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POTASSIUM CORROSION TEST LOOP DEVELOPMENT

Quarterly Progress Report No. 9

For Quarter Ending October 15, 1965

EDITED BY E. E. HOFFMAN

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SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI, OHIO 45215

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POTASSIUM CORROSION TEST LOOP DEVELOPMENT

QUARTERLY PROGRESS REPORT 9

Covering the Period

July 15, 1965 to October 15, 1965

Edited by

E. E. Hoffman

Project Manager

Approved by

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Lewis Research Center

Under Contract NAS 3-2547

February 21, 1966

Technical Management
NASA - Lewis Research Center
T. A. Moss and R. L. Davies

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

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POTASSIUM CORROSION TEST LOOP DEVELOPMENT

I INTRODUCTION

This report covers the period, from July 15, 1965 to October 15, 1965, of a program to develop a Prototype Corrosion Test Loop for the evaluation of refractory alloys in boiling and condensing potassium environments which simulate project space electric power systems. The prototype test consists of a two-loop Cb-1Zr facility; sodium will be heated by direct resistance in the primary loop and will be used in a heat exchanger to boil potassium in the secondary, corrosion test loop. Heat rejection for condensation in the secondary loop will be accomplished by radiation in a high-vacuum environment. The immediate corrosion test design conditions are shown below; it is expected that the temperature could be increased by about 400°F when testing is extended to include refractory alloys stronger than Cb-1Zr.

1. Boiling temperature, 1900°F
2. Superheat temperature, 2000°F
3. Condensing temperature, 1350°F
4. Subcooling temperature, 800°F
5. Mass flow rate, 20 to 40 lb/hr
6. Vapor velocity, 100 to 150 ft/sec
7. Average heat flux in the potassium boiler - 50,000 to 100,000 BTU/hr ft^2

The development program includes the construction and operation of three Cb-1Zr test loops, each of which are being used in a sequence of component evaluation and endurance testing. Loop I, a natural convection loop, has been operated for 1,000 hours with liquid sodium at a maximum temperature of 2260° to 2380°F to evaluate the electrical power vacuum feedthroughs, thermocouples, the method of attaching the electrodes, the electrical resistivity characteristics of the heater segment, and the use of thermal and electrical insulation. Loop II, a single-phase sodium, forced-circulation loop to evaluate the primary loop EM pump, a flowmeter, flow control and isolation valves, and pressure transducers has completed 2,650 hours of scheduled testing. This loop was operated at a maximum temperature of 2065°F and a pump inlet temperature of 1985°F. The Prototype Corrosion Test Loop, a two-loop system, includes a boiler, turbine simulator and condenser in addition to the above components. This facility will be used to develop and endurance test (5,000 hours) the components required to achieve stable operation at the corrosion test design conditions.

The quarterly progress reports issued for this program will summarize the status of the work with respect to design considerations, construction procedures, and test results. Detailed topical reports will also be issued to describe each test loop. Additional topical reports will be prepared to cover such areas as materials specification, purification of potassium and sodium, and inert gas purification and analyses.

The topical reports which have been issued on this program are listed below:

> Potassium Corrosion Test Loop Development Topical Report No. 1 - Purification and Analysis of Helium for the Welding Chamber by T. F. Lyon, NASA-CR-54168.
>
> Potassium Corrosion Test Loop Development Topical Report No. 3 - Material Specifications for Advanced Refractory Alloys by D. N. Miketta and R. G. Frank, NASA-CR-54761.

Additional topical reports are being prepared which cover material and process specifications, and the purification, analysis and handling of sodium and potassium for the various loop tests.

II SUMMARY OF PROGRESS

The Prototype Corrosion Loop reached the test design conditions on August 2, 1965, at 1500 after 100 hours of boiling and condensing operation at potassium boiler outlet temperatures in the range 1300°-1900°F.

As of October 15, 1965, 1,785 hours of stable operation have been completed. The system normally operates in an extremely stable manner with no detectable variations in potassium flow, pressure or temperatures in the two-phase potassium circuit. The stability achieved in the potassium circuit is attributed mainly to the pressure drop across the metering valve at the preheater inlet and to the wire wound plug section located in the first 12 inches of the boiler. Activation of the vapor nucleator located between the preheater and the boiler was not required to achieve stable loop operation.

Failure of a fuse in the potassium preheater power supply on 8-19-65 at 0500 caused the nucleate boiling region to move out of the 12-inch plug section and up the boiler. The resulting instabilities in the system persisted for approximately one hour until restoration of preheater power to the system returned the nucleate boiling region to the plug section and stable operation was resumed.

The pressure in the test chamber was 3.0×10^{-7} torr when the loop reached the test conditions, decreased to the 10^{-8} torr scale after 120 hours of operation and reached 2.7×10^{-8} torr after 1,785 hours of test operation. Argon and nitrogen/carbon monoxide have been the principal gaseous species of the chamber environment and after 1,785 hours of test operation comprise approximately 83% of the total indicated pressure. Argon instabilities in the getter-ion pump continue to cause momentary increases in the test chamber pressure. The argon flooding safety system which is activated by an increase in the chamber pressure was modified to avoid inadvertent test shutdown as a result of these argon releases from the ion pump.

Analysis of the performance of the loop indicates that the variations between the actual test conditions and the reference design test conditions are minor. No trends in either the performance of individual components or in overall operation which would indicate component degradation has been detected during loop operation. NASA has extended the period of Prototype Loop operation from the original 2,500 hours to 5,000 hours.

III PROGRAM STATUS

A. Prototype Corrosion Loop Operation

1. Test Start-up

The boiling and condensing operation of the Prototype Corrosion Loop was started on July 29, 1965, after the completion of the checkout of the loop control and safety circuits. The start-up procedure used was described in a previous progress report(1)*. The test loop had completed several weeks of outgassing with all liquid operation and was at the following test conditions at the start of the boiling and condensing operation:

Vacuum Tank Pressure - 1.8 x 10^{-7} torr

Primary (Sodium) Flow Rate - 3 gpm

Secondary (Potassium) Flow Rate - 0.3 gpm

Primary Sodium Temperature - 1000°-1050°F

Secondary Potassium Temperature - 270°-1000°F

The potassium loop was dumped by evacuating the surge tank and gravity draining the potassium into the surge tank. The metering valve was closed and the surge tank was pressurized with argon to 2.0 psia, forcing the liquid potassium out of the surge tank into the loop to the top of the condenser. The rise of the potassium was easily followed by temperature changes recorded by the condenser thermocouples.

The potassium fill procedure was designed to minimize the amount of liquid potassium carryover from the boiler to the test nozzles and specimens of the turbine simulator during the initial start-up and associated periods of loop instability. The test start-up plan called for a specific potassium inventory which would be pressurized into the secondary loop from the surge tank and then separated from the surplus potassium in the surge tank by means of the isolation valve. An alternate method of controlling the potassium inventory in the loop which was considered was adjustment of the argon pressure in the surge tank. The initial plan was to use the "isolation" approach because in some systems communication of a two-phase loop system with its associated surge tank has resulted in repetitive pressure, temperature, and liquid level oscillations in the system. It was demonstrated in the 100 KW loop(2) that oscillations of this type could be eliminated by closing the isolation valve and re-established by opening the isolation valve.

The potassium inventory selected for the loop was an amount sufficient to establish one liquid-vapor interface near the entrance to the boiler plug and the other interface 12 to 18 inches from the condenser exit. During the filling operation, the potassium was pressurized into the portion of the loop

*(1) = Reference

between the metering valve and the top of the condenser, and the proper inventory was determined by observing temperature changes as the potassium level rose in the condenser. Pressure sensing tests conducted after closing the isolation valve indicated that there was some leakage across the seat. Rather than risk over-torquing the valve, the decision was made to control the potassium inventory by adjustment of the surge tank pressure. The valve was torqued to a maximum of approximately five foot-pounds to dampen any oscillations which might arise during loop operation. This method of controlling the loop inventory has proven to be a completely satisfactory method of operation for the Prototype Loop as will be indicated in more detail later in this report. However this condition will be corrected in future loops and the inventory isolated from the surge tank.

Boiling operation was started by first increasing the temperature of the sodium circulating in the primary loop to 1300°F. The secondary EM pump was then turned on and a low flow of potassium was supplied to the boiler portion of the loop. The flow rate and primary temperature were gradually increased and then allowed to stabilize at a potassium vapor temperature of 1300°F and a sodium temperature of 1550°F. The outgassing rate increased considerably at this stage, and the titanium sublimation pumps were used to assist the getter-ion vacuum pumps in maintaining a 10^{-7} torr pressure level in the vacuum chamber.

During the next 96 hours, the loop temperature and potassium flow rate were gradually increased to the design operation condition. An analysis of the boiler performance at two times during the test start-up period is given in Section III.C. of this report.

The rate of increase of the test conditions was limited by the outgassing of the loop components. The titanium sublimation pumps were operated continuously during this period to maintain the pressure in the 10^{-7} torr range. The total chamber pressure and the partial pressure of the principal residual gases during this period when the test conditions were being approached is shown for the -80 to 0 test-hour period in Figure 1. Carbon dioxide (m/e-44)*, argon (m/e-40) and nitrogen/carbon monoxide (m/e-28) were the principal species present during this period. A total of approximately 600 hours of chamber bakeout preceded the initiation of test operation. Additional discussion of the total pressures of the individual species of the test chamber environment is covered later in this report.

Since significant adjustments were required to reach the design operating conditions, the interdependence of the flow rate, power level and pressure was evident during this period. The ability of the loop to return to a stable operating condition after each adjustment clearly demonstrated the intrinsic stability of the Prototype Corrosion Loop configuration. Low frequency fluctuations of the order of 2 psi or less were encountered during certain portions of the start-up period. Heating the vapor nucleator to a temperature 100° to 150°F above the boiler inlet temperature did not eliminate these minor fluctuations.

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*m/e (mass/charge).

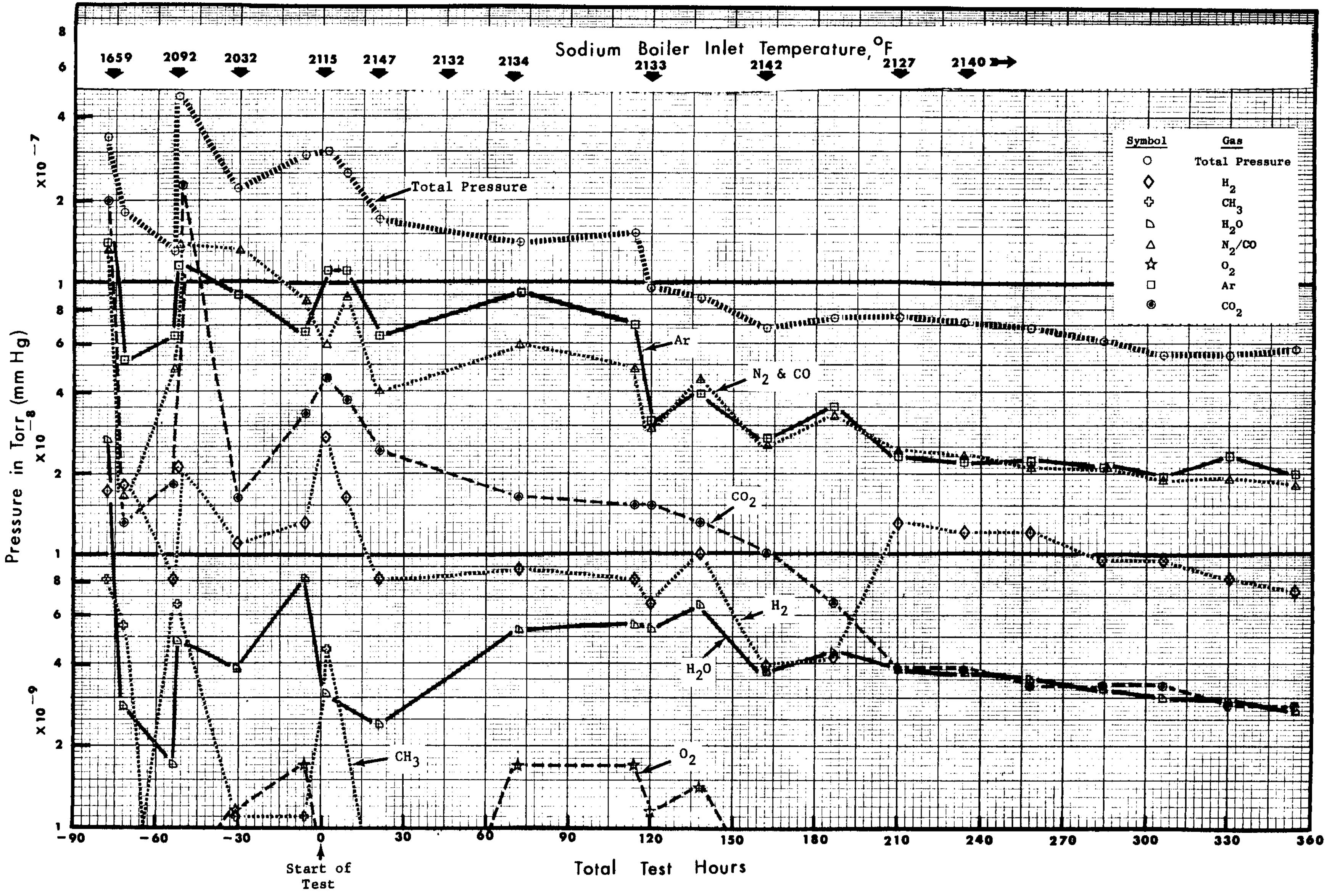

Figure 1. Chamber Pressures During Prototype Loop Operation.

The small oscillations are probably inherent in the boiling operation and not due to the common type of instability resulting from super-heated liquid flashing into vapor due to a lack of nucleating sites, as in pool boiling or capsule testing where the vapor nucleator has proven to be extremely useful(3).

Large perturbations in the flow, pressure and temperature which were recorded during certain periods of the start-up were found to be associated with shifting of the boiling zone. The shift in boiling zone was noted by observing the change in the sodium temperature profile in the boiler. Although stable loop operation was recorded with the boiling zone in the plug, the center portion and exit region of the 240-inch long boiler, the 12-inch long plug section located in the potassium entrance region appeared to be the most stable boiling location. The boiling zone could be shifted by adjusting the potassium flow rate or the power input to the sodium heater circuit. Increasing the boiler power would drive the boiling zone towards the boiler plug; increasing the potassium flow shifted the boiling zone away from the plug toward the exit. Boiling at the center of the boiler, although stable, was difficult to maintain for long periods of time. Typical changes in the temperature of the sodium heater fluid in the boiler which indicate the shifting in the potassium boiling zone referred to above are illustrated in Figure 2. The temperature differences between the three thermocouples shown indicate the relative amount of boiling of the potassium between these thermocouple locations. The lower portion of the graph illustrates the transition from the condition of boiling beyond the plug section (40°F drop in plug) to boiling in the plug section (140°F drop in plug). This transition was triggered by a slight decrease in potassium flow. The top portion of the graph in Figure 2 illustrates the movement of the boiling zone partially out of the plug section of the boiler. This movement of the boiling zone was caused by slight increases in the potassium flow rate. Slight increases in the sodium boiler inlet temperature or in the sodium flow rate in all cases caused rapid movement of the boiling region back to the plug section.

As mentioned earlier, each movement of the potassium boiling zone in the boiler was accompanied by substantial oscillations in the pressures, temperatures and flow in the potassium circuit. A typical example of the fluctuations in boiler outlet pressure which accompany movement of the boiling zone is given in Figure 3. At approximately 0040 hours, as indicated on the plots, a pressure fluctuation of approximately 20 psi was accompanied by an increase in the temperature difference between thermocouples P18 and P17 which signified movement of the boiling zone into the plug region. As may be noted in the pressure chart, fluctuations continued for approximately 35 minutes after the initial oscillation until the loop reached a steady state condition. Subsequent operation was completely stable with no pressure, temperature of flow oscillations. The design test conditions were reached at 1,500 hours on August 2, 1965. The test chamber, associated test equipment and an inset photograph of the sodium heater at temperature are shown in Figure 4.

Operation continued in a satisfactory manner until a vapor lock occurred in the potassium pump after 43 hours of test operation. This incident is described below in considerable detail because it indicates the response of the system to a major and abrupt change in test conditions.

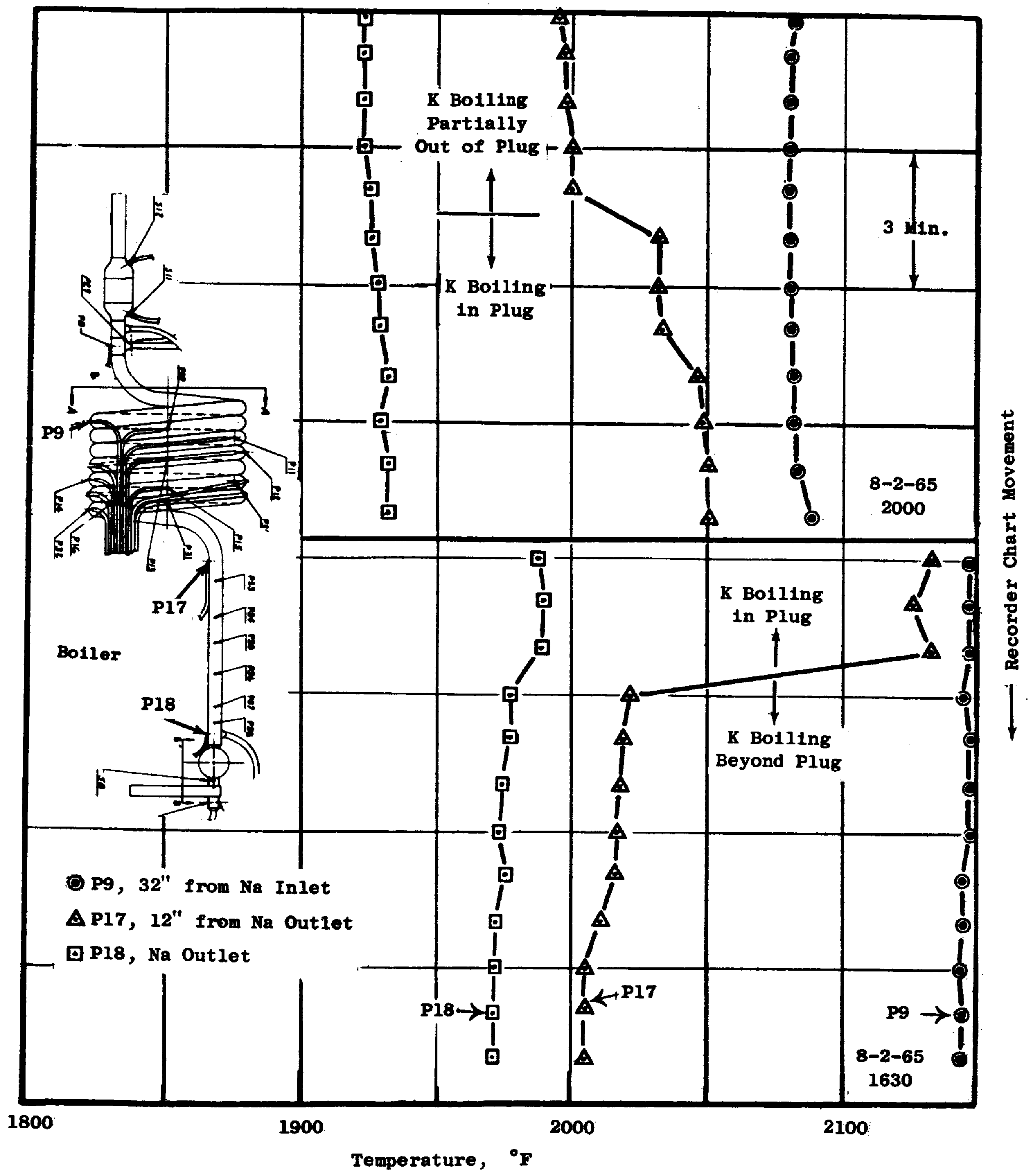

Figure 2. Sodium Temperature at Various Locations in the Prototype Loop Boiler Illustrating Movement of the Potassium Boiling Region During Test Start-up.

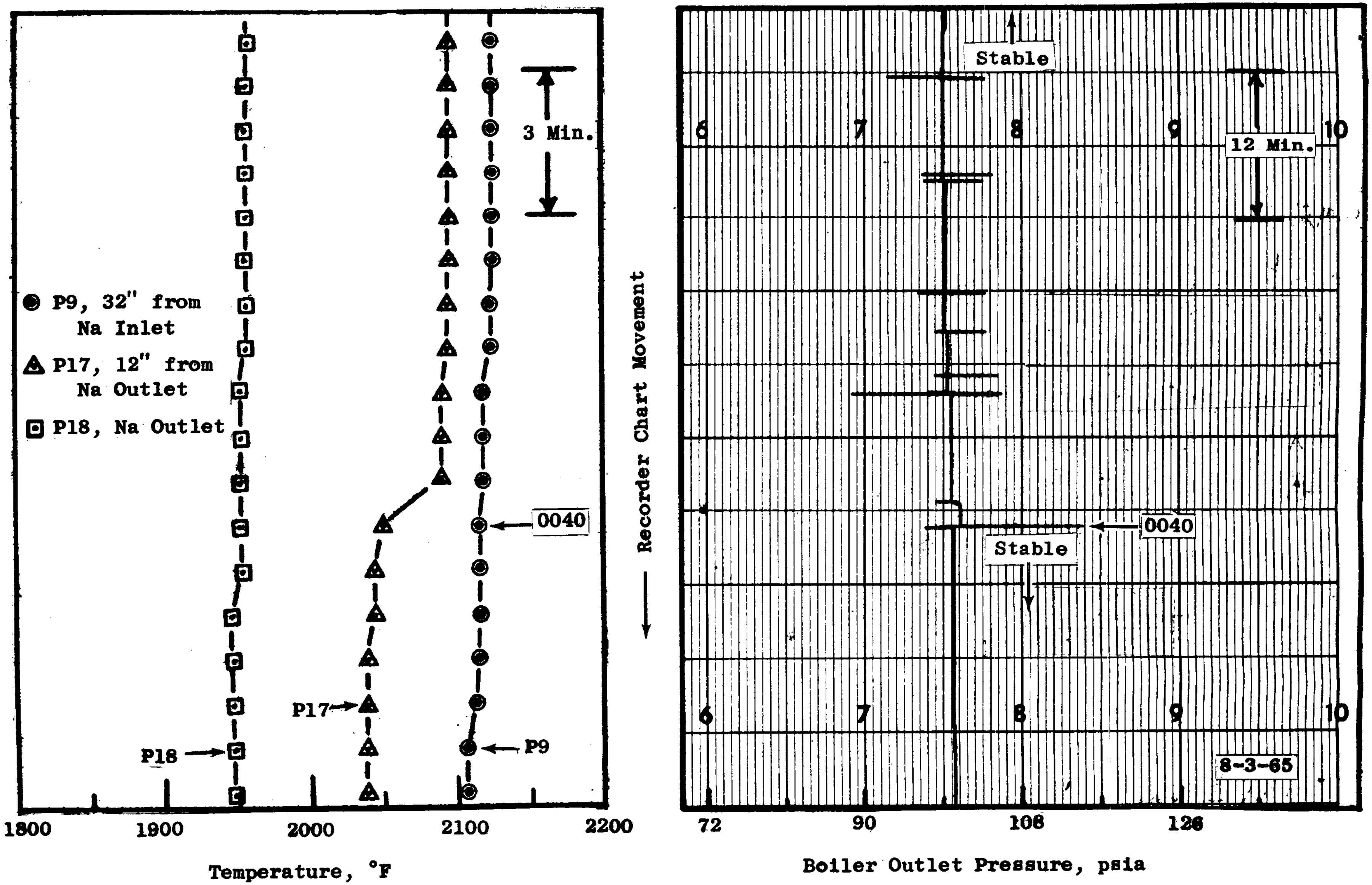

Figure 3. Boiler Temperature Changes and Boiler Outlet Pressure Fluctuations Associated with Movement of Potassium Boiling Region in the Prototype Loop.

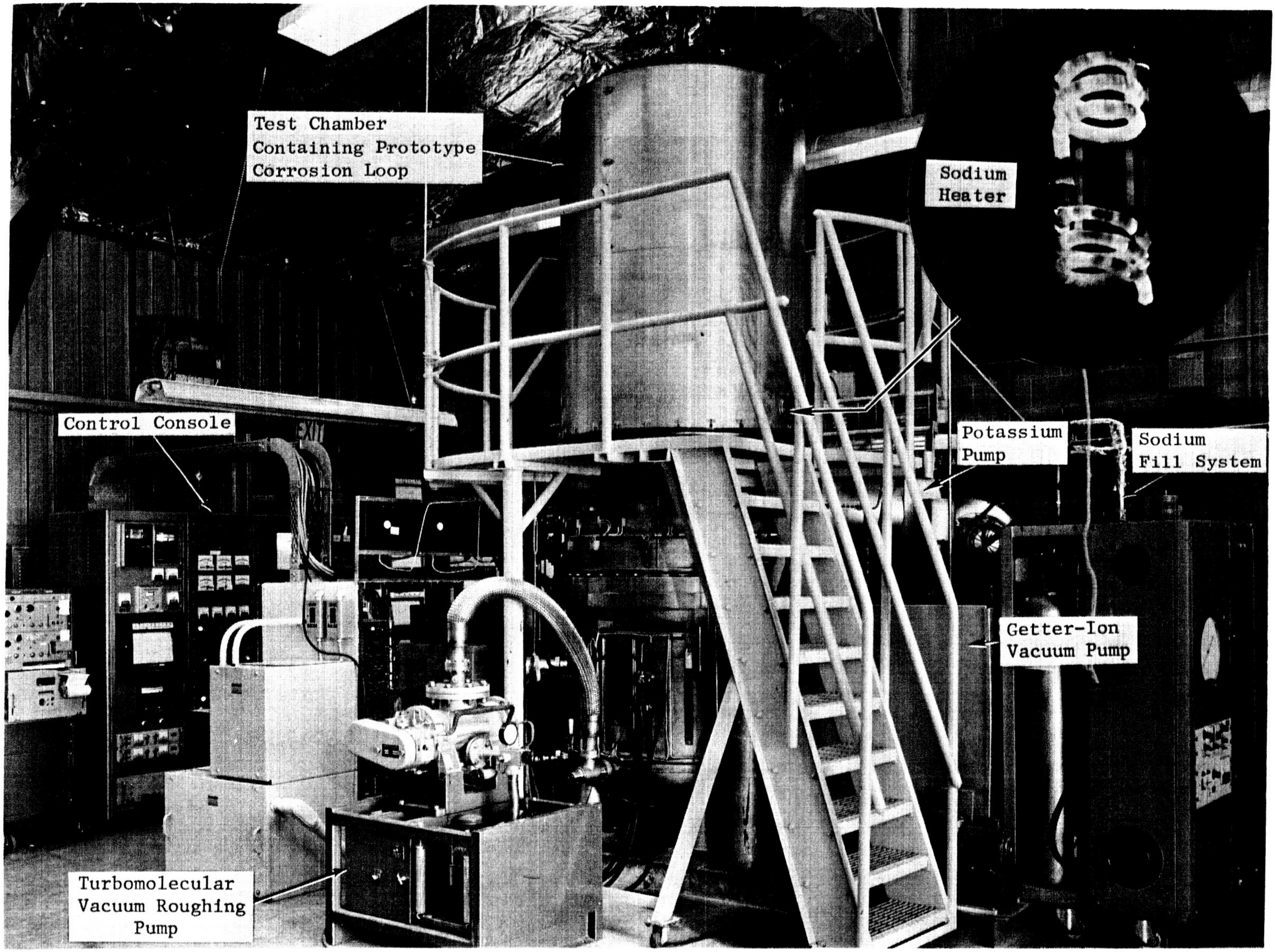

Figure 4. Prototype Corrosion Loop Test Chamber and Auxiliary Equipment With Inset Photograph of the Sodium Heater Coils as Viewed Through the Chamber Viewing Port. (Orig. C65082448)

2. Vapor Lock in the Potassium Pump

Following a series of small potassium pump power increases to boost the boiling temperature by increasing the boiler inlet pressure, the potassium flow dropped to zero within 30 seconds followed by severe flow oscillations which continued for eight minutes. All power to the loop was immediately turned off and a check of the instrument records showed that the potassium pump had vapor locked. The loop was restarted after the potassium temperature had dropped a few hundred degrees and the condenser pressure increased to 20 psia. The loop was back at the design operating conditions in less than one hour.

It was not apparent at first that the loss of potassium flow was due to a vapor locked pump since the pump inlet temperature was only 565°F, or more than 800°F below the saturation temperature. However, the pump outlet temperature was 1405°F indicating a 840°F temperature rise in the potassium in passing through the pump. The pump outlet pressure was approximately 160 psia and the pressure drop across the metering valve was approximately 60 psi at this time. The inlet and the outlet of the pump are separated, within the pump, by a thin wall cylinder and due to the relatively low flow in the potassium circuit, sufficient heat was transferred to the inlet side of the pump to raise the temperature of the inlet potassium above the saturation temperature. (A redesign of the potassium pump duct will be made to eliminate this potential problem in future test loops.) Having established the source of the trouble, the problem was easily eliminated for Prototype Loop operation by opening the metering valve slightly to reduce the pressure drop across the valve from the 60 psi previously employed to approximately 9 psi. This reduced the required pump outlet pressure which permitted a reduction in power to the pump and a decrease in the potassium temperature rise across the pump.

A description of the flow adjustments and their effect on the pump and boiler outlet temperature just prior to vapor locking the pump is given in Table I. The temperature fluctuations of the secondary loop during this period are shown in Figure 5. The fluctuations in the boiler outlet pressure in the potassium circuit when the vapor lock occurred and during the period when the loop was being restored to the test conditions are shown in Figure 6. Analysis of the loop performance following the vapor lock is summarized below.

Time, Seconds	
0-60	a) Vapor lock in pump; potassium flow dropped from 0.10 gpm to 0 gpm in 30 seconds.
	b) Temperature of vapor region thermocouples in condenser dropped sharply (1410° to 1190°F in 60 seconds).
	c) Potassium pump outlet temperature dropped from 1410° to 1250°F in 60 seconds.
	d) Some of the potassium in the loop was forced into the surge tank.

TABLE I. LOSS OF POTASSIUM FLOW RESULTING FROM POTASSIUM TEMPERATURE RISE AND RESULTANT VAPOR LOCKING OF EM PUMP

Time 8-4-65	Temperature, °F Condenser	Temperature, °F K Pump Outlet	Temperature, °F Boiler Outlet	Remarks*
0300	1393	1260	1950	K flow 0.100 gpm - K pump power (8.7 a/255 V) - pump outlet pressure - 153 psia
0815	1400	1260	1975	K pump power increased-pump outlet pressure approximately 154 psia
0830	1400	1275	1975	K pump power increased-pump outlet pressure approximately 156 psia
0845	1405	1310	1980	K pump power increased-pump outlet pressure approximately 157 psia
0920	1410	1330	1985	K pump power increased-pump outlet pressure approximately 158 psia
1015	1410	1370	1985	K pump power increased-pump outlet pressure approximately 160 psia
1030	1408	1376	1983	K flow 0.100 gpm - K pump power (10 a/303 V)-160 psia
1115	1410	1405	1990	No change, pump outlet pressure-160 psia
1130	K flow dropped from 0.10 gpm to 0 in 30 seconds and fluctuated between 0.05 and 0 gpm for approximately 8 minutes			

* No metering valve adjustments were made during this period.

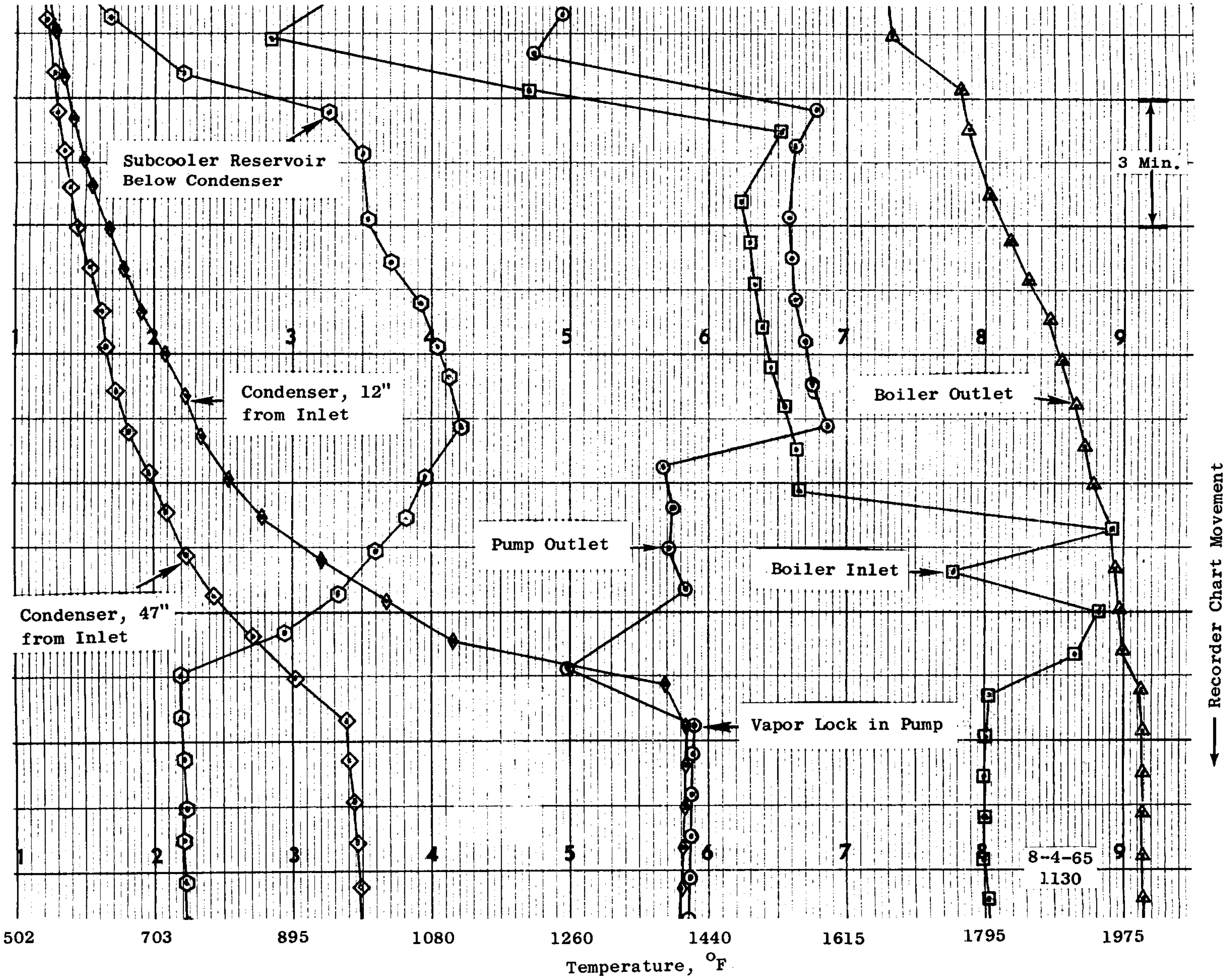

Figure 5. Temperature Fluctuations in Potassium Circuit During Period When Flow was Lost Due to Vapor Locking in the Pump.

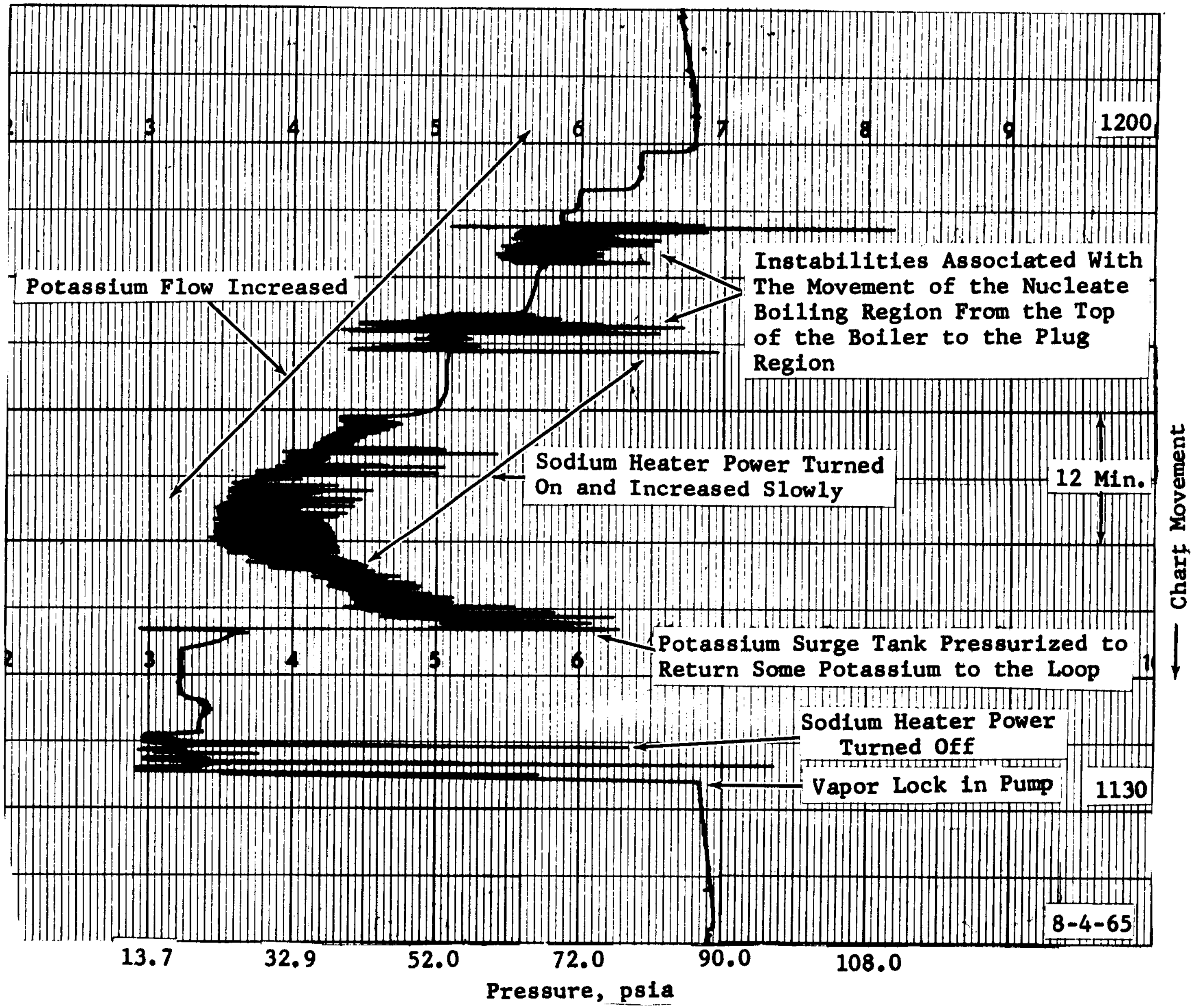

Figure 6. Fluctuations in Boiler Outlet Pressure Following Vapor Lock in Potassium Pump.

Time,
Seconds

60-120
a) Potassium temperature at boiler inlet rose from 1795°, where it had held constant during the 0-60 second period, to 1930°F.

b) Potassium pump outlet temperature rose drom 1260° to 1320°F after falling rapidly during the 0-60 second period.

c) Potassium temperature in subcooler reservoir rose rapidly from 740° to 850°F. Meanwhile, the temperatures in the condenser, both in the liquid region and vapor region, showed rapid decreases.

d) Potassium surge temperature rose.

The observations described above indicate that the increase in the EM power resulted in sufficient increases in the potassium temperature to cause a vapor lock at the pump inlet. This loss of flow caused the following things to occur:

1) Potassium was forced out of the pump by the increasing vapor pressure in the pump which caused subcooled liquid to flow back into the condenser to near the top of the condenser. This happened within 30 seconds of first indication of loss of potassium flow.

2) Potassium boiler inlet temperature rose rapidly starting 60 seconds after loss of flow resulting from reverse flow from boiler due both to the loss of pump head and the rapid rise in potassium temperature and pressure in the boiler associated with this low pump head condition.

3) Dumping of the potassium loop inventory into the surge tank.

By maintaining the pump outlet pressure below 150 psia, which is more than adequate for stable loop operation, the pump outlet temperature was easily maintained at 200°F less than the condenser temperature, thus avoiding the vapor lock problem.

3. Effect of the Metering Valve on Loop Stability

The effect of the pressure drop across the metering valve on the stability of the loop is best demonstrated by the potassium flow rate and boiler exit pressure recording shown in Figure 7. During the start-up and up to the time of the vapor locking of the pump described above, the metering valve was set at 20° from the fully closed position with a pressure drop across the valve of approximately 50 psi*. (Each 3° of rotation of the metering valve stem is equivalent to 0.001 inch of axial movement of the valve plug.) The loop operation was extremely stable with the valve in this position. After the pump vapor lock incident described above, the metering valve was opened from the 20° position to

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* The pressure drop across the valve is determined by subtracting the calculated pressure drop for the boiler (16 psi) from the total pressure drop across the metering valve and boiler as measured by slack diaphragm pressure transducers.

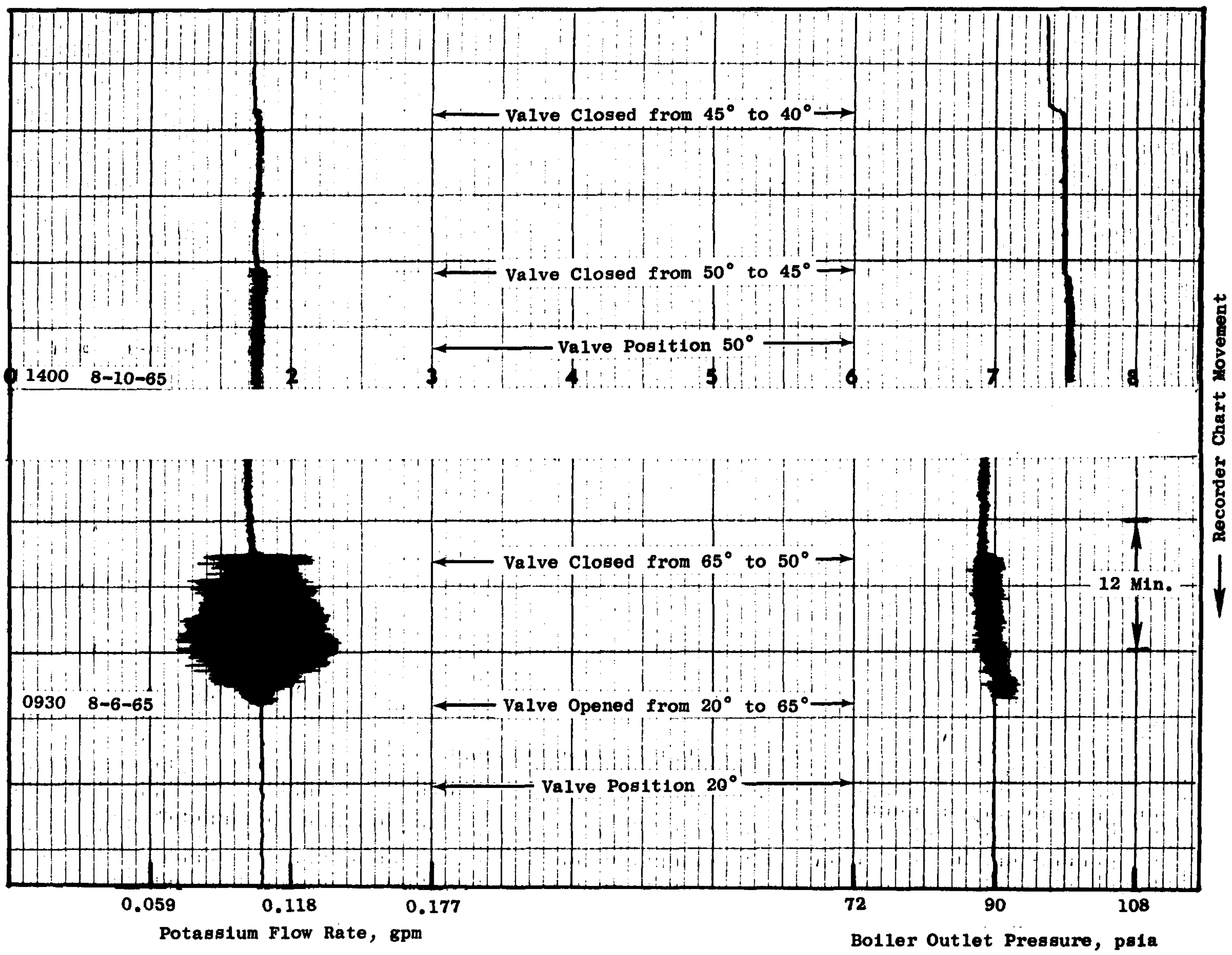

Figure 7. Effect of Metering Valve on the Potassium Flow Rate and Boiler Outlet Pressure of the Prototype Corrosion Loop.

65° open. This decreased the pressure drop across the valve to less than 4 psi. The flow became extremely unstable with high frequency flow oscillations of ± 40% of the 0.11 gpm potassium flow rate. The metering valve was then closed from 65° open to 50° open which increased the pressure drop across the metering valve to 7 psi with a decrease in the flow oscillations to less than ± 2% of the steady state flow rate. The test was continued at these conditions for the next 96 hours. At this time, the valve was closed from 50° to 40° in two 5° adjustments which increased the pressure drop across the valve to 9 psi. As shown in Figure 7, this final adjustment in the metering valve eliminated fluctuations in both the potassium flow and the boiler outlet pressure. The stressed diaphragm pressure transducer, which is located between the metering valve and the preheater inlet and is capable of sensing a 100 cps pressure oscillation, show a pressure fluctuation of less than ± 0.3 psi with the 9 psi pressure drop across the metering valve. The metering valve adjustments* described above clearly indicate the marked effect of metering valve pressure drop in obtaining the remarkable stability of operation of the Prototype Loop system.

4. Failure of Fuse in the Potassium Preheater Circuit

Loop operation continued in a stable and uneventful manner until 0500 hours on 8-19-65, when after 398 hours of test operation, a fuse in the preheater control circuit failed. This resulted in a complete loss of power to the preheater and a rapid drop in the temperature of the potassium at the boiler inlet. No apparent reason for the fuse failure could be determined and the circuit became operative with the replacement of the fuse and has functioned properly since the failure.

The observations of loop performance during the period of unstable operation following the preheater power failure caused by the defective fuse will be presented in some detail to again illustrate the response of the loop to a major change in test conditions. In Figure 8, the temperatures of several key regions in both the sodium and the potassium circuits are shown during the period following the preheater power failure. The potassium boiler inlet temperature dropped rapidly following the preheater failure and substantial oscillations of sodium boiler temperatures and potassium condenser temperatures were observed. The temperatures of these regions during the period following restoration of preheater power are given in Figure 9. The most substantial temperature fluctuations were those observed in the potassium circuit at the boiler inlet and in the lower portion of the condenser due to movement of the liquid-vapor interface in this component.

The fluctuation in the potassium boiler outlet pressure and potassium flow associated with the shifting of the nucleate boiling region out of the plug section are illustrated in Figure 10. Three minutes after the loss of preheater

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* The plug of the metering valve will be redesigned for use in the tantalum alloy loop (Corrosion Loop I, NASA Contract NAS 3-6474) to obtain pressure drop characteristics which are less sensitive to minor changes in valve stem rotation than those of the current design.

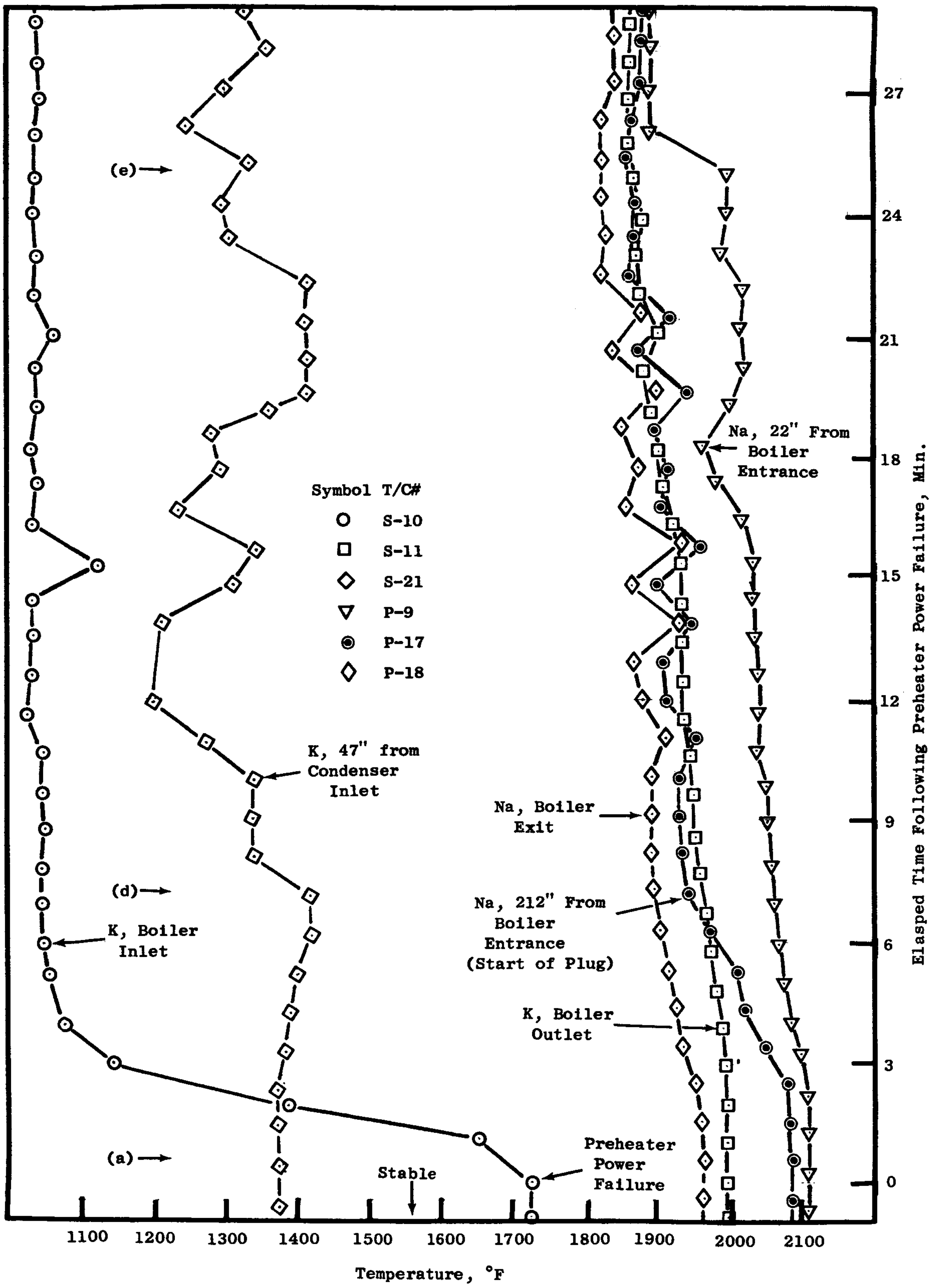


Figure 8. Temperature Fluctuations in the Sodium and Potassium Circuits of the Prototype Loop Following Failure of the Preheater Power (8-19-65, 0500).

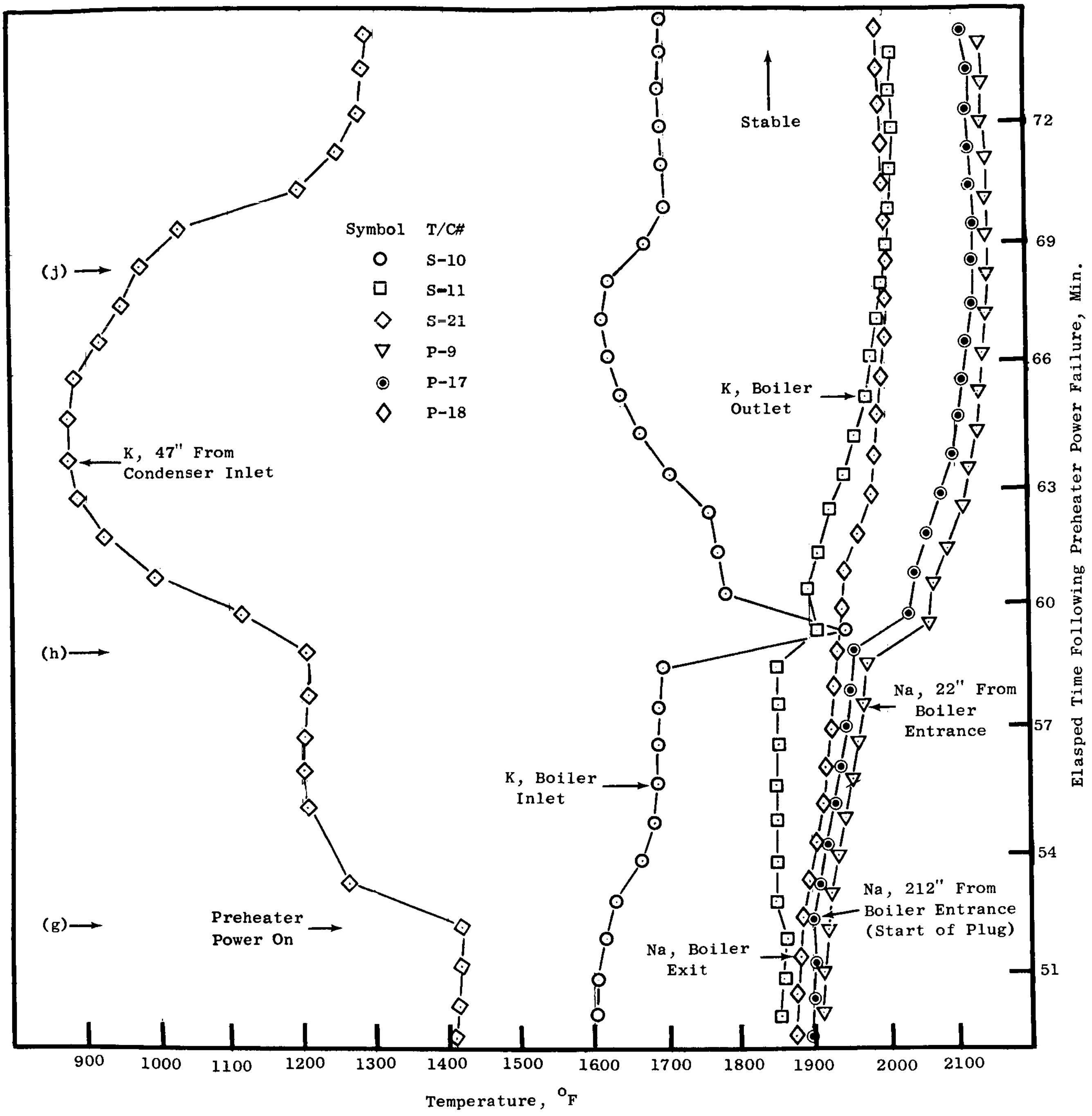


Figure 9. Temperature Fluctuations in the Sodium and Potassium Circuits During the Period When the Prototype Loop was Being Returned to Design Conditions Following Failure of Preheater Power (8-19-65, 0600).

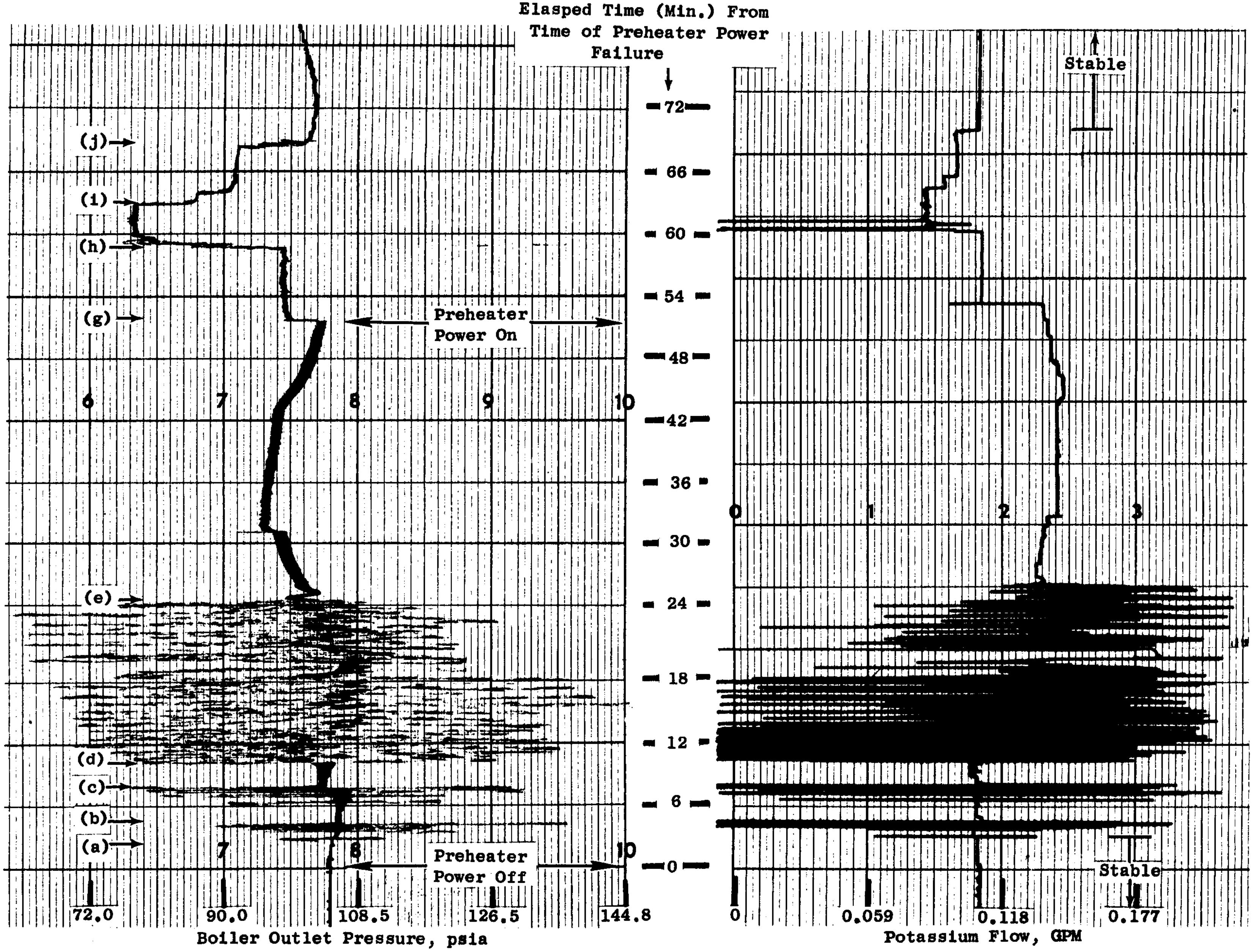


Figure 10. Fluctuations in Potassium Pressure and Flow in the Prototype Loop Following the Loss of Preheater Power in the Potassium Circuit (8-19-65, 0500).

power, the nucleate boiling region moved out of the plug and the period of substantial oscillations of pressure and flow began. As may be noted in Figure 10 during the time period from (a) to (e), there were several brief periods of improved stability and these are attributed to the temporary pauses in the movement of the nucleate boiling region along the boiler length. At the point designated (e), the nucleate boiling region had moved to near the potassium boiler exit and a period of substantially improved stability began as indicated by both the pressure and flow charts. At point (g), the preheater power was restored and at point (h) the nucleate boiling region moved rapidly from the boiler outlet region to the plug region at the boiler inlet. The sodium temperature drop across the 12-inch plug increased from 20° to 100°F in approximately one minute when this occurred, indicating that the vapor quality also increased to approximately 70% at the plug exit, which is the steady state condition.

During normal loop operation essentially no fluctuations of pressure, flow or temperatures were detected in the loop and the period of unstable operation associated with the preheater power failure afforded an excellent opportunity to observe the response of the fast response stressed diaphragm pressure transducer. This transducer is located between the metering valve and the preheater in the potassium circuit. The Sanborn chart for the period following the preheater power failure is shown in Figure 11. Although zero drift of this transducer prevents its use in measuring absolute pressure, it performs its primary function, the detection of high frequency pressure fluctuations, in a completely satisfactory manner. The shifts in the nucleate boiling region and the associated instabilities indicated in Figures 8, 9 and 10 are very evident in Figure 11. Based on the loop performance during the start-up period, the stable boiling condition resulting from boiling primarily in the plug section could also be achieved by increasing the sodium heater power input without the use of the preheater. However, this would require the operation of the sodium heater at an outlet temperature in the 2150°-2200°F temperature range, rather than 2125°-2150°F as required when the preheater is used.

5. Changes in Pressure Drop in the Potassium Circuit

In general, the test conditions have remained quite constant, with no significant changes in the pressure drop across the turbine simulator stages which might be indicative of nozzle throat erosion, corrosion, or plugging. During the first 1,785 hours of the test, small changes have been detected in the pressure drop between the metering valve inlet and the boiler outlet as measured by the slack diaphragm pressure transducers at these locations. The ratio of this pressure drop to the metering valve inlet (pump outlet) pressure during the 1,785 hours of loop operation is plotted in Figure 12. Several observations can be made regarding this plot. The relatively large effect of rather small adjustments of the metering valve is apparent, especially the 30° opening adjustment after 90 hours of operation. The effect of several of these metering valve adjustments on system stability was discussed earlier (see Figure 7) in this report. It may also be noted that the pressure drop ratio increased slightly after approximately 400 hours of operation as a result of the brief period of unstable operation resulting from the failure of the preheater power described

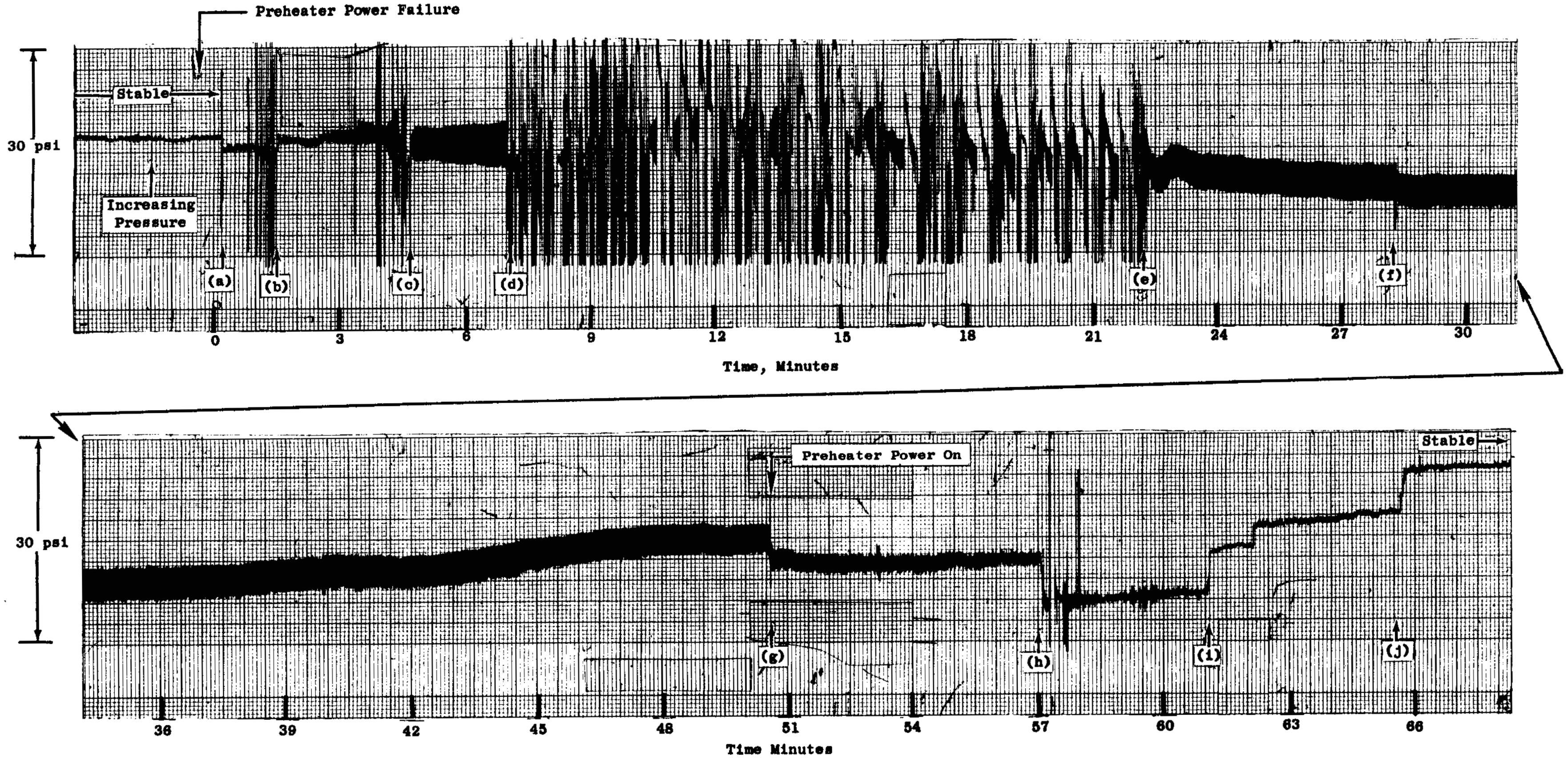
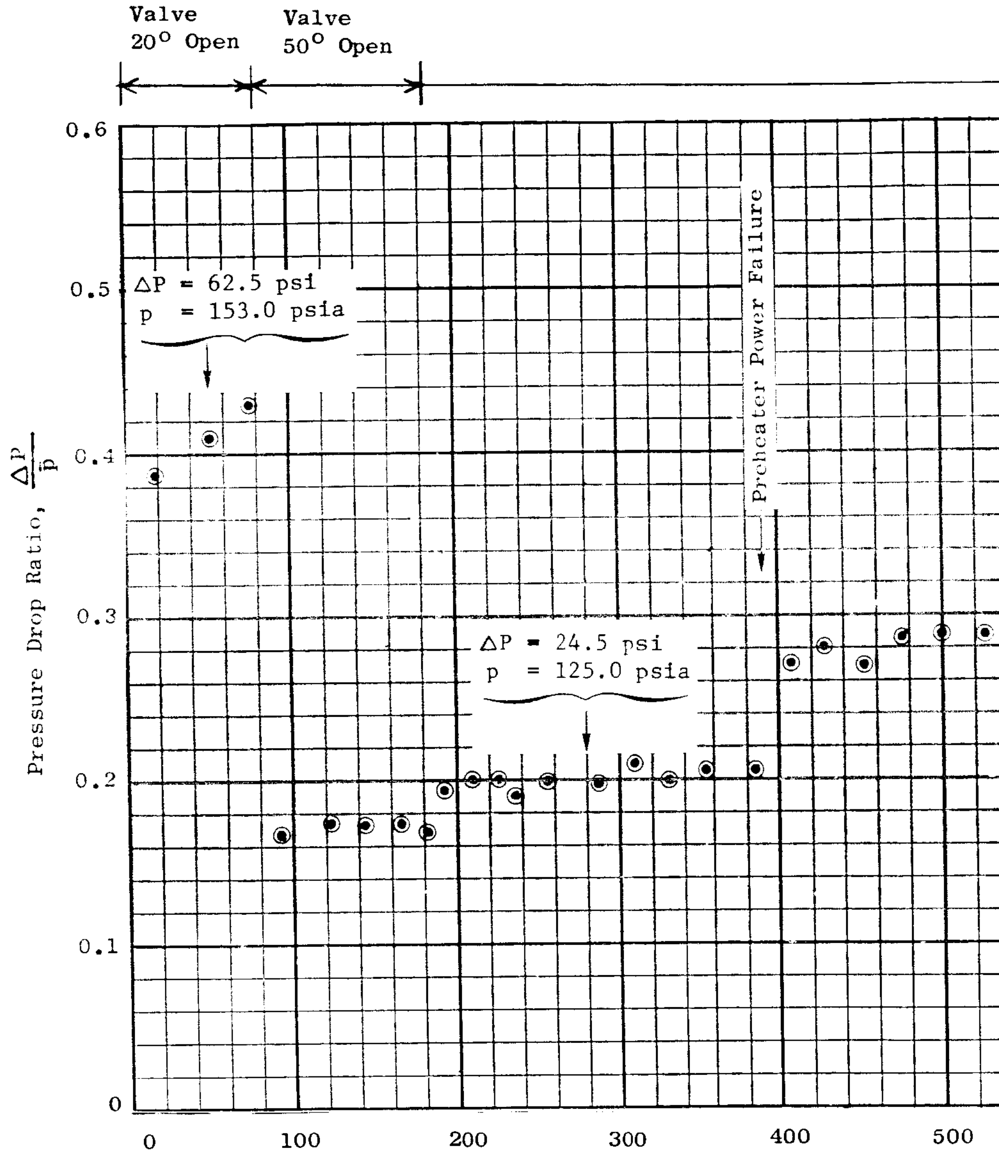


Figure 11. Fluctuations in Prototype Loop Potassium Boiler Inlet Pressure Recorded by the Fast Response Stressed Diaphragm Pressure Transducer Following Failure of Preheater Power (8-19-65, 0500 - 0600).


Valve 20° Open
Valve 50° Open
ΔP = 62.5 psi
p = 153.0 psia
ΔP = 24.5 psi
p = 125.0 psia
Preheater Power Failure
Pressure Drop Ratio, $\frac{\Delta P}{p}$
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500

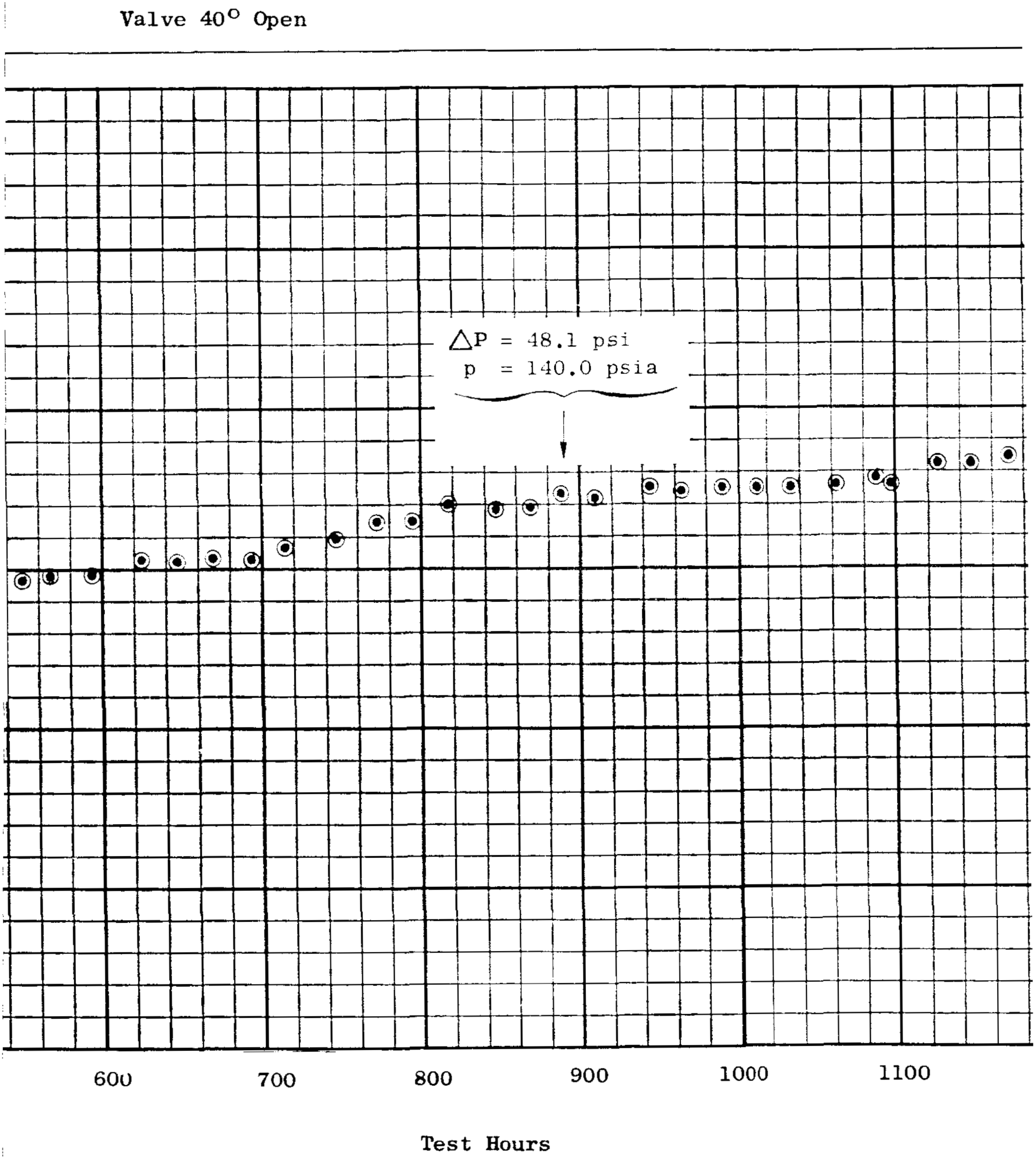


Figure 12. Change in Pressure Drop Ratio in the Prototype Cor
Loop as a Function of Time.

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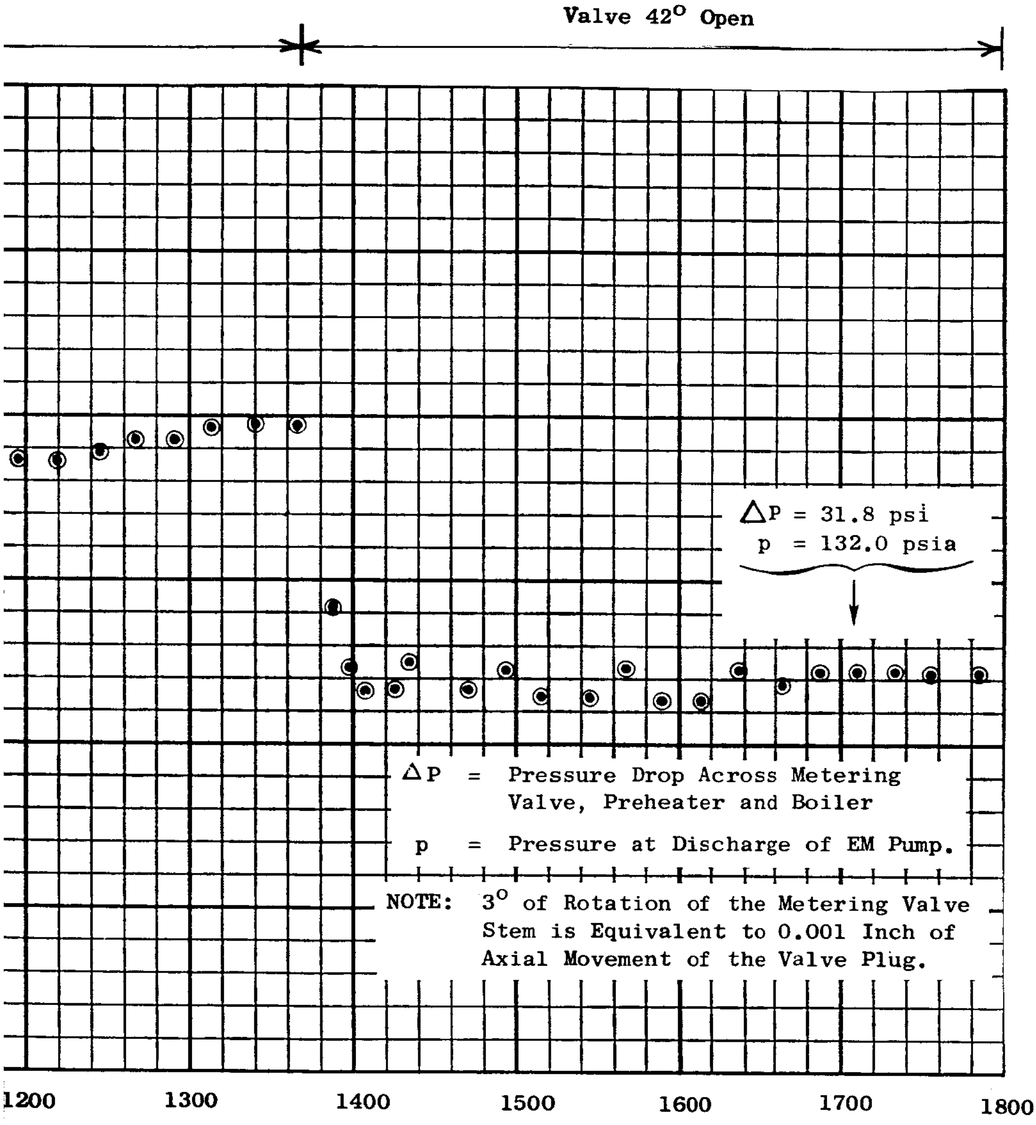


NOTE: 3° of Rotation of the Metering Valve Stem is Equivalent to 0.001 Inch of Axial Movement of the Valve Plug.

rosion

3

in the previous section of this report. During the period between 190 hours and 1,386 hours, no adjustments of the metering valve were made. However, during this period, the pressure drop ratio showed a continuous increase. It is tentatively postulated that minute amounts of solid particles, possible mass transfer particles, reduced the flow area between the Mo-TZM alloy valve plug and Cb-1Zr alloy valve seat. The flow area in the restricted region between the plug and seat, with the valve 40° open, is an annulus with an area of approximately 0.002 in^2 (4) and even quite small solid particles could have an appreciable effect on the potassium flow and pressure drop. For this reason the potassium circuit of the Prototype Loop may be particularly responsive to extremely small amounts of particulate matter in the system. However, as described in the following paragraph, this trend has not continued during subsequent operation.

After 1,386 hours of test operation, the metering valve was opened from 40° to 42° open and the marked effect on the pressure drop ratio is readily apparent. It is tentatively assumed that particulate material was flushed out of the valve at this time since the pressure drop ratio conditions which resulted were very nearly the conditions that existed when the valve was first put in the 40° open position after 190 hours of operation. In the period between 1,386 hours and 1,785 hours, no significant changes in the pressure drop ratio have been detected and this would suggest that a temperature gradient mass transfer process may not have been responsible for the change in conditions noted during the period when the valve was 40° open. More definite information regarding the factors responsible for the apparent change in the pressure drop ratio may be obtained during the evaluation following 5,000 hours of test operation.

It should be pointed out that although the pressure drop is measured between the metering valve inlet and the boiler outlet, the bulk of the pressure drop change is occurring in the metering valve. Although the absolute pressure at the metering valve outlet can not be determined because of the shift of the zero of the fast response transducer located in this area, the fact that the pump outlet pressure had to be increased to maintain a constant signal from the fast response transducer indicates that the pressure drop increase was due primarily to restriction of flow through the metering valve.

6. Fluctuations in the Electrical Power Supply to the Prototype Loop System

During test operation, minor fluctuations in the power supply to the test system necessitate minor adjustments in the heater power. The adjustments which are less than 0.5% of the total power are required approximately ten times per day to hold the sodium boiler inlet temperature variations to less than ± 5°F. Automatic temperature control equipment was incorporated into the power supply systems to the two circuits of the loop; however, during test start-up it became quite apparent that manual adjustment of the heater and EM pump power yielded more satisfactory loop performance. On several occasions during the past month, the 450 volt supply to the test system dropped approximately 5% when a large motor in an adjacent test facility was turned on. Immediate drops in the flow, pressure and temperature in the potassium circuit and in the temperature of the sodium circuit occurred when the power drop occurred but returned to the test design conditions in less than two minutes. Power drops of this type will be eliminated in future tests by modifications in the power supply system for the test area. These changes will be made following completion of the 5,000-hour test.

B. Monitoring of the Test Chamber Environment

The total pressure and the partial pressures of the various gaseous species in the test chamber during the period of loop operation up to 350 hours are shown in Figure 1. The total pressure was 3.0×10^{-7} torr when the loop reached the operating conditions and continued to drop until it reached the 10^{-8} torr range after 120 hours of testing. A slow, but steady drop in total pressure has continued until after 1,785 hours of test operation, a value of 2.7×10^{-8} torr has been reached.

Argon (m/e-40) and nitrogen/carbon monoxide (m/e-28) have been the principal species present since the test reached the operating conditions and after 1,785 hours of operation, these gases comprise approximately 83% (45% AR, 39% N_2/Co) of the total indicated pressure. The high concentration of argon is quite similar to the approximately 31% concentration observed in the Loop II test chamber after 2,500 hours of operation (5).

Since the start of the loop test, argon instabilities, which are often observed in diode-type getter-ion pumped systems (6,7), have occurred at time intervals varying from 38 to 98 hours. A typical pressure surge of this type is shown in Figure 13. The pressure surges in the test chamber associated with this rapid release of argon from the pump elements are listed in Table II. Although these pressure surges are of no significance insofar as loop contamination is concerned, they did prevent the activation of the emergency argon flooding system which was designed to provide protection for the hot refractory alloy loop components in the event of a serious leak in the vacuum system.

An overpressure relay in the getter-ion pump circuit was originally designed to fire an explosive valve when the vacuum tank pressure rose to 4×10^{-6} torr. The argon tank connected to the explosive valve would then flood the vacuum chamber with argon gas. However, this safety circuit was not activated because of the pressure excursions of large magnitude but short duration cited above. The Component Evaluation Test Loop II experiment was shutdown on two occasions (8) by the surges in the chamber pressure resulting from argon instabilities.

Initially, it was hoped that the argon instabilities would cease or diminish in amplitude so that the argon flooding system could be connected without fear of it being actuated by an argon instability in the getter-ion pump. When it became obvious that the instabilities were not diminishing in amplitude or frequency, this safety circuit was redesigned. The relay built into the ionization gauge controller was put in series with the pressure sensitive relay in the getter-ion pump system. This second relay will close when the chamber pressure exceeds 4×10^{-4} torr. Increasing the circuit activating pressure from 4×10^{-6} to 4×10^{-4} torr permits operation of the argon flooding system with low probability of it being inadvertently triggered by an argon instability.

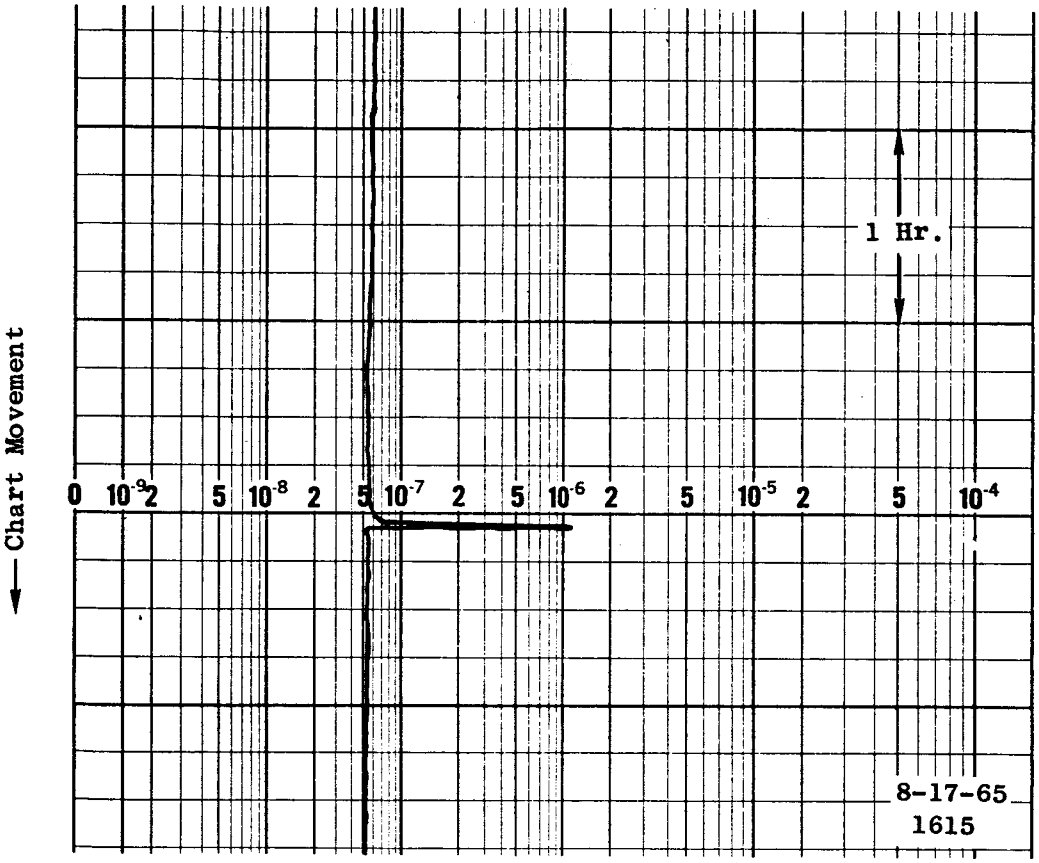


Figure 13. Typical Pressure Surge in the Prototype Loop Test Chamber Resulting From an Argon Instability in the Getter Ion Pump.

TABLE II. PRESSURE SURGES IN THE PROTOTYPE LOOP TEST CHAMBER RESULTING FROM ARGON INSTABILITIES IN THE GETTER-ION PUMP

Hours of Loop Operation	Date	Time	Pressure, Torr*	
			Base Pressure	Peak Pressure
Start of Test	8-2	1500	3.0×10^{-7}	--
305	8-15	0800	5.4×10^{-8}	3.0×10^{-6}
361	8-17	1615	5.7×10^{-8}	1.2×10^{-6}
445	8-21	0415	4.8×10^{-8}	1.5×10^{-6}
521	8-24	0730	4.8×10^{-8}	1.5×10^{-6}
567	8-26	0615	4.0×10^{-8}	4.0×10^{-7}
617	8-28	0745	4.0×10^{-8}	7.0×10^{-7}
666	8-30	0925	4.0×10^{-8}	1.5×10^{-6}
721	9-1	1555	3.5×10^{-8}	1.5×10^{-6}
783	9-4	0630	3.5×10^{-8}	1.5×10^{-6}
834	9-6	0925	3.4×10^{-8}	1.5×10^{-6}
892	9-8	1840	3.5×10^{-8}	1.0×10^{-6}
959	9-11	1400	3.0×10^{-8}	3.0×10^{-7}
1053	9-15	1200	3.1×10^{-8}	1.6×10^{-6}
1104	9-18	1045	3.0×10^{-8}	8.5×10^{-7}
1192	9-21	0645	2.9×10^{-8}	8.5×10^{-7}
1248	9-23	1445	2.9×10^{-8}	8.0×10^{-7}
1346	9-27	1712	2.8×10^{-8}	9.0×10^{-7}
1403	9-30	0155	2.8×10^{-8}	7.5×10^{-7}
1458	10-2	0920	2.7×10^{-8}	3.0×10^{-5}
1504	10-4	0650	2.8×10^{-8}	8.0×10^{-7}
1583	10-7	1415	2.9×10^{-8}	1.5×10^{-6}
1654	10-10	1315	2.7×10^{-8}	9.0×10^{-7}
1734	10-13	2100	3.1×10^{-8}	1.8×10^{-6}
1772	10-15	1055	2.8×10^{-8}	9.0×10^{-7}

* Pressure change indicated by getter-ion pump pressure recorder. Base pressure corrected to value indicated by the calibrated nude ion gauge on the chamber.

C. Boiler Performance During Start-up of the Prototype Loop

Two off-design test cases obtained on the Prototype Corrosion Loop boiler during the initial start-up are summarized in Table III. The sodium temperature distribution in the boiler for both cases are compared in Figure 14. In the run on 7-31-65, the large temperature gradient which indicates a high heat transfer and boiling rate is located near the potassium exit; in the run on 8-2-65, the large temperature gradient has moved to the potassium entrance region of the boiler. In each case, for approximately the same potassium flow rate, the potassium was completely vaporized and superheated 115° above the saturation temperature as determined by the measured vapor pressure at the exit of the boiler. The ability of the boiler to produce superheated vapor with the boiling occuring at the plug or in the last 50 inches of the 240-inch long boiler indicates the degree of over design in the boiler length and assures that the vapor entering the first stage of the turbine simulator is superheated.

Another significant difference in the two test runs is the ratio of the sodium flow rate to the potassium flow rate. Although the potassium flow rate was essentially constant for the two runs, the sodium flow rate was increased from 451 to 818 lbs/hour for the run on 8-2-65. The sodium flow rate was increased to limit the maximum heater exit temperature to 2150°F at the design test conditions.

D. Analysis of Prototype Loop Performance

Test data obtained on the loop after 259 hours of operation which is representative of the test conditions during the first 1,785 hours of loop operation are shown in Figure 15. The pressures at several locations in the potassium circuit and the corresponding saturation temperatures in the vapor and two-phase regions are listed. (The method used to measure the temperatures of loop components is discussed in detail in Section III.E. of this report.). The sodium temperature profile in the boiler and the calculated potassium quality and temperature as a function of boiler length are given in Figure 16. The calculated qualities indicated are based on the thermal calculations involving potassium flow, potassium boiler inlet temperature, sodium flow and the drop in the measured sodium temperatures as a function of boiler length. (The calibration of the sodium and potassium flowmeters is discussed in Section III.F. of this report.). The calculated boiling temperature indicated varied from 1810°F at the boiler inlet to 1880°F at approximately 122 inches from the inlet where 100% quality vapor is reached. The remaining 118 inches of boiler is used to superheat the vapor to 1995°F. The 133°F of superheat reported is the difference between the measured temperature of the potassium vapor at the boiler exit, 1995°F, and the saturation temperature, 1862°F, as determined by the measured boiler exit pressure, 100 psia. The local heat flux in the boiler calculated from the slope of the sodium temperature gradient varies from over 400,000 BTU/hr/ft^2 in the 12-inch long plug to less than 2000 BTU/hr/ft^2 in the superheat region near the exit of the boiler.

TABLE III. SUMMARY OF THE PROTOTYPE CORROSION LOOP BOILER PERFORMANCE FOR TWO RUNS DURING LOOP START-UP

Time	7-31-65, 1215	8-2-65, 1015
Sodium Flow Rate	451 lb/hr	818 lb/hr
Sodium Temperature, In	2092°F	2040°F
Sodium Temperature, Out	1872°F	1916°F
Sodium ΔT	220°F	124°F
Boiler Heat Input Including Losses	32,200 BTU/hr	33,200 BTU/hr
Potassium Flow Rate	36.1 lb/hr	37.8 lb/hr
Saturation Temperature at Boiler Exit	1754°F	1788°F
Superheat Temperature	1869°F	1903°F
Degrees Superheat	115°F	115°F
Heat Input		
Heat of Vaporization	28,100 BTU/hr	29,200 BTU/hr
Superheat	800 BTU/hr	860 BTU/hr
Preheat	1,370 BTU/hr	1,460 BTU/hr
Total Heat Input to Potassium	30,270 BTU/hr	31,420 BTU/hr
Boiler Heat Loss	2,600 BTU/hr	3,330 BTU/hr
Total Heat Transfer	32,870 BTU/hr	34,700 BTU/hr

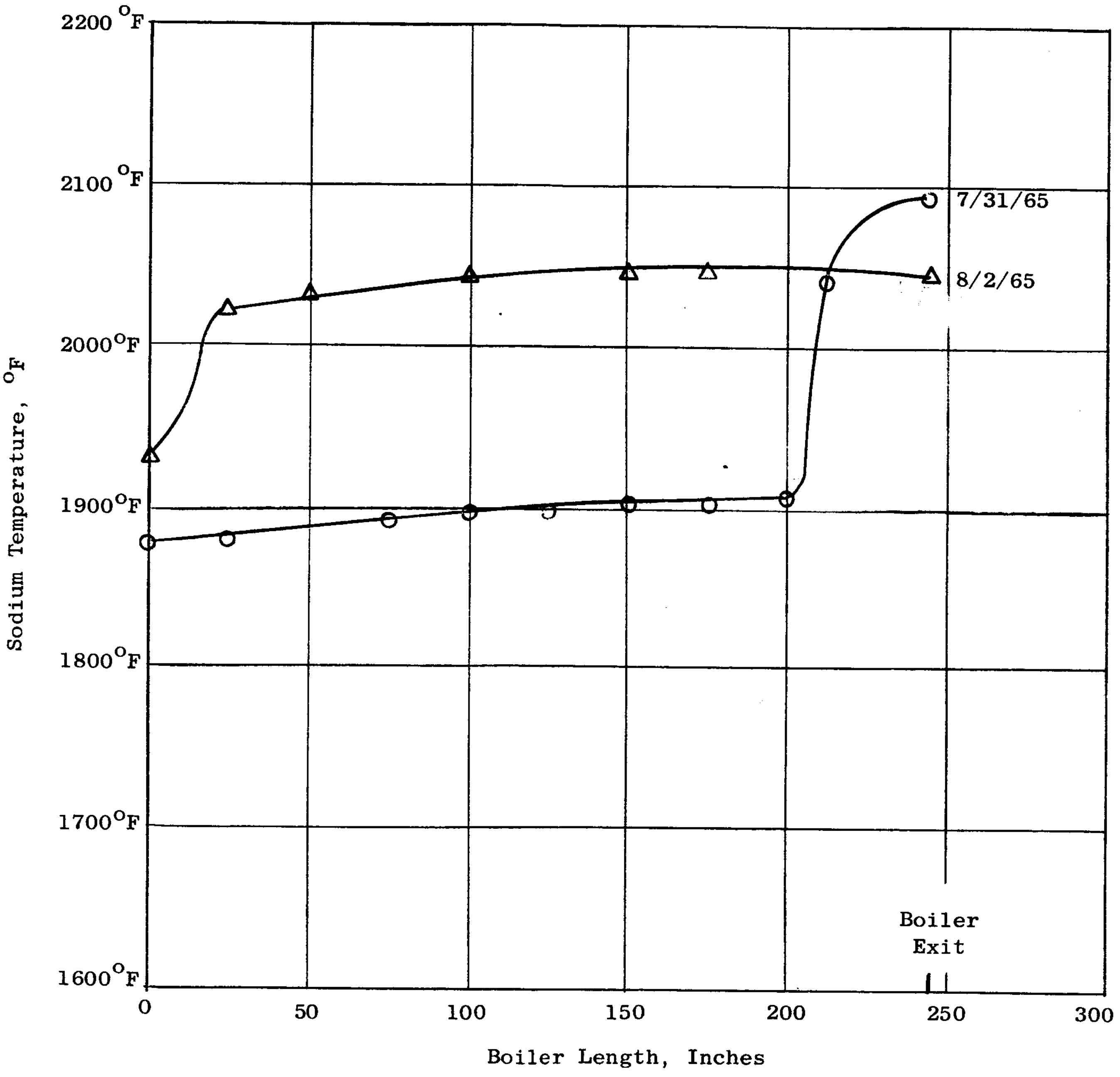


Figure 14. Sodium Temperature Distribution in the Prototype Loop Boiler for Two Off-Design Conditions During Test Start-up as Presented in Table III.

8-13-65 10:00 Hours Test Time: 259 Hours

Heater: 46.4A/378V
Preheater: 32A/92V/2.02KW
Nucleator: 3A/60V
Primary Flow: 2.43 GPM/3.72 MV
Secondary Flow: 0.110 GPM/0.185 MV
Boiling Temperature*: 1910°F
Superheat: 133°F (1995°-1862°F)

* Saturation Temperature at Boiler Entrance Pressure, 116 psia

NOTE: Temperature Shown in °F.

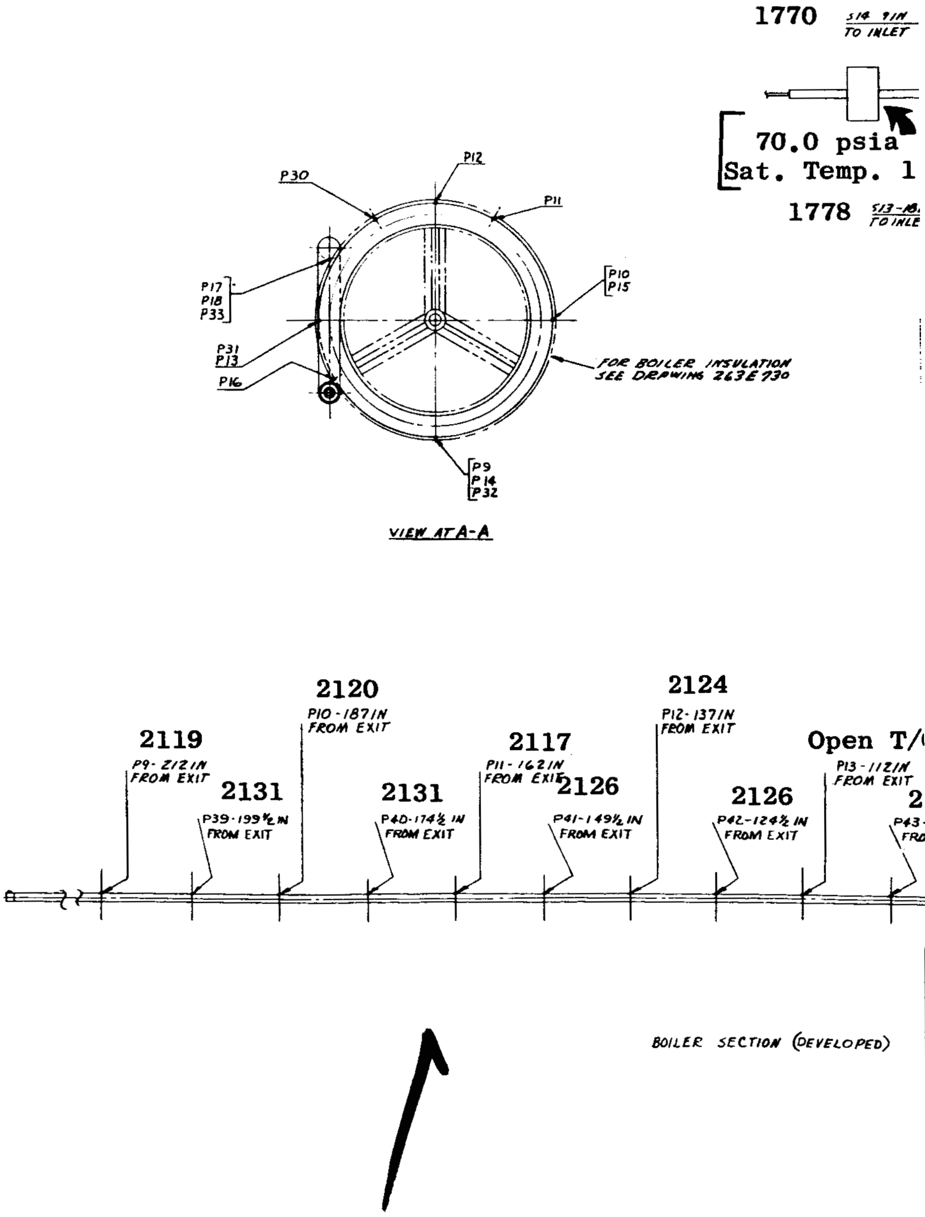
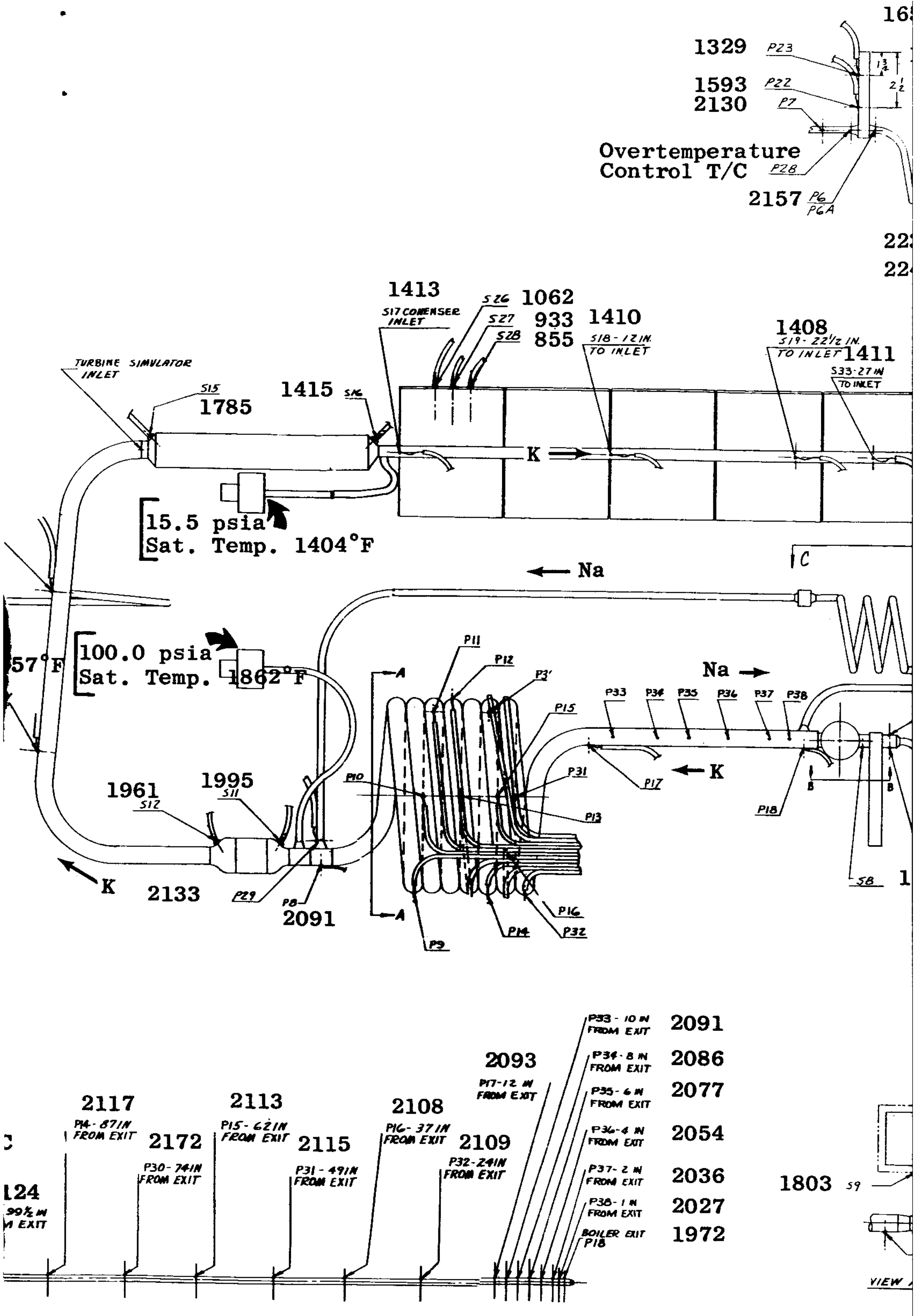


Figure 15



. Prototype Corrosion Loop Thermocouple Instrumentation Layout

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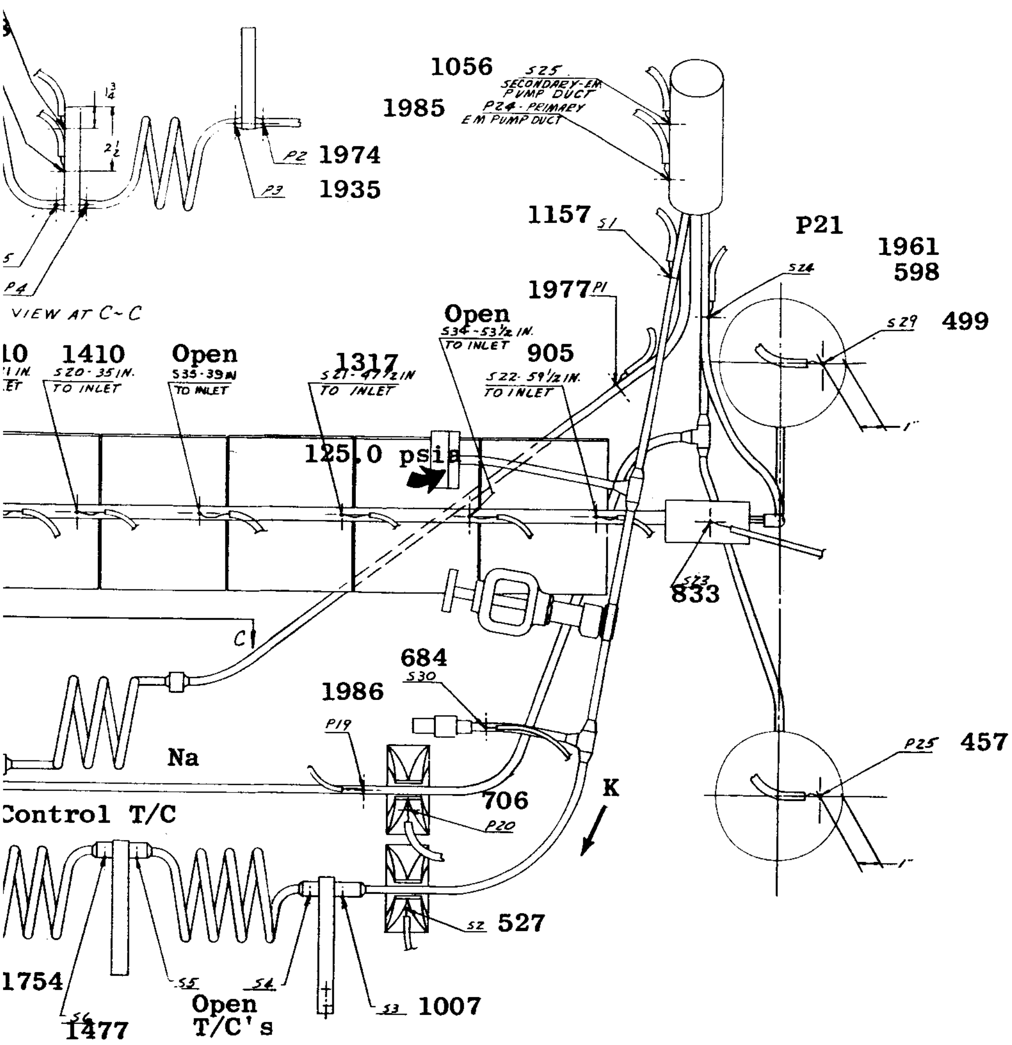
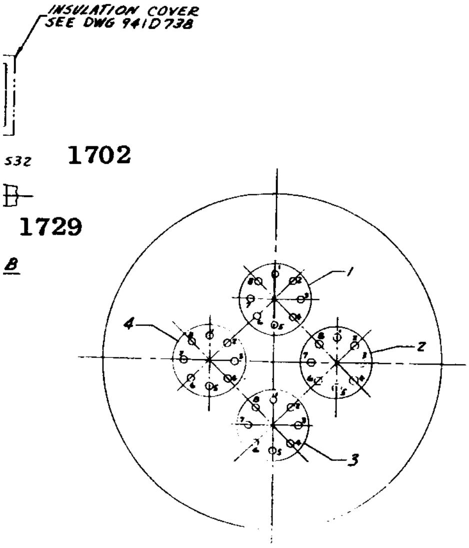
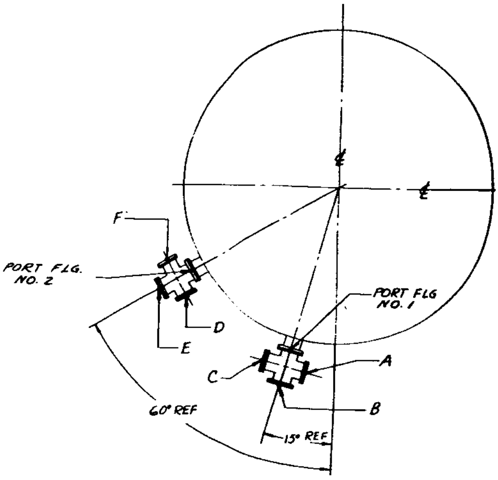




TYPICAL FEEDTHRU FLANGE AND OCTAL ARRANGEMENT REF. A,B,C,D,E&F



FEEDTHRU CHAMBER WALL

VIEW AT LOWER TANK NO SCALE

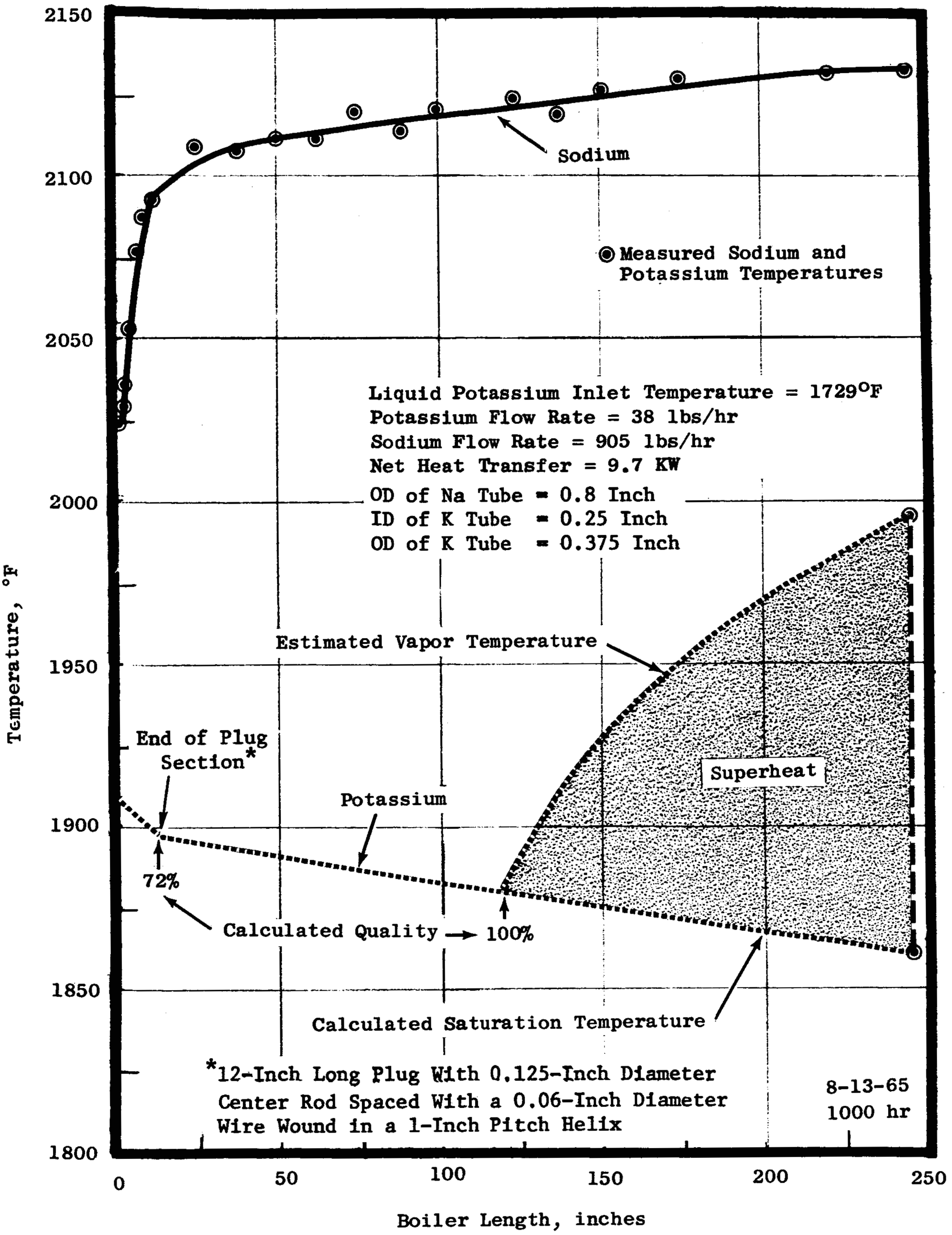


Figure 16. Temperature Distribution and Quality of Potassium in the Prototype Corrosion Loop Boiler After 259 Hours Operation.

The calculated vapor velocity at the throat of the turbine simulator nozzles varied from 1125 ft/sec in the first nozzle to 830 ft/sec in the tenth nozzle. The variance from the design throat velocity of 1000 ft/sec is due in part to differences in the actual operating conditions and the reference design. In the reference design 112.7 psia, which is equivalent to the saturation pressure at 1900°F, was assumed as the turbine simulator inlet pressure. In actual operation, the 1900°F boiling region was concentrated in the plug, rather than being uniformally distributed along the length of the boiler, resulting in a larger pressure drop between the boiler inlet and the entrance of the turbine simulator. The actual measured pressure at the inlet to the turbine simulator was 100 psia or 13 psi less than the design pressure. The lower pressure resulted in a decrease in the vapor density from 0.230 lb/ft^3 to 0.183 lb/ft^3 or approximately 10%. Since the throat velocity of a nozzle for a given flow rate is inversely proportional to the density, a higher than design velocity was reached in nozzles No. 1 to 7. On the other hand, the thorat velocities in nozzles No. 7 to 10 were less than the design velocity because the condenser was operating at 1413° or 63°F above the reference design condensing temperature of 1350°F The higher vapor density, therefore, resulted in a lower throat velocity since the density of vapor at 1413°F (16.2 psia) is 40% higher than at the design pressure of 11.6 psia. The condenser was operated at the higher than design pressure to increase the inlet pump pressure as added safety to prevent the pump from vapor locking.

An added complication in the determination of the performance of the turbine simulator was that the nozzles were originally designed using the potassium vapor properties reported by Walling and Lemmon (9) and the performance data were computed using the data of Stone, et al. (10) which became available after the Prototype Loop was partially fabricated. The variations between the actual test conditions and the reference design test conditions are considered minor and will not significantly compromise the compatibility evaluation which will be performed on test components following completion of the experiment.

E. Measurement of Prototype Loop Temperatures

All loop thermocouples were made from W-3%Re/W-25%Re wire which had been calibrated in vacuum in the 32°-2350°F temperature range. The calibration procedure and test results are given in Table IV.

A schematic drawing of the thermocouple circuit is shown in Figure 17. A typical thermocouple circuit starts at the hot junction of the thermocouple and terminates at a reference junction block (12) attached to the inside of the wall of the spool section of the test chamber. At the reference junction block, a transition from the thermocouple wire to copper wire is made mechanically and the copper wires are routed through a thermocouple vacuum feedthrough to a recording potentiometer. The temperature of each of the eight reference blocks is measured by a copper/constantan thermocouple located on each block. The procedure used in determining the temperature of the loop is described below.

The temperature of the reference junction is determined by first measuring the millivolt output of a copper/constantan thermocouple with a 32°F reference junction. The indicated emf is converted to °F from a standard copper/constantan

TABLE IV. THERMOCOUPLE REFERENCE TABLE FOR THE W-3%Re/W-25%Re WIRE USED TO INSTRUMENT THE PROTOTYPE CORROSION LOOP

	emf, Millivolts*										
Temp. → °F ↓	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
0	0.	0.	0.	0.	0.048	0.109	0.170	0.231	0.291	0.352	0.413
100	0.413	0.479	0.545	0.612	0.678	0.744	0.810	0.881	0.951	1.022	1.092
200	1.092	1.168	1.244	1.320	1.396	1.472	1.552	1.633	1.713	1.794	1.874
300	1.874	1.960	2.046	2.132	2.218	2.304	2.393	2.481	2.570	2.658	2.747
400	2.747	2.838	2.929	3.020	3.111	3.202	3.296	3.391	3.485	3.582	3.679
500	3.679	3.776	3.875	3.973	4.072	4.170	4.269	4.368	4.466	4.565	4.663
600	4.663	4.762	4.862	4.962	5.062	5.161	5.261	5.361	5.462	5.564	5.666
700	5.666	5.767	5.868	5.970	6.073	6.176	6.278	6.381	6.484	6.587	6.691
800	6.691	6.796	6.900	7.004	7.110	7.217	7.323	7.430	7.536	7.643	7.749
900	7.749	7.856	7.963	8.071	8.178	8.285	8.393	8.502	8.610	8.719	8.827
1000	8.827	8.937	9.047	9.157	9.267	9.377	9.487	9.597	9.707	9.817	9.927
1100	9.927	10.038	10.149	10.261	10.372	10.483	10.594	10.705	10.817	10.928	11.039
1200	11.039	11.151	11.263	11.375	11.487	11.599	11.712	11.824	11.936	12.048	12.160
1300	12.160	12.272	12.384	12.496	12.607	12.719	12.831	12.943	13.055	13.167	13.279
1400	13.279	13.391	13.502	13.614	13.726	13.838	13.950	14.063	14.175	14.287	14.399
1500	14.399	14.512	14.624	14.736	14.849	14.961	15.073	15.186	15.298	15.410	15.522
1600	15.522	15.635	15.747	15.859	15.972	16.084	16.196	16.307	16.419	16.530	16.642
1700	16.642	16.754	16.865	16.977	17.088	17.200	17.311	17.421	17.532	17.643	17.753
1800	17.753	17.864	17.975	18.086	18.196	18.307	18.417	18.527	18.637	18.747	18.857
1900	18.857	18.968	19.078	19.188	19.298	19.408	19.517	19.626	19.736	19.845	19.954
2000	19.954	20.063	20.172	20.282	20.391	20.500	20.609	20.717	20.826	20.934	21.043
2100	21.043	21.152	21.260	21.369	21.477	21.586	21.694	21.802	21.910	22.018	22.126
2200	22.126	22.235	22.343	22.451	22.559	22.667	22.774	22.882	22.989	23.096	23.203
2300	23.203	23.311	23.418	23.525	23.633	23.740	--	--	--	--	--

* Reference junction, 32°F

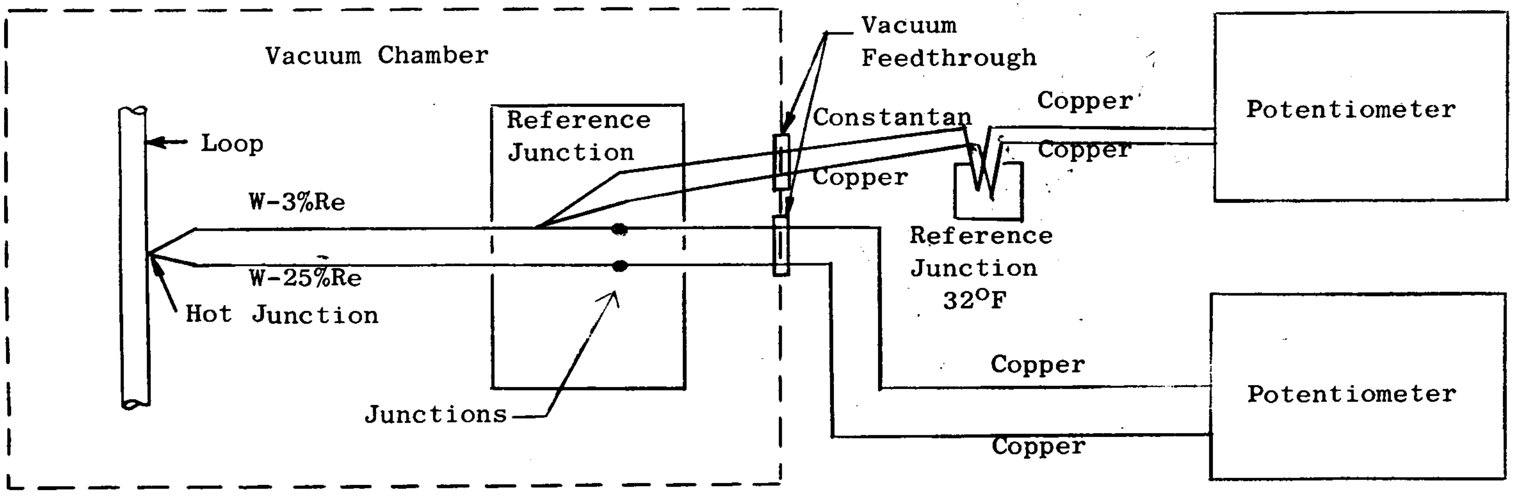


Figure 17. Schematic of the Thermocouple Circuit of the Prototype Corrosion Loop.

temperature conversion table. The reference junction temperature is converted back to a millivolt equivalent using the W-3%Re/W-25%Re conversion table. The reference junction voltage is then added to the measured loop thermocouple emf and the corrected millivolt output is converted to the true loop temperature using the W-3%Re/W-25%Re conversion table.

An example of a typical temperature determination is given below:

Reference junction T/C (copper/constantan), emf - 6.33 mv

Reference junction temperature - 284°F

Loop T/C (W-3%Re/W-25%Re) - 18.04 mv

Reference junction correction emf for 284°F - 1.75 mv

Corrected loop T/C emf - 19.79 mv

True loop temperature - 1985°F

F. Calibration of Sodium and Potassium Flowmeters

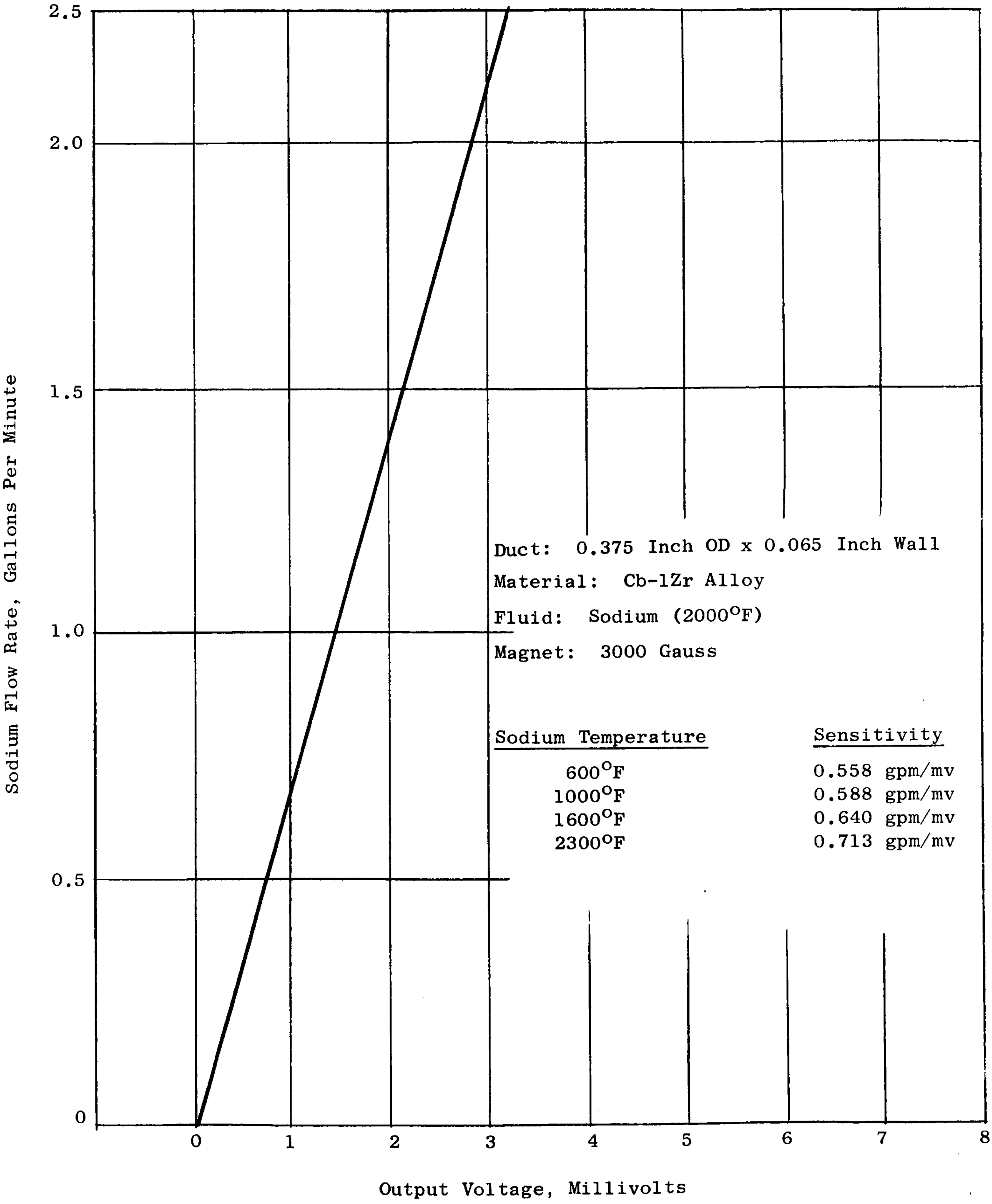
The output voltage as a function of flow rate for the Prototype Corrosion Loop primary and secondary flowmeters are shown in Figures 18 and 19. The curves shown are for fluid temperatures near the operating conditions of the loop. Flow sensitivities as a function of temperature are also included for off-design operation during the test start-up. The output voltage and sensitivities shown are based on the theoretical equation used by Affel (13), et al., with a correction factor obtained from calibration runs made prior to the test start-up and previously reported (14).

The indicated flow rate as a function of output voltage shown in Figures 18 and 19 are based on a magnetic flux density of 3000 gauss. Since the magnetic flux of a permanent magnet is a function of the magnet temperature, the indicated flow rate must be corrected by the ratio of the actual magnetic flux at the magnet temperature to 3000 gauss. The relationship of the magnetic flux as a function of magnet temperature for the Prototype Loop magnets were previously reported (15).

G. Topical Reports

Two topical reports have been issued during this reporting period and these reports are listed below:

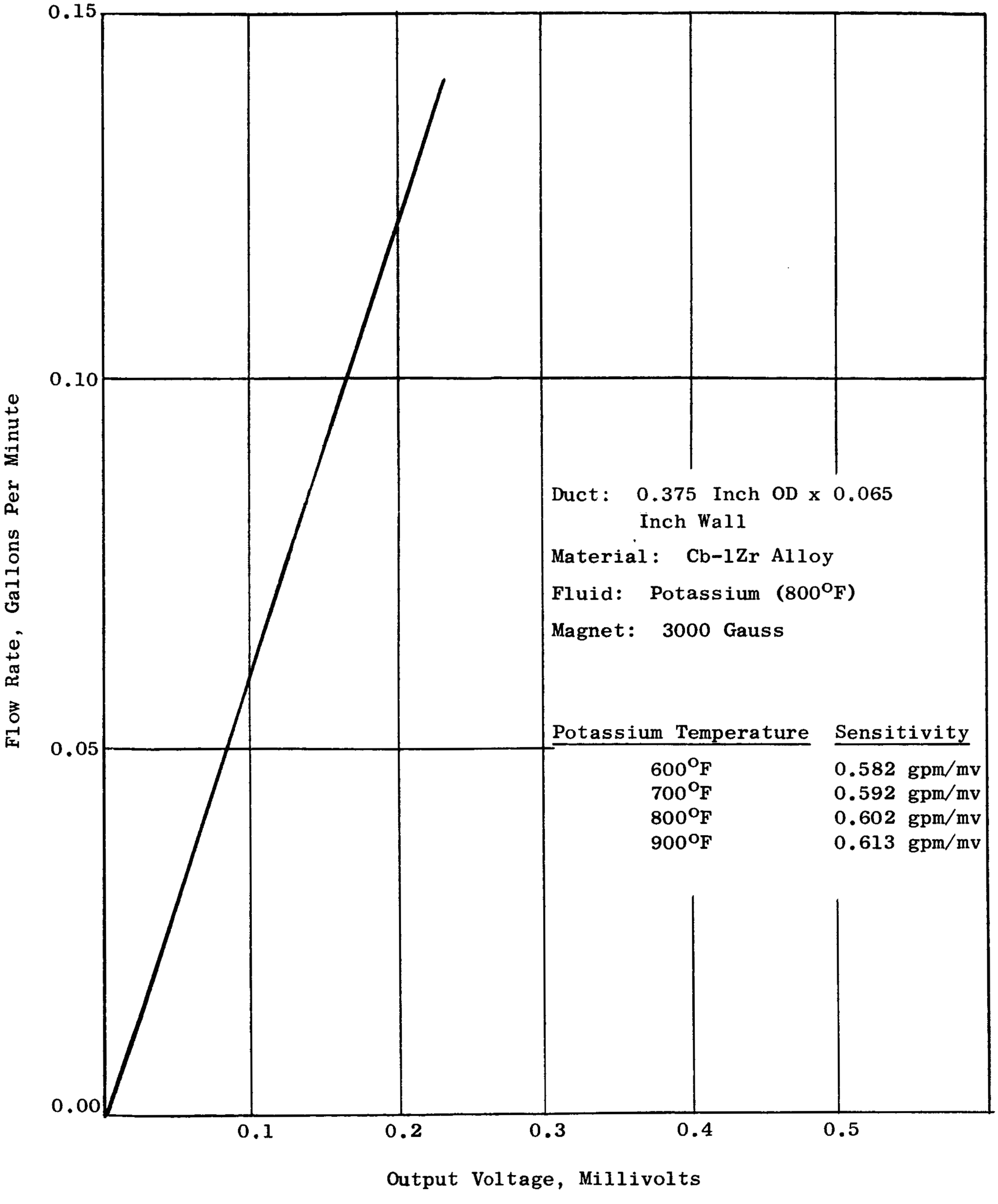
1. Potassium Corrosion Test Loop Development Topical Report No. 1, PURIFICATION AND ANALYSIS HELIUM FOR THE WELDING CHAMBER, NASA-CR-64168, T. F. Lyon, July 1, 1965.
2. Potassium Corrosion Test Loop Development Topical Report No. 3, MATERIAL SPECIFICATIONS FOR ADVANCED REFRACTORY ALLOYS, NASA-CR-54761, D. N. Miketta and R. G. Frank, October 1, 1965.



Duct: 0.375 Inch OD x 0.065 Inch Wall
Material: Cb-1Zr Alloy
Fluid: Sodium (2000°F)
Magnet: 3000 Gauss

Sodium Temperature	Sensitivity
600°F	0.558 gpm/mv
1000°F	0.588 gpm/mv
1600°F	0.640 gpm/mv
2300°F	0.713 gpm/mv

Figure 18. Output Voltage Vs Flow Rate for the Prototype Corrosion Loop Primary (Sodium) Circuit Flowmeter. Sensitivity Corrected by Thermal Energy Balance Calibration.



Duct: 0.375 Inch OD x 0.065 Inch Wall

Material: Cb-1Zr Alloy

Fluid: Potassium (800°F)

Magnet: 3000 Gauss

Potassium Temperature	Sensitivity
600°F	0.582 gpm/mv
700°F	0.592 gpm/mv
800°F	0.602 gpm/mv
900°F	0.613 gpm/mv

Figure 19. Output Voltage Vs Flow Rate for the Prototype Corrosion Loop Secondary (Potassium) Flowmeter. Sensitivity Corrected by Thermal Energy Balance Calibration.

IV FUTURE WORK

A. Operation of the Prototype Loop will continue during the next quarter, with a total of 4,200 hours of loop operation being completed by January 15, 1966.

B. Preparation of topical reports covering the various portions of the program which have been completed will continue.

REFERENCES

(1) Potassium Corrosion Test Loop Development, Quarterly Progress Report No. 7 for Period Ending April 15, 1965, NASA Contract NAS 3-2547, NASA-CR-54735, p 81.

(2) Alkali Metals Boiling and Condensing Investigations, Quarterly Progress Report No. 11 for Period Ending March 31, 1965, NASA-CR-54405, April 23, 1965, p 76.

(3) Studies of Alkali Metal Corrosion on Materials for Advanced Space Power Systems, Quarterly Progress Report No. 4 for Period Ending June 26, 1965, Contract NAS 3-6012, NASA-CR-54476.

(4) Potassium Corrosion Test Loop Development, Quarterly Progress Report No. 5 for Period Ending October 15, 1964, NASA Contract NAS 3-2547, NASA-CR-54269, p 12.

(5) Potassium Corrosion Test Loop Development, Quarterly Progress Report No. 6 for Period Ending January 15, 1965, NASA Contract NAS 3-2547, NASA-CR-54344, p 9.

(6) Barrington, Alfred E., High Vacuum Engineering, Prentice-Hall, Inc., Engelwood Cliffs, N.J., 1963, p 101.

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