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TWO-STAGE POTASSIUM TEST TURBINE

Volume III
Test Facilities

by S. E. Eckard

Prepared by
GENERAL ELECTRIC
Cincinnati, Ohio
for Lewis Research Center

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FOREWORD

The work described herein was performed as part of the Two-Stage Potassium Vapor Test Turbine Program conducted by the Space Power and Propulsion Section of the General Electric Company for the National Aeronautics and Space Administration under NASA Contract NAS 5-1143. This work was performed under the Technical Management of Joseph P. Joyce, Space Power Systems Division, NASA-Lewis Research Center.

ABSTRACT

A detailed description of the General Electric Company's 3000 KW, two phase, potassium test facility is presented. Pertinent information on operating procedures and problems is disclosed.

The potassium containment piping and component hardware in the test facility were fabricated of Type 316 stainless steel. The facility was designed to produce potassium vapor up to 1600^{o}F at 3.5 lb/sec flowrate. Maximum obtainable vapor temperature was 1587^{o}F.

The test facility was designed for Rankine cycle testing of a two-stage potassium vapor turbine. More than 2000 hours of turbine testing were completed at 1500^{o}F turbine inlet temperature. Also thermodynamic properties of potassium vapor were experimentally investigated by flowing potassium vapor through a large convergent - divergent nozzle prior to turbine testing.

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SUMMARY

Long time continuous operation of a large potassium vapor, Rankine cycle facility has been demonstrated. Potassium vapor was produced for more than 2100 hours at temperatures between 1450°F and 1550°F. Maximum vapor temperature achieved was 1587°F for approximately 30 minutes - boiler tube temperature was 1650°F. Since the boiler tube bundle was fabricated of Type 316 stainless steel, vapor temperature higher than 1587°F was not attempted. One test run was 1750 continuous hours followed by a planned shutdown. Basic problems peculiar to low pressure, high temperature alkali metal systems were solved, and a stable power producing cycle was achieved.

Normal operating limits of the major subloops and a summary of boiler and condenser operation follow.

A. Slinger Seal Loop:

Potassium flowrate to turbine seal	gpm	2
Potassium pressure to turbine seal	psig	40 to 130
Potassium temperature to turbine sezl	°F	250 ± 5
Potassium temperature from turbine seal	°F	800 to 900

B. Turbine Labyrinth Seal System:

Argon flowrate to seal bearing	lb/hr	100 to 150
Argon temperature to seal	°F	200 to 250

C. Turbine Lube Oil System:

Oil flowrate to pad bearing	gpm	2.0 to 2.5
Oil flowrate to ball bearing	gpm	0.8
Available oil pressure	psig	150 to 160
Pad bearing pressure	psig	65 to 130
Ball bearing pressure	psig	30 to 40
Lube oil temperature	°F	135

Instability of the natural recirculating boiler constituted the major cycle problem. Boiler stability was achieved in the following manner.

1. Boiler makeup was preheated to 1000-1200°F.
2. Boiler makeup was supplied directly into the top of each of the four downcomers so that carryunder of hot liquid already in the vapor drum was significantly high. (The resulting mixture in the downcomer was within 5 to 10°F of vapor discharge temperature.)
3. Liquid in the vapor drum was maintained at a lower level than previously so that conditions for greater vapor bubble carryunder were improved.

Although the 3000 KW Facility was relatively complex, having twelve critical subloops, facility operation was highly automated and required only four trained operators for each shift. Once the facility reached steady-state, the major duties of the operating personnel were data taking and routine servicing of facility equipment. The following parameters were controlled automatically after steady-state operation was achieved.

1. Boiler discharge pressure
2. Condenser pressure
3. Turbine speed
4. Liquid potassium return to the boiler (boiler feed)
5. Argon pressure to the turbine labyrinth seal
6. Potassium flowrate to the turbine slinger seal
7. Lube oil flowrate to the turbine bearings
8. Steam pressure to the steam turbine
9. Lube oil temperature for both the potassium turbine and steam turbine
10. Potassium temperature to the slinger seal
11. Liquid level in the slinger seal loop head tank

Degradation of loop components and structural materials was not encountered. Oxidation of the Type 316 SS tubes in the natural gas fired boiler effected a loss of approximately 2.5 mils on the tube wall. Since 60 mils were provided, the loss was not excessive. A layer of metallic dust, one-to-two mils thick, found in the bottom of the vapor drum evidenced some mass transfer. The exact location of metal loss has not been determined. Mass transfer was not excessive since 60 mils of tube wall was provided for liquid corrosion and since there was no evidence of plugging in the loop due to mass transfer. Limitations to indefinite life appear to be contingent on secondary components such as ball bearings, carbon face seals, instrumentation, etc., which are subject to failure irrespective of incorporation in an alkali metal system. As might be expected, thermocouples tend to drift with time at high temperature. Electronic and electrical equipment tend to fail for various reasons.

Alkali metals, such as potassium, are highly reactive when in contact with air or water. Consequently, specific handling precautions are required.

During more than two years of operating the facility at temperatures up to 1587°F vapor temperature, no extremely hazardous situations were encountered even though several small leaks did develop in earlier phases of testing.

A summary of boiler and condenser operation is presented on the following page.

BOILER AND CONDENSER

Date	Operating Time, hr	Accumulated Time, hr	Boiler		Condenser	Remarks
			Discharge Temp., °F	Vapor Flowrate, lb/sec	Operating Temp., °F	
3 Oct. 1963	10	10	1420–1570	1.4–2.6	1100–1300	Efflux pressure lines plugged; argon extraction line plugged
4 Oct. 1963	1	11	1400	---	---	C-D nozzle bolted flange leak occurred on heat-up
19 Dec. 1963	9	20	1510–1570	1.8–2.4	1200–1388	Gas valve on boiler failed
29 Dec. 1963	38	58	1400–1587[a]	1.1–2.7	1150–1385	Completed C-D nozzle test
16 July 1964	4	62	1200–1500	---	1100–1200	Turbine slinger seal leaked excessively
13 Oct. 1964	45	107	1450–1580	1.5–2.9	1100–1353	Completed initial turbine test phase, boiler vapor drum leak
26 March 1965	19	126	1450	1.6	1123	Broken tube in bearing housing
21 May 1965	53	179	1450–1550	1.1–1.2	1100–1350	Completed performance test; good stability
20 Dec. 1965	2000	2179	1500	2.0	1230	Completed 2000-hour endurance test

[a]Maximum boiler tube temperature was 1650°F.

INTRODUCTION

The Space Power and Propulsion Section of the General Electric Company has been under Contract to the National Aeronautics and Space Administration (NAS 5-1143) since May 8, 1961 for the research and development of a two stage test turbine suitable for operation with potassium vapor at temperatures up to 1600°F.

To support testing of the two stage turbine, a stainless steel test facility was designed and built by the General Electric Company at Evendale, Ohio. This facility was designed to produce a maximum flow rate of 3.5 lb/sec potassium vapor at a temperature up to 1600°F. It was a single closed loop boiling and condensing system operating on the Rankine cycle. In addition to the primary potassium loop, the facility consisted of the twelve major subloops, which were necessary for turbine testing and for safety reasons, enumerated below:

1. High pressure lube oil system for the potassium turbine
2. Low pressure lube oil system for the water brake and steam turbine
3. Slinger seal loop for providing liquid potassium to the turbine slinger seal (rotating channel seal)
4. Vacuum system for evacuating the air from the argon and potassium loops
5. Argon extraction system for removing noncondensables from the condenser
6. Argon reclamation system for cleaning and pressurizing argon for re-use
7. Shop air for heat exchanger cooling
8. Instrument air for pneumatic controllers
9. Water system for the water brake
10. Scrubber system to prevent the escape of potassium oxide into the atmosphere
11. Instrumentation including Sanborn, digital, efflux pressure, temperature measurement, etc
12. Electrical power control, up to 600 KVA

The primary potassium loop and each of these subloops are described in this report.

Design of the facility began early in 1961. Potassium vapor was first generated by the boiler on October 2, 1963. At that time a convergent-divergent nozzle was installed in the loop in place of the potassium turbine.

Potassium vapor was first expanded through the turbine on July 13, 1964. Initially, turbine rotational speed control was erratic. Modification to the boiler hardware together with a new operating procedure for the boiler and water brake turbine power absorber resulted in stable speed control. In late May 1965, turbine performance with potassium vapor was measured. In December 1965, a 2000 hour endurance test was successfully completed.

1.0 Description of Facility Components

1.1 Potassium Metal Loop

Figures 1 and 2 show the basic components and the relative arrangement of the fundamental alkali metal loop, specifically designed and constructed to provide a facility in which the performance and endurance of potassium vapor turbines can be measured. Consequently, the four principal components were: boiler, turbine, condenser, and boiler feed pump. Additional components were required for control and safe handling of the alkali metal. Such components were control valves, line heaters, pressure and temperature instrumentation, and a dump tank. The thermodynamic fluid in this loop was potassium.

Nearly all components and piping in this loop were made of Type 316H stainless steel. (Type 316 stainless steel was used in a few places.) Therefore, the temperature for all components in this loop was limited to 1630°F for long time operation (1650°F for short time operation). This material was chosen for its high temperature physical properties and relatively low cost.

Potassium vapor was produced in the natural gas fired boiler at temperatures up to 1587°F. Vapor quality at boiler discharge was about 99% as measured by a throttling calorimeter. Vapor leaving the boiler passed through an 8.0" control valve and expanded through the test turbine. After leaving the test turbine, the potassium vapor was liquified and was collected in the lower drum of an air-cooled condenser. An electromagnetic pump removed the liquid from the condenser drum at the same rate as the boiler discharge rate during steady state operation.

Potassium vapor flowrate through the test turbine was as high as 2.9 lb/sec during turbine performance testing, and the vapor flowrate was about 2.0 lb/sec during a 2000-hour endurance test. Vapor temperature into the turbine was controlled at 1450°F, 1500°F and 1550°F during various phases of testing. Temperature at the turbine exit was controlled over the range of 1100°F to 1400°F during various phases of testing.

The presence of oxygen in a system using potassium (or other alkali metals) gives rise to two serious problems: (1) corrosion of the containment material is greatly accelerated, and (2) deposits of potassium oxide in colder portions of the loop may cause the loop to become plugged. To insure high purity potassium in the alkali metal loop, hot trapping materials - both zirconium and titanium in sheet form - were built into the dump tank, condenser drum, and boiler tube bundle. These metals have a greater affinity for oxygen at high temperature than potassium. Two hundred and sixty (260) pounds of pounds of titanium sheet was installed in the dump tank. Three hundred and eighty (380) pounds of zirconium foil was installed in the condenser drum, and 217 pounds of zirconium foil was installed in the boiler tube bundle. [Two hundred (200) pounds of titanium will theoretically getter 133.5 pounds of O_2. Three hundred and eighty (380) pounds of zirconium will theoretically getter 133.5 pounds of O_2.]

Thermal stresses caused by differential temperature throughout the loop were kept at an acceptable value by allowing the loop to move unrestrained from the boiler and dump tank. The boiler and dump tank were fixed due to their large size and heavy weight. Axial thermal expansion of the 8.0" vapor pipe was about 3.0 inches from the boiler discharge. This growth was absorbed by permitting the turbine to move in the direction of pipe growth. The turbine and condenser were attached to a dolly, which was mounted on anti-friction rollers. Therefore, the turbine, condenser, and dolly were free to move under a force of less than 200 pounds. Freedom of movement for other parts of the loop was accomplished by incorporating constant force hangers and liberal pipe expansion loops.

Both the boiler vapor outlet and the turbine dolly were fixed in elevation. Bending stresses at the turbine inlet were reduced by allowing the turbine to pivot about the intersection of the center line of 8.0" vapor pipe and the turbine discharge pipe. Bending stresses at the turbine discharge were reduced by using a flexible gimballed bellows at the turbine outlet. Thermal expansion of the boiler dump line, loop dump line and boiler feed line was absorbed by providing relatively long pipe expansion loops. Spring type constant force hangers were used extensively to provide for vertical thermal expansion of nearly all pipe runs and some components such as the condenser tube bundle, E.M. flowmeter and E.M. pump.

To maintain potassium as a liquid all potassium containments were heated to a temperature exceeding 200°F. All pipe runs and components except the boiler and condenser were heated electrically by "Calrod" heating elements. These heating elements were strapped to the bottom or side of the pipe. A layer of rigidized "Inconel" 0.004" foil was used to cover the heating element. Generally 3.0 to 4.0 inches of thermal insulation was wrapped over the foil. The insulating materials used were "Fiberfrax" and "Fiberglas". The boiler and condenser were preheated by natural gas fired burners. The boiler used its regular burners for preheating. Two gas fired burners installed in the cooling air ducts of the condenser heated the condenser cooling air which, in turn, heated the condenser tube bundle.

In most cases sufficient heat energy was supplied to preheat the containment loop to 300°F - 500°F. However, some pipes were heated to 1000°F - 1200°F to reduce thermal stresses. In particular the dump tank was heated electrically to 1200°F - 1300°F in order to accelerate hot trapping action in the dump tank and to reduce thermal shock on dumping the hot metal from the boiler.

1.1.1 Boiler

The potassium boiler was a natural gas fired unit with heat being transferred by radiation to a multi-tube straight row tube bundle. Radiant heat was supplied to both sides of the double row staggered-tube tube bundle from the refractory walls of the furnace. There were 12 burners placed on each side of the fire box to provide a relatively uniform heat flux over the tube bundle.

The boiler tube bundle consisted of a 20-inch inside diameter by 1.0" wall vapor drum at the top and an 8.0" Schedule 80 pipe header at the bottom. These drums were straight and were approximately 26 1/2 feet long. Boiling occurred in the one hundred seventy four 1.50 inch diameter x 0.178 inch wall tubes. These tubes were vertical and were approximately 10 feet long. They connected the 20" vapor drum to the 8.0" bottom header. Figure 3 shows the tube bundle in detail.

Liquid flowed in the boiler by natural recirculation. There were four 4.0" downcomers connecting the vapor drum to the 8.0" header. The recirculation ratio was calculated to be in the order of 22.5 to 1 at a vapor flowrate of 2.5 lb/sec. The downcomers were equally spaced along the length of the boiler tube bundle. Each downcomer was thermally insulated for increased recirculation rate. Also, the relatively cool (1000-1200°F) boiler make-up was fed directly into the top of the downcomers to increase recirculation. Figure 4 shows pictorially the arrangement of the potassium boiler.

The vapor drum contained a baffle and screen type liquid-vapor separator. A 14" diameter x 30" high secondary separator was mounted at the top center of the 20-inch vapor drum to further reduce liquid carryover in the potassium vapor as it entered the 8" boiler discharge pipe. This was a centrifugal type separator resembling a V.D. Anderson Co. Type ID Hi-ef Purifier. An external view of the separator is shown in Figure 5. Vapor quality from the boiler was measured to exceed 99%.

A 8" diameter x 10 foot long vertical pipe filled with 217 pounds of zirconium was mounted on one end of the tube bundle and served as a hot trapping leg between the upper and lower drums.

Type 316H stainless steel was used throughout in the fabrication of the boiler tube bundle. Very rigid quality control measures were taken in the construction of the tube bundle. Samples of all raw material were tested to insure that both physical and chemical requirements were met. Seamless pipe conformed to ASTM Spec. A312-59T and tubing conformed to ASTM Spec. A213-59T. All Type 316H material was in the fully annealed condition. Grain size was within the range of 7 to 2 ASTM grain size number. One-hundred hour stress rupture tests were performed on each heat of material. Minimum allowable stress rupture properties were:

Temperature	^{o}F--1600
Time	hrs---100
Stress	psi--4000
Elongation	10% in 2 in.

Welds were radiographed and/or dye penetrant inspected for soundness. The completed tube bundle was hydrostatically pressure tested to about 1200 psi, and it was finally helium leak tested in accordance with MIL. STD. 271A (Ships), Section 8.

The tube bundle was enclosed in a steel shell which was relatively gas tight. The shell was lined with about 7.0" of light weight A.P. Green fire brick. Figure 6 shows one side of the tube bundle and furnace fire brick. The white area in the tube bundle is an insulated downcomer. During normal operation the inside surface of the fire brick reached a temperature in the order of 2300^{o}F, and the outer steel shell reached a temperature of about 300^{o}F on a hot day. The fire box had four exhaust stacks which could be closed during an emergency shutdown to prevent the escape of caustic vapors to the atmosphere. All four stacks were connected by a ceramic-lined duct which could be opened to a rock-filled static condenser and water spray scrubber during an emergency shutdown. This is further described in this report under Scrubber System. Figure 7 shows an overall view of the boiler, static condenser and scrubber system.

The boiler was capable of 3000 KW output in the form of latent heat in the alkali metal vapor. Heat input was in the order of 9000 KW, supplied by the combustion of natural gas, burning with 50% excess air.

1.1.2 Condenser

Condensing occurred in vertically arranged finned tubes. There were eighty-four (84) 1.50 inch IPS Schedule 10 tubes in the condenser. Vapor was dispersed to these tubes through an 8.0" header, and condensate was collected from these tubes in a 20" diameter drum. This drum also served as the boiler feed pump head tank, and it also contained 380 lbs. of zirconium hot trapping material. Figure 8 shows the condenser tube bundle near completion in the Fabrication Shop.

There was a continuous bleed of argon gas into the alkali metal loop from various sources, especially during turbine performance testing. Argon eventually ended up in the condenser. Argon, a noncondensable gas, would tend to reduce the efficiency of the condenser. To reduce the detrimental effects of the argon, the lower part of each condenser tube was fitted with an extended surface insert. The insert provided additional surface for condensing to take place, and it was designed to reduce the thickness of the argon boundary layer in the lower part of the vertical condenser tubes. Maintaining a relatively uniform condensing rate over the full length of the tube reduced fluctuating temperature gradients along the length and across the wall of the tube. Therefore, cyclic thermal stresses were kept within an acceptable value.

Argon gas had to be removed from the condenser at the same rate at which it entered. The removal system is detailed later in this report.

The condenser tube bundle was made of Type 316H stainless steel. The completed tube bundle was hydrostatically tested to about 800 psig., and it was helium leak checked in accordance with MIL. STD. 271A (Ships) Section 8.

The condenser tube bundle was hung on spring loaded constant force hangers. These hangers were attached to the turbine dolly so that the condenser tube bundle moved horizontally in unison with the test turbine which was also attached to the turbine dolly. Vertical expansion of the condenser tube bundle was absorbed by the constant force hangers.

The condenser tube bundle was enclosed by a thermally insulated steel box. The box was relatively air tight. Sliding seals allowed pipes and hanger rods to penetrate the air box without allowing excessive air leakage. The bottom of the air box was designed to contain 150% of the alkali metal that would normally be in the condenser drum. This was to prevent spillage of potassium to the test cell floor in case of a major rupture of the condensate drum. Air was forced through the condenser tube bundle by an induced draft rather than a forced draft fan. This simplified air seal design and reduced air ducting complexity. Also the air leakage that occurred was cold air into the air box and not hot air into the test cell. The blower had an air flowrate capacity of approximately 50,000 ft^3/min. A portion of the condenser air ducting and exhaust fan is shown near the center of Figure 7.

Inlet air to the condenser was preheated to 200°F to 250°F by recirculating a portion of the hot exhaust air. Preheating was a precaution against the possibility of solidifying the potassium in the condenser (particularly during start-up and shutdown). Air out of the condenser was 500°F to 600°F.

The inlet and outlet air ducts were made of mild steel. That portion of the duct which was inside the test cell was thermally insulated. There were two air inlet ducts and one centrally located outlet duct. All three ducts were fitted with adjustable louvers. These louvers not only regulated the air flowrate during operation but also closed to seal the condenser cooling system should the condenser tube bundle spring a leak during operation. There were two cross-over ducts between the exhaust duct and the two inlet ducts. Louvers in the crossover ducts were used to regulate the mixing of the hot exhaust air with the cold inlet air--thus maintaining preheated air into the condenser. (As mentioned previously, a small gas fired burner was in each inlet duct to preheat the air on start-up. These burners were not "on" during steady-state operation.)

1.1.3 Dump Tank

The dump tank was a 30" diameter x 24 ft long tank made of Type 316H stainless steel. It can best be described by referring to Figure 9. This tank was designed to hold about 3500 pounds of potassium with about 10% free board. The tank also contained about 260 pounds of titanium hot trapping material in sheet form.

During loop operation this tank contained about 400 pounds (called the heel) of relatively cool (800^{o}F) liquid potassium so that thermal shock to the tank on dumping higher temperature liquid would be minimized. Heating the dump tank from room temperature to its maximum operating temperature, 1200^{o}F - 1400^{o}F, caused the tank to expand about 2.0 inches. Therefore, only one tank saddle was fixed; the other saddle was on a roller free to move. The tank saddles were designed to allow free expansion of the tank diameter.

"Calrod" heating elements were applied to the tank for heating the tank and 3500 pounds of potassium to 1300^{o}F in about 8 hours. This high temperature was required to accomplish oxygen hot trapping in the dump tank.

1.1.4 E.M. Pump

The pump used in the alkali metal loop for recirculating liquid metal was an electromagnetic pump designed and built by the Medium AC Motor and Generator Department, General Electric Company. This was a helical induction electromagnetic pump, designed for pumping potassium at 1600^{o}F and lower temperatures. It was rated at 42 gpm, 150 lb/in^{2} developed pressure. The pump was hermetically sealed with no moving parts and no direct electrical connections to the liquid metal carrying components. Pressure was developed by the interaction of the magnetic field and current which flowed as a result of the voltage induced in the liquid metal contained in the pump duct. Flowrate or pressure was controlled by voltage variation supplied to the pump windings. For details on principle of operation see reference 1. Figure 10 shows a minimum calibration which was made on the pump. The pump was never required to operate at its rated temperature, flow and pressure, but it is sufficient to say that it performed well at all conditions that were required. The maximum requirements were 32 gpm (3.2 lb/sec) at 160 psi with potassium temperature at about 980°F.

The stator winding was of random construction, similar to that used in low voltage polyphase induction and synchronous motors in ratings up to 200 hp. The winding insulation system was Class H, suitable for operation at temperatures up to 200°C. Cooling air at about 1/4 lb/sec was supplied from a 90 psig shop air line to a radial duct at the center of the stator base. Two copper-constantan thermocouples were located in the end windings to provide a means of monitoring pump winding temperature during operation.

The pump duct was made of AISI Type 316 stainless steel. Entrance and exit connections to the duct were immediately adjacent to each other at the same end of the duct. Therefore, the pump duct was able to expand freely without giving rise to stress. The principal parts of the pump duct assembly were the outer tube, the inner tube, and the connector. For further detail on the pump duct refer to Figure 11.

The pump was designed to operate on a 440 volt, 3 phase, 60 cycle power supply. Voltage to the pump was regulated by a motor driven variable transformer. Up to 550 volts could be applied to the pump but, in most cases, the applied voltage was less than 300 volts.

1.1.5 Flowmeter

The flowmeter which was installed in the liquid metal loop for measuring flowrate was an electromagnetic type built by the Mine Safety Applicance Co. (See Figure 12.)

The flowmeter used in the potassium loop had a Type 316H stainless steel flowtube. This meter was designed for 1500°F operation at 150 psig pressure. The electrical signal output was 0.25 millivolt per

1 gpm flowrate (2.5 mv for 1 lb/sec flowrate) at 1100^{o}F. Under steady-state operation of the loop, the E.M. flowmeter, by measuring condenser discharge flow, provided a measurement of the amount of potassium vapor generated by the boiler. To implement this vapor flowrate measuring technique, it was necessary to maintain very accurate control on liquid level in the condenser condensate drum. A change in level of 1.0 inch represented a change in liquid potassium inventory of about 60 lbs. (The condensate drum was 20" I.D. x 7 1/2 ft long. Liquid level was held near the center line of the drum.) During turbine performance testing, this technique was not sufficiently accurate. Flowrate error as high as 20% was apparent. Eventually a more acceptable vapor flowmeter was installed in the bullet nose of the turbine. The turbine inlet bullet nose was calibrated in air for use as a vapor flowmeter. More accurate flowrate measurements were obtained and were correlated with the EMFM data. The EMFM was used to measure vapor flowrate during the 2000 hour endurance test.

1.1.6 Control Valves

All control valves in the liquid metal loop were hermetically sealed to prevent leakage of alkali metal to the atmosphere and to prevent inleakage of air to the alkali metal system. The valve body was an all welded assembly. The valve bonnet assembly included a bellows for sealing against leakage around the valve stem. The valve body, plug and bonnet assembly were made of Type 316 stainless steel. Each valve was designed to withstand 1500^{o}F at 150 psig pressure. All valves except the 8.0" valve, however, operated below 1100^{o}F. Pressure was generally less than 60 psig. In operation, the valve bonnet was pressurized with argon gas to minimize pressure differential on the relatively thin wall (.006") bellows. No difficulty was encountered with these valves during more than 2000 hours of operation. One valve bellows was replaced when it was damaged by cold operation. The liquid metal valves, except the 8.0" valve, were made by the Fisher Governor Company. Figure 13 shows their general construction. All valves were stroked by standard Fisher Governor pneumatic operators.

1.1.7 Check Valve

A check valve was installed in the boiler feed line to prevent the hot liquid metal in the boiler from flowing in reverse through the feed line in the event of E.M. Pump failure. (See Figure 14.) The check valve was a gravity actuated ball valve. Both the ball and ball seat were hard faced with stellite. The 1 1/2" valve was a special design made of Type 316 stainless steel. This valve successfully operated at 700°F - 1000°F for more than 2000 hours.

1.1.8 8.0" Vapor Line Valve

This valve was a special design by the Annin Company in accordance with G.E. specifications. It was constructed of Type 316 stainless steel with stellite surfaces on the plug, seat and steam. It was rated for 1600°F temperature and 60 psia pressure. As with the smaller control valves, the valve stem for the 8.0" valve was bellows sealed. The valve was actuated by an air piston operator. Actual construction of this valve can best be understood by referring to Figure 15.

The main function of this valve was to shut off the flow of potassium vapor in an emergency. However, its secondary function was to serve as a throttling valve during turbine performance testing. A fast bleed air solenoid valve was installed on the valve operator so that the valve would close in about 3 seconds in an emergency.

This valve generally performed well. After several thermal cycles the welded bellows developed a small crack in one of the welded joints. This bellows was replaced by a bellows having a different design and much fewer welded joints. The replacement bellows remained intact during all subsequent operation which exceeded 2000 hours. Another difficulty which was encountered with the valve was galling of the valve stem and stem guide located in the hot potassium vapor. Initially the valve stem was faced with Stellite 6 rubbing against

Type 316 stainless steel. The stainless tended to weld to the stellite. The stainless was replaced by Stellite 12 which worked well for over 2000 hours and for more than 60 full strokes of the valve. This material combination also finally galled. (Future material combinations will be high purity Al_2O_3 against Stellite 6.)

Initially, the valve was a tight shut-off valve; however, throttling caused the stellite seal and plug to "wire draw". The sealing surfaces were reground after the throttling requirements were completed.

1.1.9 Flexible Joint

A flexible joint was installed between the test turbine and condenser inlet duct to minimize bending stresses at the test turbine. Without a flexible joint at this location bending stresses due to thermal expansion of the loop could have been quite high - for the most part unpredictable.

The flexible joint was made of Type 316 stainless steel and can best be described by reviewing Figure 16. This component consisted of a thin wall bellows type flexible joint made of two-ply, 16 gauge material designed for 1600°F operation at 60 psia pressure. The joint was gimballed to provide universal angular rotation of one degree. This component was made by the Zallea Brothers Company.

The two play bellows was designed in such a way that the enclosed volume could be pressurized with argon gas. This provided a much needed leak detection method for the bellows. During normal operation, the internal pressure in the 10.0" flexible joint was below atmospheric pressure. Consequently, if both layers of the bellows developed a leak, air would have been admitted into the alkali metal system unknowingly. By pressurizing the space between the two ply bellows, a fractured ply would have resulted in argon gas leaking into the potassium system or into the atmosphere depending on which ply develops a leak. A small flowmeter in the argon supply line would have indicated a leak in the bellows assembly. Although the flexible joint was subjected to more than 30 thermal cycles and was operated at temperature up to 1450^{o}F, it did not fail in any manner.

1.1.10 Instrumentation

(a) Flowrate

Vapor flowrate was determined from steady state liquid flowrate as discussed in Section 1.1.5. A total to static pressure measurement was made at the turbine inlet during turbine performance testing. Vapor flowrate was determined from this differential pressure measurement. For detailed information on vapor flowrate measurement refer to reference 2.

(b) Pressure

Pressures in the alkali metal loop were measured by two methods, efflux and volumetric displacement.

Though the volumetric displacement devices manufactured by commercial vendors were generally reliable and accurate, their cost and size precluded their use for the very large number of pressure measurements required to be taken at the test vehicle. Therefore, an efflux system was devised for this purpose.

The efflux system consisted basically of a conventional pressure measuring system using standard total and static pressure taps as required. The pressure impulse was sensed by a pressure transducer and converted to an emf signal. However, because of the problems associated with the tendency of the alkali metal to migrate into and eventually plug the pressure taps, a means of continuously purging the pressure lines was provided. Purging was accomplished with argon gas. Only when a data reading was being taken were the pressure taps exposed to the pressure in the alkali metal loop. A detailed description of the efflux system is presented in reference 2.

Pressure in potassium liquid lines and in a few potassium vapor lines was measured by volumetric type pressure sensors made by the Taylor Instrument Company (Figure 17). These sensors consisted essentially of three parts: (1) the pressure sensitive (slack) diaphragm unit, (2) a Bourdon spring, coupled with an air transmitter, and (3) an appropriate length of connecting capillary which was filled with NaK, an alkali metal which is liquid at room temperature. When pressure was applied to the diaphragm it deflected inward slightly, displacing the liquid beneath it. The resultant movement of the transmitting liquid through the capillary in turn caused the Bourdon spring to unwind. Movement of the Bourdon spring actuated a pneumatic transmitter mechanism which in turn sent a proportionate air signal to a receiver gauge or recorder in the Control Room. The sensing diaphragm of the volumetric gauges used in the alkali metal loop were rated to operate at 1500°F - the pressure rating varied and depended on the location of the gauge. The gauge diaphragm was kept below 1000°F during facility operation by isolating the diaphragm from the hot liquid with a "goose-neck" trap. The accuracy of these gauges was 1/4%. They were, however, slightly sensitive to temperature and were corrected accordingly. For details on gauge accuracy and temperature sensitivity refer to reference 3. These gauges proved to be quite stable over long periods of time. After completion of the 2000 hour test, calibration of the gauges with pressurized argon gas revealed an indicated accuracy within 2.0% of full scale.

(c) <u>Temperature</u>

Temperature of all components, piping, etc. was sensed by thermocouples. Most were chromel-alumel. A few were iron-constantan; a few, copper-constantan. Several platinum - platinum 10% rhodium couples were on the boiler tubes. Figure 18 shows boiler thermocouple location.

Essentially all pipe thermocouples were spring loaded bayonet type combined with Thermo-Electric type pipe clamp adapters. Large components, such as the dump tank, condenser tank and the 8.0" vapor pipe, were instrumented with surface type thermocouples. These couples were inserted in a small stainless steel block which was welded to the surface. For measuring the temperature of potassium vapor, the thermocouples were inserted in a thermal-well which extended several inches into the vapor stream. A typical thermocouple probe of this type is shown in Figure 19. There were approximately 300 thermocouples located throughout the facility. In addition, there were three radiation pyrometers installed on the furnace to monitor boiler tube temperature.

All thermocouples remained in good calibration $\pm$ 10°F except those used to measure vapor temperature out of the boiler or into the turbine. After about 350 hours of operation and up to 30 thermal cycles, the thermocouples used to measure vapor temperature at 1450°F - 1580°F drifted as much as 54°F. These were replaced, and the new thermocouples showed good stability (less than 15°F drift) for the next 1750 hours at 1500°F.

(d) Liquid Level

It was necessary that the liquid level in the boiler vapor drum, condensate drum and dump tank be known within $\pm$ 1/2 inch. Since these tanks contained potassium under pressure at high temperature, conventional boiler type liquid level indicators were not acceptable. The liquid level measuring systems used in the 3000 KW Facility were nuclear radiation gauges manufactured by Ohmart Corporation and a "J-tube" resistance-type probe located on the boiler hot trap. All Ohmart level gauges utilized a gamma-emitting radioactive source (cesium-137) and a Geiger-Mueller tube detector to measure the level of liquid. Their operation depended upon the principle that the absorption of gamma radiation by any material is a function of the mass of the material lying between the radioactive source and the detector or measuring unit. Hence, a change in the potassium liquid level was reflected in the amount of radiation detected and a subsequent change in the detector output.

The boiler liquid level measuring system contained a 100 millicurie point source located on the east side of the boiler vapor drum and external to the boiler structure. The radiation detector was on the opposite side of the vapor drum and was also external to the furnace structure. Consequently, the measuring system was easily calibrated and repaired even while the boiler was in operation. Lead plates, sized to simulate known liquid levels, were inserted between the source and receiver to calibrate the level gauge.

A strip source was used in the dump tank and condenser tank liquid level measuring systems. These sources were held in a source-well which protruded into the tank - i.e. the source was in the tank. In all cases the radiation receivers were outside the tanks and well insulated against the high temperature of the tanks.

Through a pneumatic controller, the condenser drum liquid level measuring system regulated the condenser discharge valve, VPL-5 (Fig.2) so as to maintain a fixed level in the condenser drum. Condenser drum liquid level was easily maintained within 5/8 inch. When a more precise level was required, the pneumatic controller was generally switched to manual.

Dump tank liquid level was indicated with no automatic control action involved. Boiler liquid level was controlled indirectly. For example, once the facility was operating steady-state, the liquid was was pumped directly from the condenser to the boiler -- thus maintaining a constant potassium inventory in the loop. By maintaining a constant condenser level, the boiler level also remained constant. Referring to Figure 2, if the boiler level had to be increased, valve VPL-13 was momentarily opened so that potassium would be forced, by using high argon pressure, from the dump tank to the boiler. If the boiler level had to be decreased, VPL-6 was momentarily closed and VPL-13 momentarily opened. The E.M. pump would pump potassium from the condenser to the dump tank.

The radiation gauges performed well during more than 2300 hours of facility operation. One disadvantage of this type gauge was slow response -- in the order of one minute. On the other hand, the slow response resulted in an averaging indication of liquid level which was found to be a big advantage in the boiler and condenser where the liquid-vapor interface was always turbulent. The level gauges were calibrated about every 7 days by using lead plates. Gauge drift was usually minor -- less than 10% in 2 to 3 weeks. The weak link in these gauges appeared to be in two of the electronic components, the G-M tube and trigger tube. The life of these components varied from 1 day to 6 months but even they could be replaced while in operation followed by an "in-operation" calibration.

The response time of the nuclear radiation gauges was in the order of one minute. Although satisfactory for steady state or slow transient operating conditions, when faced with boiler instability, it was desirable to have a faster responding instrument to monitor boiler vapor drum liquid level. Therefore, a J-tube resistance-type liquid level probe was installed in the top of the boiler hot trap. (See Figure 3 for exact location of the J-tube.)

The J-tube gauge consisted of three concentrically-arranged conductors swaged with an insulating layer of MgO between them. The end of the enclosing sheath was welded to form an electrical contact between the three conductors and the tube was then formed into a "J" shape.

The center conductor was a voltage lead; the middle conductor, a current lead; the outer sheath, the current return. Liquid metal served as a shunt around the submerged portion of the sheath, and the voltage drop from the common junction of the three conductors was a function of the amount of sheath shunted by the liquid metal. The center conductor was a voltage lead only and carried no current with a readout device of infinite impedance. The output of the J-tube liquid level gauge was read as a millivolt signal on a continuous recorder, such as a Sanborn. Further details on the performance of a J-tube can be obtained from reference 4.

The J-tube was found to have a very fast response - in the order of one second. As suspected, it responded to the many ripples of the liquid interface in the boiler. A typical recorder tracing is shown in Figure 20. The J-tube level gauge performed well while in use. It was discontinued after boiler stability was achieved.

1.2 Potassium Metal Vapor Quality

The vapor quality control and measuring system is represented by the phantom lines on Figure 21. Basically, the vapor quality system consisted of a means for mixing saturated potassium liquid with saturated vapor and a means of determining the quality of the vapor into and out of the test turbine.

As previously mentioned, the vapor quality out of the gas fired boiler was in the order of 99%. As discussed in Paragraph 1.1.1, the boiler design, naturally, provided for the discharge of relatively dry vapor with minimum liquid carryover or entrainment. Initially, test conditions for the test turbine required steady-state vapor quality between 85% and 98%. Vapor quality was regulated by spraying of a known quantity of saturated potassium liquid into the vapor stream immediately upstream of the test turbine. The liquid was heated to near saturation temperature by a reheat coil located in the boiler vapor drum. A heat balance was performed to determine the resultant vapor quality.

To determine the vapor quality going into the test turbine, it was necessary to know the vapor quality upstream of the spray nozzle as well as the flowrate of liquid being injected. Upstream vapor quality was measured by a throttling calorimeter which worked on the same principle as a steam calorimeter. It was an effective instrument for measuring potassium vapor quality between 96% and 100%.[1] The discharge of the throttling calorimeter was piped directly to the condenser. The valve in this line served only as a shut-off valve.

1. See reference 5

A throttling calorimeter could not be used to measure the low quality vapor out of the test turbine, which varied between 80% and 96%. Therefore, a heating calorimeter was used in this region. The principle of the heating calorimeter was to superheat the wet vapor so that its thermodynamic properties could be determined from temperature and pressure measurements. Knowing the heat input and sample flowrate the initial quality of the vapor could be determined from the Mollier diagram.

Both calorimeters were based on principles described in reference 5. The vapor quality measurement systems are discussed in greater detail in Paragraphs 1.2.5 and 1.2.7. The relative position of the two calorimeters, with respect to the turbine, is shown in Figure 22.

1.2.1 Control Valves

The vapor quality system employed three control valves made by Fisher Governor Company. These valves were essentially the same as those described in Section 1.1.6.

VPL-10 was used to regulate the flowrate of saturated liquid that was sprayed into the vapor stream. VPL-1 and VPL-2 were used to control the flowrate of potassium sample passing through the throttling and heating calorimeters, respectively. In actual use the valves were either fully open or fully closed.

1.2.2 Flowmeter

This E.M. flowmeter was identical to the one described in Section 1.1.5. Its function was to measure the flowrate of liquid potassium that was being sprayed into the vapor stream.

1.2.3. Spray Nozzle

To have a relatively uniform mixing of the saturated liquid and vapor at the entrance of the test turbine, liquid was sprayed into the vapor stream under 130 to 150 psig pressure. The spray nozzle was a variable area type designed by General Electric and built by Associated Controls, Inc. A sectional view of the nozzle assembly is shown in Figure 23. The nozzle was designed to give a hollow conical spray so that impingement on the pipe wall and turbine inlet bullet nose would be minimized. The valve plug was forced closed by argon gas pressure and open by liquid potassium pressure. Argon and potassium were separated by a bellows assembly which was so sized that argon at about 40 psi pressure was required to balance 150 psi potassium pressure. Potassium entered the valve through Part 12 and was distributed uniformly to the plug, Part 1, by a multi-port ring in Part 5. Part 5 was also the piston of a dash pot to prevent valve chatter.

Argon pressure was applied through Parts 13 and 14. Bellows, Part 7, had a greater net effective area than did bellows, Part 6. Therefore, the argon pressure tended to move the plug to the closed position. Also the net effective area of the plug, Part 1, was slightly greater than bellows, Part 6. Thus the potassium pressure tended to open the valve.

The valve was constructed of Type 316 stainless steel. All wear surfaces were hard faced with tungsten carbide. The spray valve was welded into a removable spool piece that was located immediately upstream of the test turbine.

In operation a predetermined argon gas pressure was applied to the valve (30 to 40 psi). Throttling valve VPL-10 was slowly opened to allow the desired flowrate of liquid to enter the spray valve. Potassium liquid pressure increased rapidly to a pressure (about 140 to 150 psig) required to force the spray valve open - allowing the liquid to spray out at the rate set by VPL-10.

Average drop size from the spray valve as measured by water tests was in the order of 150 to 250 microns. The spray valve operated satisfactorily to the extent that a controlled amount of liquid was sprayed into the potassium vapor stream at temperatures up to 1580^{o}F. Spray pressure ranged from 100 to 150 psig depending on the potassium flowrate and E.M. pump capacity. However, the end result was severe erosion of the turbine stationary and rotor blades. Details of this test can be found in reference 6. The spray valve was also used extensively during a convergent-divergent nozzle test to vary vapor quality down to 85% at potassium temperatures up to 1580°F. Details of these tests can be found in reference 7.

1.2.4. 8.0" Vapor Pipe Heater

The 8.0" vapor line between the boiler and test vehicle was about 13 feet long. If this pipe had not been heated, some vapor would condense on the pipe wall and flow along the pipe wall (probably on the bottom) into the test turbine. This was undesirable since it would have been difficult to obtain a representative vapor sample at the throttling calorimeter as well as having obvious deleterious effects upon the operation of the high speed test turbine.

To reduce the flow of liquid on the pipe wall, Hevi-Duty Electric Company circular refractory type heating elements were located along the length of the eight inch pipe. Three heating element sections were upstream of the throttling calorimeter. These heaters were designed to vaporize the liquid (up to 2% total potassium flowrate) that tended to flow along the pipe wall.

A fourth Hevi-Duty type heater was located downstream of the throttling calorimeter. This was called a compensating heater - i.e., it supplied only enough heat energy to compensate for the heat loss from the 8.0" pipe between the throttling calorimeter and the test turbine. Heat loss was calculated from known thermal insulation properties and temperature drop across the insulation. During the 2000-hour turbine endurance test, the 3 stage heater supplied only enough heat to compensate for heat loss from the 8.0" pipe.

1.2.5 Vapor Quality Measurement Entering the Turbine

As described in Paragraph 1.2, a throttling calorimeter was used to measure vapor quality going into the test turbine. The calorimeter was very similar in design and function to a steam calorimeter. One-eighth-inch holes were located in the sampling tube for equal area sampling as shown in Figure 24. The wet vapor sample was expanded through a 1/4" orifice. A spiral ribbon at the exit of the orifice provided surface to facilitate evaporation of any superheated liquid that may have passed through the orifice. Immediately downstream of the spiral ribbon was the temperature - pressure measuring station. The pressure probe was an efflux sensor as described in Paragraph 1.1.10 during performance testing. The pressure sensor was changed to a Taylor Company volumetric gauge during the 2000-hour turbine endurance test. The thermocouple was a Cr-Al couple in a thermowell. The superheated vapor flowed through VPL-1 and then directly to the main condenser.

The throttling calorimeter continued to perform reliably throughout all phases of facility operation. When the facility was first placed into operation with a convergent-divergent nozzle in place of the turbine, the throttling calorimeter was calibrated versus the C-D nozzle in regards to vapor quality. Agreement of the two quality measuring devices was within 1/2%.

Vapor quality from the boiler was a function of vapor mass flow which might be expected. Figure 25 indicates this for one boiler temperature condition. Reference 2 presents additional information on vapor quality.

1.2.6 Vapor Quality Measurement Leaving the Turbine

Vapor quality at the exit of the turbine was expected to be in the order of 80% to 95%. This was too low a quality to measure with a throttling calorimeter. A heating calorimeter was used for this application. Its general arrangement is shown in Figure 26.

Basically, the heating calorimeter was to heat wet vapor to superheated vapor. With superheated vapor one temperature and one pressure measurement would be sufficient to establish the thermodynamic location of the vapor on a Mollier diagram. If the vapor flowrate, heat input and inlet pressure or temperature were known, the initial thermodynamic properties, including vapor quality, could be determined from the Mollier diagram.

Vapor flowrate for the heating calorimeter was determined by measuring the heat input to the superheated vapor stream by a second electrical heater immediately downstream of the superheater. Flowrate was determined from the equation $Q = W\ Cp\ \Delta t$. The temperature difference of the superheated vapor was measured with thermocouples; Q was the electrical heat input; Cp was obtained from thermodynamic tables. Actually, both the superheater and heater were made as an integral unit. After the vapor left the second heater, it passed through an open valve, VPL-2, and entered a small air cooled condenser.

Pressures were measured with the efflux probes. Temperatures were measured with Cr-Al thermocouples. Those couples which measured vapor were in thermowells.

The vapor sampling tube was drilled for equal area sampling. However, from the start it was strongly suspected that a good representative wet vapor sample would no doubt be difficult to obtain at the exit of the turbine. This belief was primarily based on the turbine scroll design which in effect would tend to sling most of the liquid against the exit pipe wall. During turbine performance testing vapor quality measured with the heating calorimeter was consistently 3% to 6% higher than it should be. This, of course, suggested that the sampling probe which was in mid stream of the exit duct was not collecting a representative sample. Exit vapor quality is also discussed in reference 2.

The heating calorimeter gave little trouble except for plugged efflux pressure taps. However, it was most difficult to maintain proper heat control for the many conditions encountered during turbine performance testing. Response of the heating calorimeter to changing conditions was in the order of 15 to 20 minutes. (The throttling calorimeter responded within seconds.) The basic concept of the heating calorimeter was sound, and it was a workable instrument for steady state applications and for application where a representative sample is obtainable.

Development effort on a compact heating calorimeter for potassium vapor is being performed under an Air Force Contract AF33(615)2495.

1.2.7 Exit Calorimeter Condenser

A vapor condenser was downstream of the heating calorimeter. Cooling of the condenser was accomplished by a controlled flow of air. The condenser also had two electrical heating elements attached to it to maintain the tube wall at 300°F to 500°F minimum temperature. This was to preclude the possibility of potassium freezing in the condenser.

The main function of the calorimeter condenser was to liquify the potassium vapor that exhausted from the calorimeter, so that the jet exhauster could perform properly. This is discussed in the next section.

1.2.8 Jet Exhauster

An exhauster was provided to create a suction on the heating calorimeter. The main condenser was the lowest pressure point in the liquid metal loop and the sampling tube for the heating calorimeter was essentially at condenser pressure. Therefore, without a suction on the exit calorimeter, it would have been impossible to extract a vapor sample from the turbine outlet.

The exhauster was a modified Schutte and Koerting #2 (482) liquid jet exhauster made of Type 316 stainless steel.

The driving fluid for the exhauster was the 250°F potassium liquid from the air-cooled heat exchanger (Paragraph 1.4.3) that went to the packed column condenser (discussed in Paragraph 1.4). Driving liquid flowrate was limited to about 12 gpm at about 15 psig. For this limited flow, the exhauster could not create a sufficient suction unless the potassium was liquified and cooled to 500 to 600°F.

1.3 Condensate Extraction System

The test turbine was a so-called wet vapor turbine - i.e., the driving potassium vapor contained a relatively high percentage of liquid. Initially it was intended to extract liquid (condensate) from each of the two stages of the turbine. The turbine casing was designed to permit collection of the condensate from each stage so that it could be drained to a collecting tank.

The condensate extraction system was primarily a "batch-type" measuring system. (Refer to Figure 27.) Phantom lines show the extraction system. Condensate from the turbine was to be collected in two separate tanks, one for each turbine stage. Measurement of condensate flowrate was to be determined by measuring the filling rate of the two tanks. When each tank was filled to a predetermined level, a drain valve was to open to discharge the potassium liquid to the main condenser condensate drum.

During preliminary testing of the potassium turbine with steam, it was determined that the percent of condensate removal was quite low. (Refer to Figure 28.) It can be seen that regardless of the absolute level of upstream injection of water to the turbine, the condensate extraction effectiveness decreased with increasing speed, and the ratio of extracted-to-injected flow has a fixed value at any given speed. In addition, most of this liquid was extracted from the second turbine stage as shown in Figure 28. The results indicated that at pertinent speeds (above 16,000 rpm) the condensate extracted is less than 10% of injected flow. Therefore, no attempt was made to extract liquid from the turbine during potassium testing.

1.4 Argon Extraction System

Argon gas entered the main liquid metal loop from two principal sources: the efflux pressure measuring system [Paragraph 1.1.10(b)] and the turbine slinger seal (Paragraph 1.11). It had to be removed to prevent flooding of the condenser with a noncondensable which would eventually destroy the condenser efficiency.

The argon extraction system consisted of two loops - a liquid metal loop and an argon loop. The system was designed to remove about 3 lbs/hr of argon from the condenser. This was accomplished by using a flow of relatively cool potassium liquid to directly condense the potassium vapor from the mixture of potassium vapor and argon which collected near the top of the condenser condensate drum. The cool K liquid flowed downward through a vertical separator cascading through a series of baffles, condensing the potassium vapor while allowing the noncondensable argon to pass upward and out to the argon portion of the system. The separator was positioned on top of the condensate drum, and it was the key component in the argon extraction system although a vacuum source was required to actually remove the argon. Other components which made up the two loops are essentially control elements.

The phantom lines shown in Figure 29 show the liquid metal portion of the argon extraction system schematically. The main E.M. pump supplied liquid potassium under pressure to a throttling flow control valve, VPL-8. This valve was set manually to provide a pre-established and constant flow rate of potassium to the packed column condenser. An E.M. flowmeter measured the flow. Potassium at 600^{o}F to 1000^{o}F from the main condenser drum passed through an air-cooled heat exchanger where it was cooled to 250-275^{o}F. This liquid potassium was also the driving fluid for the exhauster discussed in Paragraph 1.2.9. After leaving the exhauster, the liquid K entered the top of the packed column at essentially condenser pressure, 3.5 to 10 psia.

The argon portion is shown schematically in Figure 30. The exit end of the argon loop was tied into the facility vacuum system (see Paragraph 1.7) which produced the pressure drop to pull the argon from the condenser. The argon, still containing a small amount of K vapor, flowed from the packed column through a 10-foot long, 2-inch diameter pipe filled with demister wire, a 6-inch diameter vertical vapor trap, a pair of liquid nitrogen-cooled vapor traps, a pair of 200 micron filters, and thence through a flowmeter. The Fischer-Porter type flowmeter provided first, an indication that the argon system was not plugged or restricted, and second, a measurement of the actual argon extraction flowrate. The flow control valve VDE-1 discharged the now essentially pure argon into the vacuum header.

Valve VDE-1 controlled the argon flowrate through an EMF-to-air converter controller which sensed the mixture temperature near the top of the packed column. For example, if the valve tended to open, a greater quantity of hot potassium vapor and argon mixture entered the packed column. Since the flowrate of cool liquid potassium down through the column was constant, the temperature gradient in the column shifted to a higher level in the column for the higher hot mixture flowrate. Consequently, the temperature at the thermocouple location increased (normally set for 350^{o} to 400^{o}F), and VDE-1 tended to close, reducing the flowrate of the incoming gas mixture. The reverse occurred if the mixture flowrate tended to decrease below that amount required to maintain a fixed temperature at the thermocouple location. VDE-1 could also be controlled manually.

During some tests, such as the turbine endurance test, argon was not injected into the alkali metal loop at a very high rate. In this case, VDE-1 closed tight but still was not able to effect a reduction in the temperature at the packed column to the required value. This was because larger quantities of hot potassium vapor condensed higher in the column. To prevent an overtemperature in the packed column due to insufficient argon coming through the packed column, a separate argon supply was provided to actually add more argon to the packed column. This was control valve VDE-2 with a controller which sensed and responded to temperature near the top of the packed column. If the temperature at that point got too high, 500°F - 550°F, valve VDE-2 would open to admit argon until the temperature was reduced to below 500°F.

It should be noted that the total pressure at the top of the packed column was essentially the same as the pressure in the condensate drum. The total pressure was the sum of the argon partial pressure and the potassium partial pressure. The objective was to have a very low potassium partial pressure which was the vapor pressure of the potassium at the temperature involved at the top of the column.

Two liquid nitrogen traps were installed in parallel so that when one became plugged, the spare could be put into service while the plugged one was being cleaned. Initially, great difficulty was encountered keeping the LN_2 traps unplugged. However, after installing a larger vapor trap with a weight indicator and an alarm system upstream of the LN_2 traps, no difficulty was encountered keeping the argon extraction system open. For example after 2 to 3 pounds of liquid were collected in the newly installed vapor trap, VDE-1 was closed momentarily allowing the liquid to drain back to the condenser. Draining was required 1 to 2 times in 24 hours.

1.4.1 Control Valves

All valves in the argon extraction system were bellows sealed valves made by the W. Powell Company. However, all remote operated valves were equipped with Fisher Governor operators and positioners.

Automatic control air signal was supplied to VDE-1 and VDE-2 by Foxboro Type 33 EMF-to-air converters coupled with Foxboro M/52 indicator controllers. Thermocouples were Cr-Al.

1.4.2 E.M. Flowmeter

As mentioned previously, the E.M. flowmeter measured the quantity of potassium entering the top of the packed column. This flowmeter was identical to the one described in Section 1.1.5.

1.4.3 Heat Exchanger

The liquid potassium out of the E.M. pump was normally at 600°F to 1000°F. As discussed in Section 1.4, it was essential that the potassium entering the packed column be in the order of 250°F to 275°F. Therefore, the need for a heat exchanger was established. The heat exchanger was rated for 450 Btu/sec heat removal rate. The cooling medium was forced air.

The heat exchanger was a so-called hockey-stick finned tube exchanger which was designed and built by Struthers-Wells in accordance with G.E. Specifications. The material in contact with alkali metal was Type 316 H stainless steel. Air side material was mild carbon steel. Figure 31 shows the heat exchanger components ready for assembly.

Since potassium would freeze at about 150°F, the cooling air to the heat exchanger was preheated to 200-250°F to minimize the probability of potassium freezing in the heat exchanger. The inlet to the air blower for the heat exchanger contained a three-way butterfly valve which automatically mixed hot air from the main condenser exhaust stack with ambient air to maintain cooling air at 200°F to 250°F going into the heat exchanger. Preheating of the heat exchanger on start-up was also accomplished in this manner.

The air outlet of the heat exchanger contained a two-way butterfly valve. Its primary function was to regulate the flow of air through the heat exchanger, but it would also be closed to isolate the heat exchanger in the event of a potassium leak and fire. Air out of the exchanger was about 600°F to 700°F. This hot air entered an augmentor and was ducted above the top of the test cell. No difficulty was ever encountered with the heat exchanger regarding plugging or leaking. It was easily controlled to maintain the desired potassium exit temperature.

1.4.4 Packed Column Condenser

Refer to Paragraph 1.4 for discussion.

1.4.5 Vapor Cold Trap

As previously mentioned in Paragraph 1.4, two liquid nitrogen cooled vapor traps were located in the argon discharge line from the packed column. These traps were designed to cool the argon stream, which contained some potassium vapor. By so doing, the potassium vapor was condensed on the extended surfaces in the trap. However, some snow like flakes would break away from the surfaces and would be carried on through the argon piping. To trap this, a 200 micron screen filter and a 40 micron wire screen filter were installed downstream of the cold trap to collect the finer solid particles.

Liquid nitrogen was supplied to the traps automatically by a Johns and Frame Company liquid nitrogen level controller.

During steady-state operation the LN_2 traps and/or filters required cleaning every 2 to 3 weeks on the average. Occasionally, the traps would inadvertently become restricted more often and would require cleaning within 24 hours.

1.4.6 Argon Flowmeter

The argon flowmeter was a Fischer-Porter flowrator. This meter was installed in the argon extraction line to indicate plugging of the traps or filters. More important, it was desired to know the amount of argon being extracted.

1.4.7 Instrumentation

There were several Cr-Al thermocouples attached to the liquid metal pipe. These served as monitoring couples and as high temperature alarm thermocouples. The argon line from the packed column also contained a Taylor Co. volumetric pressure transmitter. This transmitter measured the condenser pressure and also provided a reliable indication of plugging in the argon extraction line immediately downstream of the packed column.

1.5 Turbine Argon Reclamation

The potassium turbine shaft contained a labyrinth seal which separated the rotating cup seal K cavity from the lube oil cavity. This seal was divided into two parts such that an argon gas flow supplied to the seal split - part going into the K cavity and the other part going into the lube oil sump. Argon flowrates up to 150 lb/hr were required to maintain this buffer seal. The high cost of high purity argon precluded discarding the argon after a single pass through the seal. Therefore, an argon reclamation system was designed which would clean and recirculate the argon gas. Makeup argon from a liquid argon supply tank contained in the order of 2 to 3 ppm oxygen and in the order of 1 to 2 ppm H_2O. Reclaimed argon, after passing through the potassium slinger seal loop, generally contained in the order of 1/2 to 1 1/2 ppm oxygen and in the order of 1/2 to 1 ppm H_2O.

The reclamation system consisted of flow and pressure control elements, gas purifying elements, and a recirculating gas compressor. To guard against the contamination of the argon gas, the reclamation system was essentially hermetically sealed. The loop was an all-welded Type 304 stainless steel installation. All valves were bellows sealed. Where mechanical joints were necessary or unavoidable, special precautions were taken to minimize inflow of even minute quantities of ambient air. The reclamation loop contained instrumentation for detecting contaminants such as oxygen, water vapor and oil vapor. The purification elements in the loop had the capacity for maintaining an argon purity equal to or better than the initial argon supply, except for oil vapor.

Figure 32 is a schematic diagram of the reclamation system. The argon compressor was a diaphragm compressor capable of pumping 300 lb/hr of argon gas at 200 psig discharge pressure (inlet pressure 5 psig). Refer to Section 1.5.1 for details.

The compressor delivered the argon gas to a 20 ft^3 discharge receiver which served as both a storage tank and as a surge tank. From the receiver tank the gas entered a filter (Linde molecular sieve) where entrained oil vapor was removed. Out of the molecular sieve the argon was delivered to four different sub-loops: (1) to the turbine labyrinth seal at 40 to 60 psia, (2) to the O_2 analyzer at 35 psia, (3) to the efflux pressure system at 115 psia, and (4) to a bearing test loop at 150 psia. (The bearing test loop was not part of the 3000 KW Turbine Facility.)

A portion of the argon from the rotating cup seal was returned to the reclamation system through the turbine lube oil sump. This argon contained relatively large quantities of oil in the form of droplets and vapor. The mixture first passed through a demister type primary oil separator. Oil entrained in this separator was returned to the defoaming tank in the turbine lube oil system. The argon-oil vapor mixture then flowed through a forced-air cooler, another demister, a free-convection cooler, a secondary cartridge-type oil separator, and then through a 6" diameter, 6 foot long, large surface area demister. The successive cooling steps in the process lowered the oil vapor pressure in the mixture, and the final large surface area demister removed most of the entrained oil vapor. The argon then flowed to a liquid nitrogen cooled vapor trap and a molecular sieve filter to remove remaining oil which was still in the gas. From the last filter unit the argon was relatively free of oil and relatively cold. Therefore, to prevent frosting of the glass tube flowmeters, the argon was heated to near room temperature in a free convection heater. The flowmeter indicated the argon flowrate across the oil side of the labyrinth seal. A pressure control valve VDR-1 on the downstream side of the flowmeter was set to maintain a predetermined pressure on the discharge side of the labyrinth seal (oil side). Argon from the control valve entered the compressor inlet receiver. The inlet receiver had a volume of 7 ft^3 and was installed to reduce pressure surges at the compressor inlet.

Although extreme measures were taken to remove essentially all traces of oil from the argon, it was found impractical to reduce the oil concentration to in the order of 5 ppm during continuous operation. Therefore, eventually the argon from the oil side of the turbine labyrinth seal was discarded after passing through VDR-1. The loss of argon at this point was reduced to 15-20 lb/hr.

Argon was also returned to the reclamation system from the potassium side of the labyrinth seal. This argon was returned by way of the so-called slinger seal loop, Paragraph 1.11. Purification of this argon took place in the slinger seal loop, since the 800°F potassium served as a good oxygen getter and since the slinger seal loop contained the necessary filtering system for removing residual potassium dust from the argon. Consequently, no additional clean up was required in the reclamation loop. After passing through liquid nitrogen cooled vapor traps in the slinger seal loop, the argon passed through a free convection heater which raised its temperature to about room temperature before it flowed through a glass tube flowmeter. The flowmeter indicated the argon flow across the K side of turbine labyrinth seal. A pressure control valve, VDR-2, maintained a preset pressure on the outlet side of the labyrinth seal. (It should be noted that valves VDR-1, VDR-2 and VDR-4 in combination set the pressure drop and consequently the flow across the labyrinth seal.) Argon from VDR-2 entered the inlet receiver.

The normal argon flowrate across the potassium side of the turbine labyrinth seal was 60 to 70 lb/hr. This argon was reclaimed at all times since this was very pure argon. The potassium in the turbine slinger seal loop removed essentially all of the O_2 and H_2O from the argon. Consequently, O_2 concentration of argon supplied to the labyrinth seal remained in the order of 1 to 1-1/2 ppm, and H_2O concentration remained at less than 1 ppm.

Argon make-up was supplied from the argon system discussed in Section 1.7. Make-up enters the reclamation system through valve VDA-7. Make-up was supplied to both the inlet and discharge receiver tanks but at different pressures. Make-up was supplied to the discharge receiver if the pressure in the tank dropped below 110 psia. Make-up was supplied to the inlet receiver if its pressure dropped below 18 psia.

Make-up was supplied to the discharge receiver so that argon would continue to be supplied to the labyrinth seal even though the compressor stopped. The make-up supply was sufficient to last for about 5 days. The pumping capacity of the diaphragm compressor was quite dependent on its inlet pressure. To maintain the desired pumping rate it was necessary that the inlet pressure to the compressor be maintained at 16 psia minimum. In addition to maintaining high compressor efficiency, it was desired to maintain all parts of the reclamation system above atmospheric pressure. This was to minimize inflow of air should a leak occur in the system.

Valve VDR-8 was a pressure relief for the discharge receiver. It was set at 125 psia. It discharged into the vacuum header instead of dumping directly to the atmosphere. This was an additional precaution against back flow of air into the argon system. VDR-9 was the pressure relief valve for the inlet receiver. This valve had a set pressure of 20 psia, and it also dumped into the vacuum header. The vacuum header contained a pressure relief valve set at 5 psig. This was to prevent high pressure in the vacuum pumps.

Since the efflux pressure measuring system contained very small bore hypodermic tubing which could be easily plugged, the efflux argon supply line contained a sintered stainless steel 5 micron filter.

This filter was immediately downstream of the efflux pressure control valve, VDR-5.

For initial clean up and helium leak checking, a vacuum was pulled on the argon reclamation system. Through a valving arrangement the entire, or portions of the, reclamation system was evacuated to less than 1 micron.

1.5.1 Diaphragm Compressor

The diaphragm compressor was a double head V-compressor made by the Corblin Company, Paris, France. The American representative was the American Instrument Company. The compressor was rated to deliver 50 SCFM (300 lb/hr) of argon at 200 psi discharge with an inlet pressure of 20 psia. The compressor was driven by a 20 hp electrical motor. The installation of the compressor and receiver tanks are shown in Figure 33.

Figure 34 shows the basic arrangement of the diaphragm compressor. Each head of the compressor consisted essentially of two cylindrical plates, each with a concave recess hollowed out in its contacting face between which a flexible metallic diaphragm was gripped and held in position by bolts.

This twin-cylinder compressor had two pistons mounted in a Vee arrangement above the same crankshaft. The pistons acted on the oil, with which the cylinder of the pump was filled, and thus imparted an oscillating motion to each diaphragm. The action of the diaphragms displaced the gas on the opposite side of the diaphragms. Through a valve arrangement a pumping action was developed.

The function of the compressor was to recirculate the argon in the reclamation system by continuously pressurizing the argon gas to about 125 psig. The diaphragm compressor generally worked well requiring only minor attention. After about 500 hours of intermittent operation one of the exhaust valves broke. A metal chip from the valve became lodged under the diaphragm causing the diaphragm to crack. After replacing the defective valve and diaphragm, the compressor operated continuously for about 2000 hours without incident.

1.5.2 Receiver Tanks

The reclamation system had Type 304 SS inlet and discharge receiver tanks, 7 ft^3 and 20 ft^3 respectively, as discussed in Section 1.5. Both were rated for 200 psig at 250°F.

1.5.3 Control Valves

There were numerous control valves in the argon reclamation system. (For survey of number and function, see Figure 32.) All valves in this system were bellows sealed. They were made by the Powell Company; operators, positioners and controllers, however, were made by Fisher Governor Company.

All valves with the second digit "M" were manually operated. Essentially isolating valves, they were either fully open or fully closed during operation. All valves with the second digit "D" were diaphragm operated. Some of these valves were self-contained pressure control valves. Valves such as VDR-7, -8, -9 were equipped with Fisher Governor Wizard controllers; valves such as VDR-4, -1, and -2 received their control signal from a remote panel loader or pneumatic pressure transmitter.

1.5.4 Molecular Sieves

Two molecular sieves were installed in the argon reclamation system. The molecular sieves were in effect a molecular filter, i.e., they allowed molecules of certain size to pass but retained molecules of larger size. The reason for having molecular sieves in the argon line was to block the flow of oil vapor that came from the test turbine or from the diaphragm compressor.

The molecular sieves did become saturated in time. Therefore, two sieves were placed in the system in parallel. While one was being used the other would be on standby. Each sieve could be isolated from the loop by closing a manual valve on the inlet and outlet side of the sieve. It is sufficient to say that the molecular sieves worked well for several hours, removing essentially all traces of oil vapor. It eventually became more expensive to remove oil vapor to the order of 5 ppm then it was to discard the argon. Therefore, the argon from the turbine oil sump was discarded, and the argon supply to the turbine labyrinth seal remained free of oil contamination. The molecular sieves were left in the system to guard against oil vapor contamination caused by a possible ruptured compressor diaphragm.

1.5.5 Oxygen Analyzer

The oxygen analyzer, a Model M-4 Minoxo Indicator by Englehard Industries, was installed to measure and record traces of oxygen in the argon. The detection range of the instrument was 0 to 100 parts per million. Accuracy was $\pm$ 5% of full scale over a 24 hour period. The basic oxygen measuring element in this instrument was a galvanic cell. This cell, which was contained in a glass tube through which the sample gas passed, consisted of a silver cathode and an anode made of active cadmium. These electrodes were separated by a porous tube saturated with potassium hydroxide.

Oxygen in the sample gas was adsorbed on the surface of the cathode and went into solution in the electrolyte as hydroxyl ions. The metallic cadmium of the anode was oxidized to cadmium hydroxide and this process caused a current to flow in the external circuit, consisting of a recorder and resistor load connected across the cell electrodes. The millivolt output from the cell was directly proportional to the oxygen concentration in the sample gas up to about 30 ppm. The argon was fed continuously through the instrument at a flowrate of 22 liters per hour. Inlet gas pressure was held between 5 and 10 psig.

Referring to Figure 32 it will be noted that an argon gas sample could be withdrawn from 3 different locations in the argon reclamation loop. A sample could be taken from the make-up supply line, upstream of the inlet receiver, or from downstream of the molecular sieve. The last location was the most important since argon went from the sieve directly to the turbine where it came in contact with potassium.

1.5.6 Water Vapor Analyzer

Since argon being supplied to the turbine labyrinth seal came in contact with alkali metal, it was imperative that the argon be free of water vapor (less than 5 ppm) as well as oxygen. Water vapor forms potassium hydroxide which in high concentration would plug the loop. An electrolytic hygrometer was used to monitor the water content of the argon flowing to the turbine. The hygrometer, "Hygromite", was made by Beckman Instrument Company.

Laws governing electrolysis as stated by Faraday are embodied in the following statement: 9 grams of water dissociates into hydrogen and oxygen gases for each Faraday (96,500 coulombs) that is applied to the water. In the "Hygromite", the law was applied in the following way: water from the gaseous sample flowing through the instrument was absorbed in a phosphorous pentoxide film, which separated two electrodes. A voltage, applied between the electrodes, caused a current to flow through the partially hydrated, phosphorous pentoxide film; the current which flowed between the electrodes was directly proportional to the number of water molecules being electrolyzed. A constant flowrate of sample gas was maintained, thus the total current through the film was proportional to the total water-vapor concentration in the sample. The current through the film was measured and read on a current meter, calibrated to read water vapor directly in parts per million by volume for a gas sample flow of 100 cc/min at 70^{o}F and 14.7 psia.

Argon gas samples, for water vapor detection, were extracted from the same locations as the argon which was sampled for oxygen content.

1.5.7 Oil Vapor Detector

To minimize the flow of oil vapor into the potassium system, the argon supplied to the turbine seal passed through a molecular sieve designed to remove traces of oil vapor. However, the molecular sieve could not remove large quantities of oil which would be present if failure of a compressor diaphragm occurred. An oil vapor detector was installed downstream of the argon compressor to sound an alarm when the oil vapor concentration increased.

The oil vapor detector consisted essentially of a high pressure cell with two optical windows at 45^{o} to each other. Argon from the discharge of the compressor flowed through the cell. An ultraviolet light source was placed adjacent to one of the optical windows, and a fluorescent emission pickup (photomultiplier) was placed adjacent to the other. The pickup was so attenuated that it was sensitive only to the fluorescent wavelength emitted by the hydrocarbon oil, when impinged upon by ultraviolet light. The device was insensitive to water vapor, gaseous hydrocarbon impurities (methane, ethane, etc.), dust, etc. in the discharge gas, but was extremely sensitive to oil in the gas stream, such as would be present if a diaphragm failed in the diaphragm-type compressor. The detector was connected into a relay circuit which would sound an alarm in the event that a slight trace of oil became present in the argon stream.

The oil vapor detecting system was made by the American Instrument Company.

1.5.8 Vapor Cold Trap

The liquid nitrogen cooled vapor traps were identical to the ones used in the argon extraction system. For description refer to Section 1.4.5. The vapor trap in the reclamation system as shown in Figure 32 was primarily for removing oil vapor and other condensables from the argon stream.

1.5.9 Oil Separator

As mentioned previously the argon coming from the lube oil side of the turbine contained a high concentration of oil vapor and droplets. The greater quantity of this oil was removed by an oil separator which was immediately upstream of the liquid nitrogen cooled vapor trap. This separator was a 6.0" diameter tank packed with wire mesh demister elements.

1.5.10 Argon Flowmeter

There were two glass tube flowmeters in the argon reclamation system. As is mentioned in Section 1.5 the argon flow to the turbine labyrinth seal was split so that part of the argon flowed into the K cavity and the remainder flowed into the oil cavity. The two flowmeters measured the amount of argon supplied to each side of the labyrinth seal.

1.6 Liquid Nitrogen System

Liquid nitrogen was used as the heat transfer medium in the various vapor traps discussed in Paragraphs 1.4.5 and 1.5.8. Liquid nitrogen was chosen as the cooling medium because: (1) drain lines were not required as would be with water, (2) at the low boiling temperature of nitrogen only a small heat transfer surface area was required,

(3) it was recommended that water be restricted from the test cell where possible, and (4) removal of oil vapor from argon, to the desired low concentration, required a low temperature trap.

There were 11 cold traps in the 3000KW Facility, some of which were not readily accessible. To maintain the desired liquid nitrogen level in these traps by manual filling would have been an impractical task. Therefore, all traps were filled automatically from a centrally located storage tank. Liquid nitrogen was delivered to each trap by double walled vacuum insulated tubing. Liquid level in the traps was maintained automatically by Johns and Frame Company liquid level controllers.

1.6.1 Storage Tank

The liquid nitrogen storage tank was a 600 gallon dewar having a continuous delivery rate up to 45 pounds per hour. Actual usage rate was about 600 gallons in 5 days.

1.6.2 Feeder Lines

These lines were double-wall vacuum-insulated tubing made of Type 304 stainless steel, fabricated and installed by Cryogenic Engineering Company. The wall thickness of the tubing was sized to withstand an operating pressure of 60 psig while not exceeding a tensile stress level of 18,750 psi. The calculated thermal efficiency of the installed line was less than 3 Btu/hr/ft.

1.6.3 Vapor Traps

Vapor traps were installed at the high points of the liquid nitrogen distribution system. These traps were to collect nitrogen gas and vent it from the system. The traps were essentially float type which open to vent when the liquid level in the trap was forced down by nitrogen gas pressure. As the gas was vented off, the liquid rose and closed the vent valve.

1.6.4 Liquid Level Control

The liquid nitrogen level controls were Johns and Frame Model SL-1 which automatically maintained liquid in each trap as long as a pressurized source of liquid nitrogen was available.

1.7 Argon Supply and Vacuum System

The argon supply and vacuum system was a relatively complex and interrelated system which can best be visualized by referring to Figure 35.

It was imperative to start with an ultra clean system which was free of contaminants such as oxygen, water vapor, oil vapor, etc. One of the best ways for obtaining the cleanliness that was required was to outgas the liquid metal containment system by evacuating it to less than 1 micron. Heating the metal containment system to about 500^{O}F greatly accelerated outgassing. Therefore the need for a relatively elaborate vacuum system was established. In addition to initial system clean up, the vacuum system was extensively used during operation and maintenance of the potassium facility. For example when a vapor trap, filter or any section of the loop was opened to the atmosphere for cleaning or other maintenance, it was necessary to evacuate that component to remove atmospheric contaminants.

A roughing pump and a high vacuum pump system were installed. The high vacuum system was a dual stage pump made by the Kinney Vacuum Company and consisted of a Model KMB-30 booster in series with a Model KC-5 high vacuum pump. The roughing pump was a Stokes Model 149. Depending on the size of the chamber being evacuated and time of pumping, pressures as low as 1 micron were obtainable in the vacuum header.

The vacuum loop was all stainless steel, most of which was Type 304. All valves were bellows sealed and in most cases were manually operated. Valves were made by the Powell Company.

Many sub-loops and components required gas pressurization during shutdown of the loop and during operation. Argon, being inert, was used for this application. As seen on Figure 35, a relatively large number of components required static pressurization during normal operation. For example: the dump tank, the glove box, the spray valve, the flexible joint, valve bellows, etc.

Argon was supplied in gas form from a 1200 gallon vacuum insulated dewar in which argon was stored in liquid form. Argon in liquid form was chosen since it was of relatively high purity (measured at less than 3 ppm O_2 and less than 2 ppm H_2O). Also total argon consumption during operation was in the order of 30 to 40 lb/hr. It was convenient to store large quantities of argon in liquid form.

All vacuum and argon control valves were bellows sealed to insure a leak tight system. These valves were made of stainless steel, and they were manufactured by the Wm. Powell Company.

1.8 Liquid Metal Valve Bellows Argon Backup

Although each liquid metal control valve contained a metallic bellows capable of withstanding the anticipated operating pressure and temperature, argon backup pressure was applied to each bellows for the following reasons: (1) The bellows material was Type 316 stainless steel and had a wall thickness of about 0.006 inches. Without argon backup, some oxidation of the bellows would occur at the higher temperatures. (2) By reducing the pressure differential across the bellows, mechanical stresses were reduced. Consequently, longer operating life was expected. (3) There was always the possibility that a bellows would develop a leak. While most of the liquid metal valves normally operate at pressures above atmospheric, at least four of the valves were normally subjected to negative pressures. Consequently, if a leak did occur in one of the low pressure valves, it was most advantageous to have argon flowing into the alkali metal loop rather than air. On the high pressure valves, the backup argon pressure was set at the average of the high and low operating levels.

Argon gas pressure was independently controlled to each liquid metal valve. A Fisher Governor Type 67R pressure regulator was used as the control element. Each regulator contained a pressure gage which indicated set pressure. As a leak indicator, a small, glass tube purge flowmeter was installed in each argon pressure line. Although the valve stem packing of the liquid metal valves always had a small leakage rate, on a bellows rupture, the flowmeter would indicate a much greater than normal flow.

A shutoff valve was upstream of each pressure regulator. This was to stop the flow or pressure to any valve as required.

Each liquid metal valve contained a purge valve. These small needle valves were opened for a short period of time at the beginning of loop start up so that air in the pressurizing line between the liquid metal valves and purge panel would be forced from the line. After purging, the needle valves were closed.

1.9 Pipe Preheaters

All parts of the potassium containment system where the potassium was handled as a liquid were heated to a temperature exceeding 200°F. As previously mentioned, preheating was accomplished in the boiler, condenser and 450 Btu/sec heat exchanger by gas-fired burners. Loop components such as the dump tank, condensate tanks and the many feet of pipe were heated by General Electric "Calrod" heating elements. An exception was the 8.0" vapor pipe which was heated by "Hevi-Duty" type heating elements. Also, a few low temperature lines were heated by Chromalox thermwire.

Heating elements were strapped against the pipe or component to be heated. The heating element and pipe were then wrapped with a layer of "Inconel" foil followed by multi-layers of thermal insulation.

1.9.1 Power and Temperature Control

Electrical power to the heating elements was controlled by manually moved variable voltage transformers, or "Variacs". In most cases temperature was controlled by setting the approximate power level required to maintain the desired temperature To prevent an excessive over-temperature a meter relay, "Simplytrol" was used in most cases to open the power circuit if the temperature exceeded a preset value. Where temperature control was not critical or where there was little danger of exceeding a safe temperature, the power circuit was opened or closed by the facility operator.

An important exception to the manual power control rule was the 8.0" vapor pipe heaters. For this application it was important that smooth bumpless temperature control of the 8.0" pipe be available. This was not only to prevent over-temperature or cyclic-temperature (resulting in cyclic stress) of the 8.0" pipe, but also to maintain a steady state vapor quality entering the turbine. Power control of the 8.0" pipe "Hevi-Duty" heating elements, except the compensating elements, was by saturable core reactors.

1.9.2 Thermal Insulation

To prevent excessive heat loss during loop preheating or during operation, all pipe and components were thermally insulated. From 2 to 4 inches of fibrous blanket type insulation was applied over the heating elements. To permit some air circulation around the pipe, thus minimizing hot spots, the insulation was held about 1/2-inch away from the pipe by spacer rings and "Inconel" sheet metal. Thermal insulation was a combination of "Fiberfrax" and "Fiberglas".

1.10 Safety and Scrubber System

In the event of an alkali metal leak in the facility, an alkali metal fire would most likely occur. The resulting caustic vapor, if expelled to the atmosphere, could be damaging to adjacent property. Consequently, at least three approaches toward safe handling of alkali metal were designed into the test facility.

First, all alkali metal containment components and piping were subjected to and passed rigid quality control tests. In addition to quality control tests on components, the completed alkali metal loop was subjected to a helium mass spectrometer leak test as per MIL. STD. 271B (Ships).

Secondly, loop components such as the boiler, condenser, and dump tank were enclosed to a high degree to minimize the rate of burning should a potassium leak occur in either of these components. For example, if the condenser tube bundle was to leak, the air box around the tube bundle could be sealed by closing the air duct louvers. The boiler could be sealed by closing the exhaust stacks. In addition to sealing the larger components, the floor of the test cell was a leak tight container which was covered with perforated pans. These pans would have restricted the flow of air to an alkali metal spillage, and consquently, the burning rate would have been restricted. The perforated floor pans were also designed to permit an alkali metal spillage to spread over a wide area, thus cooling the metal rapidly.

Thirdly, provisions were made to minimize the amount of caustic vapor that would enter the atmosphere should an alkali metal fire occur. This was accomplished by providing a scrubber system that would remove a high percentage of the caustic vapor generated. The scrubber system was elaborate and is discussed in some detail below.

The scrubber consisted of 5 major components: (1) the venturi, (2) the separator, (3) the exhaust fan, (4) the exhaust stack, and (5) the water recirculating pump. The major components of the scrubber is shown at left in Figure 7.

The scrubber was designed and constructed by the Chemical Construction Corporation. It was designed to continuously exhaust about 15,000 scfm of air. A 30" duct connected the scrubber venturi to the test cell. During operation of the facility, 15,000 scfm of air was pulled through the test cell and into the scrubber. There were two louvers on each side of the test cell wall near the ground. Outside air entered these louvers, and other smaller openings in the test cell wall, and passed up through the test cell grating to the exhaust duct. In the winter the incoming air was heated by flowing over finned steam coils before entering the test cell. There was a pressure control damper in the 30" duct between the building and the scrubber. This damper prevented a negative pressure in the test cell in excess of 2.0" of water.

Also, a valve was installed in the 30" duct which permitted isolation of the test cell from the scrubber system. This valve was operated from a switch in the Control Room so that, in the event of a serious fire in the boiler, the operator could switch all of the scrubber capacity to the boiler enclosure.

Air was pulled through the scrubber venturi where jets of water were sprayed into the air stream. Thorough mixing of water with the air in effect washed solids such as caustic vapors from the air. The mixture of air and water entered a cyclone type separator where a high percentage of the water was removed from the air. Air continued to the exhaust fan and out the exhaust stack. Water flowed to the bottom of the separator where it was available for recirculation by the recirculating water pump. Water recirculating rate was about 240 gpm.

Since the scrubber ran continuously, caustic vapors from a sudden alkali metal fire in the test cell would automatically be taken care of without requiring special action from the operator.

If an alkali metal fire occurred in the condenser, all condenser air ducting louvers would be closed by the operator, and the condenser blower turned off. At the same time, a louver in the duct between the condenser exhaust stack and the scrubber would be opened. This immediately placed the condenser air box under the negative pressure produced by the scrubber. Some air would leak into the condenser air box since the louvers were not absolutely tight, but it would be pulled to the scrubber rather than be expelled directly to the atmosphere. Consequently, caustic vapors from a leak in the condenser would not be exhausted to the atmosphere.

A leak in the potassium boiler introduced a more complicated problem than a leak in the condenser. First of all the boiler would be much hotter, and it contained much more potassium than the condenser. During normal operation, the boiler would contain about 1600 lbs of potassium at up to 1600^{o}F and vapor pressure up to 25 psig. Secondly, the boiler fire box atmosphere would be very hot and low in oxygen content. Therefore, potassium vapor would not tend to oxidize rapidly in the boiler fire box if a large boiler leak occurred. On the other hand, explosion would most likely occur if large quantities of relatively pure potassium vapor entered the water scrubber. Thirdly, it was not recommended that the liquid in the boiler be drained to the dump tank since this would cause the empty tube bundle to increase in temperature even though the burners were turned off. The tubes would be heated by the hot refractory furnace wall.

To meet the problem of a potential leak in the boiler, a static vapor condenser was located next to the boiler. This condenser was a 60" diameter by 15' high tank filled with crushed granite. A 30" diameter duct connected the boiler fire box to the static condenser. A 24" diameter duct connected the static condenser to the scrubber. The 30" duct contained a metallic diaphragm immediately adjacent to an air operated swing gate valve. (The diaphragm prevented combustion products, which are high in water content, from being pulled through the static condenser during normal operation.)

In the event of a potassium leak in the boiler, the swing gate valve would be actuated by the operator. The valve gate would rupture the diaphragm, thus opening the 30" duct to the standby static condenser. At the same time the four boiler exhaust stacks would be closed. Consequently, the alkali metal vapors would be directed to the static condenser where they would be cooled and liquefied. With about 4" negative pressure on the boiler fire box, some air would have leaked into the fire box producing caustic vapor. This air and vapor first would pass through the static condenser where it would be cooled before passing on to the scrubber. The scrubber would remove the caustic from the air before exhausting it.

As an additional precaution against caustic alkali metal vapor getting into the atmosphere, all potassium pipe between the test cell and boiler were enclosed by secondary steel containment. Also the boiler fire box was isolated from the test cell by appropriate wall seals. Therefore if the boiler had developed a leak, the potassium vapor or caustic vapor entering the test cell would have been minimized.

Another major feature of the safety system was the 8.0" vapor shutoff valve. If the test turbine casing or other test cell component had developed a leak, flow of vapor from the boiler could be stopped quickly by closing the 8.0" valve. See Section 1.1.8 for additional discussion of this valve.

Also as a safety feature, the facility control system was designed so that by closing a "Panic Switch" all liquid metal valves, air louvers, argon control valves, etc. immediately and simultaneously would go to the desired emergency position. The operation of Panic Switches numbers 1 and 2 is described in Paragraph 1.17.5. Failure of instrument air also would cause control valves to go to a safe position.

Factory Mutual Insurance Company approved fire detectors were installed at seven different strategic locations. These detectors were capable of sensing and sounding an alarm when only traces of alkali metal smoke were present. In addition to these detectors relatively good visual observation of the test loop from the control room was available to the facility operator. The smoke detectors which were installed were called Pyr-A-Larm and were made by the Pyrotronics Company.

1.11 Slinger Seal System

The potassium test turbine contained a liquid filled rotating channel seal. Details on this seal can be found in reference 6. The seal was commonly referred to as the slinger seal.

This seal was used to isolate the hot potassium vapors from the oil lubricated shaft bearings. Since the potassium vapor could come into contact with the slinger seal fluid, the slinger seal fluid had to be compatible with potassium. Therefore, the sealing fluid was also potassium.

It was also important to prevent mixing of K and oil. As previously mentioned in Section 1.4, the turbine also had a split labyrinth seal which separated the K cavity from the oil cavity. Argon gas flowed in opposite directions across this seal - thus preventing mixing of K and oil.

The slinger seal consisted of a rotating channel which was continuously supplied with potassium at about 250°F. A stationary disc extended into the channel and was immersed in the K. The dynamic head developed by rotating the K at high speed provided a barrier which prevented mixing of argon with potassium vapor. The slinger seal was designed to withstand a differential pressure in excess of 35 psi at 19,000 rpm.

Shear forces developed in the rotating seal and K vapor condensing in the seal area produced a heat load of about 36 hp in the slinger seal liquid potassium. The potassium vapor behind the second stage of the turbine was at condenser temperature (ranging from 1100°F to 1350°F). (During operation this high temperature potassium vapor flowed past the forward screw seal of the turbine shaft and condensed on the slinger seal potassium at a rate of 2 to 8 gal/hr.) The latent heat of condensation of this vapor increased the temperature of the slinger seal potassium liquid. Therefore, a continuous supply of cool K had to be supplied to the seal to prevent the K in the seal from vaporizing. Potassium was removed from the seal cavity at the same rate at which it was supplied. Generated heat resulted in a temperature rise of the slinger seal potassium. At a flow rate of about 2 gpm, the exit K temperature was in the order of 800°F. Heat was removed from the slinger seal exit K by an air cooled heat exchanger which cooled the potassium to 250°F.

Air flow to the heat exchanger was controlled automatically by a Foxboro temperature indicator-controller. Normal air flowrate was about 1/4 lb/sec.

As previously explained the K from the seal was mixed with argon coming from the labyrinth seal. To effectively separate the argon from the K, relatively low temperature (250^{o}F) was required to reduce the K vapor pressure to an insignificant level. (Refer to Figure 36.) After leaving the air cooled heat exchanger, the mixture of argon and K entered a separator where the 250^{o}F K liquid and argon were disengaged. The potassium left the bottom of the vapor separator, and the argon left from the top of the separator.

From the separator, which was also the head tank for the E.M. pump, K entered the EM pump where it was forced back to the slinger seal. Downstream of the pump was an EM flowmeter which measured the K flow to the seal. An electrical signal from the flowmeter could be used to control the throttling action of the K flow control valve, VDS-5, which could maintain a fixed predetermined flowrate to the slinger seal. However, under steady state conditions, VDS-5 was usually fully open and flow was set by regulating E.M. pump voltage.

Argon from the vapor separator contained some traces of K in the form of mist. Immediately out of the separator, the argon passed through a 2" diameter pipe demister, a 6" diameter pipe demister and a finned tube heat exchanger. The argon was further cooled to near room temperature. From the finned tube cooler, the argon entered a liquid nitrogen cooled vapor trap. Wire mesh in the vapor trap and micro filters downstream of the trap removed solid particles such as K "snow" (potassium dust resulting from the freezing of potassium droplets in the argon midstream) from the argon stream. Argon from the filters were returned to the argon reclamation system as discussed in Paragraph 1.5.

The slinger seal loop contained a dump tank which absorbed the K overflow from the separator tank when the loop was in operation. Valves VDS-3 and VDS-8 normally isolated the dump tank from the main slinger seal loop. VDS-3 was opened to fill the loop on start-up. VDS-8 and VDS-2 were normally open during operation so that the potassium liquid in the separator tank would overflow to the dump tank as potassium accumulated in the loop by condensing of vapor at the turbine slinger seal. If the separator liquid level became too low, VDS-2 and VDS-8 were momentarily closed. The dump tank was pressurized with argon followed by opening VDS-6. Potassium would be forced from the dump tank to the separator tank. The slinger seal loop prior to being installed in the 3000 KW Facility is shown in Figure 37.

1.11.1 EM Pump

The EM pump used to circulate liquid potassium to the slinger seal was a spiral duct pump made by General Electric, Large Generator and Motor Department. This pump was designed to produce at least 80 psig head at 4 gpm flow and 200 psig head at 2 gpm flow. Its principle of operation was essentially the same as the large EM pump which was installed in the main loop. However, the temperature limit of this pump was 500^{o}F. Refer to Paragraph 1.1.4.

1.11.2 Instrumentation

(a) Flowmeter
(b) Liquid Level
(c) Pressure
(d) Temperature

(a) Flowmeter - The flowmeter was a MSA flowmeter which was essentially the same as the one discussed in Paragraph 1.1.5.

(b) Liquid Level - Liquid level was measured at two locations in the slinger seal loop, in the dump tank and in the argon separator tank. In both cases nuclear radiation gages made by the Ohmart Corporation were used. These gages are described in Paragraph 1.1.10. Ten milli-curie sources were used in both applications, and the liquid levels were indicated on dials in the Control Room.

(c) Pressure - K pressure was measured at four places--downstream of the EM flowmeter (pump outlet pressure), ahead of the argon separator (slinger seal outlet pressure), downstream of the flow control valve (slinger seal inlet pressure), and at the dump tank. Pressure was measured by Taylor volumetric type pressure transmitters.

(d) Temperature - Temperature was measured at various points in the slinger seal loop by Cr-Al thermocouples which were attached to the containment wall.

1.12 <u>High Pressure Lube Oil System</u>

The turbine contained a preloaded duplex ball thrust bearing and a five pad tilting - pad journal bearing. Both bearings are lubricated with Mobil DTE 797 oil which has an absolute viscosity of 14 centipoises at the normal operating temperature of 135°F. In addition to these bearings, the turbine contained an oil lubricated stabilizing bearing which could have been forced against the shaft if unstable conditions had resulted during testing with the lightly loaded tilting pad bearing. Operation was always stable. Therefore the stabilizing bearing was never used.

A maximum of 1 gpm of lube oil was required for the ball bearing; 2.5 gpm, for the pad bearing; 2 gpm, for the stabilizing bearing. Therefore, a total maximum oil flow to the turbine was about 6 gpm. Although the normal required supply pressure was less than 200 psig, this pressure was available at the dump discharge.

As discussed earlier, a portion of the argon that was supplied to the turbine labyrinth seal entered the lube oil cavity. This argon was initially reclaimed for reuse. Consequently, it was absolutely essential that no air or other permanent contaminants entered the argon. It was mandatory that the entire lube oil system be hermetically sealed and that it function as an independent system.

Figure 38 is a schematic diagram of the turbine lube system; Figure 39 shows the lube system installation. Two pumps operated in parallel. While one pump was running, the other was on standby. The control system was designed to start the second pump and stop the first pump automatically if the first pump failed to maintain the desired discharge pressure. (Pumps could also be switched manually by the facility operator.)

From the pump, the oil flowed through a check valve followed by a filter. The primary filter removed particles larger than 40 microns, and the filter at the discharge of the emergency pump (secondary pump) was rated for removal of particles larger than 200 microns. These filters had wire screen filter elements made of stainless steel. A pair of manual shutoff valves isolated the individual filter containers so that a filter unit could be disassembled for cleaning while the other parallel pump and filter were still operating. Also, by isolating each filter, the filters could be cleaned without subjecting the entire loop to atmospheric air. A valve upstream of the filter was provided for a vacuum and argon purge connection.

After leaving the filter unit, the lube oil entered a distribution manifold containing five branch lines. Four supplied oil to the turbine; the fifth returned oil to the reservoir through a pressure relief valve VMO-1.

Oil flowrate to the turbine was manually controlled by throttling valves which were set by panel loaders located in the Control Room. Flowrate to each bearing was measured by a known calibration between ΔP and flow for sharp edge orifice plates in the supply line. The differential pressure produced by the orifice plates was sensed by a Foxboro differential pressure transmitter and output from the transmitter was fed to a receiver gage in the Control Room. Oil pressure in each supply line was sensed by a Foxboro pressure transmitter, and the transmitter air signal was also fed to a receiver gage in the Control Room.

The oil line for pressurizing the stabilizing bearing was essentially a static line with no oil flow to the turbine. To achieve good pressure control, a by-pass bleed line connected the pressure line, downstream of the throttling valve, to the oil reservoir. This line contained a manually set needle valve for regulating the rate of by-pass flow. When the stabilizing bearing was not in use, the by-pass line equalized the pressure on both sides of the stabilizing bearing by venting the piston side of the bearing.

A scavenging pump and a by-pass drain line were used to return the oil to the oil reservoir. Oil passed through a defoaming tank before it was returned to the reservoir.

The oil being returned to the reservoir contained some entrained argon gas. Argon gas was released from the liquid oil in the defoaming tank and reservoir. Liquid drained to the bottom of the reservoir. Argon and oil vapor passed upward through a wire demister. Argon flowed out the vent line at the top of the reservoir and was returned to the argon reclamation system. The reservoir contained electrical heating elements, which were used to preheat the oil to about 150^{o}F on start-up and to assist in deaerating the oil on initial fill.

An oil cooler was located between the oil reservoir and the pumps. This heat exchanger was water cooled. Water flow to the cooler was automatically controlled so as to maintain a controlled oil inlet temperature to the turbine, normally about 135^{o}F. The oil cooler was located downstream of the reservoir instead of upstream of the reservoir, as might normally be done, for the following reasons:

1. A faster response to a desired temperature change could be achieved.
2. It was desired to have minimum restriction of the turbine drain line.

1.12.1 Gear Pump

The oil pumps initially used in this system were essentially hermetically sealed. The pumps were positive displacement gear type with the electrical motor running submerged in the oil that was being pumped. The oil not only lubricated the motor bearings, but also served to remove heat from the motor windings. The pump assembly, being oil cooled and being an integral pump - motor unit, was relatively lightweight and compact.

Several times during initial phases of turbine testing, potassium of significant quantities inadvertently got into the oil system. The metallic potassium eventually damaged the submerged motor winding to the extent that the pumps were inoperative. The submerged motor pumps were replaced with pumps having appropriately tight shaft seals and air cooled motors. The second type of pump performed well during all subsequent testing.

1.13 Low Pressure Lube Oil System

The test turbine had to be rotated to about 10,000 rpm to establish the turbine slinger seal. For this purpose the potassium test turbine utilized an 8.0" Barbour-Stockwell steam turbine (Model No. 6037), which was permanently coupled to the potassium turbine, as an external drive. The relative arrangement is shown in Figure 40; the installation, in Figure 41.

Since the steam turbine had to rotate at high speed, up to 23,000 rpm, for long periods of time, a reliable liquid lubrication system was provided for the steam turbine bearings. This system was referred to as the low pressure lube system. This system was an open system, i.e., it was not hermetically sealed. Oil used in this system could not transfer air to the argon or potassium systems. The low pressure lube oil system also supplied 0.1 gpm to each of the water brake bearings.

The low pressure lube system is shown schematically in Figure 42; the installation, in Figure 43. It consisted essentially of an oil reservoir, supply pump, filter, scavenging pump, flow control valve, pressure relief valve, and a heat exchanger. The supply pump was rated for 2 gpm flow at 100 psi developed pressure. The scavenging pump was rated for 3 gpm at 15 psi pressure rise.

Normally, the flowrate to the steam turbine was 0.7 gpm. This flowrate was set by a manually operated throttling valve. A flow switch sounded an alarm in the Control Room if the flowrate dropped below 1/2 gpm.

Oil returning from the steam turbine was forced through a water cooled heat exchanger before it was returned to the oil reservoir. The supply pump and scavenging pump were driven by a single electrical motor.

1.14 Glove Box System

The initial design of the potassium test turbine incorporated bolted flanges. In order to minimize the exposure of possible leak sources to atmospheric air and to provide an inert atmosphere for disassembly, inspection, and maintenance of the test vehicle, a glove box system was incorporated into the facility. It consisted of a cylindrical chamber containing glove ports, sight ports, loading chambers and argon and vacuum systems.

The use of welded flanges on the turbine precluded the functional necessity of the glove box except for its use as a structural support for the turbine. The glove box serving as a turbine support structure is shown in Figures 44 and 45. It also served as a containment for potassium oxide in the event of leaks in the turbine area.

1.15 Power Absorbing and Torque Measuring System

The general arrangement of this system is shown in Figure 40. The power absorbing device for the potassium test turbine was a multiple disc water brake, Model C-9529-2, made by the Industrial Engineering

Company with a power absorbing capacity up to 550 hp and speed capacity up to 23,000 rpm. The brake was relatively compact. It had a predicted maintenance-free life in excess of 1000 hours since it contained stellite discs. After 2300 hours of operation at 18,500 rpm no cavitation of the discs was evident. Bearings and carbon face seals showed some wear, but still had an undetermined usable life. Figure 46 shows the appearance of the water brake rotor discs after about 300 hours of running. Figure 47 shows the same rotor after 2300 hours.

Turbine speed was measured by a magnetic pick-up and Berkley counter. Water brake shaft torque was measured by a Bytrex Corporation strain gage type torque pick-up (Serial No. A2751). The range of this sensor was 0-1250 in.-lb with an accuracy of ± 1% over the full range. The water brake torque sensor was mounted on a rigid conical structure. The water brake was cantilevered off the torque sensor. Service connections to the water brake were flexible and offered minimum resistance to the slight angular rotation of the water brake and torque sensor. (Rotation of the torque sensor was less than 1 degree for 1250 in.-lb torque.)

As indicated in Paragraph 1.13 the potassium test turbine had to be driven to a speed of approximately 10,000 rpm to establish the turbine slinger seal. This seal had to be established while the alkali metal system was relatively cool and it had to be maintained on startup, during operation, and on shutdown. A steam turbine (Paragraph 1.13) was permanently connected to the water brake shaft as shown in Figure 40. Therefore, the steam turbine was rotating when the potassium turbine was rotating. The steam turbine Bytrex torque pick-up, Serial No. A2302, had a range of 0-200 in.-lb. Its accuracy was ± 1% full scale. The torque pick-up was mounted on a second support cone which was rigidly attached to the test turbine support. The steam turbine was cantilevered off the torque pick-up as shown in Figure 40. Service lines to the steam turbine were free to pivot, thus eliminating extraneous torque or resistance to slight rotation of the steam turbine and torque sensor. The mounted steam turbine is shown in Figure 41.

Since perfect alignment of the potassium turbine shaft and water brake shaft was not possible, a flexspline coupling was used to connect the turbine to the water brake. This coupling had a nominal 3.0" diameter and was made by the Koppers Company.

The water brake required up to 10 gpm of water continuously at maximum test turbine power. Figure 48 shows the water control loop for the water brake. A predetermined water flowrate to the brake was generally established by adjusting the flow control valve WDV-1. The magnitude of power absorption was then regulated by controlling the level of water in the brake. Water level was controlled by throttling WDV-2 and WDV-2A. The water flowrate to the brake was set at a sufficient rate to maintain the exit water temperature between 185°F and 195°F. The greatest water brake stability was obtainable at this temperature level. In the event of an overspeed of the turbine, an electrical overspeed trip would open WSV-2 (Figure 48) to flood the water brake quickly with water, causing the turbine speed to decrease. WSV-2 would close at a predetermined lower speed. By regulating the amount of power absorbed by the water brake, the speed of the test turbine was maintained at the required rpm. During turbine endurance testing the water brake discharge water valve, WDV-2A, was modulated automatically by a pneumatic controller which maintained a constant turbine speed at 18,250 rpm ± 100. WDV-2A, having only a 1/4" diameter orifice, permitted maximum changes in speed of about ± 2,000 rpm.

Prior to potassium turbine testing, the Koppers flexspline coupling between the water brake and potassium turbine was removed. This permitted running the water brake and steam turbine to determine their operating characteristics, such as bearing and seal performance, and vibration characteristics. Also, it permitted checking the water brake torque meter against the steam turbine torque meter. With the steam turbine driving and the water brake absorbing power, the two torque meters were compared in output up to 120 in.-lb. In principle, the two torque meters should indicate the same torque value. If the same torque was not indicated within $\pm$ 3 in.-lb, the necessary steps, e.g., re-aligning hose connections, were taken to obtain this required accuracy.

After replacing the Koppers coupling, but before expanding potassium vapor through the test turbine, the test turbine was rotated by the steam turbine up to 18,000 rpm. Both speed and loop pressure (argon pressure at this time) were varied while steam turbine and water brake torque values were obtained at these different conditions. Since there was no water, other than seal cooling water, in the brake, the water brake torque was low, in the order of 10 to 15 in.-lb. However,

K turbine parasitic torque = steam turbine torque - water brake torque

K turbine parasitic torque includes windage loss; seal and bearing loss. This value is required to determine net blading torque during potassium testing as shown below.

During potassium testing the water brake torque meter indicates water brake torque. A small amount of steam is kept flowing through the steam turbine producing in the order of 20 in.-lb torque. (The steam turbine is kept on the line in case it is required to maintain rotation in an emergency.) The net blading torque of the potassium turbine is as follows:

$$\text{Net blading torque} = \text{Water brake torque} + \text{K turbine parasitic torque} - \text{Steam turbine torque}$$

The torque meters provided a measure of shaft torque which, with rpm, permitted a calculation of shaft power. A second method for determining shaft power was calculating the energy absorbed by the water flowing through the water brake. Water flowrate and temperature rise of the water were measured:

$$\text{Power} = C_p \, W_{H_2O} \, (t_{out} - t_{in})_{H_2O}$$

From this calculation and a speed value, water brake torque can be calculated. This method for determining water brake torque generally compared with the torque meter within ± 2%, with an occasional deviation of up to ± 8%.

1.16 Electrical Power System

Approximately 700 kva of electrical power was required to operate the 3000 KW Test Facility. Most of this power was required for moving air for cooling. For example, the scrubber blower required 250 hp, the main condenser blower required 75 hp, the 450 Btu/sec heat exchanger required 125 hp, and the boiler required 40 hp for its air blowers. The next large quantity of power, about 150 kva, was required for heating the liquid metal pipe, etc. during preheating of the loop and/or during normal operation of the loop. There were many places in the facility where electrical power was required in smaller quantities.

The center of the power system was the 750 kva substation which was located to the east of the test cell. The substation also contained 5 of the larger circuit breakers. These circuit breakers were actually starters for the big blower motors mentioned above.

All 460 volt power was distributed from a motor control center located in the test cell Equipment Room. A 480/120 V transformer was also located in this compartment for 120 volt control power.

Most of the "Calrod" type heating elements were supplied with 120 volts maximum. The dump tank and all "Hevi-Duty" type heating elements were supplied with 208/240 volts. The voltages indicated above were the maximum voltage. Actually all heating elements or groups of heating elements were connected to variable transformers such that the voltage to the element could be varied from about zero to the indicated maximum.

Circuit breakers for miscellaneous equipment were located in a power panel also located in the Equipment Room.

1.17 Control System

The control system for the 3000KW Turbine Test Facility was rather complex. Electrical, air and manual control or combinations of these were used throughout the facility. About half of the facility control valves were air operated with electrical emergency shutdown features. The remaining valves were manually operated with only a few primary flow control valves being solely electrically operated. Temperature of various parts of the facility was measured by thermocouples. The mv signals from these couples were in most cases transmitted directly to the main control panel, but a few thermocouple signals were converted to air signals for readout.

One of the major difficulties encountered with the control system centered around the instrument air. Shop air from an oil lubricated compressor was used for instrument air. Even though the air first passed through an air dryer, oil absorption unit and a number of filters, the instrument air continued to be slightly contaminated, especially with oil mist. As a result a number of air controllers and transmitters required periodic cleaning.

The electrical system presented no problem except for plant-wide loss of electrical power several times. The facility was designed to fail safe on power failure - thus no permanent damage was caused by power failure.

During checkout, startup or operation of the facility, operating personnel were in many instances scattered throughout the facility complex. Communication was an important feature associated with the facility operation. Consequently, an intercom system was installed in the facility with headset outlets located at 7 strategic locations.

With this arrangement personnel at any of the 7 stations could communicate verbally with the operator at the main control station which was located at the main control panel. Photos of the main control panels are shown in Figures 49 and 50.

The facility control system featured "fail-safe" design. That is, all critical control valves and components were spring-loaded such that, on loss of control air or electrical power, they would move to a normally open or normally closed position depending upon their respective functions. The "normal" position on loss of control was that which would prevent or minimize damage to the facility or test turbine.

Aside from power or control system failure, however, certain situations were anticipated which would require a positive, rapid action on the part of the facility operator to supersede the normal, routine shutdown procedure. Two of these situations were defined as follows and were controlled by actuating PANIC BUTTON NO. 1, or PANIC BUTTON NO. 2. PANIC BUTTON NO. 1 was to be actuated if there was a major potassium fire in the test cell, or if there was any other reason for a rapid shutdown excluding an alkali metal fire in the boiler. PANIC BUTTON NO. 2 was to be actuated in the event of a major potassium fire in the boiler.

PANIC BUTTON NO. 1 performed the following functions at once:

1) Boiler fuel supply valve was closed. (Boiler air blowers remained on and exhaust stacks remained open to accelerate boiler cooling.)
2) 8.0" vapor valve, VPL-11, was closed to stop vapor flow to the turbine.

3) Spray line throttling valve, VPL-10, was closed to stop liquid flow to the turbine.

4) 8.0" vapor pipe heaters were turned off to facilitate cooling of the vapor line.

5) Main EM pump was turned off to reduce pressure in the loop.

6) Main condenser blower was turned off to prevent potassium oxide from getting into the atmosphere.

7) 450 Btu/sec heat exchanger blower was turned off to prevent potassium oxide from getting into the atmosphere.

8) Condenser flood valve, VPA-1, was opened to pressurize the condenser and loop with argon to above atmospheric pressure.

9) Argon flow control valves, VDE-1 and VDE-2, were closed to isolate the vacuum system from high pressure and possible potassium contamination.

10) Water brake inlet water control valve, WDV-1, was opened to slow the turbine by flooding the water brake.

11) Main steam valve to drive turbine, SDV-1, was closed to stop the steam turbine from driving.

12) Slinger seal EM pump was turned off to stop flow of liquid potassium to the turbine.

13) Slinger seal heat exchanger air supply valve was closed to prevent possible atmospheric contamination.

14) Condenser discharge throttling valve, VPL-5, was closed to further isolate the condenser from hot liquid if the boiler feed check valve failed to work

15) Condenser exhaust stack discharge louver was closed to prevent possible atmospheric contamination.

16) Condenser air inlet louvers were closed and condenser fan inlet louvers were closed to prevent possible atmospheric contamination.

17) 450 Btu/sec heat exchanger air control valves were closed to prevent possible atmospheric contamination.

18) 450 Btu/sec heat exchanger liquid metal throttling valve, VPL-8, was closed to isolate the heat exchanger.

19) Condenser to scrubber air valve was opened to subject the condenser air box to a slight negative pressure which would exhaust potassium oxide from a possible condenser leak.

The scrubber was then switched to "emergency" running condition so that the water was drained and a continuous fresh supply maintained. (The scrubber automatically assumed the "emergency" condition after the water temperature increased to a preset point of about 130°F.)

PANIC BUTTON NO. 2, which was to be actuated in case of an alkali metal fire in the boiler, performed the following functions:

1) It automatically energized PANIC NO. 1.

2) Boiler air blowers were turned off to reduce the rate of burning of potassium.

3) Boiler stack covers were closed to minimize atmospheric contamination.

4) Boiler stack to static condenser valve was opened venting the boiler to the static condenser and scrubber.

2.0 Facility Performance

2.1 Convergent-Divergent Nozzle Testing

Within 30 months after beginning the design of the 3000 KW Test Facility, potassium vapor was produced by the gas fired boiler. The first boiling experiment was conducted on October 2, 1963, with a convergent-divergent nozzle substituting for the potassium vapor turbine. The C-D nozzle was initially installed in the potassium vapor loop so that a controlled checkout of the facility could be made while obtaining polytropic constant data for potassium.

The C-D nozzle was initially installed with bolted flanges at the inlet and outlet. Metal o-ring gaskets were used between the flanges. As an additional safety feature, the flanges were encased by a sheet metal covering which was seal welded to the vapor containing pipe. Argon gas was supplied between the sheet metal cover and the vapor containing pipe.

On October 3, 1963, potassium vapor flowed through the C-D nozzle at 1500^{o}F for about 5 hours. The next day the boiler produced vapor at 1570^{o}F-1590^{o}F for about 2 hours. A leak in the bolted discharge flange of the C-D nozzle necessitated shutdown. Shutdown was successful with little or no oxygen getting into the loop. An analysis of the potassium after the facility had cooled indicated 10 ppm oxygen. Except for the leaking flange, no damage was caused to the facility. Figure 51 shows the flange area after the fire.

During these initial boiling experiments, the following significant observations were made:

(a) Vapor temperature of 1590^{o}F was achieved; average boiler tube temperature was 1630^{o}F.

(b) Vapor quality from the boiler (as measured by the C-D nozzle) was better than 98% with no heat added to the 8.0" vapor line.

(c) Maximum heat transferred to the potassium by the boiler was 2850 kw at an outlet vapor temperature of 1580°F.

(d) Boiling stability appeared reasonably good above 1450°F. Above this temperature, pressure and temperature perturbations were evident, but very low in magnitude. Noise from the boiler was nil.

(e) Condenser worked well except that pressure control required excessive attention.

(f) Argon extraction from 1300°F potassium vapor was successful. However, the argon extraction line became plugged several times in 3 days.

(g) Thermal expansion of the loop, particularly the 8.0" pipe, was as predicted, e.g., 3.0 inches.

(h) Efflux pressure measuring system became plugged repeatedly with frozen potassium.

(i) The E.M. pump, flowmeter, control valves, and similar components worked well.

Effort was concentrated on replacing all bolted o-ring type flanges during the next 4 weeks. The re-installed nozzle with all welded connections is shown in Figure 52.

During the initial vapor test in early October, the efflux pressure system failed to function due to repeated plugging with frozen potassium. Potassium vapor apparently diffused upstream in the small 1/8" OD pressure sensing tubing to a region sufficiently cold enough to freeze. Consequently, on a trial basis several of the efflux lines were equipped with wire mesh vapor traps. These traps later proved to eliminate plugging of the efflux lines, and traps were installed in all efflux pressure sensing lines.

Boiling-condensing experiments resumed on November 23, 1963. However, within 36 hours, the facility was once again shut down because of leakage of several efflux pressure lines in the C-D nozzle. The efflux pressure lines were made of 1/8" OD x 0.028" wall Type 316 SS tubing which were brazed (Alloy H33) to the C-D nozzle. They were replaced with 3/8" OD x 0.125" wall tubes (Type 316 SS) which were welded to the C-D nozzle. At that time, all efflux lines were equipped with potassium vapor traps as shown in Figure 53.

During the boiling experiments conducted on November 23, the following were observed:

(a) Performance of the E.M. pump exceeded facility requirement (Figure 10).

(b) Liquid metal valves, including the 8.0" vapor valve, performed as required.

(c) Argon extraction system potassium heat exchanger was determined capable of maintaining the required 250°F potassium outlet temperature.

(d) Scrubber system, including the potassium smoke detecting system, worked satisfactorily.

(e) During 7 hours of boiling, with 28 thermocouples on the boiler tubes, some evidence of boiler instability was revealed. Boiler tube temperature ran about 50°F higher than vapor temperature. Tube temperature swings of 20°F to 30°F were evident with constant gas burner setting. Temperature distribution from bottom to top of the tubes varied about 25°F on the average. Vapor temperature out of the boiler was unsteady by $\pm$ 10°F at 1450°F and up to $\pm$ 15°F at 1375°F. This is shown in Figure 54. (At that time boiler liquid level was maintained at about 5 to 6 inches in the vapor drum.)

(f) Vapor quality from the boiler was better than 98% at 1450°F vapor temperature. Inlet throttling calorimeter indicated vapor quality within 1/2% of quality measured by the C-D nozzle.

(g) Condenser pressure as low as 2.5 psia was easily achieved with no indication of instability.

(h) The efflux pressure lines which contained the potassium vapor traps did not plug while those lines without traps plugged repeatedly.

(i) The liquid spray line was plugged. Subsequent inspection of the spray line revealed several deposits which analyzed to be high in carbon content. Origin of the deposits, although not conclusive, was suspected to be the spray line hot trap. The spray line hot trap was eventually removed from the system and no further difficulty was encountered with the liquid spraying system.

Vapor testing was continued on December 16, 1963 but it was necessary to shut down almost immediately because of several equipment failures including a small leak in the 8.0" valve bellows. However, on December 28 and 29 all formal C-D nozzle data was obtained without further failures. Significant events of this test are discussed in sections 2.1.1 through 2.1.4 and in reference 8.

During C-D nozzle testing, vapor inlet temperature settings were 1430°F, 1500°F and 1580°F. In most of these runs the condenser pressure was held at 1-1/2 to 3 psia which was well within the test plan requirements. Where vapor quality adjustment was required, the spray nozzle worked with good flowrate control and spray pressure control. In all but a few runs the spray pressure was held at about 140 psig. (Minimum requirement was 100 psig.)

2.1.1 Boiler Performance

Boiler instability was observed in the following way. At 1400°F, vapor temperature oscillated ± 10°F in a 2-minute period. At 1450°F, the temperature oscillations were normally ± 5°F. At 1500°F, vapor temperature was relatively steady. However, after an accumulation of 30 to 40 hours, the ± 10°F vapor temperature fluctuation moved to 1450°F. At 1500°F, the temperature fluctuated ± 5°F. This is shown in Figure 55. Tube wall temperature also showed a corresponding temperature perturbation which suggested slight boiler instability. (Refer to Figure 56.) Total vapor pressure as measured by the efflux pressure system at a station about 6 feet ahead of the C-D nozzle is shown in Figure 57. This too shows instability at lower temperature.

Although no attempt was made to see how fast the boiler would respond, heating from one steady state temperature to another was generally accomplished at a rate of about 100°F/hour. The heating capacity of the boiler was found to be sufficient. Up to 2850 kw was added to the potassium with boiler controls set at 40% of full range. Vapor flowrate from the boiler during C-D nozzle testing is shown in Figure 58.

Upon completion of C-D nozzle testing, the accumulated time for vapor flow at 1420°F was 19 hours; at about 1525°F, 33-1/2 hours; at 1550°F-1580°F, 15-1/2 hours.

2.1.2 Condenser Performance

There was little difficulty in obtaining a low condenser pressure (or temperature). During most of nozzle testing the condenser pressure was held steadily at 1-1/2 psia. A pressure range of 1-1/2 to 15 psia was covered during facility checkout. Once a steady state was established, there was no noticeable condenser pressure fluctuation as shown by recorder tracings in Figure 59. It was found that argon extraction from the condenser at a fairly constant rate, i.e., at the same rate that it entered, was a must.

Condenser liquid level was measured by a nuclear radiation gage, and liquid level in the condenser was directly controlled by this gage. Liquid level was automatically maintained within about 3/4". However while data points were being taken, level control was generally manual to produce a more uniform flowrate from the condenser condensate drum. Figure 59 shows the liquid potassium flowrate from the condenser while on manual control. The maximum recorded flowrate from the condenser was 4.2 lb/sec.

2.1.3 Vapor Quality

The convergent-divergent nozzle was used to measure vapor quality and was thus used to calibrate the throttling calorimeter. Vapor quality as indicated by the C-D nozzle extended over the range of 98% to 100%. At the same time vapor quality as indicated by the throttling calorimeter compared within 1/2%. Vapor quality indications better than 99% were obtained for the boiling range of 1450^{o}F to 1580^{o}F. At 1500^{o}F-1580^{o}F, quality indication was often 100% to slightly superheated with the 8.0" pipe heaters dissipating 30 to 40 kw power. Several tests indicated that the 8.0" pipe heaters conclusively increased vapor quality at least 0.2%. Figure 60 shows a comparison of vapor quality as measured by the C-D nozzle and throttling calorimeter.

The heating calorimeter did not perform satisfactorily during C-D nozzle testing nor during subsequent turbine testing. A faulty thermocouple precluded its accuracy during nozzle testing. During turbine testing this calorimeter indicated a vapor quality much higher than that determined from turbine power output versus pressure ratio across the turbine. It was strongly suspected that a good representative vapor sample was not being collected since much of the liquid from the turbine discharge was probably flowing on the pipe wall.

2.1.4 Mass Transfer in 3000 KW Facility
(Appendix)

2.2 Two Stage Turbine Testing

Upon completion of C-D nozzle testing, the facility was completely cooled to room temperature except the dump tank which contained the entire potassium inventory of about 3500 pounds. A number of facility modifications and additions were immediately started so that the facility would be ready for turbine testing in early 1964. New systems - not required for nozzle testing - included an oil lubricating system, a potassium slinger seal system, an argon reclamation system and numerous new instrumentation.

The turbine without casing was first installed in the facility on February 26, 1964 for preliminary dynamic checkout. Appropriate blank-off plates isolated the turbine from the liquid metal system. The main purpose for this installation was (1) to check out the turbine rotor stability after having been rebuilt following steam testing, (2) to check out the turbine loading and starting system in the new facility, (3) to check out the newly installed lube systems, and (4) instrumentation.

During these preliminary test runs, the water brake spline connection to the steam turbine sheared causing the steam turbine to accelerate to over 25,000 rpm with no apparent damage other than a rubbed labyrinth seal in the steam turbine. Subsequent investigation into the cause of spline failure revealed that the spline had been weakened by a hole that had been drilled in the shaft for instrument leads which were used during steam testing of the turbine. A new shaft with a stronger spline was installed.

On April 4, 1964 the turbine was completely welded into the facility essentially ready for testing. Prior to actually passing potassium vapor through the turbine, a number of preliminary tests were performed to again check out the rotating characteristics of the turbine, water brake and steam turbine. (Greater details on turbine checkout are in reference 2.) Also sub-loops such as the slinger seal loop and argon reclamation loop were checked out with the turbine rotating up to 15,000 rpm.

During preliminary testing it was found that vibration from the main condenser blower was transmitted to the test hardware. Vibratory displacement of the test hardware, caused by the condenser blower, was about 2 mils. By reducing the condenser blower speed from 960 rpm to 840 rpm, vibration caused by the blower was indiscernible.

Also during turbine preliminary tests, it was found that additional oil-argon separating capability was needed. Consequently, the lube oil system was modified to provide better separation of the oil and argon coming from the turbine bearing housing.

Early in April, 1964, the turbine was first rotated with potassium flowing to the turbine slinger seal. This was the first turbine "tare test" which actually went very smoothly. This test was conducted with the turbine slinger seal established and at turbine speeds up to 17,000 rpm. During this test a pressure differential (about 20 psi) between the main loop (condenser) and the turbine oil sump apparently caused oil to leak past a defective shaft seal and into the slinger seal loop. Consequently, oil was, unknown at the time, mixed with the slinger seal potassium. On the following day when an attempt was made to restart the slinger seal loop, the slinger seal E.M. pump would not function. It was determined that oil had indeed gotten into the slinger seal loop. A black residue was found to be clogging the E.M. pump, and most of the slinger seal loop piping was coated with the residue.

Removal of the potassium-oil compound from the slinger seal loop required the disassembly of the loop. Although several commonly used solvents were tried, no cleaning solution worked satisfactorily. Wire brushing was the only acceptable cleaning technique.

For the next 3 months major activity was concentrated on solving the oil leakage problem. A number of improvements were made to turbine seals, and additional pressure instrumentation was installed to better define and control the required delicate differential pressure across the turbine labyrinth seal. (Additional information on seal changes can be found in reference 6.)

During the search for oil leaks, the test turbine, water brake, and steam turbine were accelerated up to 17,000 rpm a number of times. During these speed runs excessive vibration was experienced in the area of the water brake. Excessive misalignment and/or unbalance of the water brake and steam turbine was causing unacceptable vibration of these components. Therefore, the supporting structures for these components were remachined, holding a tolerance on concentricity of mounting flanges within 1 mil. The water brake and steam turbine were rebalanced to be less than 0.1 gm in. out of balance. Subsequent running of this equipment effected vibrational amplitudes of less than 1 mil at speeds up to 20,000 rpm.

On July 13, 1964 the turbine was first run on potassium vapor. However, due to poor speed control (later concluded to be the result of boiler instability) and to a minor potassium leak in an efflux tube, the test was terminated after 3 hours of running. Subsequent analysis of data and inspection of the test hardware indicated that the pad bearing in the turbine became loose, causing the argon labyrinth seal and shaft forward screw seal to rub.

At that time it was not fully realized that the drastic speed perturbations were being caused by boiler instability. It was rather suspected that bearings and/or seals in the turbine were binding in some manner to cause erratic speed control. As a result the turbine bearings were improved as described in reference 6.

Figure 61 shows one of the first recorder tracings of turbine speed and water brake torque. Boiler instability was considered at this time but was not yet a prime suspect. Water brake instability was also suspected. Therefore, additional instrumentation was installed to monitor the boiler more closely. For example, boiler feed pressure was recorded on a Sanborn recorder. An accelerometer was installed on the stem of the 8.0" valve to detect possible slugs of liquid passing through the valve. The accelerometer output was also recorded on Sanborn. A differential pressure transducer was installed at the turbine inlet to measure possible perturbations in vapor flow through the turbine. Boiler discharge temperature and pressure were already on Sanborn. An E.M. flowmeter was installed directly in the boiler feed line to detect a possible correlation between speed instability and boiler feed flow.

From September 28 to October 13, 1964, the 3000 KW Facility was intermittently operated with the 2-stage turbine being driven by potassium vapor. Inlet vapor temperature to the turbine ranged from 1400°F to 1550°F for relatively long periods. Exploratory tests were performed in an attempt to find a procedure that would permit stable operation. At the same time, performance data were measured at each of the scheduled test points. These data were taken even though stable running had not been achieved.

Although all facility systems worked well, in that continuous running was obtainable, the turbine experienced numerous speed dips. Speed dips were of two basic types. Major dips were decelerations of 12,000 to 15,000 rpm in approximately 2 seconds. Minor speed decelerations consisted of gradual speed changes of 1,000 to 3,000 rpm - having a period of 10 to 20 seconds. There were times when the speed was essentially constant within a few hundred rpm for several minutes at a time. (See Figure 62.)

It was found that turbine inlet temperature could be easily maintained within the required $\pm$ 10^{o}F. Condenser pressure was also found to be very easy to maintain within limits - especially when the turbine speed was not too erratic. (Major speed dips caused argon to get into the condenser since the turbine slinger seal would "blowout" as the speed dropped below approximately 7000 rpm.)

Spraying heated liquid potassium from the nozzle permitted holding 92% and 85% vapor quality conditions without difficulty, but the 95% quality setting was erratic due to low liquid flow.

During this phase of turbine testing many experiments were conducted in an attempt to find a more stable operating condition. These will be discussed in their order of occurrence below. However, the two most noticeable influences on speed stability at this time were throttling with the 8.0" vapor valve and reduction of the boiler heating rate. Also, after 5 to 8 hours of continuous boiler operation, the frequency of major speed surges and the magnitude of minor speed changes appeared to decrease.

(a) September 28, 1964

As potassium vapor began applying power, familiar speed instability was evident. Although, in July, speed instability had been rationally analyzed to be caused by seal and/or bearing rubs, recently installed instrumentation provided new evidence indicating that internal rubs in the turbine were not causing erratic speed. The evidence pointed toward boiler instability.

During 3-1/2 hours of running, at least 3 measurements were found to be associated with speed instability. An accelerometer on the stem of the 8.0" valve indicated an acceleration within 1 second before a major speed dip. The boiler feed pressure showed a relatively slow decrease in pressure of up to 2 psi followed by a sudden rise in pressure up to 4 psi. A major speed dip occurred within 1 second after the boiler pressure started rising. The vapor velocity pickup at the turbine bullet nose showed a reduction in flow during major speed instability.

It was certain by now that boiler instability was directly associated with the erratic turbine speed, but the exact mechanism which caused the sudden speed dips of up to 15,000 rpm was not fully comprehended. However, it was strongly suspected that slugs of liquid (in the order of 8 to 10 pounds) were being discharged from the boiler and thrown into the turbine causing the turbine to decelerate rapidly. Calculations indicated that this quantity of liquid could cause the sudden decrease in speed. Also an accelerometer mounted on the stem of the 8.0" valve plug registered an acceleration of the valve plug (sometimes) a fraction of a second before the sudden speed decrease.

(b) September 29

Continued attempts to achieve boiler stability were not too successful, but it soon became evident that greater throttling with the 8.0" valve produced more stable turbine speed. By setting the boiler outlet vapor temperature at 1550°F-1560°F and throttling to 1450°F, turbine speed perturbations were less severe and less frequent. Turbine performance testing was started. However, several small leaks in efflux pressure tubing required a shutdown within several hours.

(c) September 30

It was also suspected that condenser instability was contributing to erratic speed control. However, condenser instrumentation did not verify this. (See Figure 63.)

(d) October 1 to October 3

Minor modifications and routine maintenance were performed.

(e) October 4

Two significant experiments were conducted. First, the boiler feed control valve was put on manual control and held at an absolutely steady feed rate. This test indicated no improvement to boiler stability. Second, the boiler liquid level was increased to its high limit (6.0"), followed by completely shutting off the boiler feed. The boiler feed remained off until the boiler drum liquid level decreased to its low limit (2.0"). Again, the turbine speed fluctuated as usual, including a major speed dip to 2,000 rpm. (It should be stated that it was not known that the boiler feed pipe in the vapor drum was probably broken at this time.) Another efflux tube leak required another facility shutdown.

(f) October 8

Eighty-four data points were taken in about 15 hours of continuous operation although turbine speed stability was far from desirable. Turbine speed generally varied ± 200 rpm continuously with speed variations of ± 1,000 to 2,000 rpm at 1- to 5-minute intervals. Several speed drops to around 5,000 rpm still occurred each hour, especially when a change in boiler setting was made. All remaining 1450°F data points were taken, and all 1550°F data points were taken.

At the beginning of this run, it was quite apparent that the turbine labyrinth seal was badly degraded, but with only 1/2 psi ΔP across this seal the entire test run was completed without incident.

During the 1550°F run the boiler firing rate was cut back from 35% to 10% while a minor facility problem was being corrected. During the cutback, turbine speed became exceptionally steady even though a high rate of vapor flow continued through the turbine. The cutback technique was repeated a number of times with the same results, thus new insight toward boiler stability was gained. It was reasoned that the burners were set too low in relation to the boiler tubes, thus most of the boiling was taking place in the lower portion of the tube. This, in effect, would produce a percolator effect for each tube. With the burners nearly off, heat was transferred to the tubes more uniformly from the hot refractory walls, thus more stable boiling.

2.2.1 Potassium Boiler

Testing resumed on October 13, 1964, with an objective of completing the 1600°F turbine inlet test points. Shortly after the boiler reached 1400°F-1450°F, a small amount of potassium smoke began to emanate from the boiler exhaust stacks. Further checking verified that a leak had developed some place in the boiler near the top of the vapor drum. Consequently, the facility was shut down while holding the loop under positive argon pressure.

Subsequent inspection revealed a crack in the top-middle section of the vapor drum. Up to this point in time, the boiler had been subjected to the following conditions:

Thermal cycles, fully off	- 14
Thermal cycles, standby at 1000°F	- 10
Accumulated time at 1000°F and above	- 237 hours
Accumulated time at 1450°F and above	- 103 hours
Accumulated time at 1550°F and above	- 72 hours
Accumulated time at 1570°F-1580°F	- 17 hours

A full off thermal cycle was one in which the boiler was drained of potassium and the furnace was cooled to room temperature. A standby thermal cycle was one in which potassium remained in the boiler tube bundle and the tube bundle was held at approximately 1000°F.

The actual temperature profile between the top and bottom of the vapor drum during a transient was not known since the vapor drum had not been instrumented. However, the procedure used to heat and cool the boiler would probably cause a sizable non-linear temperature distribution between top and bottom of the vapor drum. For example, when the boiler tube bundle was being heated or cooled, liquid metal was in the bottom of the drum to a depth of 4 to 6 inches. (Argon gas was in the top of the drum.) Essentially no heat was supplied to the vapor drum by the gas burners since the vapor drum was shielded from the fire box. Argon cover gas (generally at 3 to 5 psig) suppressed vaporization of the liquid potassium - thus there was no condensing of vapor on the inside of the drum to produce a uniform drum temperature. With argon in the drum, heat was supplied to the top of the drum only by conduction through the stainless steel drum wall. Since stainless steel is a relatively low thermal conductor, it was evident that the bottom of the drum within the depth of potassium was easily heated to a high temperature, but the top of the drum had a lower temperature which would be evident immediately above the potassium liquid level.

The same general type of non-linear temperature profile occurred during cooling of the vapor drum. Liquid metal was left in the bottom of the vapor drum until the tube bundle temperature decreased to $400^{o}F-500^{o}F$. Argon was always flooded into the top of the vapor drum when the boiler temperature reached $1400^{o}F-1450^{o}F$ to prevent a negative pressure in the boiler during cooling. Heat was rapidly lost from the top of the drum through the drum thermal insulation. For the tube bundle to cool from $1400^{o}F$ to $500^{o}F$ required 6 to 8 hours.

With a non-linear temperature profile, stresses of sufficient magnitude to cause yielding of the stainless steel occurred. Yielding of the metal resulted in a permanent bowing of the drum, Figure 3. The vapor drum bowed upward at the ends resulting in bending stresses. A combination of bending stress and local thermal stress no doubt caused two of the girth welds to crack. The most severe crack occurred at the centermost girth weld where stress was maximum. The resulting crack and leak of the center girth weld is shown in Figure 64.

Inspection of the internal structure of the vapor drum through this hole indicated that the boiler feed manifold was broken internally after passing through the drum wall. Consequently, cold potassium feed had been dumped directly into the vapor drum at a point far removed from any downcomer. Thus liquid recirculation throughout the boiler was greatly inhibited and may have contributed to the unstable operation.

The following corrective action was taken following the boiler leak. The damaged girth welds were repaired. Both ends of the vapor drum were supported by constant force hangers to minimize bending stresses in the vapor drum. Thermocouples were spotted at various places on the top and bottom of the drum to indicate actual temperature difference. Electrical heating elements were installed in the vapor drum cover so that, by heating the top of the drum, the temperature difference across the drum could be held to a minimum during transient conditions. Cover heating elements are shown in Figure 65.

The second major problem, boiler instability, was attacked in numerous ways: (1) An external boiler feed system was installed which assured injection of the cold feed into the 4 downcomers. (2) Additional thermal insulation was installed around the downcomers to minimize heat transfer to the liquid in the downcomers. (3) A preheating coil, shown in Figure 3, was installed to heat the boiler feed from 700°F-800°F to 1000°F-1100°F, and the boiler feed control system was revised to assure a constant liquid flowrate to the boiler. (4) A secondary, centrifugal type separator, similar to V.D. Anderson Type ID hi-ef Purifier, was installed at the boiler discharge to further dry the vapor leaving the boiler.

While these potassium boiler modifications were being made, a small glass tube water boiler was constructed to investigate the influence of artificial and natural nucleation on a natural recirculating boiler. Artificial nucleation was produced by injecting very small bubbles of argon into the top of the glass tube downcomer. Natural nucleation was produced by lowering the liquid level in the simulated vapor drum of the glass tube boiler. The liquid level was reduced until small bubbles of steam were sucked into the downcomer. Both techniques of producing nucleation greatly improved boiler stability as might be expected.

Since the introduction of more argon into the liquid metal system was not too favorable, it was decided to rely on natural nucleation by operating the boiler with a low liquid level in the vapor drum to increase carryunder of vapor bubbles into the downcomers. These vapor bubbles were to be the nucleation site for stable boiling. (Low liquid level in the vapor drum had been previously tried without success. However, the downcomers were not being supplied with the cool boiler feed because of the broken feed line in the vapor drum. Therefore, the downcomers were acting more like risers, thus precluding the carry-under of vapor bubbles.)

After the above boiler improvements were made, a condition of perfectly stable boiling and, consequently, stable speed control was achieved. The most important single condition which produced stable boiling was liquid level control in the vapor drum. A liquid level in the vapor drum not exceeding about 4.0 inches was necessary for excellent boiling stability. The $1000^{\circ}F$-$1100^{\circ}F$ liquid constantly supplied to the down-comers was well mixed with sufficient liquid carryunder to effect down-comer temperature within $5^{\circ}F$ of vapor temperature.

Figures 3 and 66 show the secondary vapor separator at the boiler dis-charge. The actual benefit to turbine speed stability attributed to the separator was uncertain. It was evident, however, that vapor quality from the boiler was slightly improved, as indicated by Figure 67. An attempt was made to measure the amount of liquid drain-ing from the centrifugal separator from a heat balance calculation for a heat exchanger in the separator drain line. No definite conclusions were made since the drain line also was a good condenser. Condensed liquid could not be differentiated from separated liquid. However, during unstable boiling, the heat exchanger measurement definitely indicated liquid slug removal by the separator.

2.2.2 Stable Facility Operation

As stated earlier, one of the most significant indicators of boiler instability, second to erratic speed, was boiler vapor drum pressure. Upon completion of boiler modification, vapor drum pressure became the primary indicator of incipient boiler instability. If boiler level inadvertently got too high by only a fraction of an inch, the vapor drum pressure would become unsteady by 1/4 to 1/2 psi without causing any speed perturbation. Consequently, boiler level would be reduced to regain constant boiler pressure precluding any turbine speed change. Figure 68 shows the correlation between speed and boiler pressure for stable and unstable boiling.

Unsteady boiling also produced a distinct sound. A sound probe attached to a boiler tube produced an audible noise similar to that resulting from the tube bundle being hit with a hammer.

Thermocouples attached to the boiler tube also revealed instability by exhibiting sharp temperature rises (spikes) of $10^{\circ}F$ to $15^{\circ}F$. One tube was instrumented with 8 thermocouples equally spaced. Figure 69 shows a minor temperature spike during essentially stable boiling.

After achieving boiler stability, another type of turbine speed instability was encountered. This was found to be caused by water brake instability. The resultant influence on speed versus torque is shown in Figure 70. This problem was quickly solved by reducing the water flowrate to the brake so that the water in the brake approached boiling. The brake was actually oversized for the existing application and the water level in the brake, therefore, was quite low. It was suspected that, when running with cold water ($120^{\circ}F$-$150^{\circ}F$), the water would momentarily become disengaged from the discs, thus unloading the turbine and allowing it to accelerate in speed. It was surmised that by reducing the water flow and allowing the water to boil in the brake, a deeper two phase fluid level would exist in the brake. The discs and water would not be disengaged, thus maintaining steady speed as shown in Figure 70. It was necessary to maintain the water discharge temperature at 185°F-195°F. The water brake was vented to atmospheric pressure. Although not actually measured, a heat balance calculation indicated that the water temperature in the brake was approximately 212°F. This was further verified by the fact that if the exit water temperature exceeded 200°F, turbine speed would suddenly accelerate, indicating unloading of the turbine. Unloading at the higher exit water temperature would suggest excessive boiling of the water in the brake.

On May 21, 1965, turbine performance testing was completed. Performance testing was conducted with a perfectly stable boiler and water brake. Vapor quality was maintained at about 99.5% into the turbine during this test. Turbine speed was generally maintained within ± 100 rpm of the set point without difficulty. About 1/2 of all test points were repeated to demonstrate repeatability of test data; repeatability was good. Refer to references 2 and 6 for greater detail.

Upon turbine disassembly, very little blade erosion was evident, and slight mass transfer was apparent. Refer to the Appendix and references 6 and 9 for greater detail.

After completing the performance test, the turbine was rebuilt. On September 9, 1965, a 2000 hour turbine endurance test began. On December 20, 1965 the facility was cooled down after completing the endurance test at 1500°F inlet vapor temperature. The turbine was stopped only once at 254 hours when, during a routine speed pickup calibration, the overspeed trip was inadvertently energized. During the 2000-hour test, all facility components performed well except for a variable transformer which controlled the main E.M. pump and the argon compressor. A standby transformer was connected to the E.M. pump almost immediately without interrupting testing. A new diaphragm and exhaust valve had to be installed in the argon compressor. A momentary power outage caused the boiler to shut off once, but it was immediately refired - losing only a few hours deviation from required discharge temperature. All systems were stable as shown by typical recorder charts in Figures 71 and 72 (cf. Figure 73) and Figures 74 and 75 (cf. Figures 76 and 77).

During the 2000 hour endurance test, several significant modifications to the test facility not only improved its overall stability, in regards to speed and temperature control, but also made it possible to operate the facility with two less operating technicians while accomplishing a higher degree of reliability. For example, an automatic control was installed to regulate the water level in the water brake, thus becoming an automatic speed controller (Figure 80) which maintained the turbine speed within $\pm$ 100 rpm ($\pm$ 60 rpm most of the time) with essentially no attention required from operating technicians. An automatic controller connected to the condenser air exhaust louver maintained a constant condenser temperature and, hence, a desired pressure despite changes in ambient air temperature or other perturbations which normally had an influence on the condenser pressure.

Two to eight gals/hr of potassium accumulated in the slinger seal loop from the condensation of potassium vapor that passed through the forward labyrinth seal. This condensate would flood the argon-potassium separator in the slinger seal loop if the excess liquid were not drained away. Maintaining the desired liquid level required almost constant attention. Even while the turbine was running during endurance testing, an overflow drain was installed between the slinger seal separator and dump tanks. This drain line permitted automatic drainage of the separator tank, thus reducing operator attention. (Refer to Figure 36; the overflow drain line is the one in which valve VDS-8 is installed.)

Other minor improvements were made which, altogether, permitted a reduction in operating personnel.

2.2.3 Post Test Inspection

Post test inspection of the facility indicated essentially no damage as the result of long time operation. The lower bearing of the 8.0" valve was galled which prevented the valve from fully closing during cool down. The seat of the valve was in excellent condition.

All boiler and condenser welds which could be inspected were undamaged. Oxidation of boiler tubes was only moderate, about 2-1/2 mils loss of tube wall on the average.

Mass transfer from the boiler deposited in the 8.0" pipe or on the inlet to the turbine was not visually detectable. During the endurance test, vapor was not throttled by the 8.0" valve, and the 8.0" pipe line heaters compensated only for heat loss from the 8.0" vapor line. Essentially no vapor drying was accomplished between the boiler and turbine. A small mass buildup, discussed in references 6 and 9, occurred on the turbine blades.

Figure 79 shows the potassium turbine after completion of the 2000-hour endurance test. There was no indication of incipient leaks or other external degradation except moderate oxidation of the stainless steel.

Inspection of the water brake and steam turbine after 2000 hours of running revealed no significant damage except for the water brake spline connection to the steam turbine. As shown in Figure 80, this spline showed significant wear. On disassembly of the water brake-steam turbine support structure, the water brake was about 7 mils out of line. This may have contributed to excessive spline wear. One water brake ball bearing and one steam turbine ball bearing were rough running but far from inoperative. The water brake discs, with more than 2300 hours accumulated running time, also were undamaged (Figure 47). Cavitation of the rotor or stator discs was nil.

3.0 Conclusions

Long time continuous operation of a large potassium vapor, Rankine cycle, facility was demonstrated with no insurmountable difficulties. Operation of the relatively complex facility was straight forward - requiring only a limited number of well trained operating personnel. Control of this facility was adaptable to conventional automatic control units, pneumatic as well as electronic.

The potassium containment piping and component hardware were fabricated of Type 316 stainless steel. The boiler was operated at about 1550°F, tube temperature, for over 2000 hours. From oxidation measurements and from stress rupture calculations, it was concluded that only about 5% of the boiler life had been used. Degradation of loop components and structural materials was not encountered. Evidence of minor mass transfer was evident but was so slight as to be of no consequence.

When dealing with potassium specific handling precautions are required, but during more than two years of facility operation, no extremely hazardous situations were encountered.

In conclusion, the entire test facility performed as it was designed with a few minor exceptions which were of little importance. Inspection and evaluation of the facility upon completion of more than 2000 hours of operation reveals no indication that the facility could not continue to be operated for at least an additional 10,000 hours at 1500°F vapor temperature.

APPENDIX

OBSERVED MASS TRANSFER IN 3000KW FACILITY

I Observation

Upon completion of C-D nozzle testing, two types of mass transfer deposits were observed on removal of the C-D nozzle. A very fine gray dust deposit was found on the inside of the 8.0" pipe and on the wall of the 10" pipe. The thickness of this layer was in the order of a few microns. It could only be detected by wiping the pipe with a clean white rag. More significantly, the elbow immediately downstream of the C-D nozzle contained a relatively hard metallic buildup on the outer radius of the elbow. The length of the buildup was in the order of 12-14 inches extending across the C-D nozzle flange where it was welded to the condenser. The width of the deposit was in the order of 2-3 inches. The maximum thickness of the deposit was about 40 mils but tapered off to no thickness very rapidly. (See Figure 81 showing general area of deposit.) The deposit had the appearance of a flame sprayed metal deposit. The deposit including the gray dust was found to be magnetic at room temperature. It was found to be primarily Ni, Cr and Fe, mostly Ni and Fe. With some effort the deposit was removed with a hammer and chisel - finished by hand grinding. Estimated weight of total hard deposit was 15-25 grams. There was also a small amount of relatively hard metallic deposit in the throat of the C-D nozzle. This deposit was mostly along the bottom of the throat. Estimated weight is 0.5 to 1 gram.

During boiler modification in October - December 1964, the boiler vapor drum, boiler lower header, boiler hot trap, 8.0" vapor pipe and 8.0" valve were inspected a number of times and in a number of ways. Gray dust deposits were found in all of the above areas. The thickness of the dust deposits in the 8.0" pipe and around the

8.0" valve was nil but evident when the pipe wall was wiped with a white rag. No "foil-like" or hard metallic deposits were noticed at the discharge of the 8.0" valve. However, this area was not closely inspected for such deposits. On the other hand if a deposit had been there and had been in the process of peeling off, it would have been noticed since we were looking for abnormal surface appearance, cracks, etc.

The boiler hot trap looked relatively clean with only a minor discoloration of the Zr hot trapping material. Of course, a thin layer of gray dust appeared there.

The greatest accumulation of gray metallic dust was found on the bottom of the vapor drum and boiler bottom header. The thickness of dust was estimated to be 1 to 3 mils in general - 5 mils at some places. The dust deposit was not tightly packed, and it was easily removed with a rag. The total weight of the deposit was estimated to be less than 200 grams.

The turbine was removed from the facility and disassembled during October - December, 1964. No hard metal deposits were found in the turbine. Some metallic dust was evident after cleaning potassium from the turbine.

After the May 1965 turbine performance test, "foil-like" metal deposits were found on the turbine inlet nozzle and first stage buckets. These deposits were also found on some of the Station #1 instrumentation probes. These deposits were mechanically held by the various probes and nozzle partitions. There was no apparent metallurgical bond except on the turbine buckets. Even here the particles could be lifted off with relative ease.

During turbine performance testing the 8.0" valve was used to throttle the K vapor from as high as 1550°F to 1450°F. Total throttling time was about 10 hours. Since throttling wet vapor tends to dry the vapor, it was immediately suspected that a metallic deposit had occurred downstream of the 8.0" valve at that time. Also, since the 8.0" pipe was heated 20°F to 50°F hotter than the K vapor, liquid on the pipe inside wall was evaporated and left its dissolved metal behind. Upon examining the 8.0" pipe, a "foil-like" metal deposit was found immediately downstream of the 8.0" valve. The location and general shape of the deposit is shown in Figure 82. (This deposit was removed from the pipe.) Figure 83 also shows this deposit. The deposit was less than 1 mil in thickness, in general, and its total weight was estimated to be less than 10 grams. However, it was obvious that a considerable amount of foil deposit had peeled off the pipe and had been carried into the turbine. Figure 84 shows a small amount of the foil which was caught by the throttling calorimeter probe and one of the total pressure probes at Station #1. Additional details on mass transfer are included in reference 10.

To verify further that a hard metal deposit tended to occur where wet vapor was dried by throttling, the throttling calorimeter was cut apart for inspection. Although not extremely pronounced, a gray metal deposit was found on the inside wall of the pipe and along the twisted ribbon.

Hard metal deposit was not found on the discharge side of the turbine, in the area of the turbine, or in the condenser. The vertical 10" pipe going into the condenser was quite clean. The top 8.0" headers of the condenser were inspected with a borescope. No metal deposits were found other than a light coating of gray dust.

The coldest part of the condenser was the horizontal run of the condenser tubes between the fin tube and condensate drum. Eight of these tubes were radiographed to detect any buildup in wall thickness. No buildup was detected.

Another potential location at which mass transfer buildup might occur was near the outlet of the boiler tubes. During the October - December inspection, no buildup was discovered in this area. In August 1965, however, two of the boiler tubes were radiographed. No change in wall thickness was detected.

II Pressure Drop

During the May 1965 performance test, throttling with the 8" valve was used to achieve turbine inlet vapor temperature of 1450°F. Temperature drop from as high as 1550°F was encountered, but most of the time the temperature drop was from about 1500°F to 1450°F. The total time of throttling was about 10 hours. Pressure difference across the 8.0" valve ranged from 5 to 10 psi. This was sufficient pressure drop to change the vapor quality by about 1%. Therefore dissolved metal in the potassium (if the potassium liquid were saturated) or entrained small particles of metal would tend to precipitate out of the flowing potassium vapor. It was surmised that sufficient force was available in the turbulent vapor stream out of the valve to slam the small metal particles against the pipe wall where they stuck to form a layer. To get a 5 to 10 psi pressure drop the 8.0" valve was about 85% closed.

During all 1550°F performance testing, the 8.0" valve was wide open. The data in Tables I and II are presented to indicate the order of magnitude of pressure drop across the wide open 8.0" valve and to show possible pressure drop between the boiler vapor drum and Station #1.

Table I. Indicated Pressure Drop Across Wide Open 8.0-in. Valve

Test Point	Boiler Discharge Temp., °F[a]	Station #1 Temp., °F	Vapor Quality, %	Indicated ΔP, psi
331R	1560	1553	99.2	0.96
332R	1560	1549	99.2	1.50
333R	1560	1550	99.1	1.37
334R	1560	1548	99.2	1.64
335R	1562	1552	99.2	1.38
336R	1562	1550	99.2	1.65
363R	1558	1548	99.9	1.36
364R	1558	1549	99.9	1.23
365R	1556	1550	99.9	0.42
366R	1557	1547	99.9	1.35

[a]This temperature recorded on Sanborn. The thermocouple was not calibrated. A second couple, also not calibrated, at same location consistently indicated 1545°F. There is, no doubt, some T.C. error in these readings.

Table II. Measured Pressure Drop Across Combined Vapor Separator And Wide Open 8-in. Valve

Test Point	Boiler Vapor Drum Taylor Gage, psia	Station #1 Taylor Gage, psia	Measured ΔP, psi
331R	33.7	31.1	2.6
332R	34.0	30.8	3.2
333R	33.7	30.8	2.9
334R	33.7	30.7	3.0
335R	33.7	31.1	2.6
336R	33.7	30.8	2.9
363R	33.4	30.7	2.7
364R	33.7	30.5	3.2
365R	33.0	31.0	2.0
366R	33.0	30.6	2.4

Taking the temperature drop between the boiler discharge (Sanborn) and Station #1 (digital) at face value, a 10° temperature drop was evident with the valve wide open. This was about 1-1/2 psi on the average. However, $10^{\circ}F$ was within the error of an uncalibrated thermocouple, and this ΔT was not considered to be exact.

Table II indicates about a 3 psi drop between the boiler vapor drum and Station #1. Of course, Taylor gages are not exact but ΔP no doubt was in this order of magnitude.

The high vapor quality with the valve wide open during $1550^{\circ}F$ runs would indicate very little mass transfer in the liquid phase during endurance testing.

III Conclusions

Based on observations, it was evident that a thin "foil-like" metal deposit was formed immediately downstream of the 8.0" valve during performance testing. The deposit was most likely formed during the $1450^{\circ}F$ runs when the vapor was throttled and further dried by the 8.0" pipe heaters. It was further concluded that the foil peeled off during the $1550^{\circ}F$ test runs when the valve was wide open and the vapor flow rate was maximum. An additional support to this conclusion was the fact that the remaining foil in the pipe, upon completion of testing, appeared to be in a state of peeling off rather than building up.

Since no hard or "foil-like" deposit was found except where a throttling action occurred, it was apparent that a drop in temperature (or chilling) does not result in a hard metal deposit. (Chilling of potassium saturated with dissolved metal most likely resulted in precipitation of metal, ending as fine dust particles.) This was evident by most of the loop being coated with metal dust to varying degrees. It was concluded that the dust type metal deposits eventually settled out in the boiler lower header and to some extent the boiler vapor drum. Also, some of the dust no doubt was trapped by the large filter bed at the outlet of the 450 Btu/sec heat exchanger. This filter normally was at $250^{\circ}F$. The filter, however, has not been opened for inspection.

After 254 hours of continuous running at $1500^{\circ}F$ vapor temperature with no throttling or drying of the vapor in the 8.0" pipe, the 8.0" pipe and turbine inlet nozzle diaphragms were inspected for mass transfer deposits. No visual deposits could be detected. Also after 2000 hours operation at the same condition, no visible mass transfer deposits were evident in the 8.0" pipe or the inlet to the turbine.

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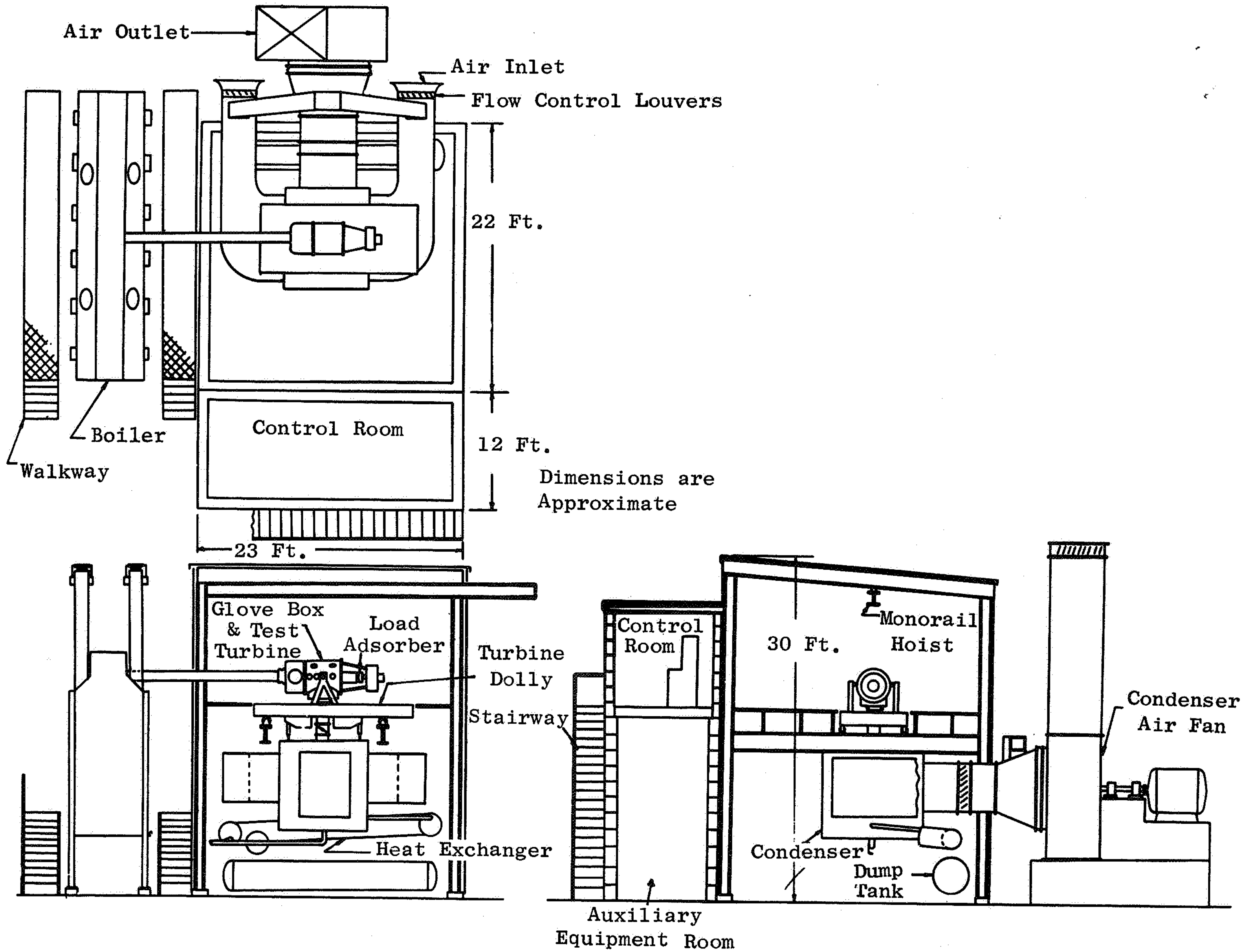


Figure 1. 3000 KW Potassium Vapor Test Facility.

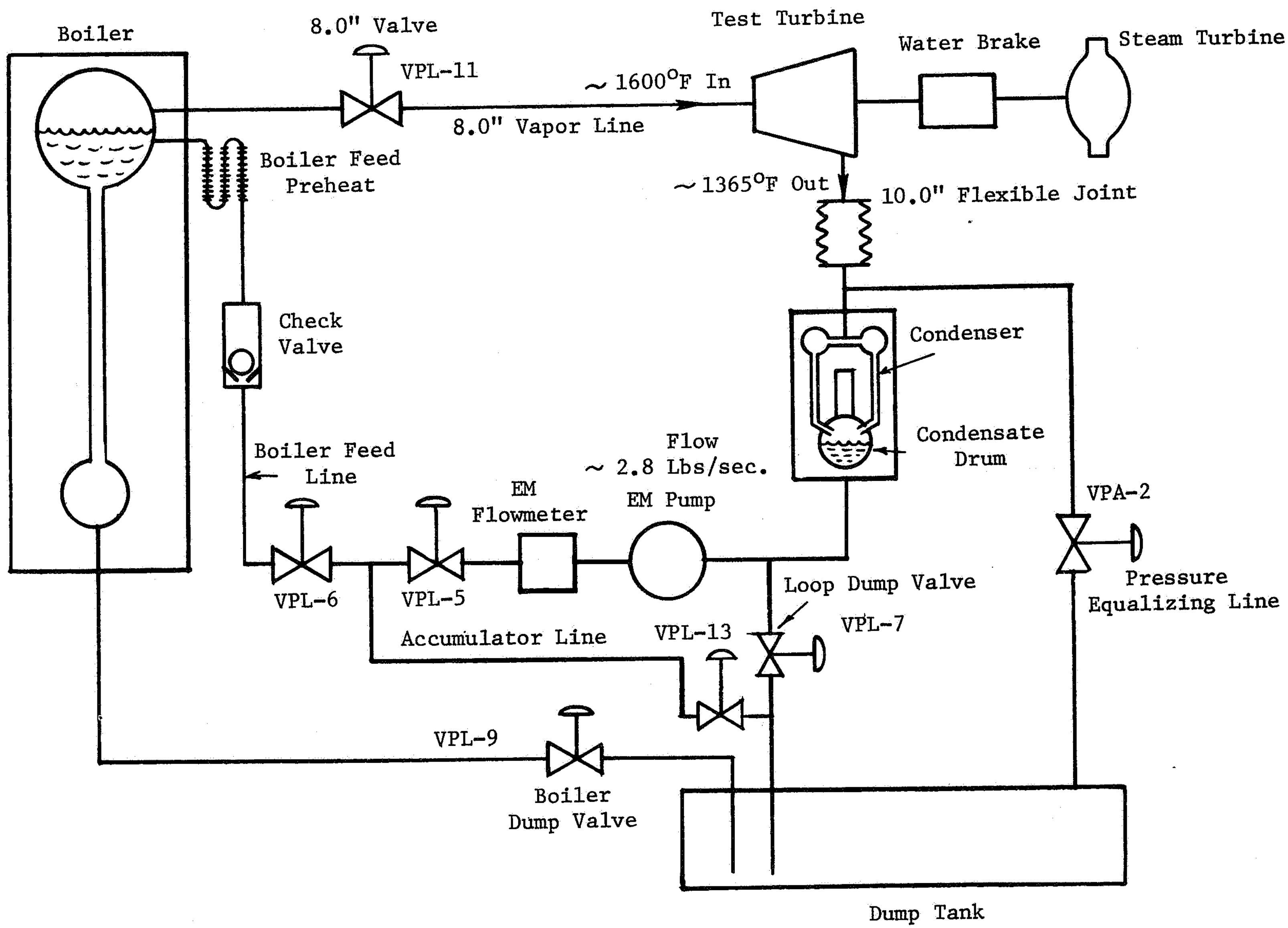


Figure 2. Basic Schematic of Potassium Metal Loop.

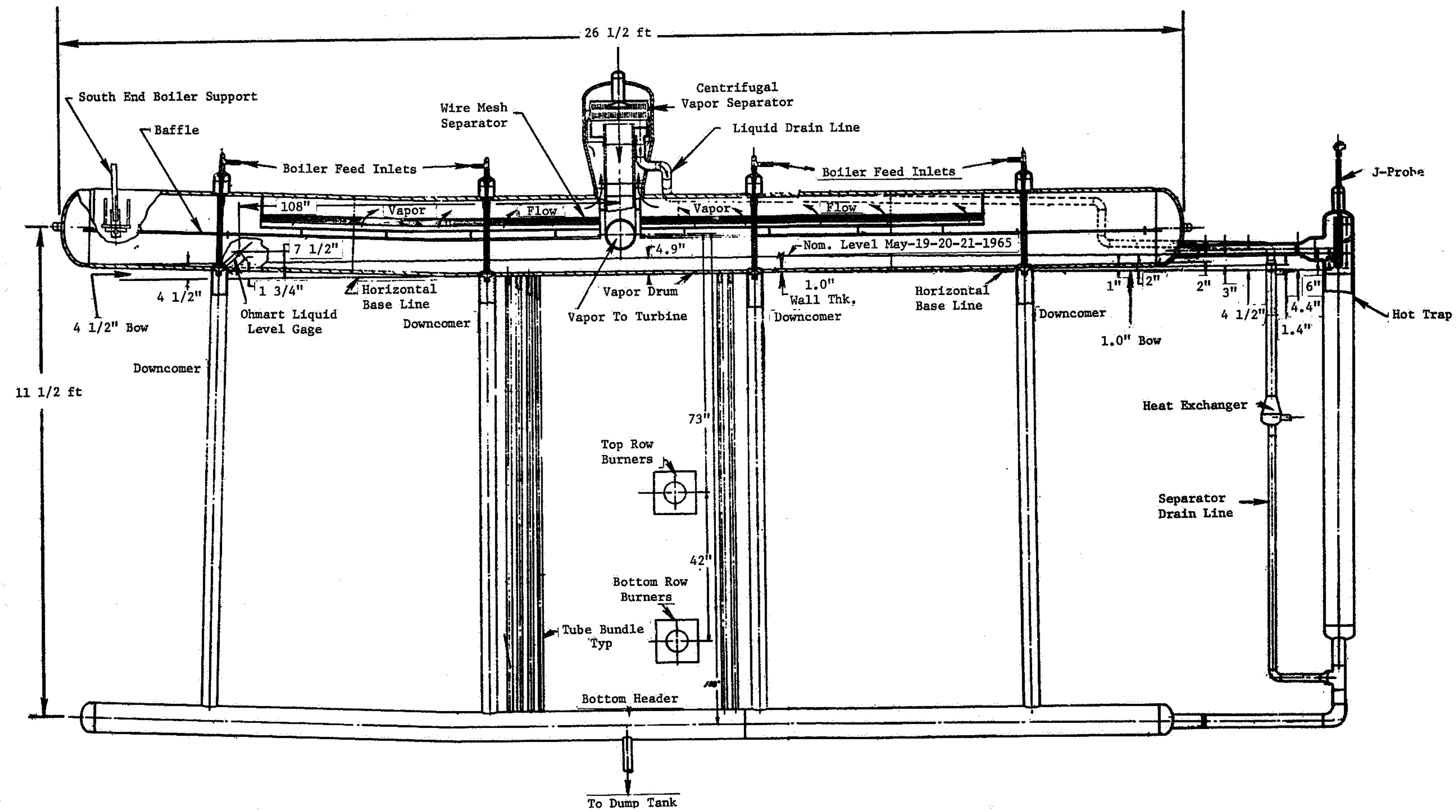


Figure 3. Cross Section of Tube Bundle Showing Bow in Vapor Drum.

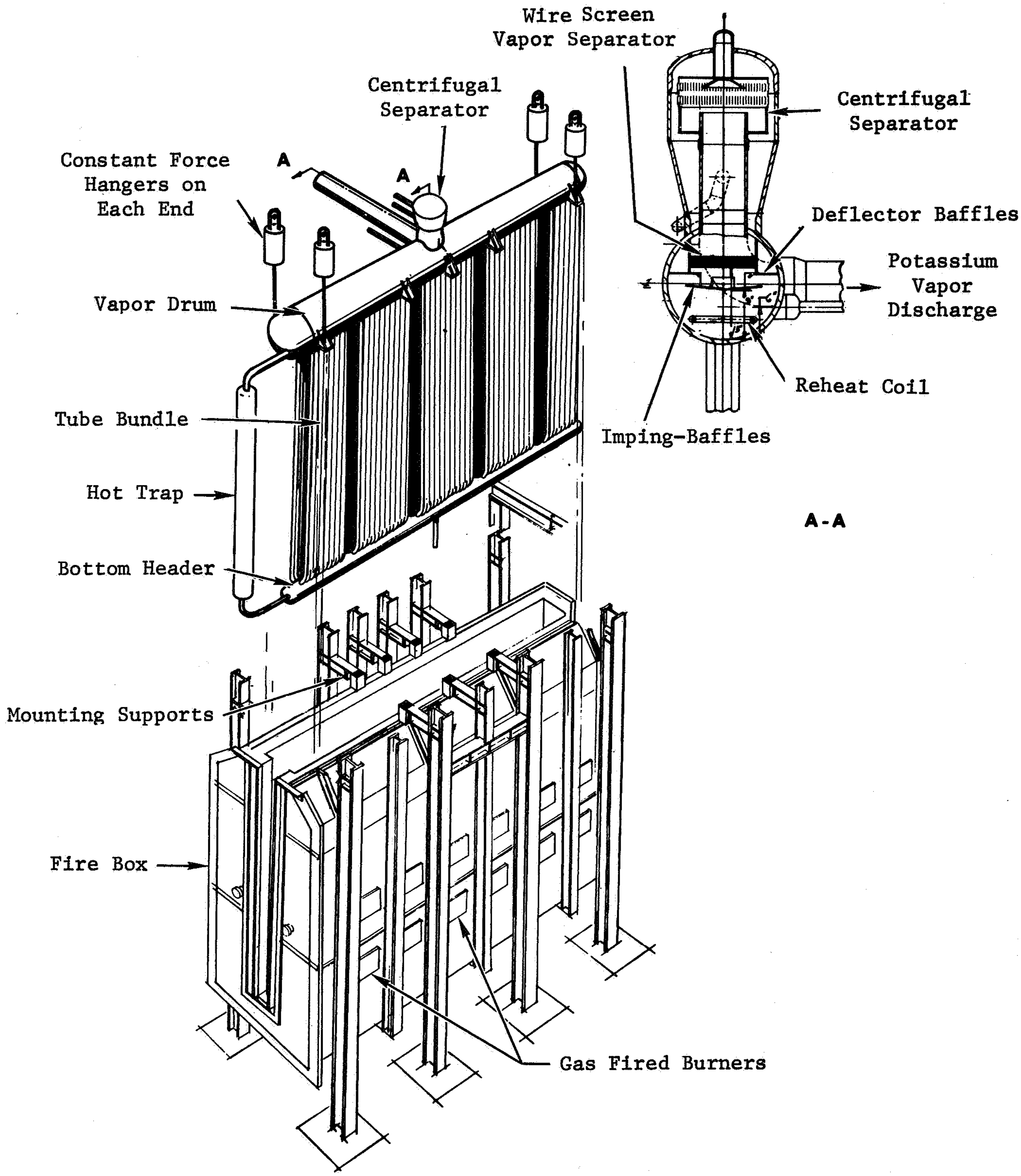


Figure 4. Pictorial View of Potassium Boiler.

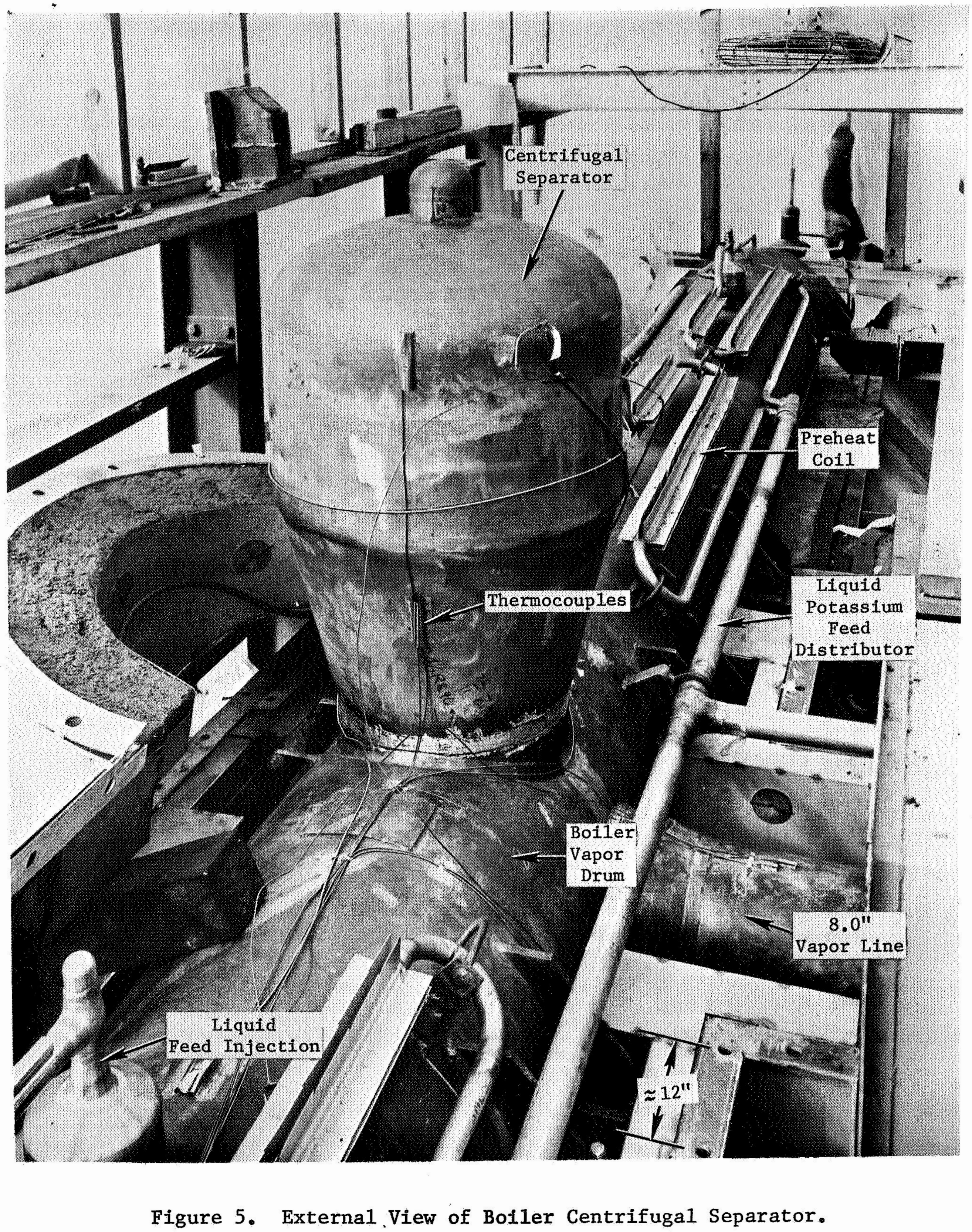


Figure 5. External View of Boiler Centrifugal Separator.

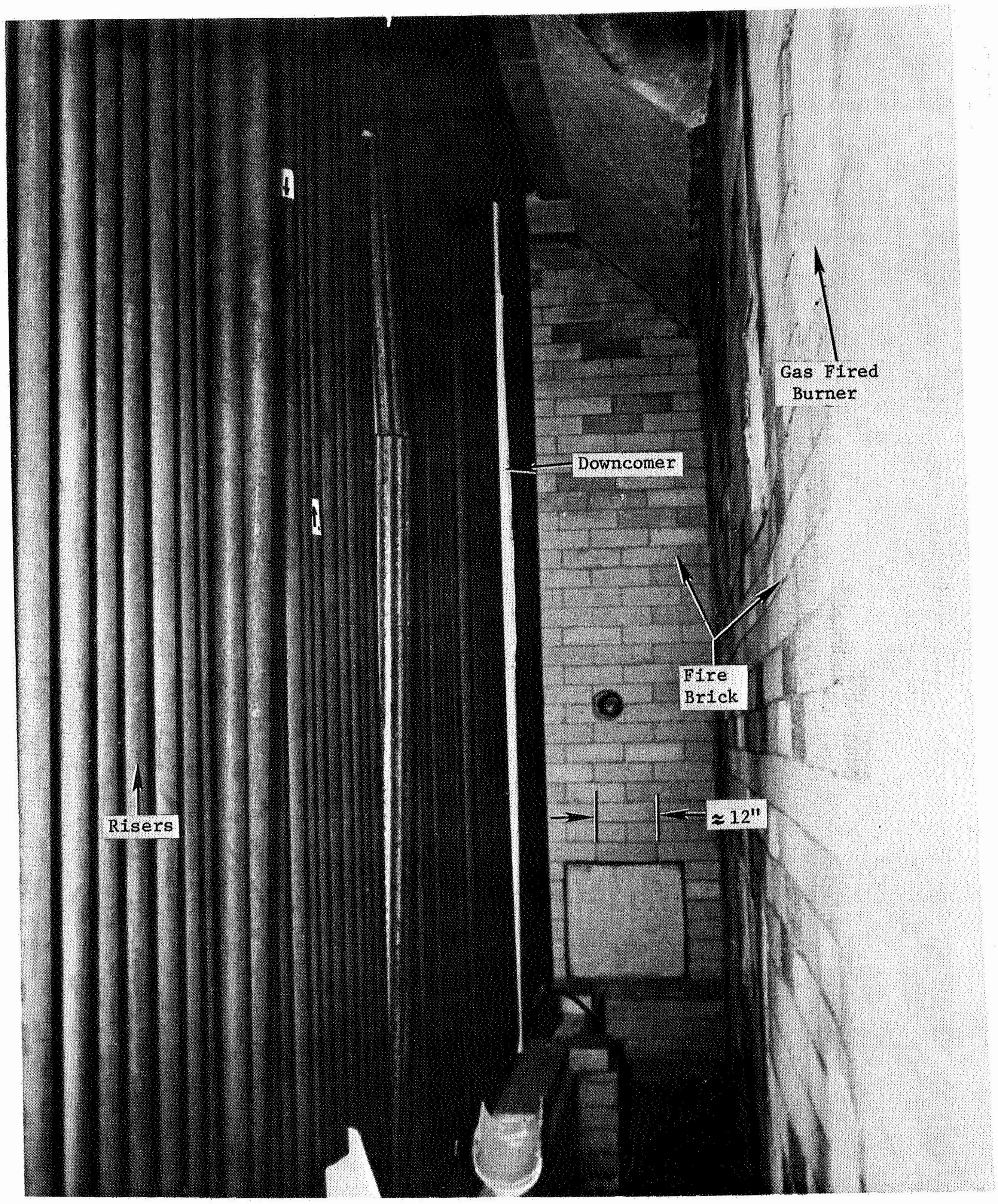


Figure 6. Boiler Tube Bundle.

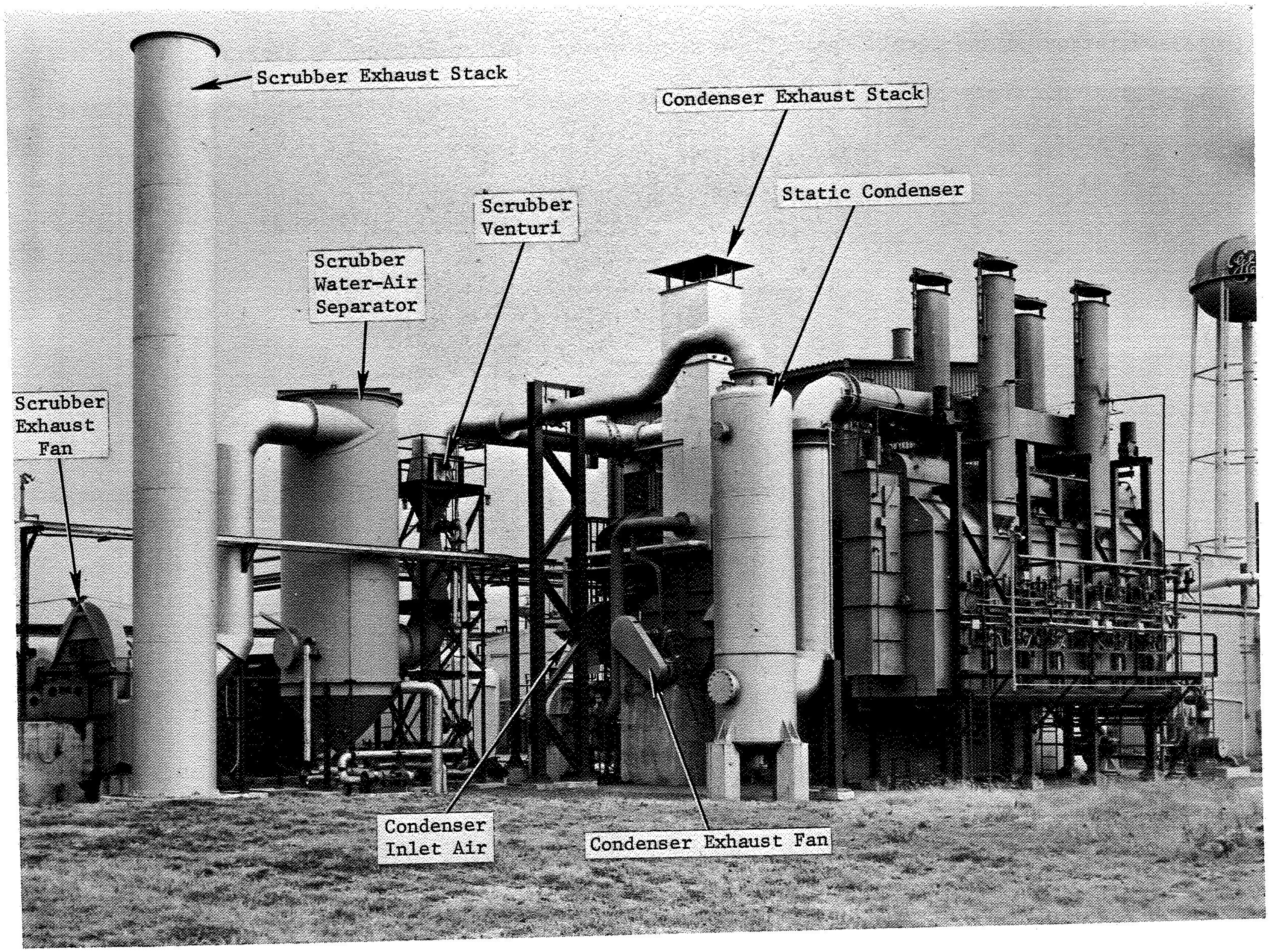


Figure 7. External View of 3000 KW Test Facility.

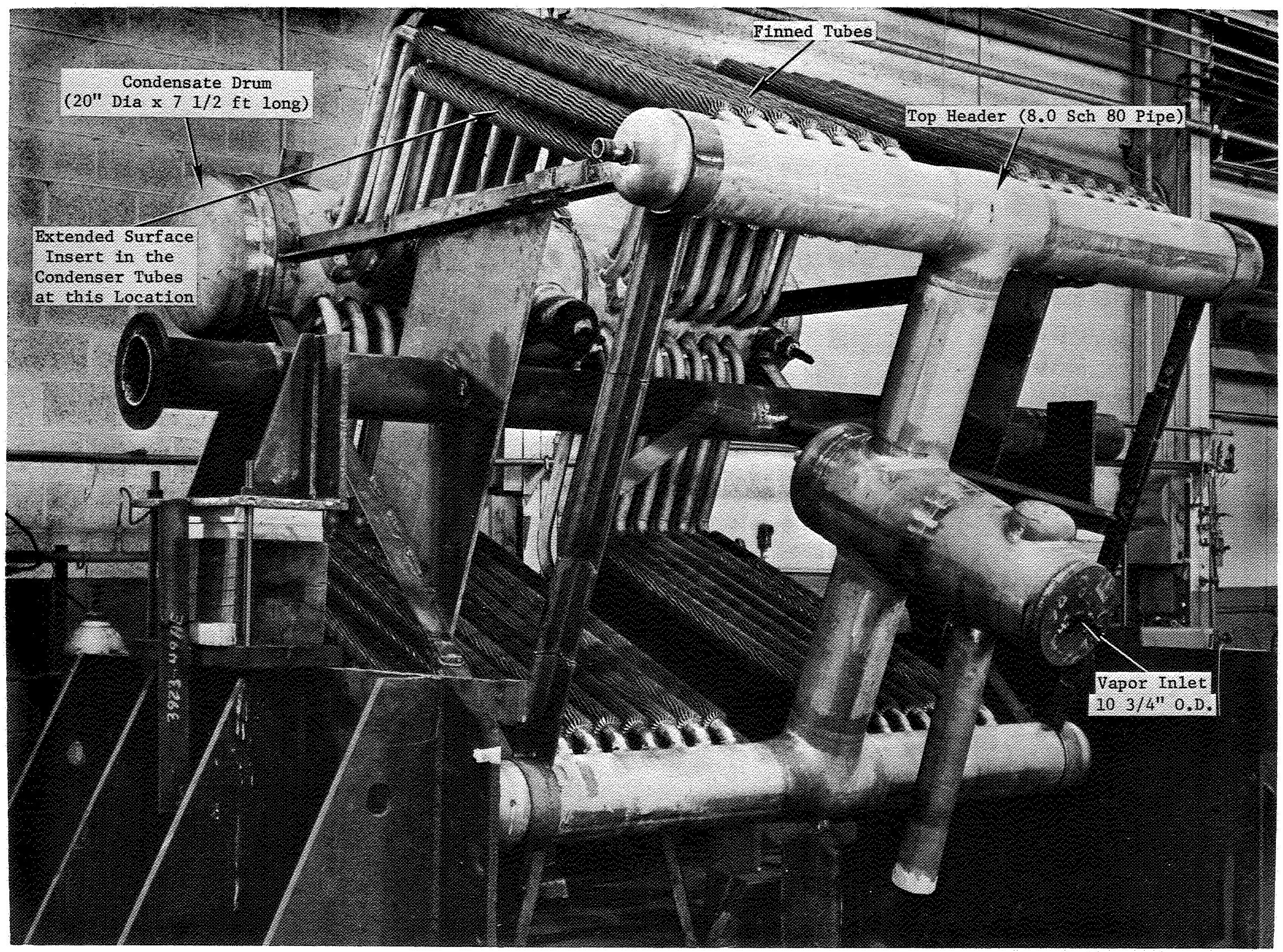


Figure 8. Condenser Tube Bundle Being Fabricated. (110^{o} out of normal position).

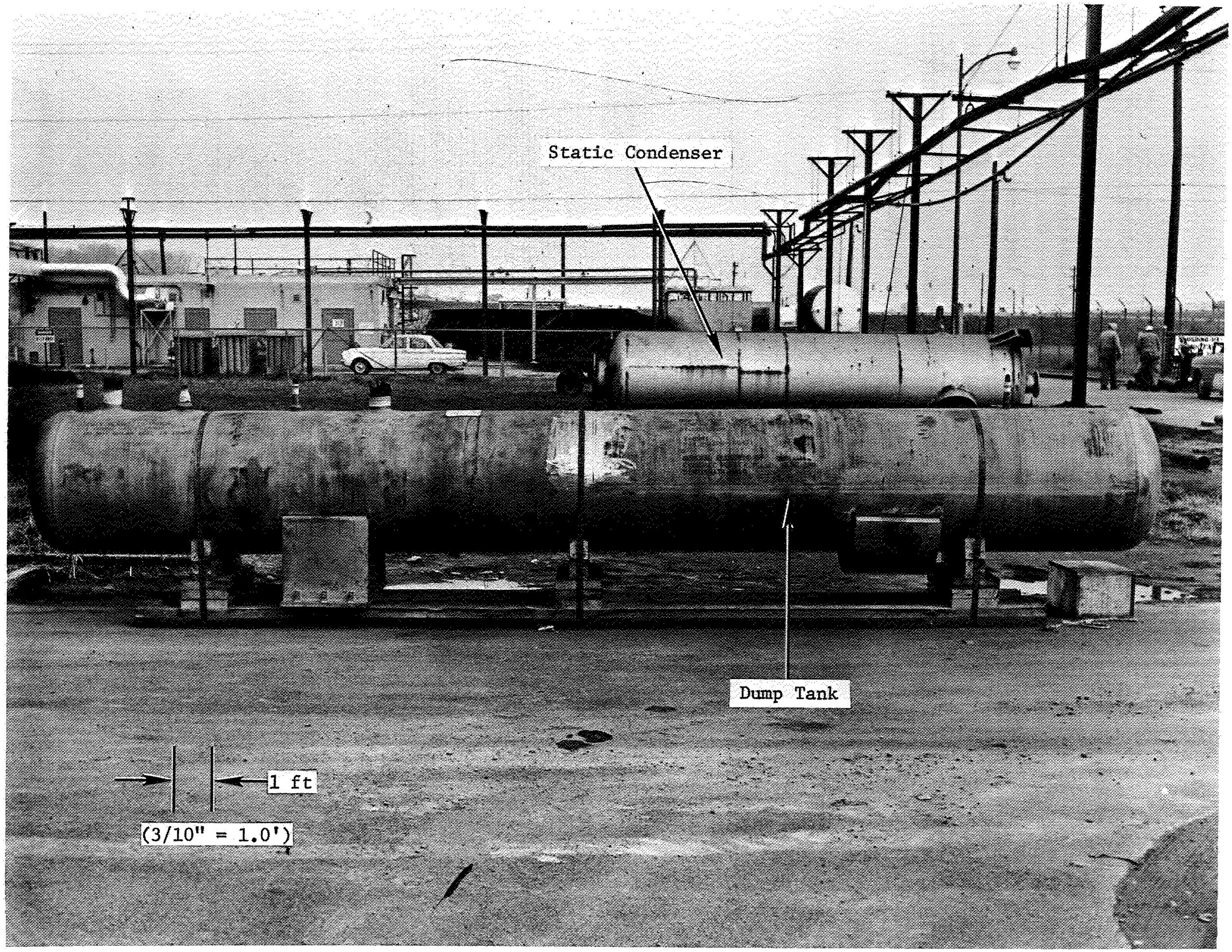


Figure 9. 3000 KW Facility Dump Tank.

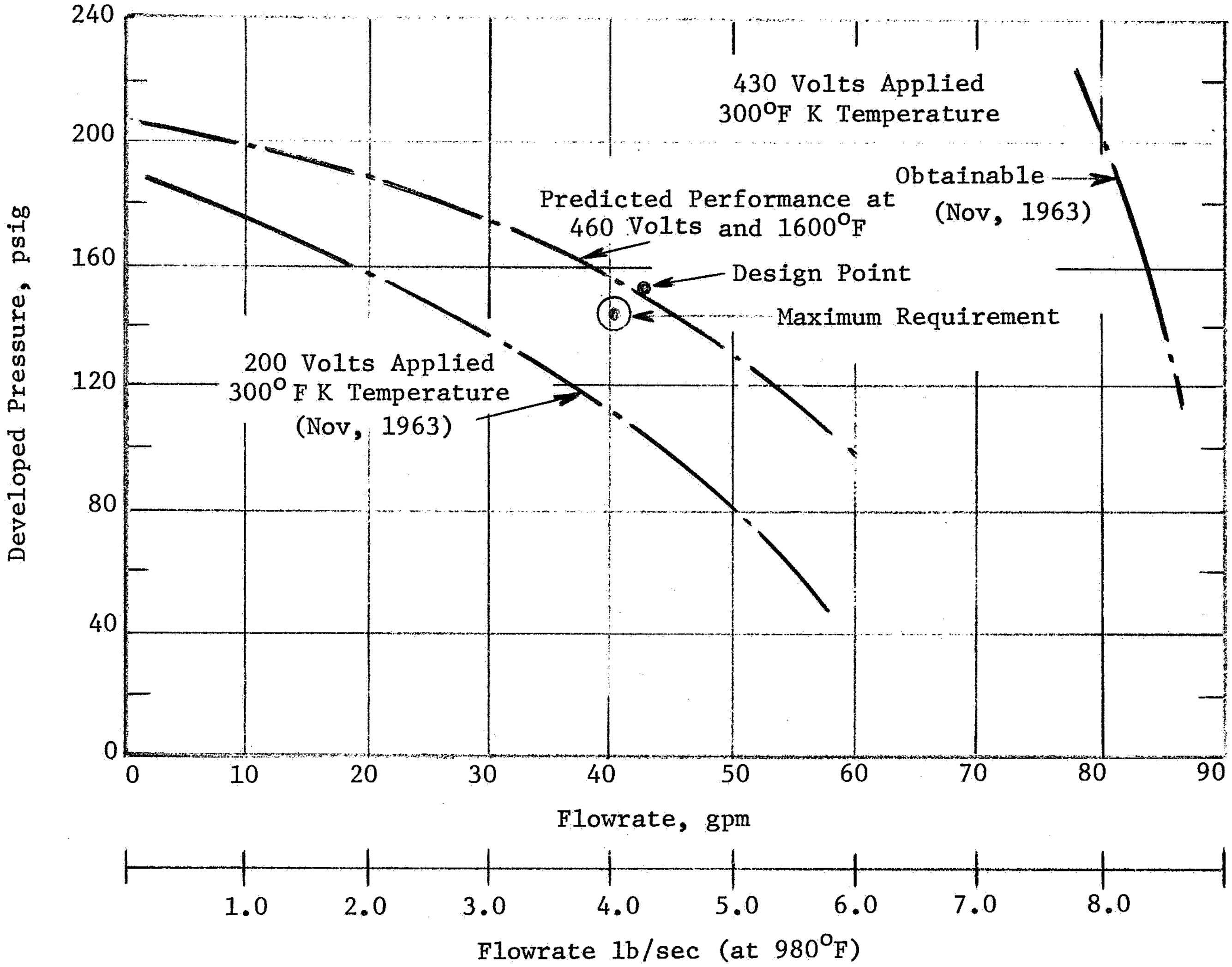


Figure 10. Em Pump Calibration.

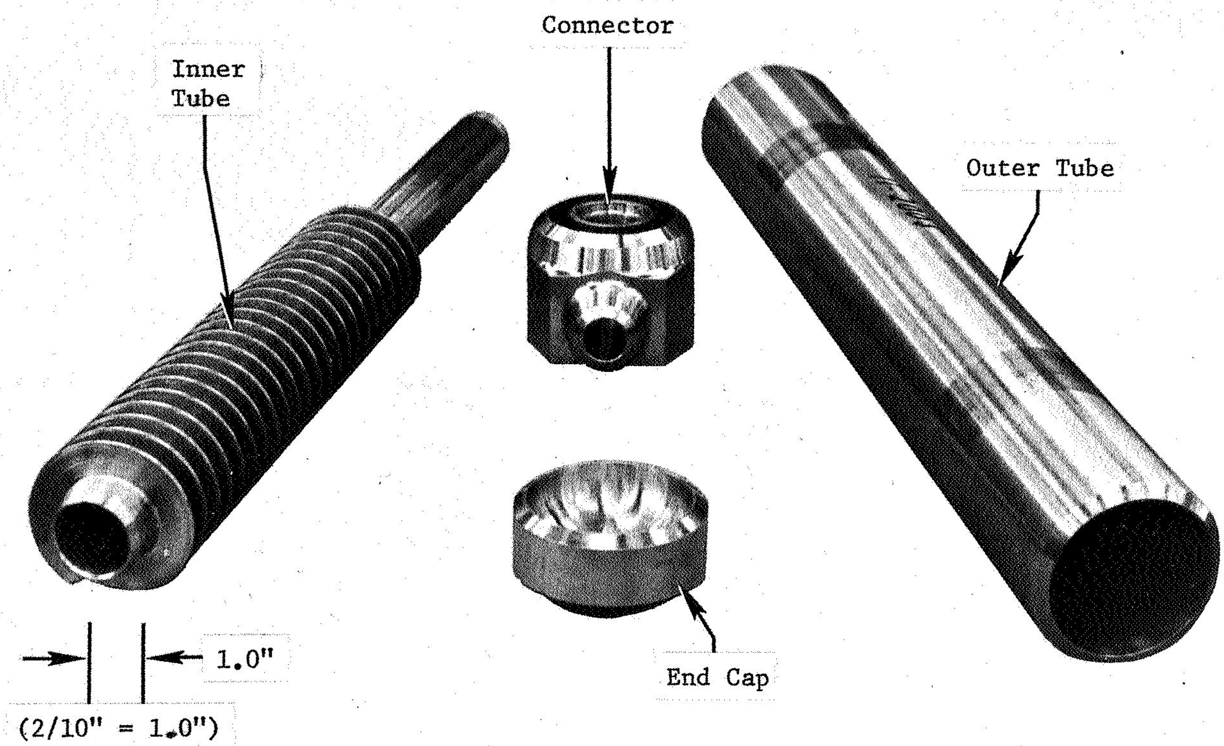


Figure 11. 3000 KW Facility EM Pump Duct.

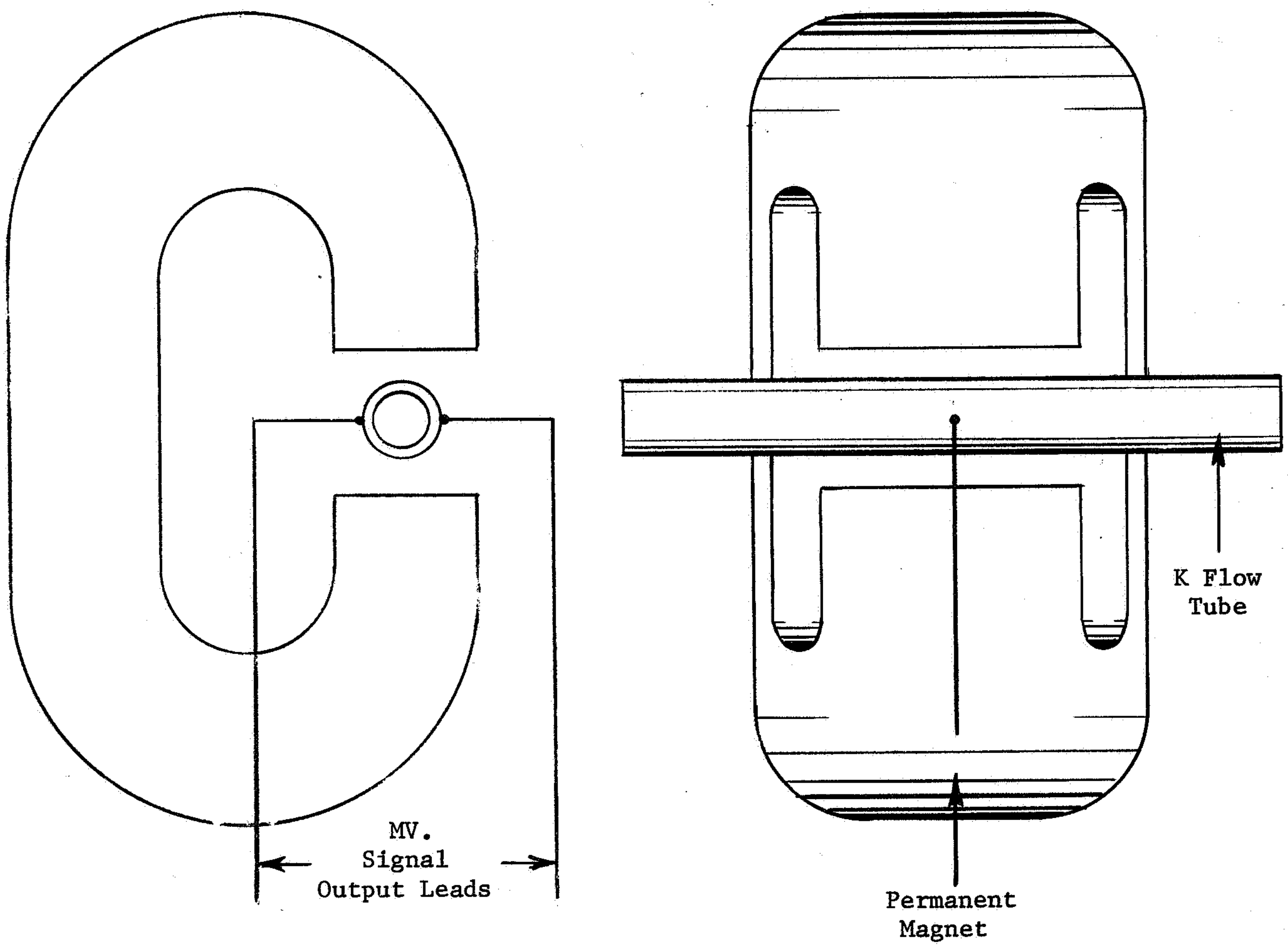


Figure 12. Typical EM Flowmeter.

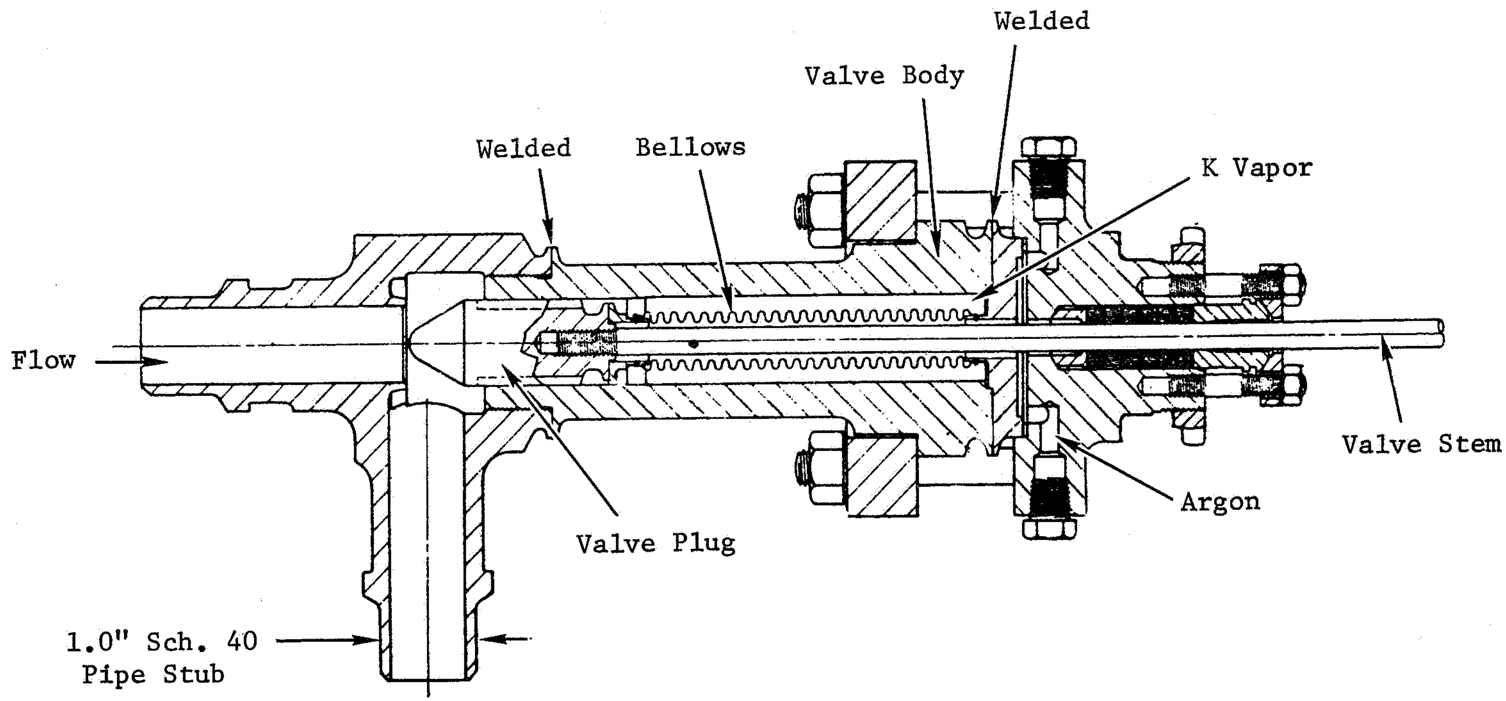


Figure 13. Fisher Governor Company Liquid Metal Valve.

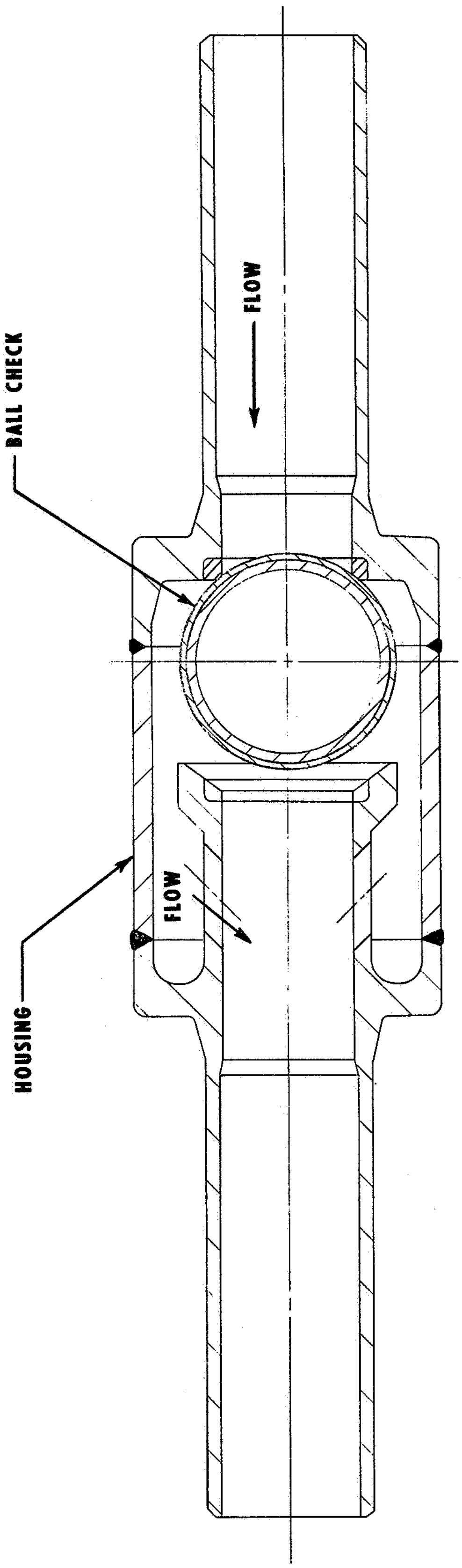


Figure 14. Boiler Feed-Line Check Valve.

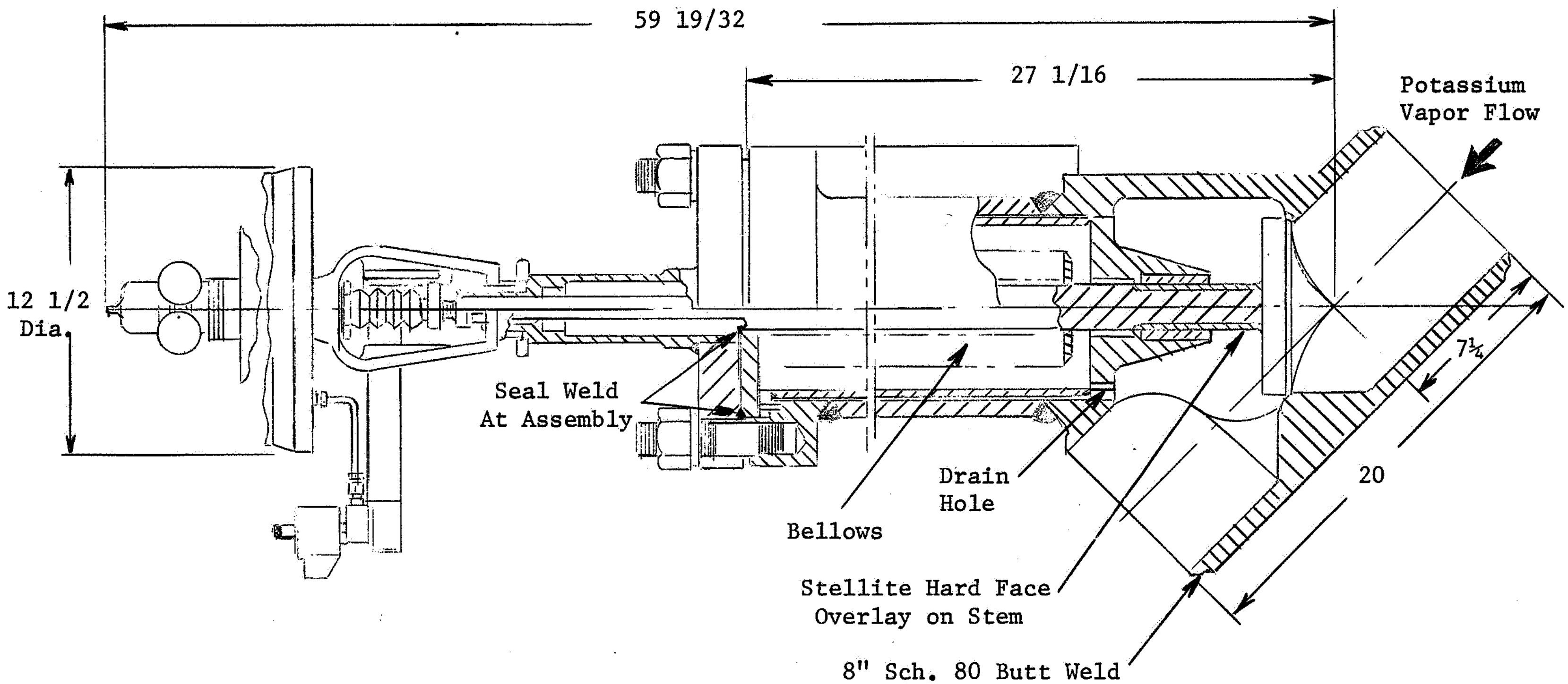


Figure 15. Annin Company 8.0" Liquid Metal Valve.

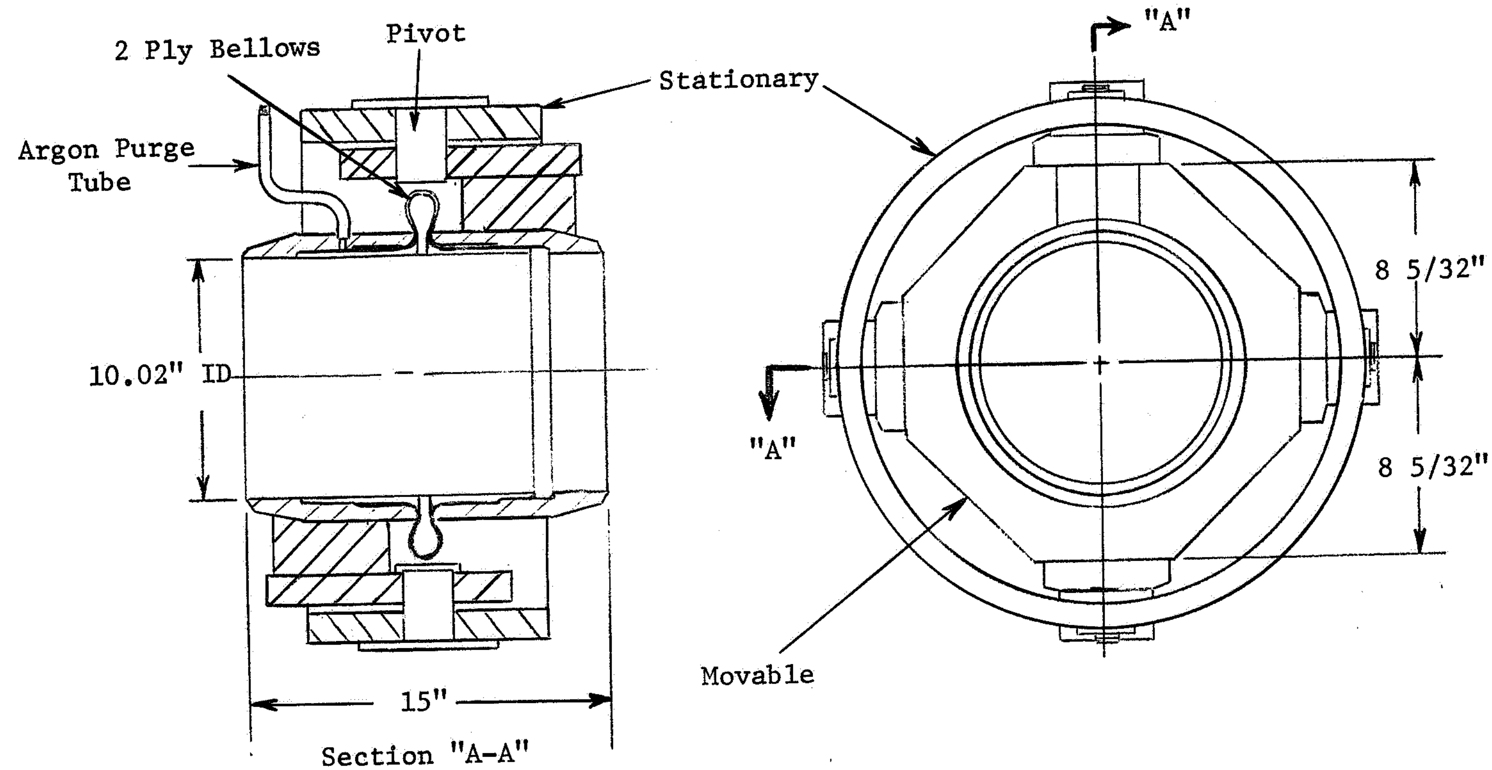


Figure 16. High Temperature Flexible Joint.

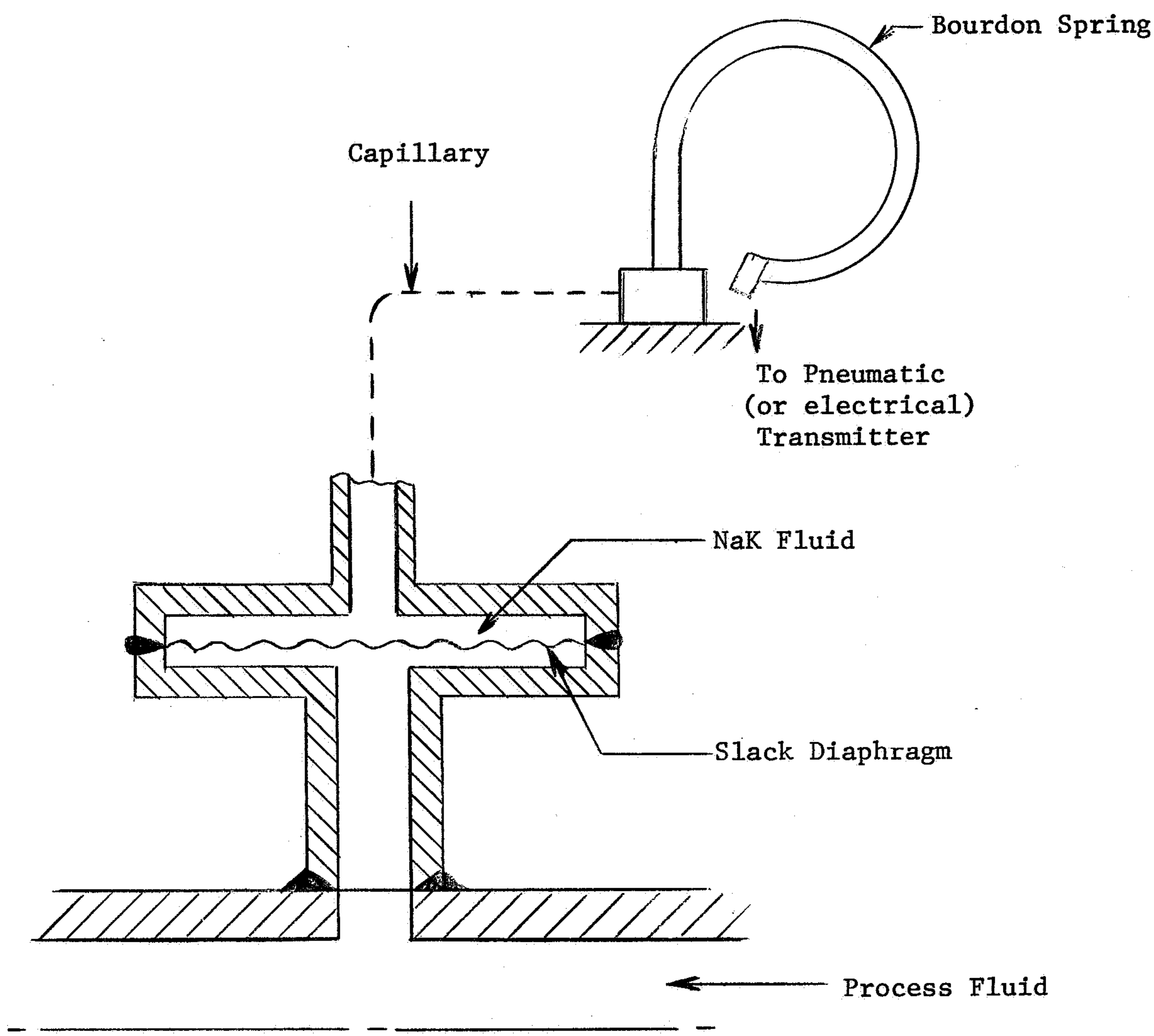


Figure 17. Basic Concept of Taylor Instrument Company Slack Diaphragm Pressure Sensor.

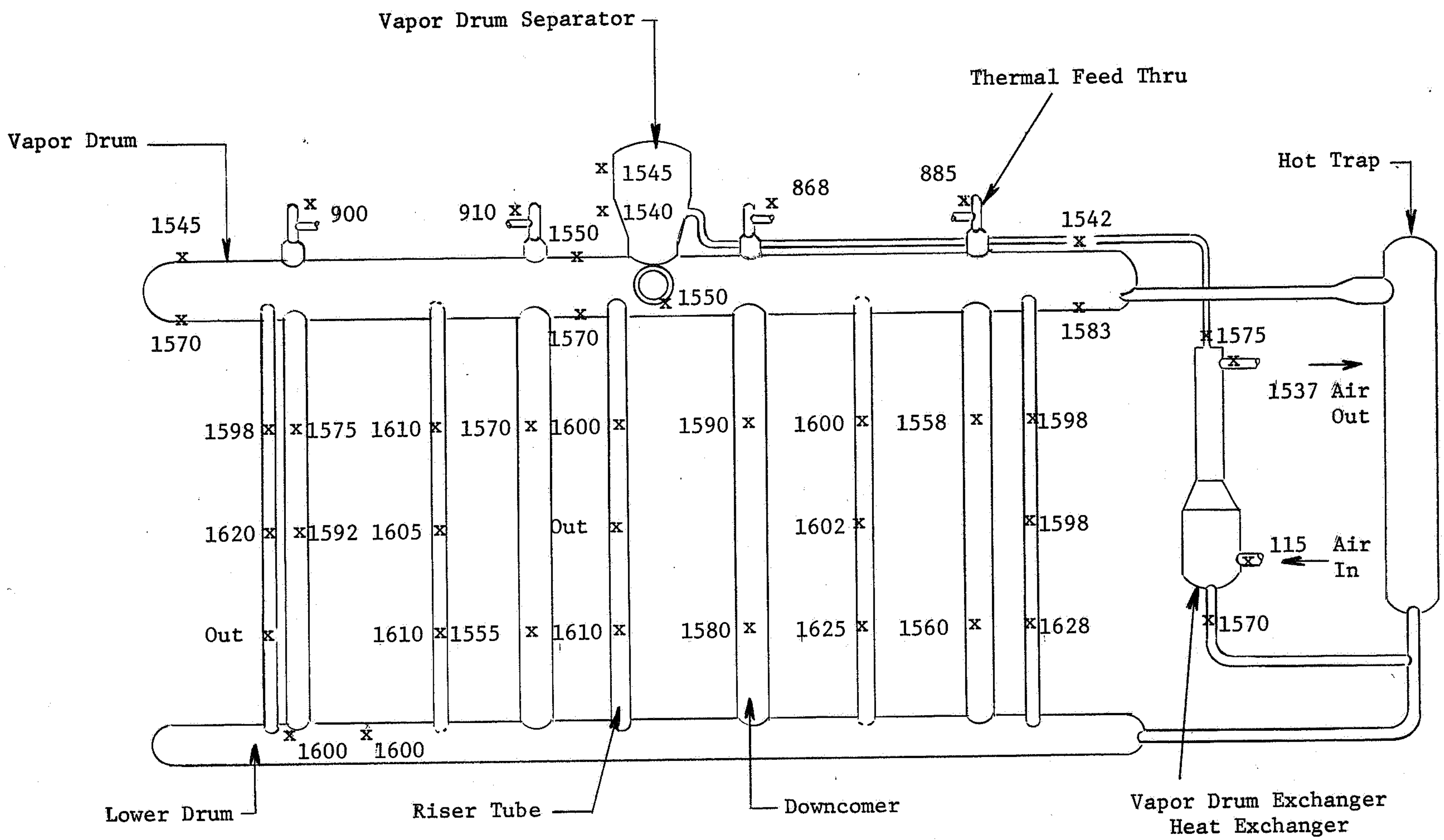


Figure 18. Boiler Thermocouple Location and Temperature Profile for 1550°F Vapor Temperature.

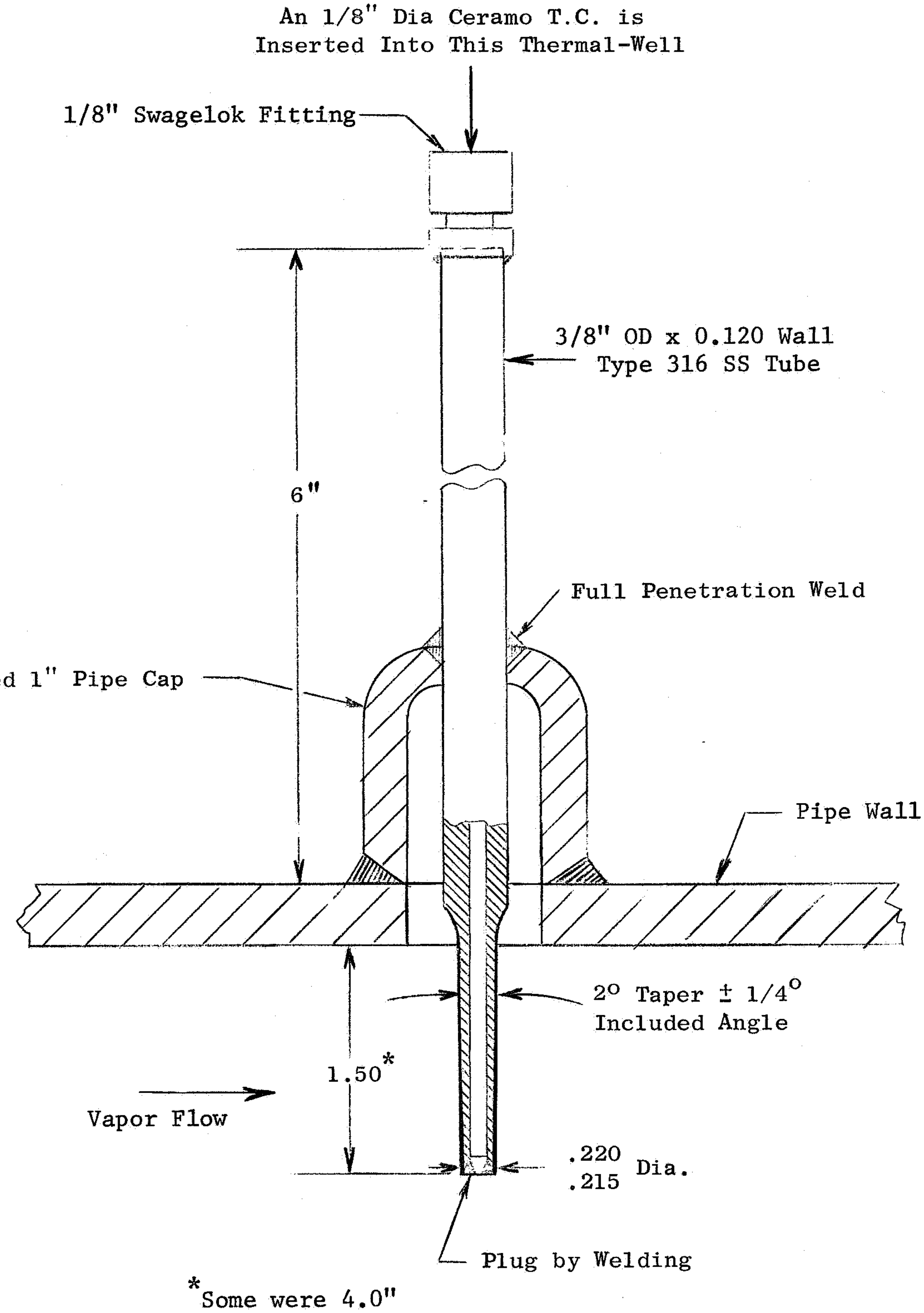


Figure 19. Potassium Vapor Temperature Thermal-Well.

Figure 20. Boiler Liquid Level Gage, J-Probe.

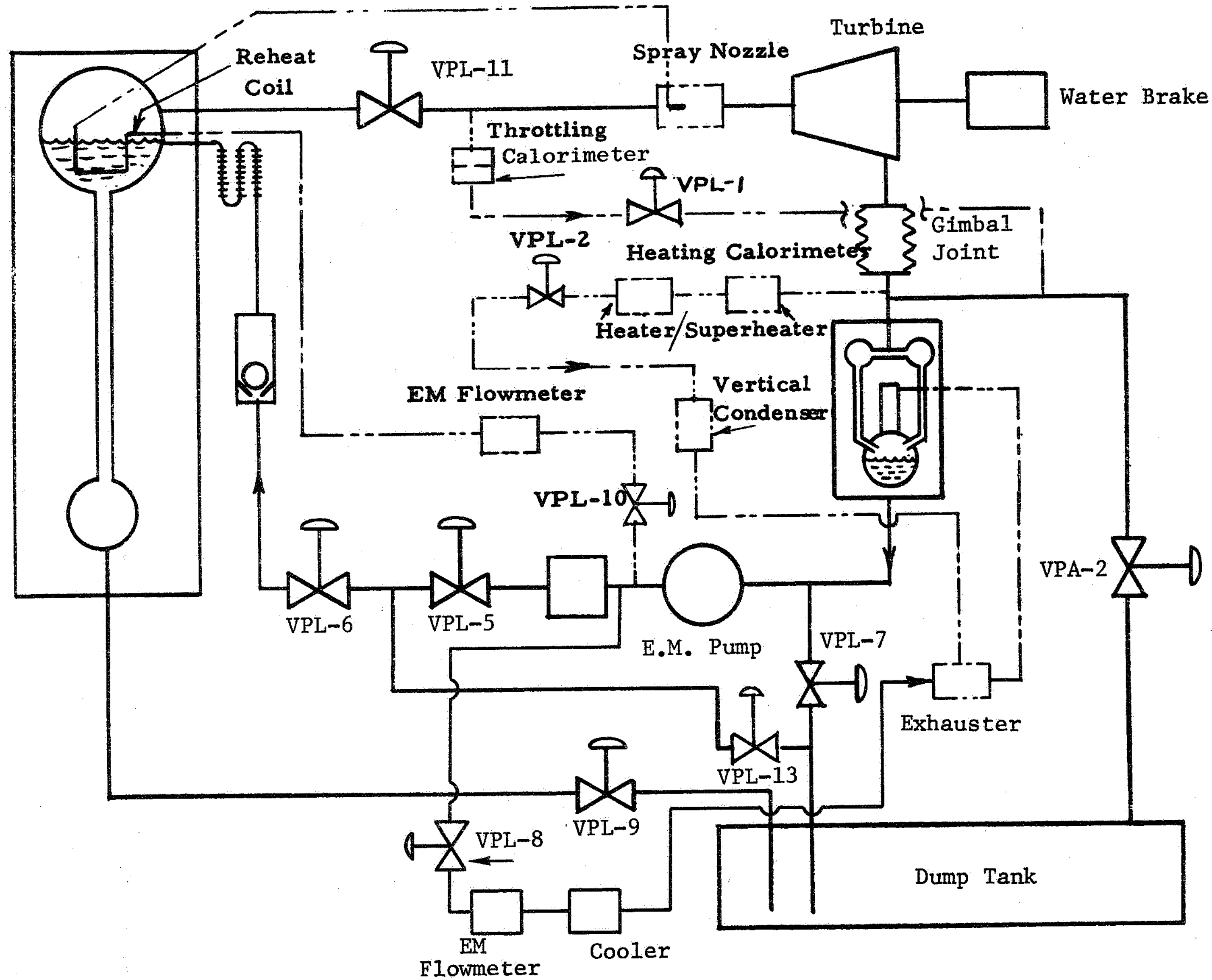


Figure 21. Potassium Vapor Quality System - Schematic.

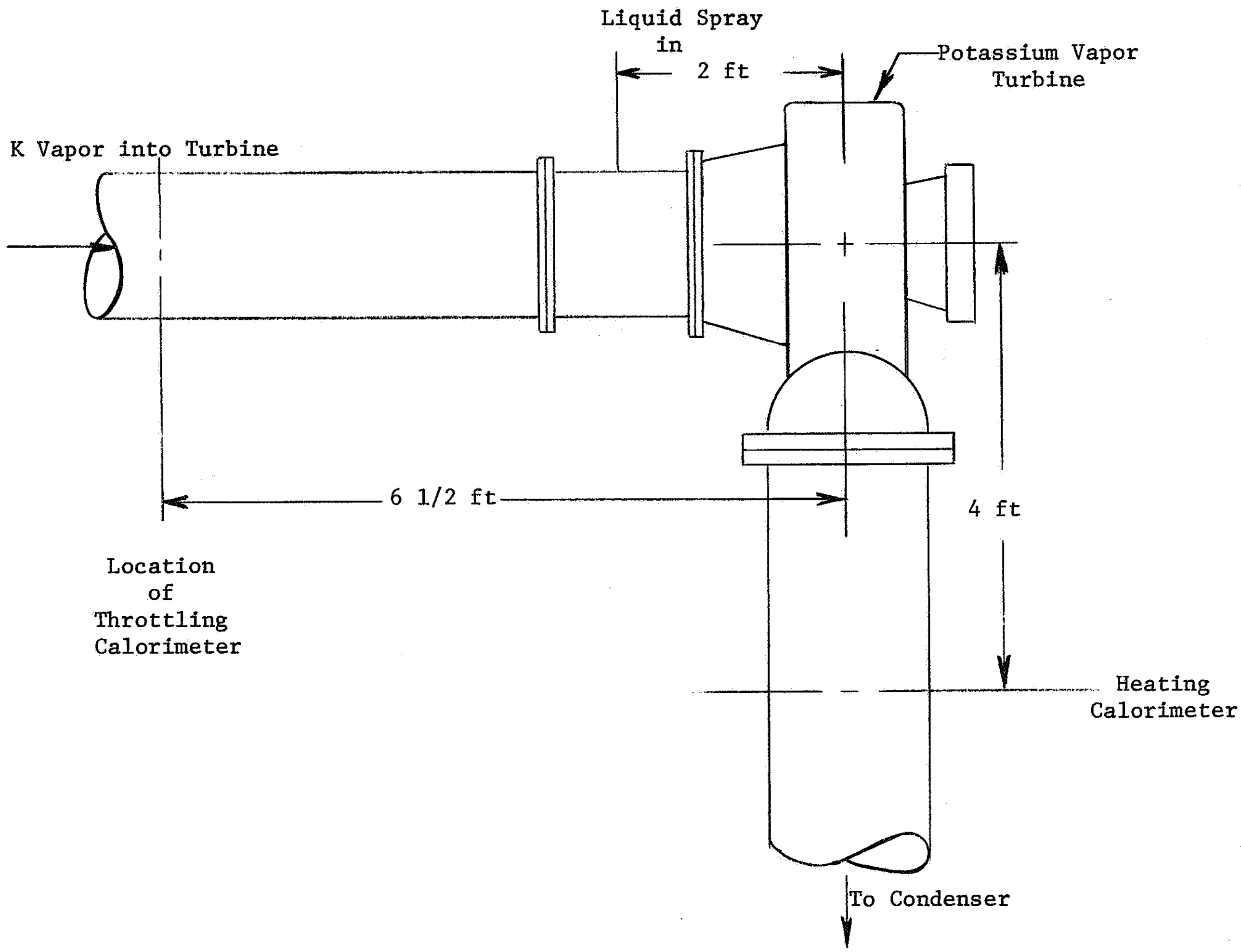


Figure 22. Location of Throttling and Heating Calorimeters.

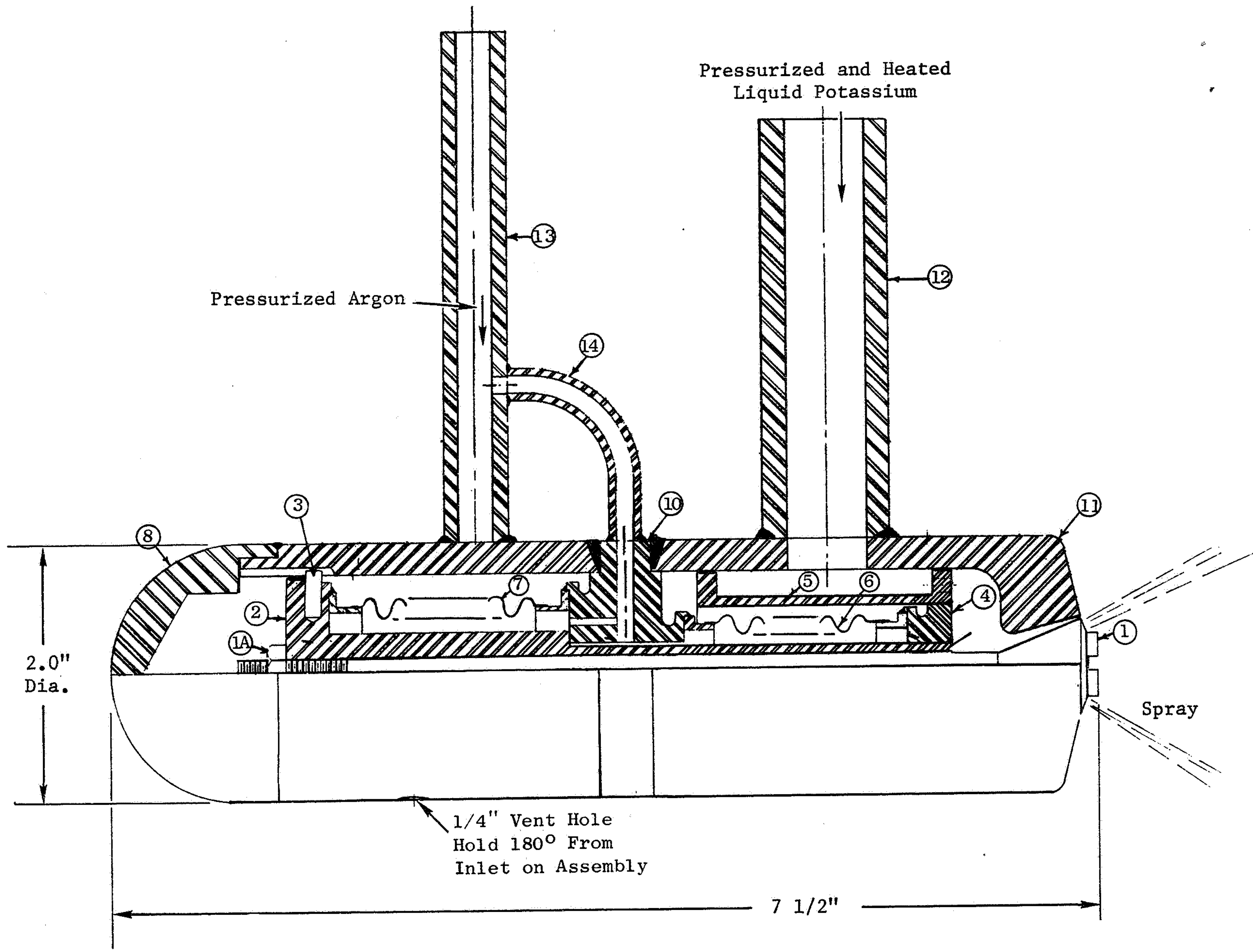


Figure 23. Spray Nozzle Construction.

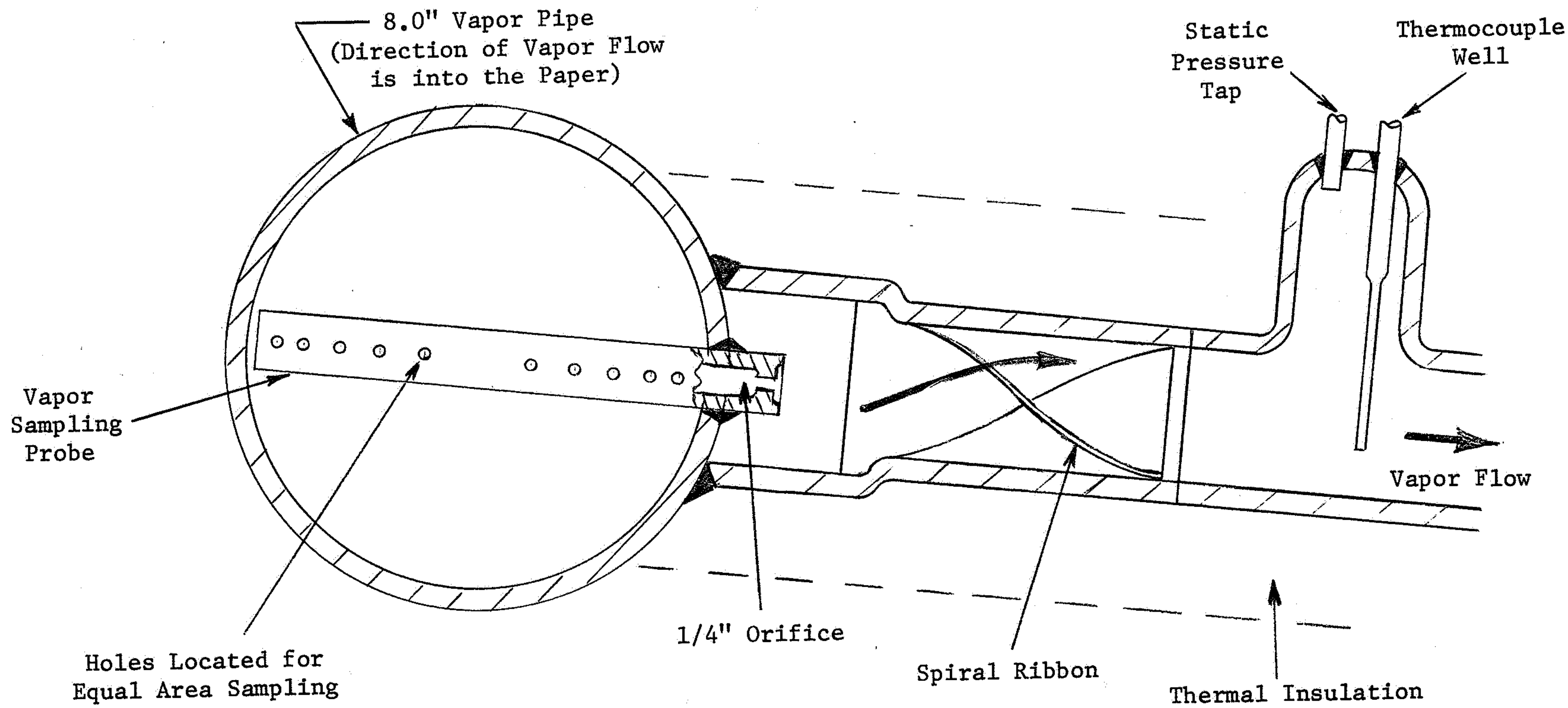


Figure 24. Throttling Calorimeter.

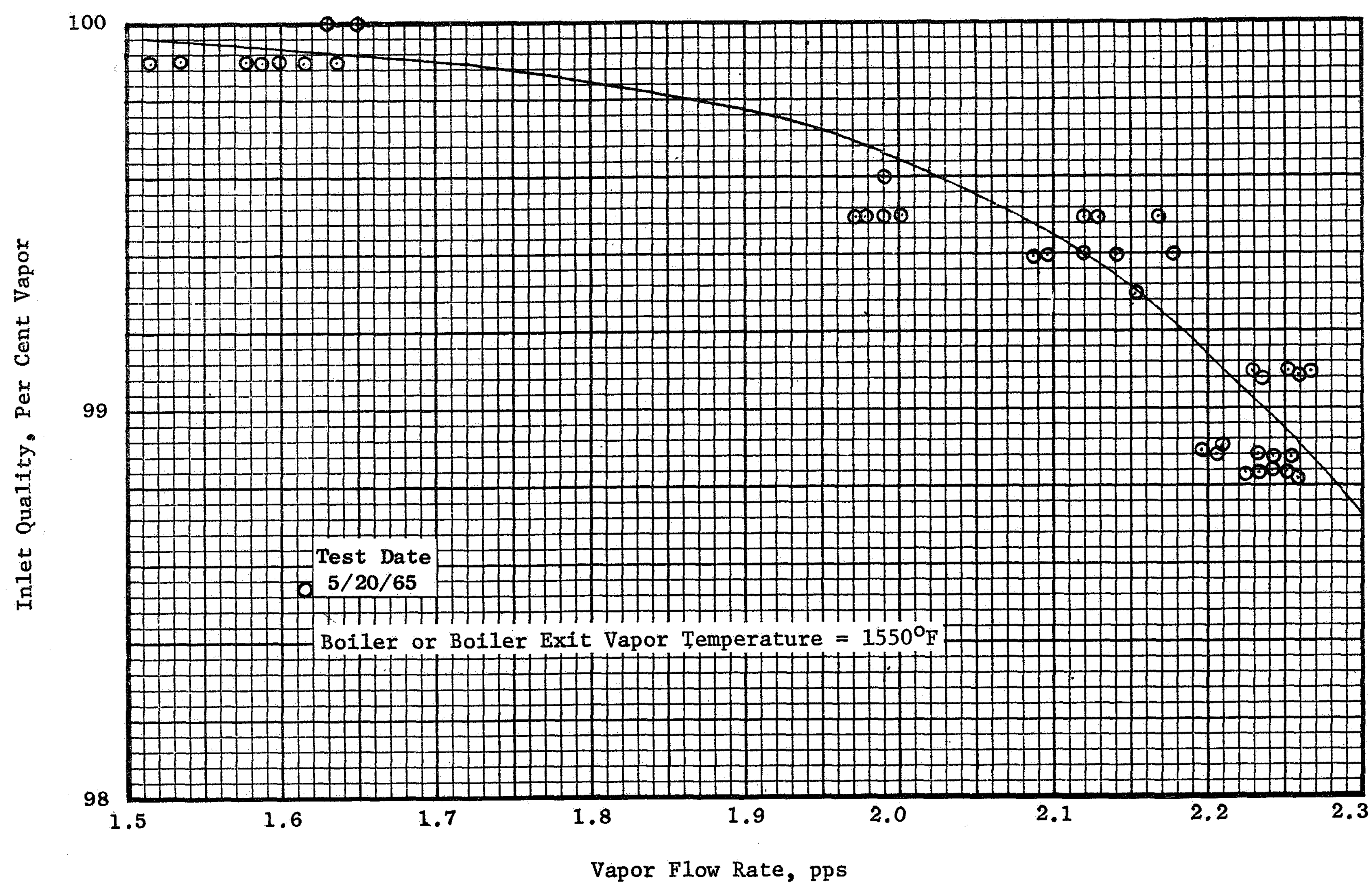


Figure 25. Boiler Vapor Quality Versus Mass Flow.

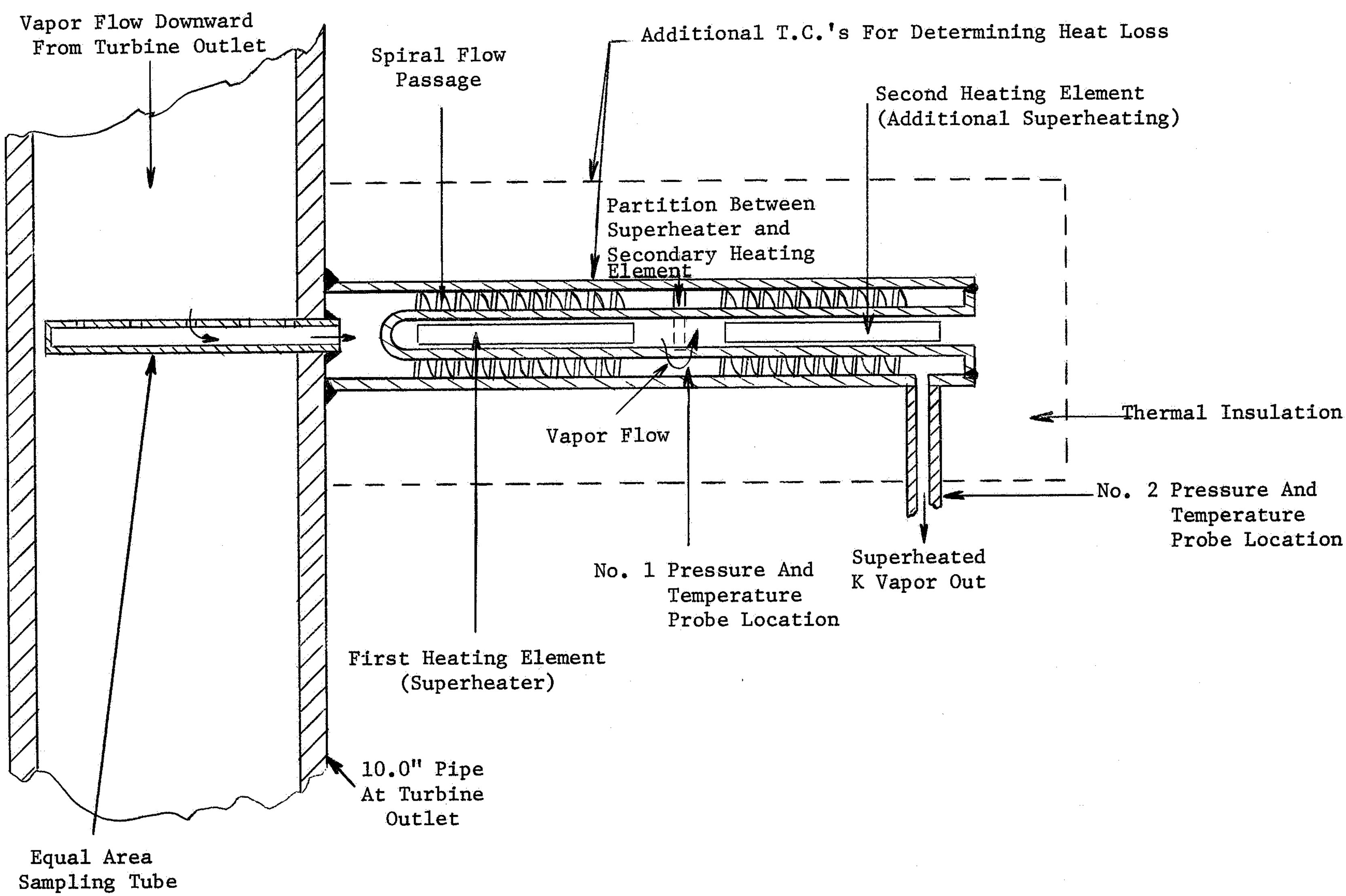


Figure 26. General Arrangement of Heating Calorimeter.

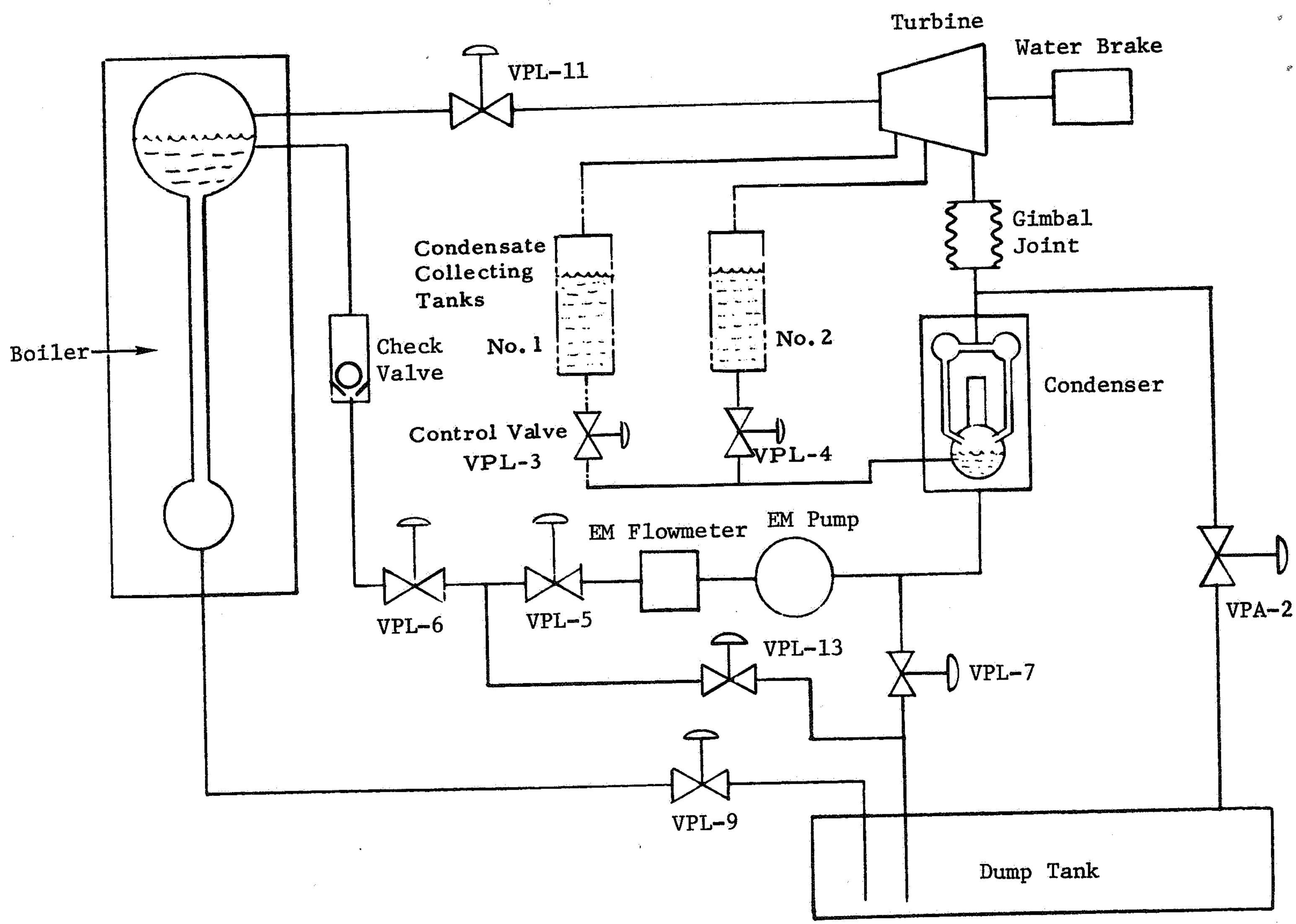


Figure 27. Condensate Extraction System.

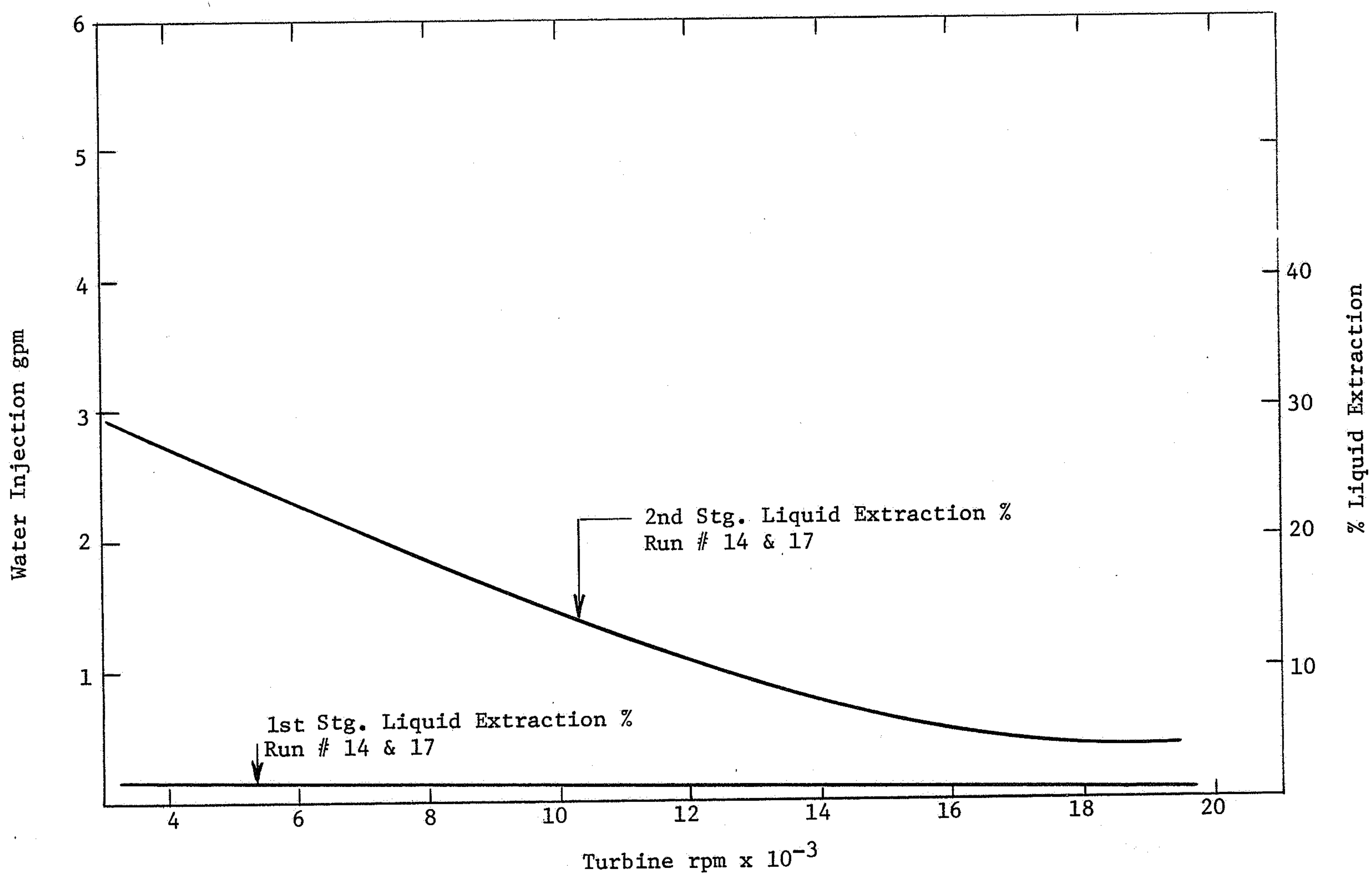


Figure 28. Effectiveness of Moisture Extraction During Steam Testing of the Two Stage Potassium Turbine.

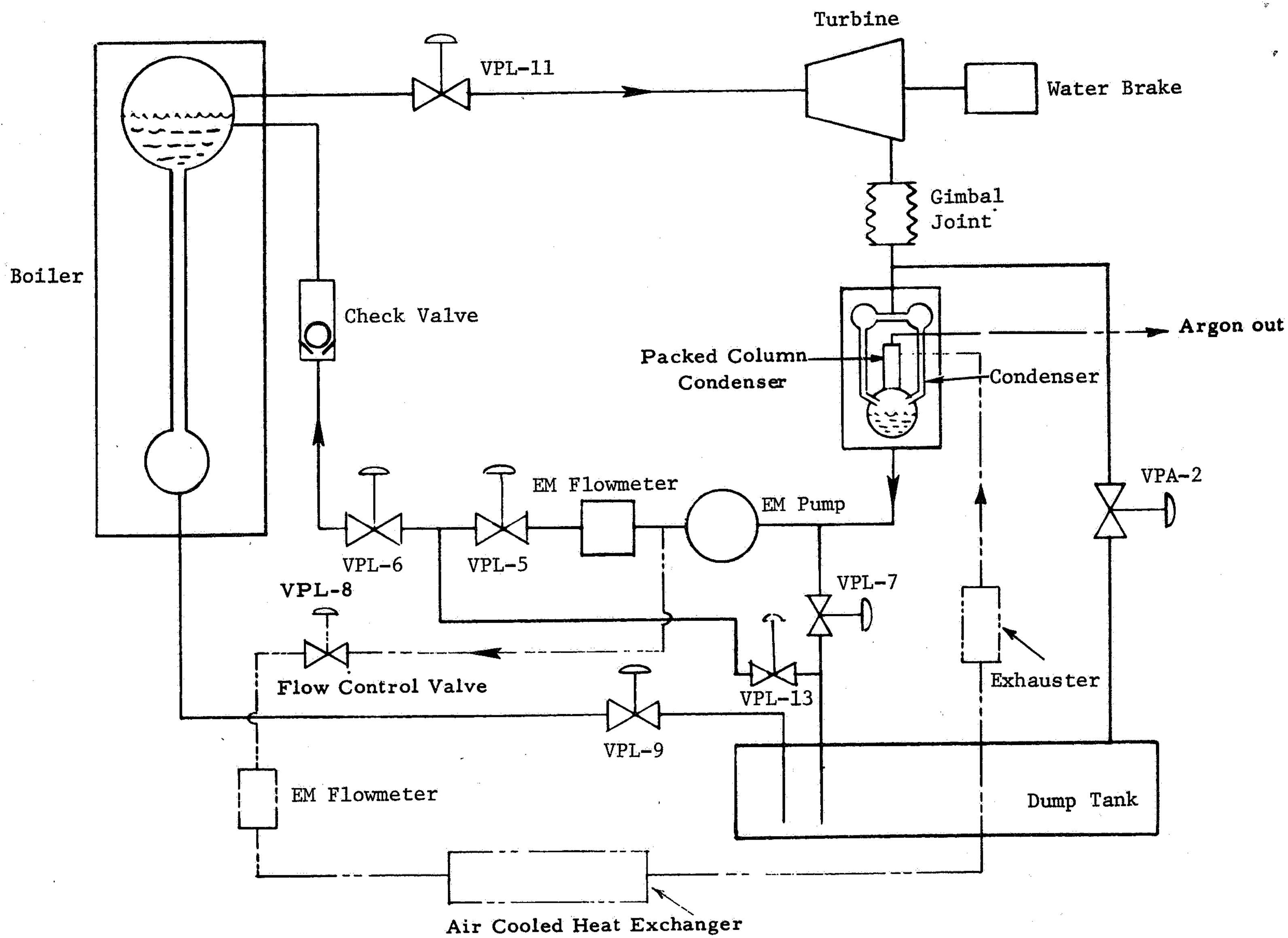


Figure 29. Argon Extraction System - Liquid Metal Loop.

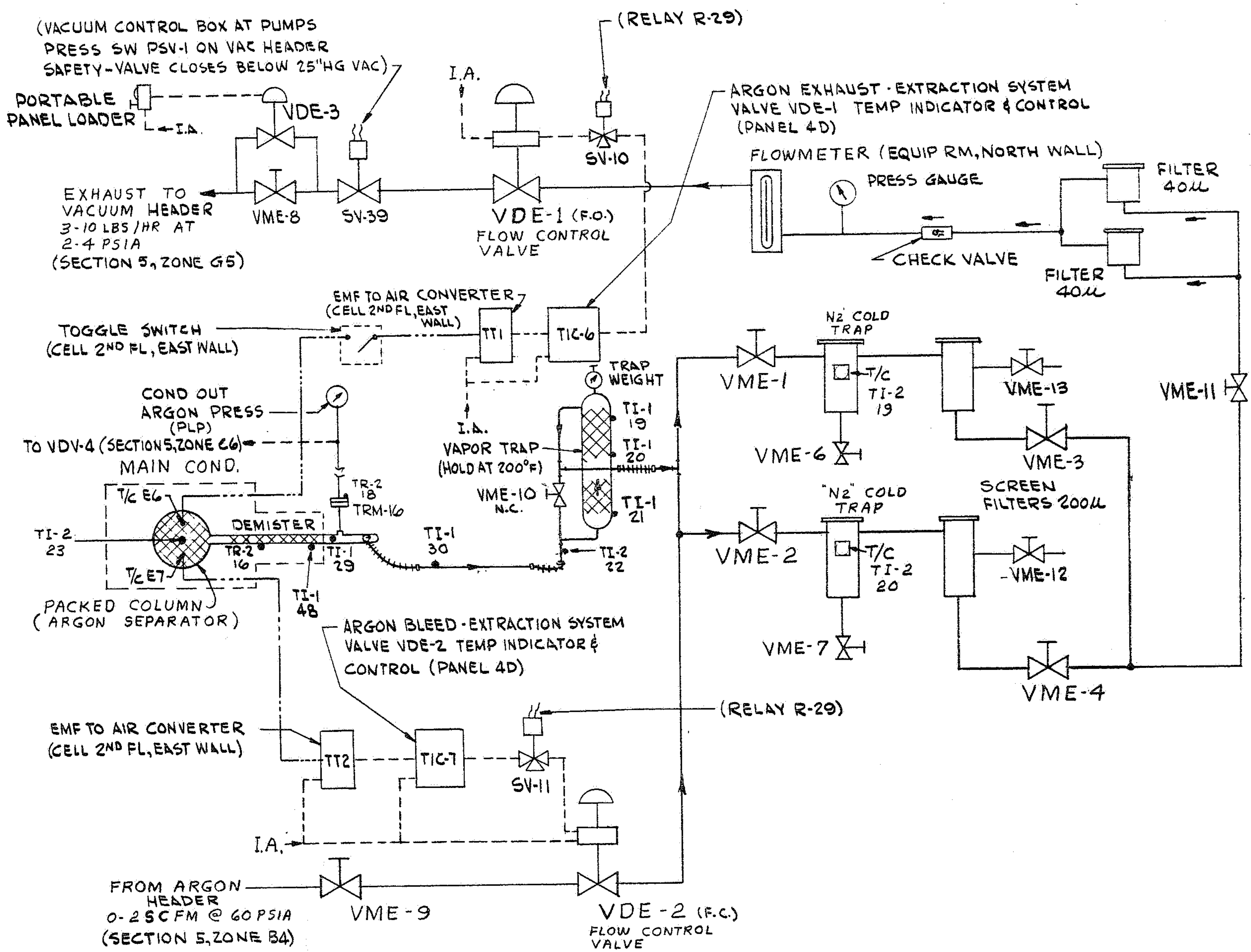


Figure 30. Argon Extraction System - Argon Loop.

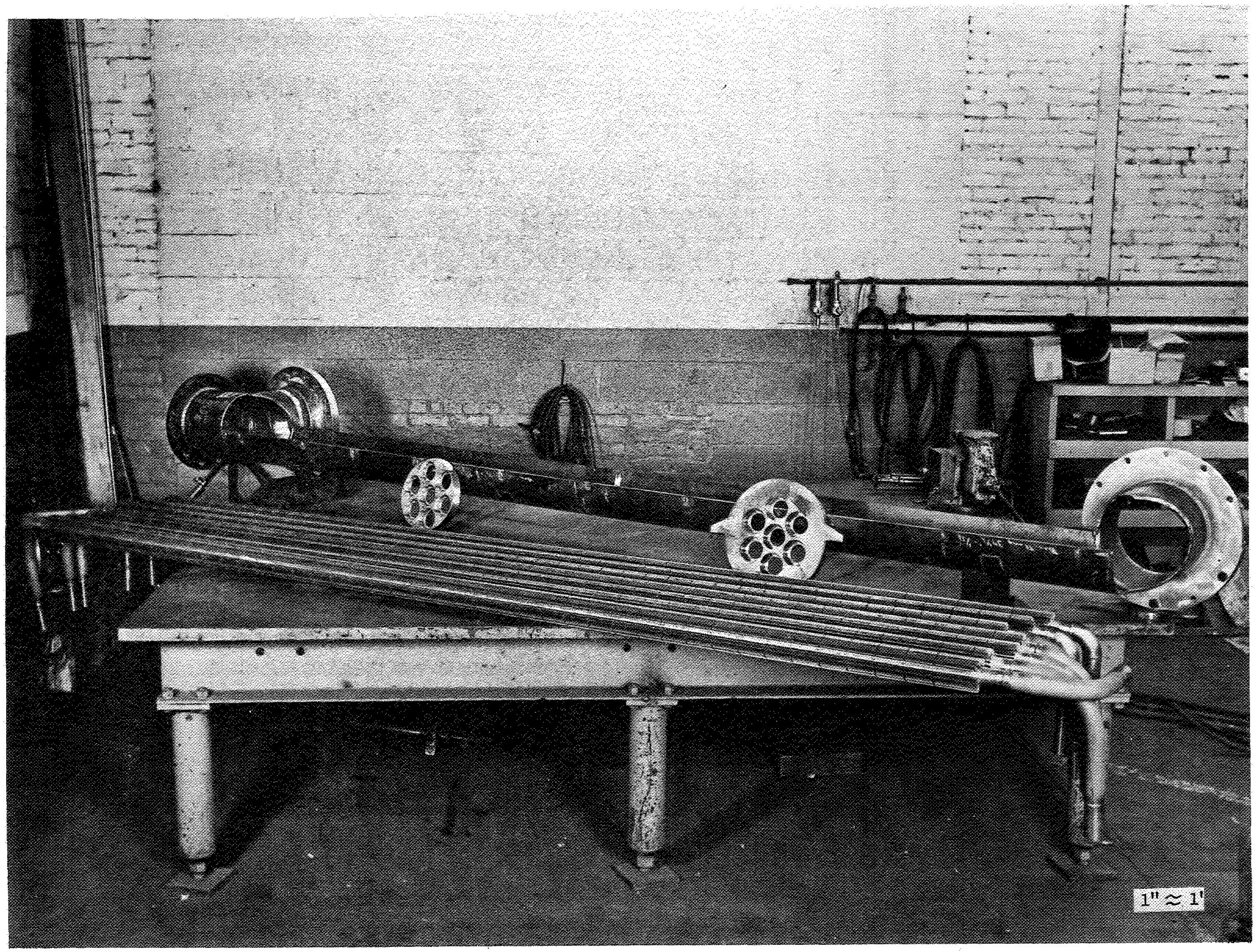


Figure 31. 450 Btu/Sec Heat Exchanger in Fabrication Shop.

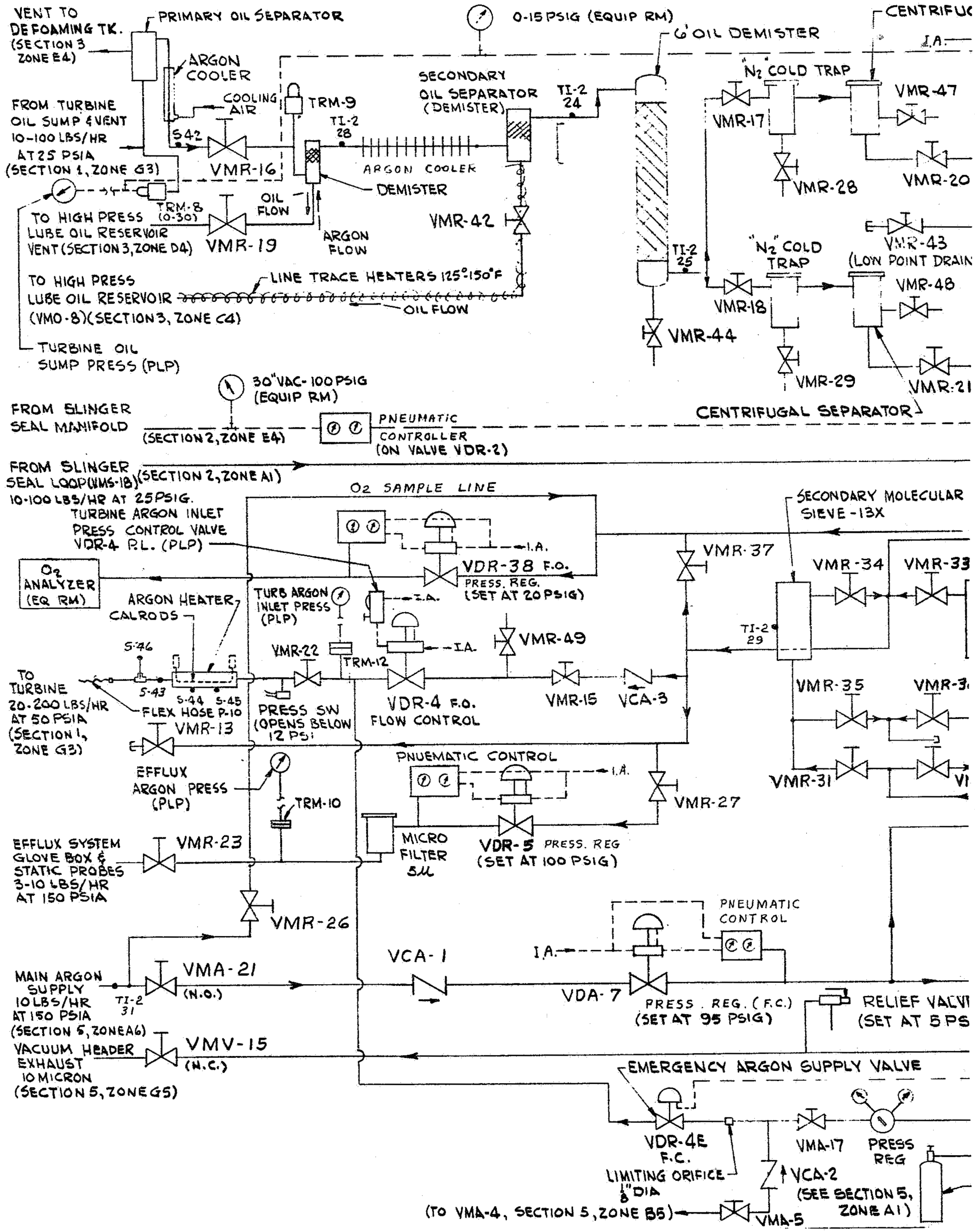
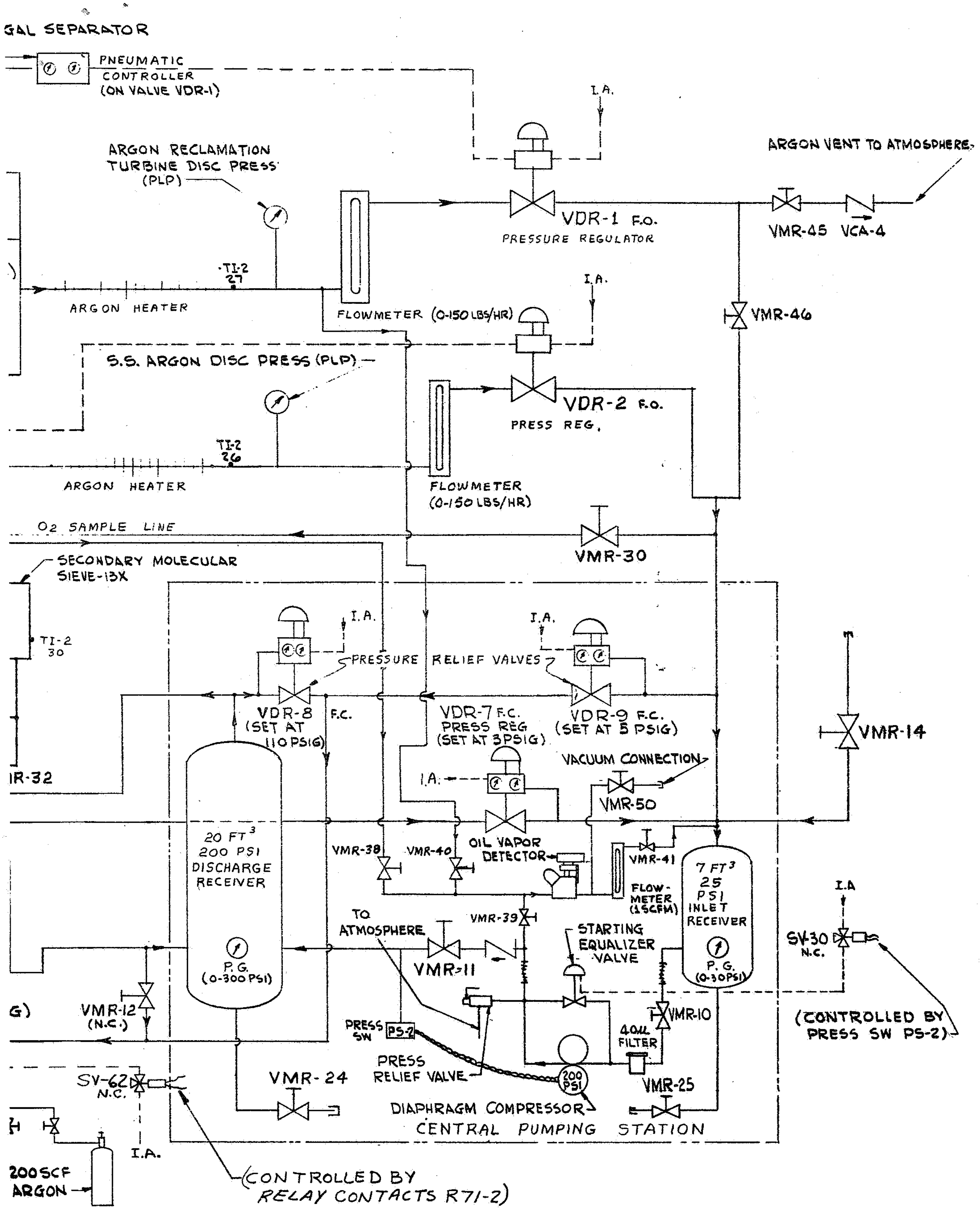


Figure 32. Schematic of Argc



a Reclamation System.

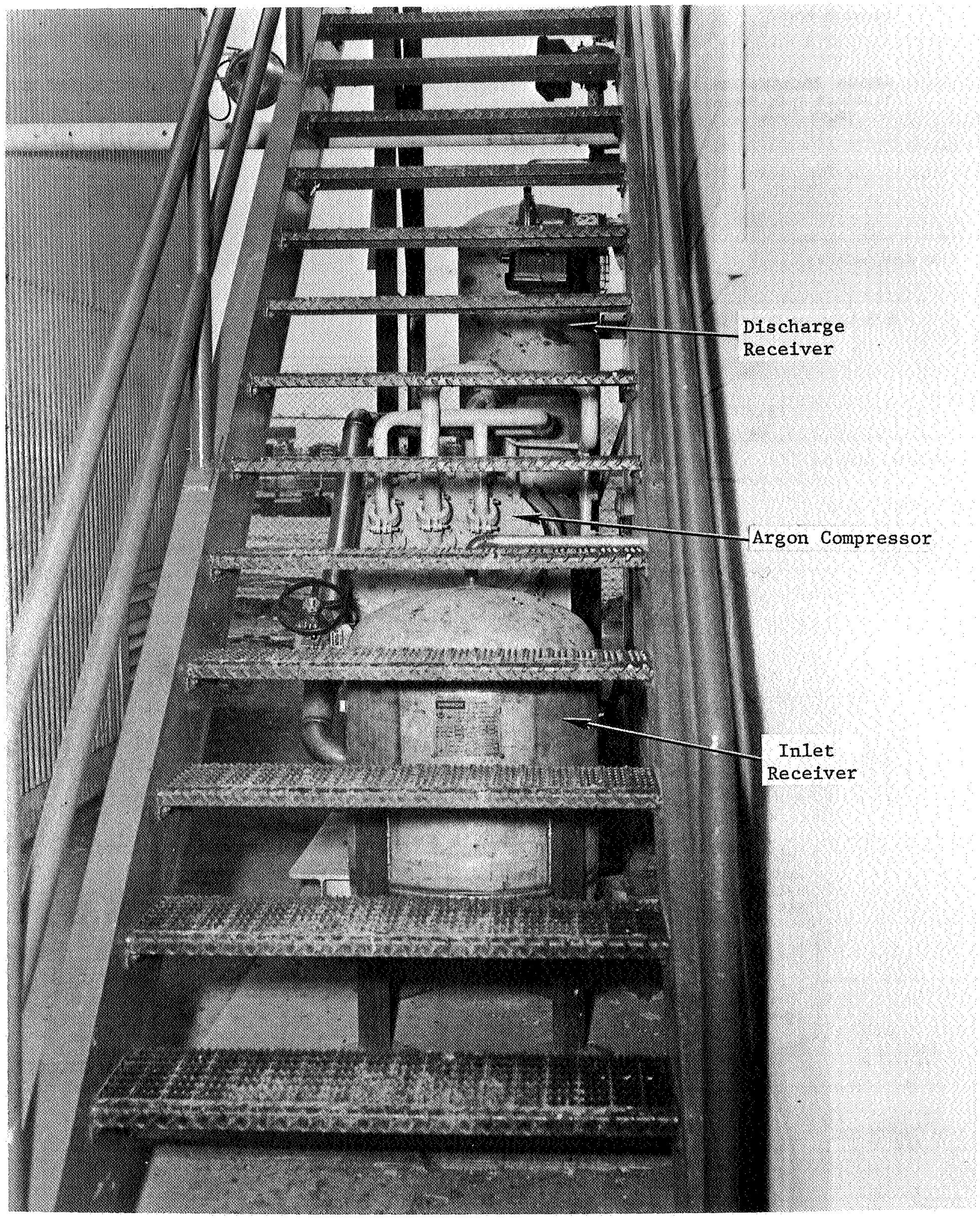


Figure 33. Argon Compressor.

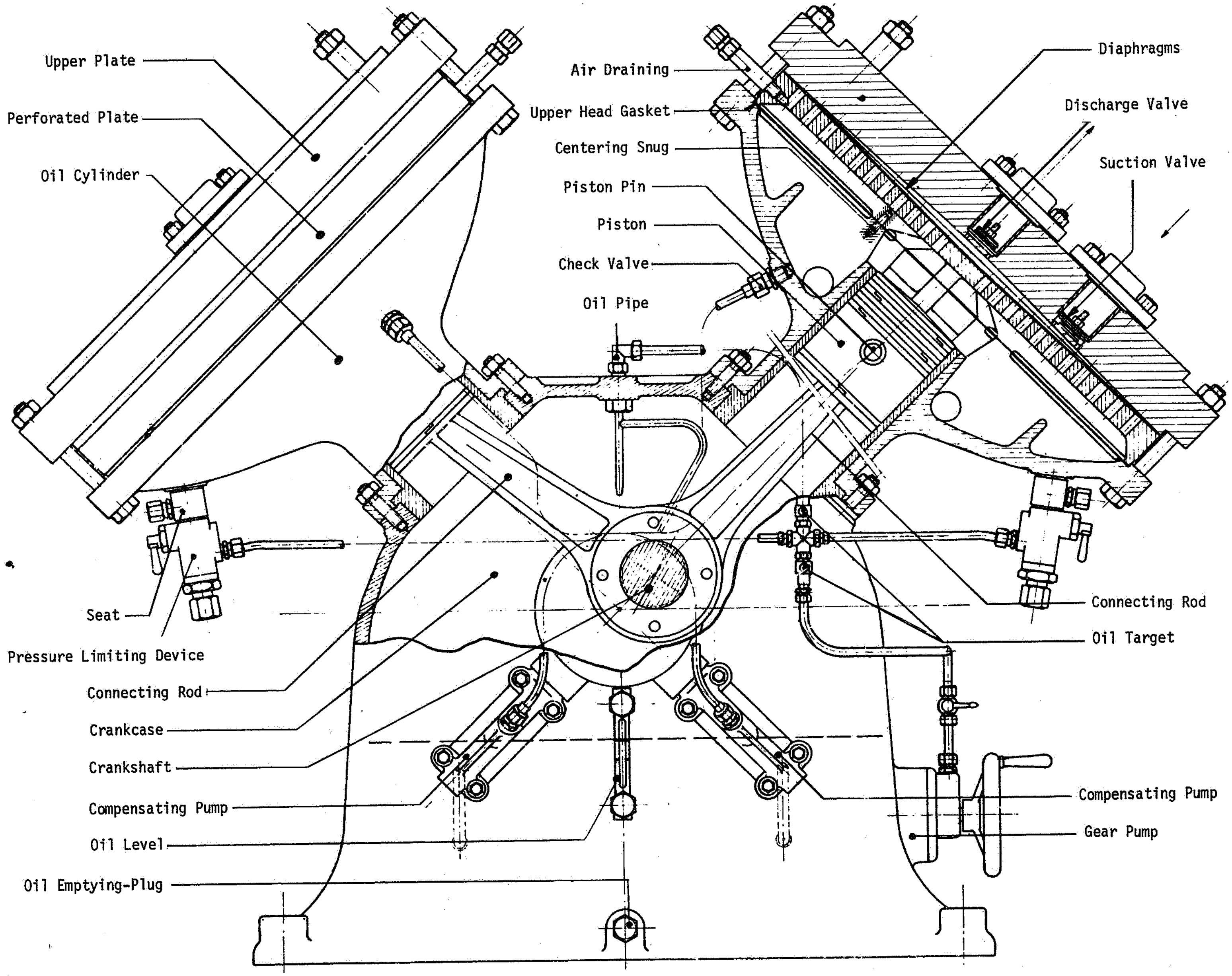


Figure 34. V Type Diaphragm Compressor.

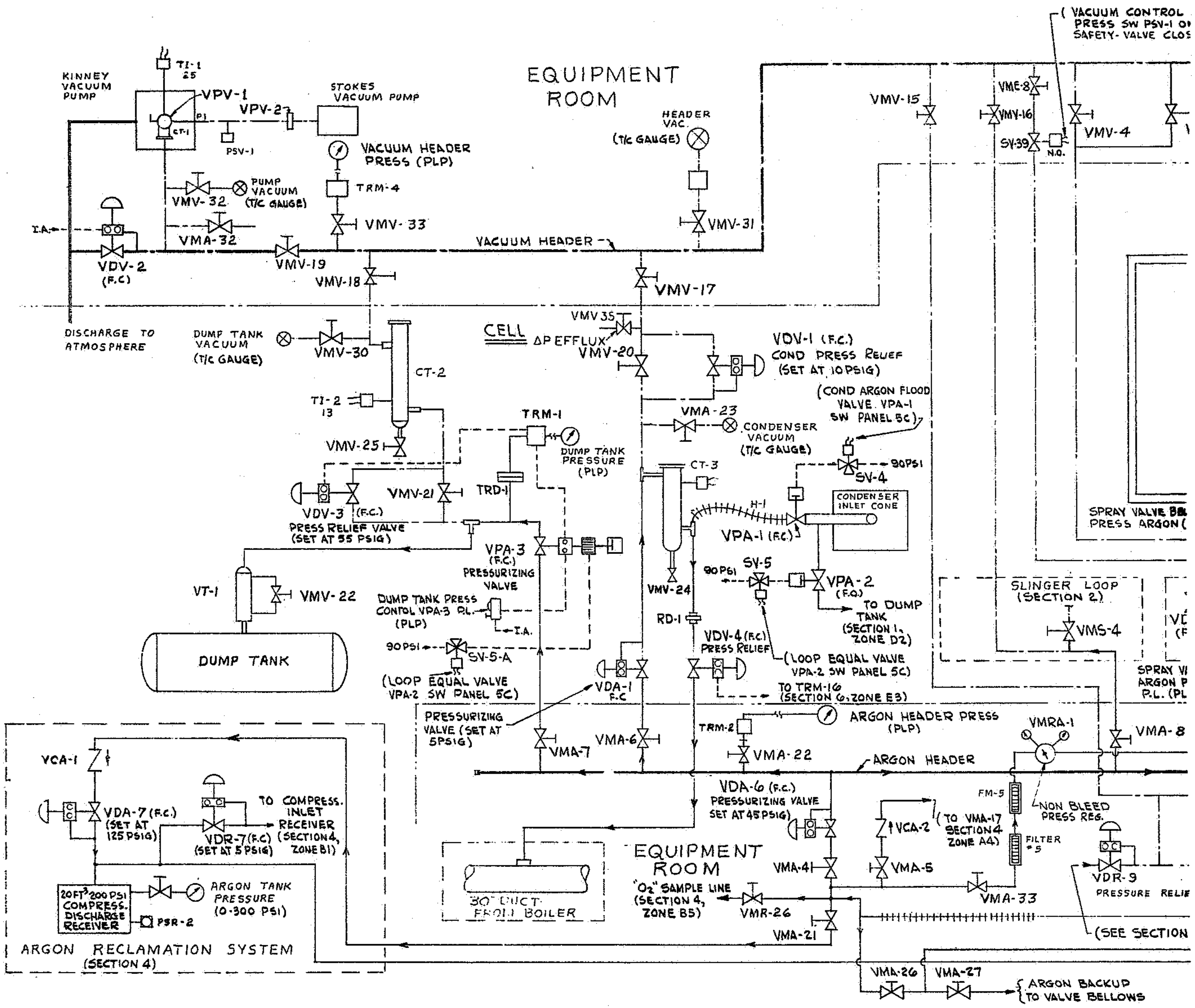
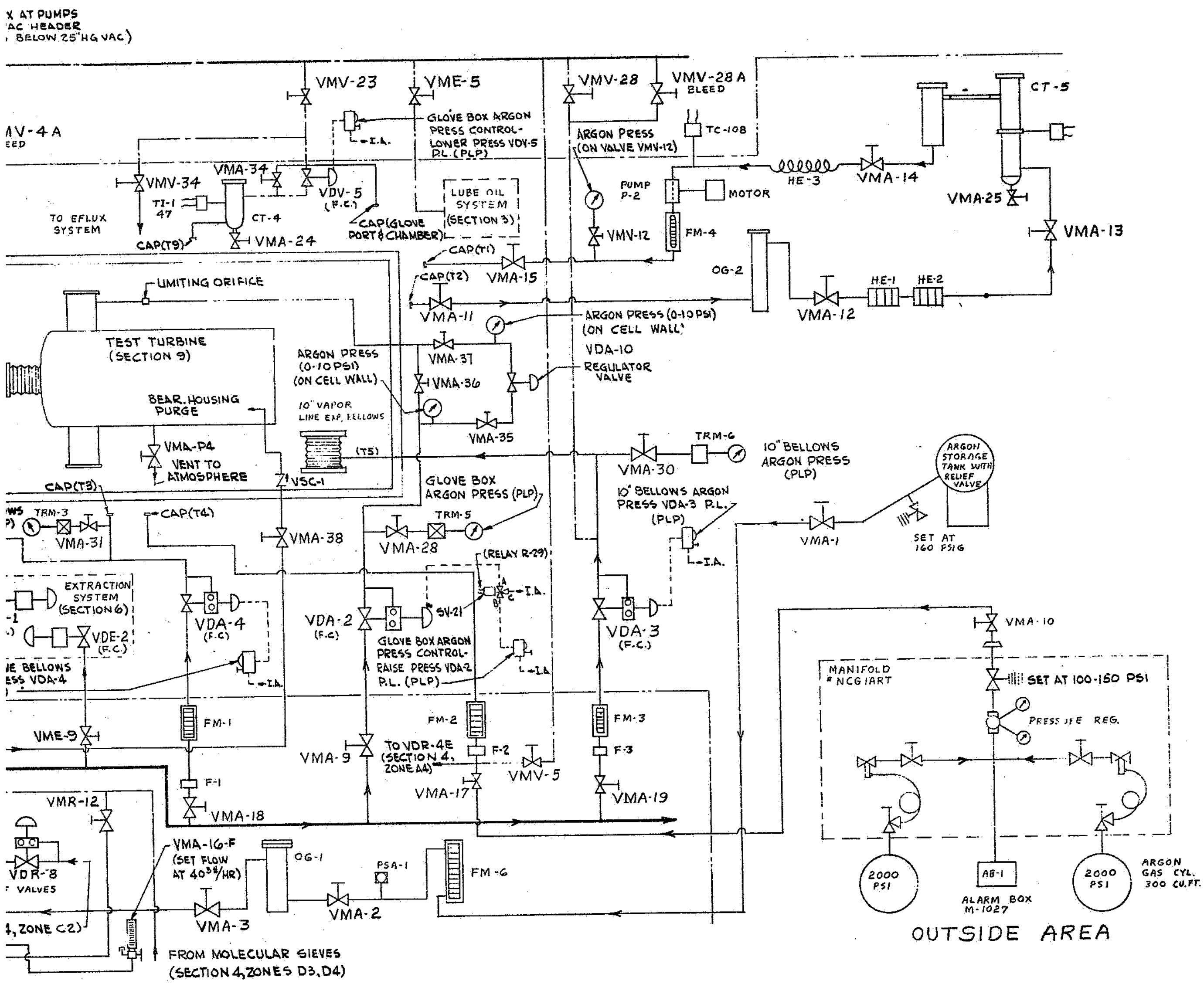


Figure 35. Schemati



: of Argon and Vacuum System.

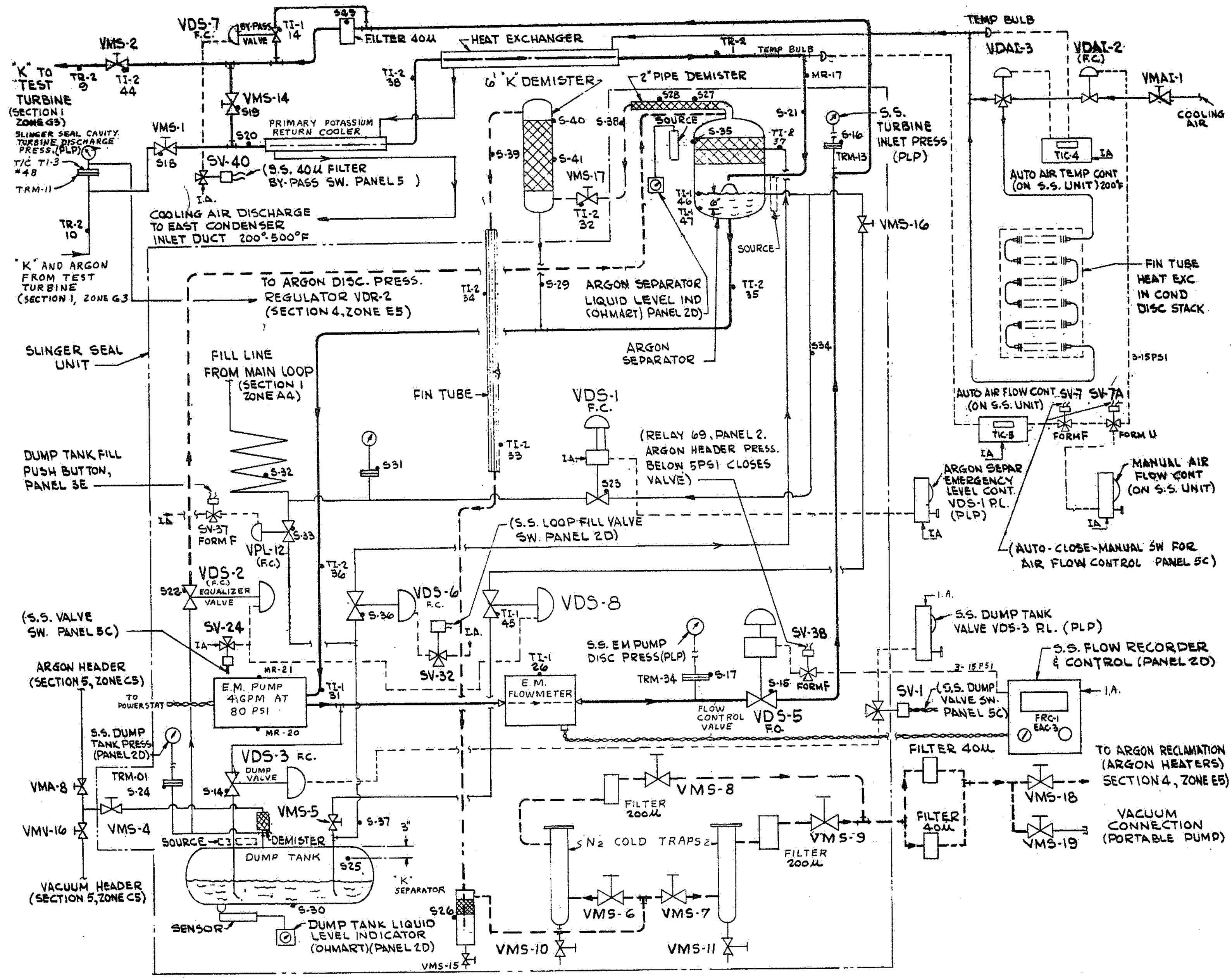


Figure 36. Slinger Seal Loop Schematic.

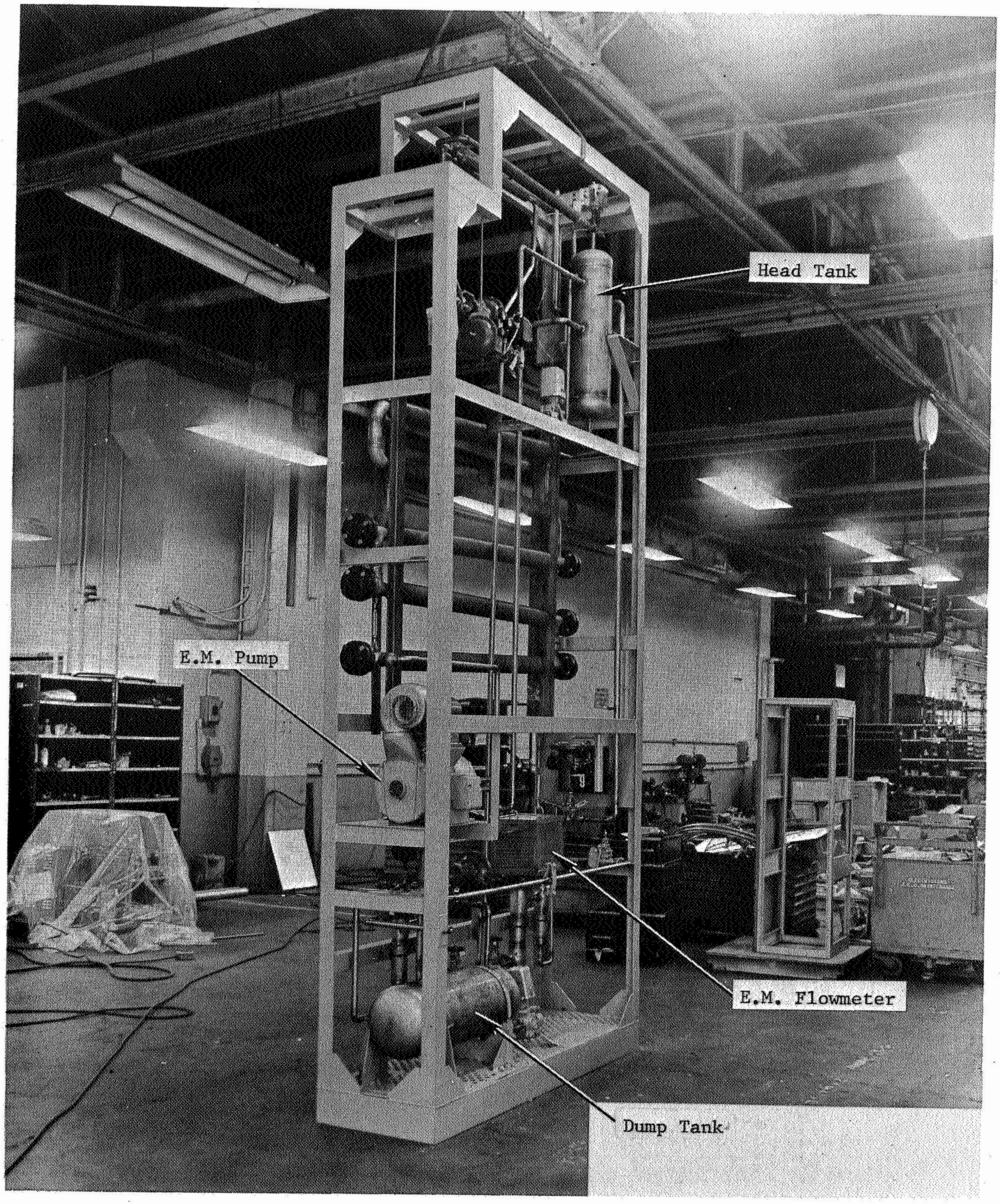


Figure 37. Slinger Seal Loop in Fabrication Shop.

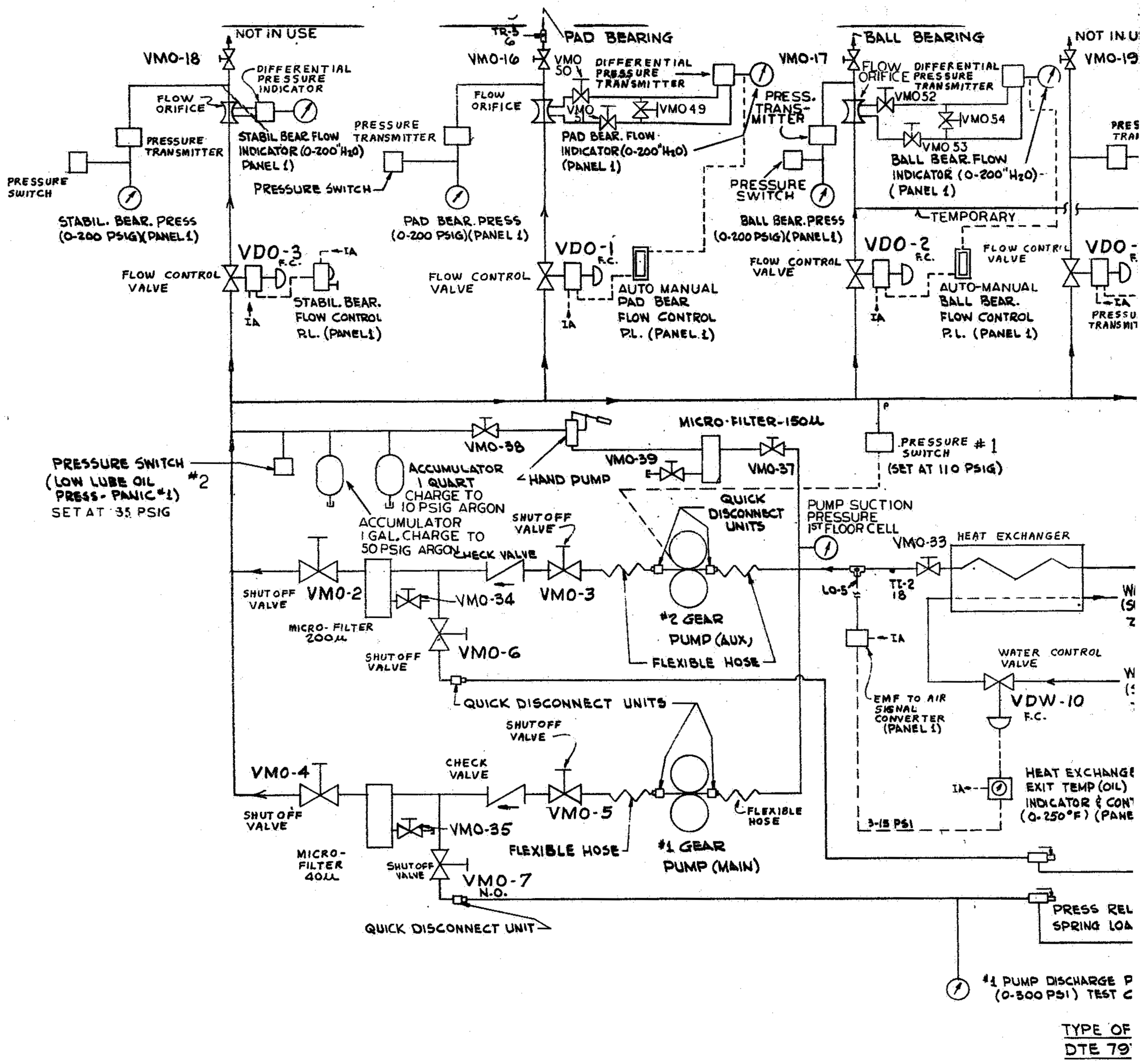
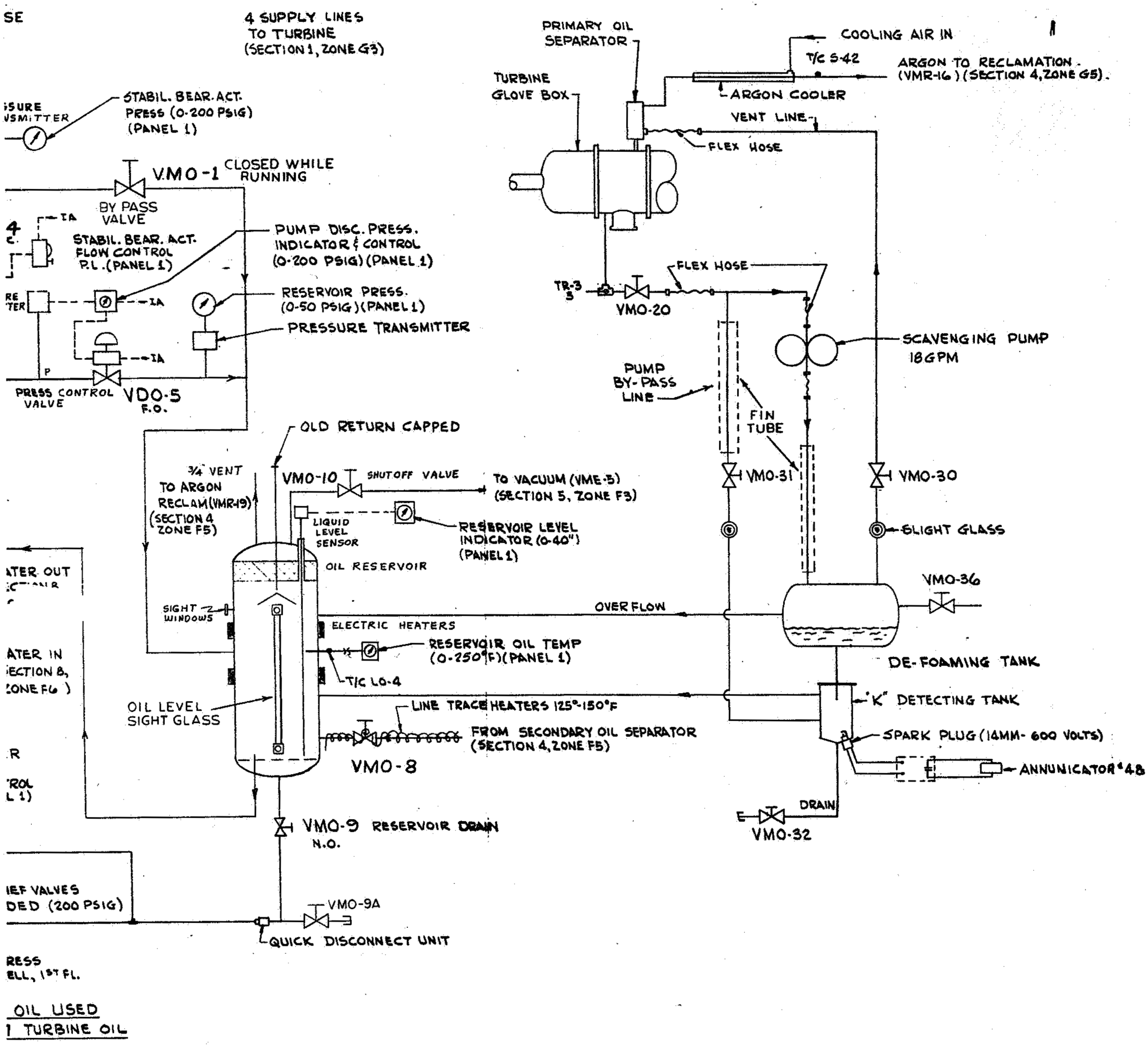


Figure 38. Turbine



Oil System Schematic.

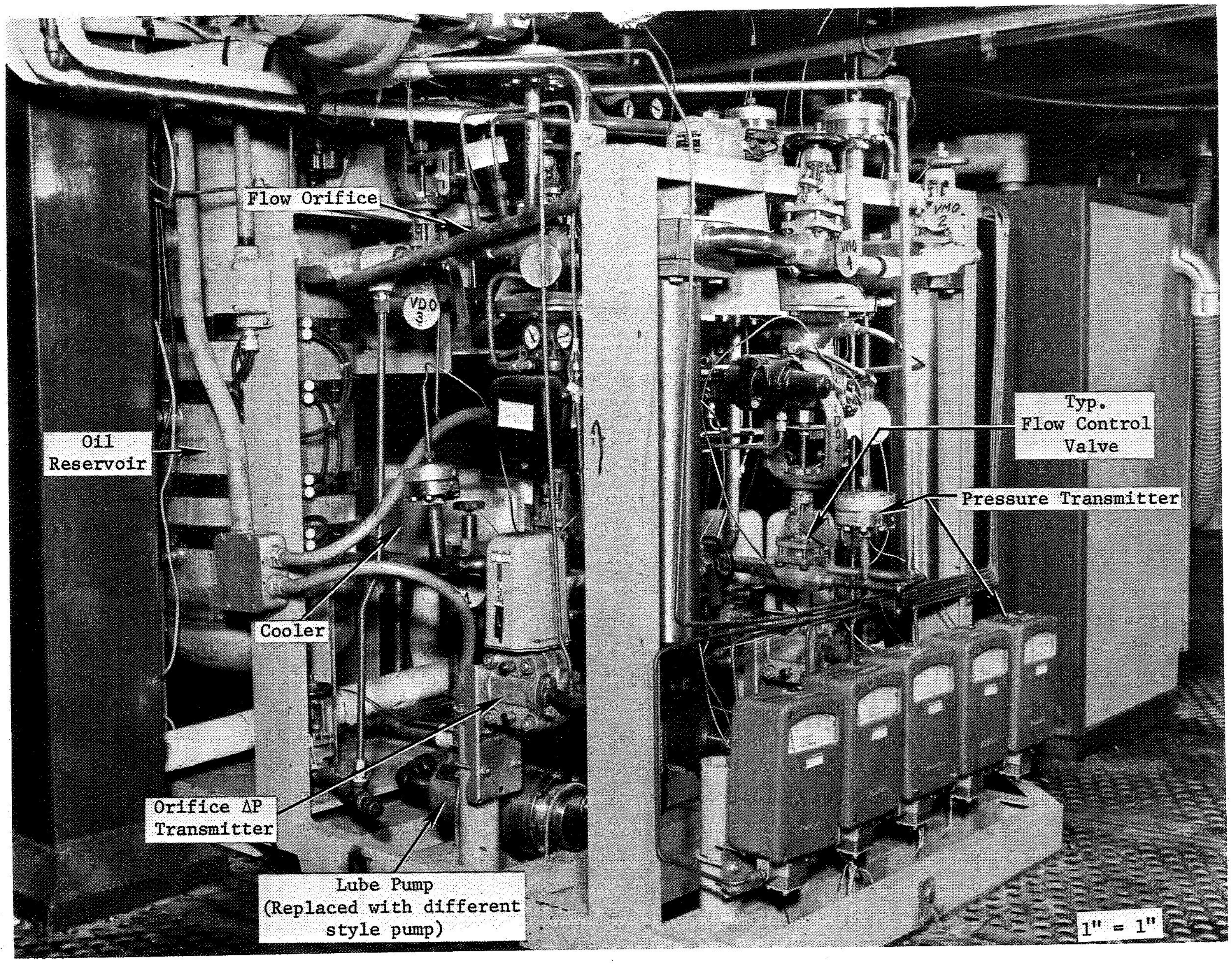


Figure 39. High Pressure Lube System.

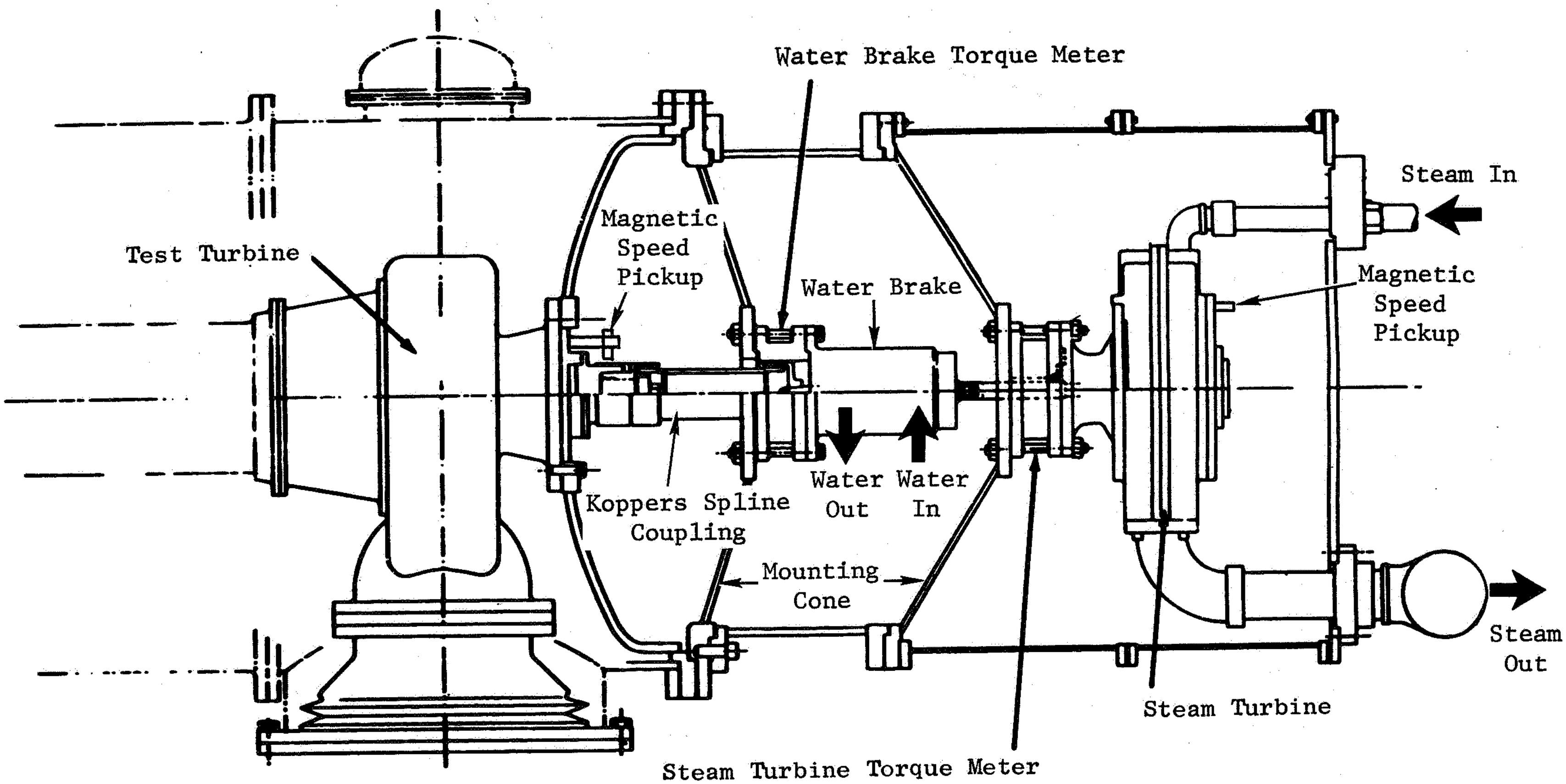


Figure 40. Power Absorbing and Starting System.

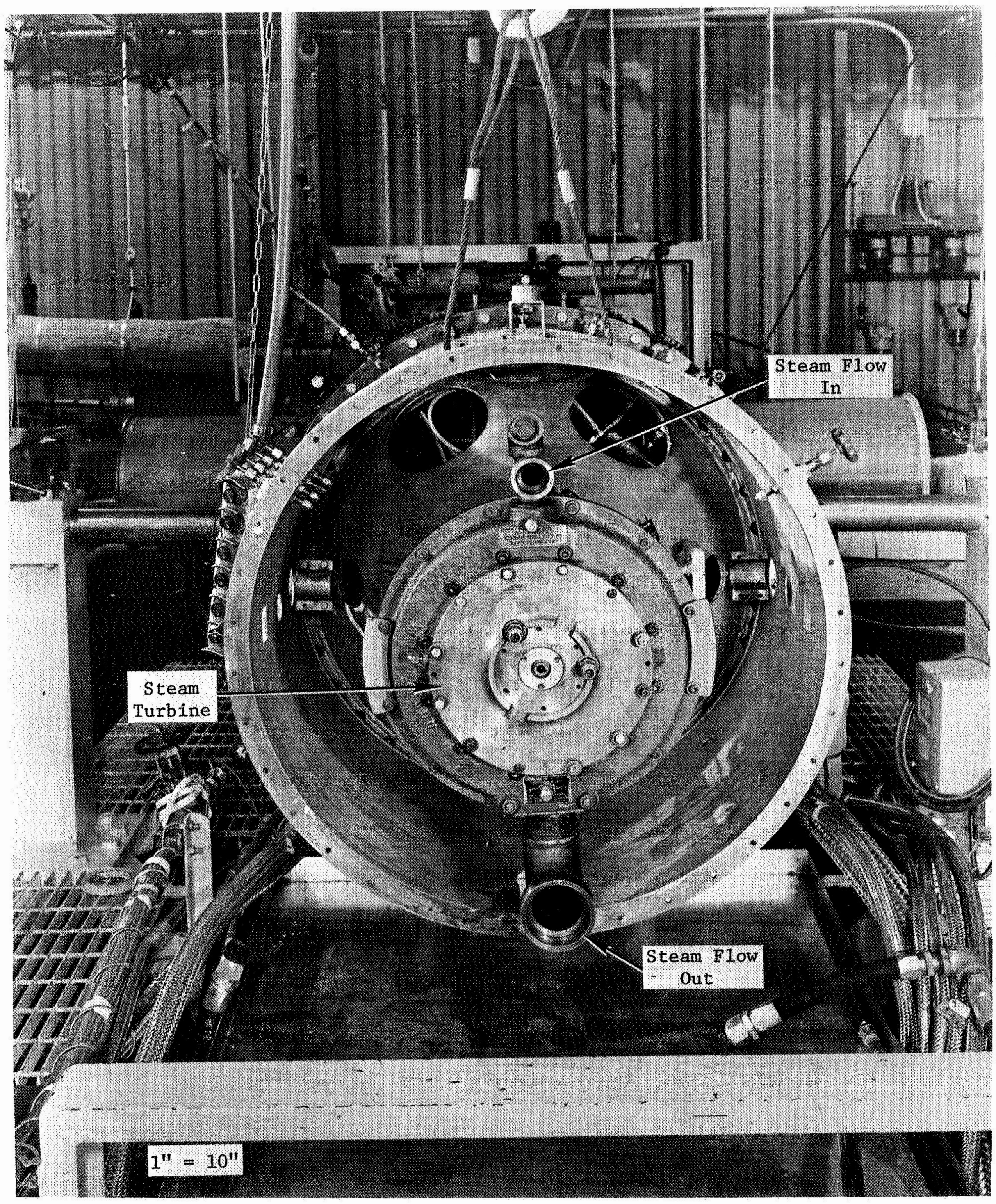


Figure 41. Steam Turbine Installation.

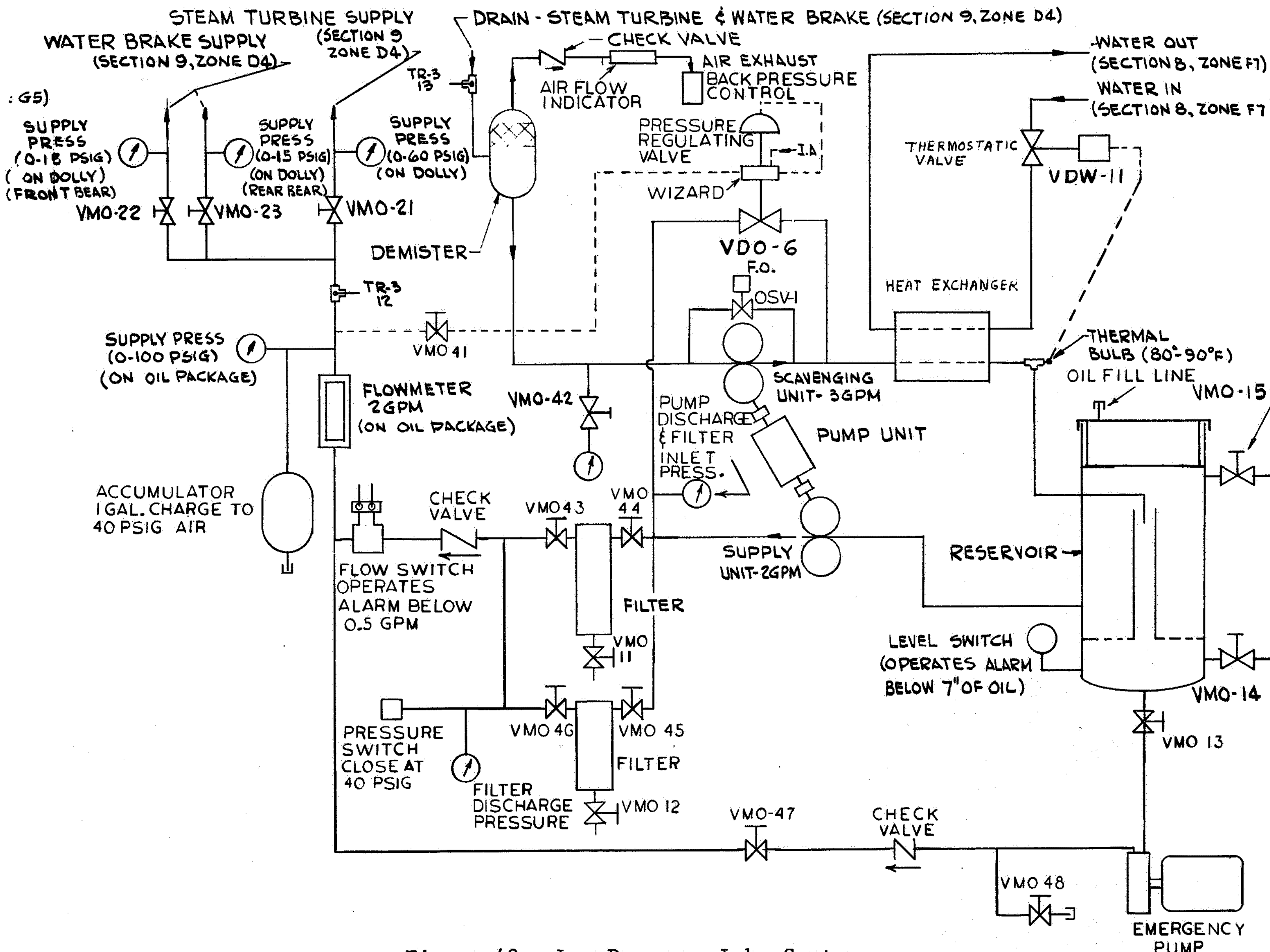


Figure 42. Low Pressure Lube System.

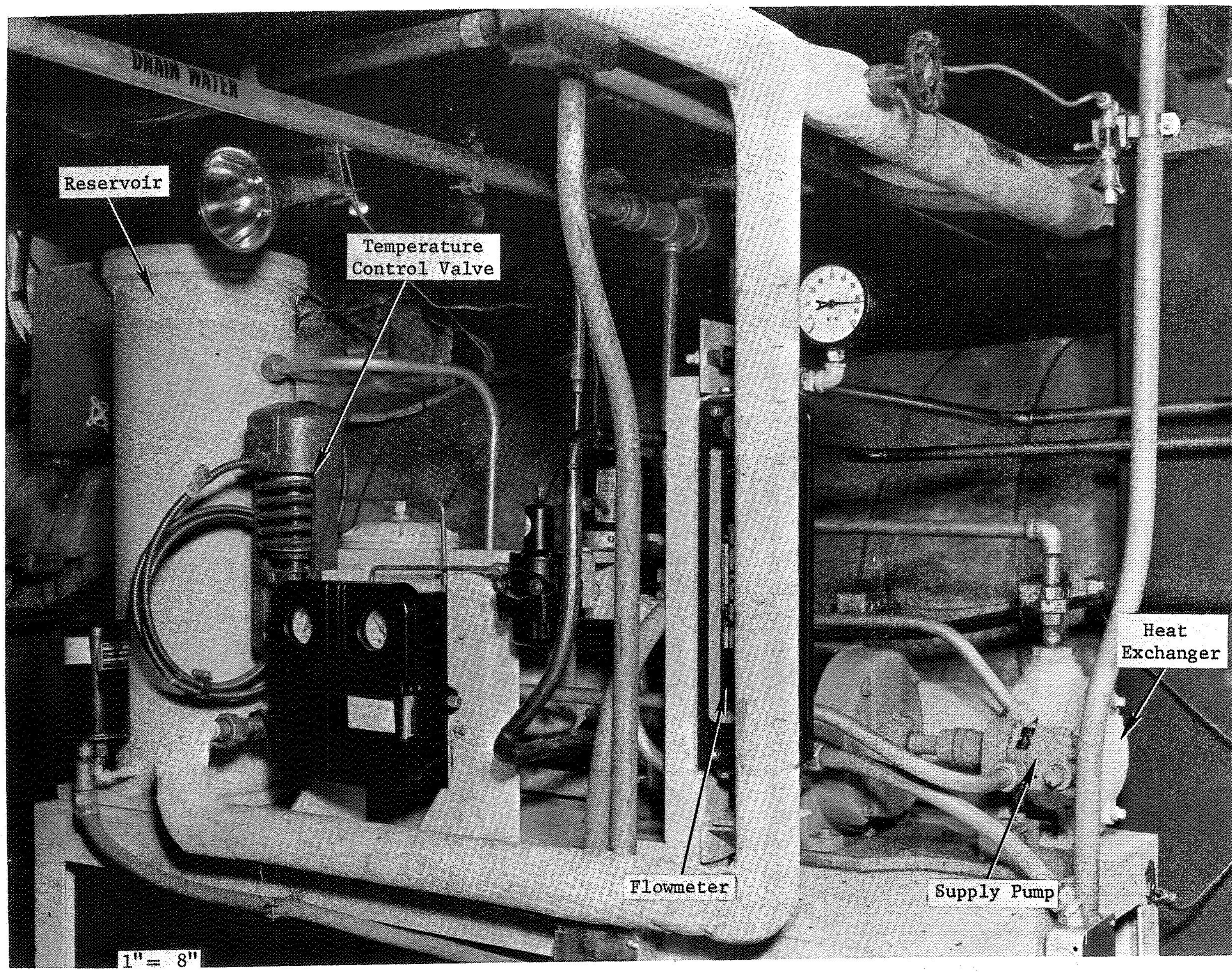


Figure 43. Low Pressure Lube System.

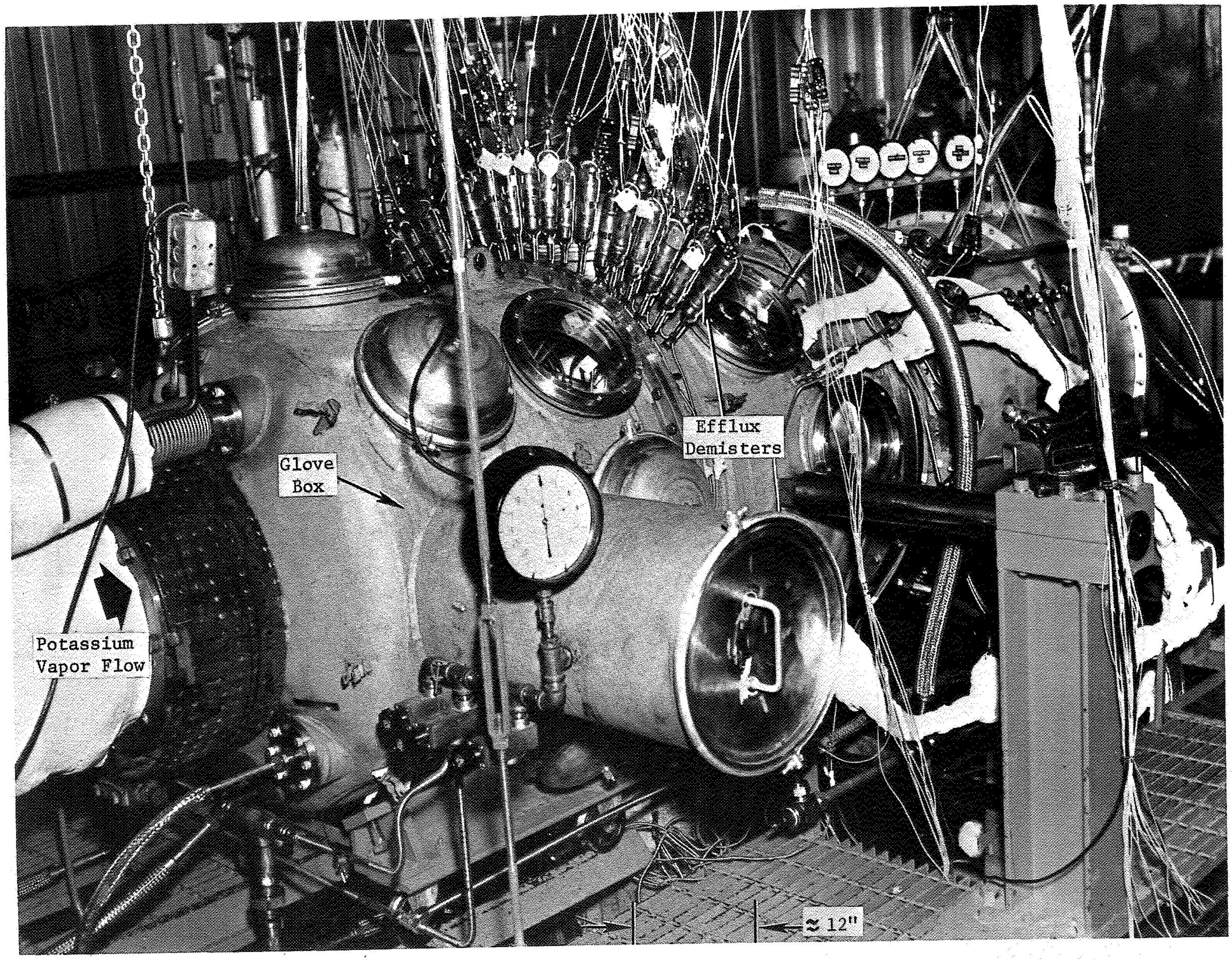


Figure 44. Glove Box - Turbine Support Structure.

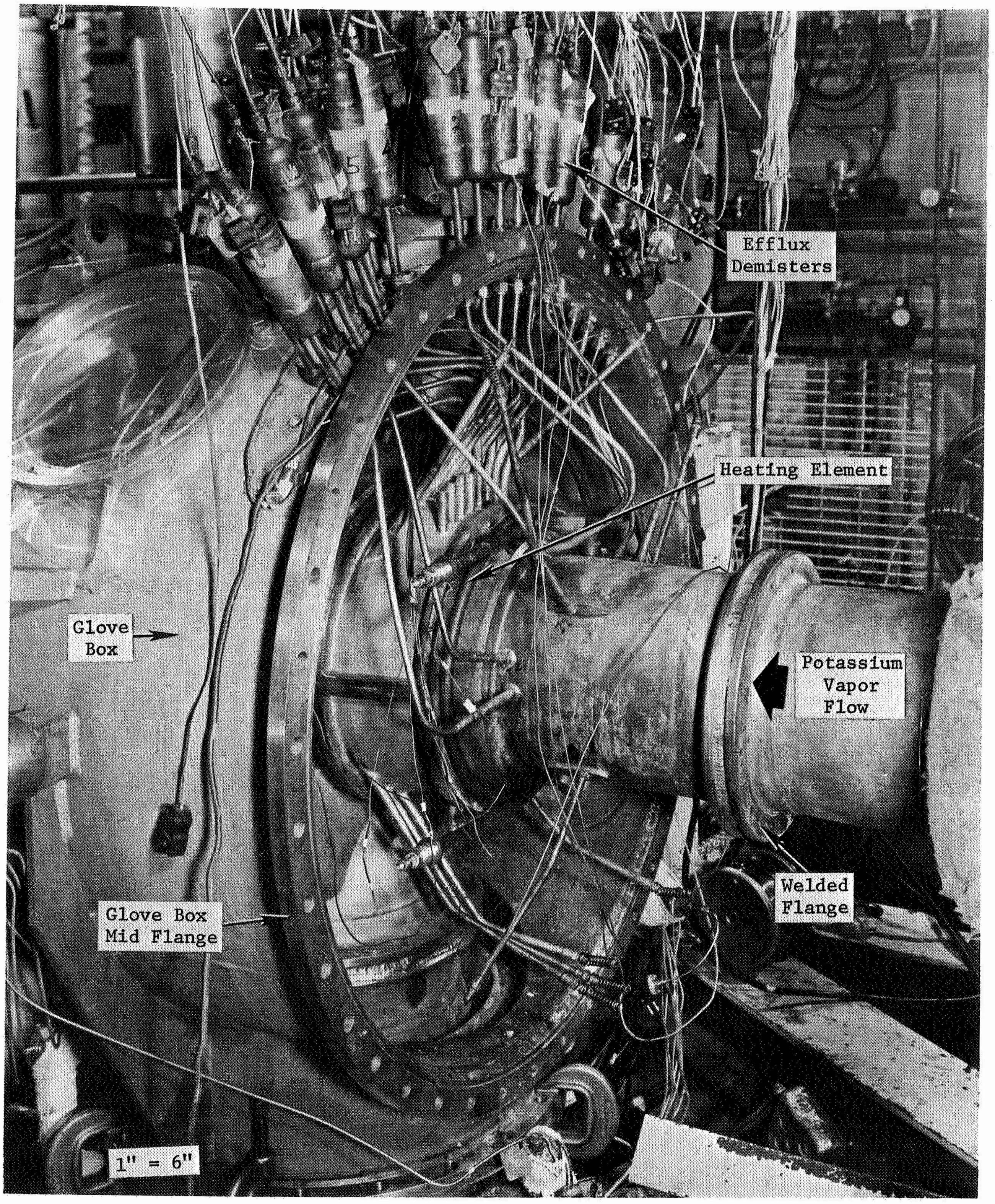


Figure 45. Turbine Ready for Thermal Insulation.

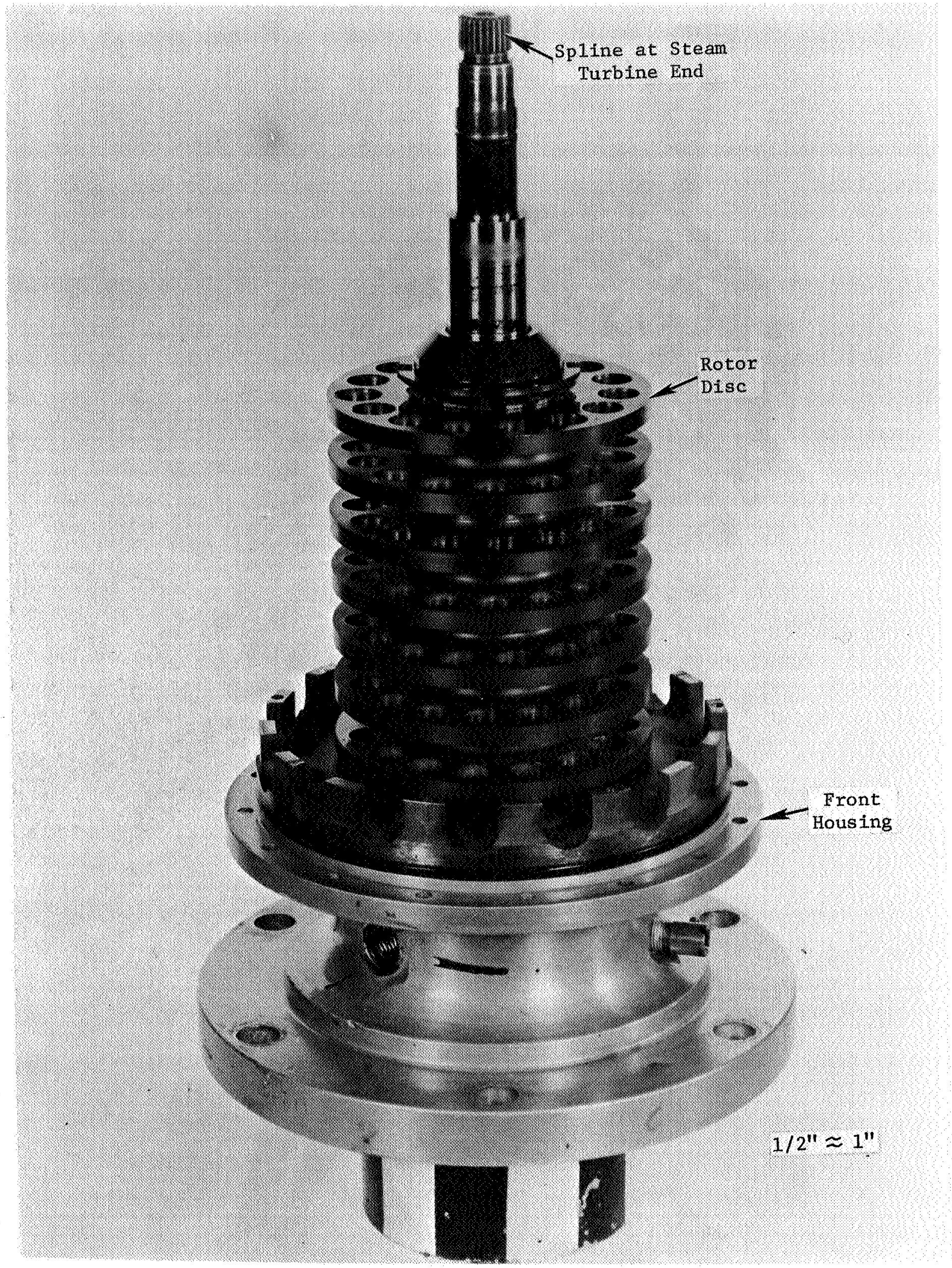


Figure 46. Water Brake Rotor Discs After 300 Hours.

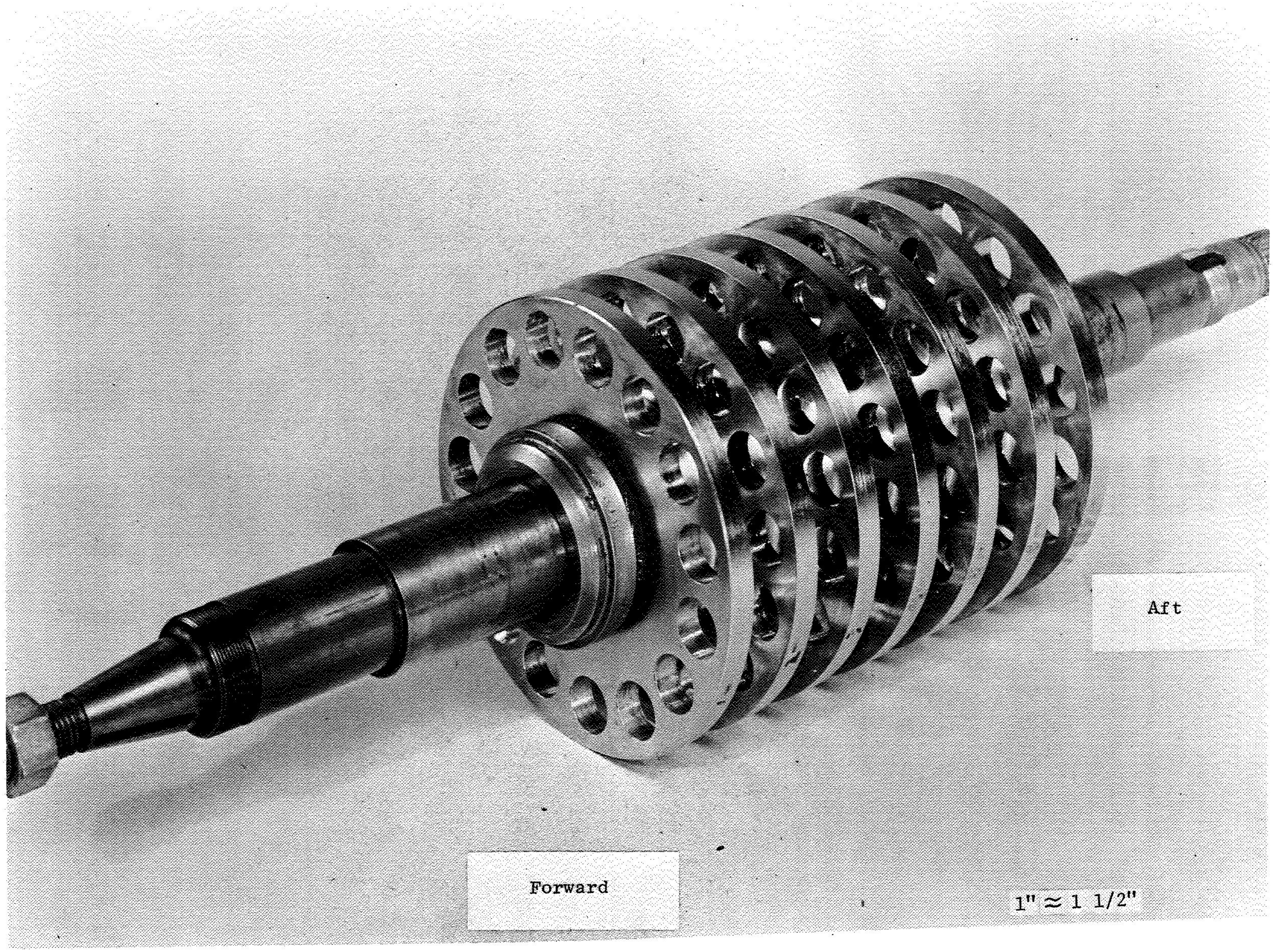


Figure 47. Water Brake Discs After 2300 Hours.

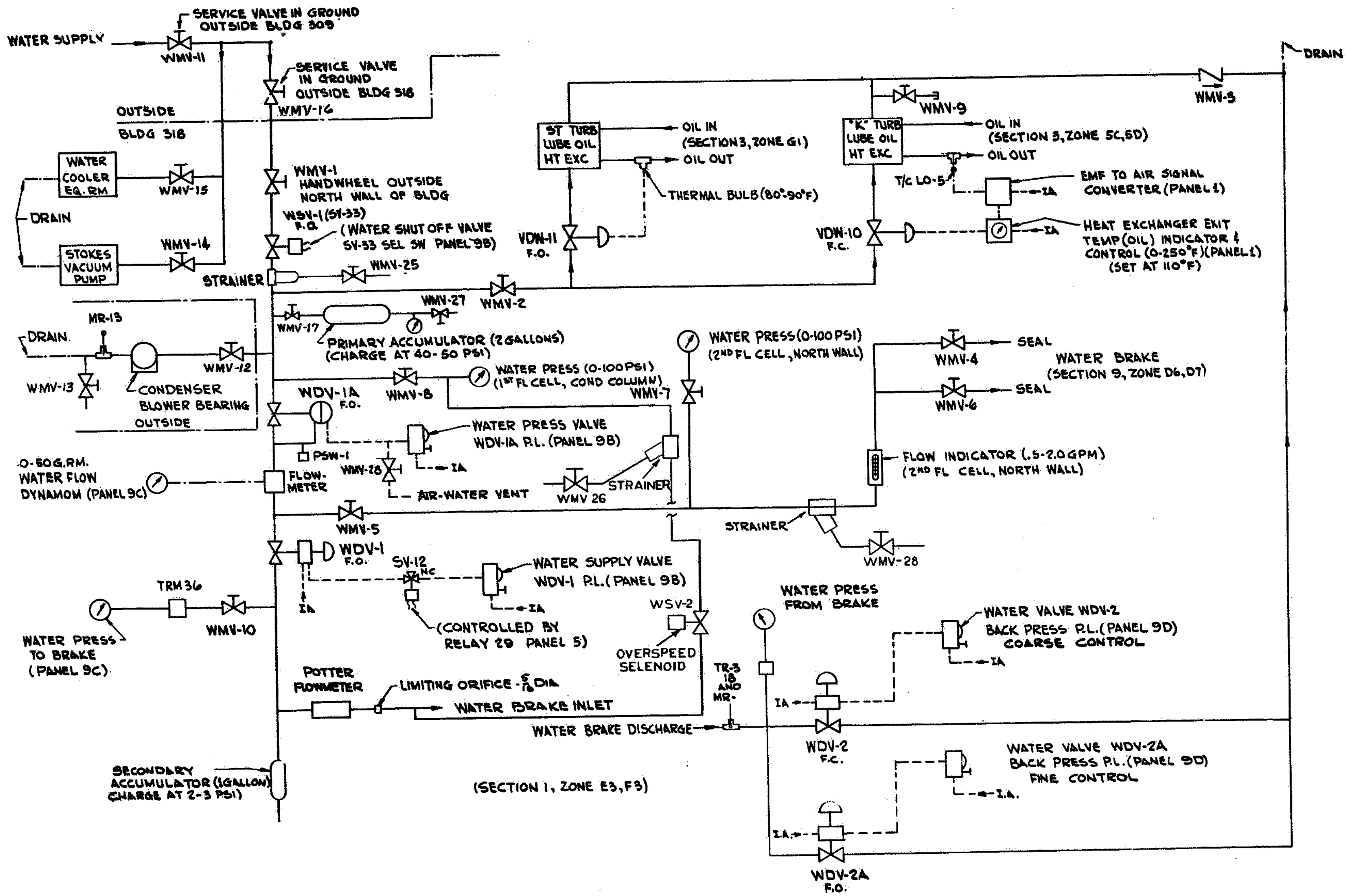


Figure 48. Schematic-Water Brake Control.

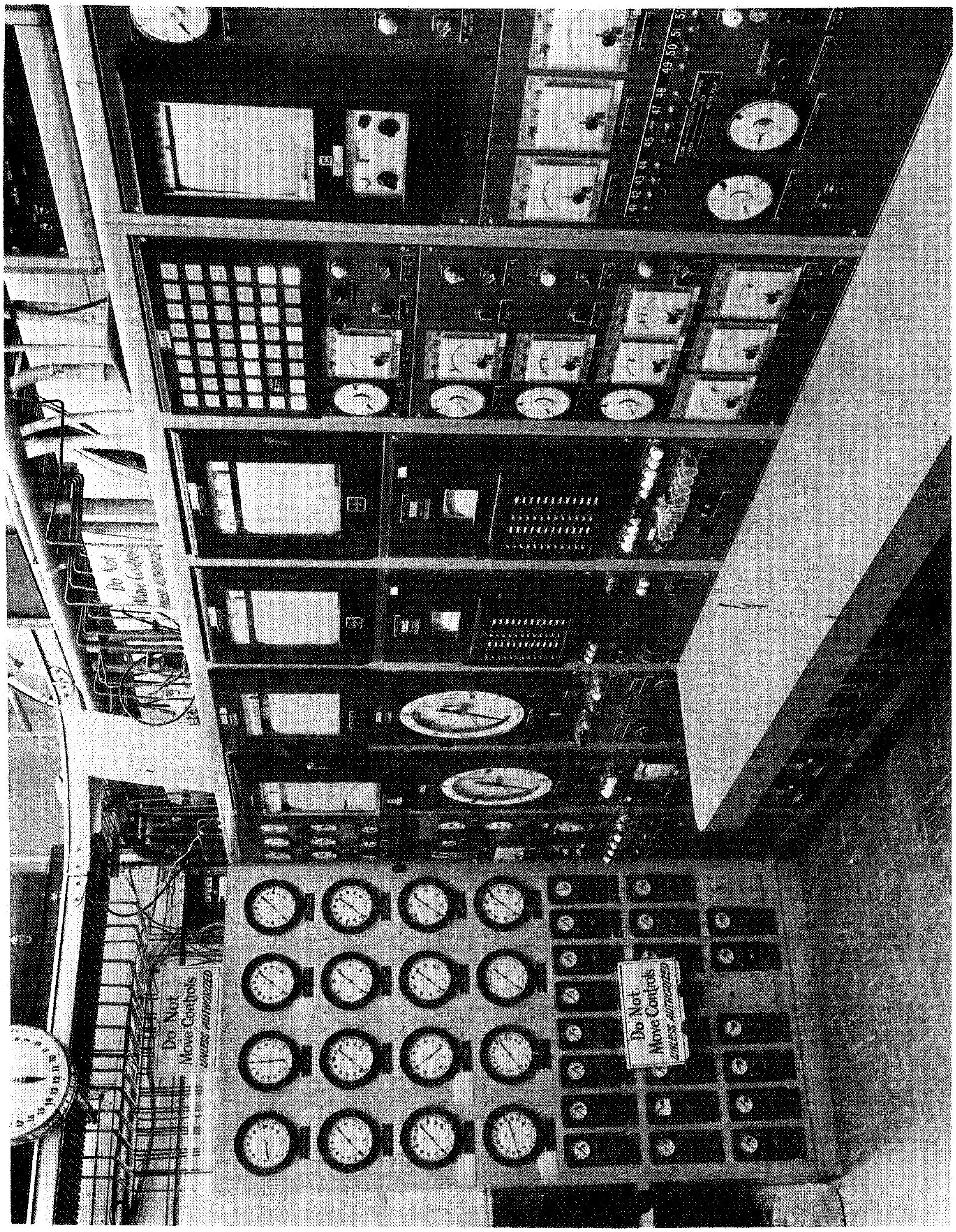


Figure 49. Main Control Room Looking West.

Figure 50. Main Control Room Looking East.

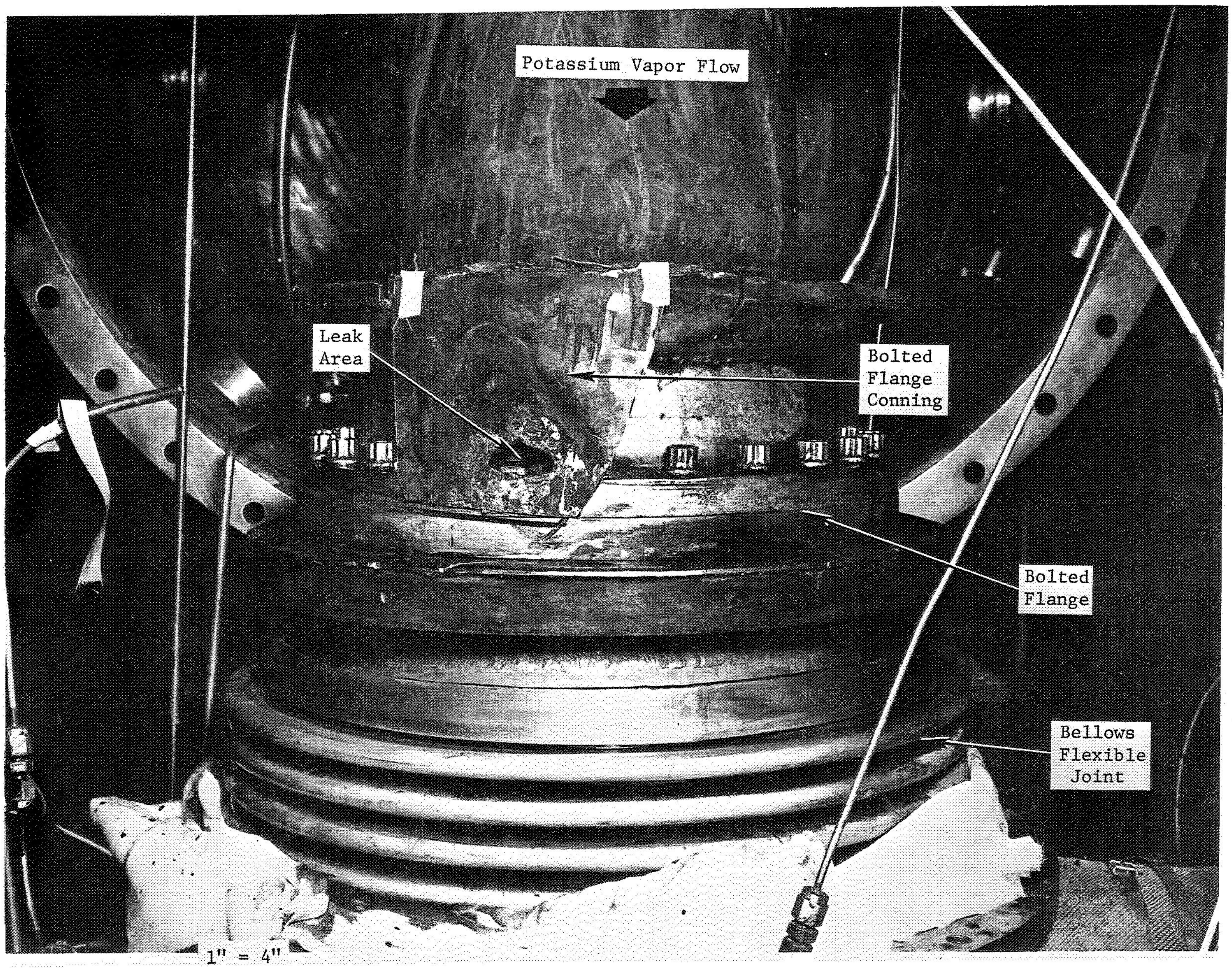


Figure 51. C-D Nozzle Bolted Flange Following Leak.

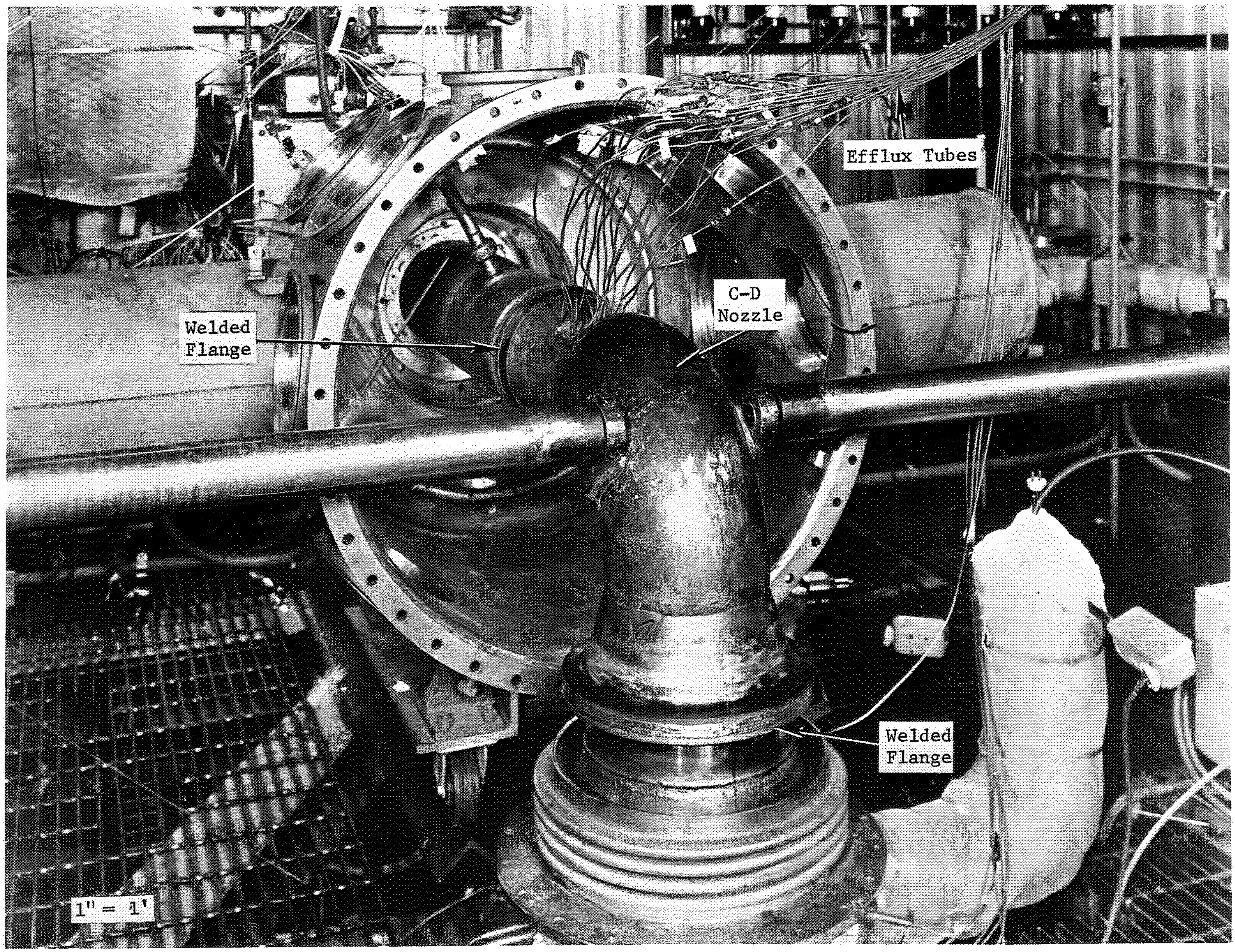
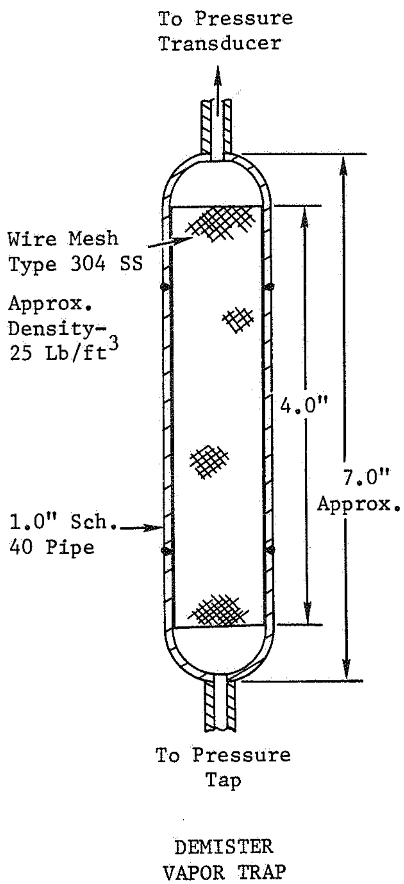


Figure 52. C-D Nozzle, Showing Welded Connections.



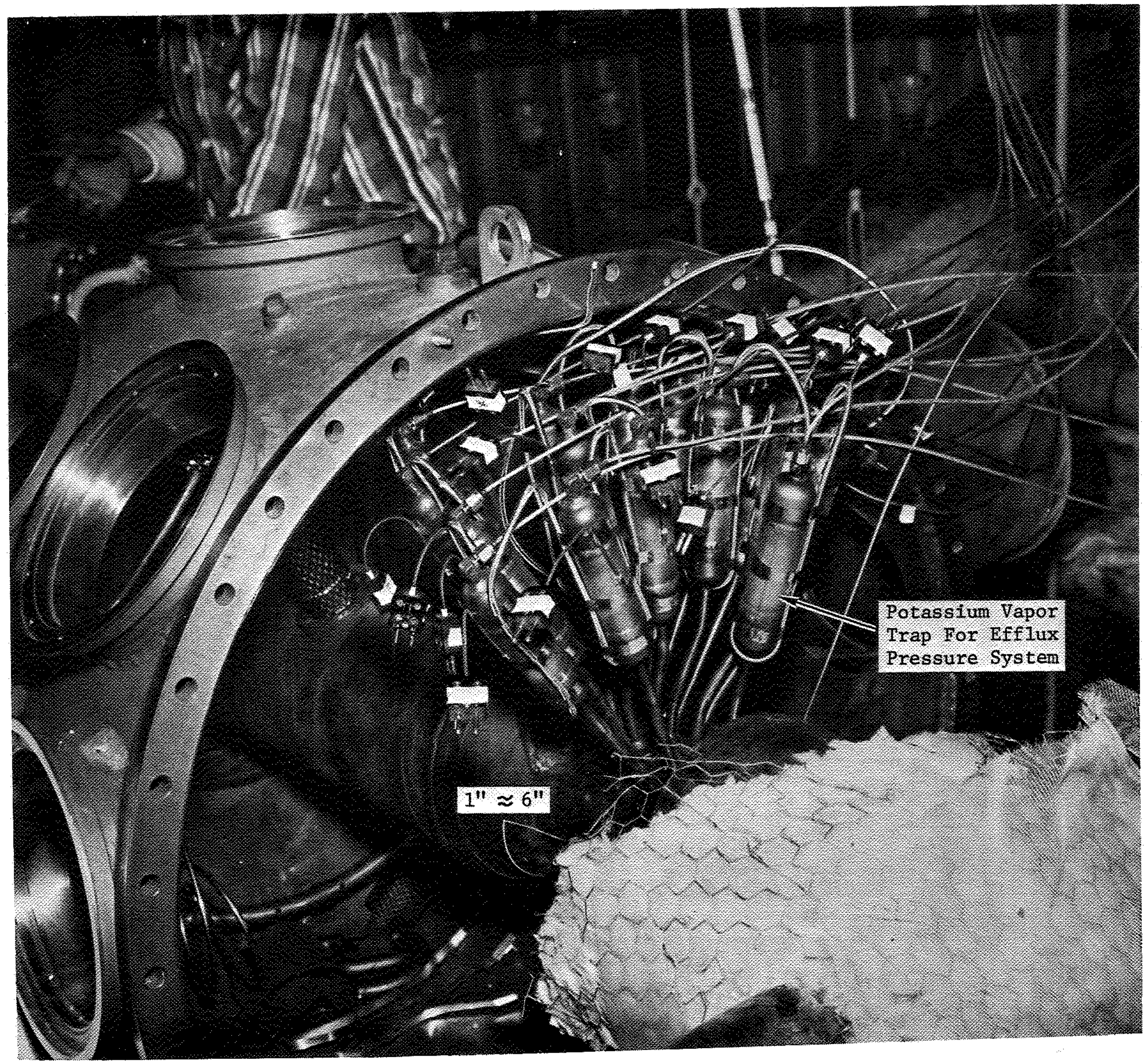


Figure 53. Installation of Efflux Vapor Traps on C-D Nozzle.

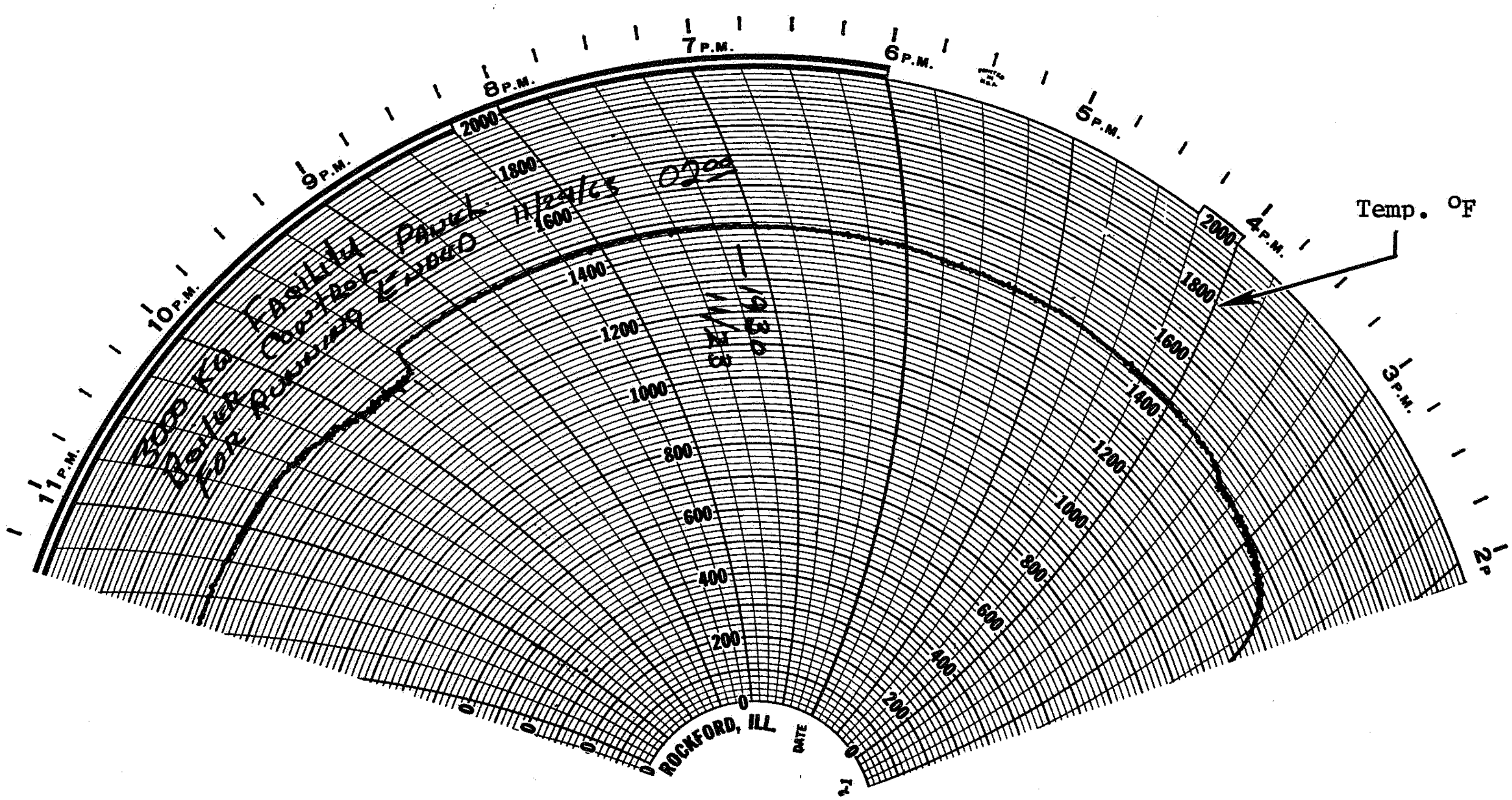


Figure 54. Boiler Discharge Vapor Temperature on November 24, 1963.

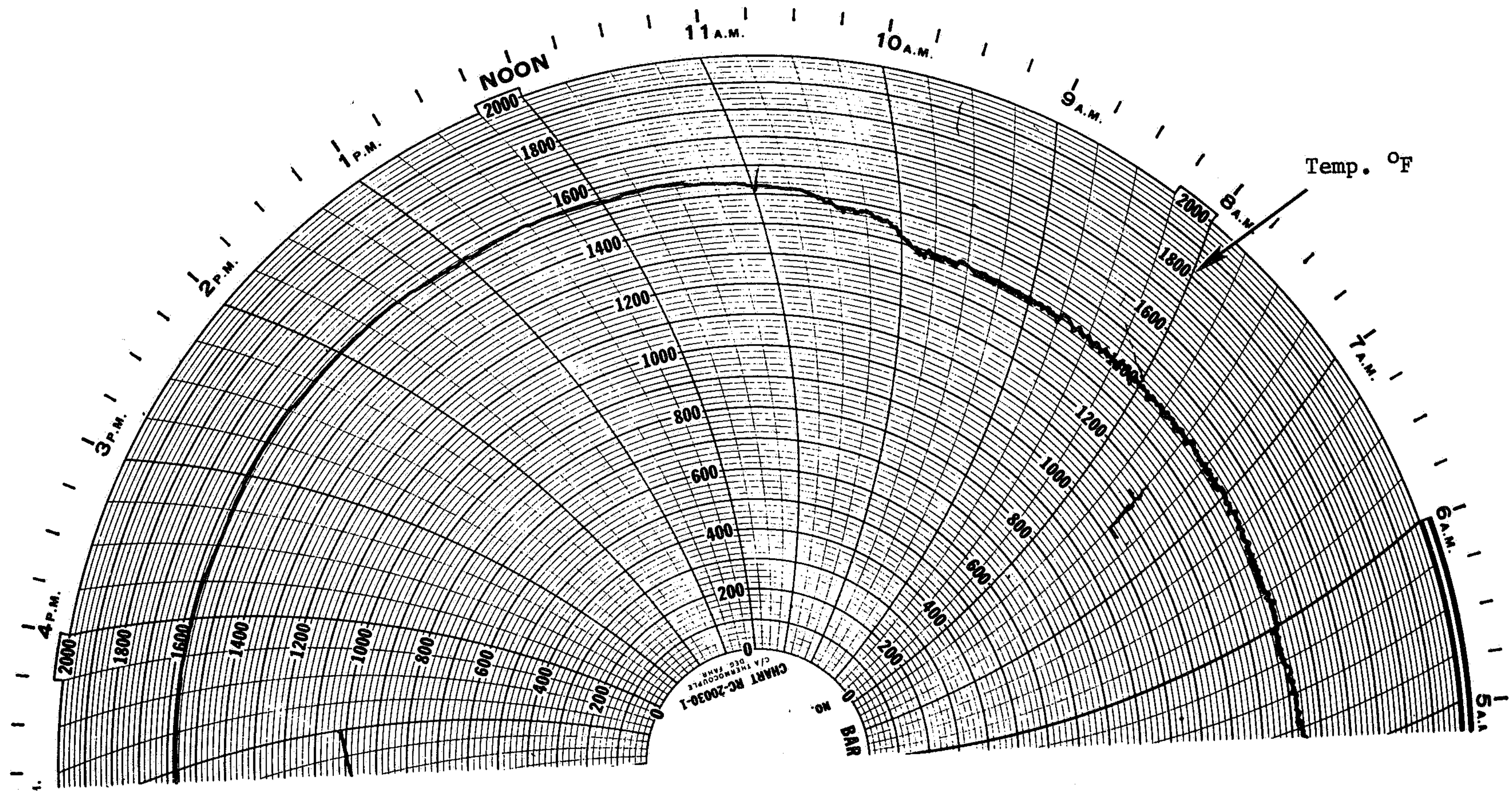


Figure 55. Boiler Discharge Vapor Temperature on December 29, 1963.

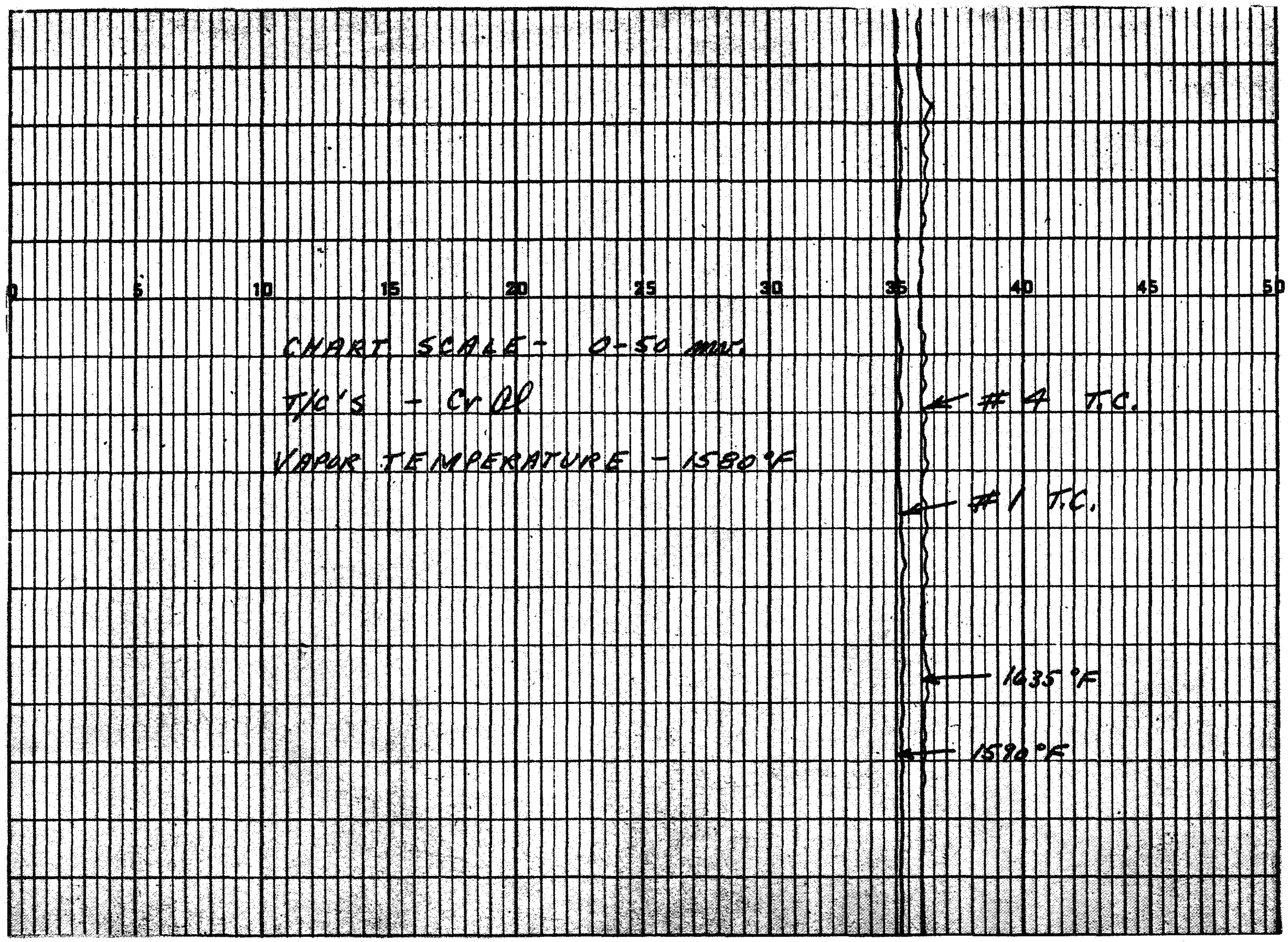


Figure 56. 3000 KW Boiler Tube Temperature.

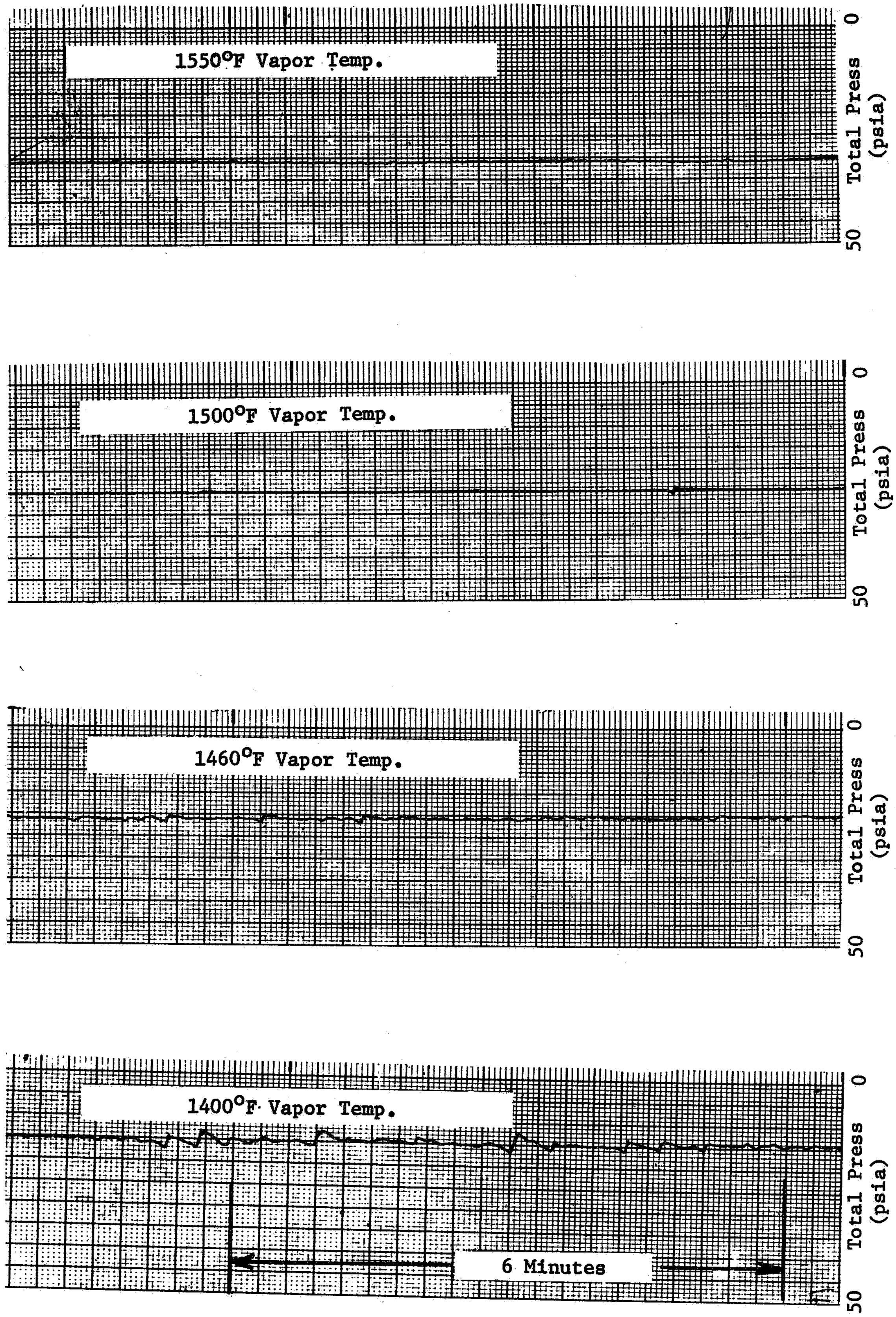


Figure 57. Total Vapor Pressure at C-D Nozzle Inlet.

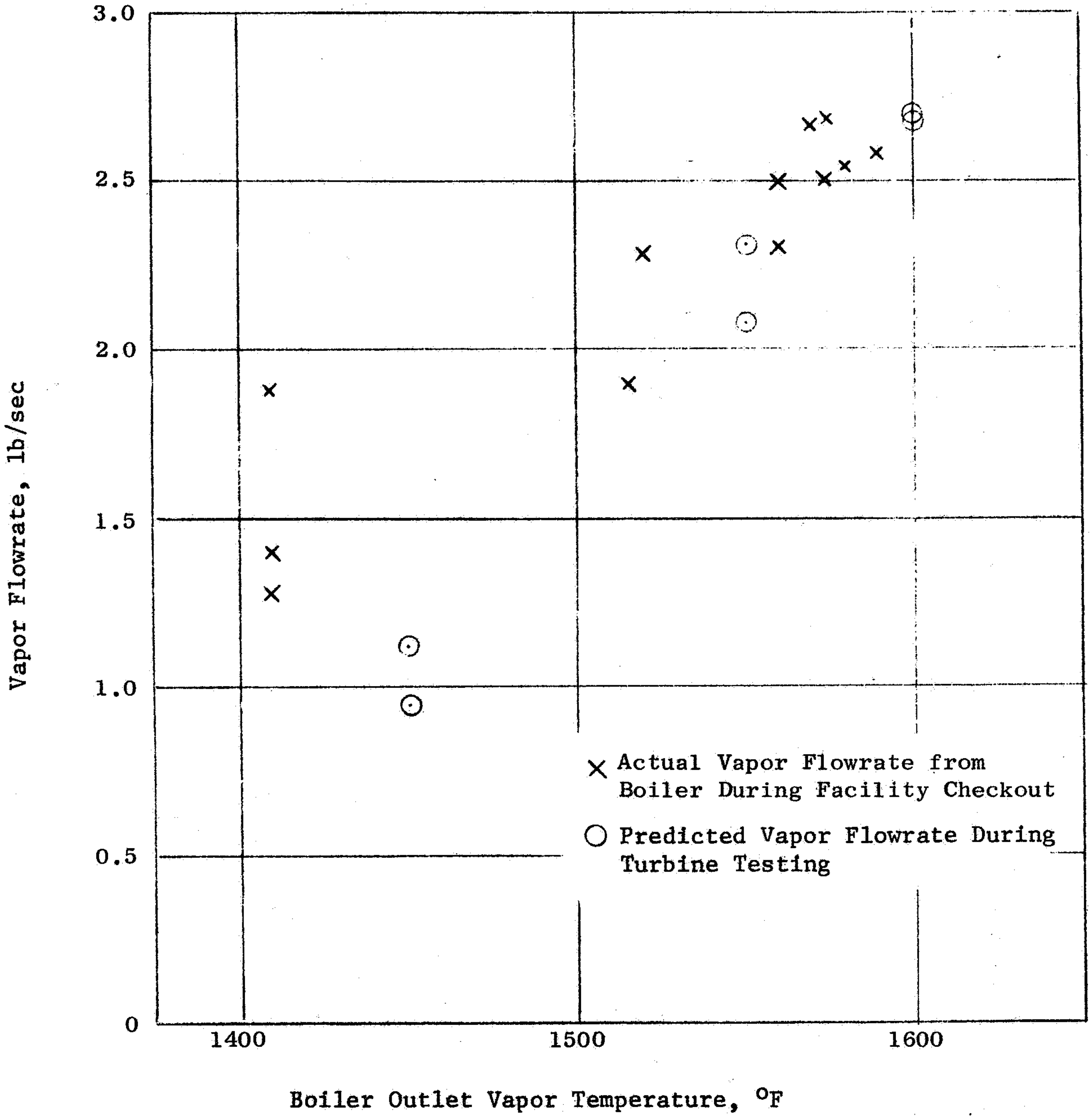


Figure 58. Vapor Flowrate From Boiler During Nozzle Testing.

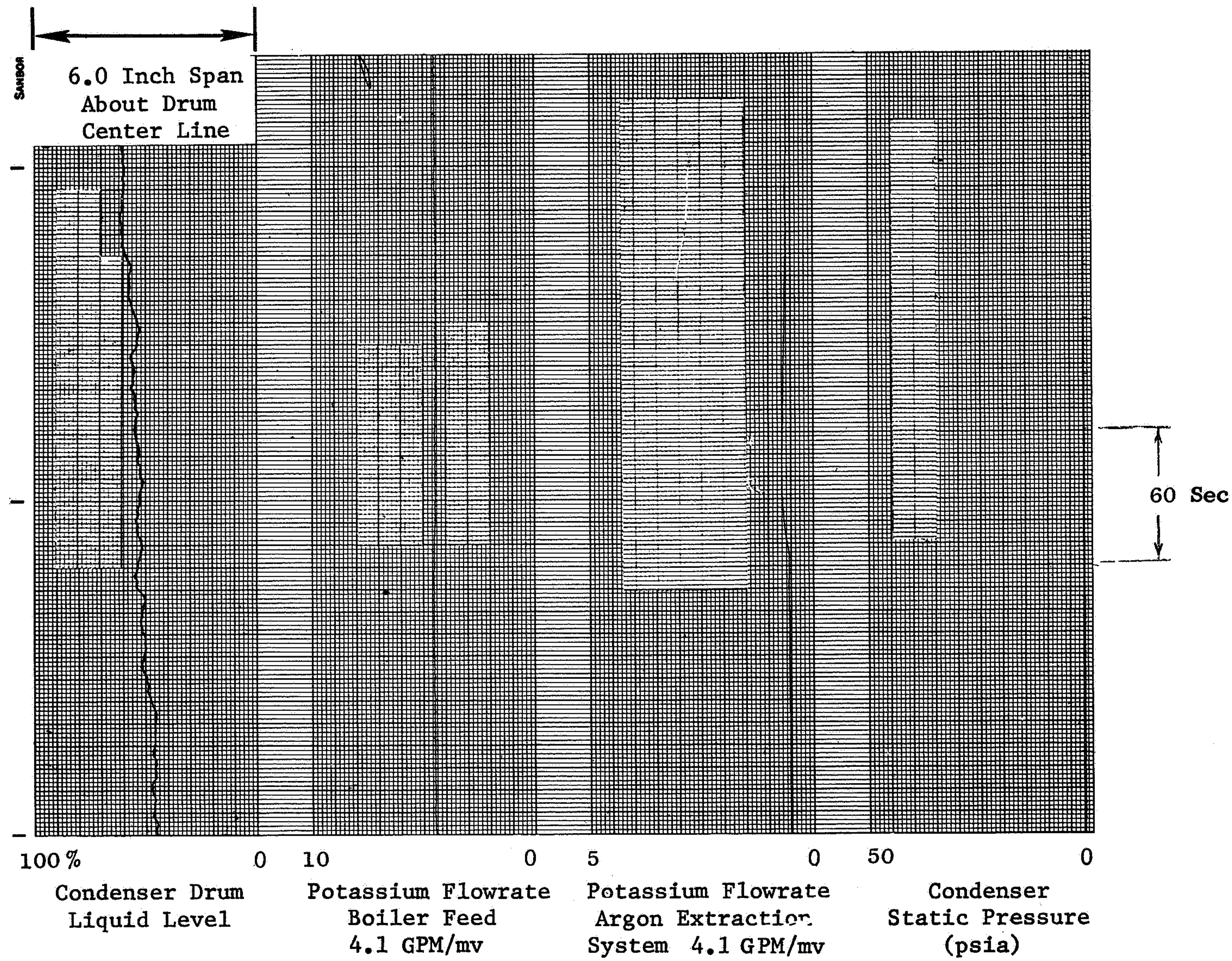


Figure 59. Sanborn Chart Showing Typical Condenser Test Conditions During C-D Nozzle Testing.

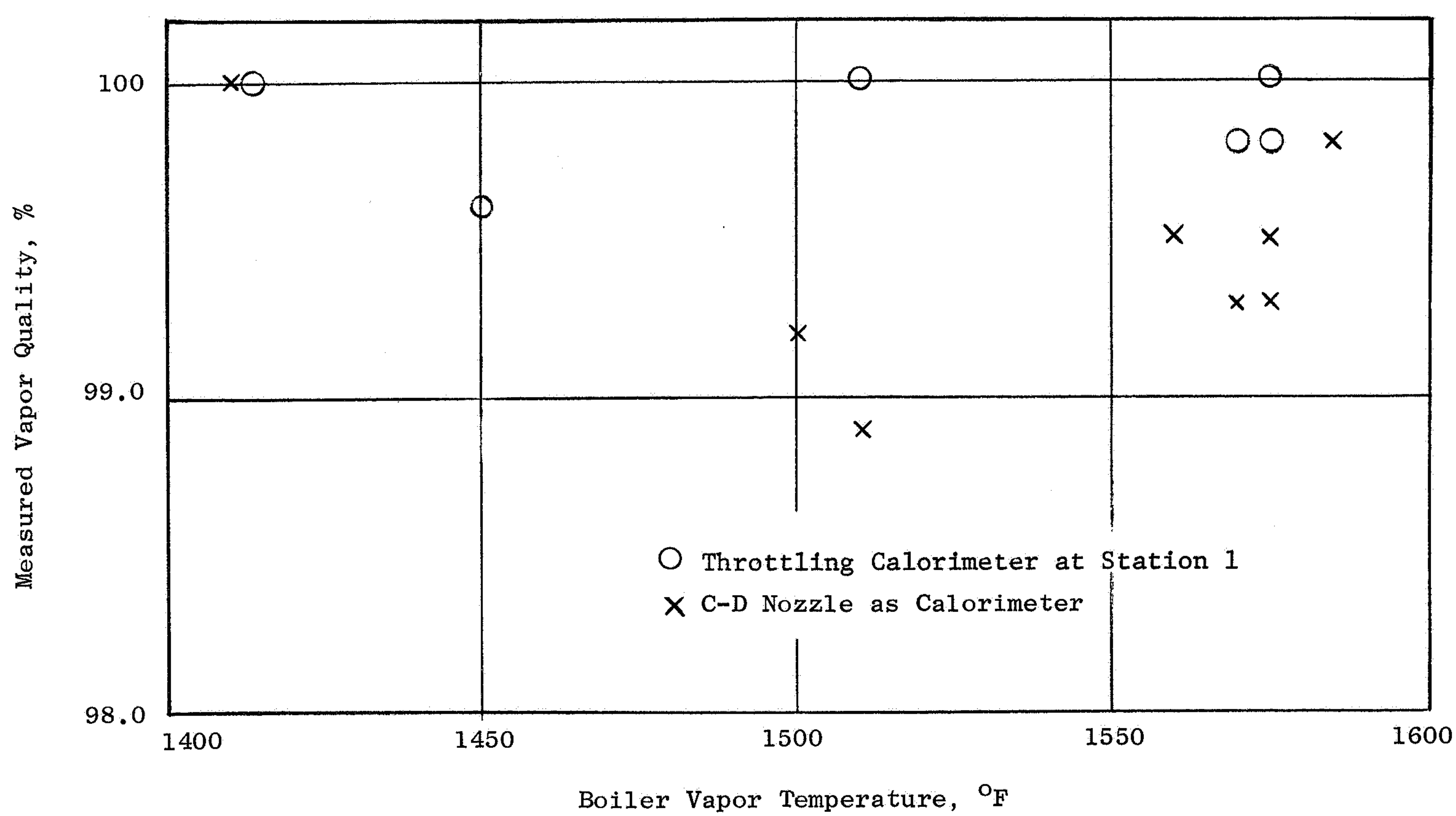


Figure 60. Typical Vapor Quality During C-D Nozzle Testing.

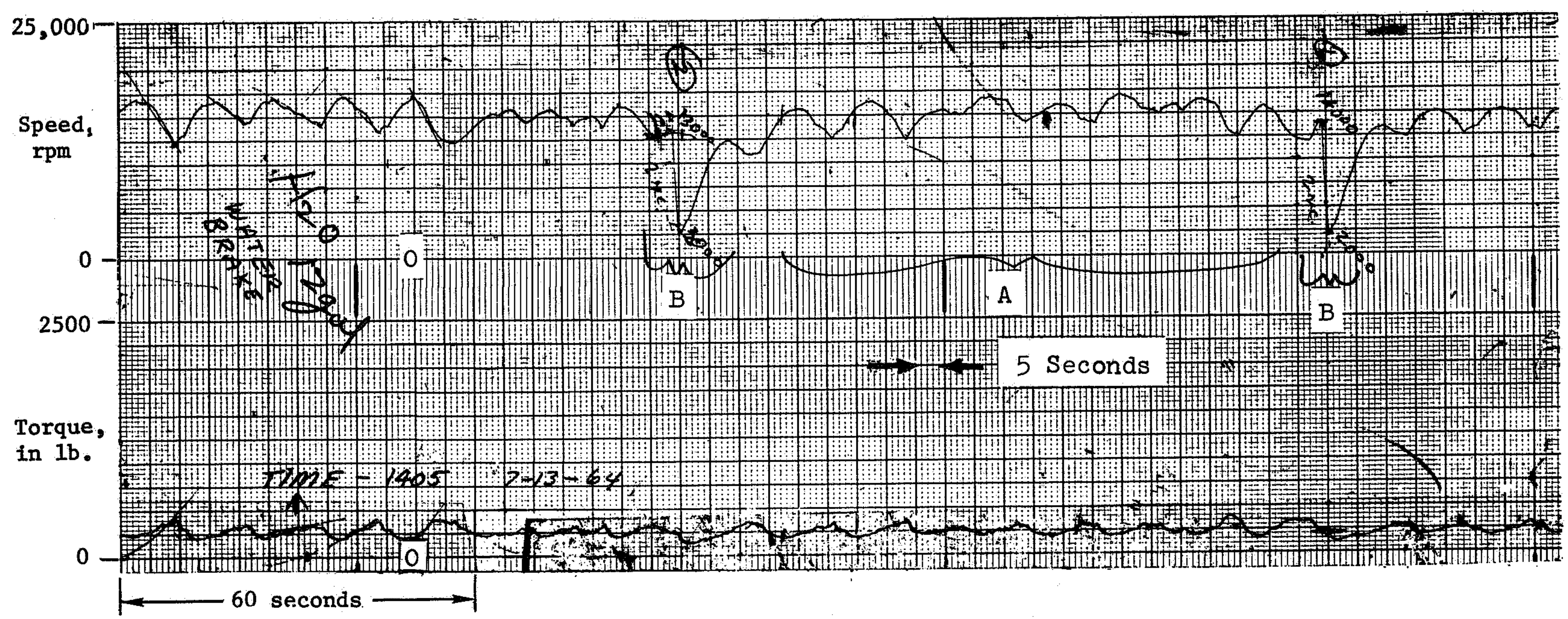


Figure 61. Turbine Speed Fluctuation.

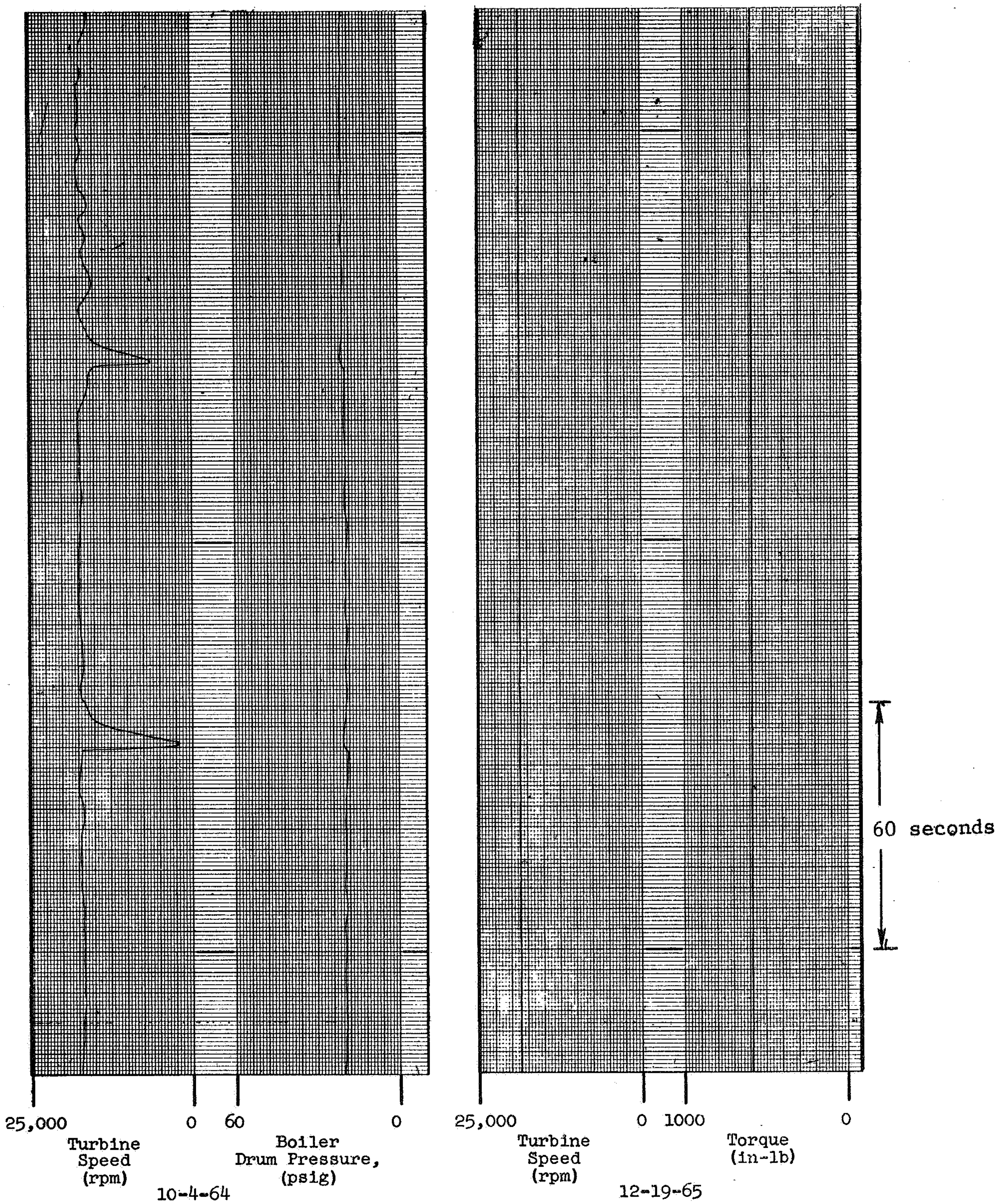
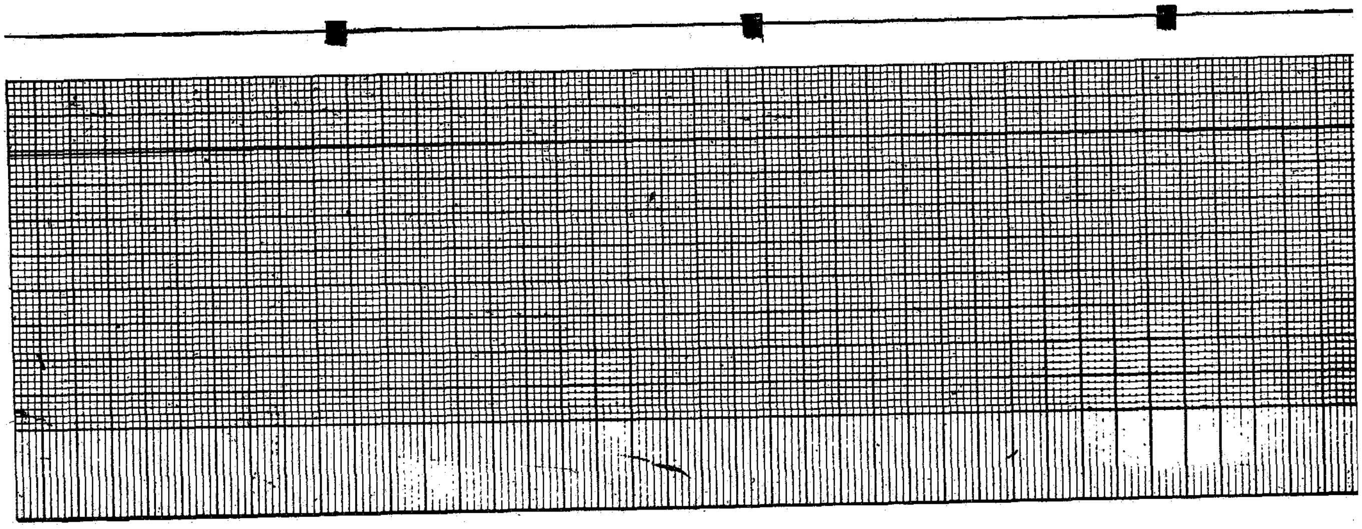
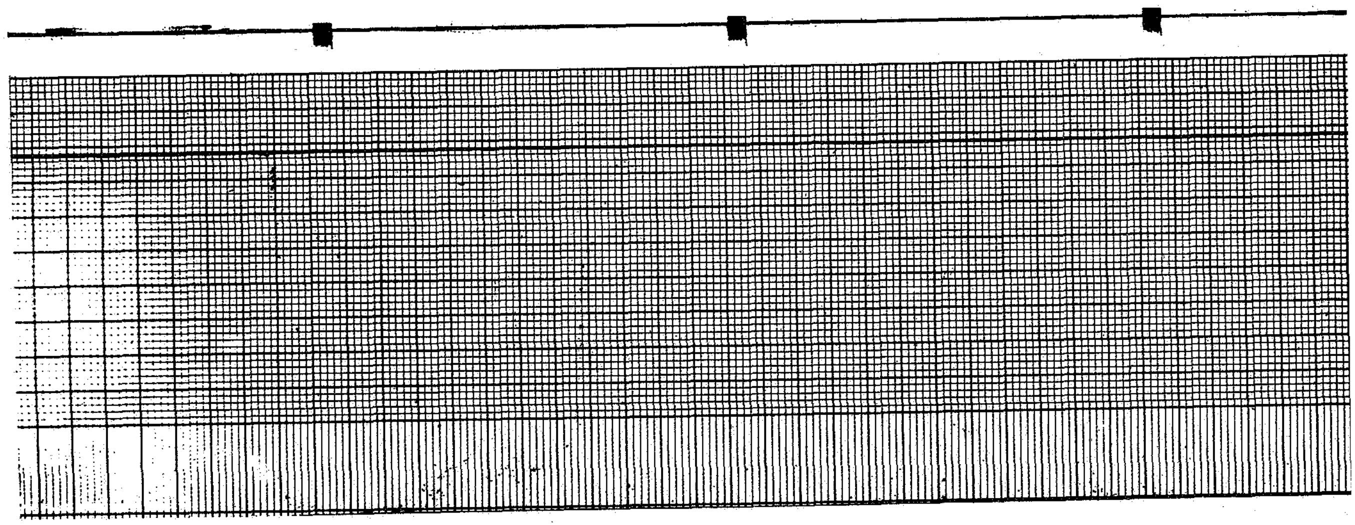


Figure 62. Sanborn Recorder Tracing of Turbine Speed.





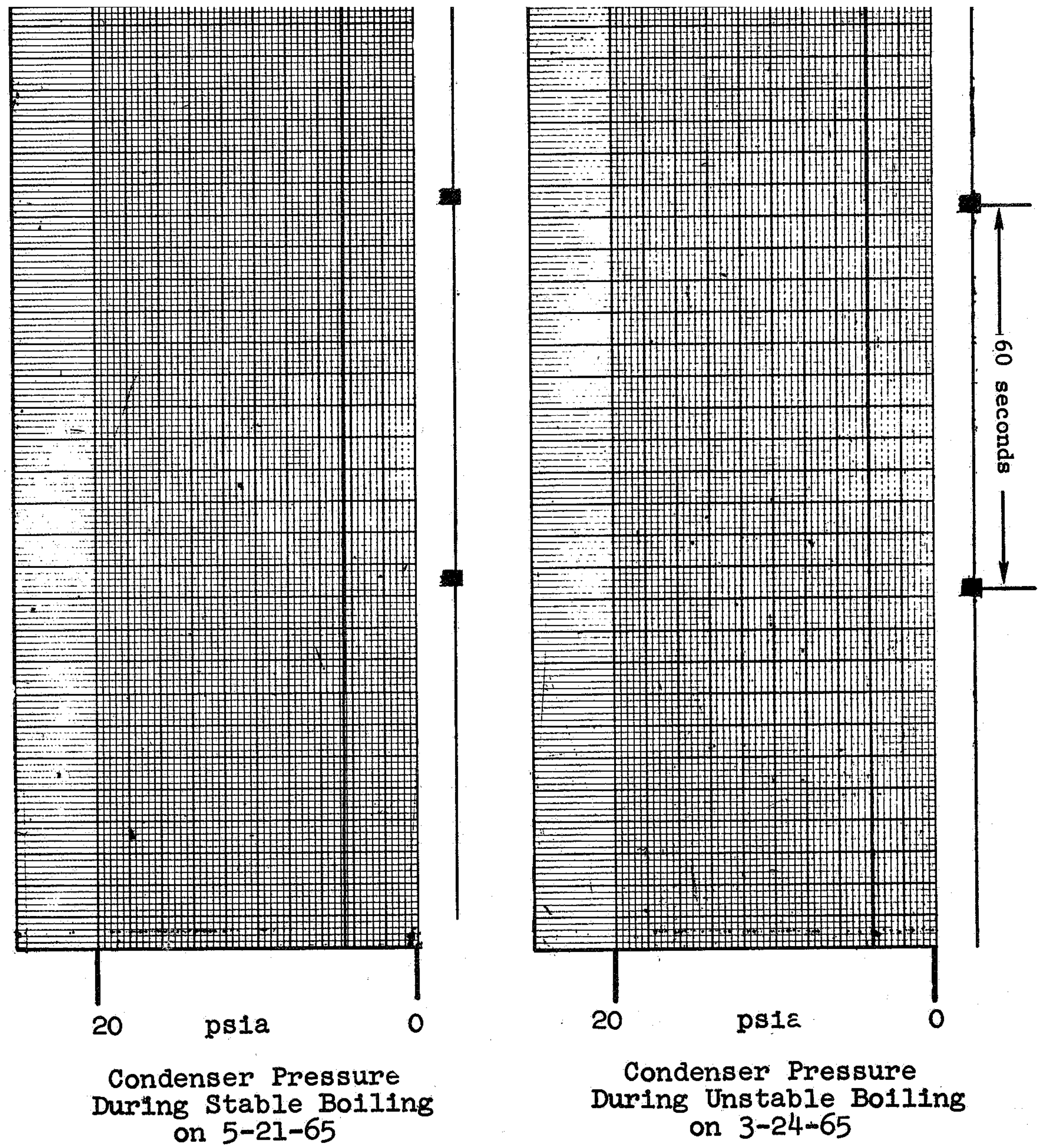


Figure 63. Comparison of Condenser Pressure During Stable and Unstable Boiling.

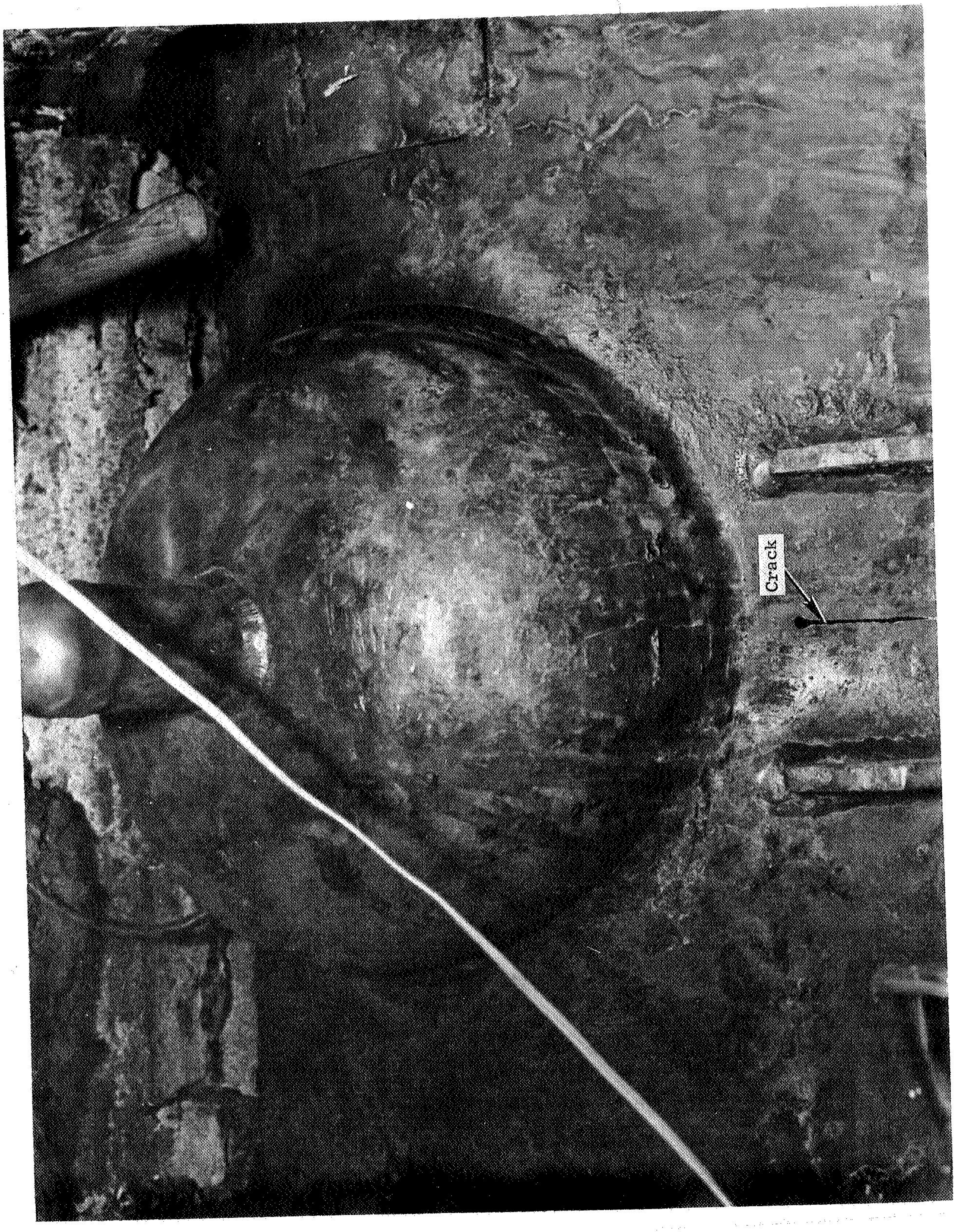


Figure 64. Crack in Boiler Vapor Drum.

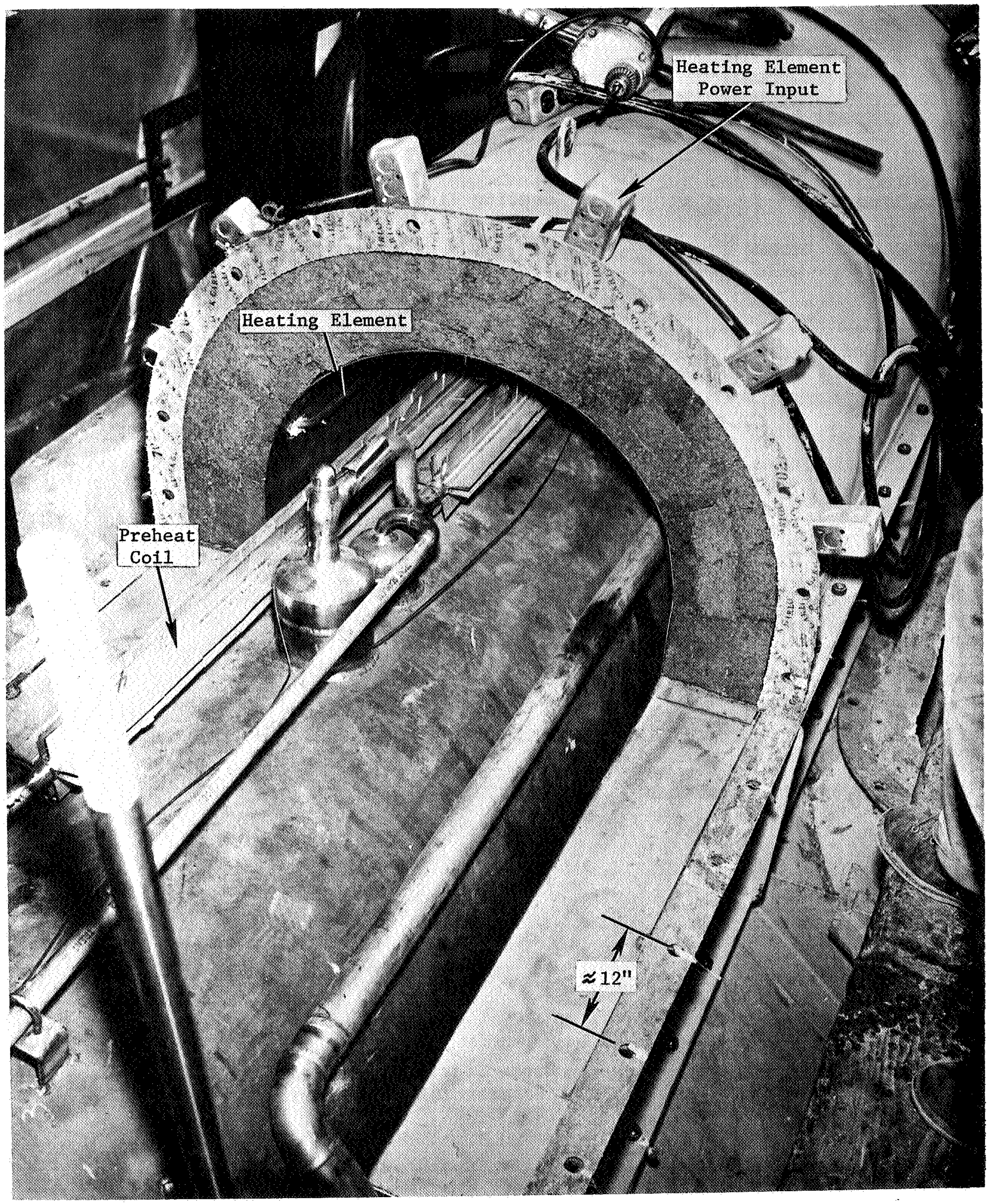


Figure 65. Boiler Vapor Drum - Heating Elements and Preheat Coil.

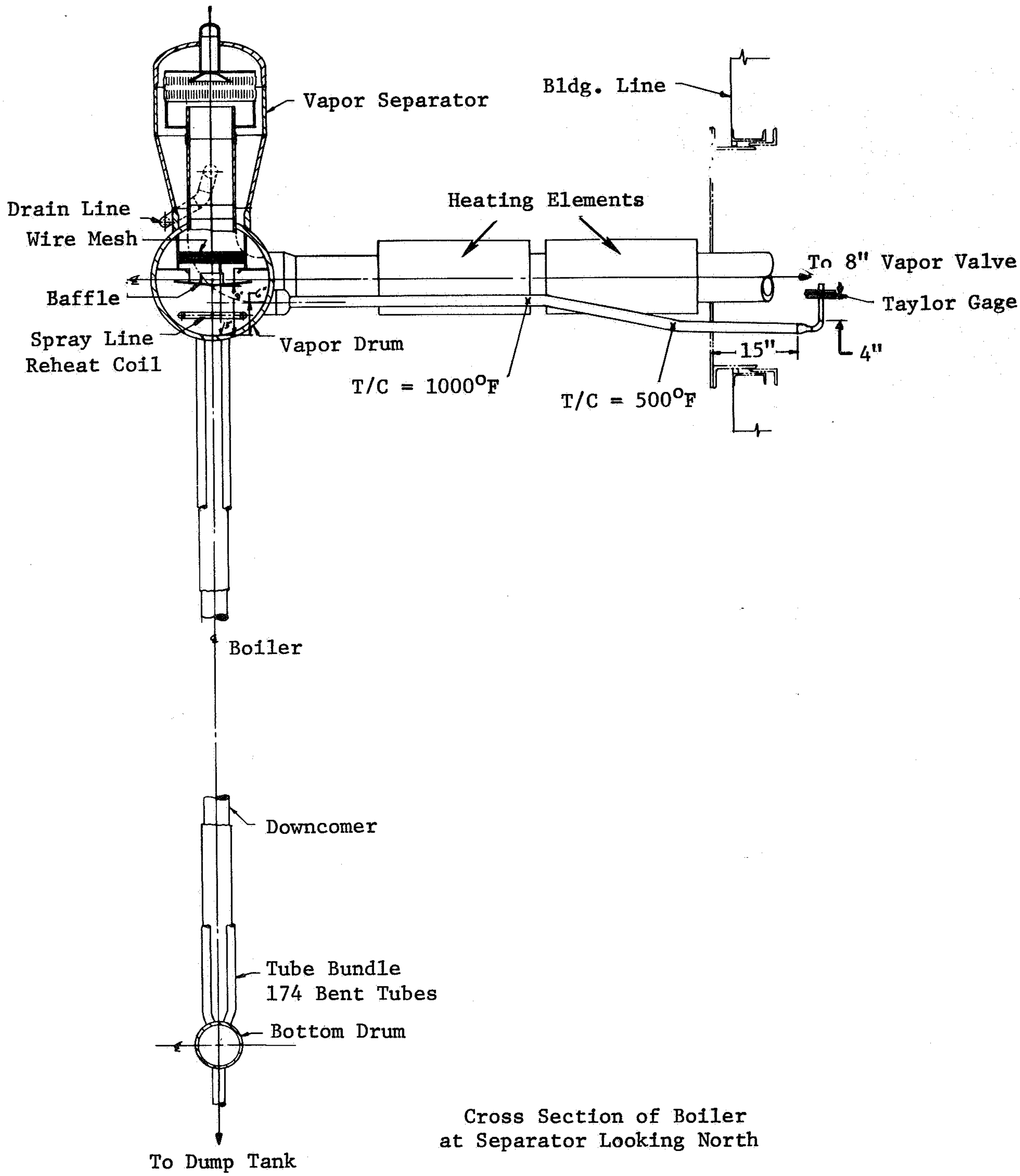


Figure 66. Secondary Separator.

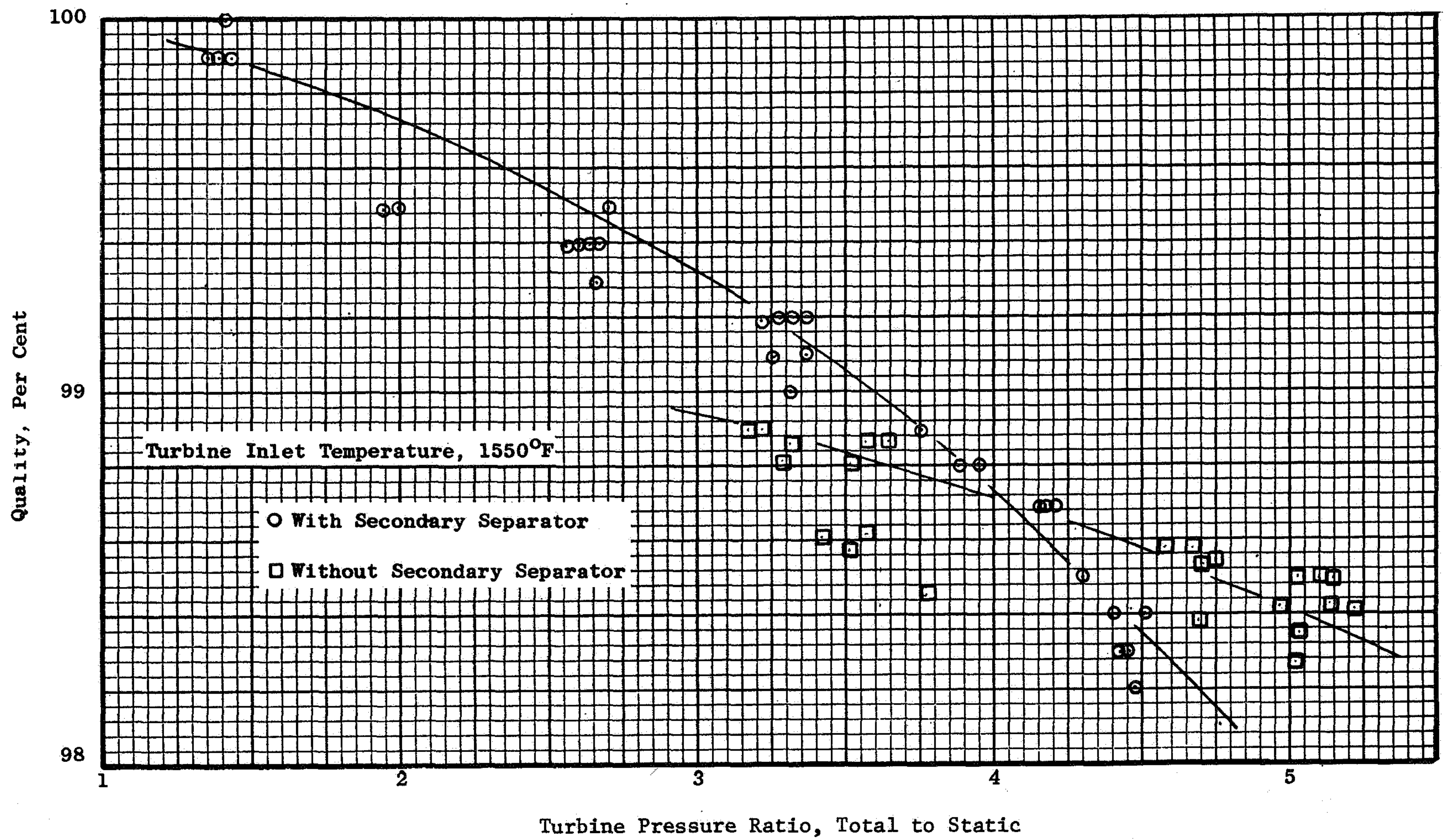


Figure 67. Comparison of Vapor Quality With and Without Secondary Separator.

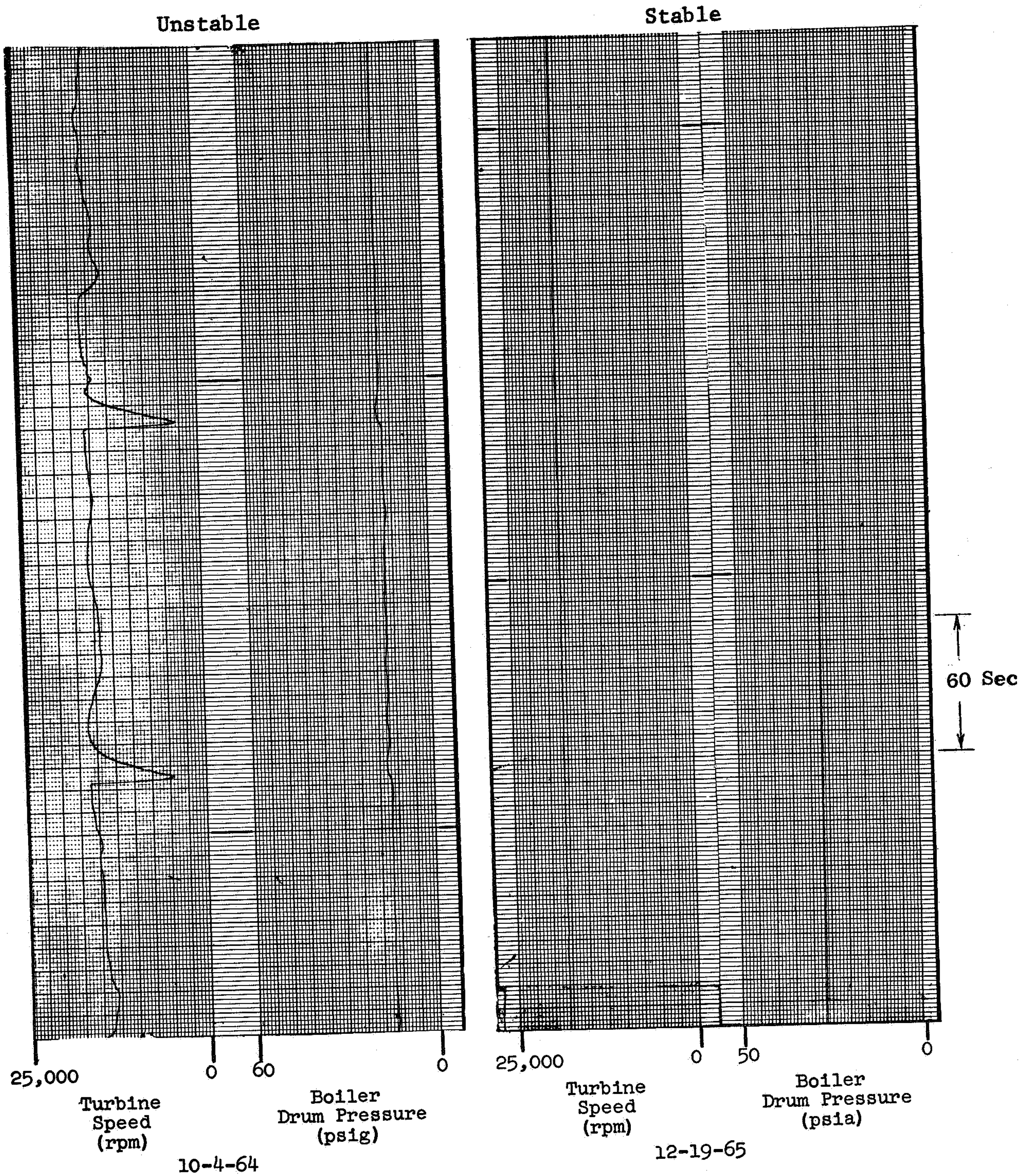
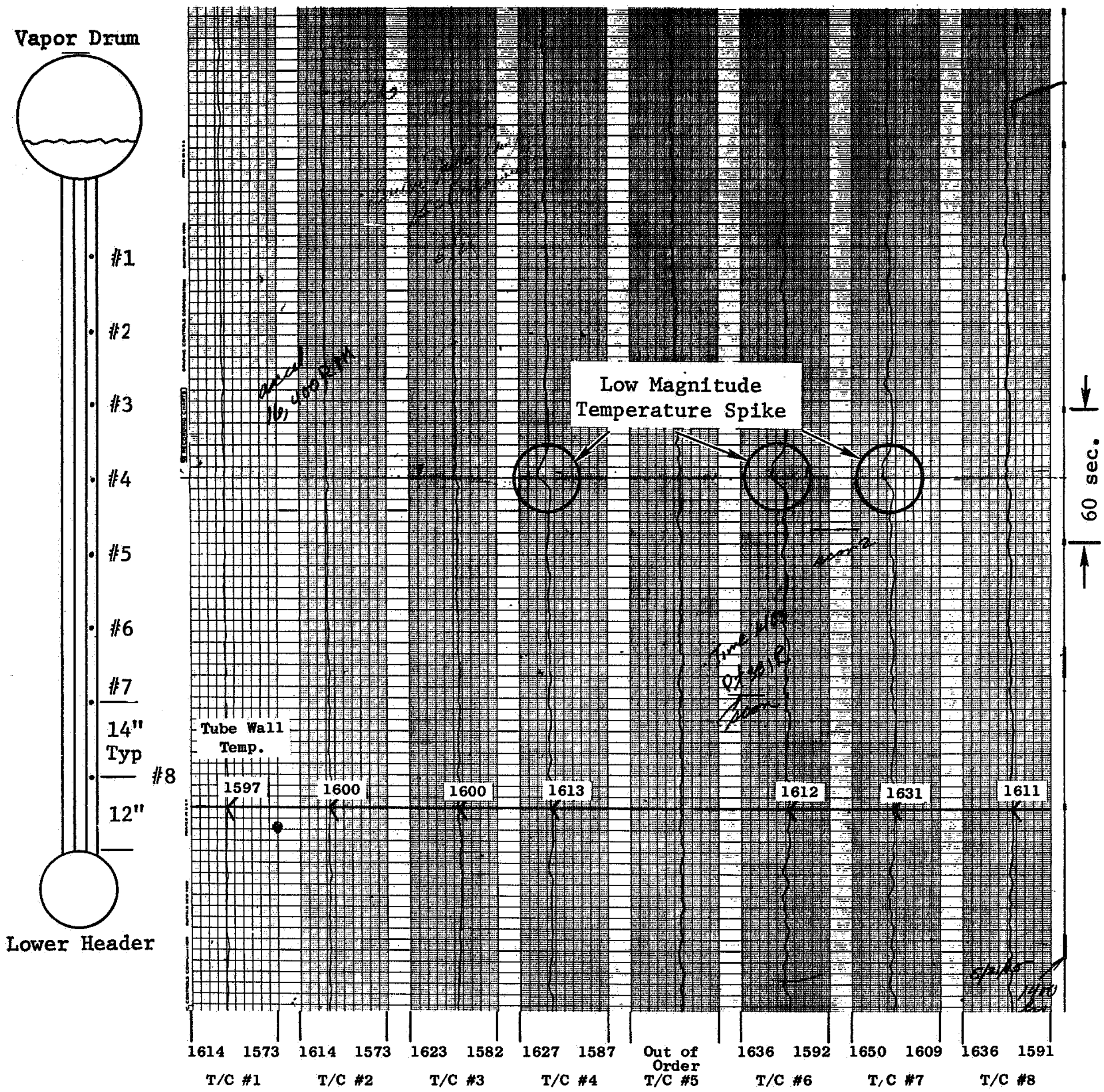


Figure 68. Comparison of Vapor Drum Pressure During Stable and Unstable Boiling.



Boiler Tube Temperatures (Tube No. 37E)
(Boiler Discharge Vapor Temperature - 1560°F)

Figure 69. Boiler Tube Temperature Profile During Stable Boiling.

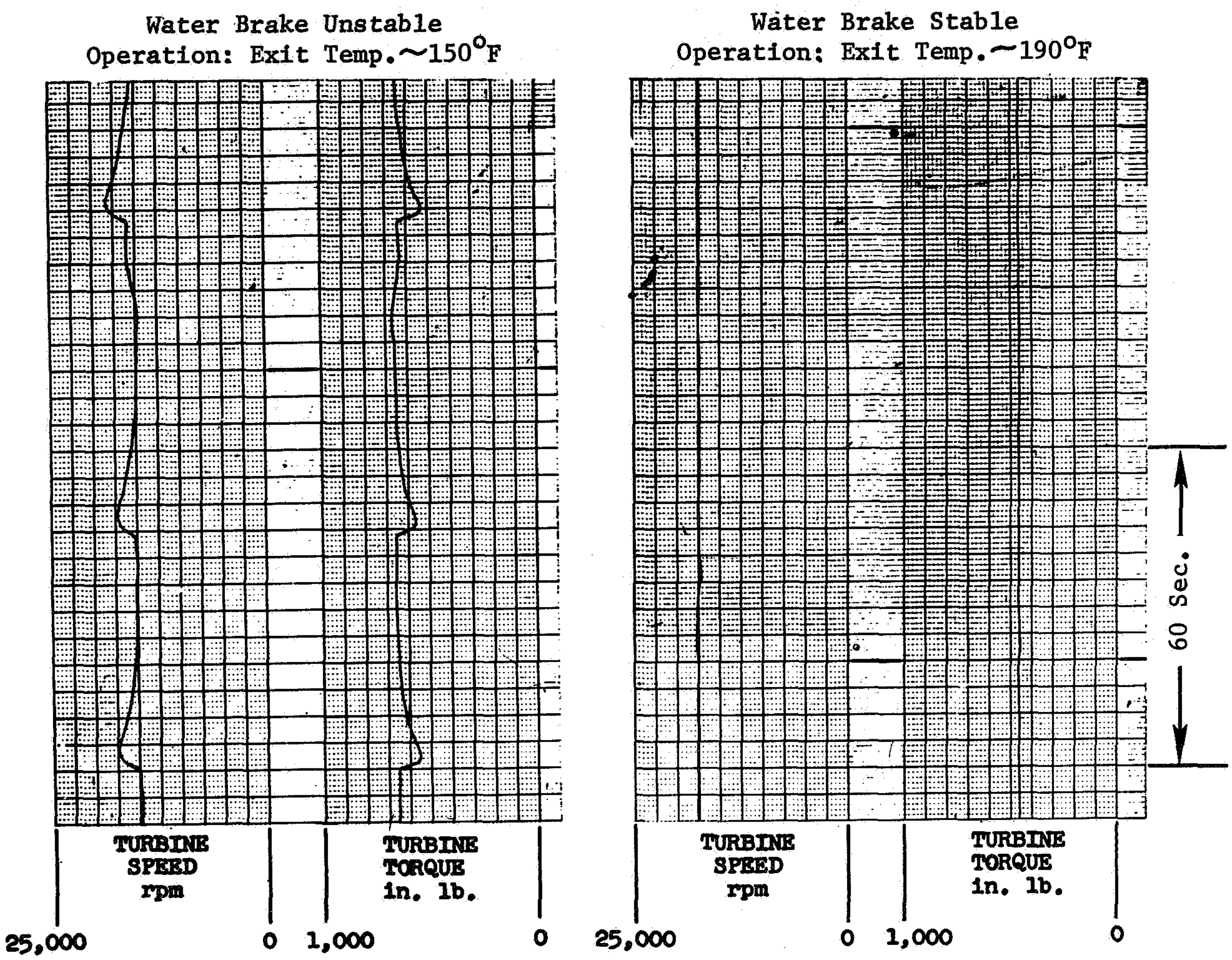


Figure 70. Comparison of Water Brake Stable and Unstable Operation.

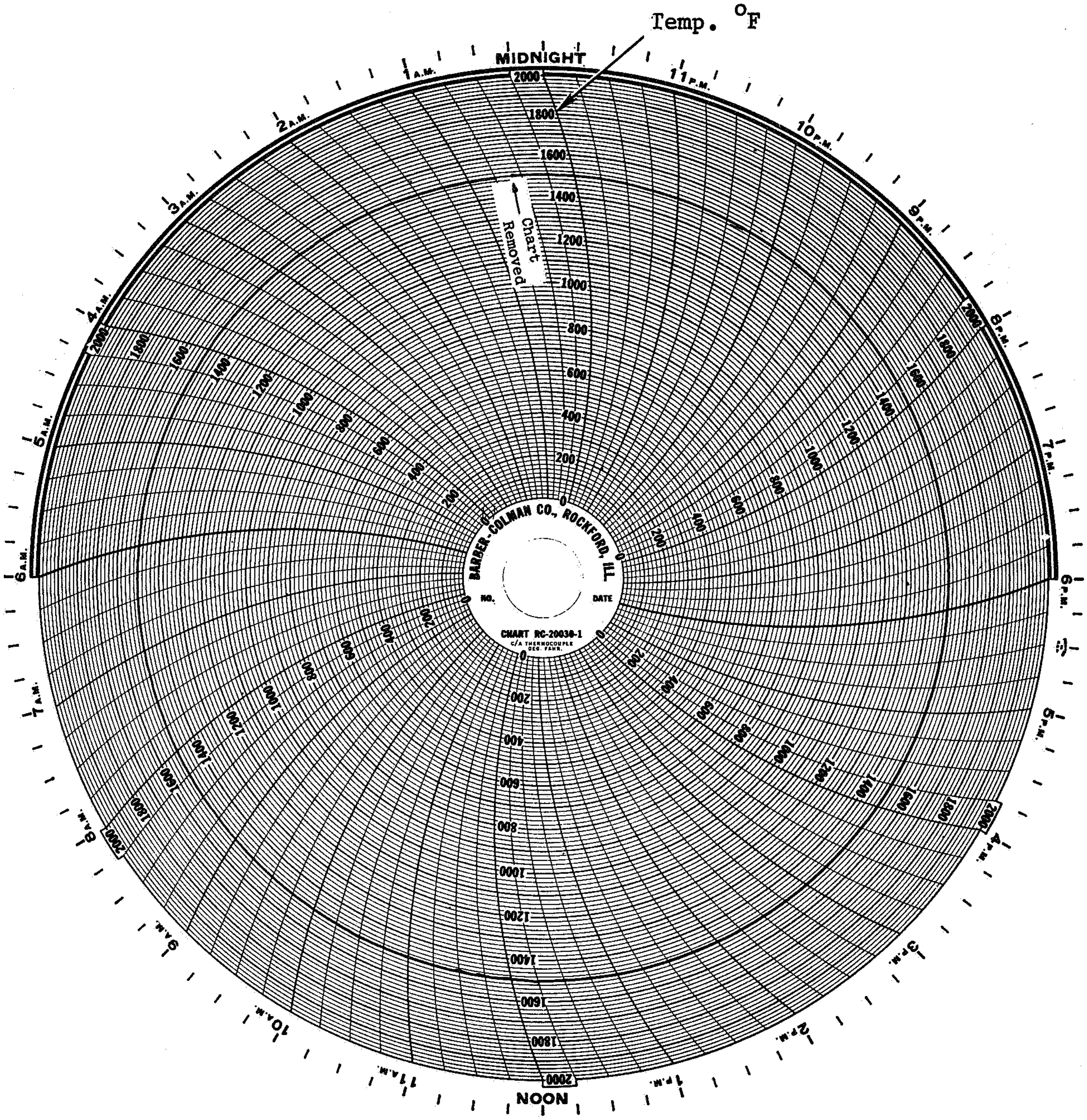
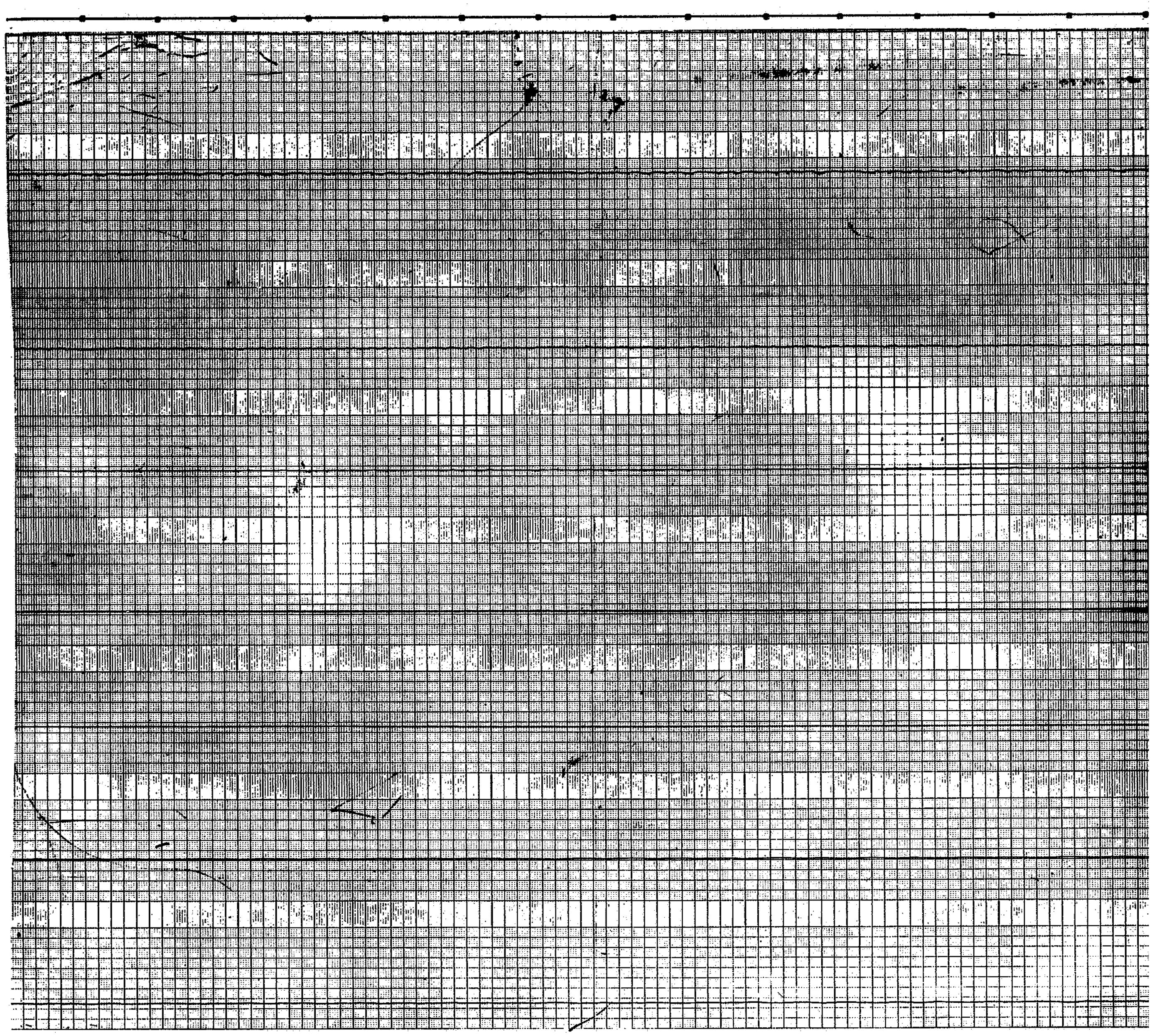


Figure 71. Typical Boiler Discharge Vapor Temperature During 2000 Hour Endurance Test.



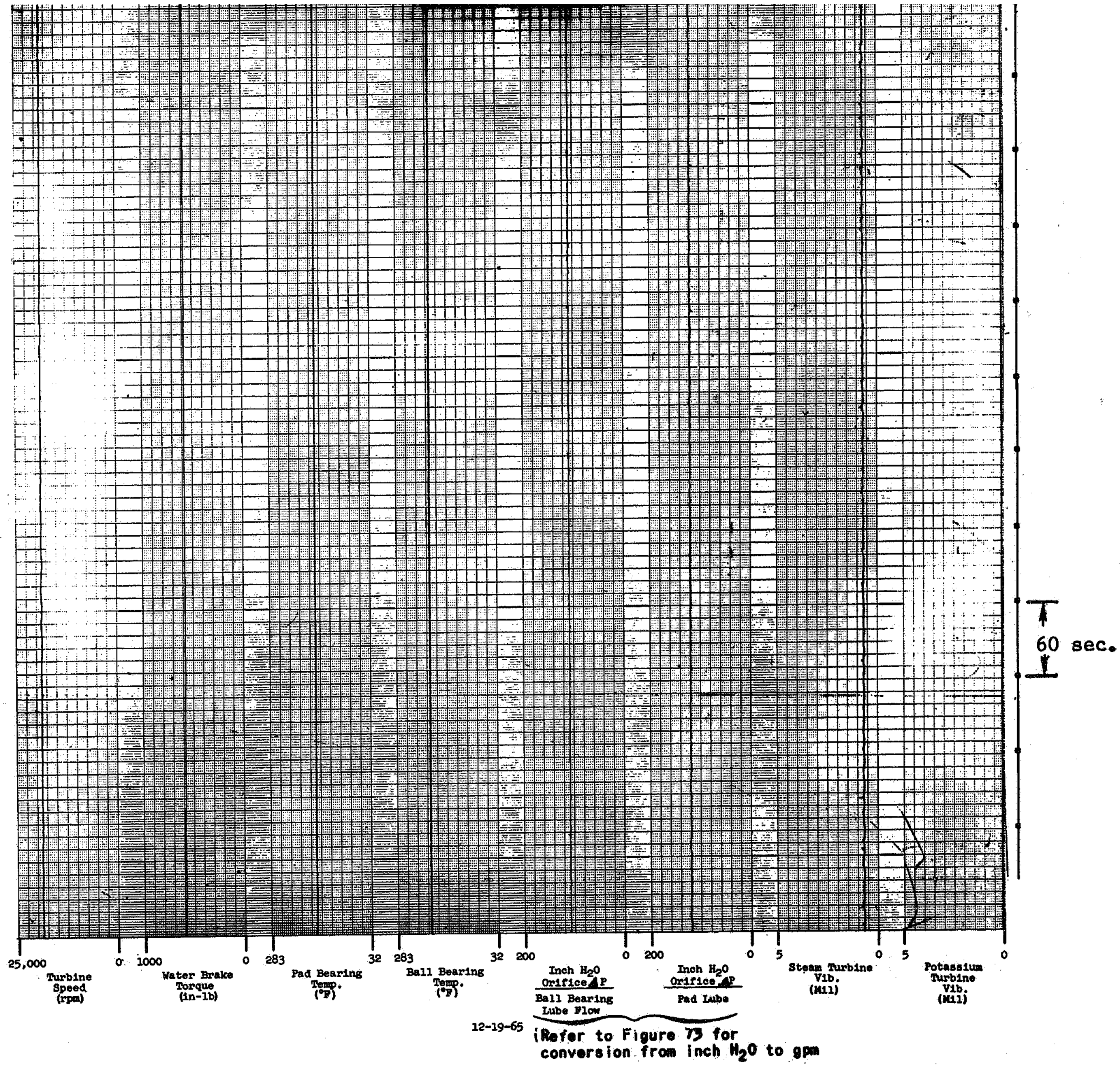


Figure 72. Typical Sanborn Tracing During 2000-Hour Endurance Test (Sanborn A).

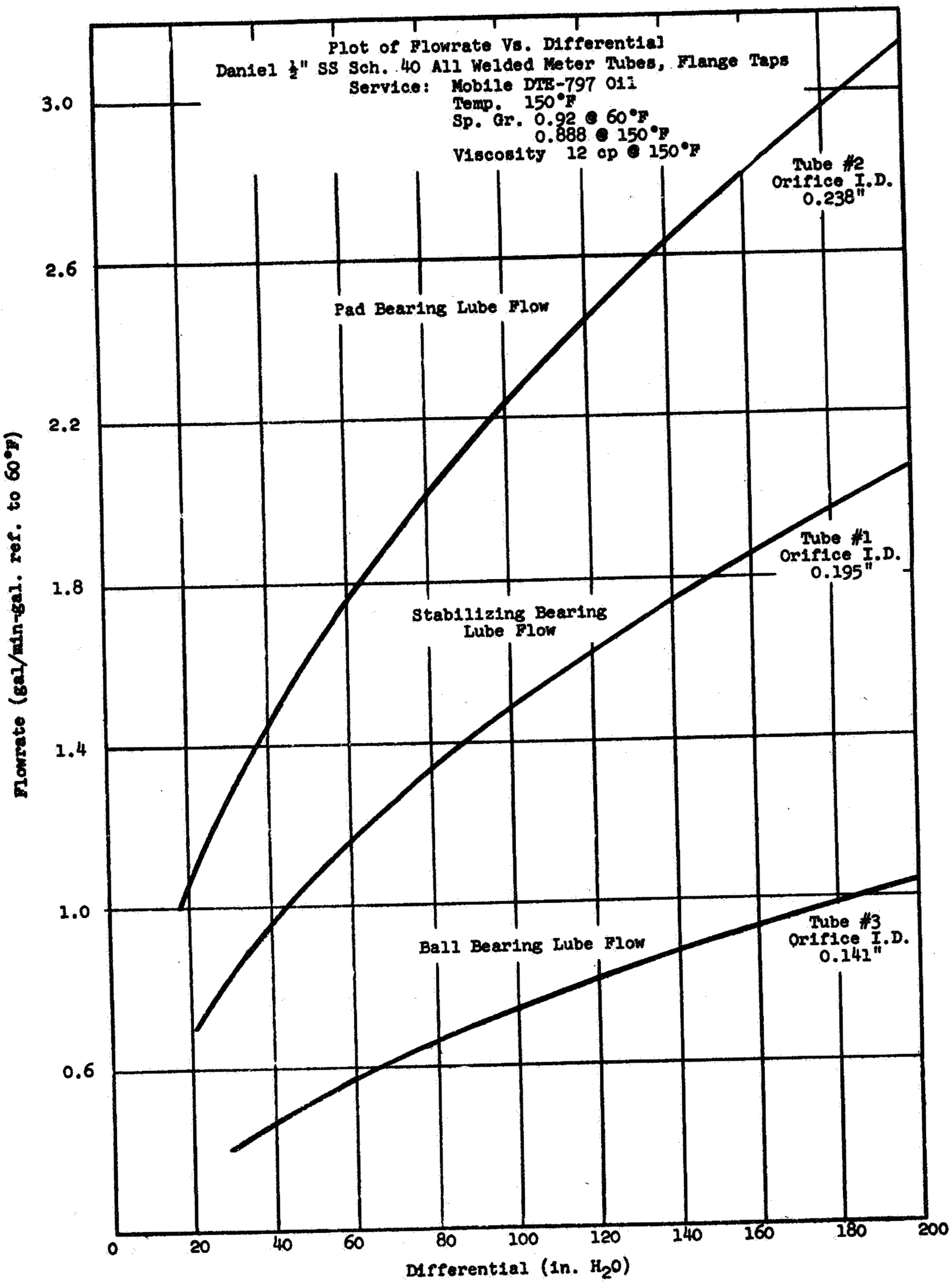
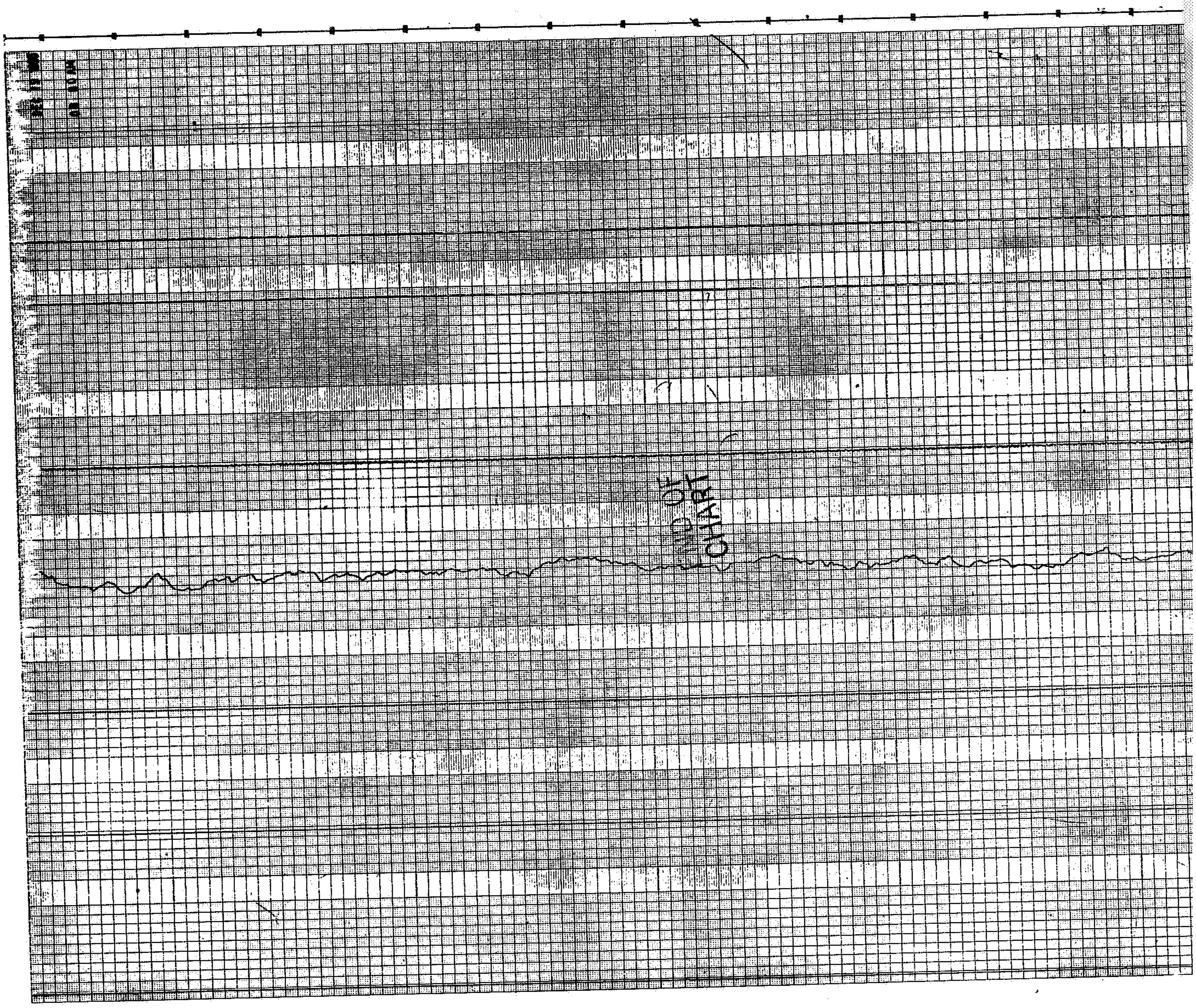


Figure 73. Lube Oil Flowrate.


END OF CHART

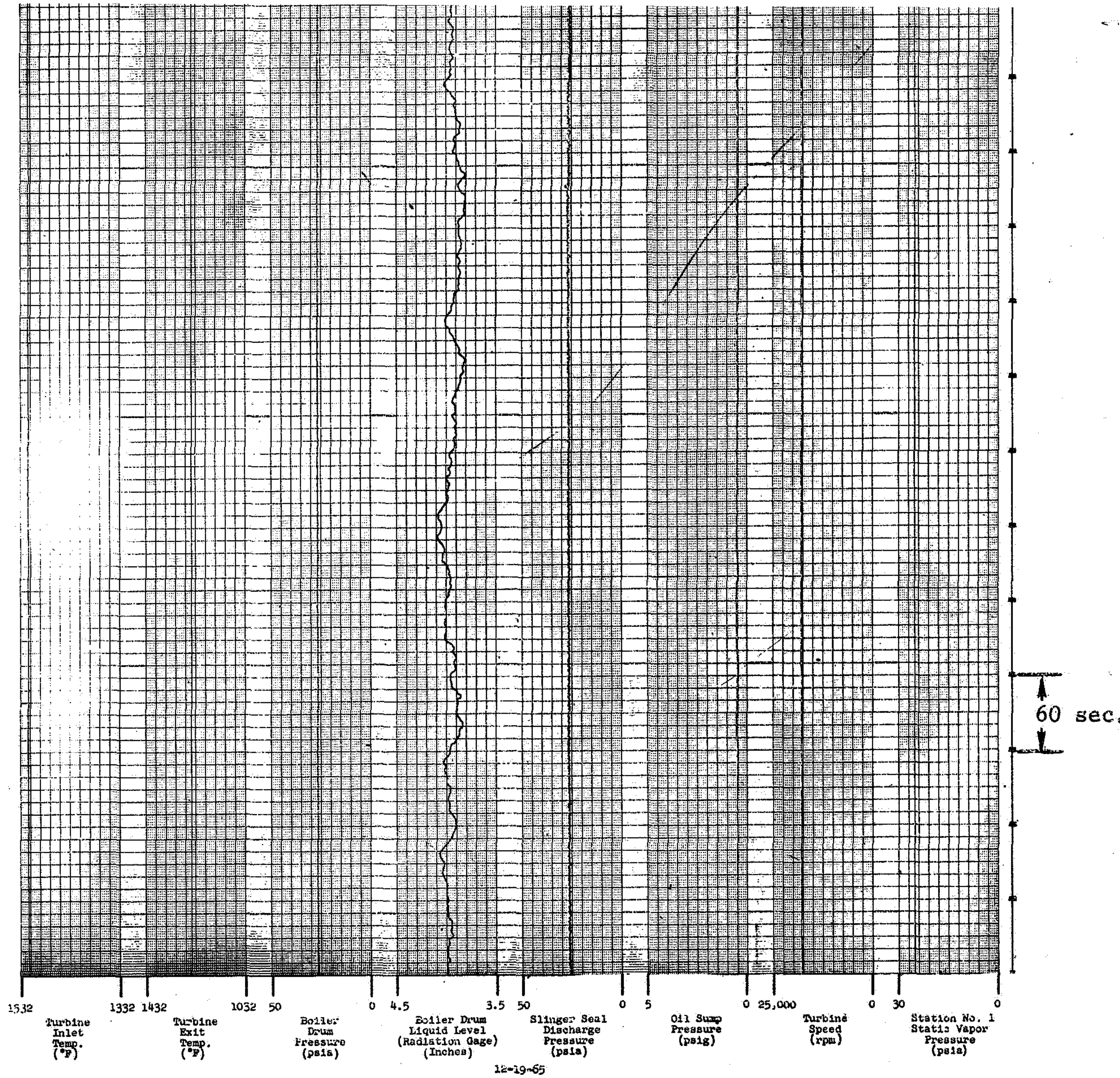
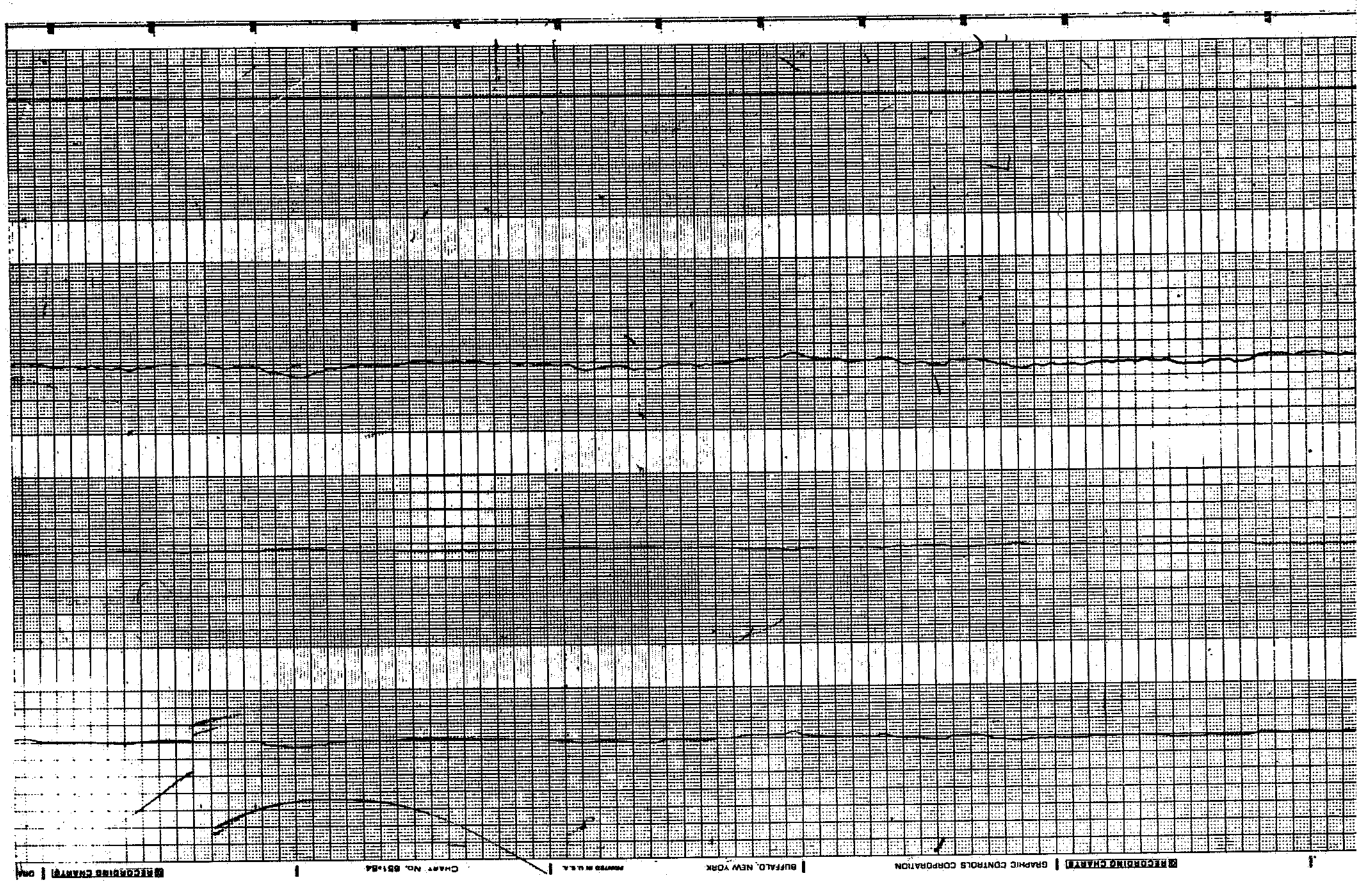


Figure 74. Typical Sanborn Tracing During 2000-Hour Endurance Test (Sanborn B).



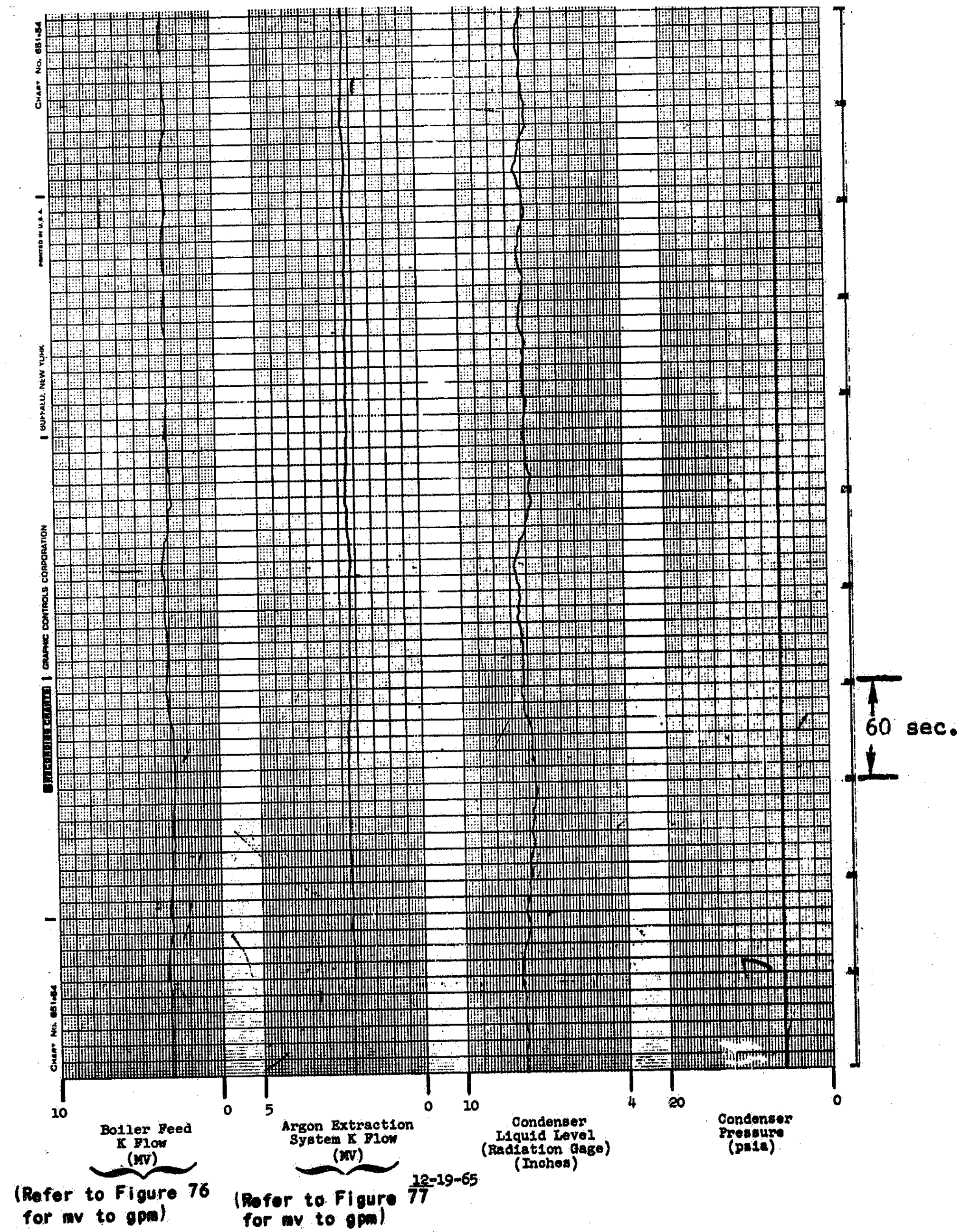


Figure 75. Typical Sanborn Tracing During 2000-Hour Endurance Test (Sanborn C).

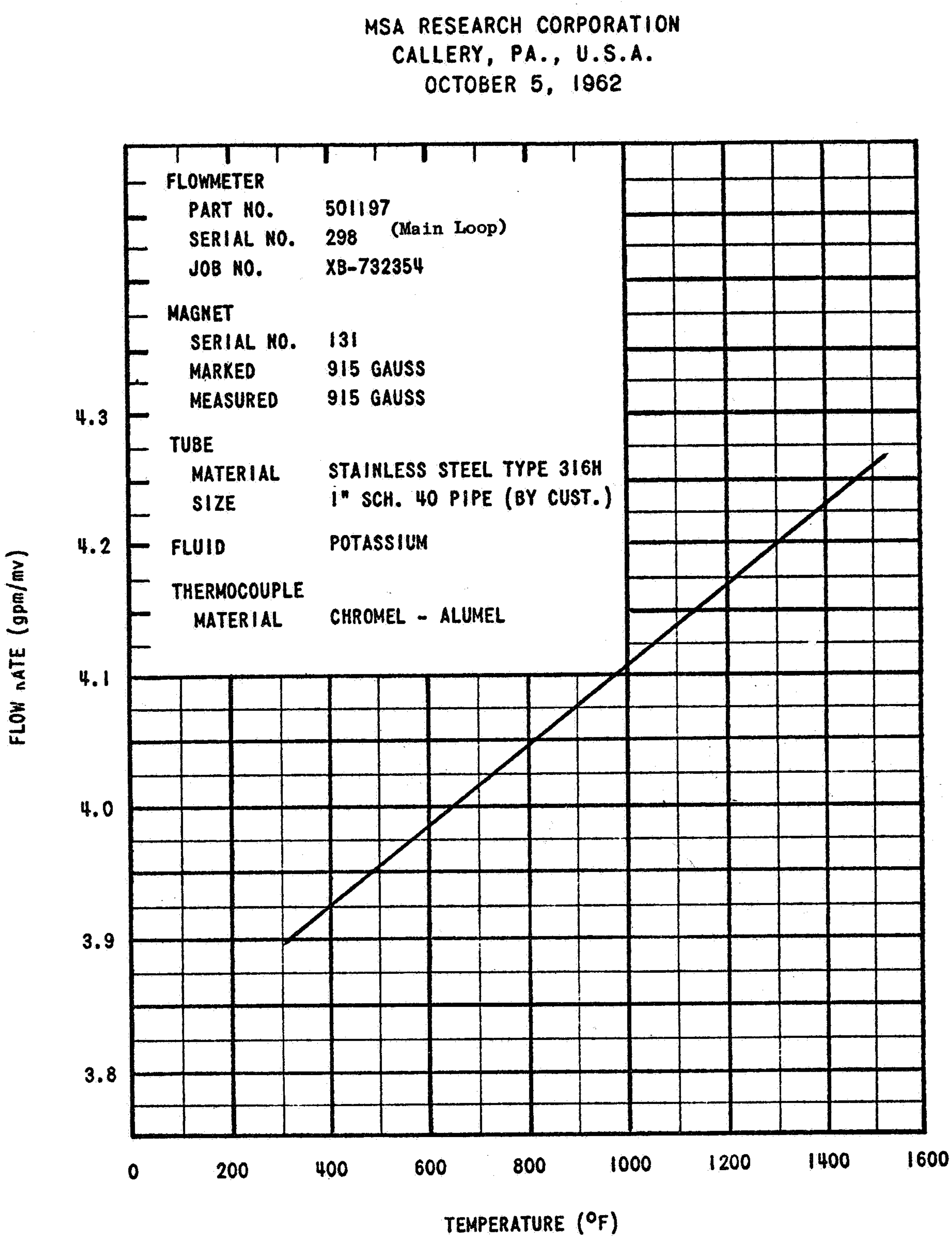


Figure 76. Flowmeter Calibration Curve Main Loop.

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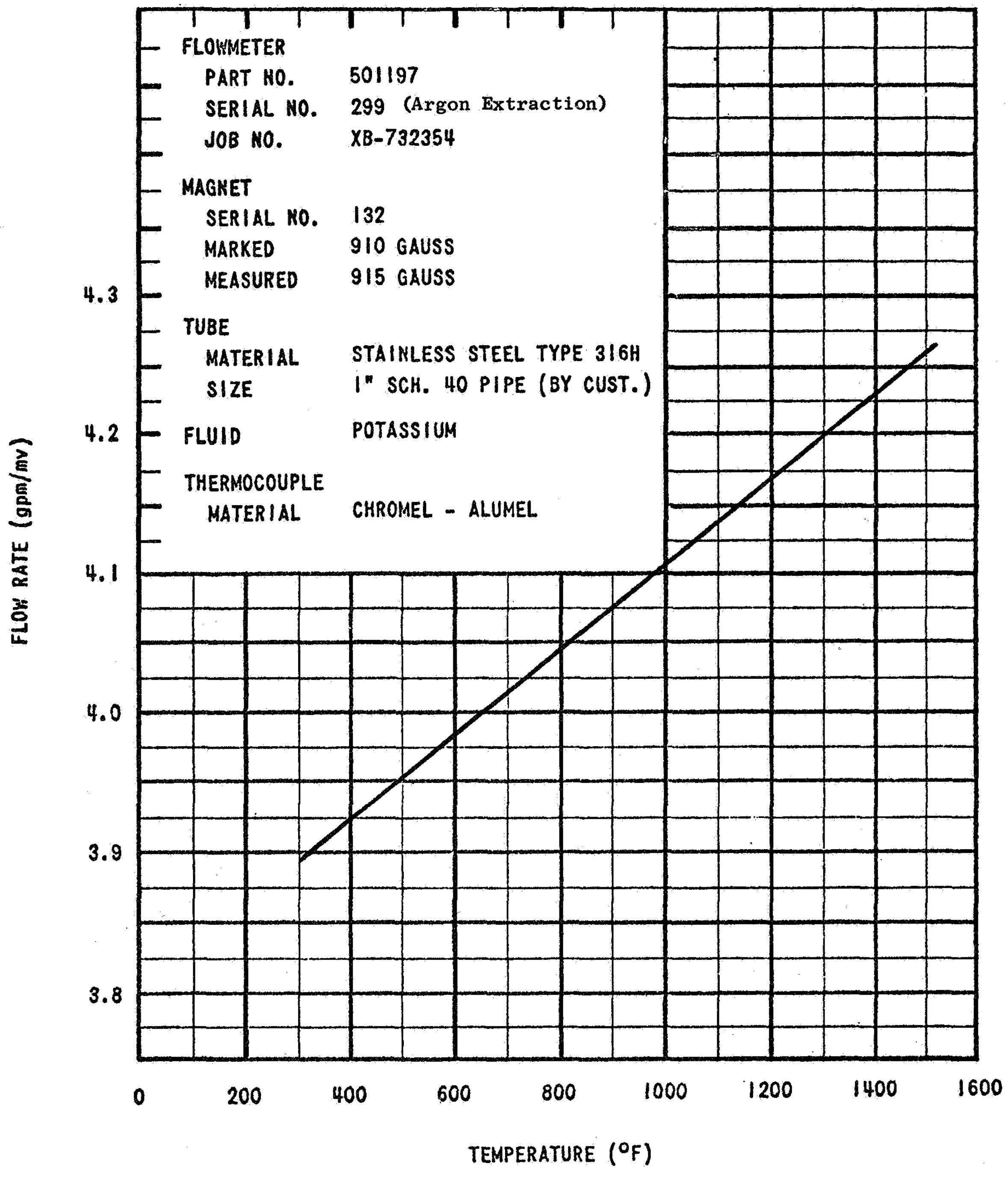

Figure 77. Flowmeter Calibration Curve Argon Extraction Line.

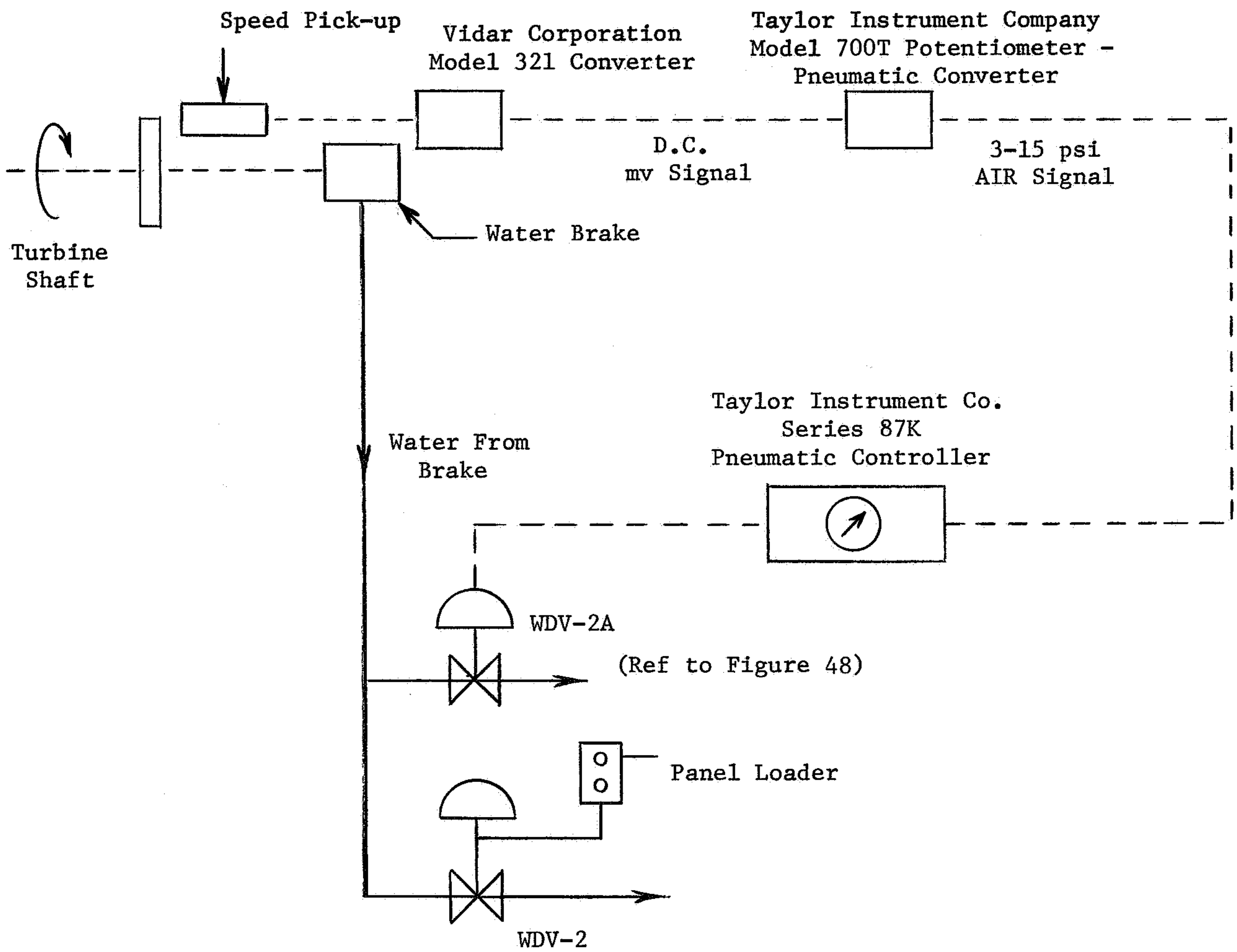

Figure 78. Basic Automatic Speed Control.

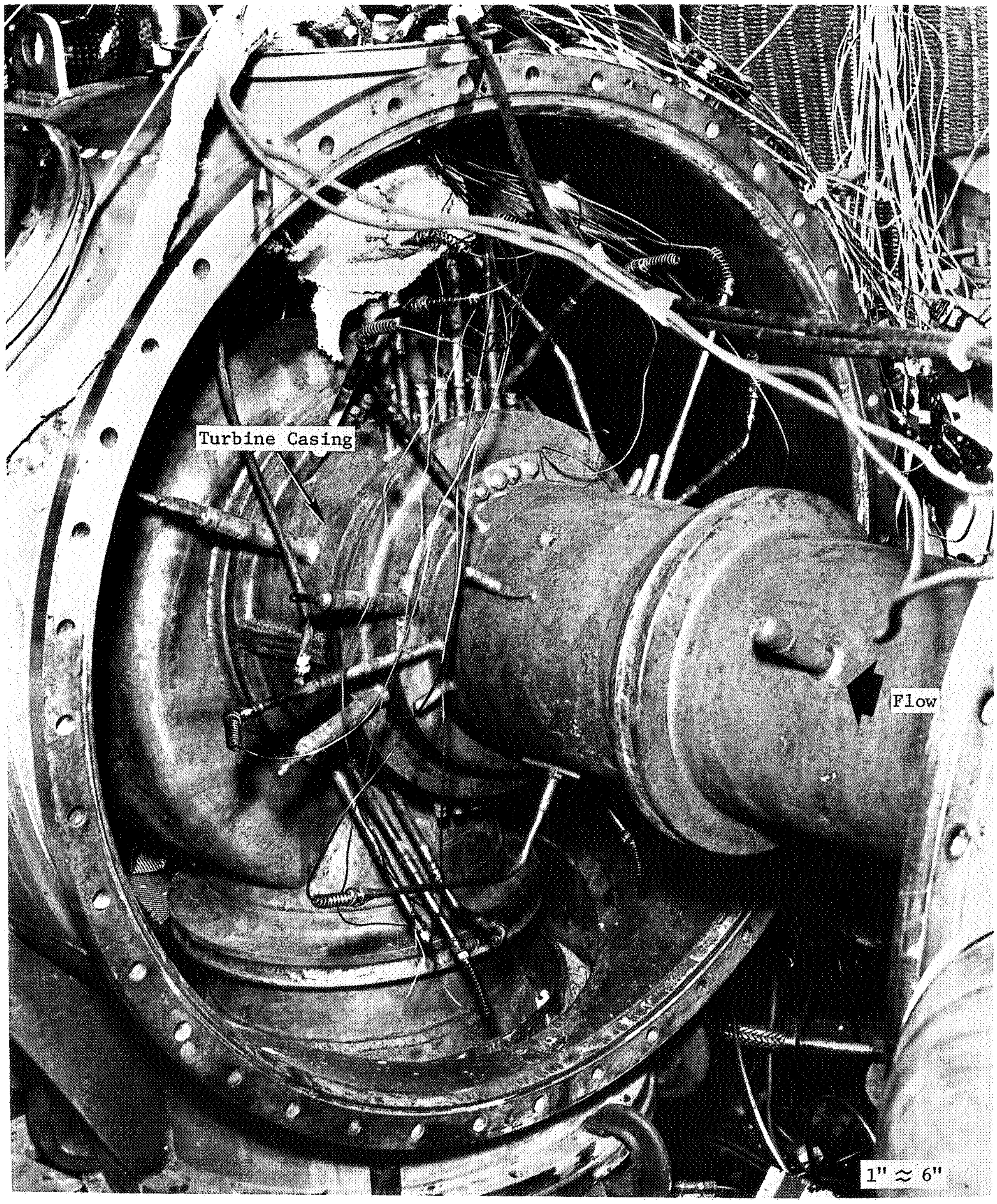

Figure 79. Turbine Casing After 2000 Hours of Operation.

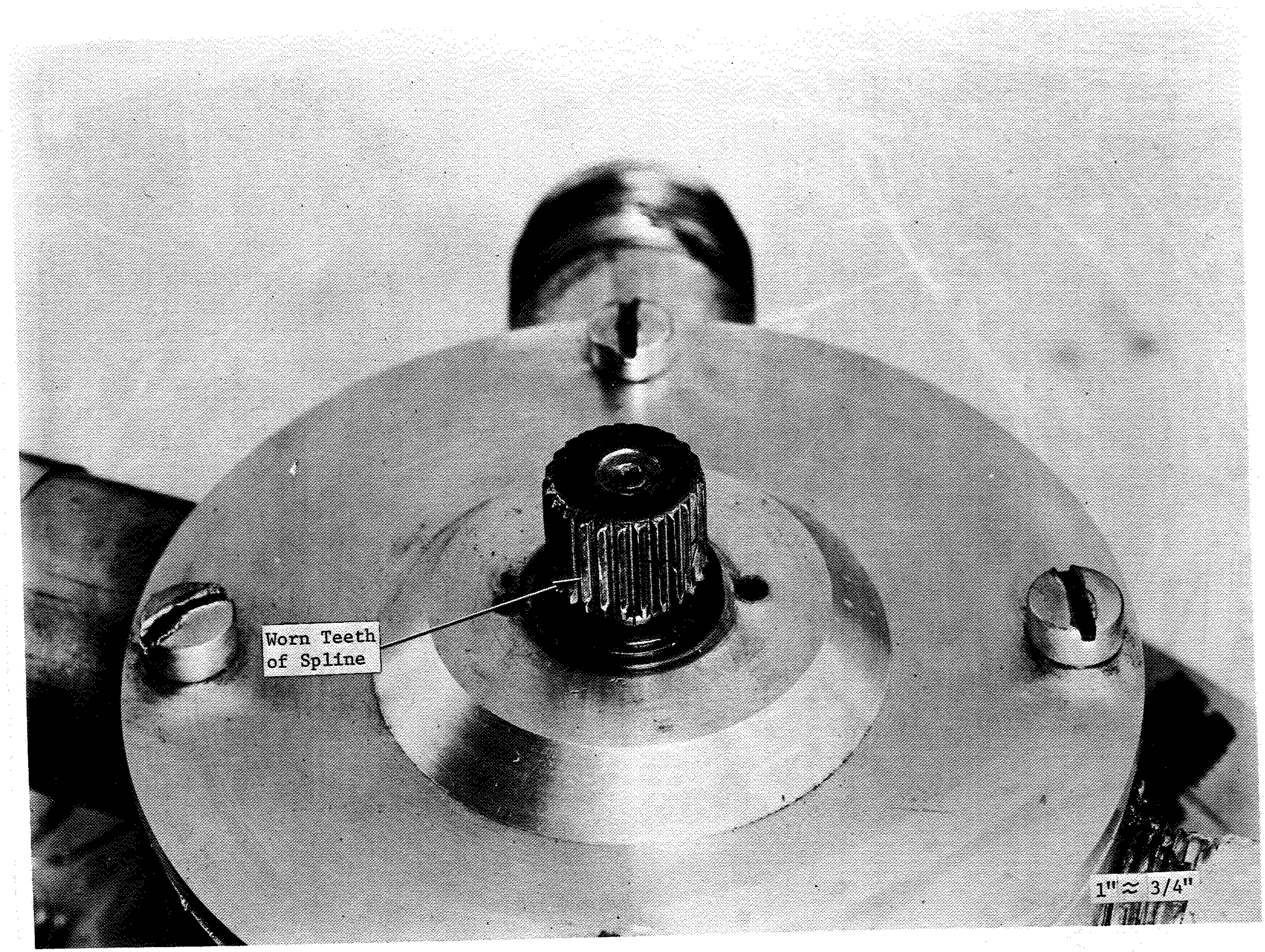

Figure 80. Water Brake Spline After 2000 Hours.

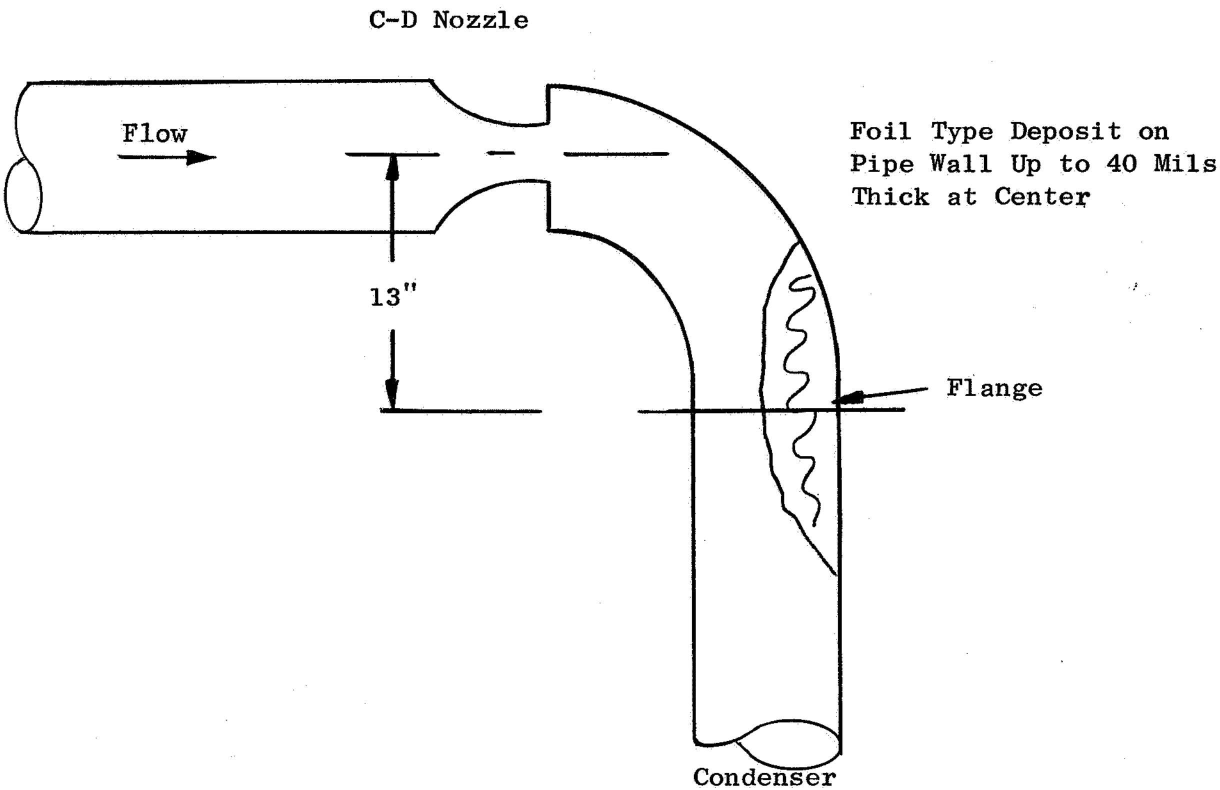

Figure 81. Mass Transfer Deposit in C-D Nozzle.

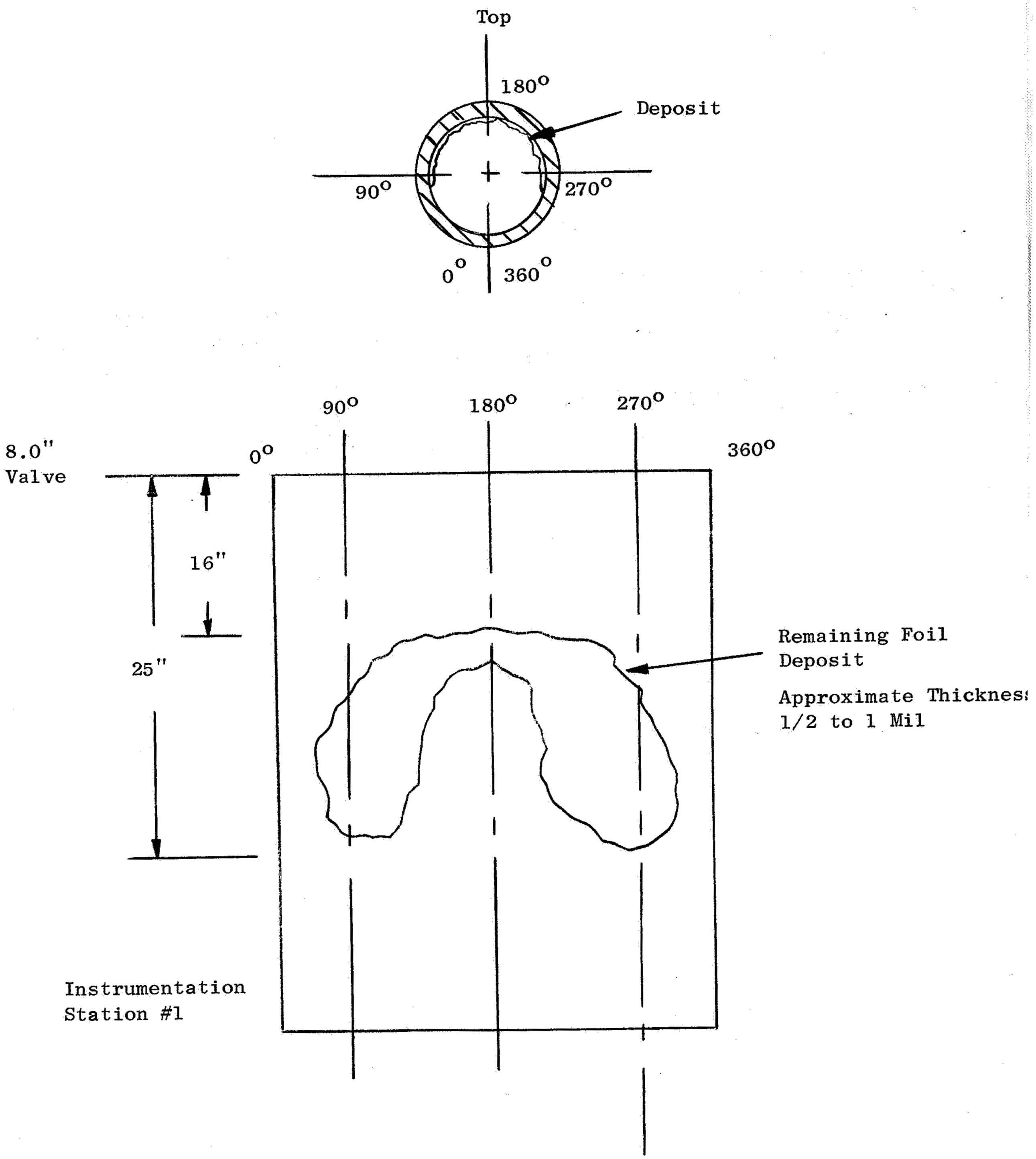

Figure 82. Mass Transfer Deposit Downstream of 8.0" Valve.

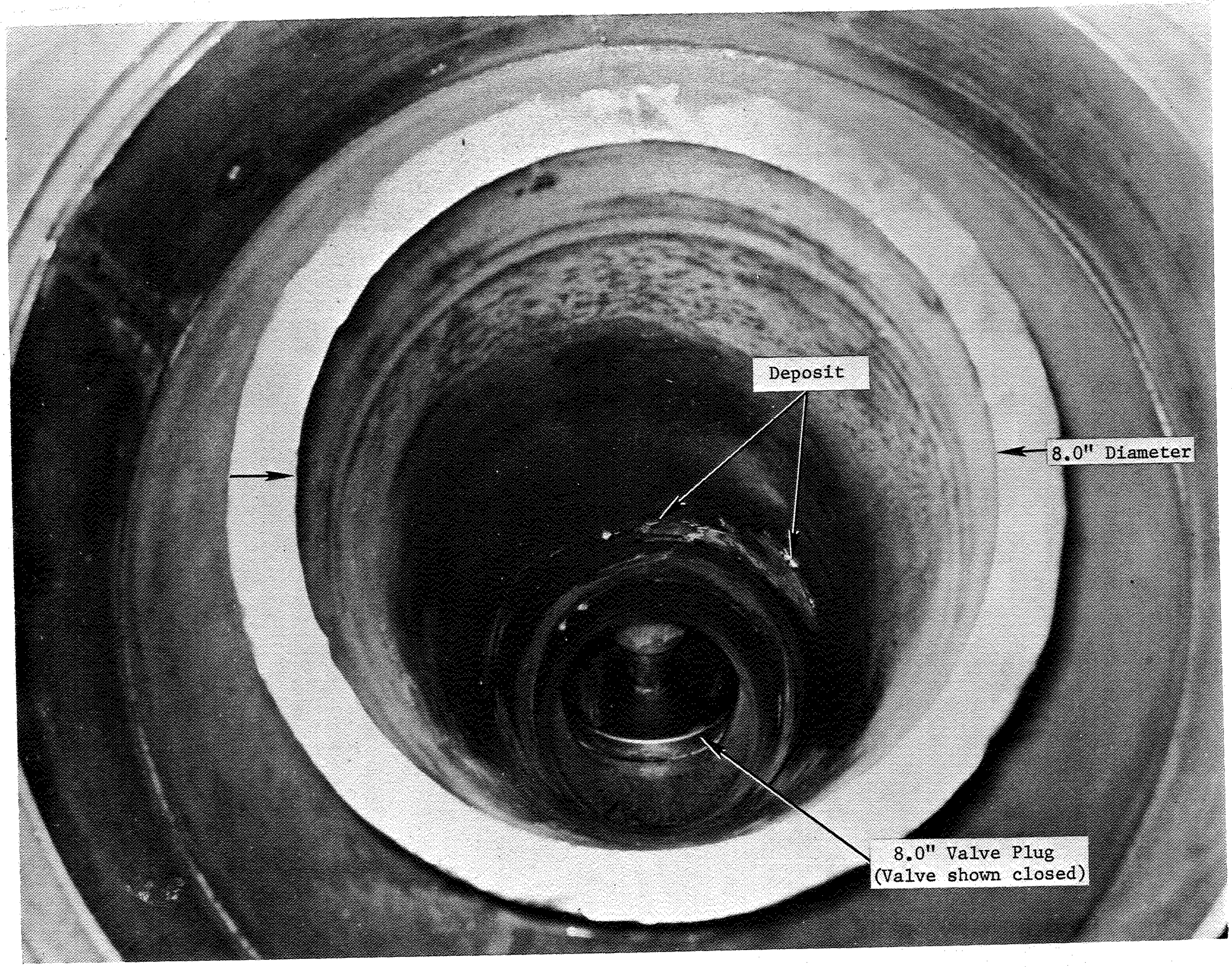

Figure 83. Mass Transfer Deposit Downstream of 8.0" Valve.

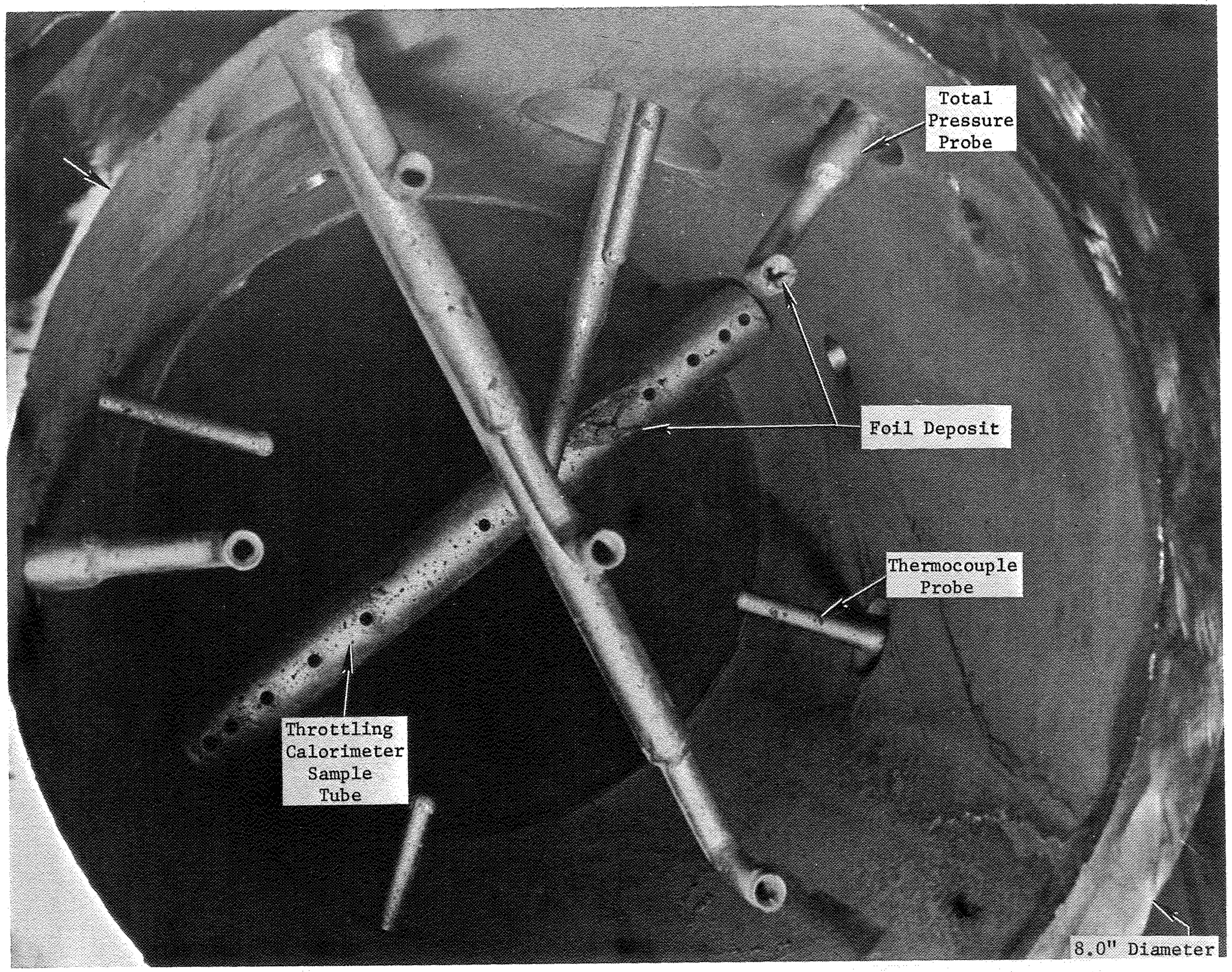

Figure 84. Mass Transfer "Foil" on Throttling Calorimeter Sample Tube.

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