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TECHNICAL MEMORANDUM

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TITLE: Status Report of PCS-G Systems Analysis

ABSTRACT

The results to date of the continuing systems analysis on PCS-G is presented herein. The STRAP-3 (SNAP-8 TRansient Analysis Program) computer code was used to simulate PCS-G startup and shutdown. A low pressure mercury injection system is described which uses the differential pressure across the lubrication and coolant pump as a source of hydraulic power to operate the diaphragm of a mercury reservoir. Two groups of computer test runs were made. The first group of runs consisted of startup runs commencing with preinjection component and system conditions which represented the worst which could reasonably exist in operational use. These conditions were altered to stress various system parameters on the theory that a system which can startup satisfactorily under the worst conceivable conditions would be suitable for the actual conditions encountered in operational use.

This study shows that the system as designed, using the pretest reactor temperature coefficients, while previously satisfactory, is now only partially satisfactory using AI supplied post-test reactor coefficients.

KEY WORDS: startup/shutdown, transient analysis, PCS-G

APPROVED:
DEPARTMENT HEAD
L. P. Lopez

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

CONTENTS

TABLES

FIGURES

FIGURES (Cont'd.)

I INTRODUCTION

The objective of this technical memorandum is to present the status of the analytical study on the SNAP-8 Restart System. Specifically it contains a description of the system studies, the method of simulation on the digital computer, the analytical techniques used, the computer results obtained, and the conclusions from the computer results.

II SYSTEM DESCRIPTION

A. GENERAL SYSTEM DESCRIPTION

The system studied is shown schematically in Figure 1. The lubrication and coolant (L/C) system has been omitted for purposes of clarity, however, the dynamic power requirement of the L/C system was not omitted from the consideration in the analysis of the system.

The primary NaK loop fluid flows from the reactor through the boilers placed in series. In Figure 1 schematic, boiler #1 is part of the parallel or redundant power conversion system (not shown) and acts to delay and dampen reactor outlet temperature transients. Boiler #2 is the active boiler with the PCS (power conversion system) shown. The flow is routed through a reverse flow start heat exchanger, which under startup transfers approximately 70 kw from the primary loop to the heat rejection loop. The primary loop pump supplies the pressure head required to circulate the flow on through the reactor.

The mercury loop consists of the active boiler, TAA, shut-off valve, condenser, mercury pump, and flow control valve. Shown in Figure 1 is the MIS (mercury injection system) attached to the mercury loop at three locations; namely, MPMA suction and discharge, and boiler inlet. A more detailed description of the MIS is presented in paragraph II, C, below.

The heat rejection loop receives NaK flow from the start loop, mixes it with condenser flow and passes it, in turn, through the parasite load resistor, radiator and pump. For this analytical study a control valve, which simultaneously controls both condenser and start loop flow in inverse manner, was simulated. At this time it is anticipated that the start loop flow will be managed by a simple shut-off valve instead of being integrated with the condenser control valve. This expected change does not significantly affect the analytical results presented herein.

B. CRITERIA

The synthesis of the restartable SNAP-8 system was based upon the set of criteria shown in Table 1. Item 7 in Table 1 states that the system complies with the latest reactor constraints. The system's synthesis was predicated upon reactor temperature coefficients which were estimated. Recent tests upon the S8DR reactor conducted at Atomics International reveal changes in these coefficients which produce a violation of constraints when operating the system as synthesized. On the basis of the pretest coefficients, the system violated no constraints.

C. MERCURY INJECTION SYSTEM

The mercury injection system (MIS) selected for incorporation into the SNAP-8 is shown schematically in Figure 2. It consists of a mercury reservoir, a piston actuator, and a four-way valve. The MIS functions to supply mercury to the MPMA at an acceptable pressure during startup and to provide a low pressure sink for receiving mercury during the shutdown recharging process.

The reservoir consists of a chamber, the volume of which is varied by a piston operated by an actuator. The back face of the piston is evacuated. The chamber is sealed by a bellows to permit the volume variation to take place. The reservoir is originally loaded with approximately 400 lbs of mercury.

The actuator portion of the MIS consists of two bellows-sealed chambers filled with lube and coolant fluid and separated by a piston. The actuator piston area will be .495 of the reservoir piston area. During injection the differential pressure produces a force on the actuator piston which is transmitted to the reservoir piston producing the required mercury pressure at the MPMA suction at the full power condition.

The four-way L/C valve supplying the MIS actuator is shown schematically in Figure 3. The valve is designed similar to a servo valve with a spool and has the capability of compensating for varying G forces in the range of 0-1.5 G. The four ports of the valves are connected to the suction and discharge of the L/C PMA and the normally high pressure and normally low pressure sides of the MIS actuator. Figure 3 shows the spool in the normal operating position under zero gravity. The L/C PMA differential pressure of 70 psi is reduced to 26 psi by the throttling action of the spool. This pressure differential is applied across the actuator piston to produce 13 psi in the reservoir and, hence, at the MPMA suction.

The spool position is determined by the force balance upon it. The forces in the spool are the hydraulic forces, the spring force, and the spool weight. The pressure differential across the actuator position acts on an area of approximately .0492 in^2 on the spool in opposition to the spring and spool weight forces. With a 1.5 G gravity force the spool positions itself to produce 34.8 psi in the reservoir (shown in Figure 4). This value is predicated upon the MIS being located at the MPMA elevation. The "g-force" compensation feature is designed to render the mercury loop operation insensitive to variation in gravity force. By this means the mercury loop will not vary.

The four-way L/C valve described above may be replaced by a standard four-way valve of the SNAP-8 application is one in which the gravitational force is a constant at all times and in the range of 0-1.56.

III SIMULATION DISCUSSION

The system described above was programmed for the IBM 360 digital computer and is designated STRAP-3 (Startup TRAnsient Program). The code consists of fifty-two subroutines and represents the electrical generating system dynamically. EGS startups and shutdowns can be simulated with this code. The code contains provisions for generating a tape which, when used with a CALCOMP plotter, can plot any or all of the system parameters versus time. The code also contains provisions for retaining the extreme values of a set of critical parameters and comparing them with their constraints.

IV ANALYTICAL TECHNIQUES

The method of analysis has been iterative in nature. A method of control is devised which, on the basis of hand calculations, appears feasible. The control components are represented mathematically and then programmed for incorporation in the STRAP-3 code. The STRAP-3 code is run through the IBM 360 simulating startup and shutdown. The runs, in the early stages, show deficiencies and areas for improvements. The control concept is modified and the process reiterated until satisfactory performance is achieved.

The computer runs discussed above were divided into two groups. The first group of runs (nominal runs) were made with nominal system conditions to find control component design characteristics which would permit the system to startup and shutdown satisfactorily. Successful results demonstrated feasibility of control concepts but not necessarily their practicality. The second group of runs (limit runs) were made with system conditions reasonably biased throughout to find those modifications to the control components specifications which would permit the system to startup and shutdown satisfactorily under the worst conditions likely to be encountered under system use. Satisfactory results of this second groups of runs indicated not only feasibility of the control concepts but practicality as well.

The worst conditions are described as those which drive to their extremes those system parameters which are designated as the most critical. The critical system parameters with their limiting values are as follows:

	Parameters	Limiting Value
1.	Reactor NaK Inlet Temperature Rate of Change Over a 5 Second Period	9.17°F/sec
2.	Reactor NaK Inlet Temperature Rate of Change Over a 30 Second Period	5.0°F/sec
3.	Reactor NaK Outlet Temperature Rate of Change Over a 5 Second Period	9.17°F/sec
4.	Reactor NaK Outlet Temperature Rate of Change Over a 30 Second Period	5.0°F/sec
5.	Reactor NaK Outlet Temperature	1375°F
6.	Reactor Power	675 KW
7.	Condenser Pressure	40 PSIA
8.	Radiator Inlet Temperature	700°F
9.	MPMA Suction Specific Speed	14,700

These critical system parameters were chosen on the basis of component limitations and susceptibility to excursions under transient operation. The list is not unalterable as future system tests and possible component malfunctions may necessitate additions of other parameters.

V COMPUTER RESULTS

The computer runs described in Section IV were performed and the more significant parameters were plotted. The group of nominal startup and shutdown runs and limit runs are discussed in the following paragraphs.

A. NOMINAL STARTUP

A figure has been presented (Figure 5) to indicate the general method of startup of the PCS-G after PNL heatup. The FCV is opened to permit 3% flow to occur. Upon signal that boiler inlet mercury line has been filled the FCV is ramped to the 50% flow position in 25 seconds. The actual flow lags the FCV by approximately 25 seconds. The plateau flow level (~50%) is held to stabilize the system. At the plateau flow rate the system is self-sustaining. Following a stabilization period of approximately 10 minutes, the FCV is ramped to full flow in approximately 500 seconds. The flow follows the FCV opening closely during the power ramp since the MPMA is up to full speed.

A nominal startup run was performed with the second boiler in the PNL being the active boiler. The significant results are presented in Figures 6 through 10. (It is to be noted that all results shown will be from the point in time after the boiler inlet line has been filled.) In this run the TAA picked up the PMA's at 6600 rpm at approximately 20 seconds and proceeded to full speed reaching it at 55 seconds (Figure 6). Condenser pressure reached the switchover level of 3.5 psia at 60 seconds when the combined condenser and boiler mercury inventory was 50 pounds. The depressed reactor temperatures with the new temperature coefficients of reactivity caused the power to surge to 717 KW, thereby exceeding the 675 KW maximum allowable power (Figure 7). The reactor outlet temperature surged to 1392°F, thereby exceeding the 1375°F maximum allowable. It is evident from Figure 7 that at full pump speed the temperature at the inlet to second boiler lags that of the reactor outlet by almost 30 seconds.

The stabilization of the system at the plateau flow level must be regarded from several standpoints. The flow rates are the first to stabilize since they are dependent upon pump speeds (Figure 8). The boiler and condenser inventories settle out at plateau levels at about 200 seconds after the start of the speed ramp. The HRL temperatures reach a degree of stabilization at about 275 seconds. The condenser pressure control operates at 240 seconds to increase the NaK flow to the condenser, otherwise temperature stabilization would have occurred sooner. Figure 9 shows the considerable thermal inertia of the radiator by the large time lag between the radiator inlet and outlet temperatures. Figure 6 shows that the reactor and PNL takes more than the 350 seconds computer run time to achieve stabilization. The power and resulting temperatures in the PNL show an underdamped subsystem behavior. This oscillatory characteristic is attributed to the small reactor temperature coefficients.

The effects of the changes in the reactor temperature coefficients of reactivity shown in Table 2 are presented in Figure 10. The old coefficients produce power and reactor outlet temperature surges which are less than the 675 KW and 1375°F maximum allowable values, whereas the new coefficients cause these limits to be exceeded.

In system operation the active boiler may be ahead of the inactive boiler when the alternate PCS is operated. When this occurs the inactive boiler acts as a thermal capacitance to reduce the power and reactor outlet temperature surges which occur. As shown in Figure 11 the maximum power and reactor outlet temperature are 702 KW and 1385°F, which are below the corresponding values of 717 KW and 1392°F when operating the other boiler.

From the plateau level the power ramp to full power occurs over 500 seconds with a linear increase in mercury flow rate. Figures 12 and 13 show the significant parameters during a nominal power ramp. The reactor power shows gentle undulations as a result of the drum movements with no surges such as those experienced during the initial startup. Turbine and pumps are at full speed during this period of the startup. The condenser NaK flow rate is increased by the HRL-FCV which operates to maintain condenser inlet pressure in the range of 11-14 psia. The condenser NaK inlet temperature rises to reflect the increase in the radiator temperature.

B. NOMINAL SHUTDOWN

Figure 14 shows the general method of shutting down the PCS-G. From full power a power ramp of 500 seconds down to the plateau level is made by operating the FCV in reverse of the manner of startup. The plateau level is held for 600 seconds to allow for the system to stabilize. The FCV is then closed down to a small flow (3-7% of full flow) in approximately 133 seconds. The purpose of the small flow is to provide pressurization in the mercury loop during the recharging of the MIS. After the MIS recharging operation the FCV and MIS valves are closed down sealing the mercury within the MIS.

Figures 15-17 show the important parameters plotted versus time from a normal shutdown computer run. Figure 15 shows the reductions of mercury flow starting at 10 seconds from the plateau flow down to the pressurization flow. With the flow reduction, the system reaches the point where it is no longer self-sustaining and the TAA and PMA's drop in speed until at 72 seconds the switchover speed of 6600 rpm is reached and the PMA's are loaded onto the inverter. The relatively unloaded TAA accelerates briefly and then decelerates (Figure 15). Most of the boiler inventory is shifted over to the condenser prior to the recharging operation. At 200 seconds the recharging operation begins with the opening of the MIS recharge valve. With the small flow (3-7%) maintaining pressurization in the loop the condenser is emptied at 275 seconds.

The reactor power, shown in Figure 16, declines from the plateau power level in response to the boiler inlet temperature signals. Reactor outlet temperature exceeds the maximum allowable value of 1375°F due to the underdamped characteristic demonstrated by the reactor with the new temperature coefficients.

The primary loop flow follows the PPMA speed only while the other flows are influenced by both pump speed changes and actions of the mercury FCV and HRL-FCV (Figure 17).

C. LIMIT TEST RUNS

The limit runs were made to test the simulated system on its satisfactoriness under the worst reasonable conditions likely to be encountered and in their worst possible combinations. The intent was to alter the control settings and characteristics, if necessary, to stay under the critical limits of the system. Recent changes in the reactor temperature coefficients have caused certain reactor limits to be exceeded. The results presented in the following paragraphs show the present status.

1. Reactor Limit Test

The reactor critical parameters listed in paragraph IV above were tested in a startup run and the results are shown in Figures 18-21. The TAA acceleration was acceptable, with the PMA's switchover and full speed occurring at 18 and 60 seconds, respectively (Figure 18). The worst case conditions in the reactor occur with the active boiler ahead of the inactive boiler. Figure 19 shows the power and reactor outlet temperature surges to peaks of 730 KW and 1413°F, respectively, which exceed the limits set by Atomics International. The method of circumventing this problem area has not been devised as yet.

Figure 20 shows the condenser and boiler inventories with injection from the MIS being completed at 70 seconds and flow from the condenser beginning. Condenser NaK flow remains constant, as determined by the initial HRL-FCV valve setting, until 230 seconds at which time it opens further to depress the rising condenser pressures.

Figure 21 shows the condenser inlet temperature on the mercury side as well as the radiator inlet and outlet temperatures. The large radiator thermal inertia is evident in the long time lag of the outlet temperature when compared with the inlet temperature.

Figure 22 shows a comparison of reactor limit test runs using both old and new reactor temperature coefficients. The location of the nominal power and reactor outlet maximums shown as points makes evident the need to include limit computer runs in the system analysis of the SNAP-8 PCS-G. It is apparent that any system change which would result in the nominal case maximums being within the maximum allowable limits would not necessarily result in a satisfactory system.

2. TAA Limit Test

The TAA limit test run was conducted to test if the turbine would develop sufficient power to pickup the PMA load and rise to full speed. Figures 23-26 show the results of the computer test run. Figure 23 reveals the TAA speed versus time. PMA pickup occurs at 30 seconds after start of boiler injection. Due to the conditions imposed upon the system for this test the turbine at 30 seconds develops insufficient power to sustain the pickup speed of 6600 rpm and therefore experiences some deceleration down to 5000 rpm. At this point, which occurs at 65 seconds, the rising mercury vapor flow to the TAA increases, reaccelerating the turbine. A second deceleration is experienced at 150 seconds when the condenser pressure rises, thereby, increasing the turbine back pressure. This also is overcome by the increasing vapor flow and the system continues bootstrapping to the full speed of 12000 rpm at 250 seconds.

The boiler representation in the STRAP-3 code was modified for this limit run to simulate a boiler which would have an inventory of 60 pounds at the full power condition. Figure 23 shows the delay in vapor flow to the TAA with respect to boiler flow which results from this modification.

Figure 24 shows how the gradual TAA acceleration and resulting slow flow rate increase produces a virtual elimination of the power and temperature surge in the reactor.

Figure 25 shows the condenser and boiler inventories for the run as well as the flow rates throughout the system. The condenser inventory rises to a peak of 110 pounds at 160 seconds and then with the opening of the condenser isolation valve the condenser inventory drops and the boiler inventory rises. The flow rates shown in this figure follow the PMA speeds with the PNL taking 250 seconds to reach its full flow levels. The condenser NaK flow was restricted by the HRL-FCV initial setting.

The condenser and radiator temperatures showed (Figure 26) a gradual climb which is attributed to sluggishness of the whole system under the conditions imposed.

Figure 27 compares the TAA speed and liquid mercury flow rate of this TAA Limit Test with the nominal test run.

3. Condenser and Radiator Limit Test

The condenser and radiator limit test was conducted to test if the condenser pressure and radiator inlet temperature, under reasonably extreme and unfavorable conditions, would exceed allowable limits of 40 psia and 700°F respectively. Figures 28-32 inclusive show the pertinent results of this test.

Figure 28 shows that the TAA picks up the PMA's at about 20 seconds and reaches full speed at 80 seconds. The conditioned boiler results in the mercury vapor flow and liquid flow to be only slightly out of phase, unlike the TAA limit test. The condenser pressure rises rapidly due to the initial higher HRL temperatures, the 40 pounds of mercury in the condenser, and the rapid speed rise of the rotating components.

Figure 29 shows the reactor power and temperature curves which exceed the maximum allowable values, however, not to the degree which occurs when the reactor limit test in conducted.

Figure 30 shows the dynamics of condenser and boiler inventories. The run is started with an excessive amount of mercury in the condenser (40 pounds) as a condition of the limit test. The HRL-FCV starts to open from the preset opening position when the condenser pressure rises above the 14 psia level at 210 seconds. When at 460 seconds into the run the condenser pressure rose 20% above the upper deadbank limit of 14 psia the MIS is opened and works in conjunction with the HRL-FCV to suppress the pressure back into the control range. The MIS acts to draw mercury out of the loop and, thereby, serves as a safety backup to condenser overpressurization. In the event future system testing reveals that such a backup procedure is unnecessary it can be removed from the programmer. The MIS action to assist the HRL-FCV in condenser pressure suppression is evidenced by the decrease in the condenser inventory and the spiked condenser outlet flow rate curve.

Figure 31 shows the rapidly rising condenser and radiator temperatures. The lack of smoothness in the condenser temperatures curve is due to the intermittent operation of the MIS which draws greater flow from the condenser. Figure 32 shows the condenser pressure and radiator inlet temperature in relation to the maximum allowable values of 40 psia and 700°F respectively. It is apparent that under the extreme conditions of this test that the limits have not been exceeded.

VI SUMMARY AND CONCLUSIONS

The STRAP-3 code contains subroutines which compute and retain the extreme values of the most critical variables reached in every run. These extreme values are normalized by subtracting them from the maximum allowable values and the results divided by the maximum allowable values. The normalized quantities are referred to as the margins of safety and for a system to be acceptable these must never be negative under any forseeable conditions or combinations of conditions. By normalizing the values it permits comparison between them.

The margins of safety for both the nominal and the limit computer test runs are presented in Tables 3 and 4. Table 3 shows positive margins of safety for all the critical variables with the exception of the reactor outlet temperature and power which show the negative values -.009 and -.06, respectively under nominal speed ramps and a negative value of -.005 for reactor outlet temperature on shutdown. Results of nominal runs are regarded as of academic interest only since acceptance of a system design will be predicated largely upon the results of the limit test. Table 4 also shows positive margins of safety for all critical variables with the exception of the reactor outlet temperature and power which show values of -.02 and -.12

respectively, which are significantly worse than those for the nominal run.

The TAA Limit Test and the Condenser and Radiator Limit Test show successful results. For the TAA Limit Test no specific variable was being tested against some maximum allowable value, but rather the objective was to see if satisfactory startup could be achieved and this was demonstrated. For the Condenser and Radiator Limit Test the critical variables under observation were condenser pressure and radiator inlet temperature and these variables showed margins of safety values of +0.55 and +.04 respectively.

The conclusions regarding the status of the PCS-G system analysis is as follows:

1. Mathematical model of SNAP-8 EGS was prepared.

2. Computer code and methodology for SNAP-8 systems analysis was developed.

3. Concurrence of MIS design by all concerned was achieved.

4. Method of startup and shutdown was synthesized which meets critical system constraints with pretest reactor temperature coefficients.

5. Results with post-test reactor coefficients show analysis must be redone and may require modification to reactor control system.

RESTART SYSTEM CRITERIA

1. 20 starts without servicing.
2. 100 start cycles design requirement (servicing permissible).
3. Both manned and unmanned concepts considered.
4. Operation at 0 'g' and up to 1 'g'.
5. Startup and shutdown to be fully automatic.
6. Restart after controlled and certain emergency shutdowns.
7. Comply with latest reactor constraints.
8. Utilize operating requirements and characteristics of existing hardware.
9. Utilize existing hardware where possible.
10. Restrict motion of mercury during launch and maneuver.
11. Contain mercury after shutdown.
12. Restart system to be readily adaptable for mercury inventory trim.
13. Boiler conditioned to permit self-sustained operation.
14. Turbine or vapor line preheat using mercury vapor not required.
15. Mercury loop evacuated and sealed prior to initial startup.
16. PCS to be capable of more than one startup attempt.
17. Restart system design should not require flight verification test.
18. Suitable with redundant PCS.

Table 1

Table 2

REACTOR TEMPERATURE
COEFFICIENTS OF REACTIVITY
IN UNITS OF CENTS OF REACTIVITY/^{0}F

	PRE-TEST VALUES	POST-TEST VALUES
LOWER GRID	-6.0×10^{-2}	-10.0×10^{-2}
FUEL	-10.0×10^{-2}	-10.0×10^{-2}
UPPER GRID	-7.0×10^{-2}	0.0

Table 3

MARGINS OF SAFETY
CRITICAL SYSTEM PARAMETERS
NOMINAL OPERATION

	Max. Allow Value	Speed Ramp		Power Ramp	Shutdown
Boiler Number		#2	#1	#2	#1
Reactor Inlet Short $\dot{T}$	9.17^0F/sec	+.68	+.66	+.94	+.82
Reactor Inlet Long $\dot{T}$	5.0^0F/sec	+.54	+.54	+.92	+.70
Reactor Outlet Short $\dot{T}$	9.17^0F/sec	+.72	+.72	+.96	+.70
Reactor Outlet Long $\dot{T}$	5.0^0F/sec	+.51	+.52	+.94	+.65
Reactor Outlet Temp.	1375^0F	-.009	-.006	+.02	-.005
Reactor Power	675 KW	-.06	-.048	+.15	+.51
Condenser Pressure	40 PSIA	+.63	+.63	+.55	+.65
Radiator Inlet Temp.	700^0F	+.09	+.09	+.04	+.08
MPMA N_s	14,700	+.42	+.42	+.60	+.86

MARGINS OF SAFETY
CRITICAL SYSTEM PARAMETERS
LIMIT OPERATION

	Max. Allow Value	Reactor Limit Test	TAA Limit Test	Condenser Limit Test
Boiler Number		#2	#1	#2
Reactor Inlet Short $\dot{T}$	9.17^0F/sec	+.69	+.89	+.70
Reactor Inlet Long $\dot{T}$	5.0^0F/sec	+.50	+.82	+.54
Reactor Outlet Short $\dot{T}$	9.17^0F/sec	+.70	+.93	+.72
Reactor Outlet Long $\dot{T}$	5.0^0F/sec	+.47	+.85	+.52
Reactor Outlet Temp.	1375^0F	-.02	+.04	-.02
Reactor Power	675 KW	-.12	+.51	-.06
Condenser Pressure	40 PSIA	+.63	+.84	+.55
Radiator Inlet	700^0F	+.14	+.20	+.04
MPMA N_s	14,700	+.15	+.50	+.30

Table 4

SNAP-8 EGS REPRESENTED BY THE STRAP-3 CODE
(BOILER #2 ACTIVE)

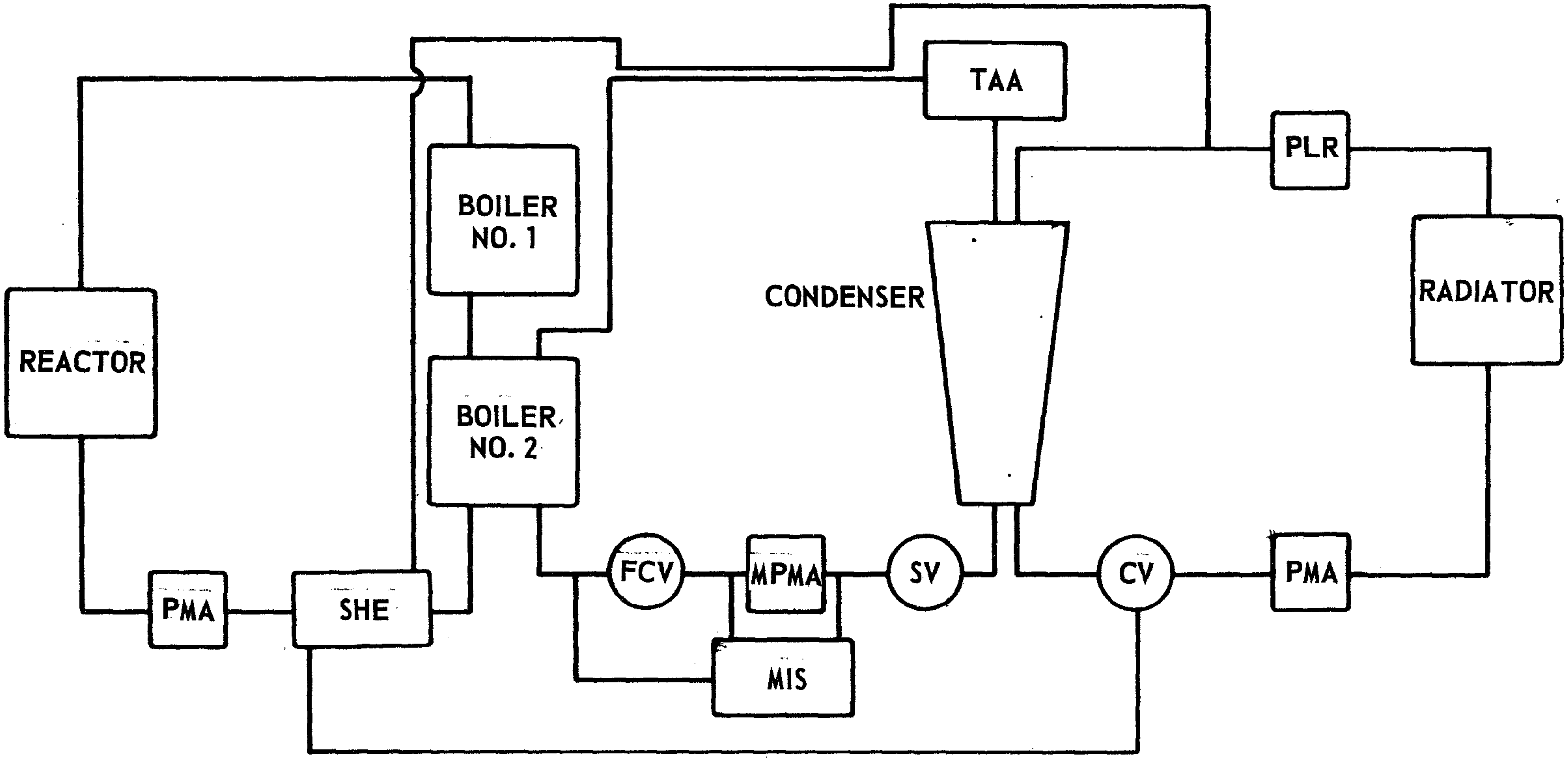


Figure 1

SCHEMATIC OF L/C PRESSURE DIFFERENTIAL SYSTEM

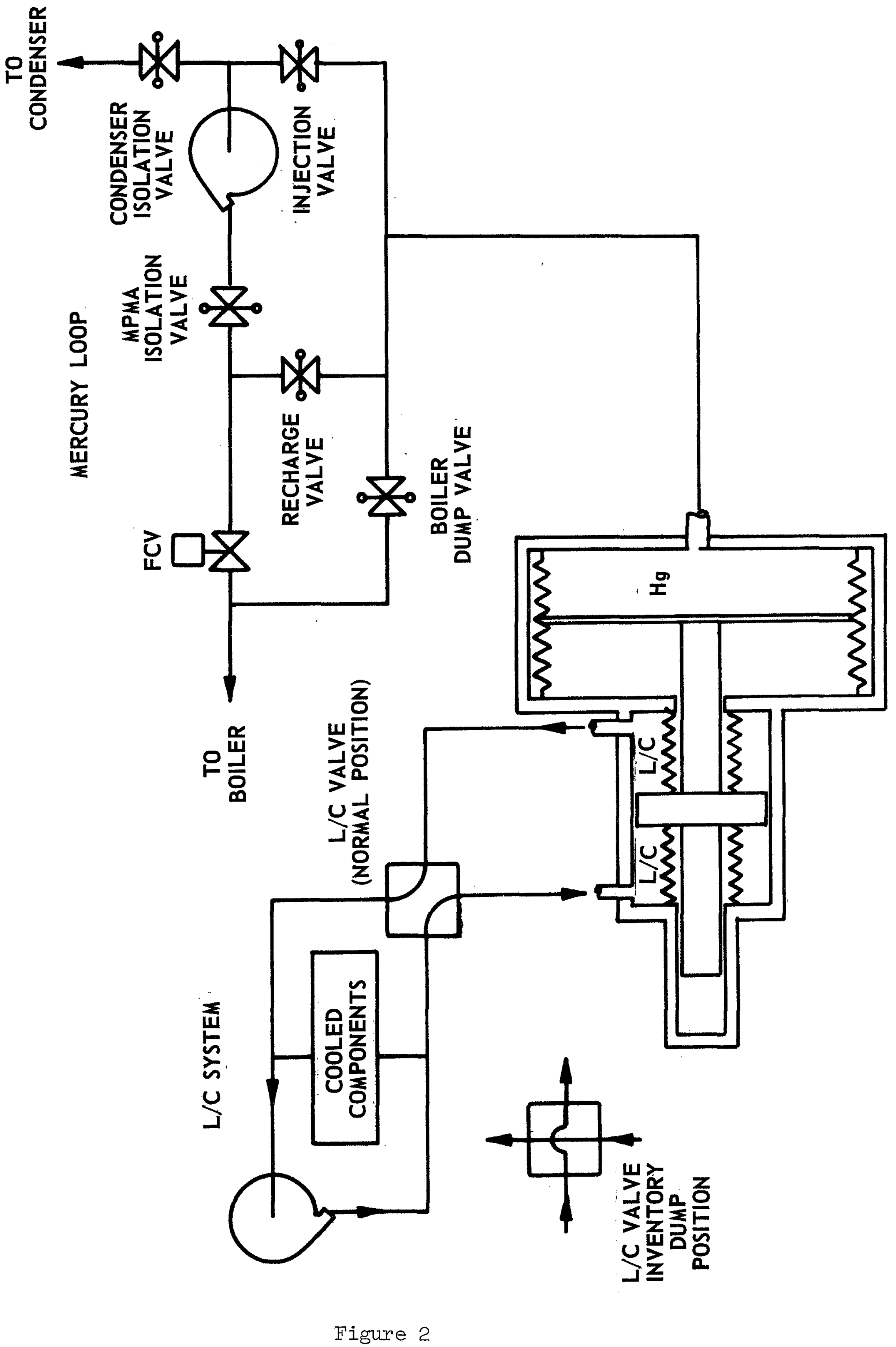
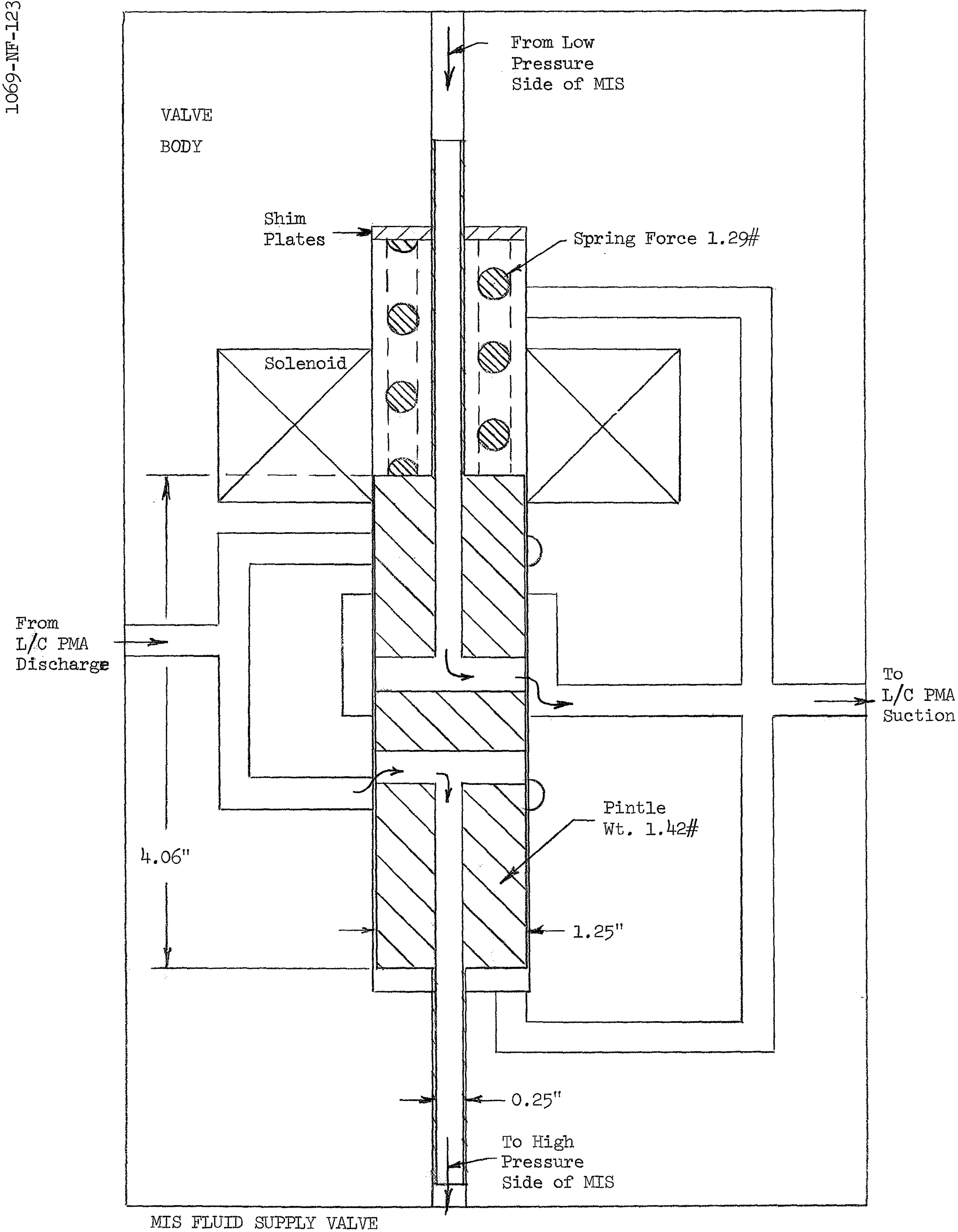
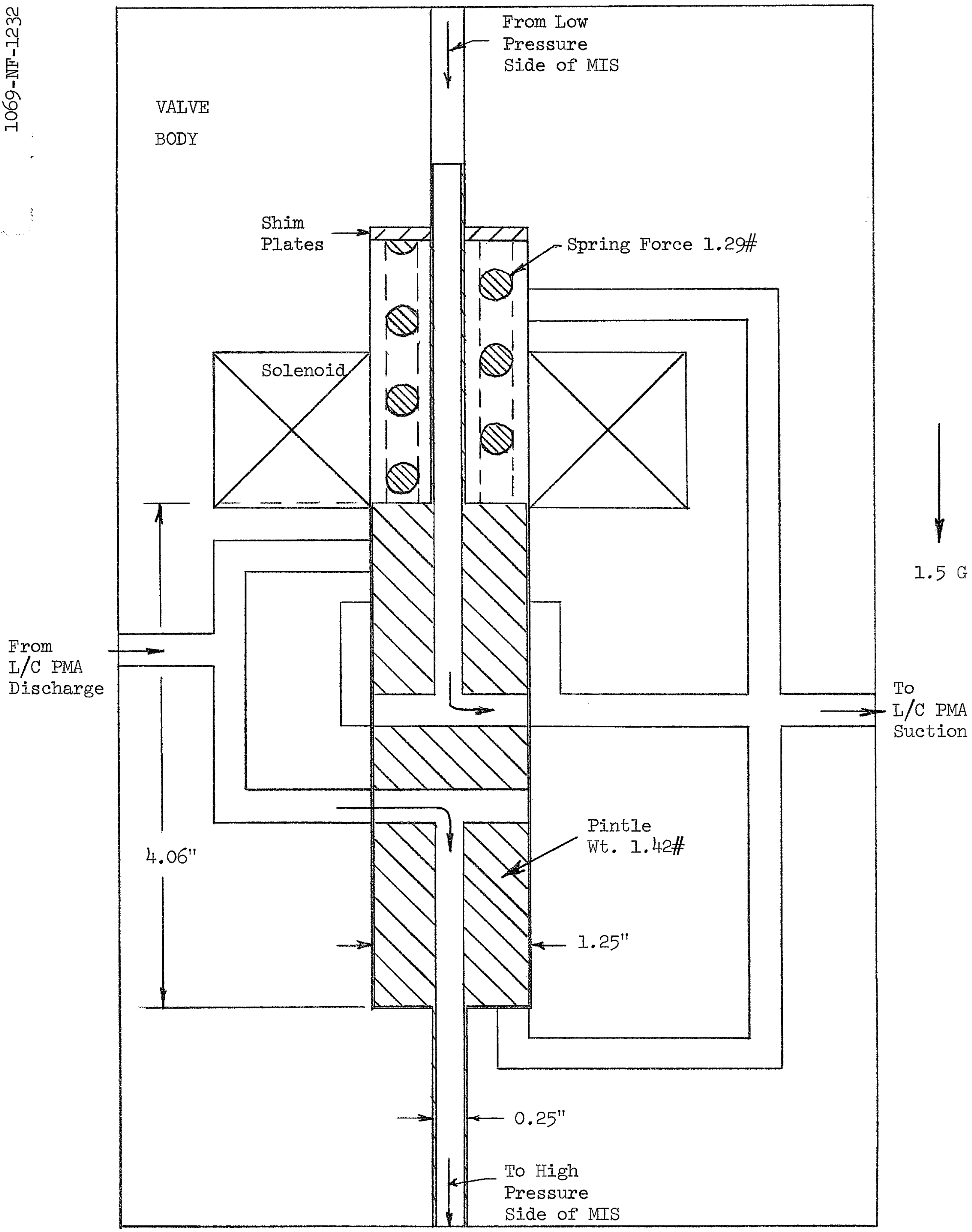


Figure 2



MIS FLUID SUPPLY VALVE
(OG POSITION)

Figure 3



MIS FLUID SUPPLY VALVE
(1.5 G POSITION)

Figure 4

GENERAL MERCURY FLOW RATE PROFILE DURING STARTUP

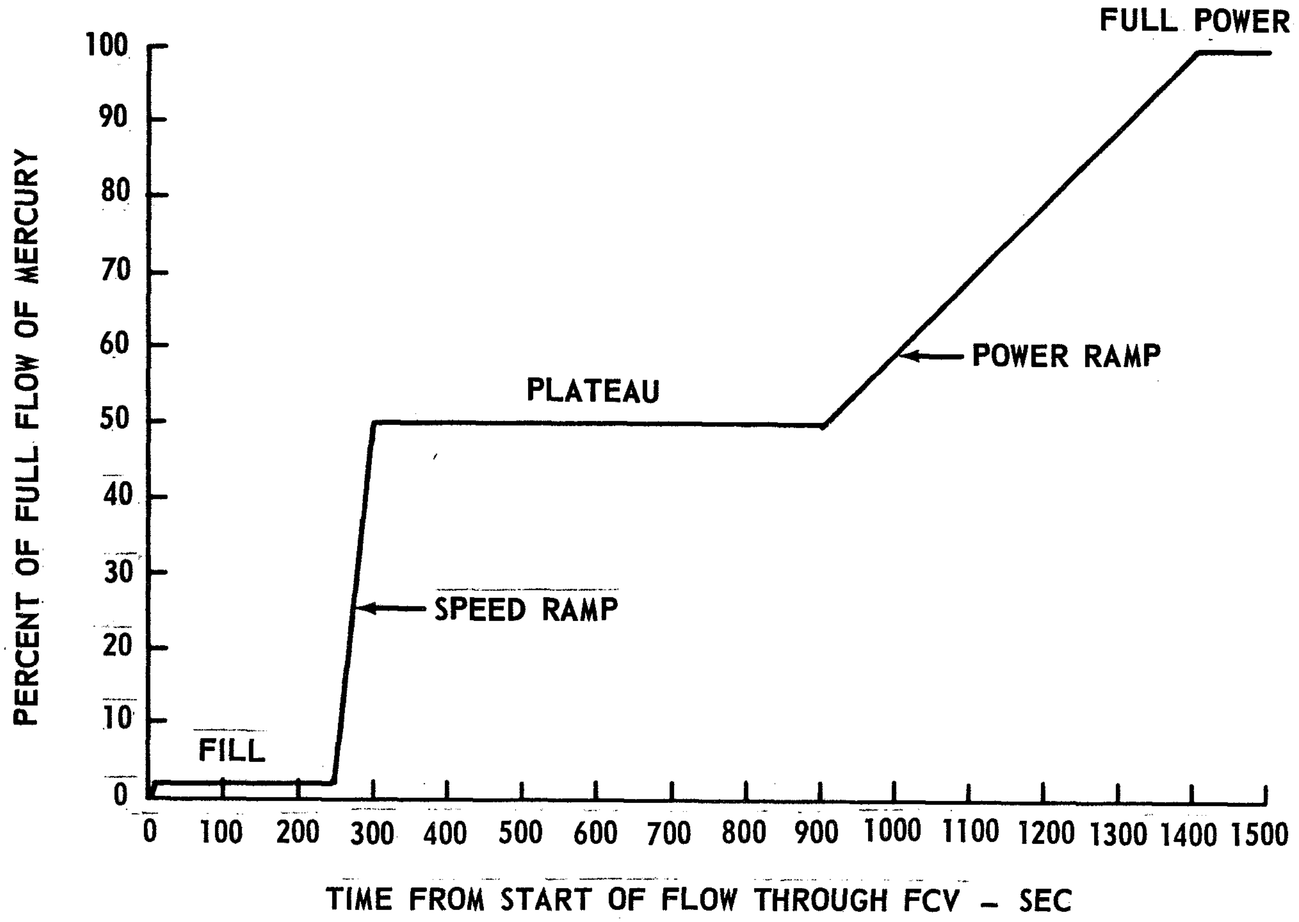


Figure 5

NOMINAL STARTUP CONDITIONS, INJECTION INTO BOILER #2, S8DR TEST COEFF's

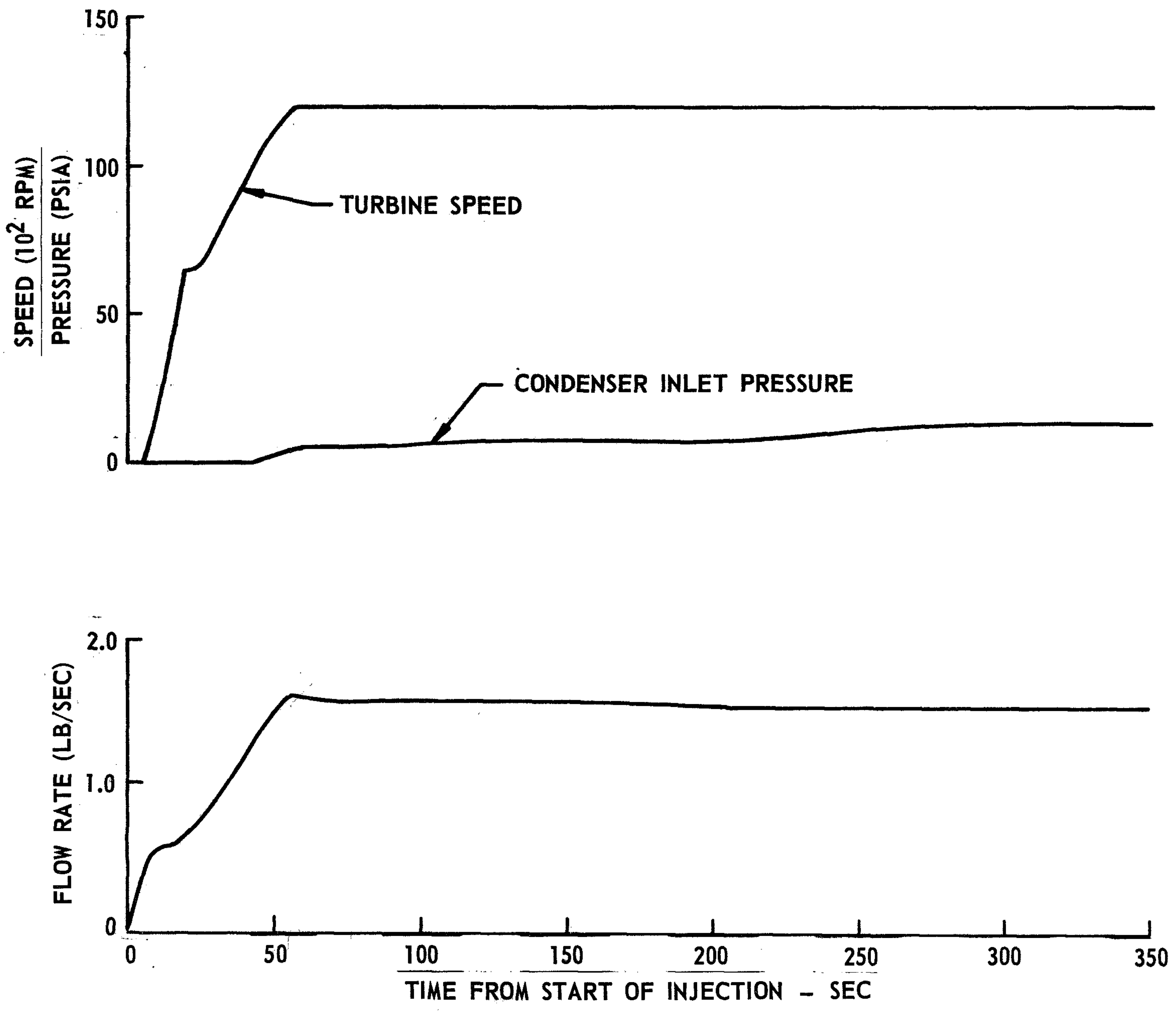


Figure 6

NOMINAL STARTUP CONDITIONS, INJECTION INTO BOILER #2, S8DR TEST COEFF's

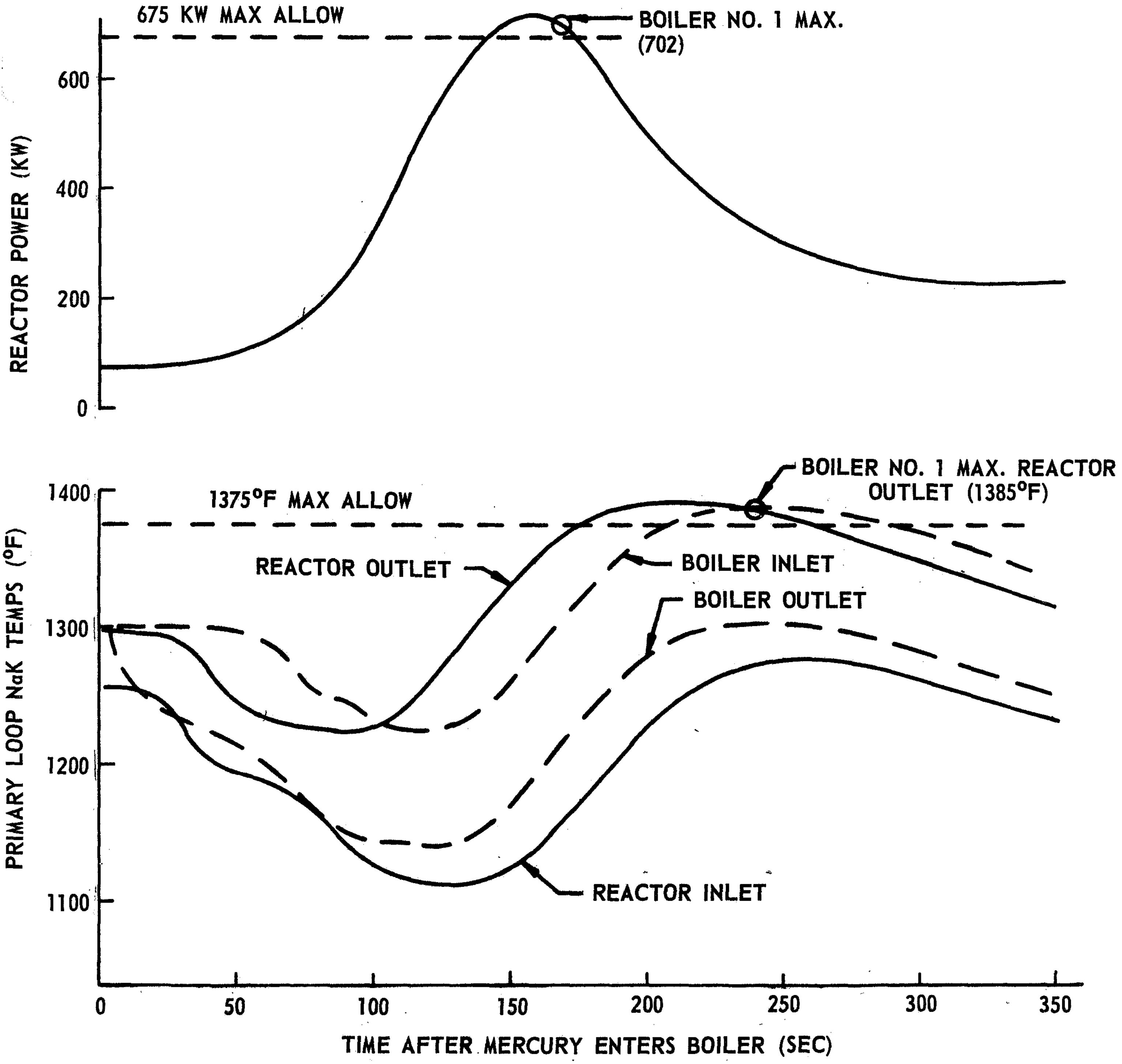


Figure 7

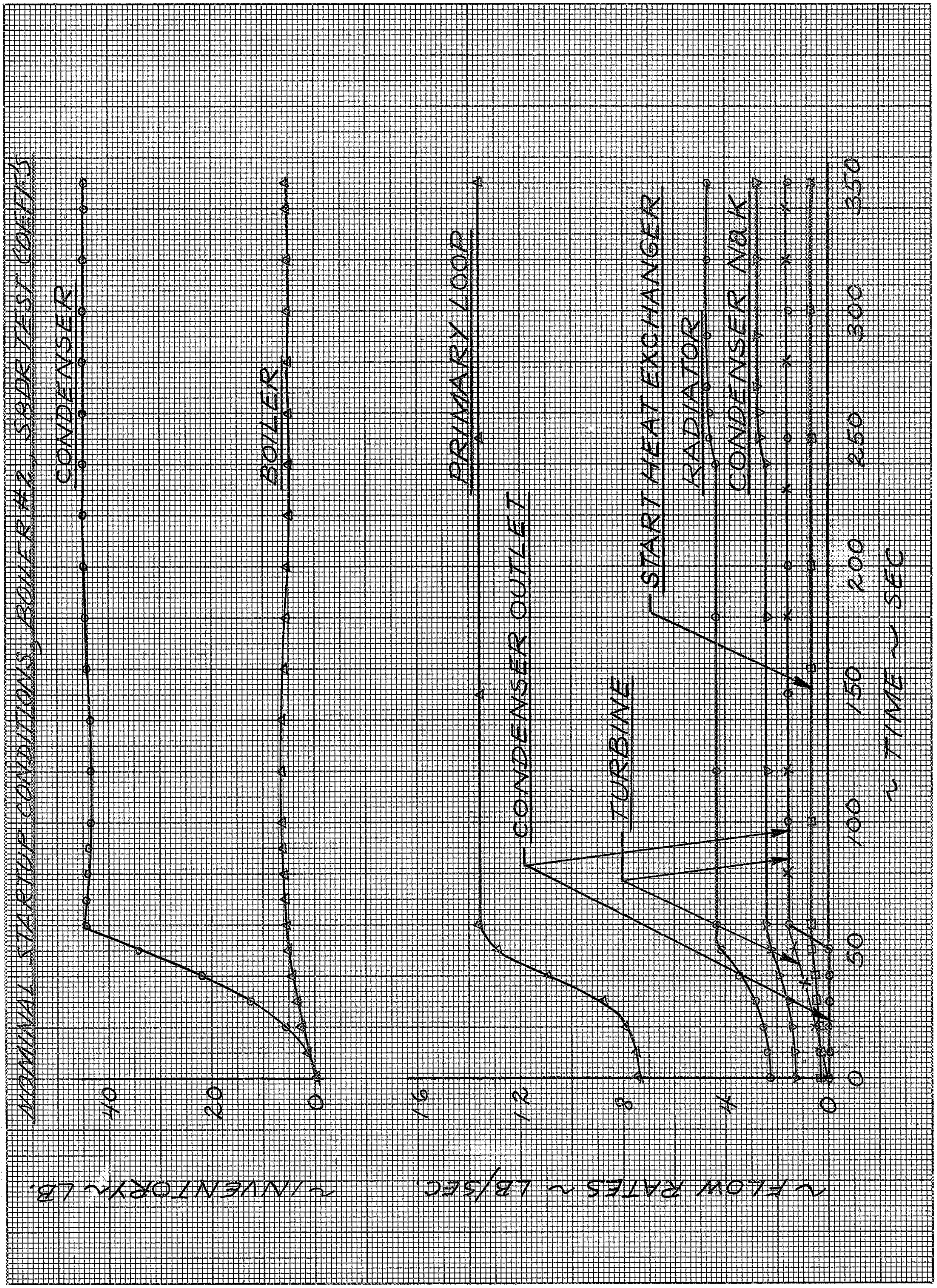

NOMINAL STARTUP CONDITIONS, BOILER #1, SBDR TEST COEFFS
~INVENTORY~LB.
40
20
0
CONDENSER
BOILER
~FLOW RATES ~ LB/SEC.
16
12
8
4
0
PRIMARY LOOP
CONDENSER OUTLET
TURBINE
START HEAT EXCHANGER
RADIATOR
CONDENSER NaK
0
50
100
150
200
250
300
350
~TIME ~ SEC

Figure 8


NOMINAL STARTUP CONDITIONS, BOILER #2, SBDR TEST COEFF'S
~ TEMPERATURE ~ °F
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
~ TIME ~ SEC
①
②
③
① CONDENSER INLET - Hg
② RADIATOR INLET - NaK
③ RADIATOR OUTLET - NaK

Figure 9

EFFECTS OF REACTOR COEFF's ON REACTOR PARAMETERS FOR NORMAL STARTUP
(BOILER #2)

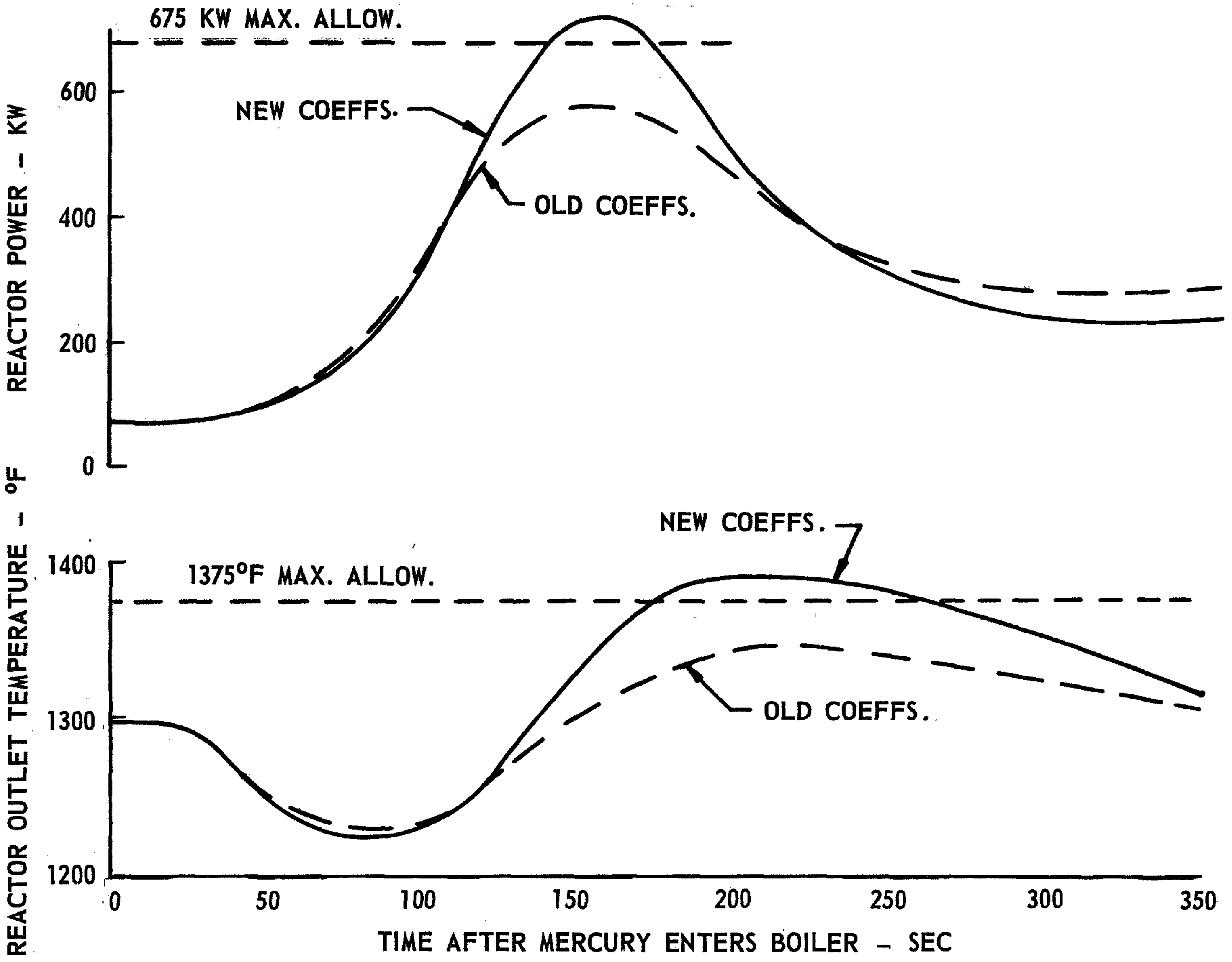
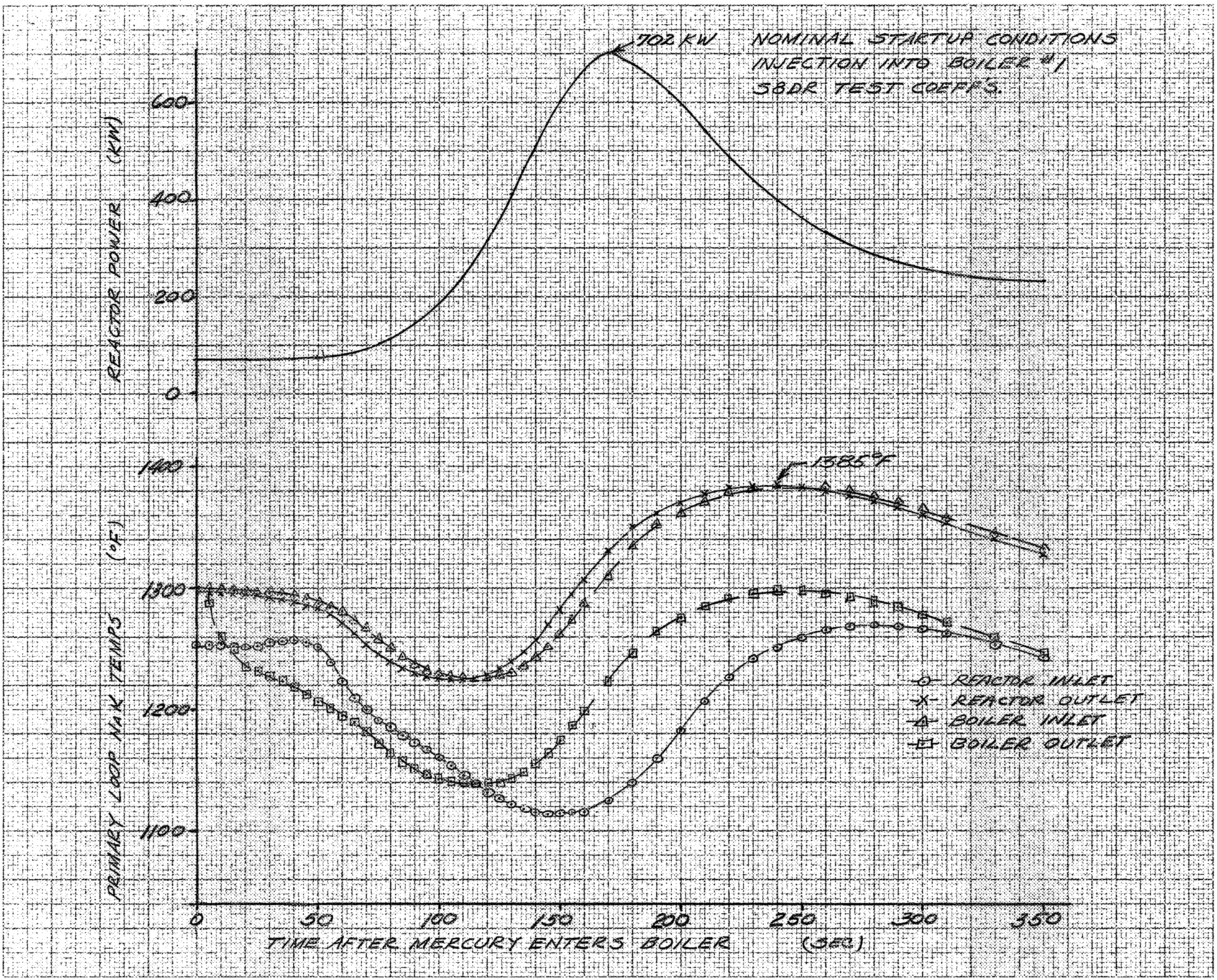


Figure 10



○ 101
× 102
△ 103
□ 104

Figure 11

NOMINAL POWER RAMP, S8DR TEST COEFF's (BOILER #2)

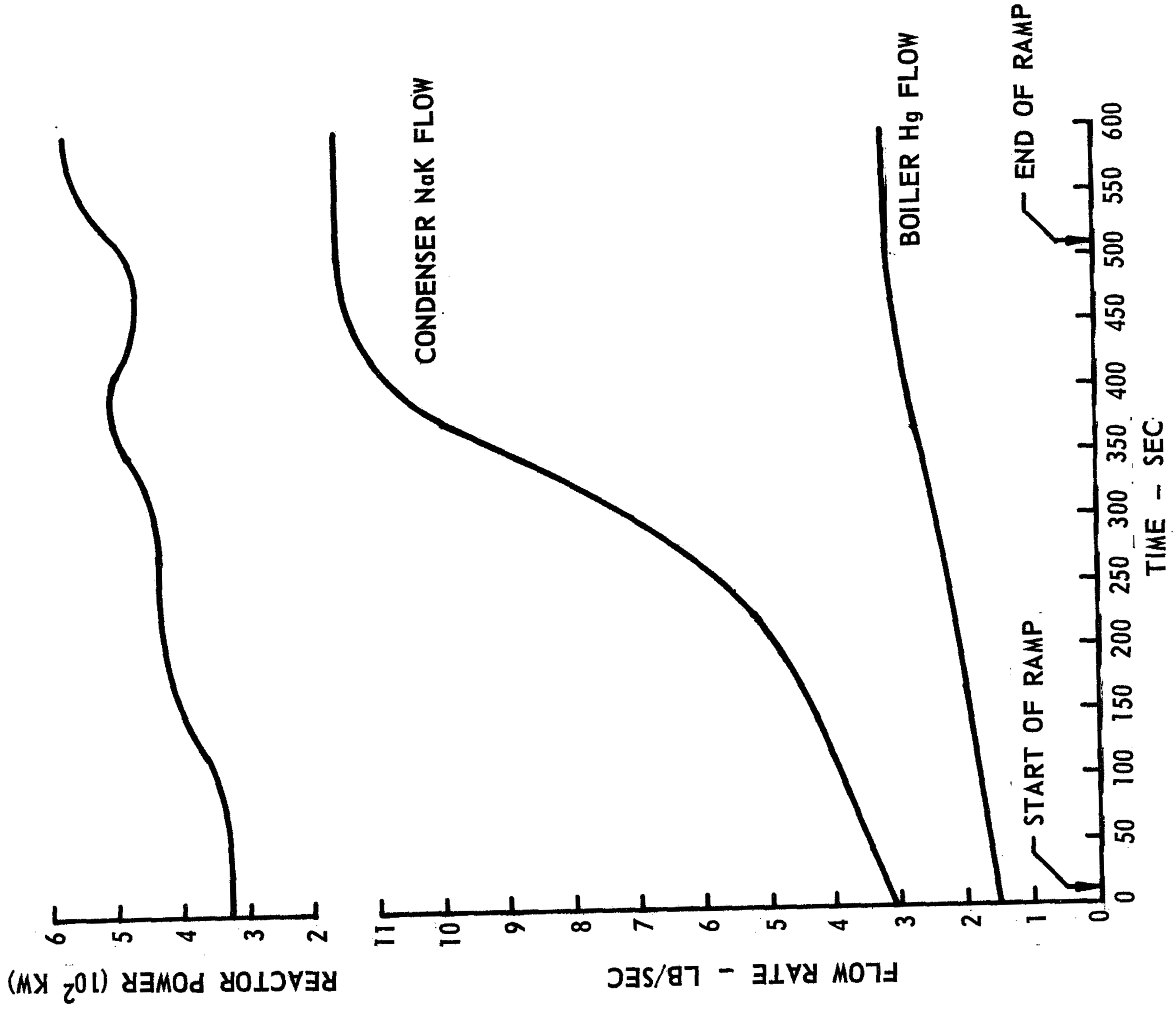


Figure 12

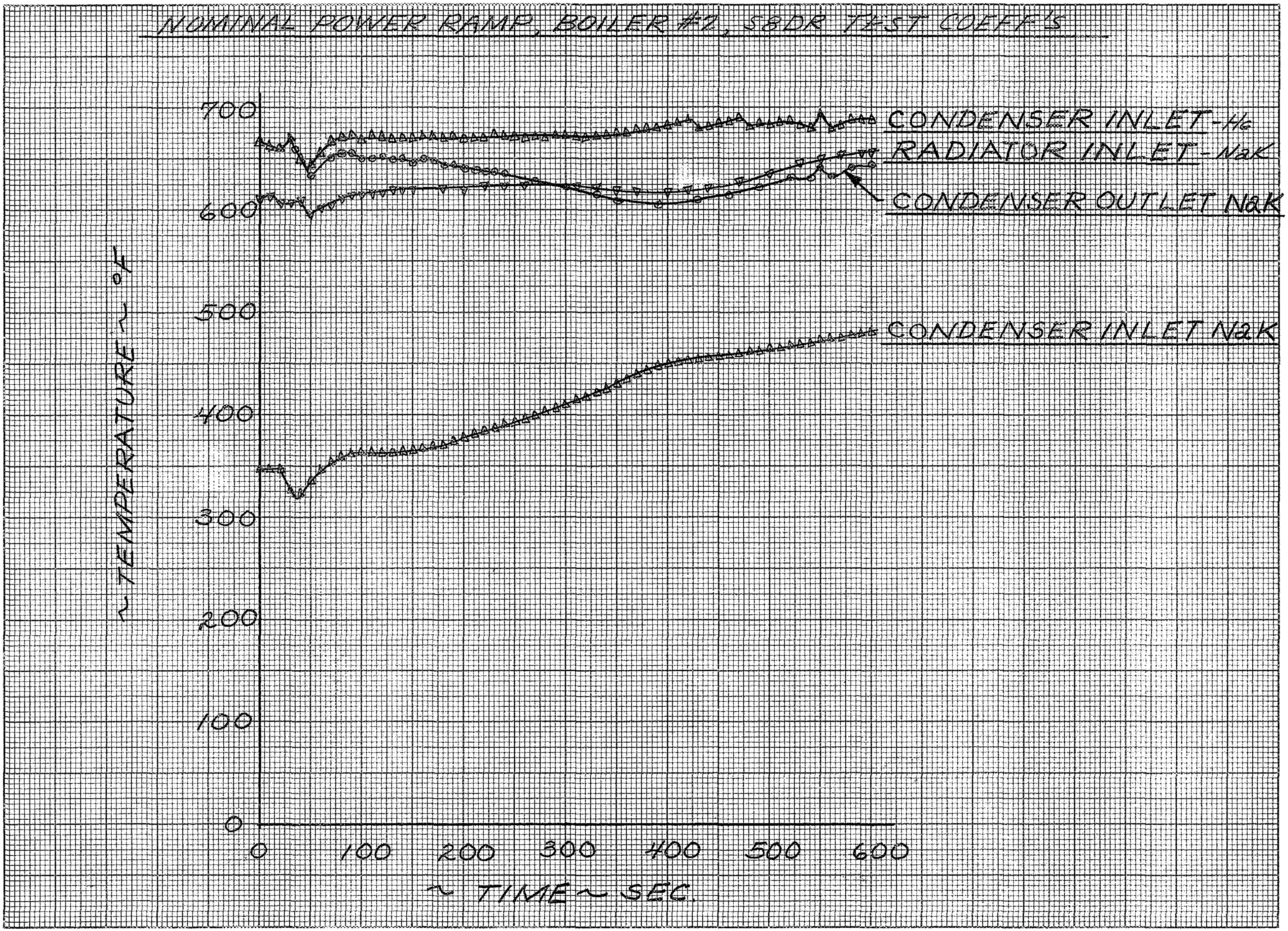

NOMINAL POWER RAMP, BOILER #2, S8DR TEST COEFF'S
CONDENSER INLET-Hg
RADIATOR INLET-NaK
CONDENSER OUTLET NaK
CONDENSER INLET NaK
~ TEMPERATURE ~ °F
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
~ TIME ~ SEC.

Figure 13

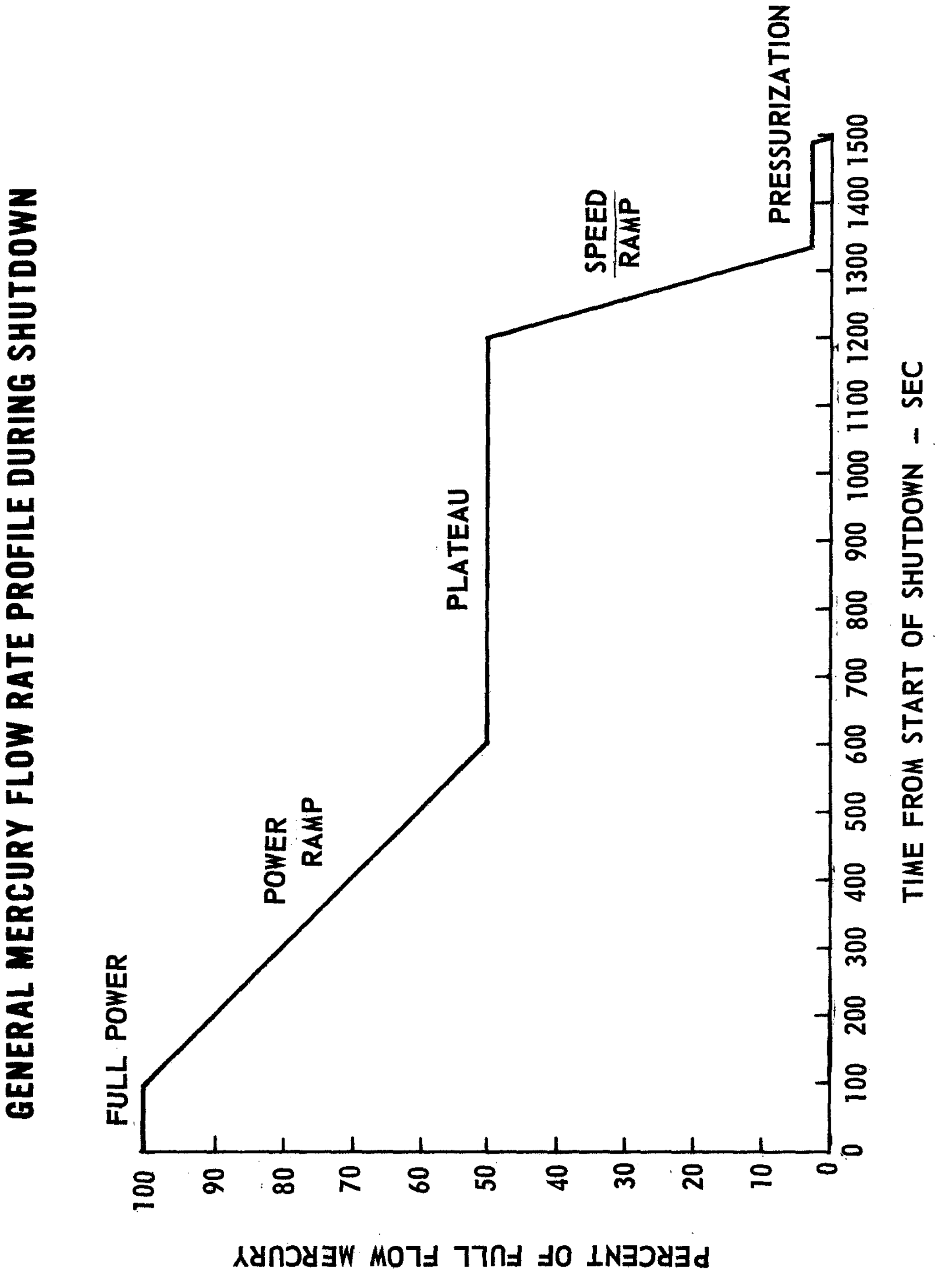
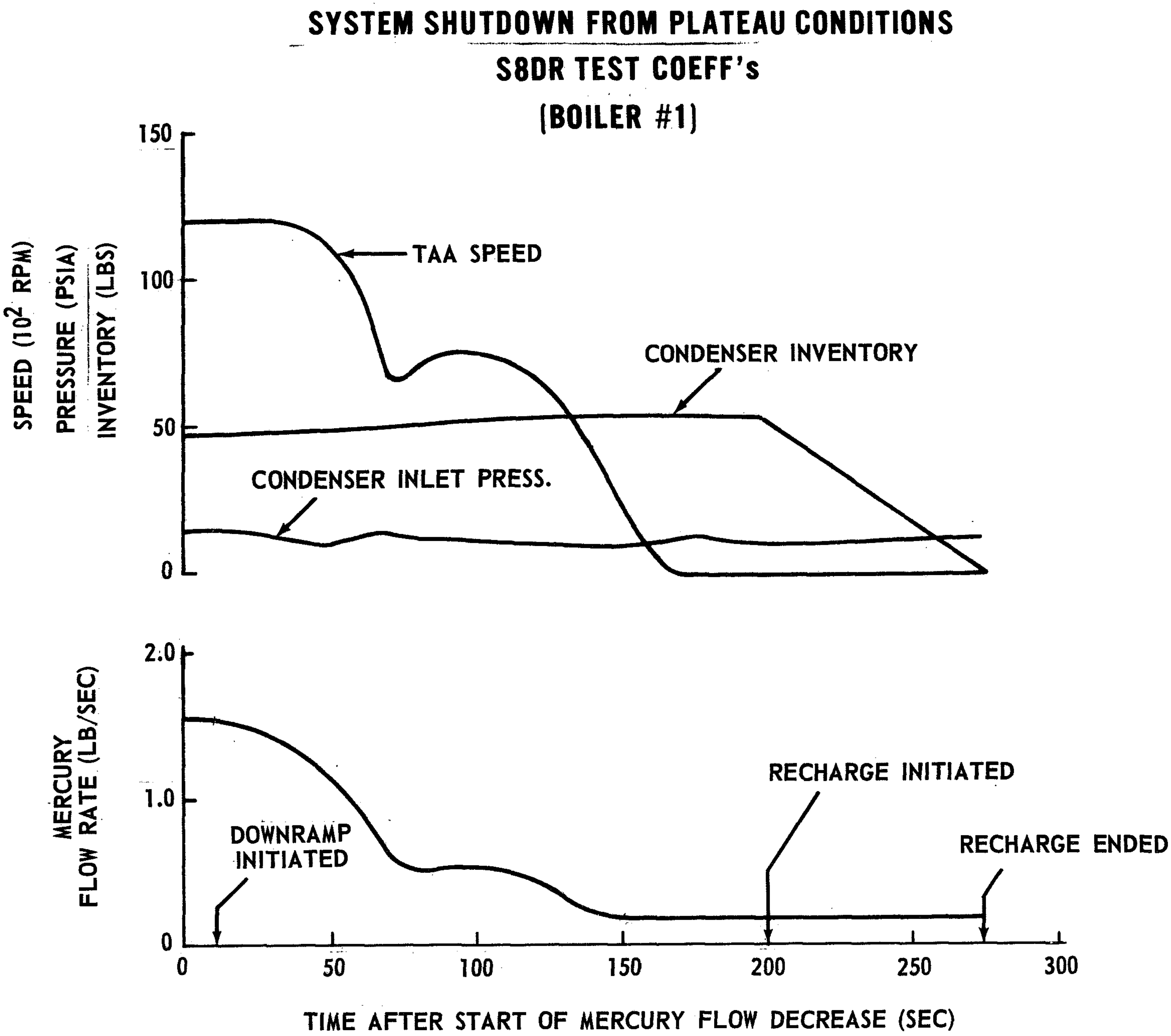

GENERAL MERCURY FLOW RATE PROFILE DURING SHUTDOWN
FULL POWER
POWER RAMP
PLATEAU
SPEED RAMP
PRESSURIZATION
PERCENT OF FULL FLOW MERCURY
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
TIME FROM START OF SHUTDOWN – SEC

Figure 14



SYSTEM SHUTDOWN FROM PLATEAU CONDITIONS
S8DR TEST COEFF's
(BOILER #1)

Figure 15

SYSTEM SHUTDOWN FROM PLATEAU CONDITIONS
BOILER #1 OPERATING, S8DR TEST COEFF's

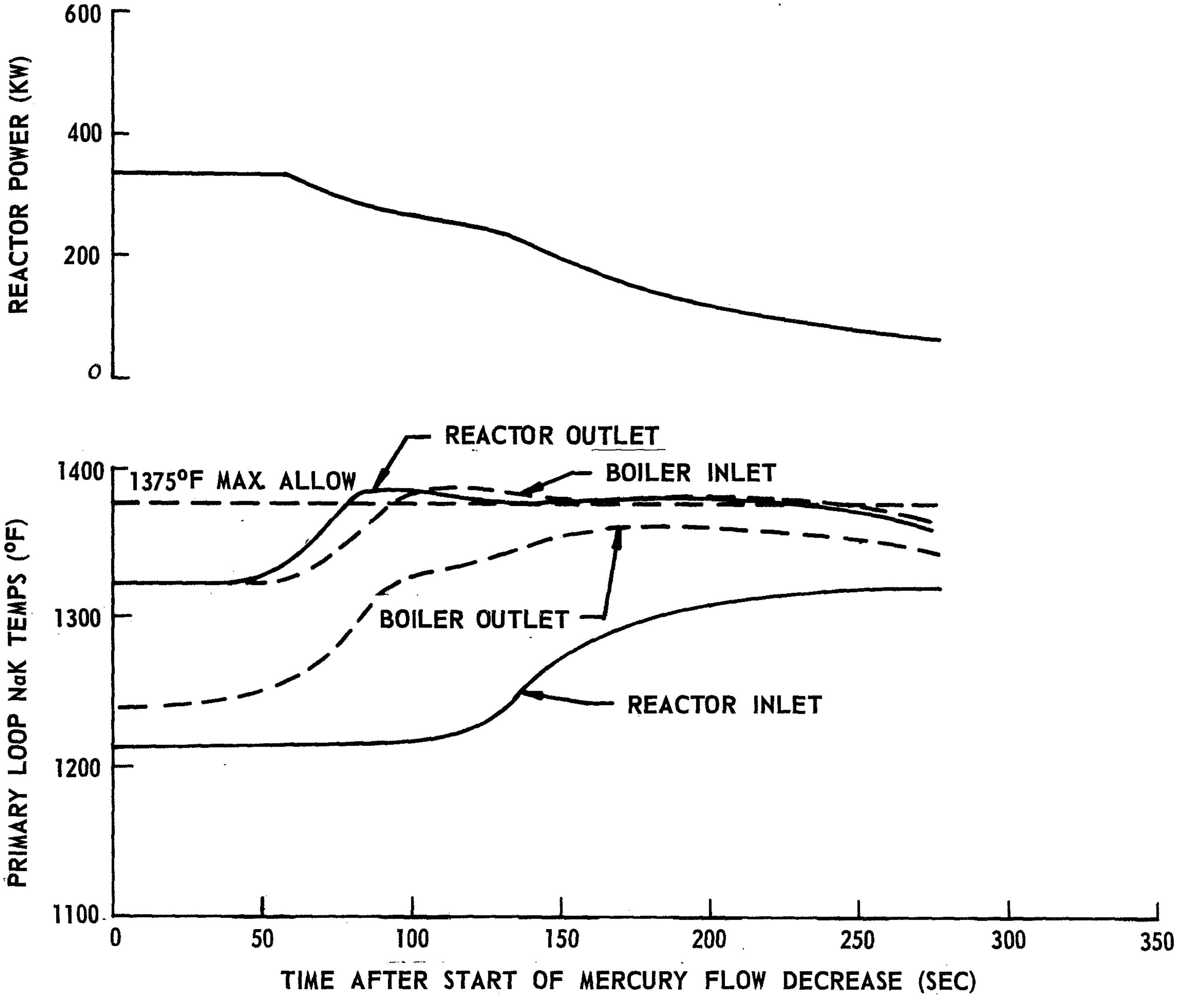


Figure 16

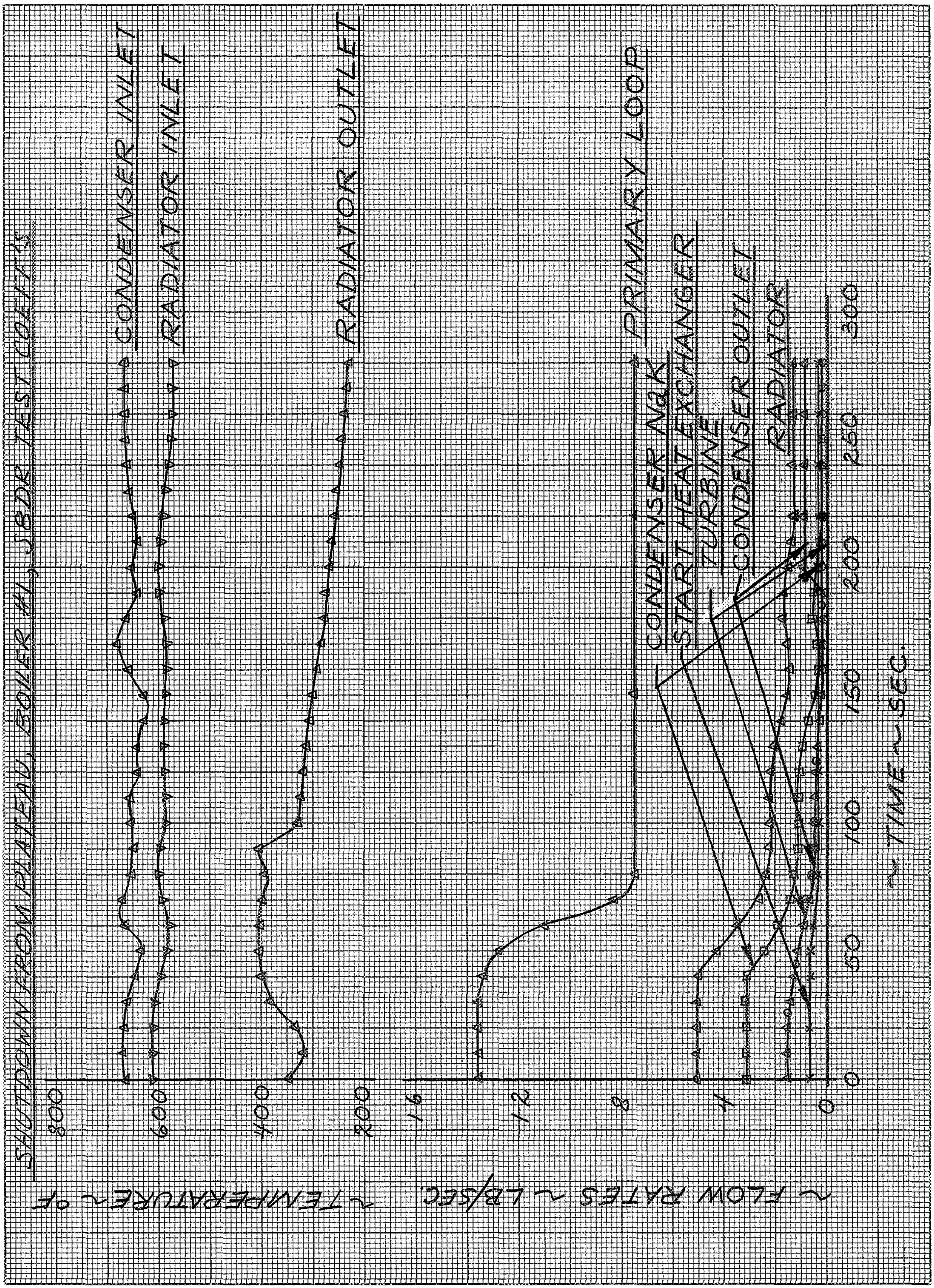

SHUTDOWN FROM PLATEAU, BOILER #1, SBDR TEST COEFF'S
~ TEMPERATURE ~ °F
800
600
400
200
CONDENSER INLET
RADIATOR INLET
RADIATOR OUTLET
~ FLOW RATES ~ LB/SEC
16
12
8
4
0
PRIMARY LOOP
CONDENSER NaK
START HEAT EXCHANGER
TURBINE
CONDENSER OUTLET
RADIATOR
0
50
100
150
200
250
300
~ TIME ~ SEC.

Figure 17

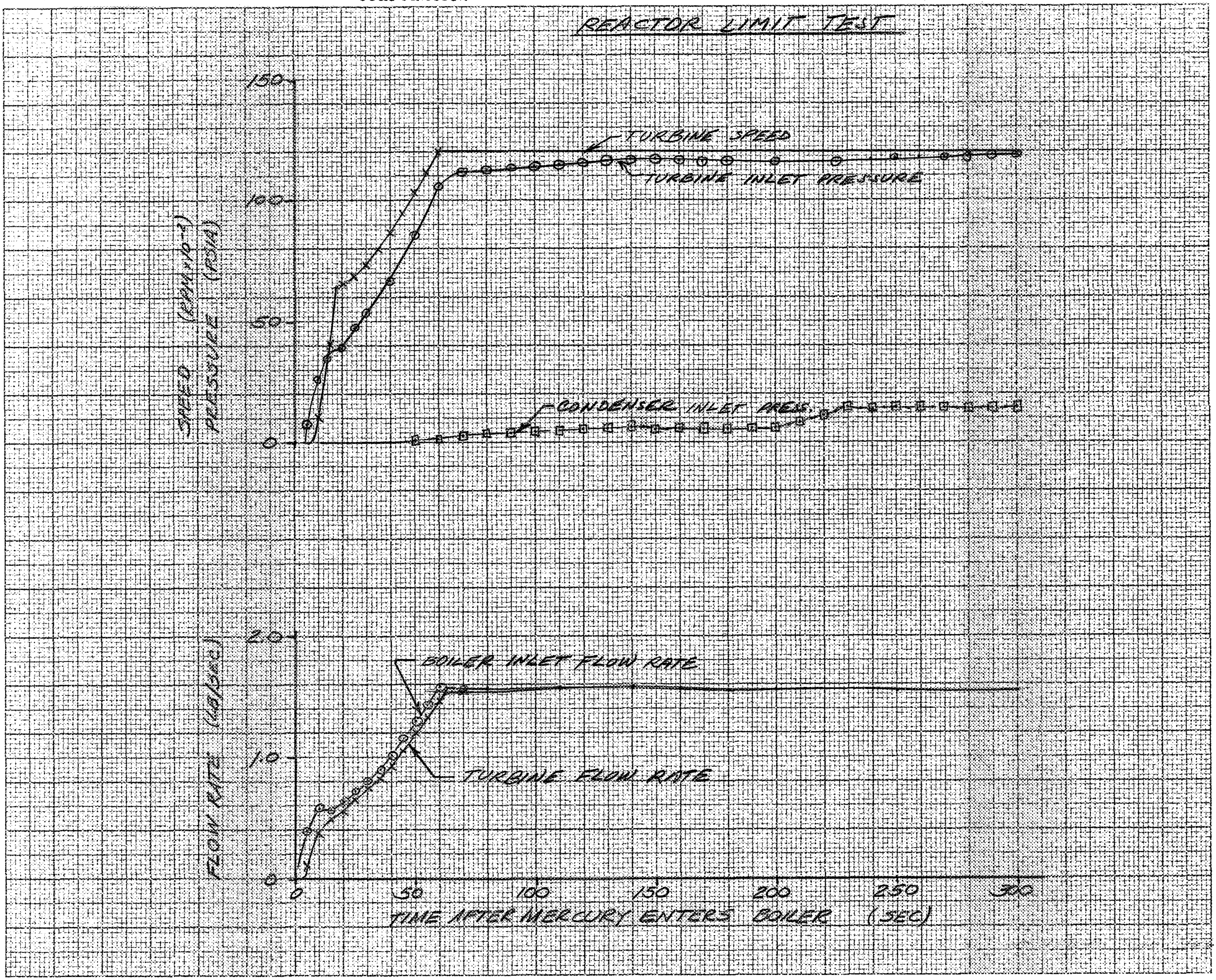

REACTOR LIMIT TEST
SPEED (RPM×10⁻²)
PRESSURE (PSIA)
150
100
50
0
TURBINE SPEED
TURBINE INLET PRESSURE
CONDENSER INLET PRESS.
FLOW RATE (LB/SEC)
2.0
1.0
0
BOILER INLET FLOW RATE
TURBINE FLOW RATE
0
50
100
150
200
250
300
TIME AFTER MERCURY ENTERS BOILER (SEC)

Figure 18

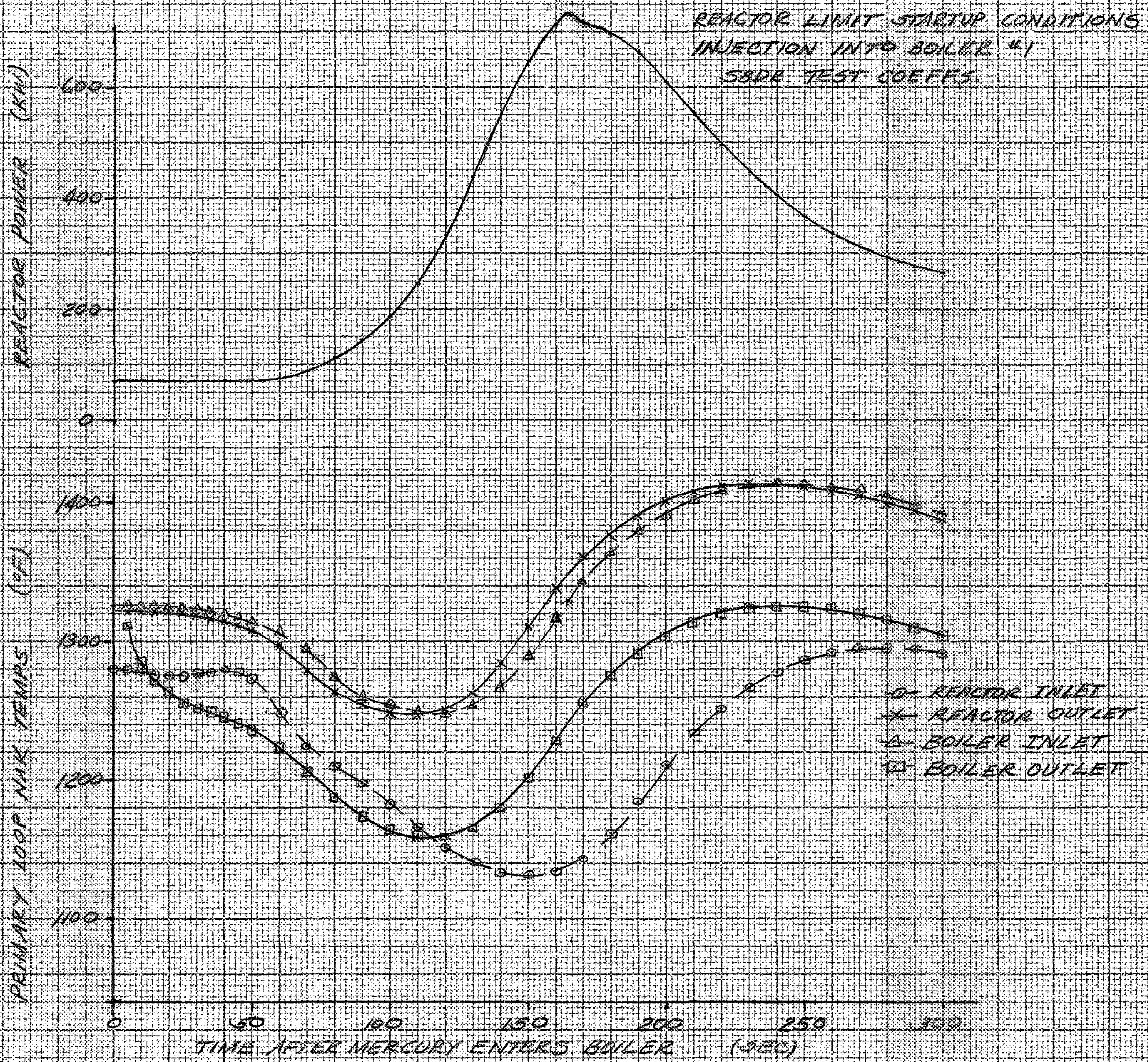

REACTOR LIMIT STARTUP CONDITIONS
INJECTION INTO BOILER #1
SSDE TEST COEFFS.
REACTOR POWER (KW)
600
400
200
0
PRIMARY LOOP NAK TEMPS (°F)
1400
1300
1200
1100
○ REACTOR INLET
× REACTOR OUTLET
△ BOILER INLET
□ BOILER OUTLET
0
50
100
150
200
250
300
TIME AFTER MERCURY ENTERS BOILER (SEC)

Figure 19

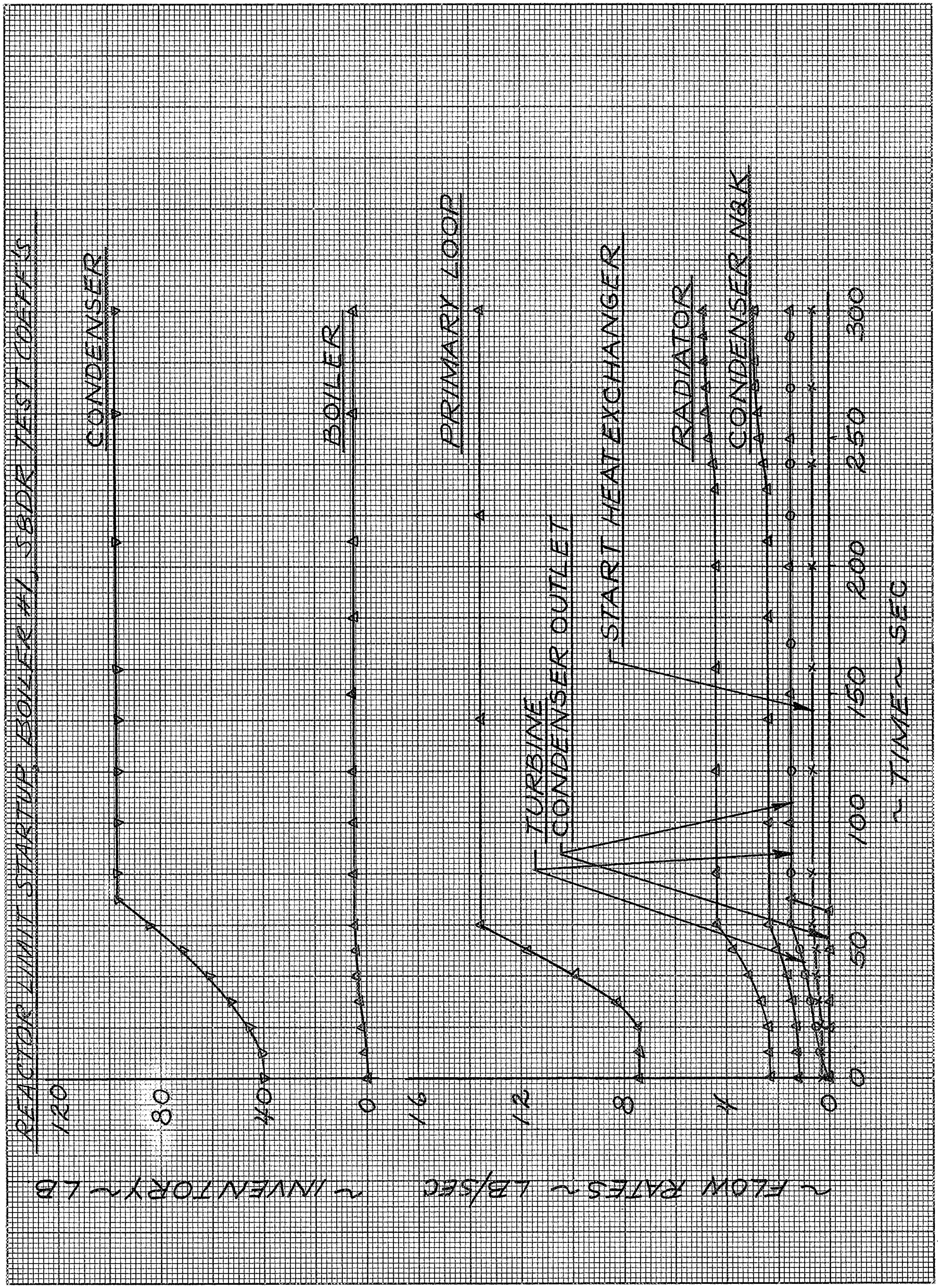

REACTOR LIMIT STARTUP, BOILER #1, SBDR TEST COEFF'S
CONDENSER
BOILER
PRIMARY LOOP
TURBINE
CONDENSER OUTLET
START HEAT EXCHANGER
RADIATOR
CONDENSER NaK
~ INVENTORY ~ LB
120
80
40
0
~ FLOW RATES ~ LB/SEC
16
12
8
4
0
0
50
100
150
200
250
300
~ TIME ~ SEC

Figure 20

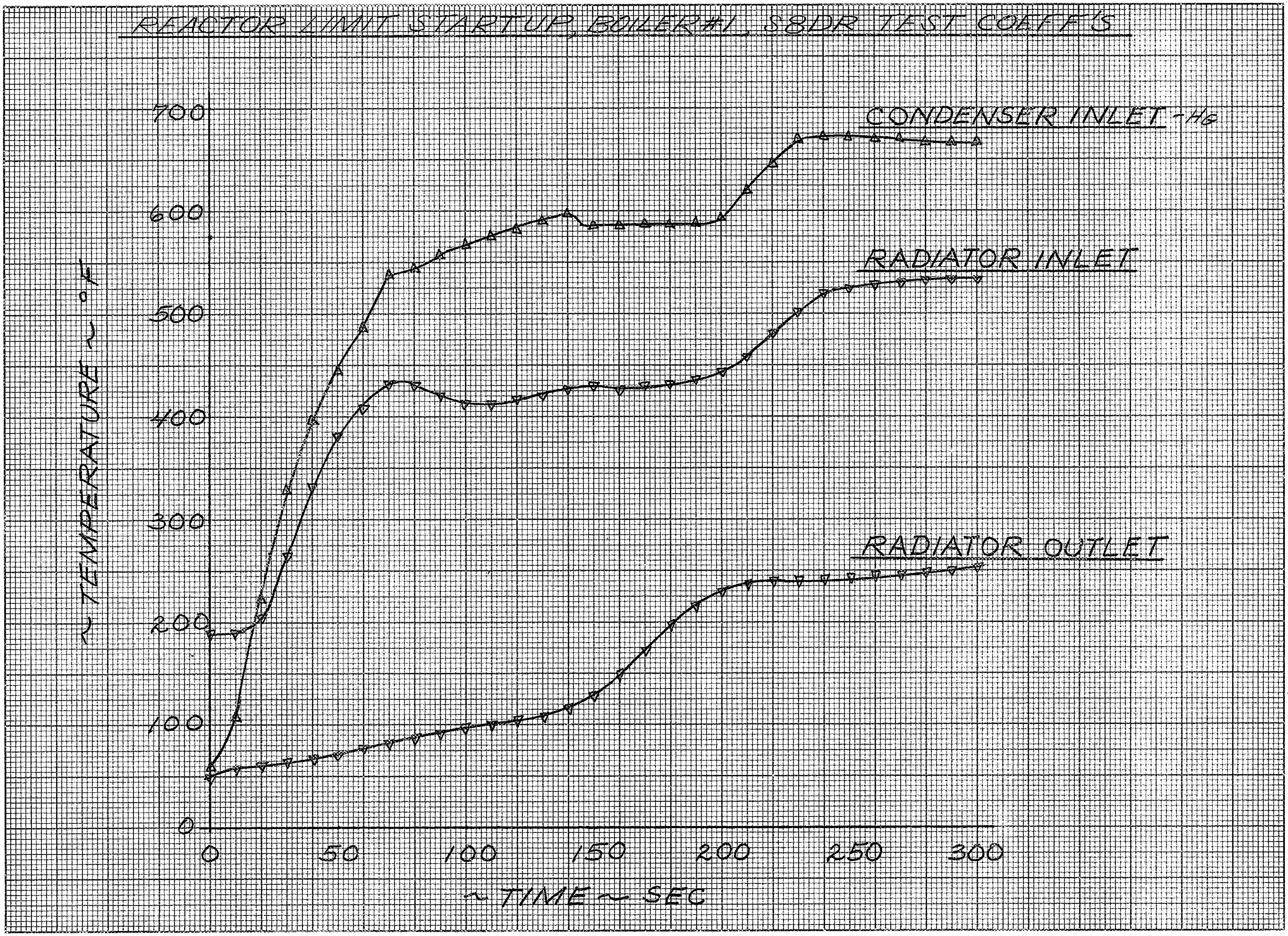

REACTOR LIMIT STARTUP, BOILER#1, S8DR TEST COEFF'S
CONDENSER INLET - Hg
RADIATOR INLET
RADIATOR OUTLET
~ TEMPERATURE ~ °F
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300
~ TIME ~ SEC

Figure 21

REACTOR TEMPERATURE COEFFICIENT CHANGE EFFECTS ON REACTOR LIMIT TESTS (BOILER #2)

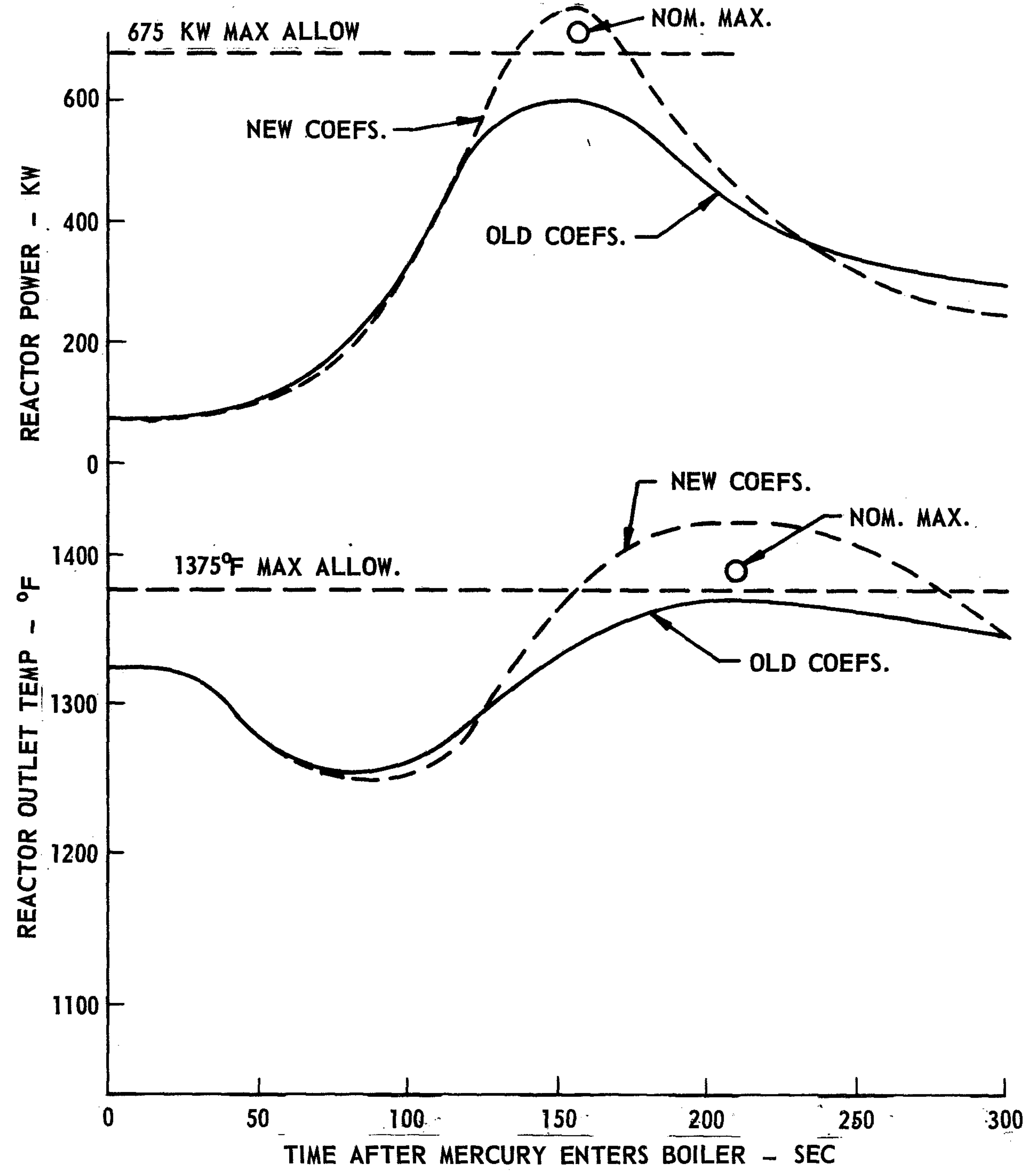


Figure 22

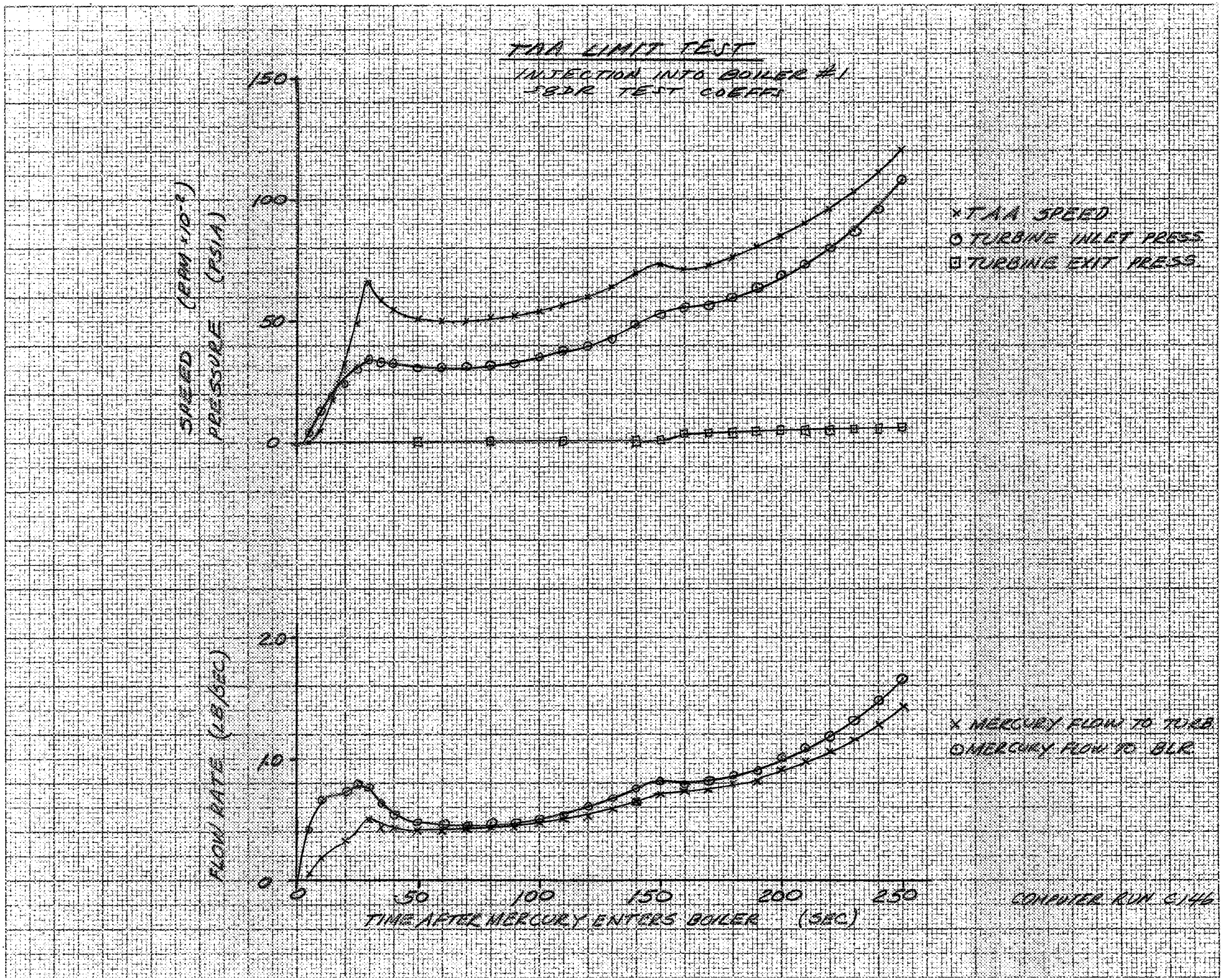

TAA LIMIT TEST
INJECTION INTO BOILER #1
58DR TEST COEFFS
SPEED (RPM × 10⁻²)
PRESSURE (PSIA)
150
100
50
0
× TAA SPEED
○ TURBINE INLET PRESS
⊡ TURBINE EXIT PRESS
FLOW RATE (LB/SEC)
20
10
0
× MERCURY FLOW TO TURB
○ MERCURY FLOW TO BLR
0
50
100
150
200
250
TIME AFTER MERCURY ENTERS BOILER (SEC)
COMPUTER RUN C146

Figure 23

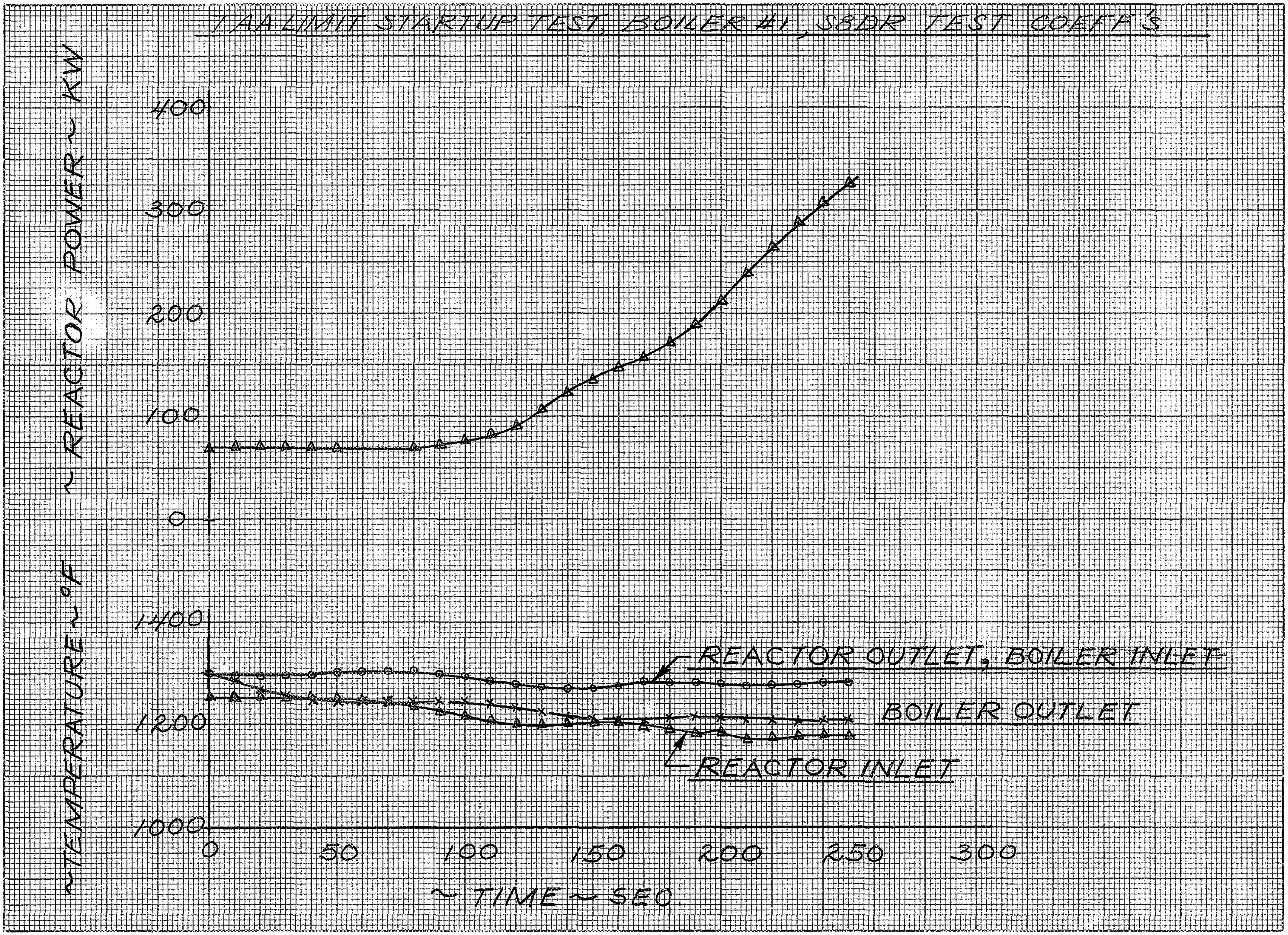

TAA LIMIT STARTUP TEST, BOILER #1, SBDR TEST COEFF'S
~ REACTOR POWER ~ KW
400
300
200
100
0
~TEMPERATURE ~ °F
1400
1200
1000
REACTOR OUTLET, BOILER INLET
BOILER OUTLET
REACTOR INLET
0
50
100
150
200
250
300
~ TIME ~ SEC

Figure 24

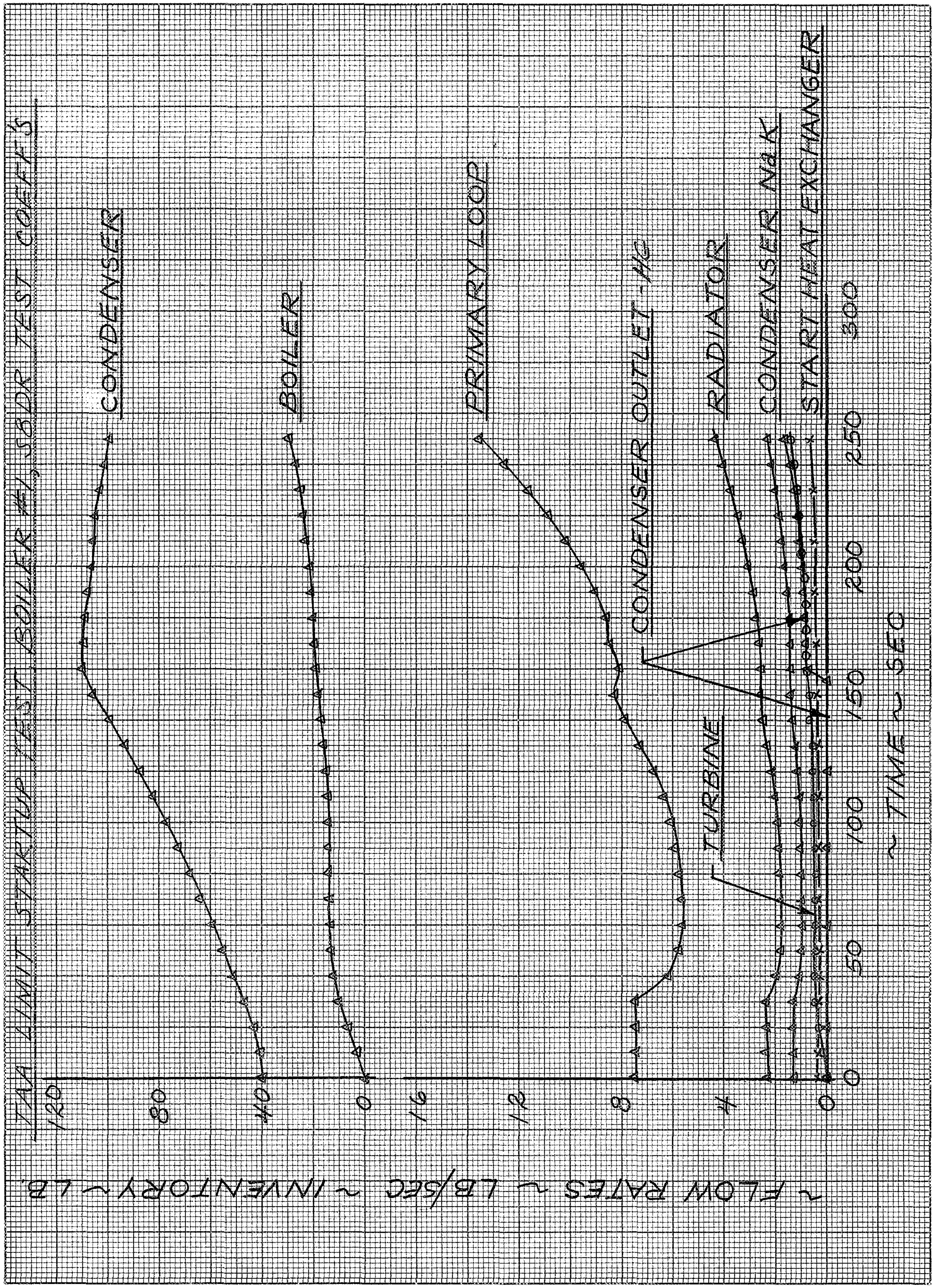

TAA LIMIT STARTUP TEST BOILER #1, SSDR TEST COEFF'S
CONDENSER
BOILER
PRIMARY LOOP
CONDENSER OUTLET - HG
RADIATOR
CONDENSER NaK
START HEAT EXCHANGER
TURBINE
120
80
40
0
16
12
8
4
0
0
50
100
150
200
250
300
~ TIME ~ SEC
~ FLOW RATES ~ LB/SEC ~ INVENTORY ~ LB.

Figure 25

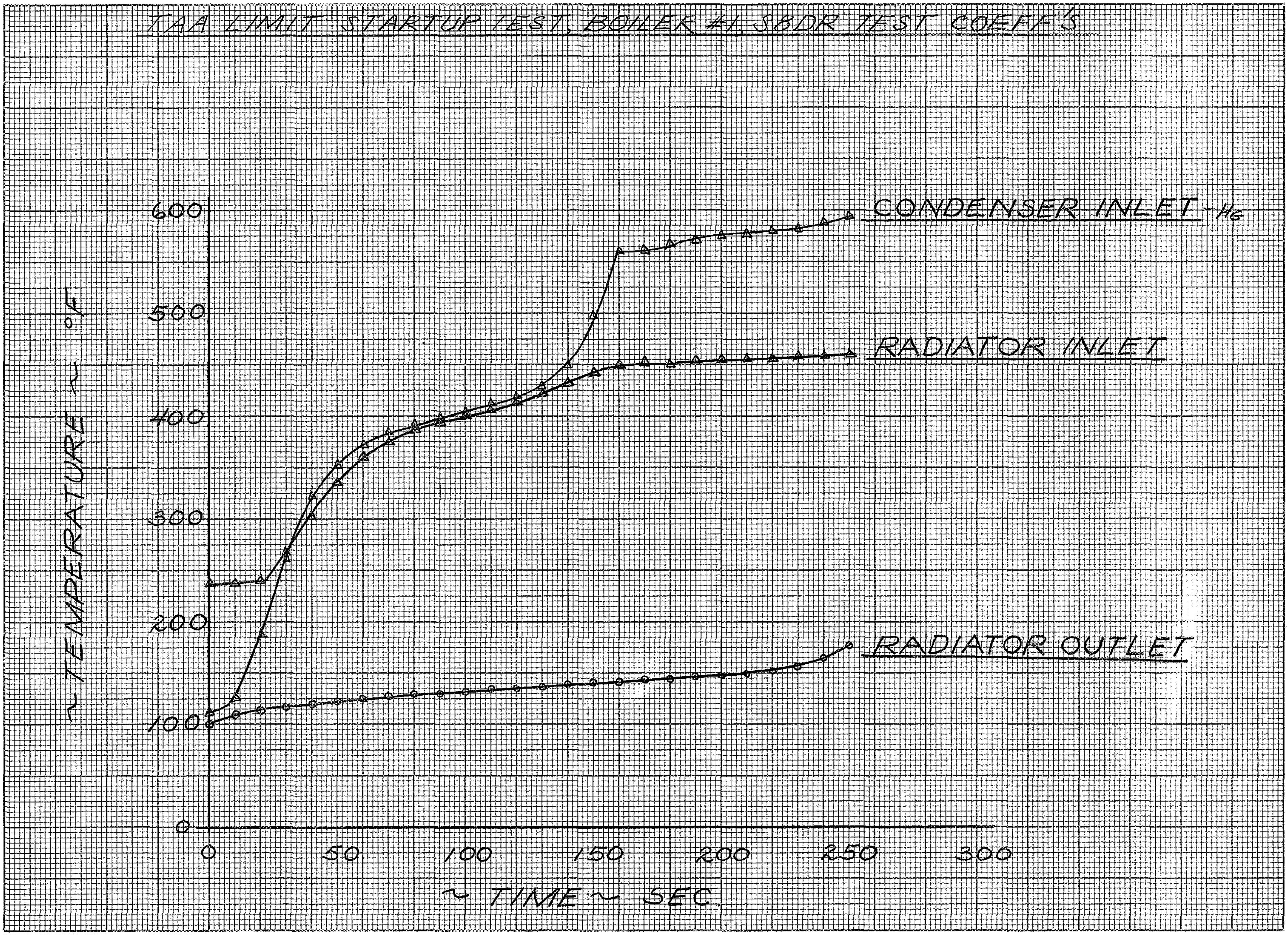

TAA LIMIT STARTUP TEST, BOILER #1, S8DR TEST COEFF'S

Figure 26

TAA LIMIT TEST
S8DR TEST COEFF's
(BOILER #1)

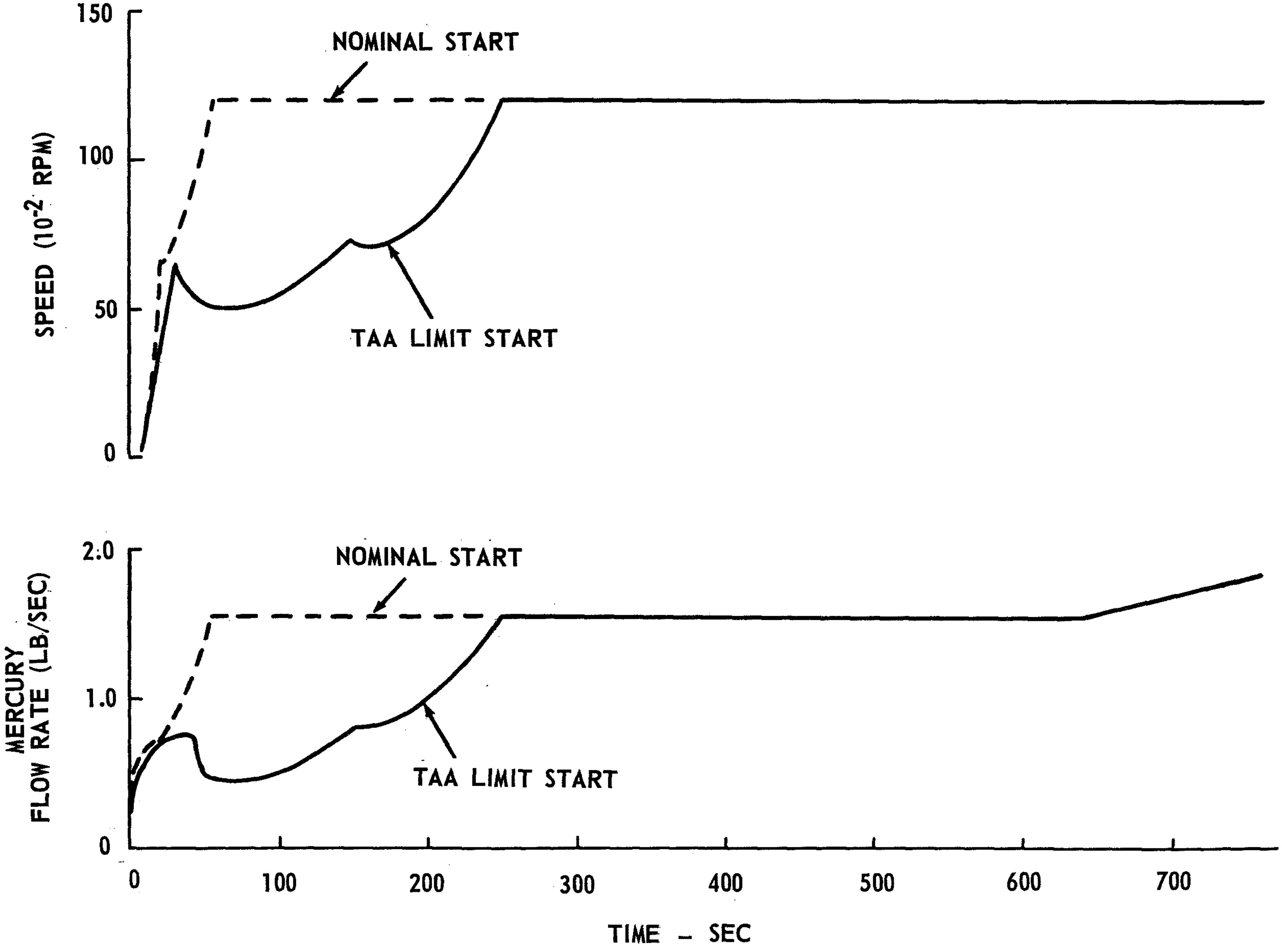


Figure 27

1069-NF-1255

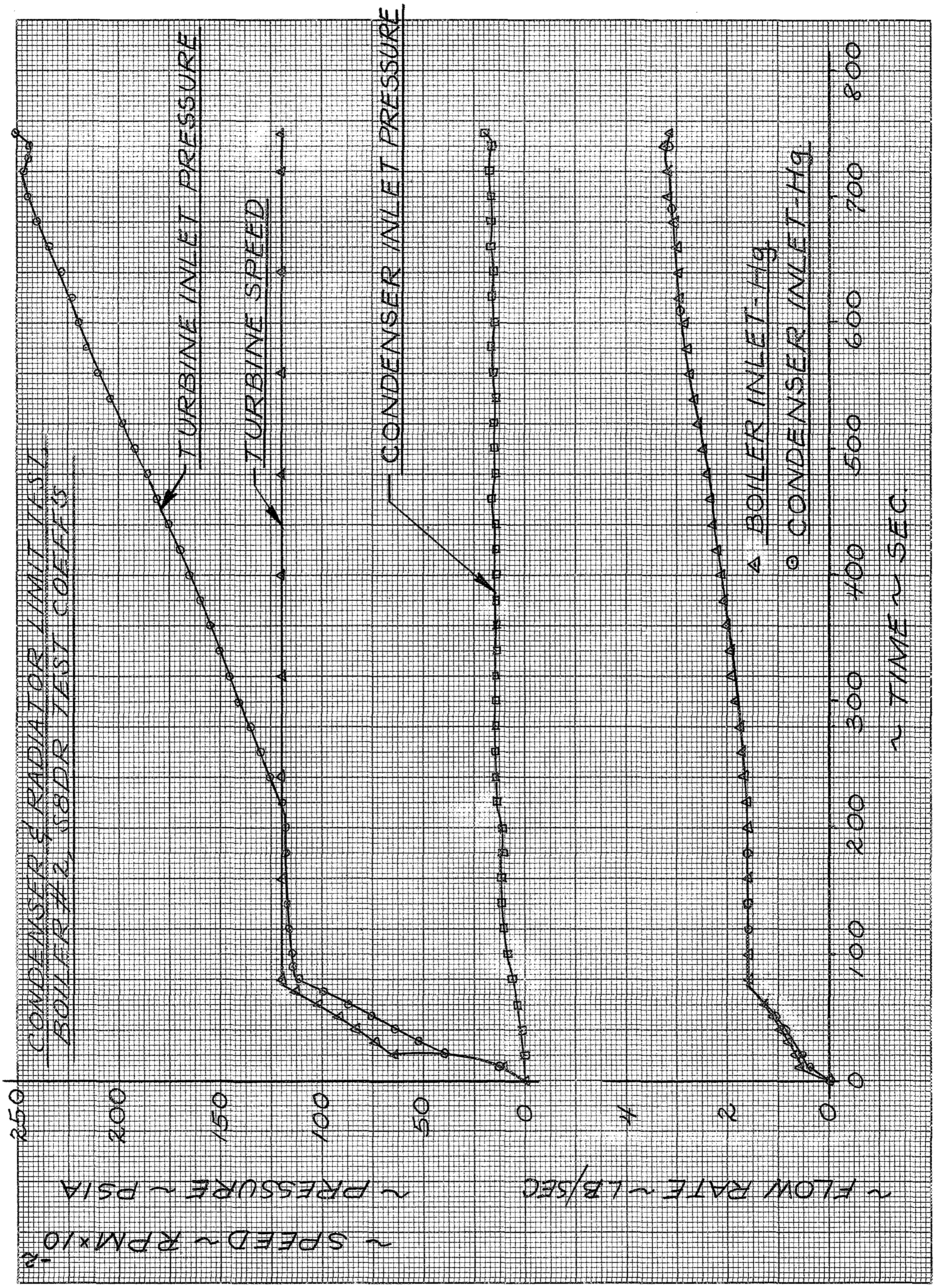


Figure 28

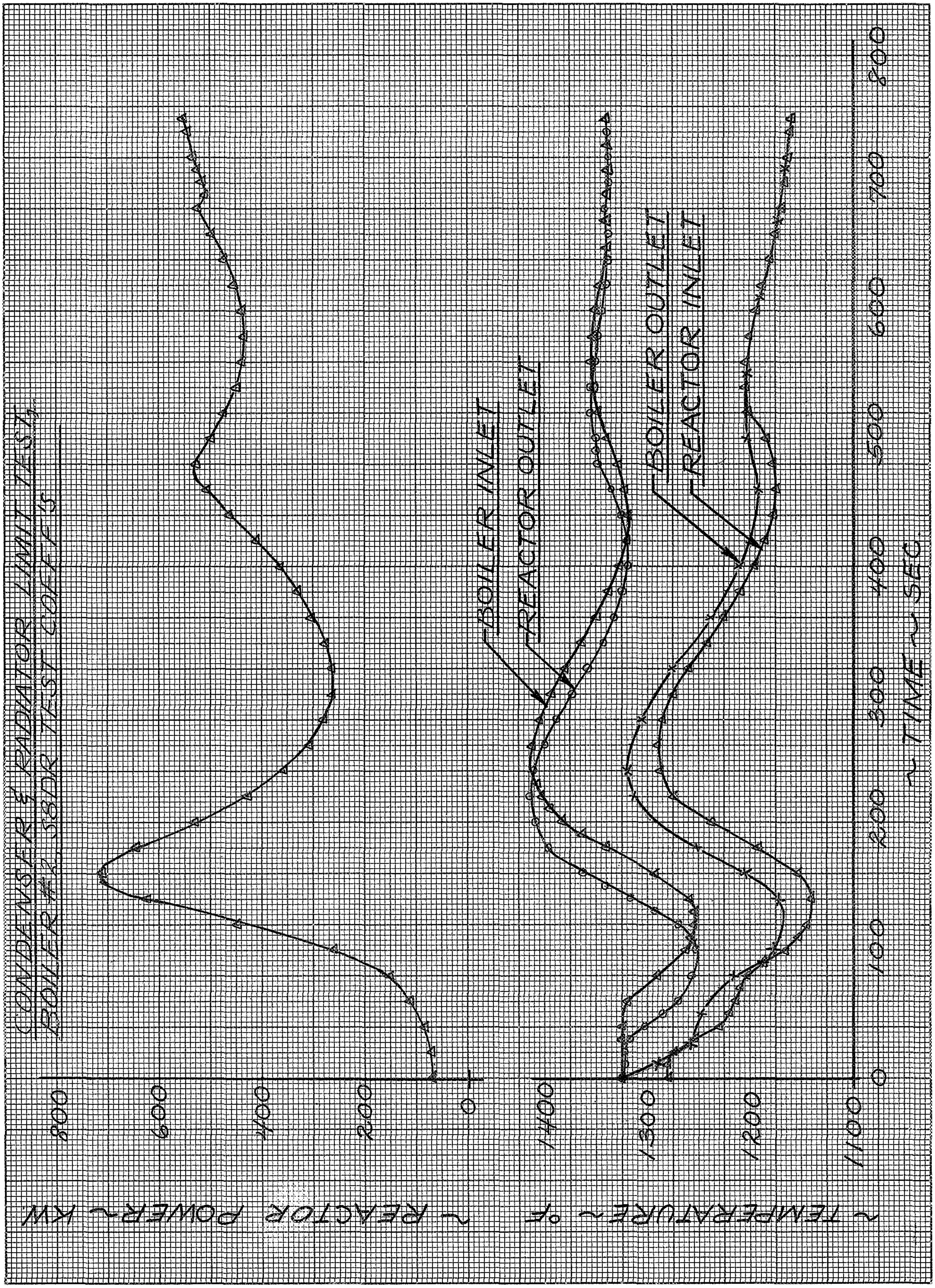

CONDENSER & RADIATOR LIMIT TEST,
BOILER #2, SBDR TEST COEFF'S
~ REACTOR POWER ~ KW
0
200
400
600
800
~ TEMPERATURE ~ °F
1100
1200
1300
1400
BOILER INLET
REACTOR OUTLET
BOILER OUTLET
REACTOR INLET
0
100
200
300
400
500
600
700
800
~ TIME ~ SEC

Figure 29

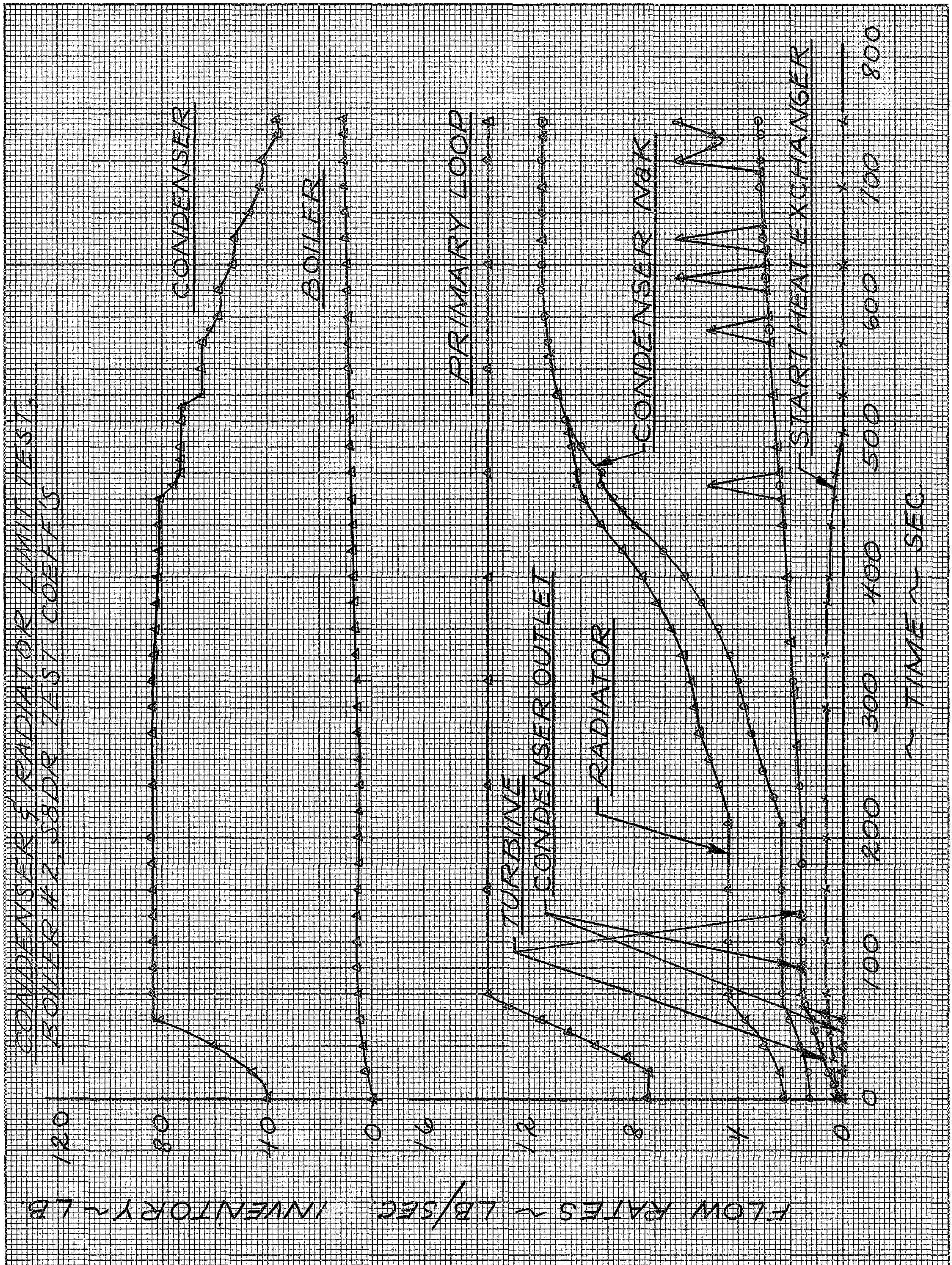

CONDENSER & RADIATOR LIMIT TEST.
BOILER #2, 58DR TEST COEFF'S
CONDENSER
BOILER
PRIMARY LOOP
TURBINE
CONDENSER OUTLET
RADIATOR
CONDENSER NaK
START HEAT EXCHANGER
120
80
40
0
16
12
8
4
0
0
100
200
300
400
500
600
700
800
~ TIME ~ SEC.
FLOW RATES ~ LB/SEC. INVENTORY ~ LB.

Figure 30

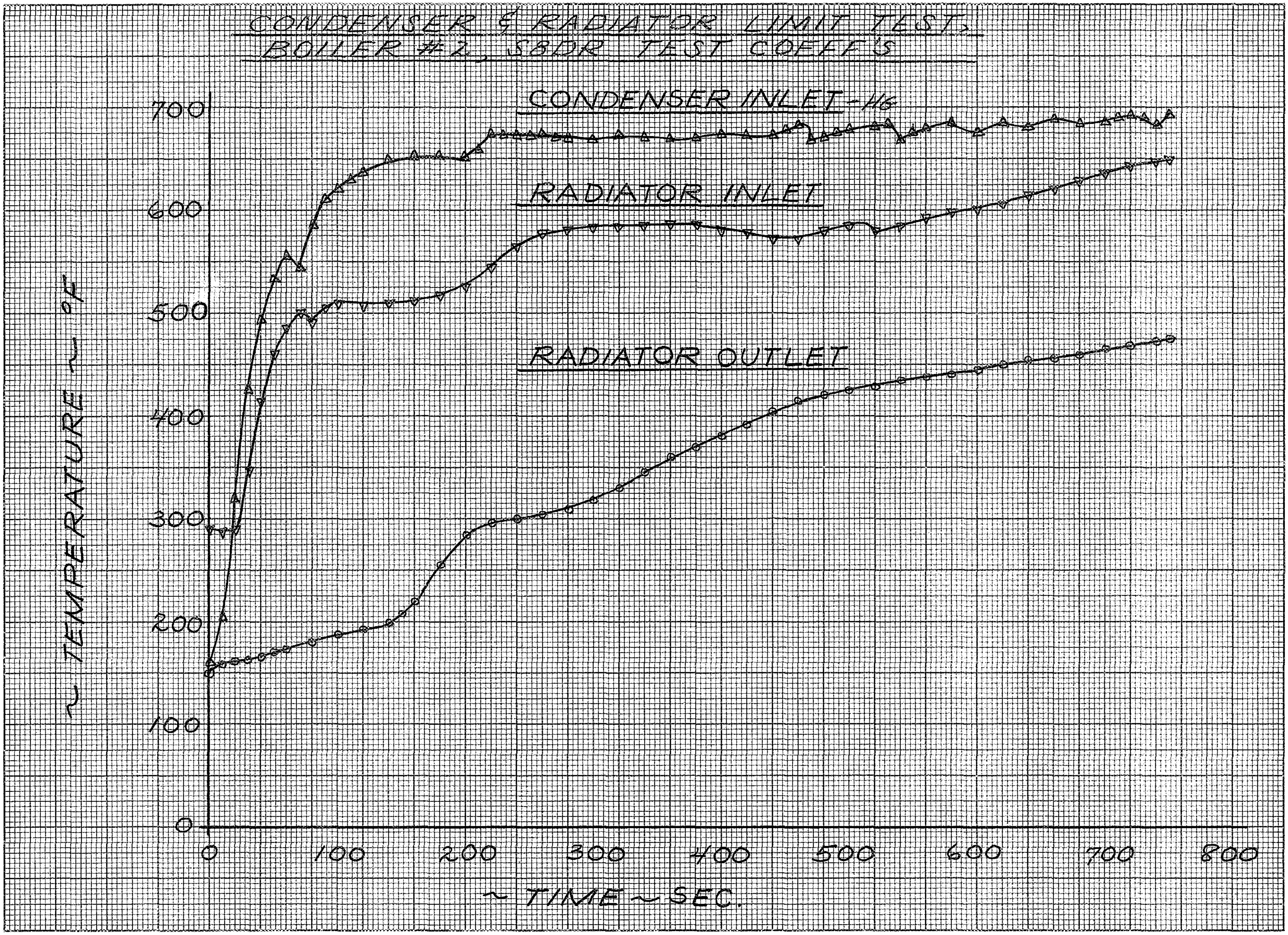

CONDENSER & RADIATOR LIMIT TEST,
BOILER #2, SBDR TEST COEFF'S
CONDENSER INLET-Hg
RADIATOR INLET
RADIATOR OUTLET
~ TEMPERATURE ~ °F
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
~ TIME ~ SEC.

Figure 31

CONDENSER AND RADIATOR LIMIT TEST

S8DR TEST COEFF's (BOILER #2)

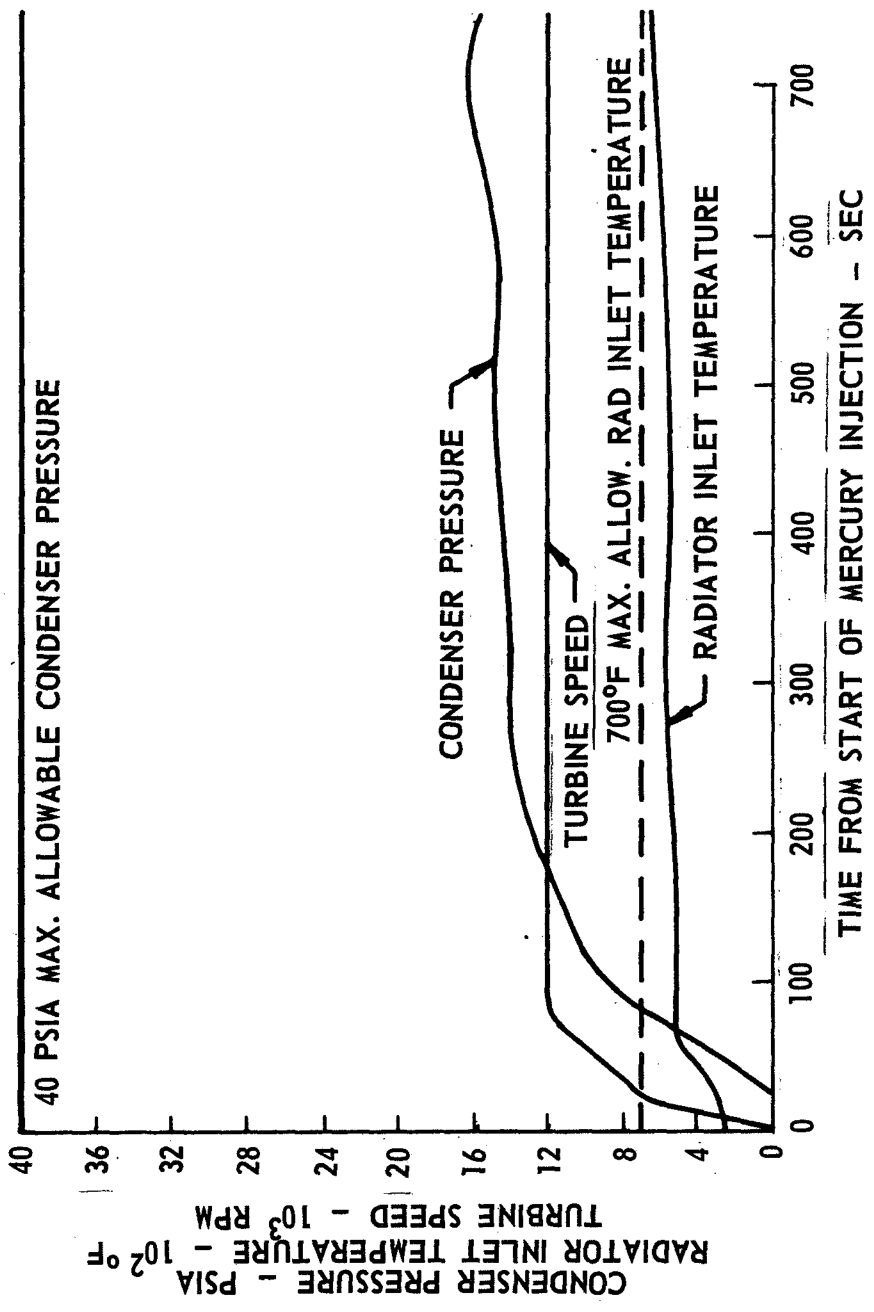


Figure 32