/10/69	04:41	46983	1265	1150	1.65	8088	433	1254	271	160	111	107	274	92
332		06:01	43220	1260	1134	1.39	8122	427	1249	270	160	110	93	270	93
335		07:30	43050	1278	1151	1.33	8092	430	1267	268	160	108	112	287	93
337		08:09	42596	1294	1167	1.35	7982	429	1283	265	159	106	130	304	93
339		09:20	42520	1306	1177	1.32	7975	430	1293	264	160	104	140	314	94
341		10:05	42510	1321	1192	1.30	8055	427	1308	267	162	105	153	327	93
343		11:04	39585	1319	1181	1.11	8054	429	1308	267	162	105	143	326	93
345		12:19	39865	1305	1167	1.11	8030	429	1293	263	161	102	133	312	94
347		13:15	39846	1290	1155	1.12	8053	433	1279	263	161	102	121	299	92
349		15:36	39821	1263	1124	1.16	8066	417	1251	258	160	98	93	271	95

TABLE V. - BOILER DATA TAKEN BETWEEN STARTUP # 10 AND # 11.

DATE AND TIME OF STARTUP # 10 ARE 4/10/69 AND 20:07, RESPECTIVELY.

R.O. ______

DATE ______

CADDE RDG. NO.	DATE OF CADDE RDG.	TIME OF CADDE RDG	NAK FLOW RATE	NAK INLET TEMP.	NAK OUTLET TEMP.	NAK PRESS. DROP	HG FLOW RATE	HG INLET TEMP.	HG OUTLET TEMP.	HG INLET PRESS.	HG OUTLET PRESS.	HG PRESS. DROP	PINCH POINT TEMP. DIFF.	SUPER HEAT	OUTLET QUAL. (HEAT BAL.)
	MO/DAY/YR	HR:MIN	LB/HR	°F	°F	PSI	LB/HR	°F	°F	PSIA	PSIA	PSI	°F	°F	%
362	4/10/69	20:22	46614	1285	1181	2.07	6750	233	1270	235	132	103	163	320	95
363		20:33	46769	1288	1160	2.16	8475	263	1274	311	166	145	96	289	94
364		20:38	47046	1284	1146	2.15	9282	274	1275	343	183	160	65	274	92
365		21:04	47067	1286	1138	2.12	10148	330	1277	352	200	152	54	262	92
366		21:16	47379	1288	1127	2.07	11015	366	1278	358	223	135	43	244	94
367		21:26	47437	1287	1112	2.05	11989	396	1278	364	243	121	28	228	95
368		21:33	47474	1286	1106	2.03	12373	390	1277	366	252	114	22	221	95
369		21:36	47549	1286	1106	2.02	12382	379	1278	367	251	116	23	222	94

TABLE VI. - BOILER DATA TAKEN BETWEEN STARTUP #20 AND #21. DATE AND TIME OF STARTUP #20 ARE 5/17/69 AND 17:08, RESPECTIVELY.

R.O. ______

DATE ______

CADDE RDG. No.	DATE OF CADDE RDG. MO/DAY/YR	TIME OF CADDE RDG. HR:MIN	NAK FLOW RATE LB/HR	NAK INLET TEMP. °F	NAK OUTLET TEMP. °F	NAK PRESS. DROP PSI	HG FLOW RATE LB/HR	HG INLET TEMP. °F	HG OUTLET TEMP. °F	HG INLET PRESS. PSIA	HG OUTLET PRESS. PSIA	HG PRESS. DROP PSI	PINCH POINT TEMP. DIFF. °F	SUPER HEAT °F	OUTLET QUAL. (HEAT BAL.) %
393	5/17/69	19:02	45489	1290	1179	1.60	7491	442	1279	269	148	121	135	311	92
394		20:49	45345	1289	1181	1.48	7451	442	1279	250	147	103	151	312	91
395		21:33	45219	1293	1182	1.38	7448	440	1279	245	148	97	156	311	92
396		22:18	45323	1289	1182	1.37	7445	438	1279	241	147	94	158	312	90
397		23:02	45193	1292	1182	1.36	7476	438	1279	240	148	92	160	312	92
398	5/18/69	00:02	45489	1289	1182	1.36	7438	439	1279	237	148	89	161	311	90
399		01:02	45501	1290	1181	1.37	7459	438	1279	234	148	86	163	312	91
400		02:04	45197	1288	1181	1.39	7475	438	1278	234	148	86	163	310	89
401		03:02	45475	1290	1182	1.37	7485	439	1279	233	148	85	165	311	90
402		04:02	45493	1289	1182	1.37	7476	440	1280	230	148	82	167	312	90
403		05:02	45228	1291	1182	1.39	7473	437	1279	224	148	76	171	311	91
404		06:02	45354	1292	1183	1.33	7477	440	1280	221	148	73	175	312	92
405		07:03	45584	1288	1181	1.31	7491	439	1279	218	148	70	175	310	90
406		08:01	45517	1290	1182	1.32	7527	442	1280	219	149	70	176	310	91
407		09:03	45478	1290	1181	1.43	7568	441	1279	219	150	69	174	309	91
408		10:07	45285	1288	1182	1.36	7528	437	1279	219	149	70	176	310	88
410		11:57	45379	1291	1182	1.39	7514	437	1277	216	148	68	179	309	91
411		12:48	45545	1291	1182	1.37	7460	434	1278	214	148	66	180	310	92

TABLE VII. - BOILER DATA TAKEN BETWEEN STARTUP #93 AND #94. DATE AND TIME OF STARTUP #93 ARE 6/9/69 AND 13:16, RESPECTIVELY.

R.O.

DATE

CADDE RDG. No.	DATE OF CADDE RDG.	TIME OF CADDE RDG.	NAK FLOW RATE	NAK INLET TEMP.	NAK OUTLET TEMP.	NAK PRESS. DROP	HG FLOW RATE	HG INLET TEMP.	HG OUTLET TEMP.	HG INLET PRESS.	HG OUTLET PRESS.	HG PRESS. DROP	PINCH POINT TEMP. DIFF.	SUPER HEAT	OUTLET QUAL. (HEAT BAL.)
	Mo/Day/Yr	HR:MIN	LB/HR	°F	°F	PSI	LB/HR	°F	°F	PSIA	PSIA	PSI	°F	°F	%
514	6/9/69	13:38	45683	1271	1167	1.89	6743	247	1258	311	132	179	96	308	93
515		13:48	45883	1274	1172	1.88	6779	251	1263	317	133	184	97	311	89
516		13:55	45722	1283	1181	1.89	6849	250	1269	320	134	186	102	317	91
517		14:01	45946	1280	1177	1.96	6757	254	1268	316	132	184	102	317	91
518		14:06	45759	1282	1178	1.85	6726	253	1267	317	131	186	103	317	92
519		14:14	46284	1281	1178	1.90	6851	263	1269	318	134	184	101	316	91
520		14:33	46081	1283	1177	1.84	6825	275	1267	317	134	183	101	315	94
521		14:38	46356	1281	1179	1.82	6827	273	1269	315	132	183	104	318	91
522		14:44	46093	1280	1178	1.89	6702	255	1267	315	132	183	103	316	92
523		14:52	45914	1282	1178	1.81	6779	268	1268	315	133	182	104	317	93
524		14:55	45908	1281	1178	1.78	6775	269	1268	316	132	184	103	317	91
525		14:59	46274	1279	1179	1.82	6760	270	1267	316	133	183	103	316	90

TABLE VIII. - BOILER DATA TAKEN BETWEEN STARTUP # 122 AND # 123.

DATE AND TIME OF STARTUP # 122 ARE 6/25/69 AND 09:32, RESPECTIVELY.

R.O. ______

DATE ______

CADDE RDG. No.	DATE OF CADDE RDG.	TIME OF CADDE RDG.	NAK FLOW RATE	NAK INLET TEMP.	NAK OUTLET TEMP.	NAK PRESS. DROP	HG FLOW RATE	HG INLET TEMP.	HG OUTLET TEMP.	HG INLET PRESS.	HG OUTLET PRESS.	HG PRESS. DROP	PINCH POINT TEMP. DIFF.	SUPER HEAT	OUTLET QUAL. (HEAT BAL.)
	MO/DAY/YR	HR:MIN	LB/HR	°F	°F	PSI	LB/HR	°F	°F	PSIA	PSIA	PSI	°F	°F	%
594	6/25/69	10:20	45707	1300	1116	1.53	12207	431	1292	376	248	128	26	239	95
595		10:37	45769	1301	1117	1.52	12243	407	1292	378	248	130	26	239	94
596		10:55	45774	1302	1117	1.49	12266	405	1292	377	248	129	28	240	94
597		11:13	45513	1302	1115	1.47	12248	404	1293	377	248	129	25	240	95
598		11:19	45903	1302	1118	1.50	12279	405	1292	379	248	131	27	239	94
599		11:27	45751	1299	1116	1.47	12276	407	1292	377	248	129	26	239	93
600		11:38	45795	1300	1116	1.44	12226	406	1291	377	249	128	26	239	95
601		11:45	45553	1301	1117	1.39	12227	405	1292	377	249	128	27	239	94
602		11:53	46003	1302	1118	1.40	12239	443	1292	377	248	129	26	239	96
603		11:59	45622	1300	1118	1.45	12213	464	1291	376	248	128	26	239	94
604		12:21	45738	1302	1117	1.40	12203	420	1291	377	249	128	27	239	95
605		12:28	45586	1302	1118	1.38	12235	420	1291	376	249	127	28	239	94
606		12:36	45799	1301	1116	1.44	12273	420	1292	377	249	128	25	239	95
607		12:56	45560	1299	1119	1.44	12193	489	1290	375	248	127	27	238	94
608		13:08	45519	1301	1118	1.43	12119	473	1291	377	248	129	25	239	96
609		13:16	45925	1301	1117	1.35	12344	426	1291	377	249	128	27	238	94
610		13:25	45835	1301	1118	1.41	12189	405	1292	377	248	129	28	240	94
611		13:33	45761	1303	1116	1.35	12215	405	1291	376	248	128	27	238	96
612		13:39	45699	1302	1117	1.36	12245	406	1292	376	249	127	27	238	95
613		13:49	45810	1298	1116	1.38	12323	406	1291	377	249	128	27	238	92
614		13:59	45625	1301	1117	1.36	12199	401	1291	377	249	128	27	239	94
615		14:06	45982	1301	1118	1.39	12241	406	1291	377	248	129	28	239	94
616		14:14	45761	1302	1121	1.38	12166	483	1291	376	247	129	29	239	94
617		14:29	45622	1301	1118	1.31	12182	407	1292	376	248	128	29	240	94
618		14:40	45718	1303	1116	1.37	12250	380	1293	377	249	128	28	240	95

TABLE VIII. - CONTINUED.

R.O.

DATE

CADDE RDG No.	DATE OF CADDE RDG. MO/DAY/YR	TIME OF CADDE RDG. HR:MIN	NAK FLOW RATE LB/HR	NAK INLET TEMP. °F	NAK OUTLET TEMP. °F	NAK PRESS. DROP PSI	HG FLOW RATE LB/HR	HG INLET TEMP. °F	HG OUTLET TEMP. °F	HG INLET PRESS. PSIA	HG OUTLET PRESS. PSIA	HG PRESS. DROP PSI	PINCH POINT TEMP. DIFF. °F	SUPER HEAT °F	OUTLET QUAL. (HEAT BAL.) %
619	6/25/69	14:49	45298	1304	1115	1.34	12267	364	1293	377	249	128	27	240	95
620		14:54	45839	1302	1116	1.36	12279	361	1292	377	249	128	28	240	94
621		14:58	46024	1301	1116	1.35	12228	363	1292	377	249	128	28	239	95
622		15:00	45778	1302	1115	1.37	12289	363	1292	377	250	127	27	240	94
623		15:03	45779	1303	1116	1.37	12267	364	1293	378	249	129	28	241	94
624		15:37	45777	1299	1118	1.37	12232	433	1292	376	248	128	28	239	93