Master

Pump Two-Phase Performance Program
Volume 7: Test Facility Description

NP-1556, Volume 7
Research Project 301

Final Report, September 1980

Work Performed by

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Windsor, Connecticut

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This final report under RP301 documents the findings of an experimental research effort to develop a data base on reactor coolant pump single- and two-phase performance behavior. Tests were performed on a geometrically scaled model of an actual reactor coolant pump. Both steady-state and transient blowdown tests were performed over sufficiently large ranges of thermal-hydraulic operating conditions and typical pump performance parameters to cover calculated hypothetical loss-of-coolant accident (LOCA) conditions.

PROJECT OBJECTIVES

Current analytic pump models used in LOCA analyses are based on a limited amount of experimental data. The goals of this project were (1) to establish a sufficiently large data base of steady-state and transient pump performance data to substantiate, and ultimately improve, analytic pump models currently used for reactor coolant pump LOCA analysis; and (2) to obtain data on pump characteristics under two-phase transient blowdown conditions to aid the evaluation of reactor coolant pump overspeed.

PROJECT RESULTS

The pump data base collected in this project is considered sufficiently large and diverse to cover a significant range of pump performance of primary importance to LOCA analysis. Initial evaluation of the test results indicates that pump rated head and torque degrade significantly under two-phase flow conditions. Pump free-wheeling speed (pump motor power off) is closely coupled to the volumetric flow rate through the pump during a blowdown transient. The maximum free-wheeling speed observed was near twice the rated speed for a discharge break equal to the flow area of the pump. For smaller size discharge breaks, the peak speed observed was less than twice the rated speed. With electric power to the pump drive motor on throughout the blowdown, however, the pump speed was maintained at an almost constant value.

Additional reduction and analysis of this data base is required before it can be used to support the development of an improved analytic model for pump two-phase performance.

This final report consists of eight volumes, as presented in the table of contents in the first volume. Volumes 1, 2, 3, 4, and 7 present the results and conclusions, as well as substantial discussion and description, of the entire project and the test data. Volumes 5 and 6 present the tabulated test data in computer printout and graphic format, which will be useful for further analyses. Volume 8 contains a description of the data processing methods. Volumes 2 through 8 are available from the Research Reports Center* upon request.

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ABSTRACT

The primary objective of the C-E/EPRI Pump Two-Phase Performance Program was to obtain sufficient steady-state and transient two-phase empirical data to substantiate and ultimately improve the reactor coolant pump analytical model currently used for LOCA analysis. A one-fifth scale pump, which geometrically models a reactor coolant pump, was tested in steady-state runs with single- and two-phase mixtures of water and steam over ranges of operating conditions representative of postulated loss-of-coolant accidents. Transient tests were also run to evaluate the applicability of the steady-state-based calculational models to transient conditions.

This project has produced test data which can appropriately be utilized for reactor coolant pump modeling in LOCA analyses. The steady-state test data show general coherence of the test results and overall pump performance trends for a model pump that should be representative of a reactor coolant pump to the extent that scaling laws apply. Both head and torque data correlate well in the form of homologous curves. Two-phase head degradation curves are approximately comparable to head degradation curves obtained in other test programs. Two-phase torque degradation curves have also been developed. The collected data should be useful for analytical model development.

Volume VII: Test Facility Description

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Section 1

INTRODUCTION

This volume describes the test facility in which the 1/5 - scale model of the Palisades reactor coolant pump was tested. The test loop was located in the Kreisinger Development Laboratory (KDL) at Combustion Engineering, Inc., Windsor, Connecticut. This facility was designed to provide single - and two-phase steam water conditions at pressures up to 1200 psi.

In the following sections the test loop and the test pump are described. All instrumentation and the data acquisition systems are presented, as well as loop operating procedures.

Section 2

TEST LOOP

2.1 GENERAL

The loop was designed to meet the objectives of this project, and in the following sub-sections, the test facility requirements and the guidelines for design, fabrication, and operation of the loop are described. The test loop layout is schematically shown in Figure 2-1.

2.2 MAIN LOOP DESCRIPTION

The pump test loop is presented in simplified form, schematically, in Figure 2-1, and isometrically in Figure 2-2. The high pressure (HP) drum is shown in the upper left corner of Figure 2-1. This component provides a convenient starting point for a description of the flow paths through the pump test loop. Water flowed out of the HP drum to the first recirculation pump (PAC 12), then to the second recirculation pump (PAC 16). From here, the water flowed through a water flow control valve (HPW-6 or HPW-7) and entered the mixing tee, where steam from the boilers could be injected. The resulting steam-water mixture then flowed to the test pump, from where the mixture continued through the loop flow control valve (HPSW-1) and returned to the HP drum. Here the steam and water were separated, and the steam could be discharged to the atmosphere through valve HPS-6. The separated water was eventually recirculated through the loop.

The HP drum was fitted with a spray type feed water heater. Make-up from the deaerator entered the drum from the boiler feed pump. Heated boiler feedwater could be extracted at point D and pumped into the test boiler drum with a centrifugal pump (PAC 6).

Steam from the high pressure boiler could be introduced at the mixing tee by opening a valve (HPS-3 or HPS-4). Low-pressure steam from the LP boiler entered the mixing tee through valve HPS-5, when required.

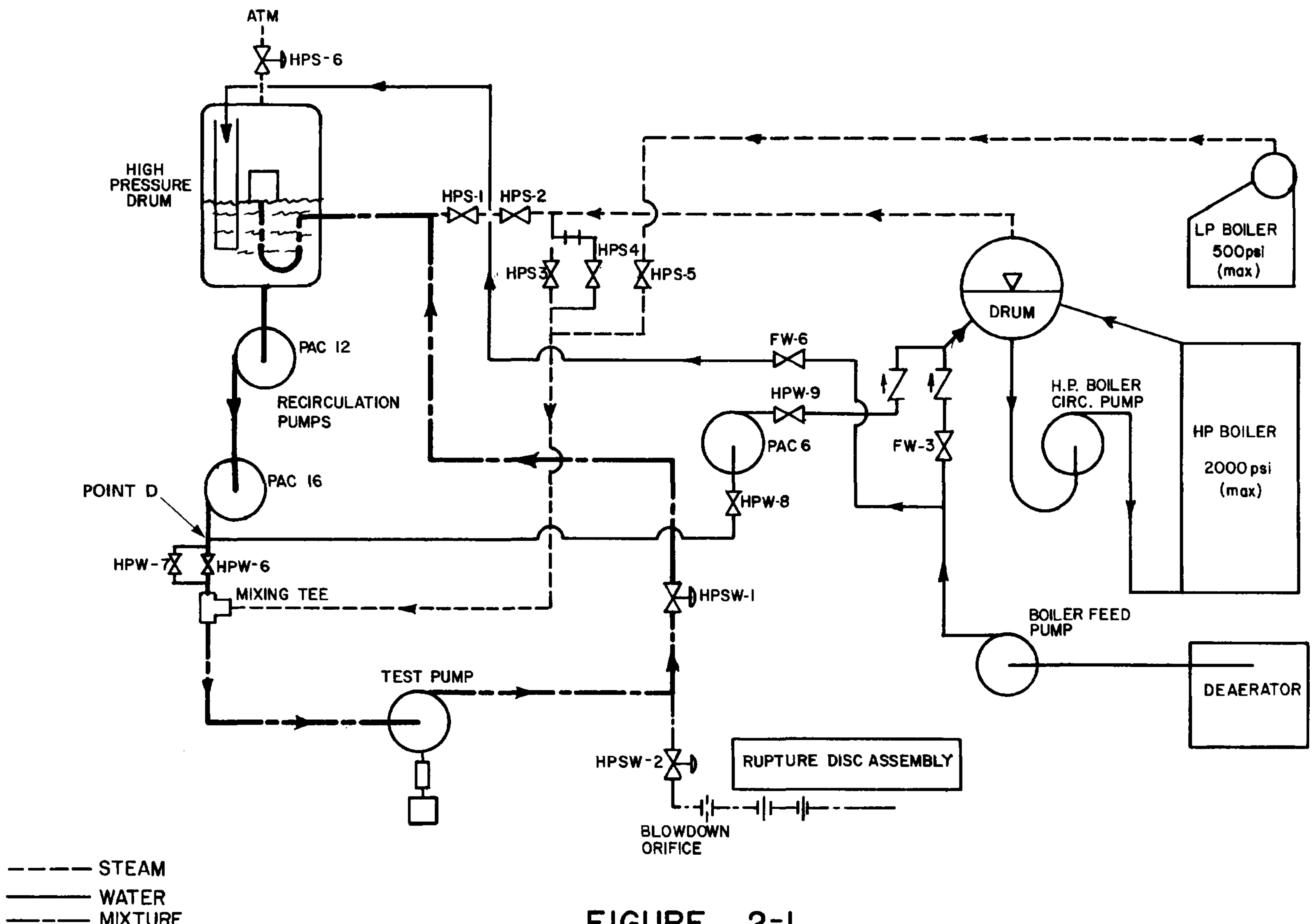

FIGURE 2-1
SCHEMATIC DIAGRAM OF PUMP TEST LOOP

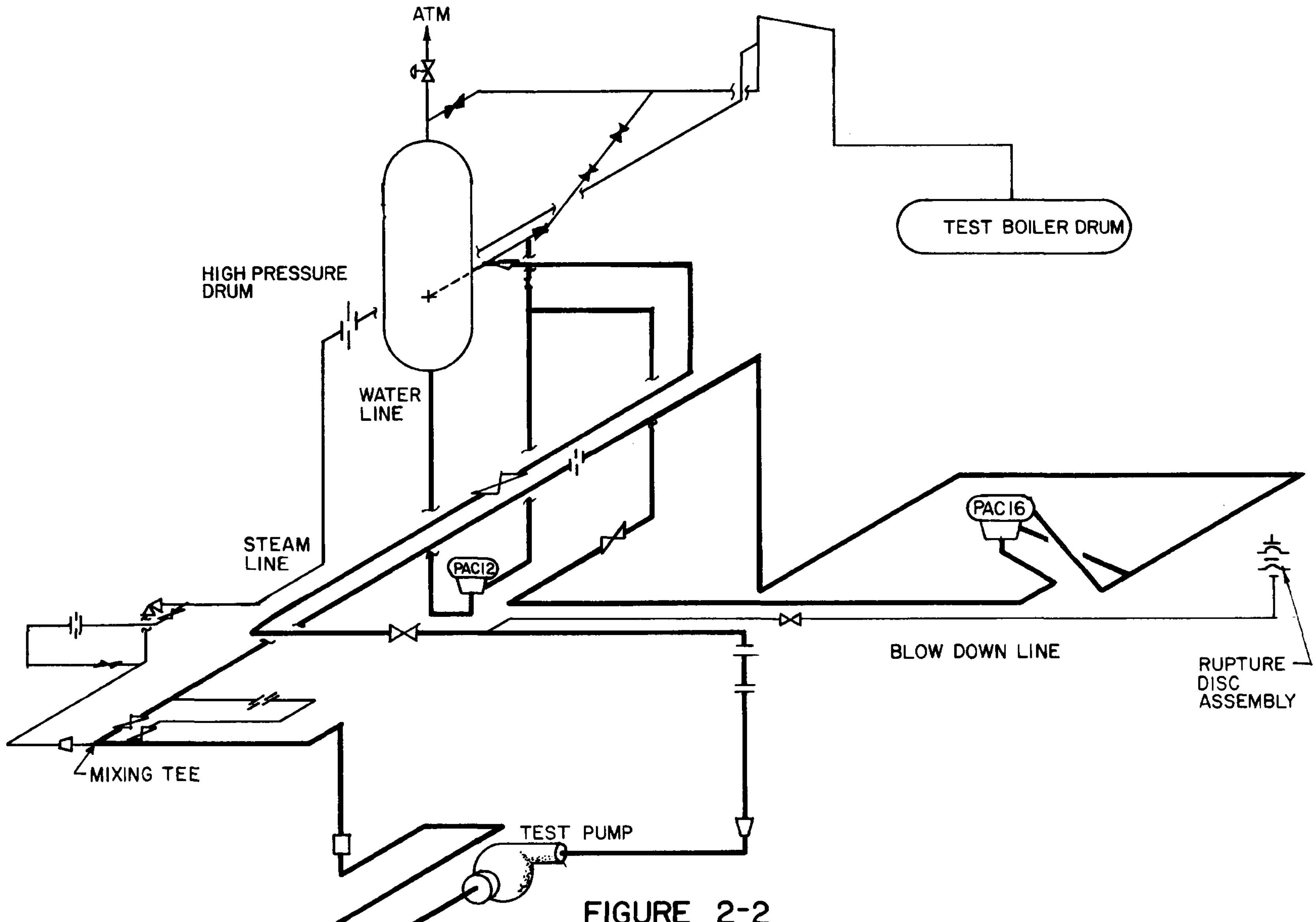

FIGURE 2-2
OBLIQUE DIAGRAM OF PUMP TEST LOOP

The loop was fitted with a rupture disk assembly, which was provided for the purpose of conducting transient blowdown tests.

2.2.1 Piping

The general piping arrangement is shown in Figure 2-3, and Figure 2-4 is an isometric view, showing loop elevations and pipe lengths. The test loop piping was designed in accordance with the ANSI Power Piping Code (Reference 2). All piping material was made of SA-106B, a carbon steel specification, or equivalent. The test loop piping was 12-inch Schedule 120, with the exception of the pump inlet and outlet piping, which was 6-inch Schedule 80, and the feedwater piping, which was 3-inch Schedule 160. The maximum working pressure was 1350 psi, which was governed by the maximum allowable casing pressure of the PAC 6 pump.

The 12-inch piping was selected to minimize friction losses, and thus maximize the head available to the test pump from the two driver pumps. The 6-inch Schedule 80 piping in the vicinity of the test pump was selected as being the closest commercially available size to the test pump 6-inch inlet and outlet nozzle areas. The slight mismatch in inside diameters (6 inches vs. 5.761 inches) was accommodated by a 1° taper on the pump suction and discharge.

The piping, as shown in Figure 2-3, General Piping Arrangement, was supported from steel framing which was attached to the building columns. The support structure for the blowdown piping was located outside the building, and was designed to carry the major thrust of the blowdown reaction force to the ground. The piping inside the building was supported on spring hangers, except in the vicinity of the test pump. Here, stanchions were provided to restrain vertical movement. A weight and thermal expansion analysis was conducted to determine the reactions at the hangers and the test pump. This was accomplished with the aid of a computer program described in Reference 3. The reactions at the pump are tabulated in Table 2-1. Flanged joints were provided for access to orifice plates, and for changing flow direction to the model test pump. As shown in Figure 2-3, the piping was arranged so that certain portions were interchangeable. All flanges were of the 1500-lb class, and had a pressure rating of 2580 psi at 650°F. They were raised face weld neck type, and utilized spiral-wound gaskets.

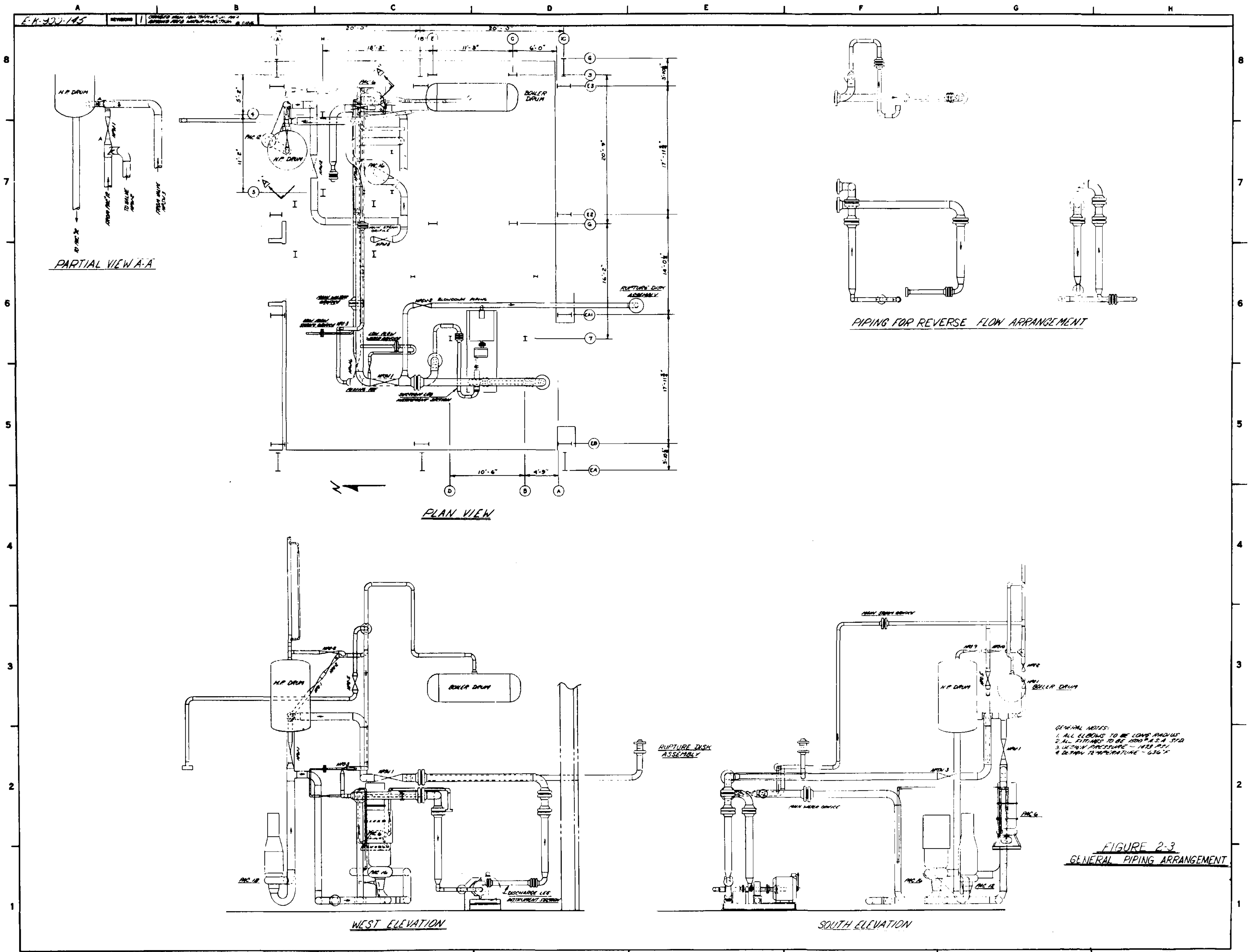

FIGURE 2-3
GENERAL PIPING ARRANGEMENT

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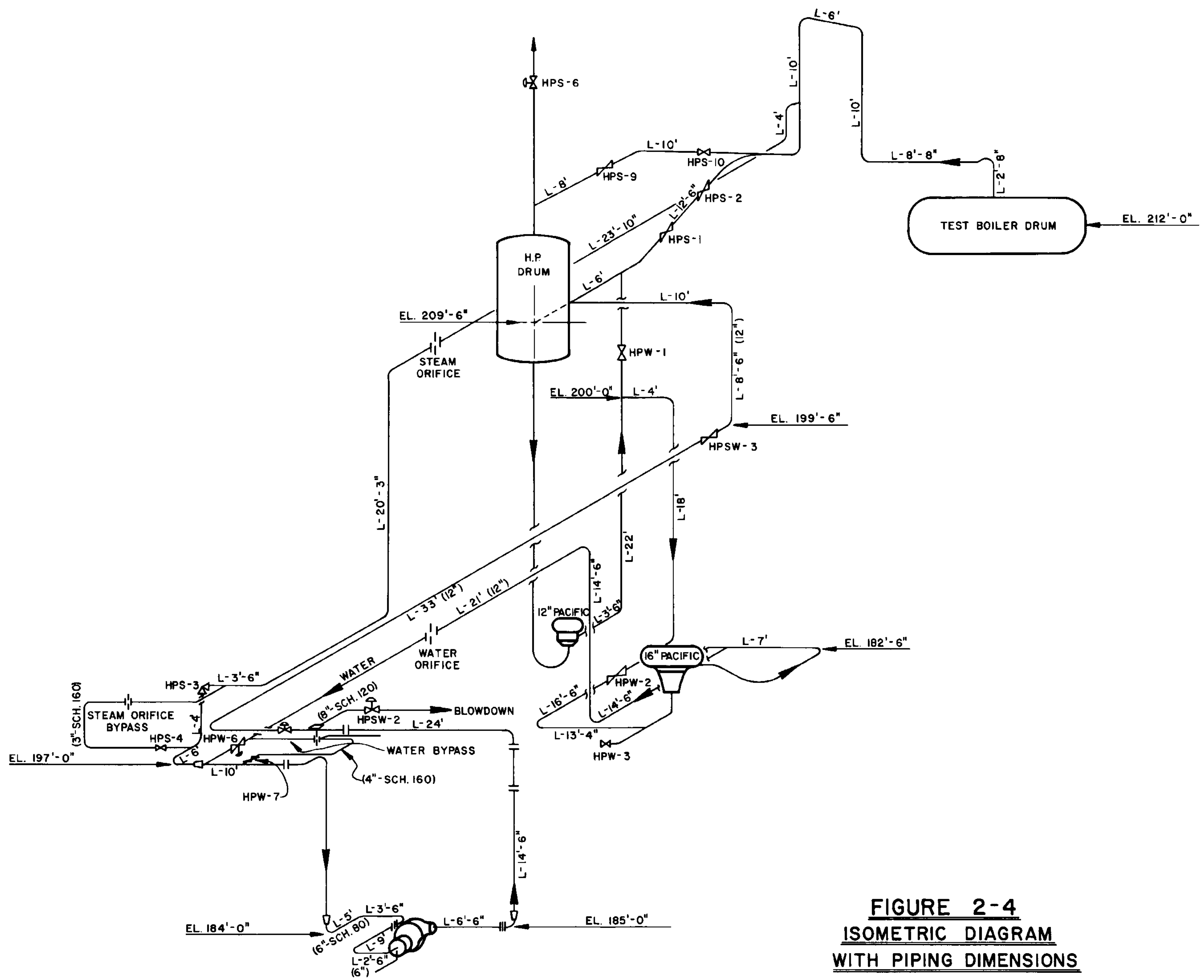

FIGURE 2-4
ISOMETRIC DIAGRAM WITH PIPING DIMENSIONS

NOTES:

1. ALL LENGTHS ARE CENTERLINE TO CENTERLINE OR CENTERLINE TO COMPONENT.
2. FLOOR ELEVATION 181'-0".
3. PIPE AND FITTINGS: 12" SCH 120 AND 6" SCH 80.
4. DO NOT SCALE.

FIGURE 2.4

ISOMETRIC NEW PIPING ARRANGEMENT
PWR RCP TEST FACILITY
PHASE I STEADY STATE TESTS

C-E POWER SYSTEMS
COMBUSTION ENGINEERING, INC.

Scale: NONE
Drawn By: [signature] Date: 3/17/79
Checked By: Date:
Approved By: Date:
Comp. Code:
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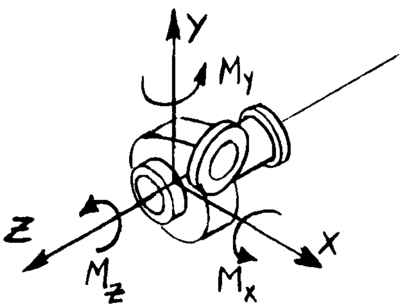

FORCES	MOMENTS
Lbf.	ft-Lbf.
Fx = 2972	Mx = 3431
Fy = 727	My = 21
Fz = 2421	Mz = 266

TABLE 2-1 PIPING REACTIONS AT THE TEST PUMP DUE TO THERMAL EXPANSION

2.2.2 Components

2.2.2.1 Valves. All valves were of the 1500 lb class, and had a pressure rating of 2580 psi at 650°F, and were welded into the piping. Table 2-2 contains a listing of the major test loop valves, giving the manufacturer's name, function and pertinent characteristics. Locations of various valves in the test loop are shown in Figure 2-3 and 2-4. Figure 2-5, Pump Test Loop Piping Diagram, shows valve locations schematically, with the corresponding valve identification code and nomenclature.

2.2.2.2 Pumps. The two driver pumps were boiler recirculation pumps built by Pacific Pumps, Inc. They were hydraulically connected in series, so that their head curves were additive. Head/capacity curves for the individual pumps as shown in Figure 2-6, and combined head/capacity curves are shown in Figure 2-7. The 12-inch Pacific pump (PAC 12) was rated at 4700 gpm with a developed head of 130 feet and was powered by a 200 hp, 440V, 3-phase motor. The 16-inch Pacific pump (PAC 16) was rated at 7000 gpm with a developed head of 160 feet and was powered by a 350 hp, 440V, 3-phase motor. Both pumps required seal injection water. Each pump was equipped with its own oil cooler and oil pump system for bearing lubrication.

A 6-inch Pacific circulating pump (PAC 6) was provided as a feedwater booster pump to return heated feedwater from the loop back to the boiler. This pump was rated at 1600 gpm with a developed head of 112 feet and was powered by a 50 hp, 440V, 3-phase motor.

2.2.2.3 High Pressure Drum. The high pressure drum was a carbon steel vessel, 60 inches inside diameter by approximately 10 feet high, designed for 2000 psi working pressure. Fabrication details are shown in Figure 2-8. Internally, the high pressure drum was fitted with two steam-water separators, a spray type feedwater heater, and a screen covering the downcomer. These items are shown in Figure 2-9.

2.2.2.4 Piping Shock and Sway Suppressors. Hydraulic shock and sway suppressors were installed on the loop piping as shown in Figure 2-10 and 2-11. Figure 2-10 illustrates the locations of the suppressors for forward flow test conditions, and Figure 2-11 illustrates the locations for reverse flow. This figure also

TABLE 2-2

LIST OF MAJOR LOOP VALVES

Note: Valve identification numbers are referenced to Figure 2-5.

Identification No.	Function	Manufacturer	Type-Description
HPSW-1	Test Pump Flow Control, plus fast shut-off in case of emergency, pump trip. Was also used as loop return shut-off to direct flow through test pump during blow-down.	ITT-Hammel-Dahl	12" NPS - 3500 GPM water 1000 PSIG, ΔP = 6 PSI. Air actuator, 3-15 PSI signal piston actuator with Positioner and 3-way solenoid override to stroke in one second.
HPW-1	Shut-off. Normally closed to direct water flow to 16" Pacific. Opened during single phase steam operation to allow water recirculation.	Powell Co.	8" NPS Gate Valve, with manual chain operator.
HPW-2	Shut-off. Normally open.	Powell Co. Figure 11303	12" NPS Gate Valve with gear drive, manual operated.
HPSW-3	Shut-off. Normally open.	Powell Co. Figure 11303	12" NPS Gate Valve with gear drive, manual operated.
HPS-1	Shut-off. Steam line from 2000 psi boiler. Normally closed, except for single-phase water and low void fraction two-phase operation.	Powell Co.	6" Gate Valve with manaul chain operator.

TABLE 2-2

LIST OF MAJOR LOOP VALVES

Note: Valve identification numbers are referenced to Figure 2-5. (Cont'd.)

Identification No.	Function	Manufacturer	Type-Description
HPS-2	Shut-off. Steam line from 2000 psi boiler. Normally closed (see HPS-1).	Powell Co.	6" Gate Valve with manual chain operator.
HPS-6	Loop Pressure Control valve, Controls steam flow from drum to regulate system pressure	ITT-Hammel-Dahl	4" NPS-rated for 70,000 lb/hr. sat. steam at 2000 psi. to atm. with air actuator and positioner.
HPSW-2	Blowdown valve. Normally closed. Used for transient blowdown tests.	ITT-Hammel-Dahl	8" NPS - designed for blowdown from 2000 psi to atm. with full size trim and balance rings. Chrome plated trim. Furnished with quick release to stroke closed in one second.
HPS-3	Shut-off valve. Isolate flow of steam to mix tee.	Edwards	6" angle type manual.
HPW-6	Water flow control - 12" water line to mixing tee.	Powell Co. Figure 11303	12" NPS Gate Valve with gear drive, manually operated.

TABLE 2-2

LIST OF MAJOR LOOP VALVES

Note: Valve identification numbers are referenced to Figure 2-5. (Cont'd.)

Identification No.	Function	Manufacturer	Type-Description
HPW-7	Low range water flow control. Orifice bypass line.	Powell Co.	4" NPS Gate Valve with manual operation.
HPS-4	Shut-off valve. Steam orifice low flow valve.	Conval	4" Y Globe valve with manual operation.
(NONE)	Instrument root valves Normally open. Used to isolate P&ΔP cells from main fluid.	Rockwell-Edwards	1/2" NPS Stop valve Cat. No. 952Y, socket weld, glove, carbon steel body.
(NONE)	Vent valves. Installed on all high spots in piping.	Rockwell-Edwards	1/2" NPS Stop Valve Cat. No. 3676, Socket Weld.
(NONE)	Drain valves. Installed at low spots of draining.	Rockwell-Edwards	1" NPS Stop Valve (globe), socket weld Cat. No. 3624.
(NONE)	Rupture disk assembly. Acts as quick-opening valve.	Black, Sivalls, Bryson Co.	Consists of two rupture disks in a holder. The chamber between the disks can be pressurized so that eack disk is loaded below the burst pressure until actuation by increasing or decreasing intermediate pressure.

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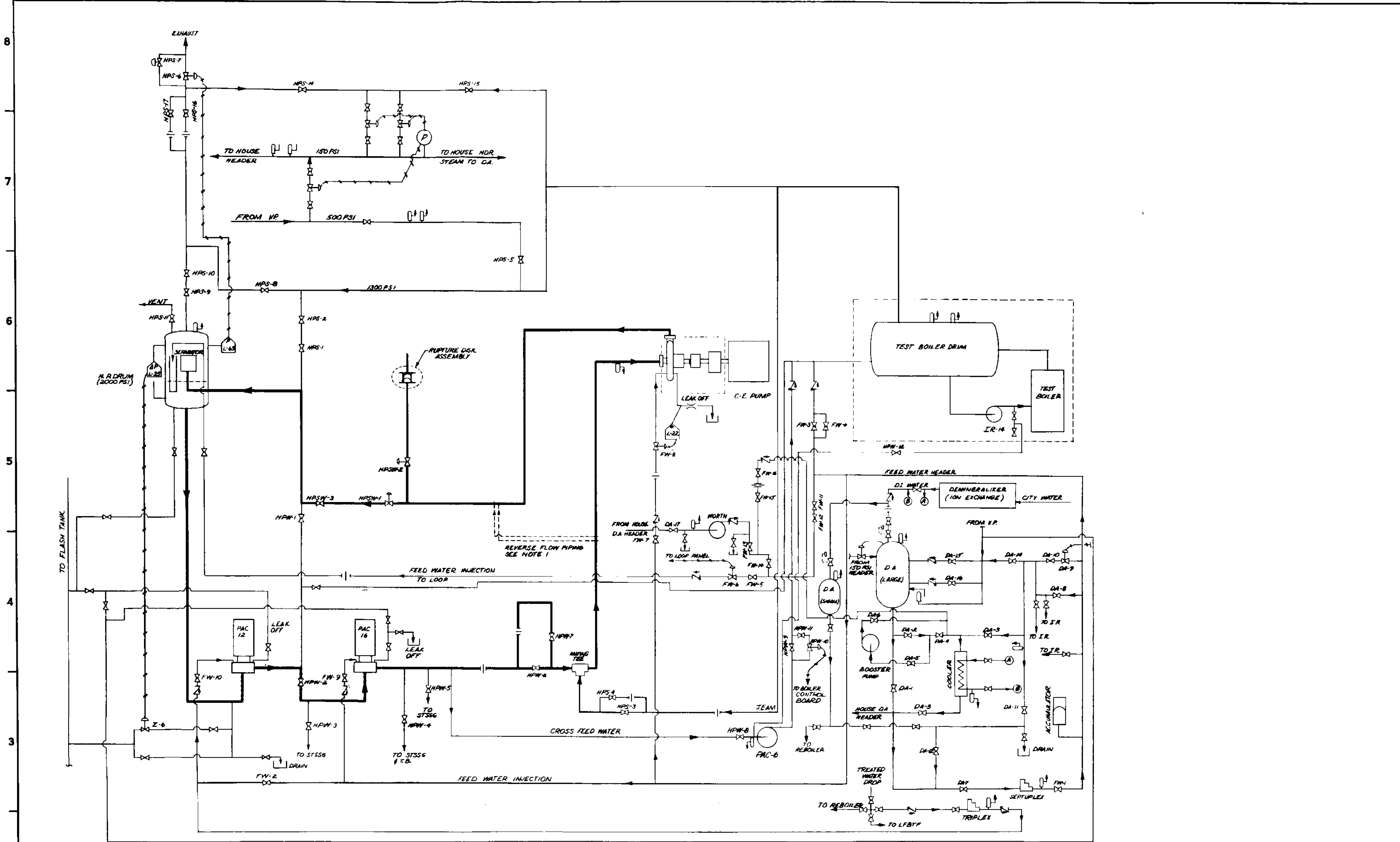


VALVE IDENTIFICATION

VALVE No.	DESCRIPTION
DA-1	COOLER BYPASS VALVE
DA-2	COOLER INLET VALVE
DA-3	COOLER OUTLET VALVE
DA-4	BOOSTER PUMP BYPASS VALVE
DA-5	BOOSTER PUMP INLET VALVE
DA-6	BOOSTER PUMP OUTLET VALVE
DA-7	SEPTUPLEX INLET (SUCTION) VALVE
DA-8	MANUAL DA RETURN
DA-9	PNEUMATIC D.A. RETURN
DA-10	ISOLATION - PNEUMATIC D.A. RETURN
DA-11	RETURN TO SEPTUPLEX SUCTION (IN SERIES W/DA-12)
DA-12	RETURN TO SEPTUPLEX
DA-13	RETURN TO COOLER
DA-14	RETURN TO DA
DA-15	RETURN INTO UPPER PLENUM OF DA
DA-16	RETURN INTO LOWER PLENUM OF DA
DA-17	WORTHINGTON CENTRIFUGAL INLET VALVE

VALVE No.	DESCRIPTION
HPS-1	BOILER DRUM TO H.P. DRUM ISOLATION VALVE
HPS-2	BOILER DRUM TO H.P. DRUM ISOLATION VALVE
HPS-3	MAIN STEAM FLOW VALVE (6" ANGLE VALVE)
HPS-4	STEAM BYPASS VALVE
HPS-5	VP BOILER TO LOOP ISOLATION VALVE (CROSS TIE SYSTEM)
HPS-6	PNEUMATIC VENT FOR TEST BOILER AND LOOP
HPS-7	PNEUMATIC VENT FOR TEST BOILER AND LOOP
HPS-8	TEST BOILER TO VENT ISOLATION VALVE
HPS-9	H.P. DRUM TO VENT ISOLATION VALVE
HPS-10	H.P. DRUM TO VENT ISOLATION VALVE
HPS-11	2" VENT ON TOP OF H.P. DRUM
HPS-14	LOOP STEAM TO HOUSE HEADER
HPS-15	BOILER STEAM TO HOUSE HEADER
HPS-16	MAIN MANUAL VENT VALVES
HPS-17	BYPASS MANUAL VENT VALVES

VALVE No.	DESCRIPTION
HPW-1	DRUM INTERNAL ISOLATION VALVE
HPW-2	LOOP ISOLATION VALVE
HPW-3	STSS6 ISOLATION VALVE
HPW-4	STSS6 ISOLATION VALVE
HPW-5	STSS6 ISOLATION VALVE
HPW-6	MAIN WATER FLOW CONTROL VALVE
HPW-7	BYPASS WATER FLOW CONTROL VALVE
HPW-8	PAC 6 SUCTION VALVE
HPW-9	PAC 6 MAIN FLOW CONTROL VALVE
HPW-10	PAC 6 PNEUMATIC BYPASS CONTROL VALVE
HPW-11	PAC 6 MANUAL BYPASS SHUT-OFF VALVE
HPW-12	PAC 6 BLOWDOWN CIRCULATION VALVE

VALVE No.	DESCRIPTION
FW-1	SEPTUPLEX OUTLET VALVE
FW-2	TRIPLEX OUTLET VALVE (LOCATED AT MEZZANINE LEVEL)
FW-3	LARGE BOILER FEED VALVE
FW-4	SMALL BOILER FEED VALVE
FW-5	MANUAL LOOP FEEDWATER VALVE
FW-6	PNEUMATIC LOOP FEEDWATER VALVE
FW-7	TEST PUMP INJECTION MANUAL SHUT-OFF
FW-8	TEST PUMP INJECTION CONTROL VALVE
FW-9	PAC-16 SEAL INJECTION VALVE
FW-10	PAC-12 SEAL INJECTION VALVE
FW-11	SEPTUPLEX LOOP FEEDWATER VALVE
FW-12	SEPTUPLEX LOOP FEEDWATER VALVE
FW-13	WORTHINGTON CENTRIFUGAL OUTLET VALVE
FW-14	WORTHINGTON CENTRIFUGAL LOOP FEEDWATER VALVE
FW-15	WORTHINGTON CENTRIFUGAL OUTLET BYPASS
FW-16	WORTHINGTON CENTRIFUGAL OUTLET BYPASS

VALVE No.	DESCRIPTION
HPSW-1	TPPP LOOP FLOW CONTROL VALVE
HPSW-2	TPPP BLOWDOWN VALVE
HPSW-3	TPPP ISOLATION VALVE

NOTES:

1) FOR REVERSE FLOW TESTING, PIPING SWITCH IS MADE AS INDICATED

2) DIFFERENTIAL PRESSURE CELLS ARE INSTALLED SO THAT A PRESSURE RISE IN POSITIVE FLOW DIRECTION, AS INDICATED BY THE ARROWS IS DEFINED AS POSITIVE. FOR REVERSE FLOW TESTING, THE DIFFERENTIAL PRESSURE CELL AT LOCATION L-61 IS REVERSED

FIGURE 2-5

PIPING DIAGRAM

CE / EPRI PUMP TEST FACILITY

C-E POWER SYSTEMS
COMBUSTION ENGINEERING INC

Scale: N/A

Drawn By: [signature] Date: 9-20-78

Checked By: [signature] Date: 9-20-78

Approved By: [signature] Date: 9-20-78

Drawing No.: E-K-900145-53 Rev.: 0

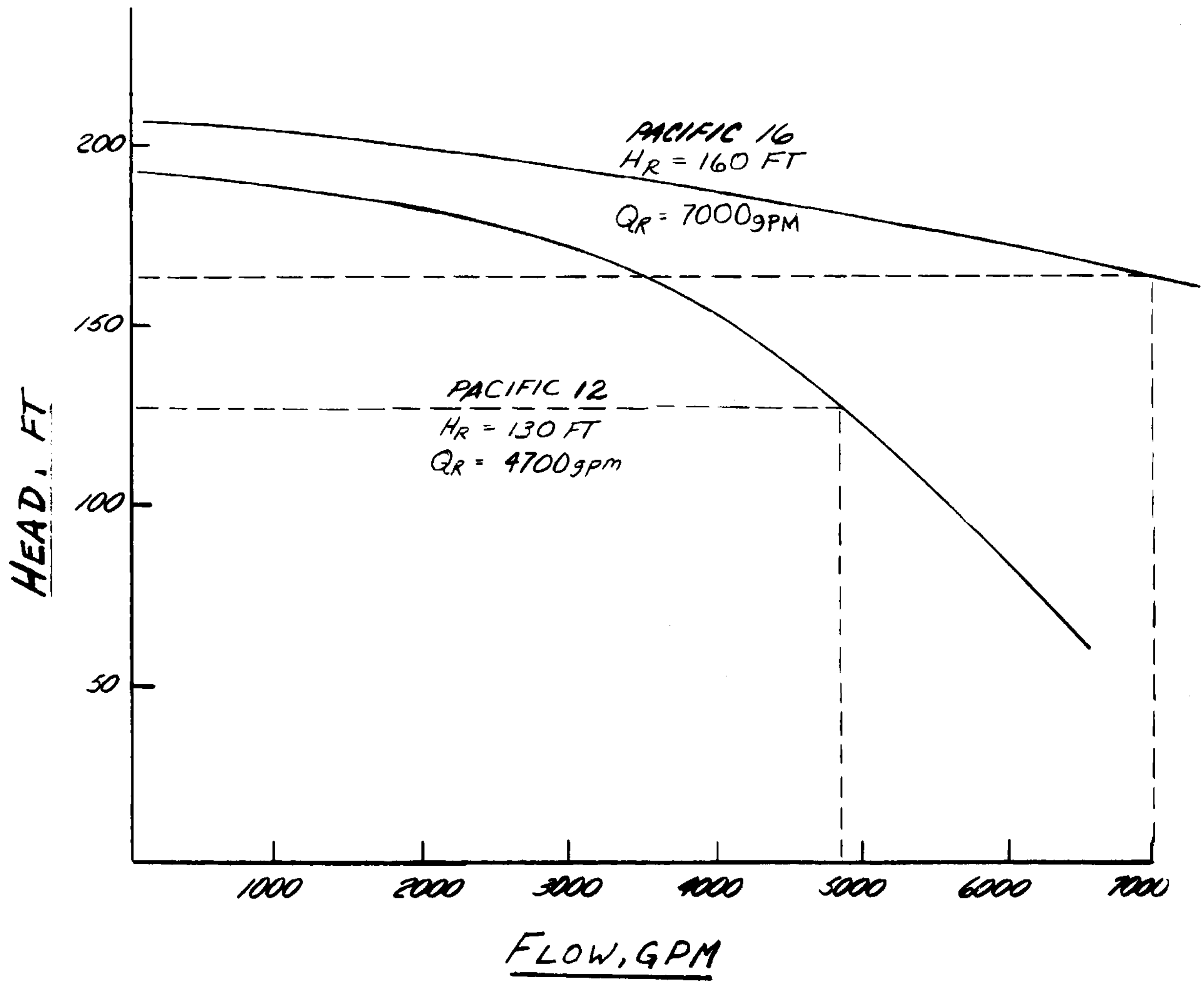


FIGURE 2-6 PERFORMANCE CURVES FOR PAC 12 & PAC 16 RECIRCULATING PUMPS

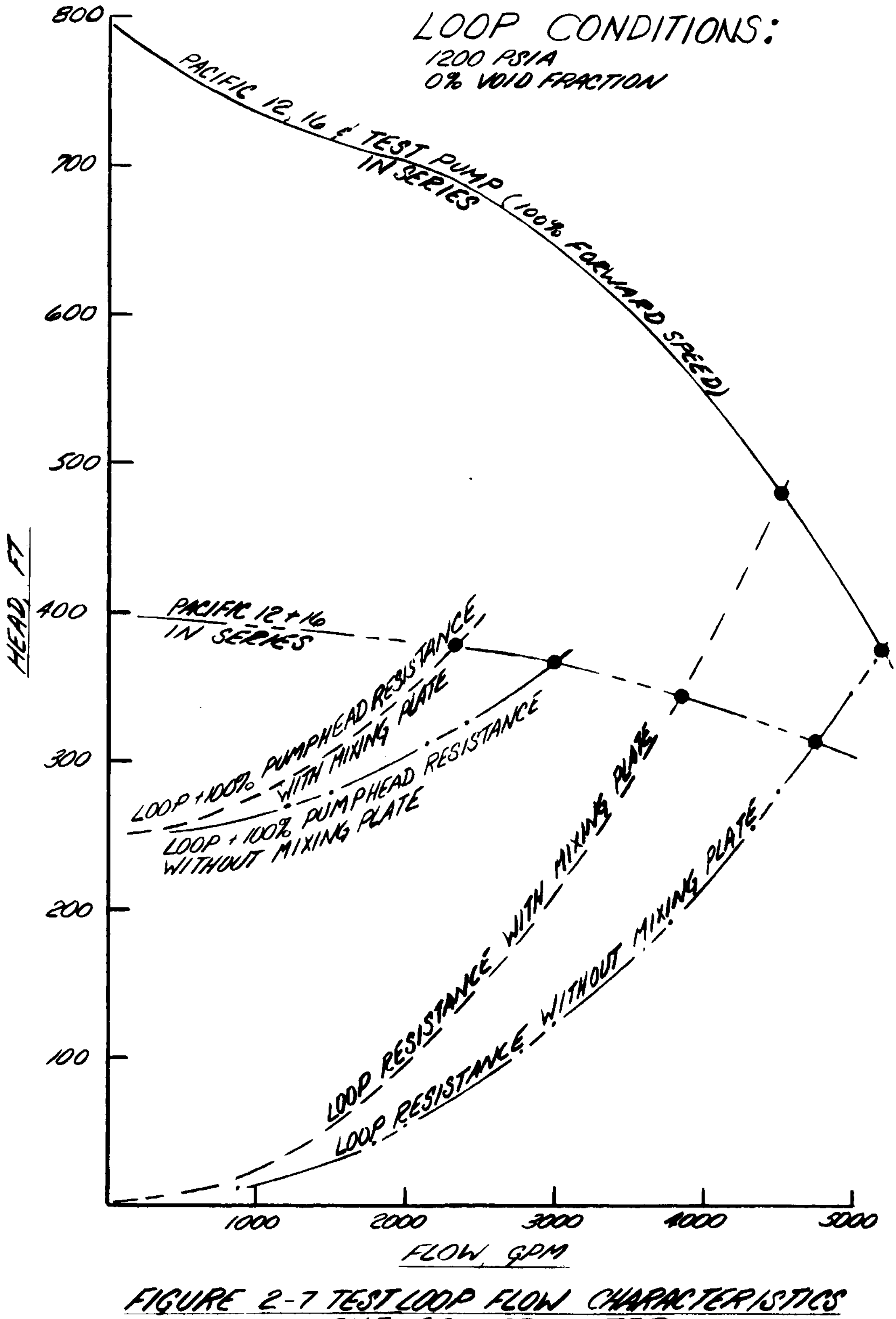


FIGURE 2-7 TEST LOOP FLOW CHARACTERISTICS
SUB-COOLED WATER

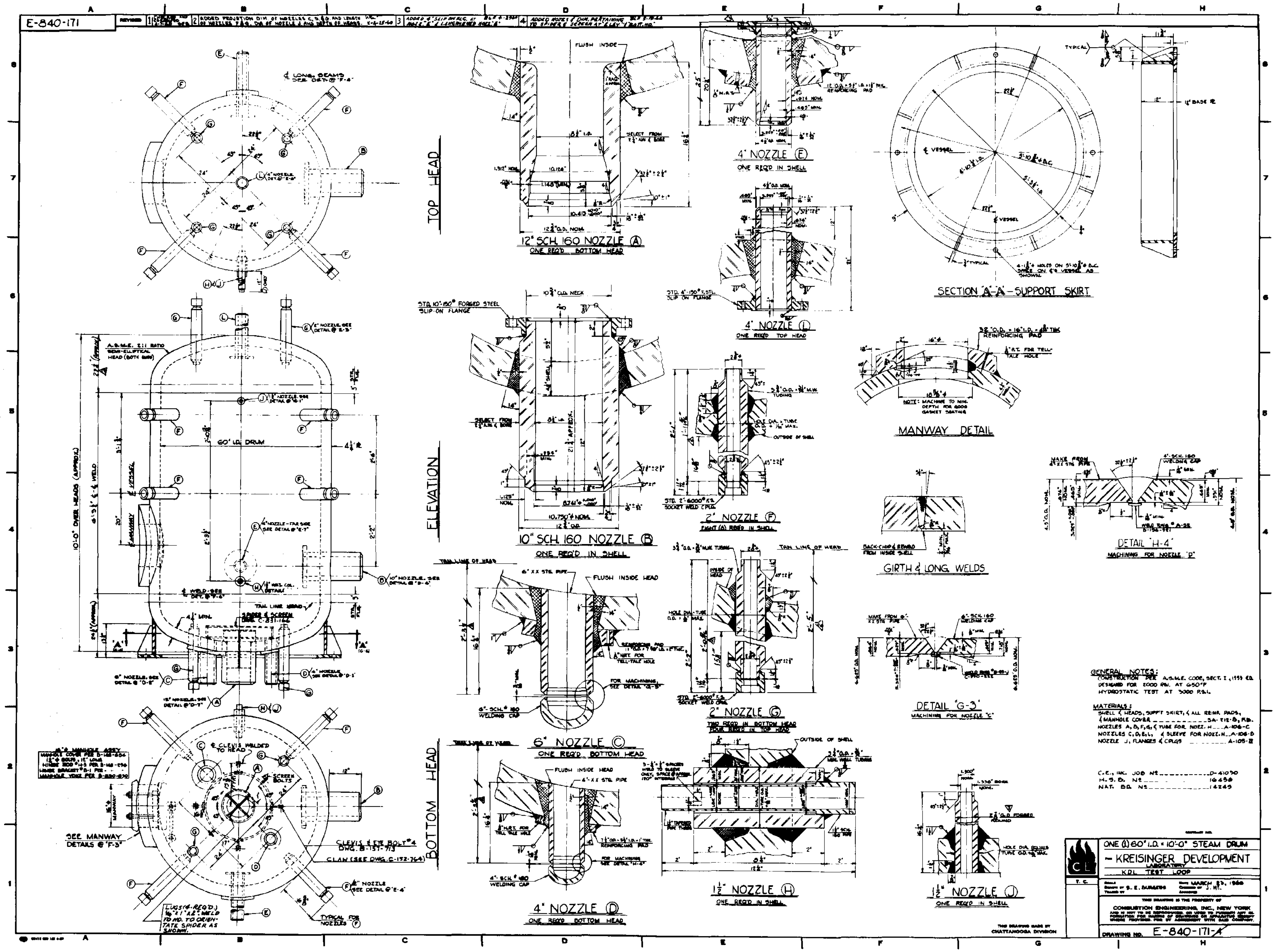


Figure 2-8. High Pressure Drum Drawing

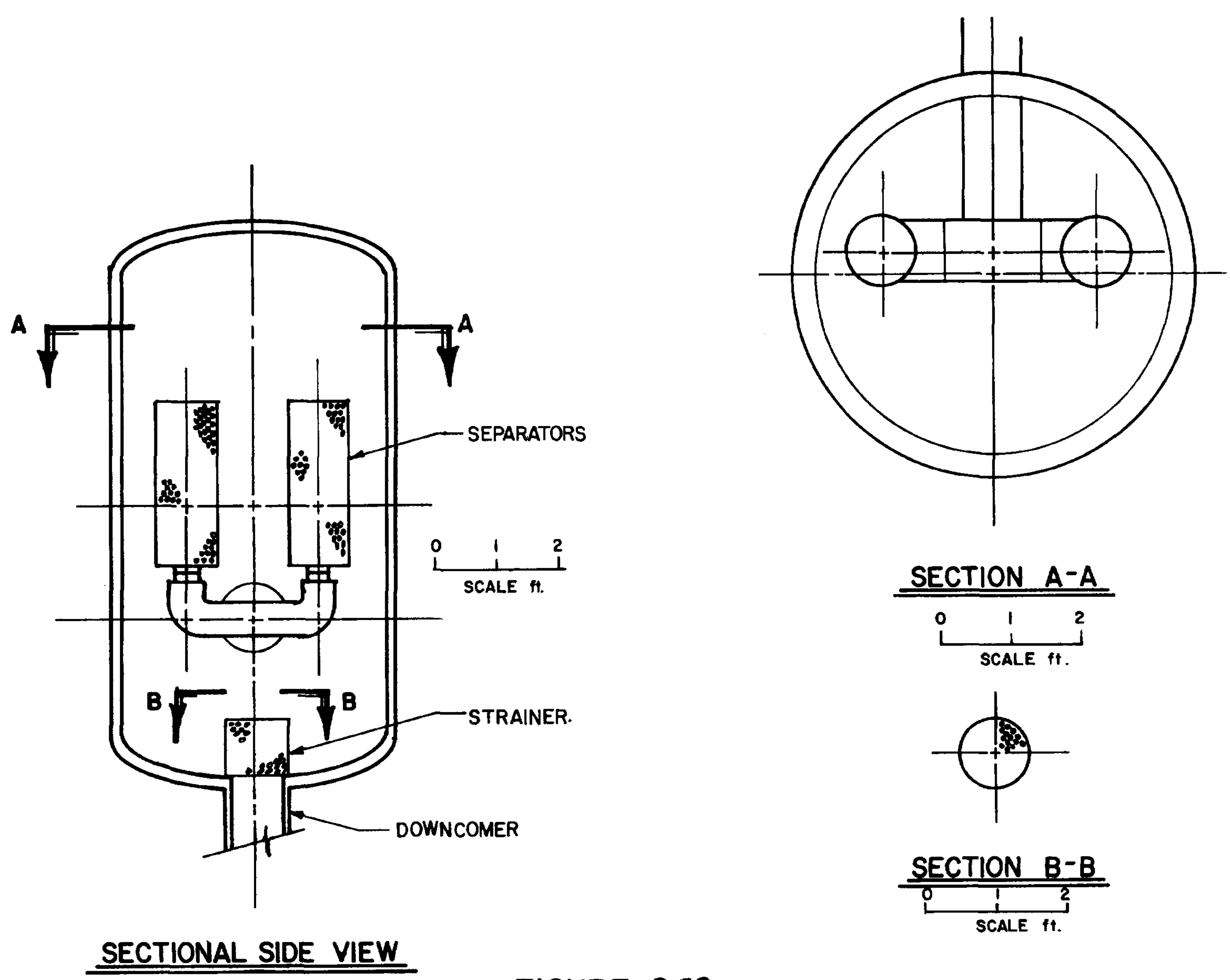
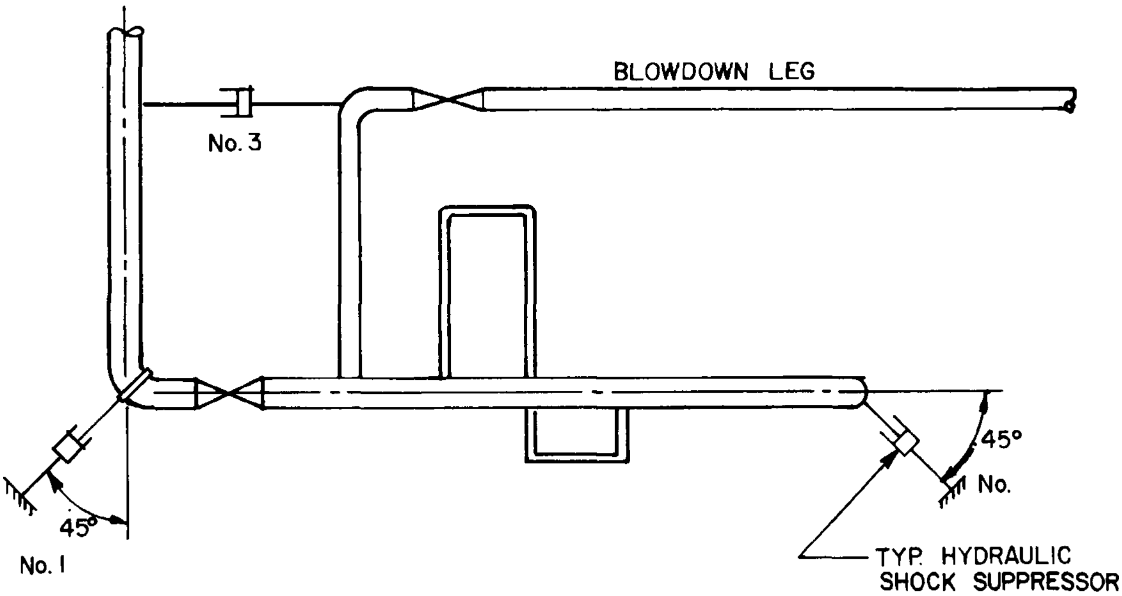
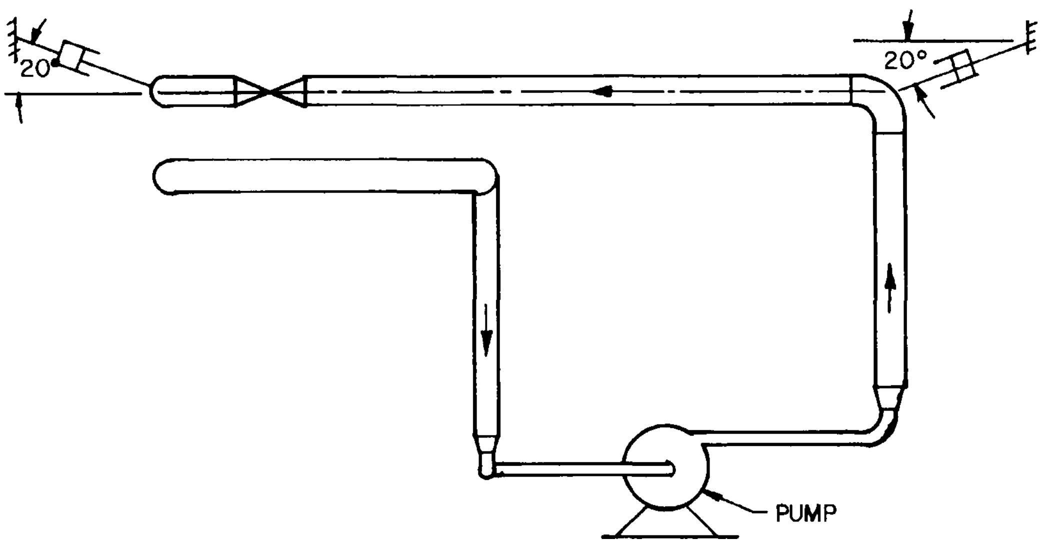


FIGURE 2-9
HIGH PRESSURE DRUM INTERNALS



PLAN VIEW



ELEVATION VIEW

FIGURE 2-10
LOCATION OF SHOCK SUPPRESSORS FOR FWD FLOW TEST

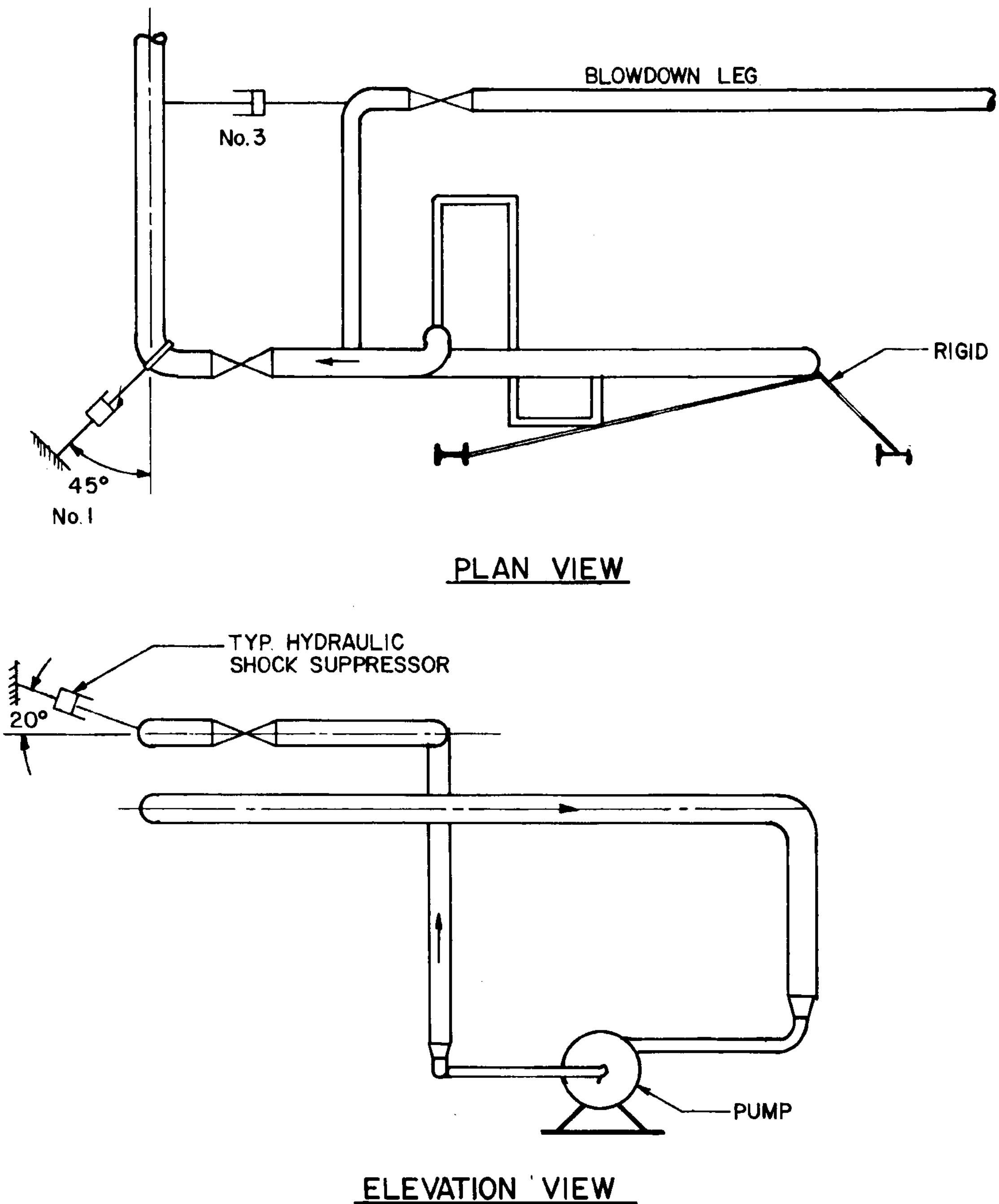


FIGURE 2-11
LOCATION OF SHOCK SUPPRESSORS FOR REVERSE FLOW TEST

illustrates a hinge which limited the travel of the test pump discharge piping in the horizontal plane. The suppressors were ITT GRINELL, TYPE 201, with a load rating of 12,500 lbf, 2 1/2-inch bore, and 5-inch stroke. The function of the suppressors located on the return leg from the test pump was to restrain piping sway due to water hammer and other conditions resulting from the steam-water flow regimes in the test loop. The suppressor mounted between the blowdown leg and the main piping loop restrained the horizontal impulse reaction component of a blowdown force so as to reduce the bending stresses at the 12-inch x 8-inch branch tee. These suppressors allowed free thermal expansion movement, without restraint, but when the excitation exceeded an acceleration of 2 ft/sec^2 or a velocity of 10 inches/min., these units acted as rigid struts.

2.2.2.5 Steam-Water Mixing Tee. The purpose of the steam-water mixing tee was to homogeneously mix the steam and water flows for two-phase steady-state test points. Details of the steam-water mixing tee are shown in Figure 2-12.

When the test conditions required a water flow in excess of 550 gpm, the main water orifice was used. The main water flow path was through the branch of the 12-inch tee, then through the annulus formed by the 5-inch pipe and the 12-inch pipe. The steam flowed from the boiler and through the perforations in the 5-inch pipe, where it mixed with the main water flow.

For test conditions requiring a water flow lower than 550 gpm, the water flowed through the low-flow water orifice and into the 4-inch spray nozzle, where it was atomized and dispersed into the steam flow.

2.2.2.6 Flow Measurement Orifices. The primary elements selected for measurement of water and steam flows were square-edged orifice plates, designed and installed according to ASME Standards for Flow Measurement (Reference 4). Their locations are shown in Figures 2-3 and 2-5.

Low-flow orifices were provided for both water and steam flows. Their purpose was to allow a wide flow measurement range with no loss in flow measurement accuracy. There were valves which permitted isolation of the low-flow orifices.

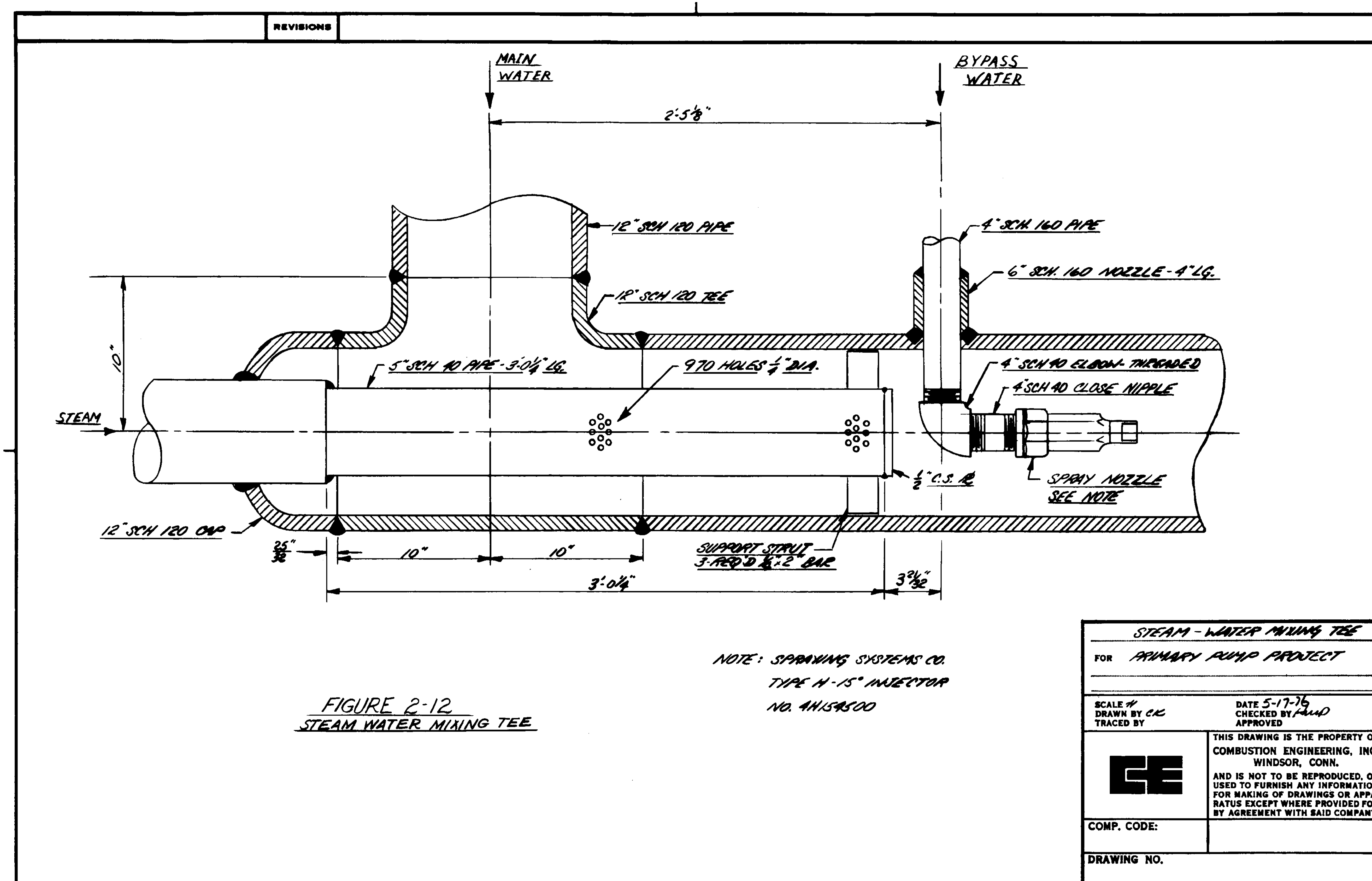


FIGURE 2-12
STEAM WATER MIXING TEE

All orifices were installed in horizontal pipe runs and were mounted between orifice type flanges, which were fitted with flange type pressure taps. The piping was bored for concentricity 4 diameters upstream and 2 diameters downstream of each orifice plate. In the case of the main water flow orifice, sufficient length of straight pipe upstream was not available and flow straightener was installed 8 pipe diameters upstream of the orifice. Details of the flow straightener are shown in Figure 2-13.

Figure 2-14 illustrates a standard installation of a flow measurement orifice and tabulates pertinent dimensions. This figure also specifies locations of instrument taps relative to the orifice plate, according to standard ASME procedures.

A detailed description of the instrumentation is available in Section 4.

2.2.2.7 <u>Flow Homogenizing Plates</u>. The capability existed for installing a perforated plate to homogenize the two-phase flow before entering the instrument spool upstream of the test pump. For forward flow testing, this plate could be installed at the inlet to the suction instrument spool, while for reverse flow testing it could be installed at the normal outlet to the discharge instrument spool (upstream of the discharge instrument spool for reverse flow). Details of these plates are shown in Figure 2-15 and locations of these plates are shown in Figures 2-16 and 2-17.

2.2.2.8 <u>Rupture Disc Assembly</u>. The rupture disc assembly (RDA) was located outside the building at the blowdown piping leg as seen in Figure 2-3. The function of the RDA was to rapidly initiate a transient depressurization (blowdown) of the test loop. Details of the construction are shown in Figure 2-18. The RDA consisted of two rupture discs, each rated at less than final system pressure, mounted between three specially designed holders, which, in turn, were mounted between piping flanges. The space between the two discs was connected to a nitrogen source for control of the rupture pressure. During the heat-up and steady-state operation prior to a transient test, the interdisc pressure was maintained at approximately half the system pressure, so that each disc was loaded below its rupture pressure. In order to cause the RDA to open, the pressure between the disc was suddenly decreased. The inner disc, and in turn, the outer disc, ruptured from over-pressure, allowing

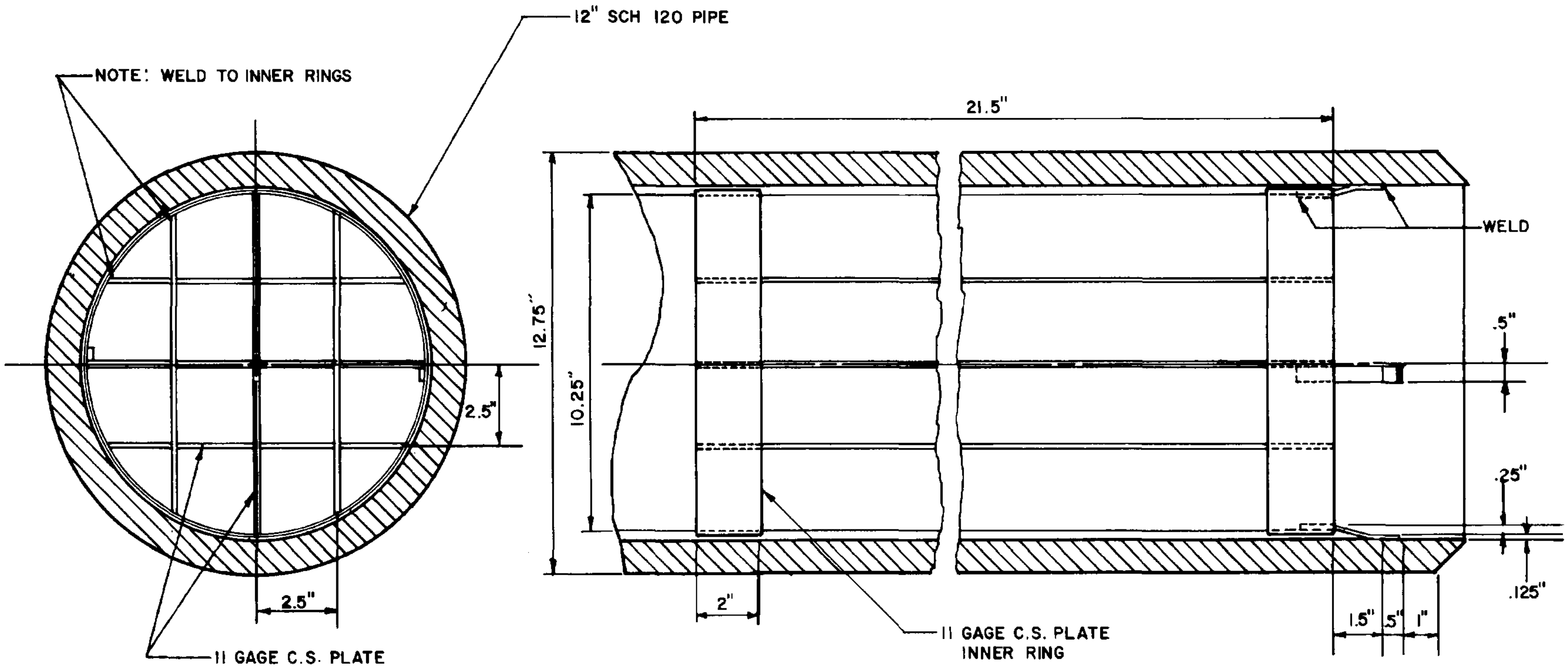
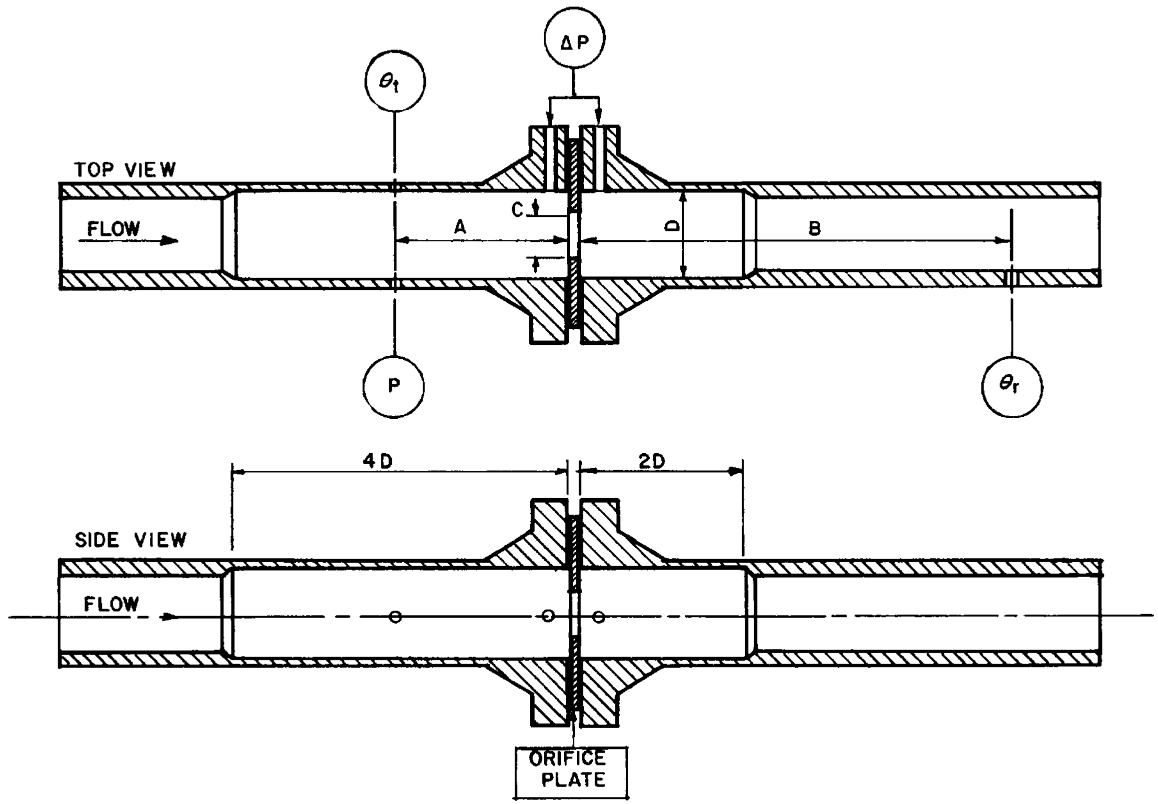


FIGURE 2-13

FLOW STRAIGHTENER FOR WATER ORIFICE



NOTES:

1. DIAMETER SHOULD NOT DEPART FROM THE AVERAGE DIAMETER BY MORE THAN .33%
2. AVERAGE DIAMETER WALL THICKNESS AND CONCENTRICITY MUST REMAIN AS SPECIFIED BY CODE.
3. THE BORED SURFACE IS TO BE FREE OF SCALE PITS & BUMPS. SURFACE ROUGHNESS NOT TO EXCEED 350 MICROINCHES
4. ALL INSTRUMENT TAPS LOCATED HORIZONTALLY

LEGEND
θ_t = THERMOCOUPLE
θ_r = RESISTANCE TEMPERATURE DEVICE
P = PRESURE CELL
ΔP = DIFFERENTIAL PRESURE CELL

DIMENSIONS (in)

	A	B	C	D
MAIN WATER	24.5	60.5	5.8048	10.908
LOW FLOW WATER	7.25	18.0	2.1488	3.610
MAIN STEAM	11.5	30	3.9397*	5.734
LOW FLOW STEAM	7.5	15.5	1.2322	2.770
TEST PUMP INJECTION	36(TC) 11(P)	-	.811	1.727

* C=3.1615 FOR TESTS 209 to 297

FIGURE 2-14
STANDARD ORIFICE RUN

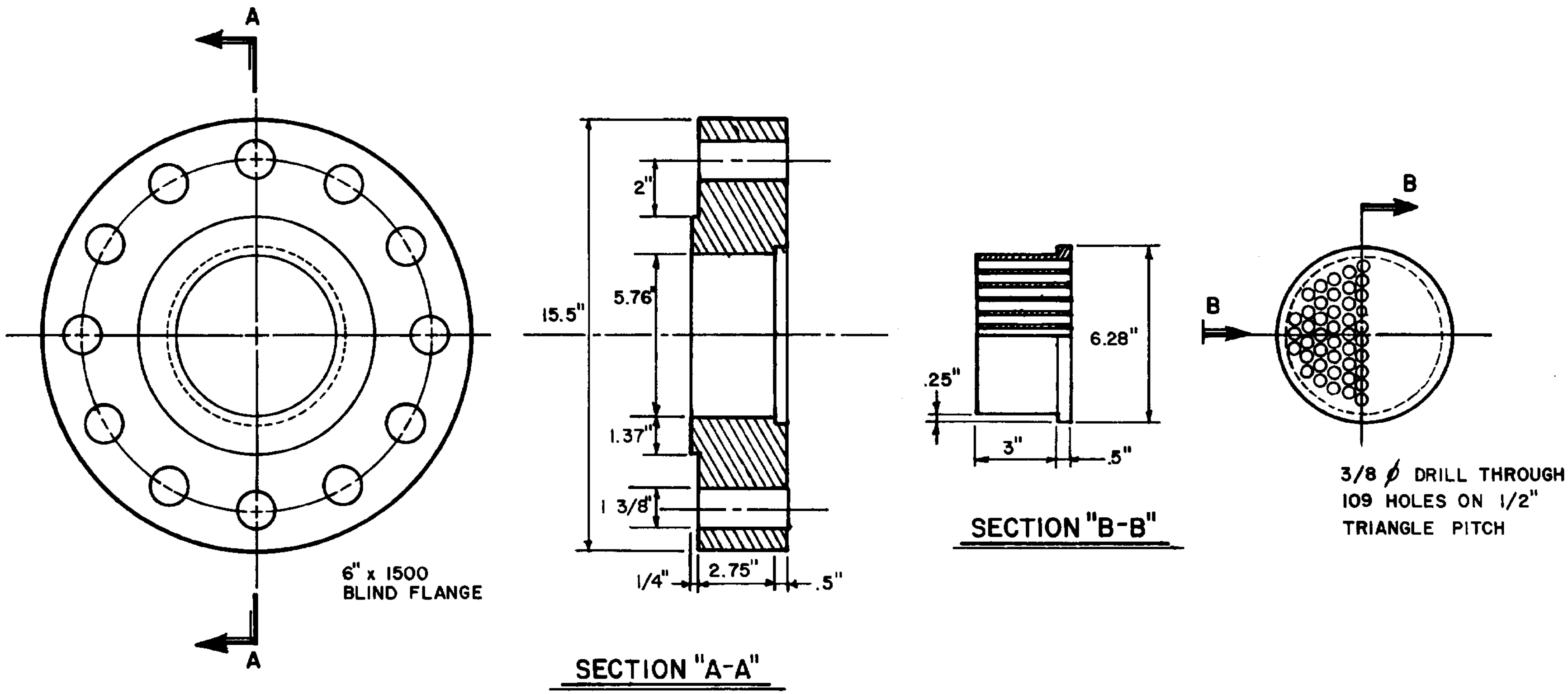


FIGURE 2-15
FLOW HOMOGENIZING PLATE

REVISIONS

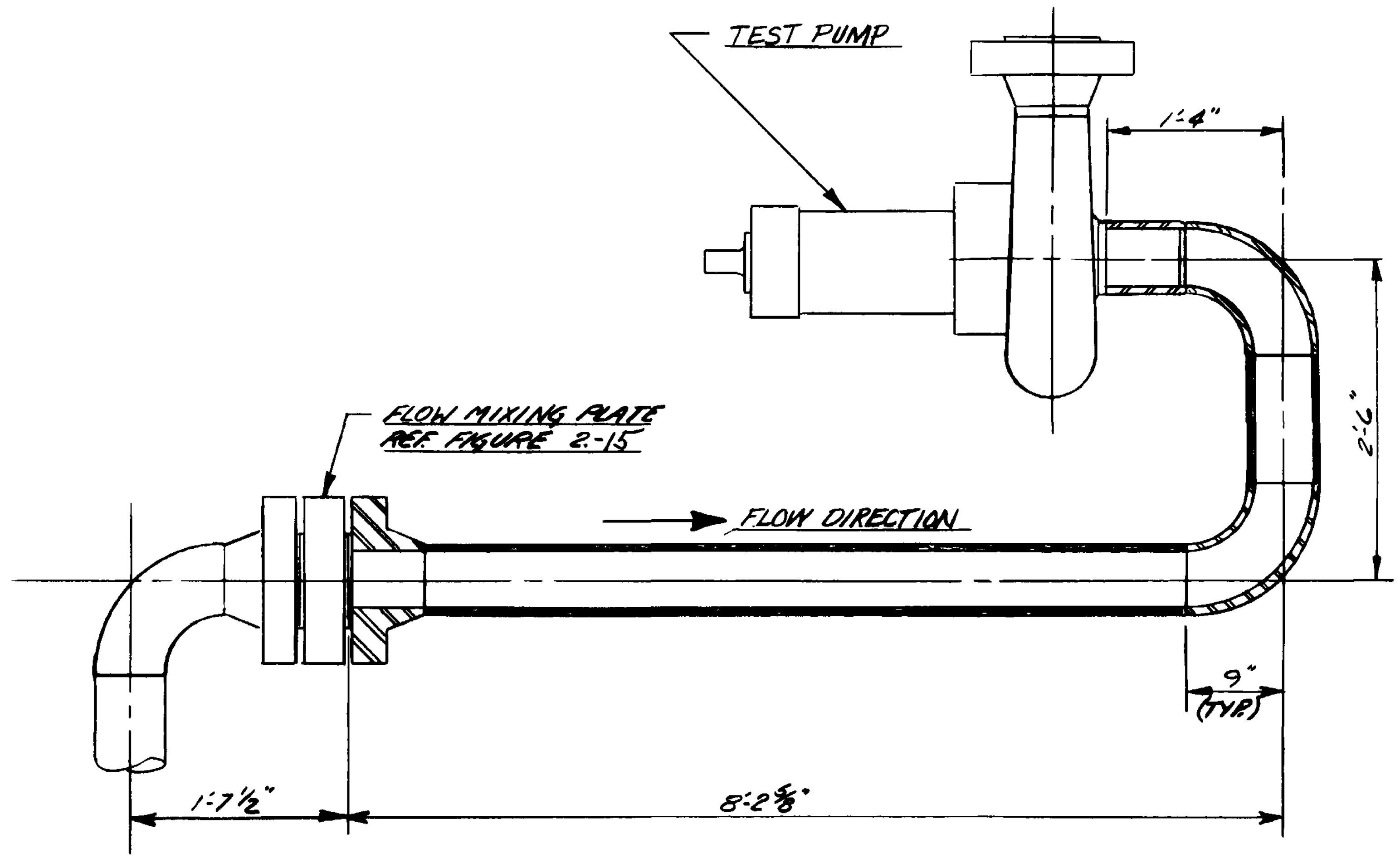


FIGURE 2-16
LOCATION FOR SUCTION FLOW HOMOGENIZING PLATE

FOR ARRANGEMENT OF C.E. PUMP SUCTION PIPING

SCALE —
DRAWN BY CK
TRACED BY

DATE 5-17-76
CHECKED BY [illegible]
APPROVED

CE

COMP. CODE:

DRAWING NO.

REVISIONS

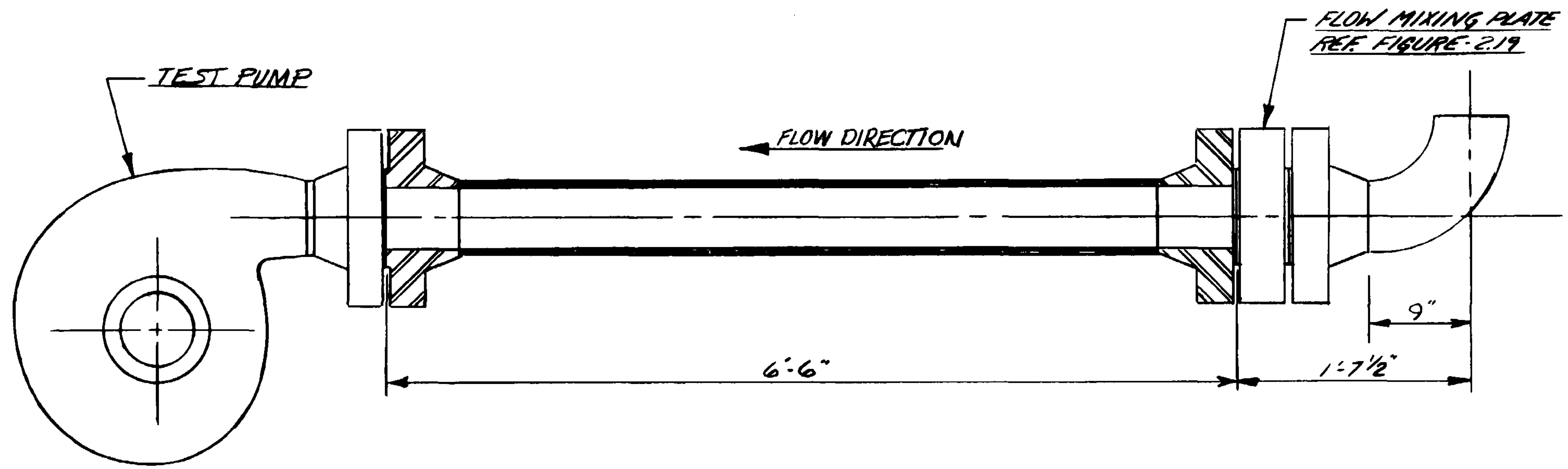


FIGURE 2-17
LOCATION FOR DISCHARGE FLOW HOMOGENIZING PLATE

FOR ARRANGEMENT OF C.E. PUMP DISCHARGE PIPING

SCALE
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DATE 5-17-76
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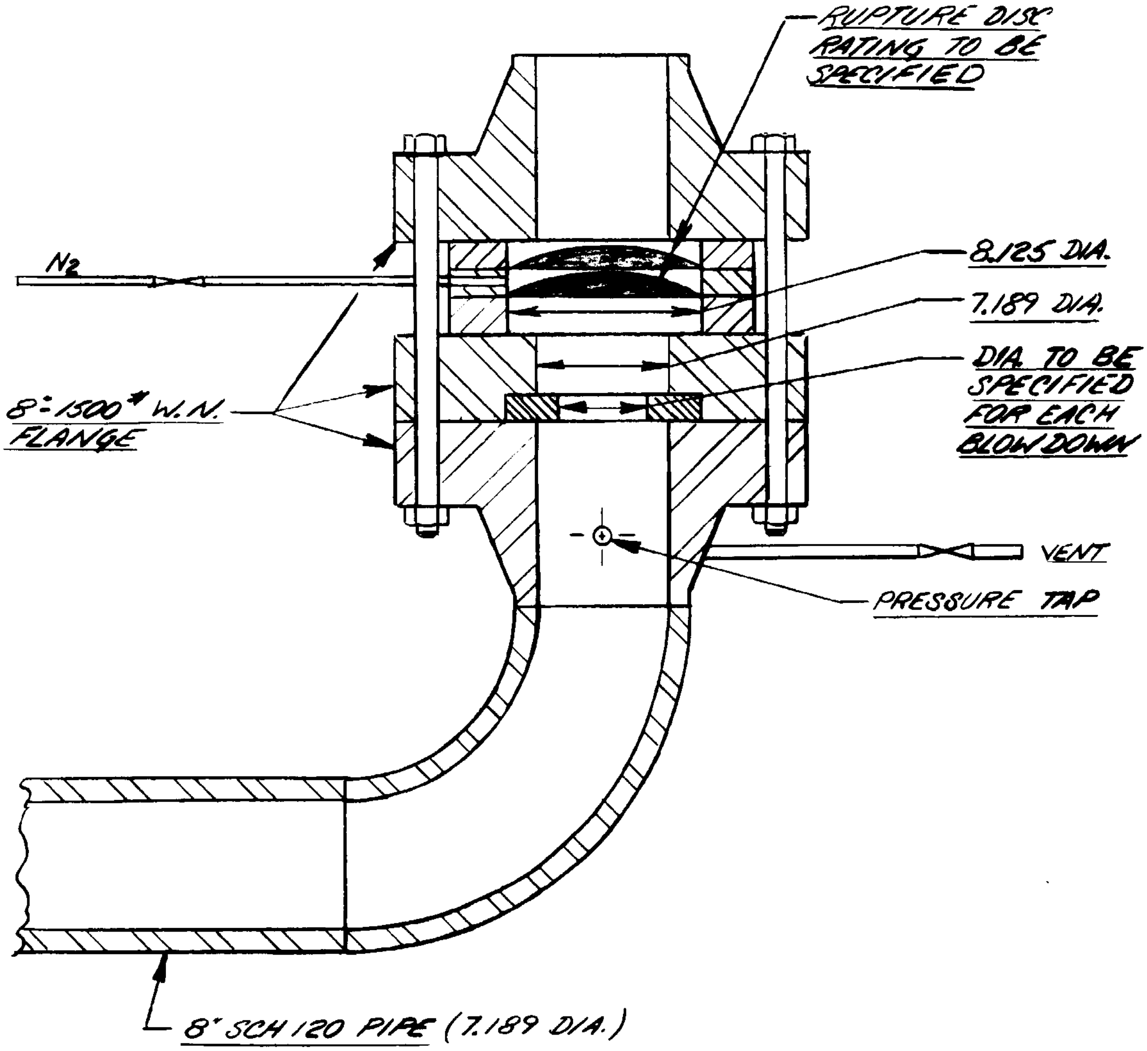


FIGURE 2-18 RUPTURE DISC ASSEMBLY

the loop to blow down. An orifice holder was mounted between the bottom flange and the RDA. This holder accepted orifice plates which were sized to control the rate of depressurization.

2.2.3 Loop Control Systems

The test loop was controlled by a combination of manual and automatic systems. The steady-state loop parameters to be controlled were: (1) Test loop pressure; (2) High pressure drum water level; (3) Steam flow rate; and (4) Water flow rate. Control valves are shown schematically in Figure 2-5. The loop pressure was controlled by a pneumatically operated steam discharge throttling valve (HPS-6), which received a control signal from the high pressure drum pressure transducer. The set point for this controller was adjusted manually in order to achieve the test pump upstream pressure requirement. Feedwater flow to the high pressure drum was adjusted to a constant flow rate by manually varying the control air pressure to the pneumatic valve FW-6. This flow rate was dependent on the steam flow rate and the leak-off flows of the PAC 12, PAC 16, and test pump.

Drum water level was controlled by the rate of blowdown through valve Z-6 which was located at the suction of PAC 12. This valve is shown schematically in Figure 2-19. Z-6 was a pneumatically operated valve, receiving a control signal from the high-pressure drum water level ΔP transducer. The loop water flow rate was controlled by throttling HPW-6 or HPW-7 located upstream of the mixing tee. These were manually operated valves. Steam flow was controlled by a manual setting of the boiler firing rate.

Pump injection water to the PAC 12 and PAC 16 pumps was controlled manually from the feedwater header. The feedwater header pressure was controlled automatically from 200 psi to 400 psi above boiler operating pressure. This assured a positive differential for injection of pump gland seal water.

2.2.3.1 Flow Control Systems. The facility had three automatic/remote manual control systems and two remote manual control systems. These systems allowed the operator to control loop water inventory, loop pressure, test pump injection, and loop water flow. A discussion of each system follows.

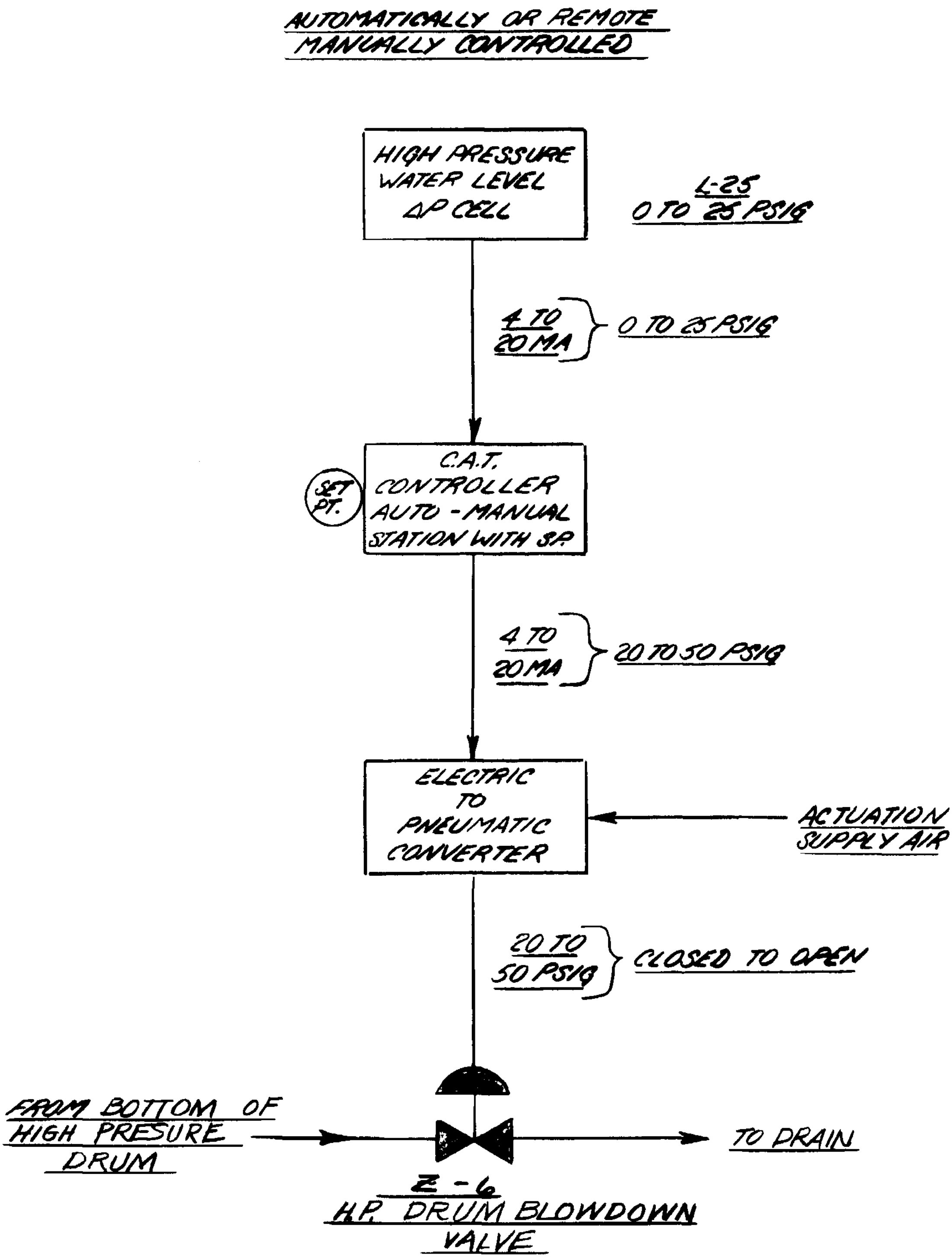


FIGURE 2-19 LOOP SCHEMATIC FOR Z-6 PNEUMATIC H.P. DRUM LEVEL VALVE

One of these systems was the high pressure drum blowdown valve system, Z-6 as shown in Figure 2-19. A differential pressure transmitter measured water level in the high-pressure drum. The transmitter output was fed to a current-adjusting type (CAT) controller where a comparison was made with water level set point. The CAT output then fed an electric-to-pneumatic converter. The pneumatic output then commanded the valve to either open or close until drum water level was equal to set point. Manual override allowed the operator to open or close the valve independent of transmitter measurement.

Another system was the steam vent valve system, HPS-6, as shown in Figure 2-20. A pressure transmitter measured pressure in the high-pressure drum. The transmitter output fed a CAT controller where a comparison was made with drum pressure set point. The CAT output then fed an electric-to-pneumatic converter. The pneumatic output then commanded the valve to either open or close until drum pressure was equal to set point. Manual override allowed the operator to open or close the valve independent of transmitter measurement. Increasing the valve opening caused a decrease in drum pressure.

The third system was the test pump seal injection water flow valve system, FW-8 shown, in Figure 2-21. A thermocouple measured the test pump injection outlet temperature. The thermocouple output feed a CAT controller where a comparison was made with set point. The CAT output fed an electric-to-pneumatic converter. The pneumatic output adjusted the valve until the injection outlet temperature was equal to set point. Maintaining an injection outlet temperature higher than the injection inlet temperature assured that no cold injection seal water would flow into the loop water flow. Manual override allowed the operator to control the valve position independent of temperature measurement. Increasing the valve opening allowed greater injection water flow to the throttle bushing.

The loop also had several manually controlled valves. One of these was the flow control valve, HPSW-1, shown in Figure 2-22. Under normal steady-state operation, this pneumatic valve was controlled by a hand-operated pressure regulator at the control panel. During blowdown or in the case of an emergency pump trip, fast closing of the valve was required. This was accomplished automatically by venting the lower side of the piston on the actuator (solenoid D), supplying a closed control air signal to the positioner (solenoid B), and supplying house air to the top side of the piston on the actuator.

AUTOMATICALLY OR REMOTE MANUALLY CONTROLLED

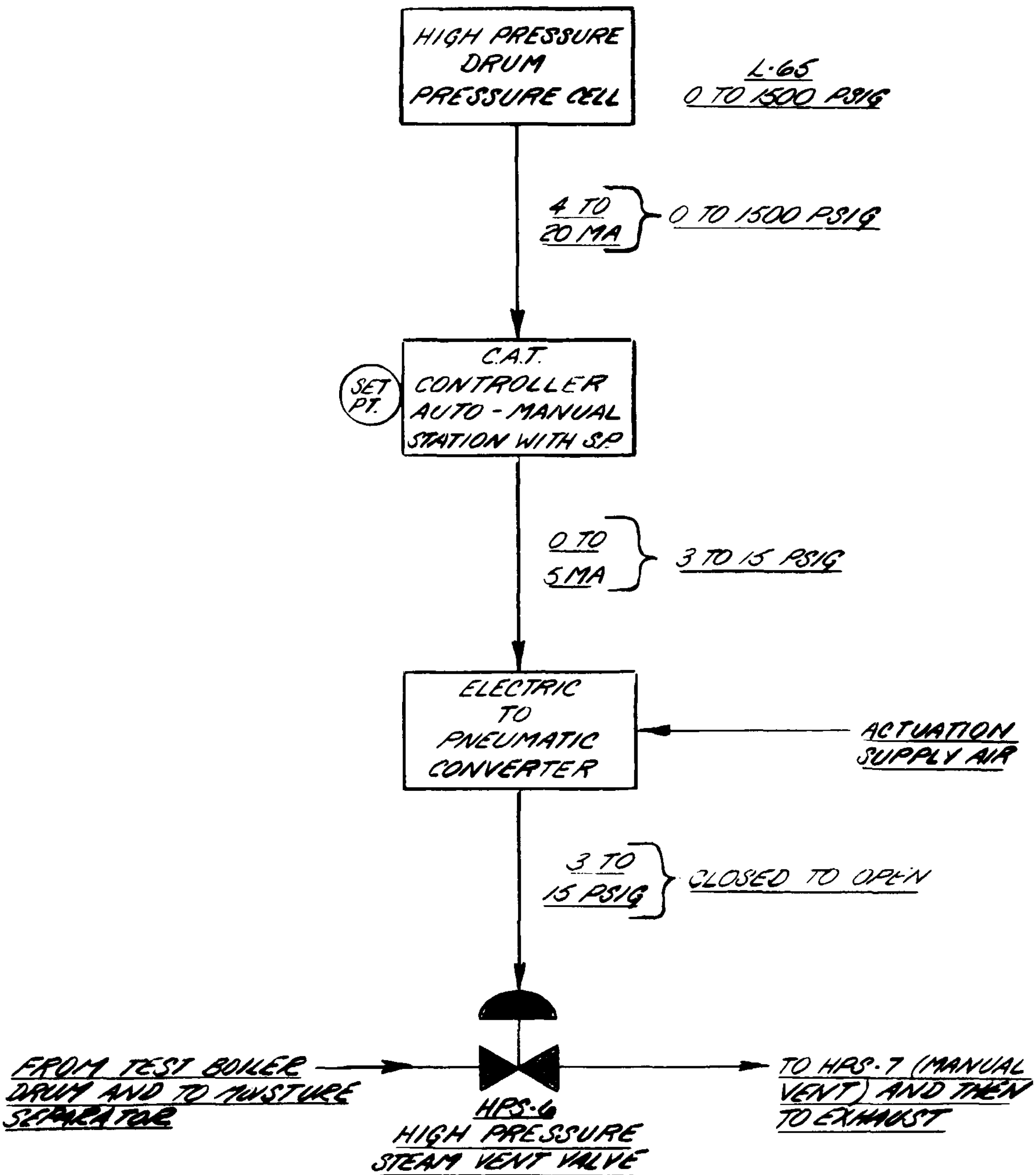


FIGURE 2-20 LOOP SCHEMATIC FOR HPS-6 PNEUMATIC VENT FOR LOOP

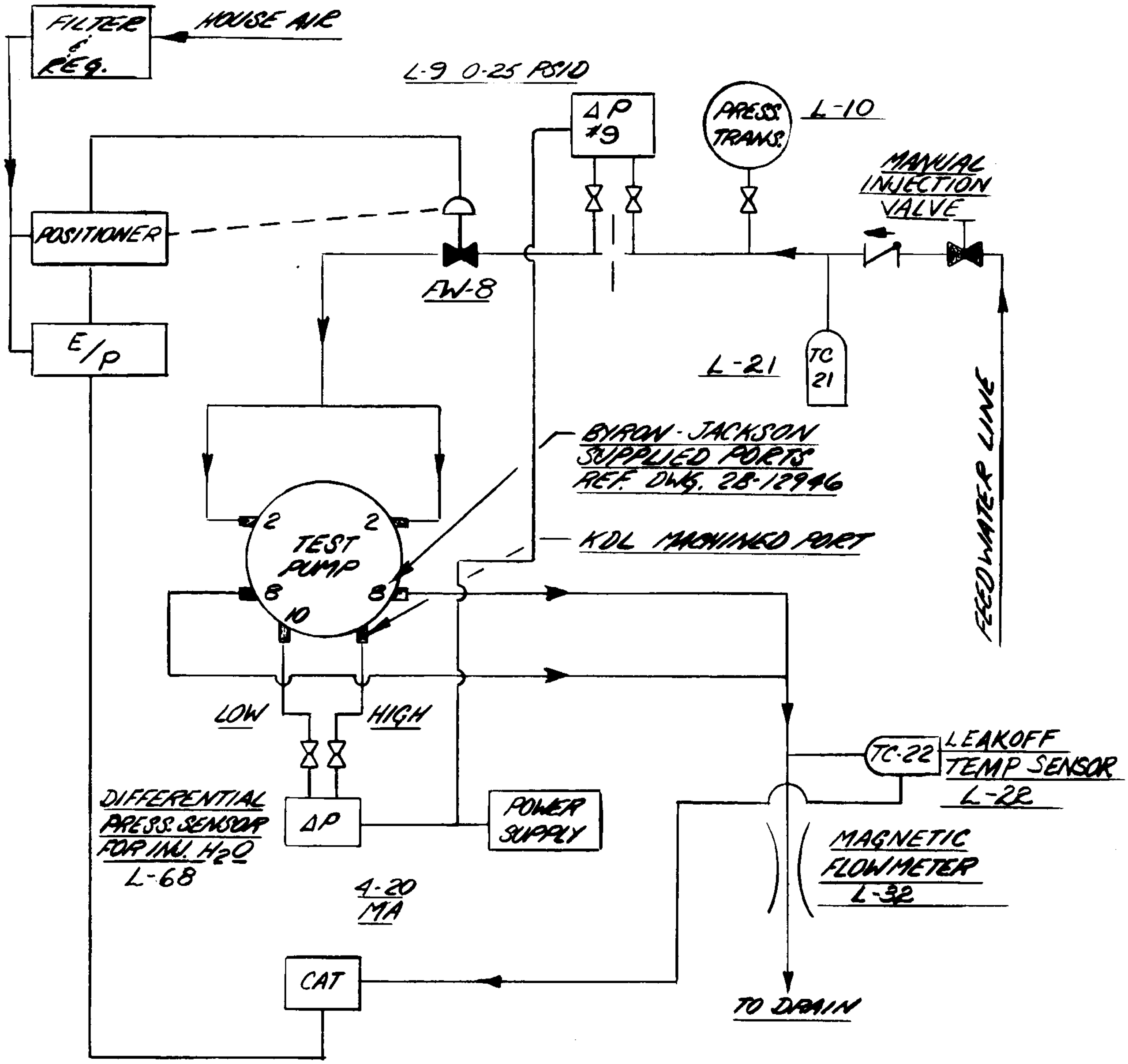
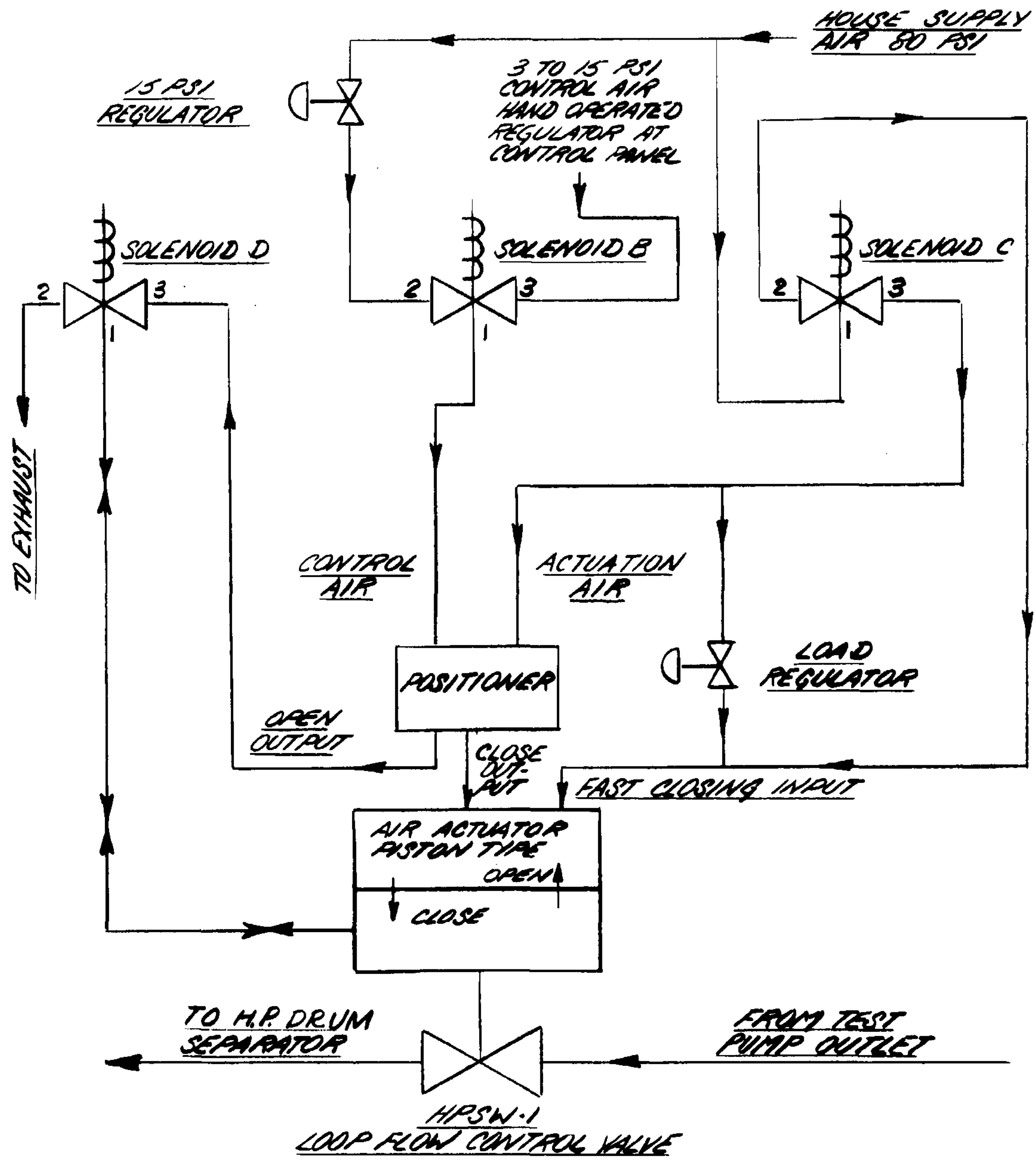


FIGURE 2-21 SEAL INJECTION SYSTEM FLOW DIAGRAM



NORMAL OPERATION: SOLENOIDS DE-ENERGIZED, PORTS 1 & 3 OPEN, 2 CLOSED

EMERGENCY CLOSING (FAST): SOLENOIDS ENERGIZED, PORTS 1 & 2 OPEN, 3 CLOSED

FIGURE 2-22 LOOP SCHEMATIC FOR HPSW-1
REMOTE MANUALLY CONTROLLED LOOP FLOW CONTROL VALVE

A flow schematic of the loop blowdown valve, HPSW-2, is shown in Figure 2-23. Under normal steady-state operation, this pneumatic valve was controlled by a hand-operated pressure regulator at the control panel. However, this valve remained closed during steady-state testing. Prior to blowdown, the valve was commanded to open. Upon initiation of blowdown, this valve remained open until an emergency pump trip or an emergency close command (operator initiated) caused the valve to close.

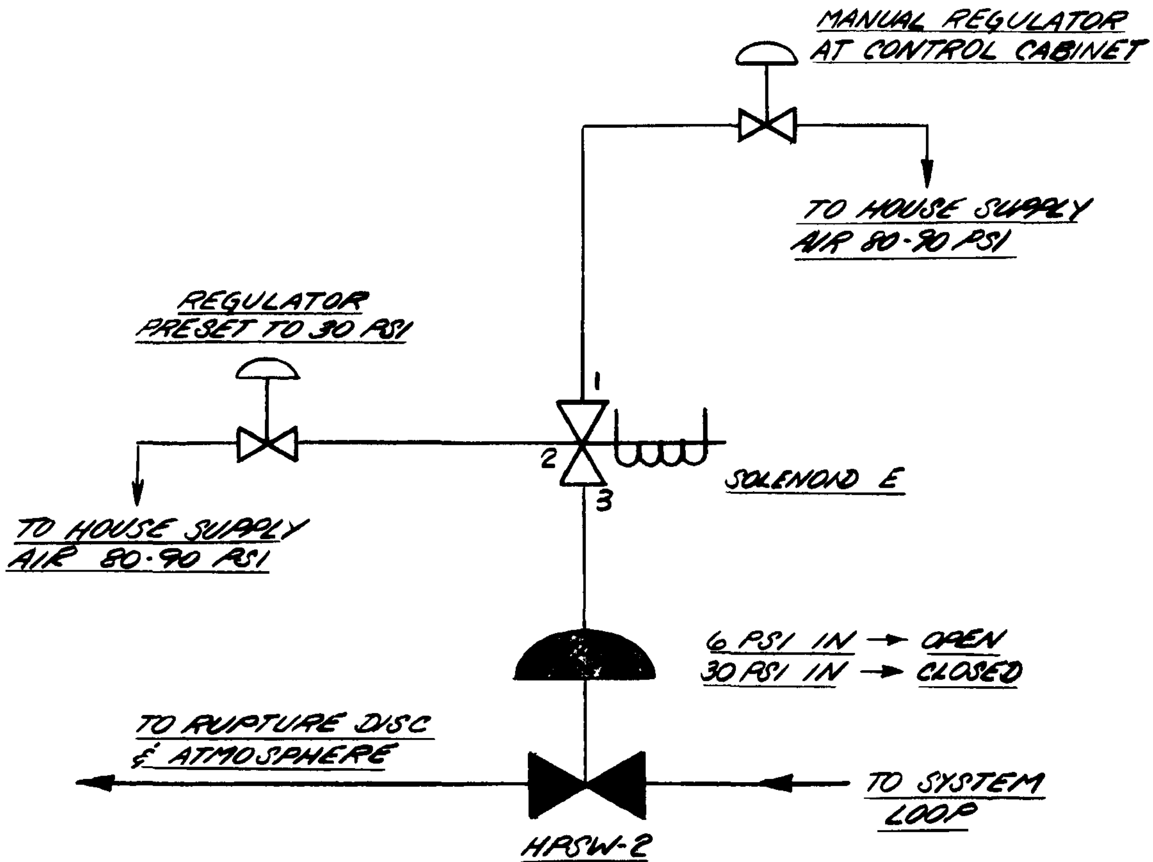
2.2.3.2 Control Logic For Blowdown. Blowdowns were operator-initiated either from the control panel or remotely. Once started, the blowdown sequence timer initiated a series of events in a pre-programmed sequence. The normal order of events was: (1) Start FM data acquisition system; (2) Close loop flow control valve (HPSW-1); (3) Rupture discs; (4) Trip test pump; (5) Close blowdown valve (HPSW-2).

Provision was made so that any of the above events could be selected and spaced at the desired time intervals. For example, in locked-rotor and power-on blowdowns Step 4, trip test pump, was eliminated. Step 5, close blowdown valve, was normally performed manually at the end of the blowdown. Test pump overspeed would also cause the valve to close and terminate the blowdown. Details of transient operating procedures may be found in Section 5. A description of initial conditions and any special procedures for each blowdown can be found in Volume III, Section 2.

2.2.3.3 Test Pump Protection System. The test pump motor would trip on loss of pump lubricant, loss of gear box lubricant, pump overspeed, or manual engagement of a trip switch. In addition, several safety interlocks were built into the motor-pump controller. These interlocks included motor-pump overcurrent, over-temperature of motor windings, loss of control air to the controller electronics, undervoltage to the motor, loss of a motor phase voltage, and loss of magnetic flux to the motor's rotor. Although these interlocks primarily provide protection for the motor driver, they in effect assured safe operation of the motor-pump assembly by causing the assembly to trip off line.

2.2.3.4 Alarms. Visual and audible alarms were provided to alert the operator of abnormal and potentially harmful operating conditions. Alarms were activated

REMOTE MANUALLY CONTROLLED VIA A PNEUMATIC LOAD REGULATOR. SHOWN FOR NORMAL OPERATION AND BLOWDOWN OR EMERGENCY CLOSING OF THIS VALVE.



NORMAL OPERATION:

SOLENOID 3 DE-ENERGIZED. FLOW FROM PORT 1 TO 3 2 BLOCKED. EMERGENCY OR BLOWDOWN CONDITIONS, SOLENOID ENERGIZED ALLOWING FLOW FROM 2 TO 3, CLOSING 1. (FAST CLOSING)

FIGURE 2-23 LOOP SCHEMATIC FOR HPSW-2 BLOWDOWN VALVE for high temperature of the test pump inboard radial bearing, outboard radial bearing, thrust bearing oil outlet, and test pump injection outlet flow. Alarms were also activated for a low pressure condition of the high-pressure oil injection system and for low oil level in the oil reservoir. Two additional alarms (visual and audible) were provided to annunciate a trip condition: 1) trip exists because of test pump overspeed; 2) trip exists because of a C-E installed trip.

The C-E installed trips were low lubrication pressure to the test pump bearings, and a manually operated emergency trip.

2.2.4 Auxiliary Systems

The auxiliary systems for the test loop included: 1) the high-pressure boiler; 2) the low-pressure boiler; 3) the water treatment systems; 4) the electric power supply system; and, 5) the compressed air system.

The high-pressure boiler was the major source of steam for the test loop. This boiler had a 50 million Btu/hour heat input capability, either oil or gas-fired. It was rated for 50,000 lbm/hour of steam at 1200 psia pressure, with preheated feedwater. Steam was saturated (<0.2% moisture) coming from the boiler drum. The low pressure boiler was a package type unit, of the same heat input capacity, rated for 42,000 lbm/hour of saturated steam at 500 psia.

Water treatment facilities consisted of two mixed-bed demineralizers (one in standby), with a capacity of 200 gpm. This system was automatically controlled by conductivity monitors which shut down the system if the water conductivity exceeded a specific conductance of 102 micromhos/cm. The boiler and loop feedwater passed through a deaerating feed heater, with a water capacity of 200 gpm, where oxygen was removed from the makeup water. This unit was maintained on line continuously, so as to assure an uninterrupted supply of deareated water. Water temperature from the deaerator was approximately 240°F. A feedwater cooler was provided to reduce the feed temperature to the 150-180°F range. This was a requirement for gland seal injection water for the loop test pump and booster pumps.

Electric power was supplied from a 3500 KVA, 480 V, 60 HZ load center.

Compressed air for operation of pneumatic control valves was supplied from the regular shop air system, through a drier and filter system.

2.3 LOOP CAPACITY

The loop volume and flow rate capacities are described below for steady-state and transient tests.

2.3.1 Loop Volume

Figure 2-24 shows the loop isometrically with all loop flow piping labeled. Each labeled element is identified in Table 2-3. The calculated volume and equivalent length/diameter ratio is also given. The later was used to perform loop friction loss calculations. The volumes were summed to provide a calculated value for total loop volume calculations. This number was important in that it provided information on the total water inventory upstream of the test pump prior to blowdown.

In order to check the calculated volume, a measurement of loop volume with an accurate water totalizer was made. The total loop volume upstream of the test pump at 50°F, with HP Drum level 64.75 inches above drum bottom, were:

- Forward Flow Piping Mode - 284.8 ft^3
- Reverse Flow Piping Mode - 291.0 ft^3

This includes water trapped in the return line between the HP Drum and HPSW-1, which amounted to 37.2 ft^3. These values agreed with the calculated ones within 10 ft^3. The full procedure for this measurement is contained in Appendix A.

Assuming that the loop was in a saturated condition at 1000 psia the volumes given above for a HP Drum level of 64.75 inches correspond to a preblowdown mass upstream of the test pump of 13,200 lbm for the forward flow piping mode and 13,500 lbm for the reverse flow piping mode. This calculation neglects the increase in volume HP drum, pipes, etc. which occurs during loop heat up.

No two blowdowns commenced with exactly the same HP Drum water level. Therefore, it was necessary to calculate the water level for each blowdown test separately using the HP drum level differential pressure cell output (L-25). The formulas for the mass of water upstream of the test pump are:

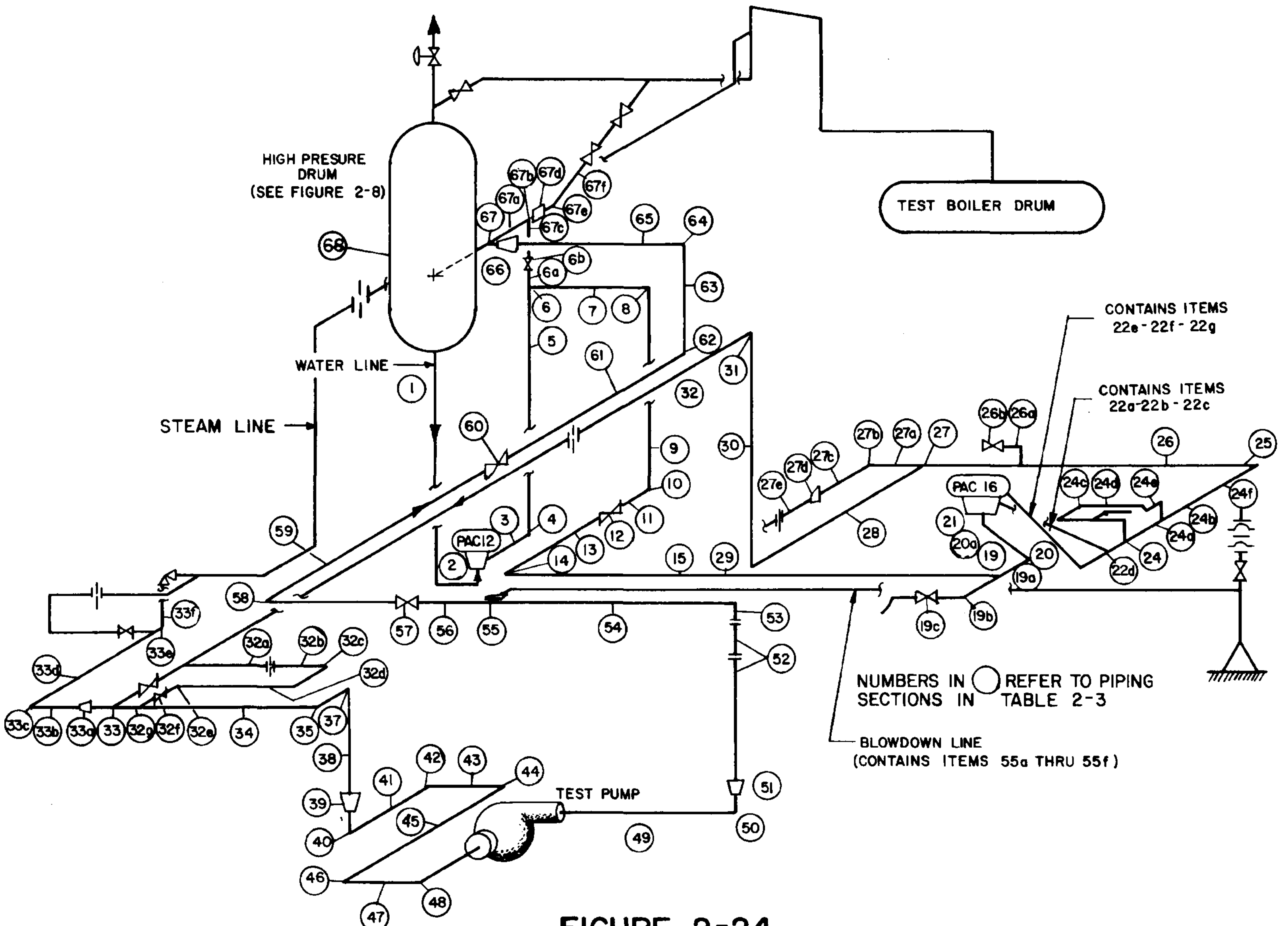


FIGURE 2-24

LOOP PIPE SECTION IDENTIFCATION

TABLE 2-3

Loop Piping

Reference Figure 2-2

Section Number	Fitting Or Length St-Pipe (ft)	Equivalent L/D	Section Volume (ft^3)
1	21.5	24	13.55
2	elbows	40	2.64
-	PAC-12	-	2.00 (estimated)
3	2	2.23	1.26
4	elbow	20	1.49
5	11.75	13.1	7.41
6	tee	60	1.29
6A	reducer	K=0.36	1.14
6B	valve	-	0.25
7	1.7	1.9	1.07
8	elbow	20	1.49
9	15	16.74	9.46
10	elbow	20	1.49
11	5.5	6.14	3.47
12	valve	K=0.19	1.78
13	4	4.46	2.52
14	elbow	20	1.49
15	10.5	11.71	6.62
19	tee	60	1.29
19A	2.5	2.79	1.58
19B	12x8 reducing elbow	-	1.07
19C	valve	-	1.07
20	45° elbow	16	0.75
20A	2	2.23	1.26
21	elbow	20	1.49
-	PAC-16	-	2.00 (estimated)
22	-	-	-
22A	elbow	20	1.49
22B	elbow	20	1.49
22C	5.5	6.14	3.47

TABLE 2-3

Loop Piping

Reference Figure 2-2 (Cont'd.)

Section Number	Fitting Or Length St-Pipe (ft)	Equivalent L/D	Section Volume (ft^3)
22D	tee	20 through run	1.29
		60 through branch	
22E	elbow	20	1.49
22F	3.5	3.91	2.21
22G	45° elbow	16	0.75
24	tee	20	1.29
24A	elbow	20	0.19
24B	4	8.33	0.72
24C	elbows	40	0.38
24D	5	10.41	0.91
24E	valve	-	0.18
24F	2	2.23	1.26
25	elbow	20	1.49
26	4.2	4.69	2.65
26A	elbow	20	1.49
26B	valve	-	1.07
27	tee	60	1.29
27A	0.83	0.93	0.53
27B	reducing elbow	-	1.07
27C	6.25	10.43	1.76
27D	8x6 reducer	-	-
27E	1.25	2.6	0.23
28	11.5	12.83	7.25
29	elbow	20	1.49
30	11.5	12.83	7.25
31	elbow	20	1.49
32	18.7	20.87	11.79
32A	5.73	20	0.37
32B	2.87	10	0.19
32C	elbows	40	0.10

TABLE 2-3

Loop Piping

Reference Figure 2-2 (Cont'd.)

Section Number	Fitting Or Length St-Pipe (ft)	Equivalent L/D	Section Volume (ft^3)
32D	7	24.4	0.45
32E	elbow	20	0.05
32F	valve	-	0.06
32G	4.5	15.7	0.29
33	tee	60	1.29
33A	6x12 reducer	K=0.55	0.56
33B	0.25	0.55	0.04
33C	elbow	20	0.19
33D	4	8.73	0.66
33E	elbow	20	0.19
33F	2.75	6	0.29
34	7.7	8.59	4.85
35	elbow	20	1.49
37	elbow	20	1.49
38	10.6	11.83	6.68
39	12x6 reducer	K=0.31	0.25
40	elbow	20	0.19
41	3.5	3.91	0.63
42	elbow	20	0.19
43	2	4.16	0.36
44	elbow	20	0.19
45	8.5	17.70	1.54
46	elbow	20	0.19
47	1	2.08	0.18
48	elbow	20	0.19
49	8	16.66	1.45
50	elbow	20	0.19
51	6x12 reducer	K=0.50	0.25
52	12.1	13.51	7.63
53	elbow	20	1.49

TABLE 2-3

Loop Piping

Reference Figure 2-2 (Cont'd.)

Section Number	Fitting Or Length St-Pipe (ft)	Equivalent L/D	Section Volume (ft^3)
54	16.5	18.42	10.40
55	tee	20	1.29
55A	12x8 reducer	K=0.21	0.29
55B	8	13.35	2.26
55C	elbow	20	0.44
55D	43	71.77	12.12
55E	elbow	20	0.44
55F	valve	K=7.59	1.89
56	0.75	0.84	0.47
57	valve	K=5.66	2.52
58	elbow	20	1.49
59	12.75	24.28	13.71
60	valve	K=0.19	1.78
61	5.5	6.14	3.47
62	elbow	20	1.49
63	5.5	6.14	3.47
64	elbow	20	1.49
65	7	7.81	4.41
66	12x8 reducer	K=0.21	0.29
67	tee	60	0.30
67A	1	1.76	0.28
67B	tee	20	0.30
67C	3.5	6.16	0.99
67D	reducer	K=0.18	0.10
67E	elbow	20	0.15
67F	6	13.9	0.99
68	HP Drum	-	202.1 max. (w/o internals)

Forward Flow Piping Mode -

$$M_F = V_{OF}\,\rho_w + C\rho_w\,[1728\,\frac{\Delta P}{(\rho_w - \rho_s)} - L_c\,\frac{\rho_s}{(\rho_w - \rho_s)}\,]$$

Reverse Flow Piping Mode -

$$M_R = V_{OR}\,\rho_w + C\rho_w\,[1728\,\frac{\Delta P}{(\rho_w - \rho_s)} - L_c\,\frac{\rho_s}{(\rho_w - \rho_s)}\,]$$

Where

M_F	= mass upstream of the test pump in forward flow piping mode (lbm).
M_R	= mass upstream of the test pump in reverse flow piping mode (lbm).
V_{OF}	= 216.8 ft^3 = volume upstream of the test pump when L_w = 0 for forward flow piping mode.
V_{OR}	= 223.0 ft^3 = volume upstream of the test pump when L_w = 0 for reverse flow piping mode.
L_w	= water level in the HP Drum measured above the lower ΔP tap, which is 22.25 inches above the drum bottom (in)
C	= 1.60 ft^3/in = volume per inch of drum height neglecting drum internals.
ΔP	= differential pressure between water level taps (lbf/in^2).
L_c	= 68.2 inches = vertical distance between differential pressure taps.
ρ_w	= density of saturated water (based on HP Drum pressure) in the HP Drum (lbm/ft^3)
ρ_s	= density of saturated steam (based on HP Drum pressure) in the HP Drum (lbm/ft^3).

These formulas give the mass upstream of the test pump to within approximately 70 lbm. However the mass calculated from the formula is not necessarily the same as the total mass passing through the test pump during the blowdown because of the seal injection and leak off systems for both booster pumps (PAC 12 and PAC 16) and the test pump. Efforts were made to reduce the effect of the injection flows by automatically regulating the pressure of the feedwater injection system. This normally prevented inward flow of cold injection water. However, some system water did escape through the pump leakoffs during the course of the transient. It is this leakoff flow which causes uncertainty in the total mass passing through the test pump.

2.3.2 Loop Flow Capacity

Prior to commencement of the testing phases calculation of anticipated loop flow capabilities were made. Primary limitations were, (1) booster pump head/flow capacity (limited water flow) and (2) boiler steam output limit (limited flow at high void fractions). Shakedown tests were used to confirm and adjust these limits.

Data from the testing provided accurate limits on system performance. These results are presented graphically in Figure 2-25.

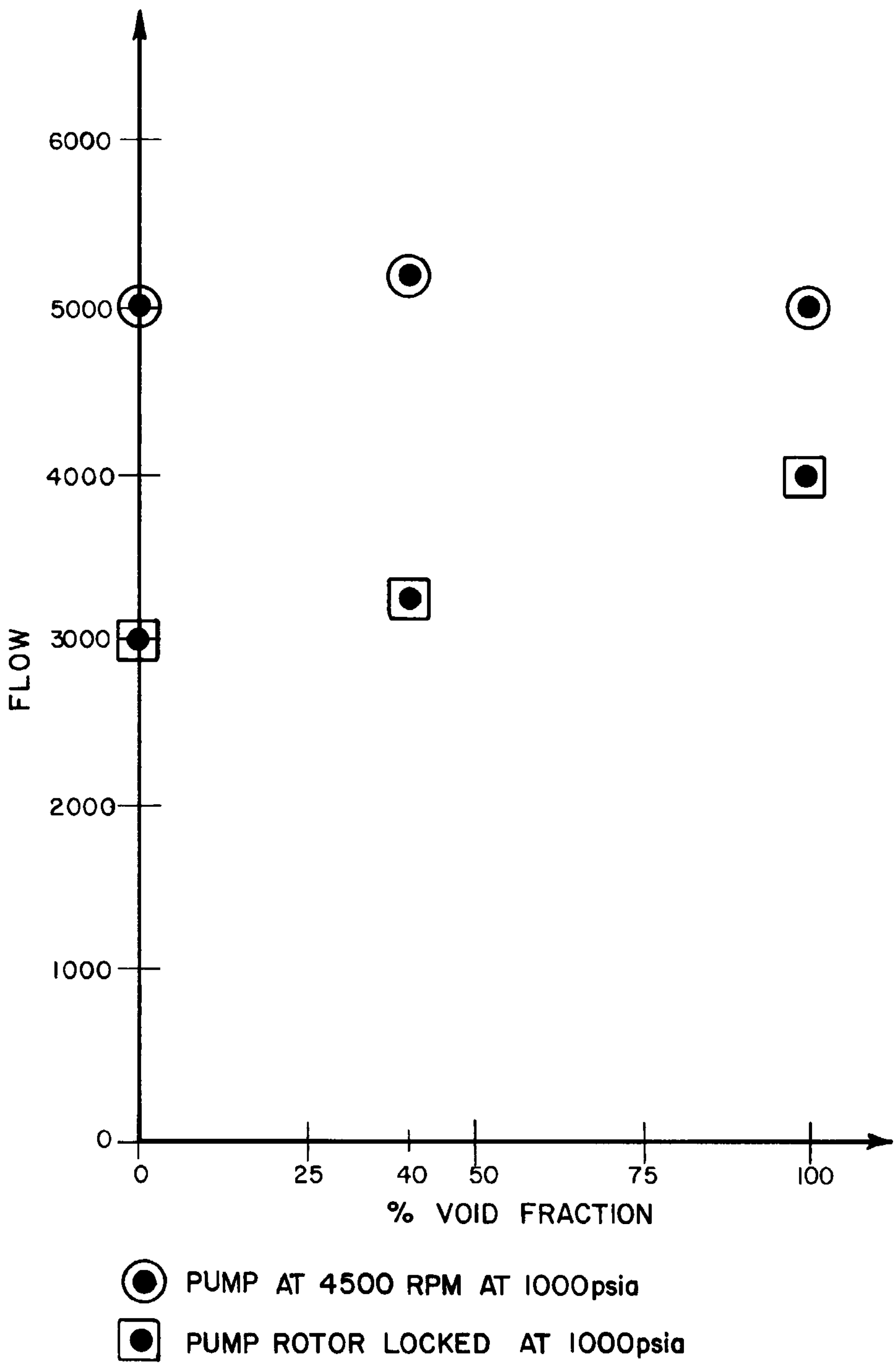


FIGURE 2-25

MAXIMUM FLOW RATES BASED ON STEADY STATE TEST DATA

Section 3

TEST UNIT

The C-E/EPRI test unit consisted of the model pump, a torque-speed transducer, 1:5 speed increaser, and a drive motor. It was mounted horizontally on a common base plate as indicated by Figure 3-1. The speed of the test unit was controlled by a solid-state adjustable-frequency AC drive system which provided control between pump speeds of + 1000 rpm to + 9000 rpm and -1000 rpm to -9000 rpm.

3.1 C-E/B-J MODEL PUMP

3.1.1 Design Description

A cross-sectional view of the C-E/B-J model test pump is given in Figure 3-2. Additionally, Figures 3-3, 3-4, 3-5, and 3-6 are photographs of the test pump made during assembly. The pump hydraulic components were designed to a 1/5 geometric scale of a typical reactor coolant pump. The rated or peak efficiency pump parameters for water at 62.3 lbm/ft^3 were:

Head, ft	252
Flow Rate, gpm	3,500
Torque, ft-lb	308
Speed, rpm	4,500
Specific Speed	4,200

The full size pump characteristics can be derived from the model performance using the following relationships:

Head: $$H_{NSSS} = 25\ H_{mod} \left(\frac{880}{N_{mod}}\right)^2$$

Flow: $$Q_{NSSS} = 125\ Q_{mod} \left(\frac{880}{N_{mod}}\right)$$

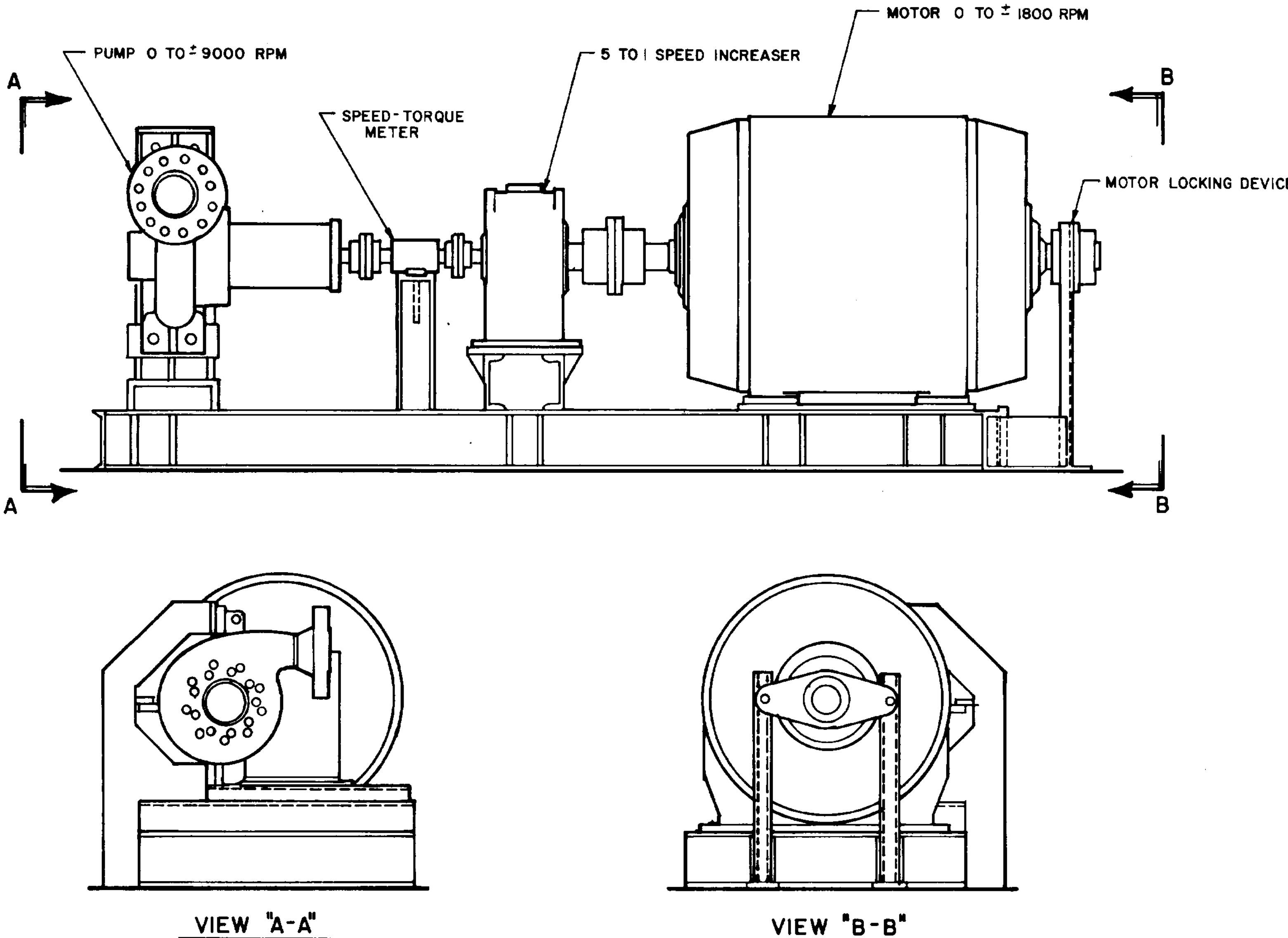


FIGURE 3-1
C-E MODEL PUMP ARRANGEMENT OF DRIVE TRAIN

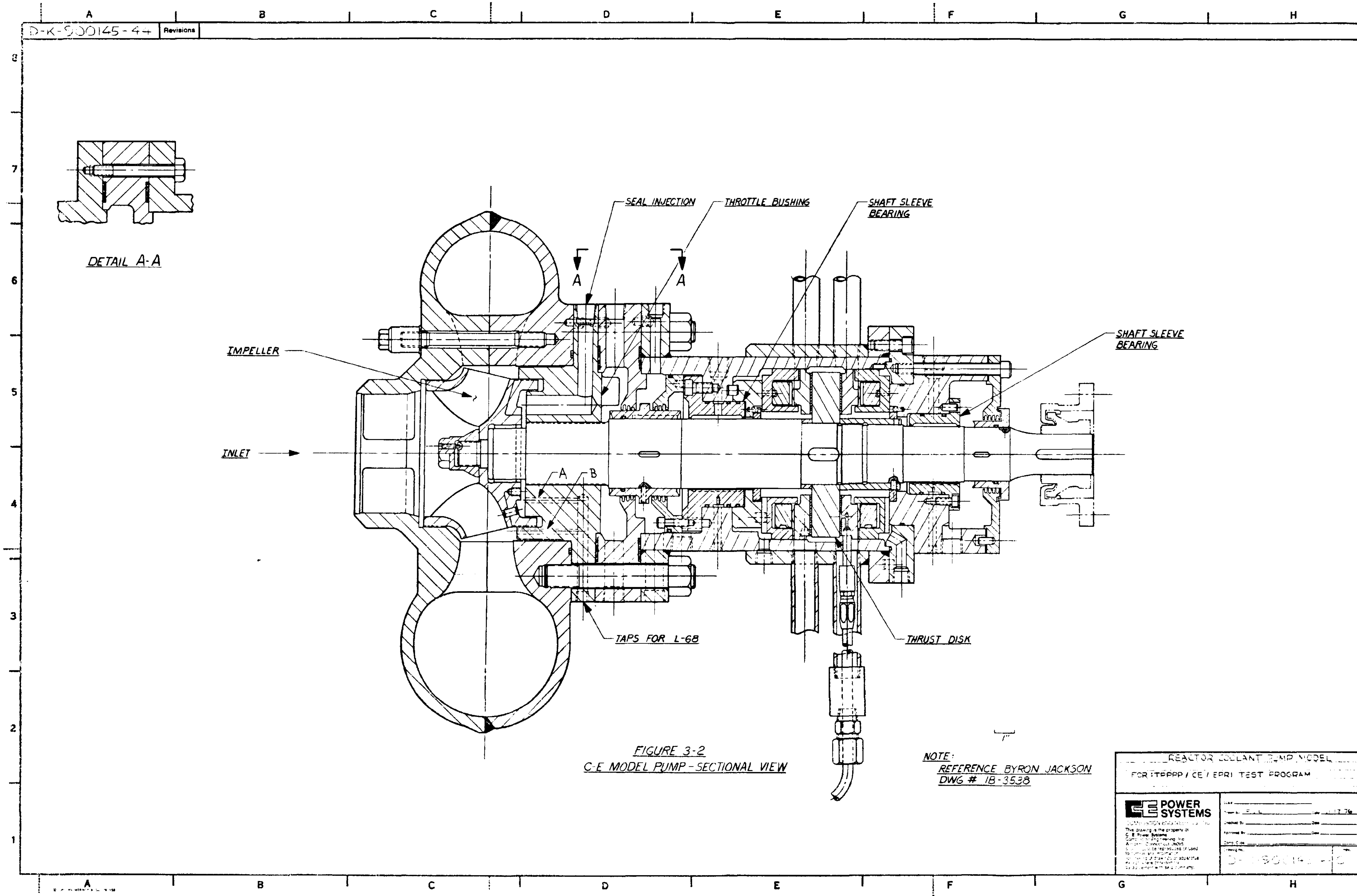


FIGURE 3-2
C-E MODEL PUMP - SECTIONAL VIEW

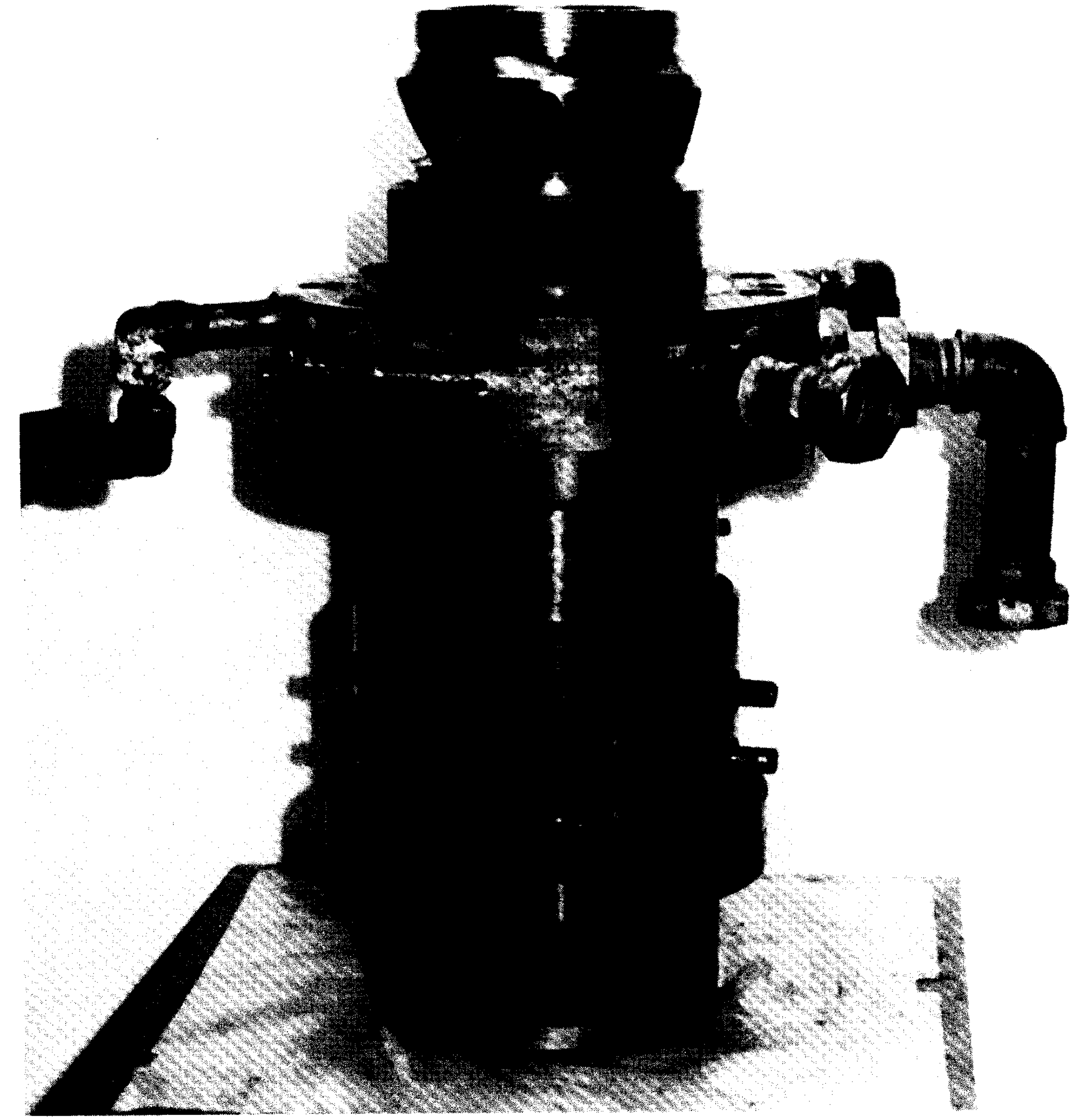


FIGURE 3-3
TEST PUMP BEARING ASSEMBLY WITH IMPELLER

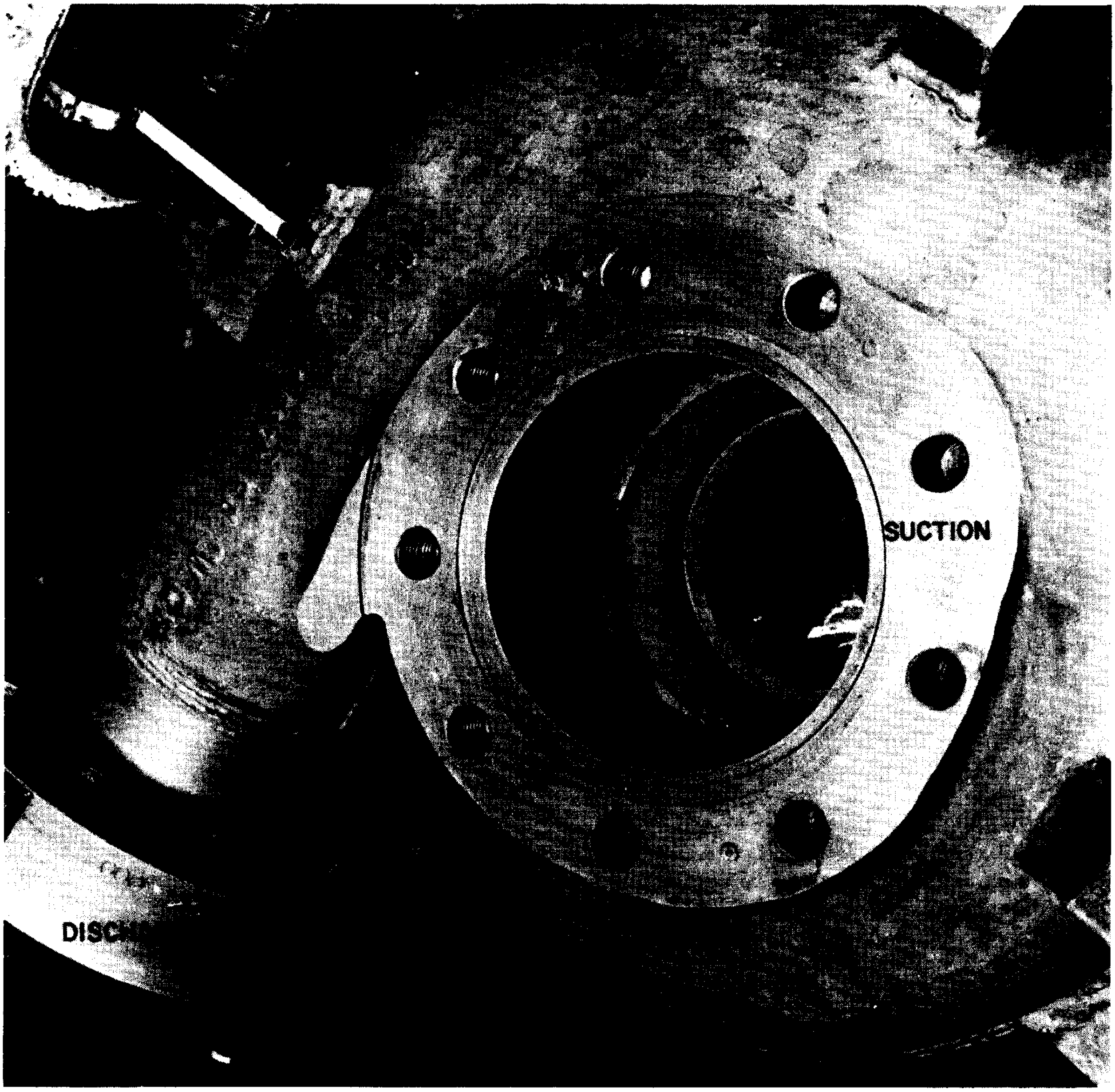


FIGURE 3-4

TEST PUMP CASING

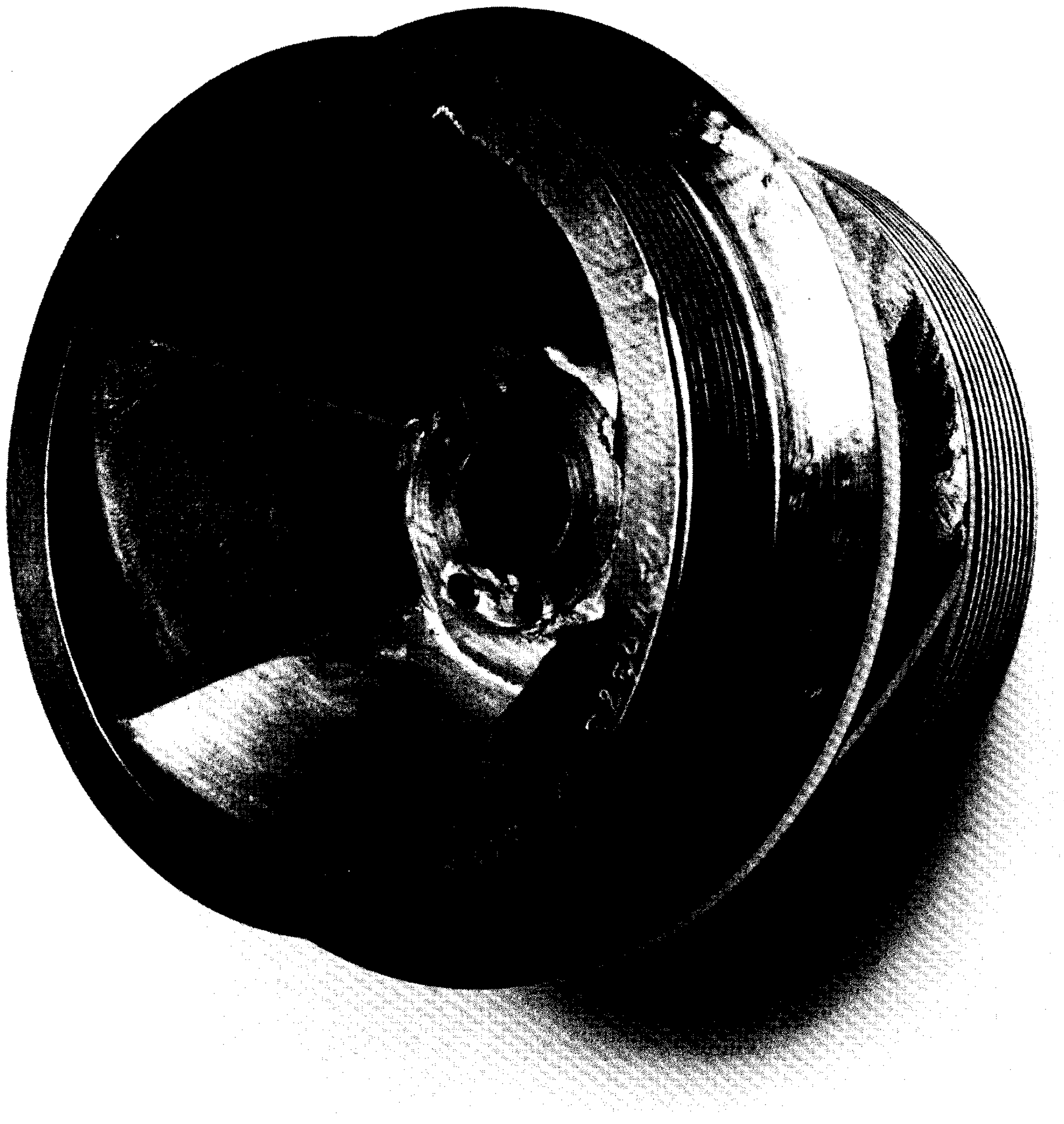


FIGURE 3-5
TEST PUMP IMPELLER SUCTION SIDE

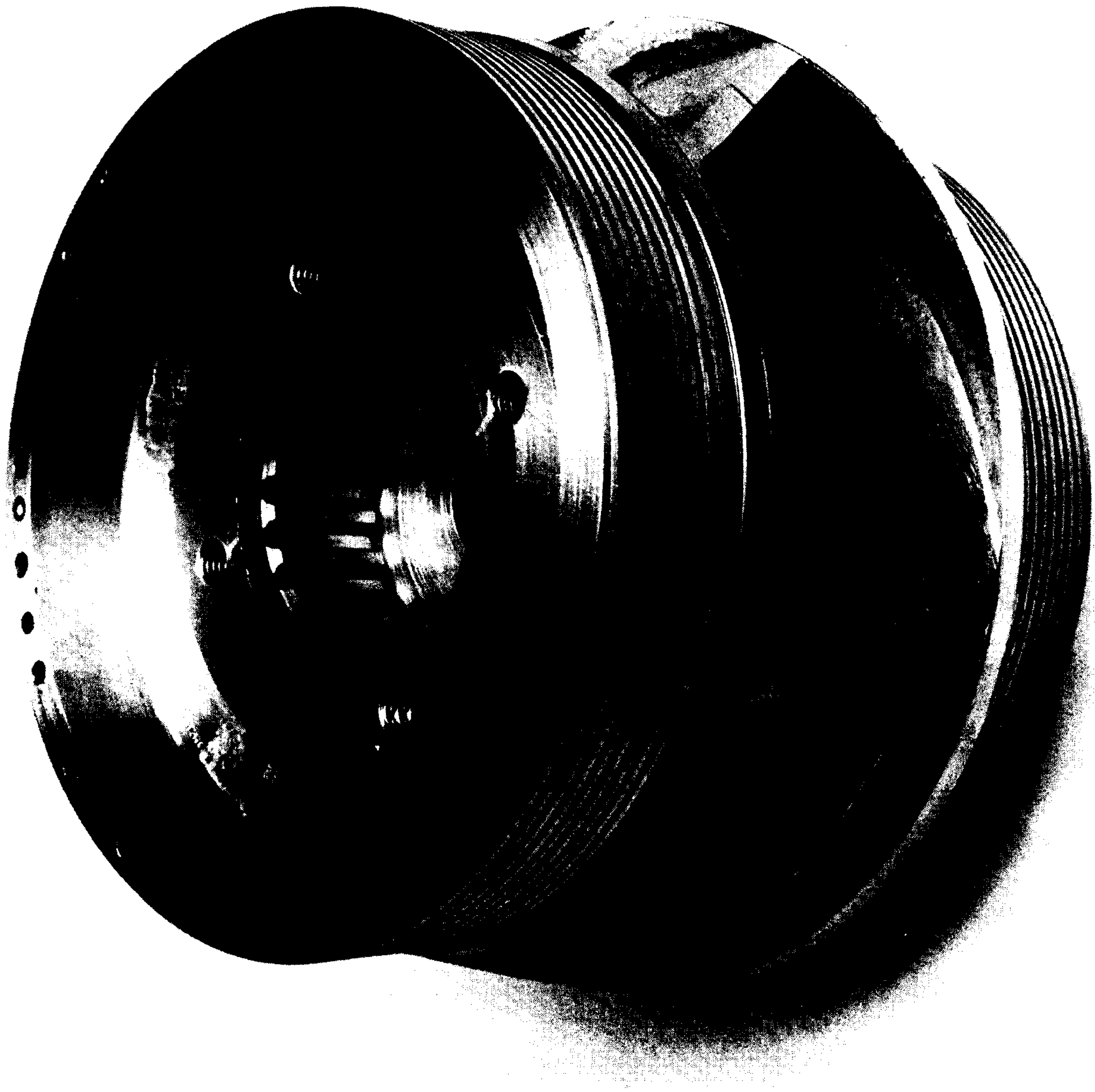


FIGURE 3-6
TEST PUMP IMPELLER - REAR

where,

NSSS refers to Typical NSSS pump

mod refers to C-E/B-J Model Pump

A full discussion of the scaling equations may be found in the Preliminary Test Plan (Reference 1).

The radial loads of the test pump shaft were supported by oil lubricated journal bearings designed for continuous operation between 0 and $\pm$ 10,000 rpm.

Major modification's were made to the thrust bearing assembly prior to the start of testing to assure more reliable operation and to allow start-up of the test pump at full loop pressure (1200 psi). The modifications included the installation of pivoted segmental thrust bearings (Kingsbury thrust bearing) and a high pressure (2500 psi) oil injection system. The high pressure oil injection system permitted starting the test pump at full loop pressure by forcing lubricating oil between the Kingsbury thrust bearings and the thrust disc. This forced lubrication prevented metal to metal contact between the thrust disc and the thrust bearings which could damage the bearings and prevent rotation of the test pump. In addition to the high pressure oil injection there was a low pressure (15 psig) oil injection system. This low pressure oil system provided large quantities of oil to the inboard radial bearing, outboard radial bearing, and the thrust bearing assembly.

The test pump seals were of the non-contacting labyrinth type and had relatively high leakage rates.

The test pump's seal injection system served two functions: (1) It prevented system heat from reaching the bearing housing by absorbing shaft heat; and (2) It prevented flashing of water into steam which would then invade the bearing oil system and cause lubrication breakdown.

The flow injection and throttle bushing leakage flow rate and temperature were measured and included in the loop heat balance calculations.

Tests were performed to determine the bearing friction torque as a function of system pressure and pump speed. Section 4.5.1 in Volume II discusses the procedure used for these tests. From the friction tests, the following empirical equation was obtained:

$$T = [A_1P + A_2P^2 + A_3 \, |N_p| + A_4 \, (N_p)^2]/12$$

where

T = friction torque (ft-lbf)

P = loop pressure (psi)

N_p = pump speed (rpm)

An analysis of the results obtained may be found in Volume II, Section 4.5.1, and Appendix B to Volume II.

The pump casing was designed in accordance with the ASME Code. The following stresses were calculated based on a design condition of 2000 psi and 575°F.

	Calculated (psi)	Allowable (psi)
Maximum wall stress	12,383	14,000
Maximum weld stress	9,140	10,500
Case Stud stress	32,900	40,000
Vane stud stress	99,000	yield = 200,000

The pump case studs bolted the pump case and the cover together. They were subjected to the hydrostatic end force on the cover. The vane studs and the casing peripheral weld held the two casing halves together. The vanes were cast integral with the casing halves, and therefore were split in the middle.

The moment of inertia of the impeller was determined by measuring its period of oscillation while supported on a knife edge. The value obtained was 1.32 $lbm\text{-}ft^2$. The weight of the impeller was 22.475 lb. The moment of inertia of the other components of the drive train (pump shaft, gear box, motor, couplings) was calculated and added to that for the impeller resulting in a total moment of inertia of 24.6 $lbm\text{-}ft^2$.

3.1.2 Water Performance Testing

In April 1973, hydraulic cold water performance tests were performed by the pump manufacturer, Byron-Jackson (B-J). A complete four-quadrant diagram was developed within a speed range from design speed froward to design speed in reverse and a range of flow rates from 210% of design flow forward to 160% of reverse design flow. The four-quadrant diagram showing the actual data points measured is given in Figure 3-7. The complete test report is included in Reference 6.

3.1.3 Test Arrangement

The test pump was designed and built to be mounted with a horizontal axis of rotation and inlet flow. NSSS reactor coolant pumps have a vertical axis of rotation and vertically upward inlet flow. A horizontal model was used in this project due to cost and schedule limitations, but performance results were not expected to be affected much by gravity except perhaps for two-phase flows combining low flow rates with low pump speeds.

The suction and discharge piping in the vicinity of the pump was scaled with a configuration close to 1/5 of a typical C-E reactor coolant system. Figure 3-8 shows the respective piping lengths with the only significant difference being A_1. The test pump piping was 6-inch schedule 80 pipe with an inside diameter slightly smaller (5.76 inches) than the 6-inch pump inlet and discharge. The two sizes were mated with a one-degree tapered transition piece at A_1. Modeling the two suction elbows was expected to effectively simulate NSSS piping effects for all but very low flows.

3.2 PUMP DRIVE SYSTEM

The model pump drive system included a speed increaser, a drive motor, and a variable frequency motor control system.

3.2.1 Speed Increaser

The speed increaser was of a horizontal, parallel shaft design. The housing was split horizontally on a plane through the center of the shafts. The single reduction gear train utilized helical gears and was supported by ball bearings. All axial thrust forces resulting from gear tooth loads were absorbed by the bearings and were contained within the housing.

The speed increaser was rated up for 300 hp and 1800/9000 rpm. It was capable of handling momentary overloads of 450% rated torque and 230% rated speed.

⊙ - POINTS ACTUALLY TESTED

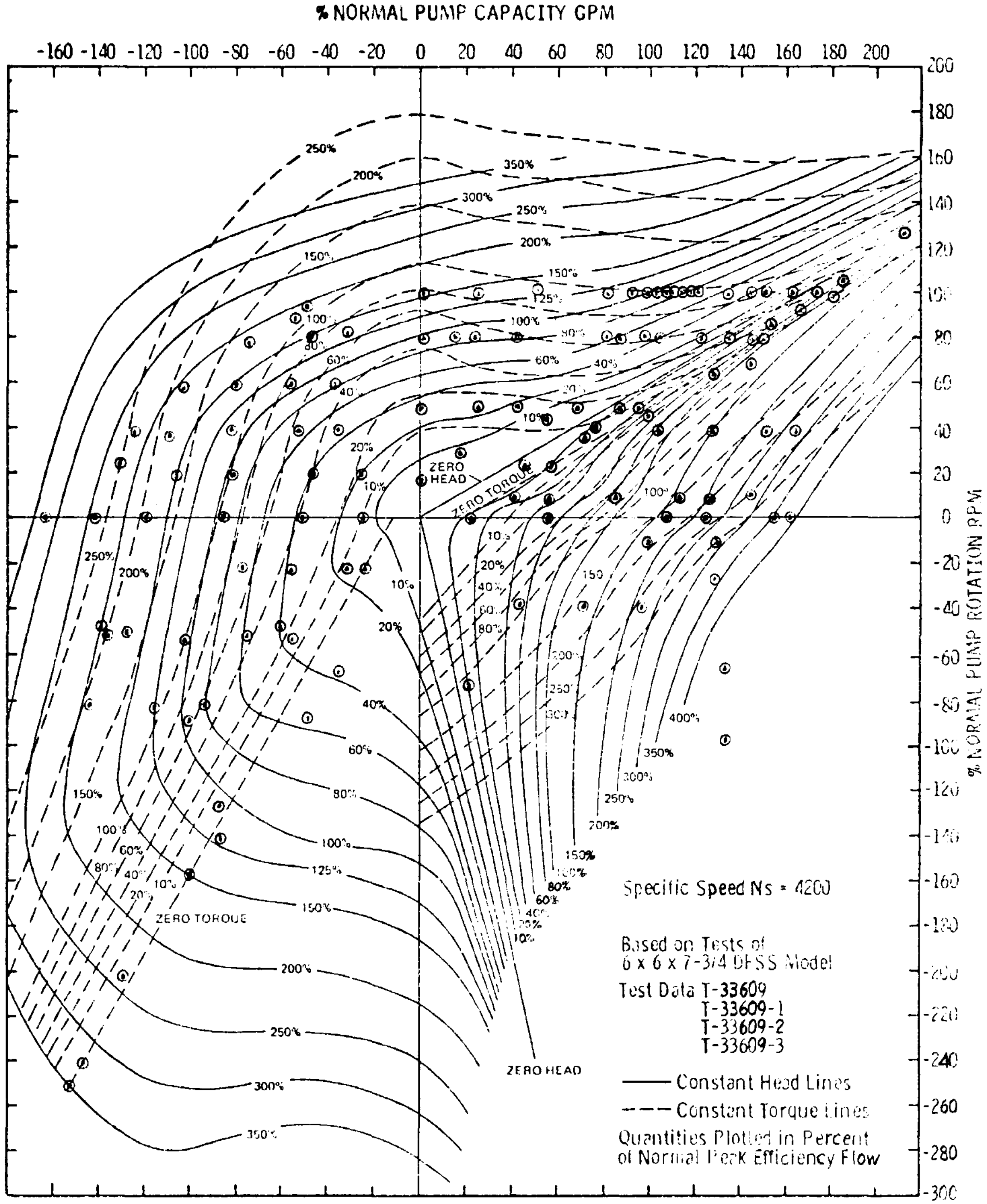
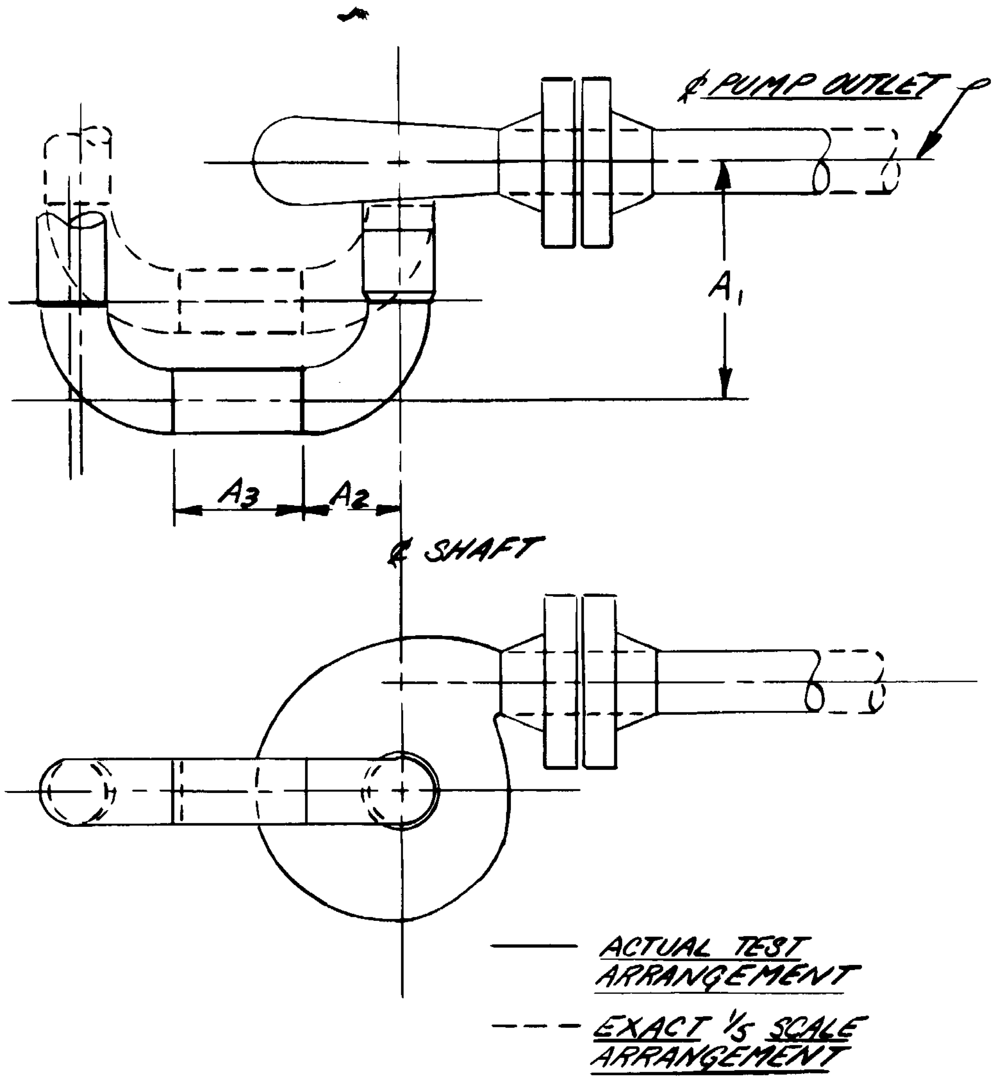


FIGURE 3-7 CE MODEL PUMP
COLD WATER PERFORMANCE CHARACTERISTICS



DIMENSION(1)	CE-NSSS (30" ID)	MODEL (6" ID)
A_1	2.1	3.7
A_2	1.5	1.5
A_3	1.9	2.0

NOTE(1) ~ DIMENSIONS ARE GIVEN IN NUMBER OF PIPE DIAMETERS

FIGURE 3-8 COMPARISON OF CE MODEL AND NSSS PUMP SUCTION AND DISCHARGE PIPING

The gears and bearings were pressure lubricated. The lubrication system consisted of an independently driven oil pump and a heat exchanger with suitable gages and pressure relief valves.

The couplings between the torque meter and the speed increaser, as well as between the motor and the speed increaser, were double engagement gear couplings.

3.2.2 Drive Motor

The drive motor was of a horizontally mounted Allis-Chalmers squirrel cage induction type rated for 300 hp at 900 rpm. It was designed for a speed range of 0 to ± 1800 rpm and provided constant torque when operating between 10 and 30 Hz (300-900 rpm) and constant power between 30 and 60 Hz (900-1800 rpm). This horsepower/torque characteristic is shown in Figure 3-9. In the case of transient tests, the motor was capable of running up to 3,300 rpm. The shaft was allowed to accept a maximum torque of 7,200 ft-lbf, or approximately 400% of its rated capacity for a maximum 1,000 stress cycles. An outline drawing of the motor is shown in Figure 3-10.

The Allis-Chalmers motor was provided with a dual shaft extension. The shaft end opposite the test pump was used for mounting a rotor locking device in addition to the tachometer generator. The motor was capable of operation in 100% relative humidity and was furnished with stator thermocouples to monitor the stator temperature. The tachometer was used by the motor drive electronics to measure speed for feedback to the motor speed controller.

3.2.3 Variable Frequency Control System

The drive system was all Allis-Chalmers link adjustable frequency system. The current link converter differed from a voltage link converter in that a DC current (instead of a DC voltage) was impressed sequentially on the three phases of an induction motor to produce a rotating field.

The control system regulated frequency and current (motor torque). With this type control, the motor current was limited to safe values at either steady or transient loadings. The motor overload torque capability at any speed was pre-set to assure maximum torque per ampere. The horsepower/torque characteristics for the motor and drive system are shown in Figure 3-9.

ALLIS CHALMERS CURRENT LINK VARIABLE SPEED DRIVE
MOTOR TYPE : 30·JS·8 (600 HP FRAME)
RATING : 300 HP AT 30 HZ (900 RPM)
: 1800 FT-LBF AT 30 HZ (900 RPM)

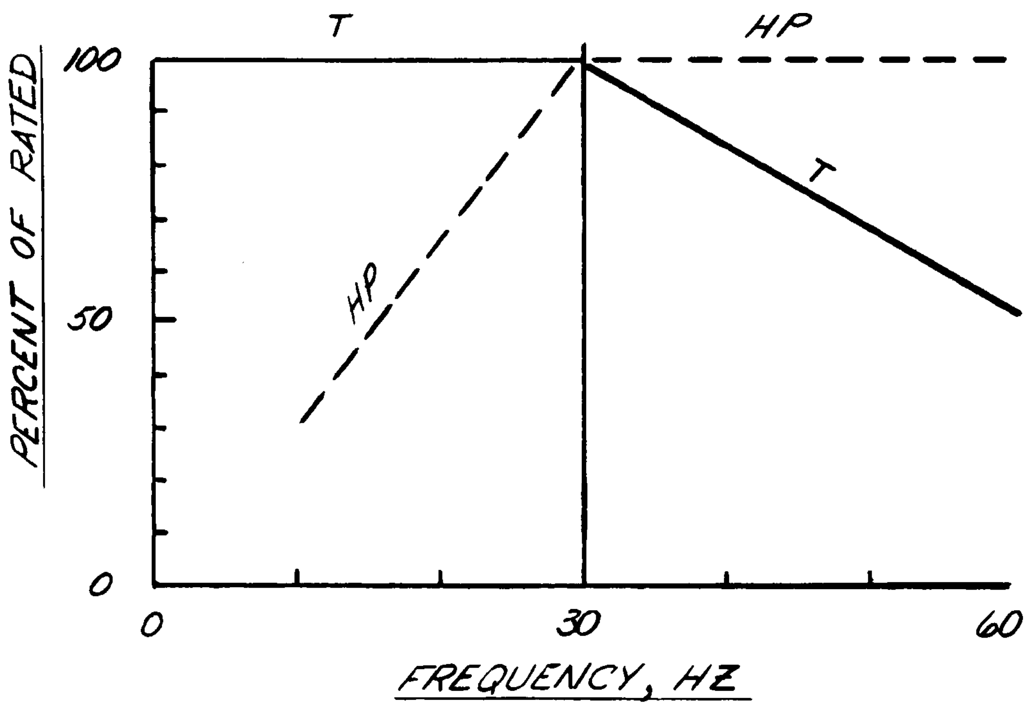


FIGURE 3-9 DRIVE UNIT PERFORMANCE CHARACTERISTICS

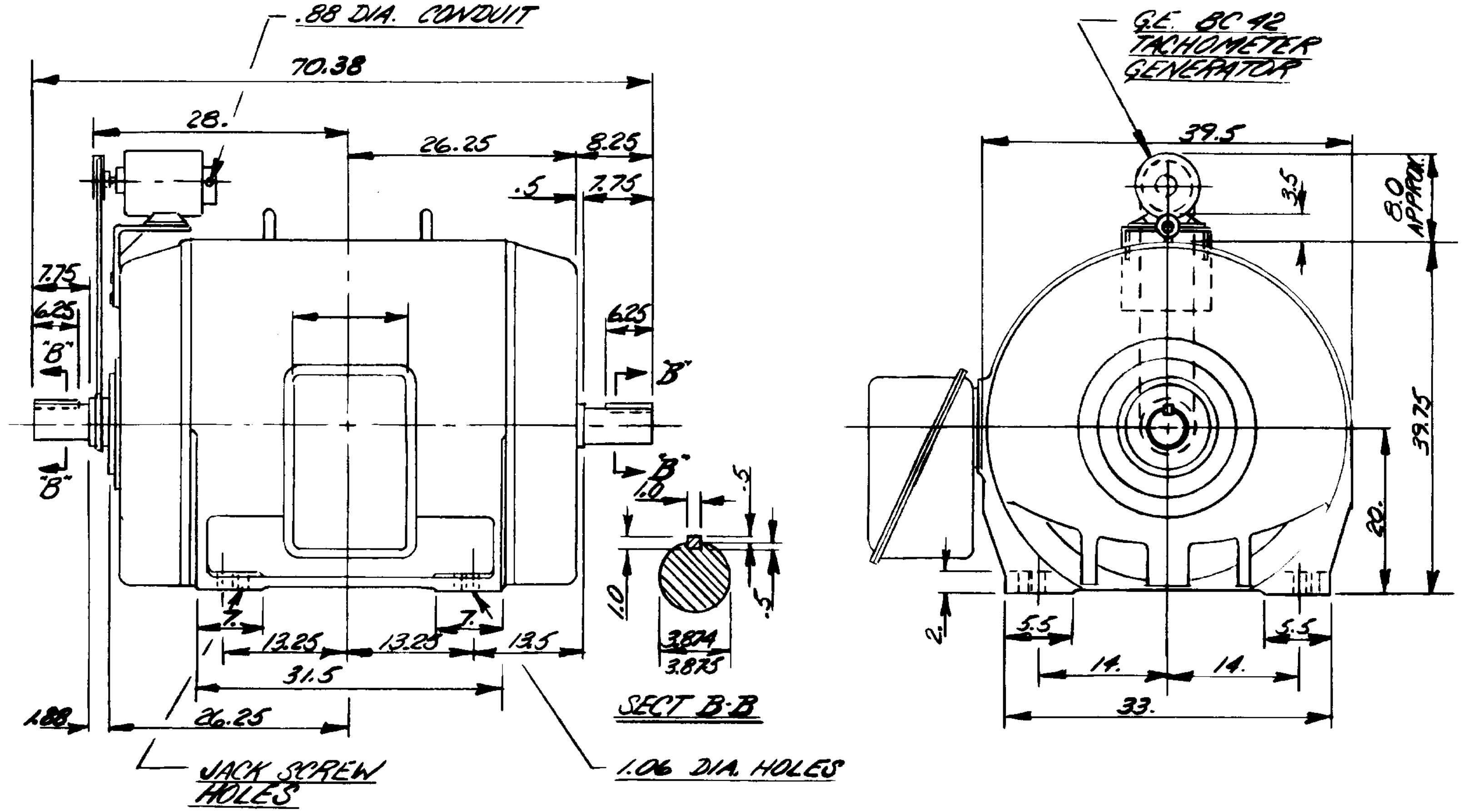


FIGURE 3-10 VARIABLE SPEED DRIVE UNIT MOTOR OUTLINE

Section 4

TEST INSTRUMENTATION

In order to meet the objectives of the Pump Two-Phase Performance Project a careful analysis was made of the types of pump performance data required for both steady-state and transient tests and the level of accuracy desired. This analysis led to the conclusion that pumps under single-and two-phase conditions could be characterized in terms of pump head and torque for a given pump speed, volumetric flow rate, fluid density and void fraction. In addition, other variables which might prove important were pressure, flow regime (for two-phase flow) and initial HP drum inventory (for transients). For transient testing all the above parameters had to be measured as a function of time. Once performance quantities were identified, the next step was to identify the parameter(s) required to determine each of the required quantities. Finally, instruments were selected and acquired from commercial vendors to measure each parameter. In many cases, the instruments required were state-of-the-art. Table 4-1 lists those instruments selected for each parameter. In some cases modifications and/or extensive calibration studies were necessary to obtain the required measurement capability. However, an instrumentation development effort was not within the scope of this project. Further details concerning data requirements may be found in the Preliminary Test Plan (Reference 1).

The next sub-section considers each of the measured parameters and their measurement location in the test loop. Individual instrumentation types are described in detail in Section 4.2. Instrumentation calibration is briefly covered in Section 4.3. Finally, Section 4.4 discusses the two data acquisition systems used.

Each test instrument location on the test loop was assigned a Location or L-number. These numbers referred to specific physical instrument location points as shown in Figure 4-1. Note that it was possible, in some cases, to

Table 4-1

SUMMARY OF INSTRUMENTATION CHARACTERISTICS

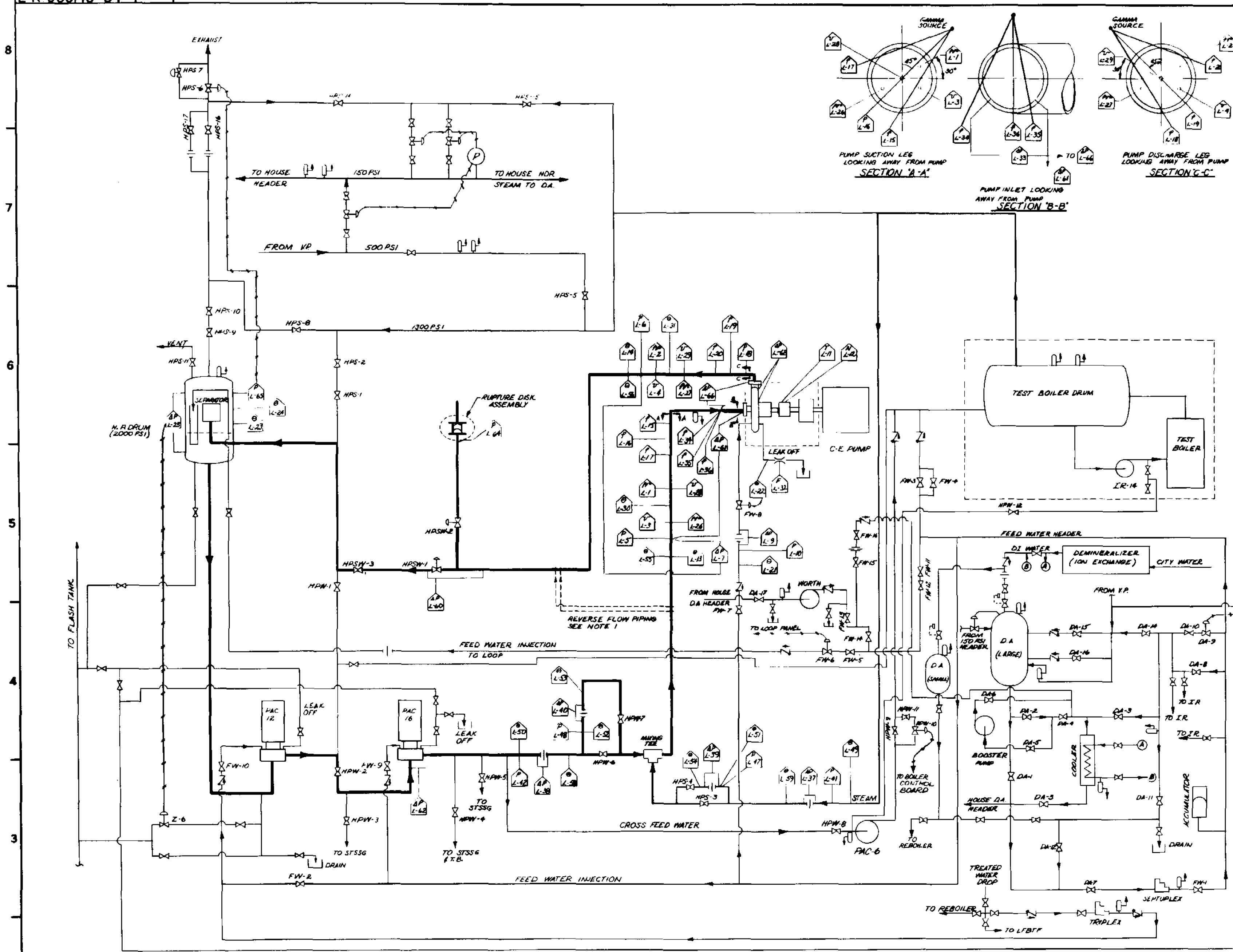
Parameter Measured	Type of Transducer	Manu. Model No.	Accuracy % Full Scale: Manu. Spec.	Accuracy % Full Scale: Measured Range (High - Low)	Time Constant (millisecond): Manu. Spec.	Time Constant (millisecond): Measured	Range(s)
Pressure	Capacitance Diaphragm	Rosemount Model #1104	±0.15	0.21 - 0.01	25	4.3 ±1.5	0-1500 psi
Differential Pressure	Capacitance Diaphragm	Rosemount Model #1151DP	±0.2	0.16 - 0.03	167		Varied See Table 4-2
	Strain Gage	BLH Electronics HMD	±0.5	0.067 - 0.022	<1	3.6 ±1.4	0 - ±200 psid 0 - ±500 psid
Momentum	Drag Disc (strain Gage)	Ramapo V5300-6 RBD Probe & SGA 300B Transmitter	±0.54		25	52.6 ±1.8	0-120, 200, 300, 400, 600, 1000 thousand $lbm/ft\text{-}sec^2$
Velocity	Turbine Meter	Flow Technology, Inc., & Anadex PI608	±0.64		70	108 ±22	0-90, 300 fps

Table 4-1 (Cont'd.)

SUMMARY OF INSTRUMENTATION CHARACTERISTICS

Parameter Measured	Type of Transducer	Manu. Model No.	Accuracy % Full Scale: Manu. Spec.	Accuracy % Full Scale: Measured Range High - Low	Time Constant (millisecond): Manu. Spec.	Time Constant (millisecond): Measured	Range(s)
Fluid Density & Void Fraction	3-Beam Gamma Densitometer	Measurements, Inc. AECL	±0.5	0.072 - 0.064	1.6	1 ±1	0-62.4 lbm/ft^3 0-62.4 lbm/ft^3
Temperature	RTD	Rosemount Model #108 MB Platinum Resistance Type	±0.2°F	0.11F - 0.08F			0-600F
Temperature	Thermocouples	Conax Model G 0.040" Dia.	±0.375		90		0-600F
Torque	Strain Gage	Lebow Model #1600 & Daytronic Model 878A	±0.35	0.05	3	2.5 ±2	0-2000 in-lbf. 0-1200 ft-lbf.
Speed	Magnetic	Lebow Model #1600 & Daytronic Model 878A	±0.05		20	23 ±1	0-10,000 rpm
Magnetic Flow	Magnetic	Foxboro 696A Converter	1%				0-50 GPM 0-100 GPM

E-K-900145-54



INSTRUMENTATION

P - PRESSURE CELL
ΔP - DIFFERENTIAL PRESSURE
θ - TEMPERATURE
- TURBINE METER
- DRAG DISK
ρ - DENSITOMETER
- PNEUMATIC SIGNAL

LO - LUBRICATION OIL
F - MAGNETIC FLOW METER
T - TORQUE METER
N - SPEED METER
TC - THRUST PADS
SG - THRUST PADS

LOCATION No.	DESCRIPTION	RANGE	SCANNER NUMBER	
L-1	SUCTION LEG DRAG DISK (HI)	VARIED	S-1	
L-2	DISCHARGE LEG DRAG DISK (HI)	VARIED	S-2	
L-3	SUCTION LEG TURBINE METER (LO)	VARIED	S-3	S-28*
L-4	DISCHARE LEG TURBINE METER (LO)	VARIED	S-4	S-29**
L-5	SUCTION LEG PRESURE CELL	0-1500 PSI	S-5	
L-6	DISCHARGE LEG PRESURE CELL	0-1500 PSI	S-6	
L-7H	PUMP LEG-TO-LEG ΔP CELL (BLH)	± 300 PSID	S-7	
L-7H	PUMP LEG-TO-LEG ΔP CELL	VARIED	S-7A	
L-7L	PUMP LEG-TO-LEG ΔP CELL (BLH)	± 200 PSID	S-8	
L-7	PUMP LEG-TO-LEG ΔP CELL	VARIED	S-8A	
L-9	PUMP INJECTION INLET ΔP CELL	0-25 PSID	S-9	
L-10	PUMP INJECTION INLET PRESURE CELL	0-1500 PSID	S-10	
L-11	PUMP TORQUE METER	0-200/0-1200 ft-lb	S-11	
L-12	PUMP SPEED METER	0-10,000 RPM	S-12	
L-13	SUCTION LEG THEMOCOUPLE	0-600°F	S-13	
L-14	DISCHARE LEG THEMOCOUPLE	0-600	S-14	
L-15	SUCTION LEG DENSITOMETER, BEAM 1	0-62.4 lb/ft³	S-15	
L-16	SUCTION LEG DENSITOMETER, BEAM 2	0-62.4 lb/ft³	S-16	
L-17	SUCTION LEG DENSITOMETER BEAM 3	0-62.4 lb/ft³	S-17	
L-18	DISCHARGE LEG DENSITOMETER, BEAM 1	0-62.4 lb/ft³	S-18	
L-19	DISCHARGE LEG DENSITOMETER, BEAM 2	0-62.4 lb/ft³	S-19	
L-20	DISCHARGE LEG DENSITOMETER, BEAM 3	0-62.4 lb/ft³	S-20	
L-21	PUMP INJECTION INLET THERMOCOUPLE	0-600°F	S-21	
L-22	PUMP INJECTION OUTLET THERMOCOUPLE	0-600°F	S-22	
L-23	HIGH PRESURE DRUM ID THERMOCOUPLE	0-600°F	S-23	
L-24	HIGH PRESURE DRUM OD THERMOCOUPLE	0-600°F	S-24	
L-25	HIGH PRESURE DRUM LEVEL ΔP CELL	0-2.5 PSID	S-25	
L-26	SUCTION LEG DRAG DISK (LOWER)	VARIED	S-26	
L-27	DISCHARGE LEG DRAG DISK (LOWER)	VARIED	S-27	
L-28	SUCTION LEG TURBINE METER	VARIED	S-28	S-3*
L-29	DISCHARGE LEG TURBINE METER	VARIED	S-29	S-4**
L-30	SUCTION LEG DRAG DISK THERMOCOUPLE	0-600° F	S-30	
L-31	DISCHARGE LEG DRAG DISK THERMOCOUPLE	0-600°F	S-31	
L-32	PUMP INJECTION OUTLET FLOW	VARIED	S-32	
L-33	INLET ACROSS PIPE ΔP	± 300 in.	S-33	
L-34	INLET DENSITOMETER, BEAM 3	0-62.4 lb/ft³	S-34	
L-35	INLET DENSITOMETER, BEAM 1	0-62.4 lb/ft³	S-35	
L-36	INLET DENSITOMETER, BEAM 2	0-62.4 lb/ft³	S-36	
L-37L	MAIN STEAM ORIFICE ΔP CELL	0-3.5 PSID	S-37	
L-37H	MAIN STEAM ORIFICE ΔP CELL	0-25 PSID	S-43	
L-38L	MAIN WATER ORIFICE ΔP CELL	0-3.5 PSID	S-38	
L-38M	MAIN WATER ORIFICE ΔP CELL	0-25 PSID	S-44	
L-38H	MAIN WATER ORIFICE ΔP CELL	VARIED	S-69	
L-39L	BYPASS STEAM ORIFICE ΔP CELL	0-3.5 PSID	S-39	
L-39H	BYPASS STEAM ORIFICE ΔP CELL	0-25 PSID	S-45	
L-40L	BYPASS WATER ORIFICE ΔP CELL	0-3.5 PSID	S-40	
L-40H	BYPASS WATER ORIFICE ΔP CELL	0-25 PSID	S-46	
L-41	MAIN STEAM ORIFICE PRESURE CELL	0-1500 PSI	S-41	
L-42	MAIN WATER ORIFICE PRESURE CELL	0-1500 PSI	S-42	
L-47	BYPASS STEAM ORIFICE PRESURE CELL	0-1500 PSI	S-47	
L-48	BYPASS STEAM ORIFICE PRESURE CELL	0-1500 PSI	S-48	
L-49	MAIN STEAM ORIFICE THERMOCOUPLE	0-600°F	S-49	
L-50	MAIN WATER ORIFICE THERMOCOUPLE	0-600°F	S-50	
L-51	BYPASS STEAM ORIFICE THERMOCOUPLE	0-600°F	S-51	
L-52	BYPASS WATER ORIFICE THERMOCOUPLE	0-600°F	S-52	
L-53	BYPASS WATER ORIFICE RTD	0-600°F	S-53	
L-54	BYPASS STEAM ORIFICE RTD	0-600°F	S-54	
L-55	SUCTION LEG RTD	0-600°F	S-55	
L-56	DISCHARGE LEG RTD	0-600°F	S-56	
L-57	AMBIENT TEMPERATURE THERMOCOUPLE	0-200°F	S-57	
L-58	MAIN WATER ORIFICE RTD	0-600°F	S-58	
L-59	MAIN STEAM ORIFICE RTD	0-600°F	S-59	
L-60	LOOP FLOW CONTROL VALVE ΔP CELL	0-200 PSID	S-60	
L-61	SUCTION LEG TO INLET FLANGE ΔP CELL	0-10 PSID	S-61	
L-62	PAC 16 ΔP CELL	0-200 PSID	S-62	
L-64	BLOWDOWN LEG PRESSURE CELL	0-1500PSI	S-64	
L-65	H.P. DRUM PRESSURE CELL	0-1800 PSI	S-65	
L-66	TEST PUMP FLANGE TO FLANGE ΔP CELL	VARIED	S-66	
L-68	PUMP VOLUTE TO IMPELLER BACK ΔP CELL	0-25 PSID	S-68	

* FOR TESTS 209-243 and 298-453

** FOR TESTS 209 — 608

VALVE IDENTIFICATION

VALVE No.	DESCRIPTION
DA-1	COOLER BYPASS VALVE
DA-2	COOLER INLET VALVE
DA-3	COOLER OUTLET VALVE
DA-4	BOOSTER PUMP BYPASS VALVE
DA-5	BOOSTER PUMP INLET VALVE
DA-6	BOOSTER PUMP OUTLET VALVE
DA-7	SEPTUPEX INLET (SUCTION) VALVE
DA-8	MANUAL DA RETURN
DA-9	PNEUMATIC DA RETURN
DA-10	ISOLATION - PNEUMATIC DA RETURN
DA-11	RETURN TO SEPTUPLEX SUCTION (IN SERIES W/DA-12)
DA-12	RETURN TO SEPTUPLEX
DA-13	RETURN TO COOLER
DA-14	RETURN TO DA
DA-15	RETURN INTO UPPER PLENUM OF DA
DA-16	RETURN INTO LOWER PLENUM OF DA
DA-17	WORTHINGTON CENTRIFUGAL INLET VALVE

VALVE No.	DESCRIPTION
HPS-1	BOILER DRUM TO H.P. DRUM ISOLATION VALVE
HPS-2	BOILER DRUM TO H.P. DRUM ISOLATION VALVE
HPS-3	MAIN STEAM FLOW VALVE (6" ANGLE VALVE)
HPS-4	STEAM BYPASS VALVE
HPS-5	VP BOILER TO LOOP ISOLATION VALVE (CROSS TIE SYSTEM)
HPS-6	PNEUMATIC VENT FOR TEST BOILER AND LOOP
HPS-7	PNEUMATIC VENT FOR TEST BOILER AND LOOP
HPS-8	TEST BOILER TO VENT ISOLATION VALVE
HPS-9	H.P. DRUM TO VENT ISOLATION VALVE
HPS-10	H.P. DRUM TO VENT ISOLATION VALVE
HPS-11	2" VENT ON TOP OF H.P. DRUM
HPS-14	LOOP STEAM TO HOUSE HEADER
HPS-15	BOILER STEAM TO HOUSE HEADER
HPS-16	MAIN MANUAL VENT VALVES
HPS-17	BYPASS MANUAL VENT VALVES

VALVE No.	DESCRIPTION
HPW-1	DRUM INTERNAL ISOLATION VALVE
HPW-2	LOOP ISOLATION VALVE
HPW-3	STSSG ISOLATION VALVE
HPW-4	STSSG ISOLATION VALVE
HPW-5	STSSG ISOLATION VALVE
HPW-6	MAIN WATER FLOW CONTROL VALVE
HPW-7	BYPASS WATER FLOW CONTROL VALVE
HPW-8	PAC 6 SUCTION VALVE
HPW-9	PAC 6 MAIN FLOW CONTROL VALVE
HPW-10	PAC 6 PNEUMATIC BYPASS CONTROL VALVE
HPW-11	PAC 6 MANUAL BYPASS SHUT-OFF VALVE
HPW-12	PAC 6 BLOWDOWN CIRCULATION VALVE

VALVE No.	DESCRIPTION
FW-1	SEPTUPLEX OUTLET VALVE
FW-2	TRIPLEX OUTLET VALVE (LOCATED AT MEZZANINE LEVEL)
FW-3	LARGE BOILER FEED VALVE
FW-4	SMALL BOILER FEED VALVE
FW-5	MANUAL LOOP FEEDWATER VALVE
FW-6	PNEUMATIC LOOP FEEDWATER VALVE
FW-7	TEST PUMP INJECTION MANUAL SHUT-OFF
FW-8	TEST PUMP INJECTION CONTROL VALVE
FW-9	PAC-16 SEAL INJECTION VALVE
FW-10	PAC-12 SEAL INJECTION VALVE
FW-11	SEPTUPLEX LOOP FEEDWATER VALVE
FW-12	SEPTUPLEX LOOP FEEDWATER VALVE
FW-13	WORTHINGTON CENTRIFUGAL OUTLET VALVE
FW-14	WORTHINGTON CENTRIFUGAL LOOP FEEDWATER VALVE
FW-15	WORTHINGTON CENTRIFUGAL OUTLET BYPASS
FW-16	WORTHINGTON CENTRIFUGAL OUTLET BYPASS

VALVE No.	DESCRIPTION
HPSW-1	TPPP LOOP FLOW CONTROL VALVE
HPSW-2	TPPP BLOWDOWN VALVE
HPSW-3	TPPP ISOLATION VALVE

NOTES:

1) FOR REVERSE FLOW TESTING, PIPING SWITCH IS MADE AS INDICATED

2) DIFFERENTIAL PRESSURE CELLS ARE INSTALLED SO THAT A PRESSURE RISE IN POSITIVE FLOW DIRECTION, AS INDICATED BY THE ARROWS IS DEFINED AS POSITIVE. FOR REVERSE FLOW TESTING, THE DIFFERENTIAL PRESSURE CELL AT LOCATION L-61 IS REVERSED

FIGURE 4-1

PIPING & INSTRUMENTATION DIAGRAM

CE / EPRI PUMP TEST FACILITY

C-E POWER SYSTEMS
COMBUSTION ENGINEERING INC

Scale N/A
Date 9-22-78
Date 9-22-78
Date 9-20-78

E-K-900145-54 | Rev 0

connect more than one instrument to the location specified by a particular L-number. Two or even three Δp cells of different ranges could be physically connected to the same set of taps. However, each instrument was electrically connected to only one port of the steady-state data acquisition system (data scanner). In addition, certain instruments were also connected to the ports of the transient data acquisition system (FM system). Table 4-2 is a list of all test instrumentation utilized in the pump test program. Instruments are listed sequentially by scanner number assignment. The second column lists the location number. Where more than one instrument was attached at a particular location number a letter designator follows the L-number to identify the relative range of the cell attached (L-low, M-medium, H-high). Following the description column is a column showing various ranges the instrument had during testing. Volume VIII covers the history of the instrumentation in greater detail.

Besides test instrumentation there was a second group of instruments, known as loop instrumentation, provided to aid the test operator. Many instruments served both functions. Those test instruments which also served as loop instruments are indicated in the final column of Table 4-2. No further discussion of loop instrumentation will be provided.

4.1 DESCRIPTION OF MEASUREMENT LAYOUT

In order to simplify the discussion of test instrumentation an arbitrary division into measurement groups was made. These groups were largely based on instrument location and include (1) flow orifices, (2) test pump instrumentation, and (3) miscellaneous instrumentation. Each is discussed in turn below.

4.1.1 Orifices

In order to achieve the desired accuracy and range in loop flow rate measurement for steady-state testing, steam flow and water flow were measured, each with two orifices. Each orifice run included pressure and temperature sensors to allow for an accurate determination of density at each orifice. The relative location of these instruments in the loop is shown isometrically in Figure 4-2.

A standard orifice installation is shown in Figure 4-3. This figure specifies instrumentation location relative to the orifice plate according to standard

Table 4-2

TWO PHASE PUMP PERFORMANCE PROGRAM

INSTRUMENTATION LIST

Scanner Channel Number	Instrument Location Number	Description	Range	Other Readouts[a]
0		*Short for DVM*		
1	L-1	Pump Suction Drag Disk	0-200,000 lb/ft-sec^2 0-300,000 lb/ft-sec^2 0-400,000 lb/ft-sec^2 0-600,000 lb/ft-sec^2	P-0
2	L-2	Pump Discharge Drag Disk	0-200,000 lb/ft-sec^2 0-400,000 lb/ft-sec^2 0-600,000 lb/ft-sec^2	
3 or 28[b]	L-3	Pump Suction Turbine Meter	0-300 ft/sec, 0-90 ft/sec	
4 or 29[c]	L-4	Pump Discharge Turbine Meter	0-300 ft/sec, 0-90 ft/sec	
5	L-5	Pump Suction Pressure Cell	0-1500 psi	P-1, mvG-1
6	L-6	Pump Discharge Pressure Cell	0-1500 psi	mvG-2
7	L-7H	Pump D/P Cell (Hi) (Leg-to-leg)	0-$\pm$500 psid (BLH)	mvG-3
7A	L-7H	Pump D/P Cell (Hi) (Leg-to-leg)	0-200 psid -100/0/200 psid	mvG-3
8	L-7L	Pump D/P Cell (Lo) (Leg-to-leg)	0-$\pm$200 psid	mvG-3
8A	L-7L	Pump D/P Cell (Lo) (Leg-to-leg)	0-25 psid -8/0/+16 psid	mvG-3
9	L-9	Pump Inlet Injection D/P Cell	0-25 psid	mvG-4
10	L-10	Pump Inlet Injection Pressure Cell	0-1500 psid	
11	L-11	Pump Torque Meter	0-1200 ft-lbf 0-2000 in-lbf	mvG-6, P-2

Table 4-2 (Cont'd.)

TWO PHASE PUMP PERFORMANCE PROGRAM

INSTRUMENTATION LIST

Scanner Channel Number	Instrument Location Number	Description	Range	Other Readouts[a]
12	L-12	Pump Speed Meter	0-10,000 RPM	T, mvG-7, P-3
13	L-13	Pump Suction Thermocouple	0-600°F	TG-1
14	L-14	Pump Discharge Thermocouple	0-600°F	TG-2
15	L-15	Pump Suction Densitometer, Lower Beam 1	0-62.4 lb/ft^3	
16	L-16	Pump Suction Densitometer, Center Beam 2	0-62.4 lb/ft^3	
17	L-17	Pump Suction Densitometer, Upper Beam 3	0-62.4 lb/ft^3	
18	L-18	Pump Discharge Densitometer, Lower Beam 1	0-62.4 lb/ft^3	
19	L-19	Pump Discharge Densitometer, Center Beam 2	0-62.4 lb/ft^3	
20	L-20	Pump Discharge Densitometer, Upper Beam 3	0-62.4 lb/ft^3	
21	L-21	Pump Inlet Injection Flow Thermocouple	0-600°F	TG-3
22	L-22	Pump Outlet Injection Flow Thermocouple	0-600°F	TG-4, A
23	L-23	High Pressure Drum ID Thermocouple	0-600°F	TG-5
24	L-24	High Pressure Drum OD Thermocouple	0-600°F	TG-6
25	L-25	High Pressure Water Level D/P Cell	0-2.5 psid	mvG-8, P-4

Table 4-2 (Cont'd.)

TWO PHASE PUMP PERFORMANCE PROGRAM

INSTRUMENTATION LIST

Scanner Channel Number	Instrument Location Number	Description	Range	Other Readouts[a]
26	L-26	Pump Suction Drag Disk	120,000 lb/ft-sec^2 400,000 lb/ft-sec^2 600,000 lb/ft-sec^2 1,000,000 lb/ft-sec^2	
27	L-27	Pump Discharge Drag Disk	120,000 lb/ft-sec^2 400,000 lb/ft-sec^2 600,000 lb/ft-sec^2 1,000,000 lb/ft-sec^2	
28 or 3[b]	L-28	Pump Suction Turbine Meter	0-90 ft/sec, 0-300 ft/sec	
29 or 4[c]	L-29	Pump Discharge Turbine Meter	0-90 ft/sec, 0-300 ft/sec	
30	L-30	Pump Suction DD Thermocouple	0-600°F	TG-16
31	L-31	Pump Discharge DD Thermocouple	0-600°F	TG-17
32	L-32	Pump Injection Outlet Flow (Magn. F.M)	0-50 GPM 0-100 GPM	
33	L-33	Pump Suction D/P BLH (Inlet/Across Pipe - 90°)	0-±500 inches H_2O	
34	L-34	AECL Densitometer, Outer Beam 1	0-62.4 lb/ft^3	
35	L-35	AECL Densitometer, Inner Beam 3	0-62.4 lb/ft^3	
36	L-36	AECL Densitometer, Center Beam 2	0-62.4 lb/ft^3	
37	L-37L	Main Steam Orifice DP Cell (Lo)	0-3.5 psid	
38	L-38L	Main Water Orifice DP Cell (Lo)	0-3.5 psid	
39	L-39L	Bypass Steam Orifice DP Cell (Lo)	0-3.5 psid	

Table 4-2 (Cont'd.)

TWO PHASE PUMP PERFORMANCE PROGRAM

INSTRUMENTATION LIST

Scanner Channel Number	Instrument Location Number	Description	Range	Other Readouts[a]
40	L-40L	Bypass Water Orifice DP Cell (Lo)	0-3.5 psid	
41	L-41	Main Steam Orifice Pressure Cell	0-1500 psi	mvG-9
42	L-42	Main Water Orifice Pressure Cell	0-1500 psi	mvG-10
43	L-37H	Main Steam Orifice DP Cell (Hi)	0-25 psid	mvG-11, P-5
44	L-38M	Main Water Orifice DP Cell (Mid)	0-25 psid	mvG-12, P-6
45	L-39H	Bypass Steam Orifice DP Cell (Hi)	0-25 psid	mvG-5, P-7
46	L-40H	Bypass Water Orifice DP Cell (Hi)	0-25 psid	mvG-13, P-8
47	L-47	Bypass Steam Orifice Pressure Cell	0-1500 psi	
48	L-48	Bypass Water Orifice Pressure Cell	0-1500 psi	
49	L-49	Main Steam Orifice Thermocouple	0-600°F	TG-7
50	L-50	Main Water Orifice Thermocouple	0-600°F	TG-8
51	L-51	Bypass Steam Orifice Thermocouple	0-600°F	TG-14
52	L-52	Bypass Water Orifice Thermocouple	0-600°F	TG-15
53	L-53	Bypass Water Orifice RTD	0-600°F	mvG-18
54	L-54	Bypass Water Orifice RTD	0-600°F	mvG-19
55	L-55	Pump Suction RTD	0-600°F	mvG-16
56	L-56	Pump Discharge RTD	0-600°F	mvG-17
57	L-57	Ambient Temperature	0-200°F	TG-13

Table 4-2 (Cont'd.)

TWO PHASE PUMP PERFORMANCE PROGRAM

INSTRUMENTATION LIST

Scanner Channel Number	Instrument Location Number	Description	Range	Other Readouts[a]
58	L-58	Main Water Orifice RTD	0-600°F	mvG-14, P-9
59	L-59	Main Steam Orifice RTD	0-600°F	mvG-15
60	L-60	Loop Flow Control Valve DP Cell	0-200 psid	
61	L-61	Pump Suction (Inlet Leg-to-Flange)	0-10 psid	
62	L-62	PAC-16 Pump DP Cell	0-200 psid	
63				
64	L-64	Blowdown Leg Pressure Cell	0-1500 psi	
65	L-65	H.P. Drum Pressure Cell	0-1500 psi	
66	L-66	Pump Flange-to-Flange DP Cell	0-200 psid -100/0/200 psid	
67		Blowdown Sequence Indicator		
68	L-68	Pump Impeller (Front-to-Back) D/P	0-25 psid	
69	L-38H	Main Water Orifice D/P (Hi)	0-50 psid 0-100 psid	

[a]Legend: Other readouts:
P: Panel Meter
T: Trip Function
A: Alarm
mvG: Speedomax Millivolt Recorder
TG: Speedomax Temperature Recorder

[b]L-3 was read by S-28, and L-28 was read by S-3 for tests 209-243 and 298-453

[c]L-4 was read by S-29, and L-29 was read by S-4 for tests 209-609.

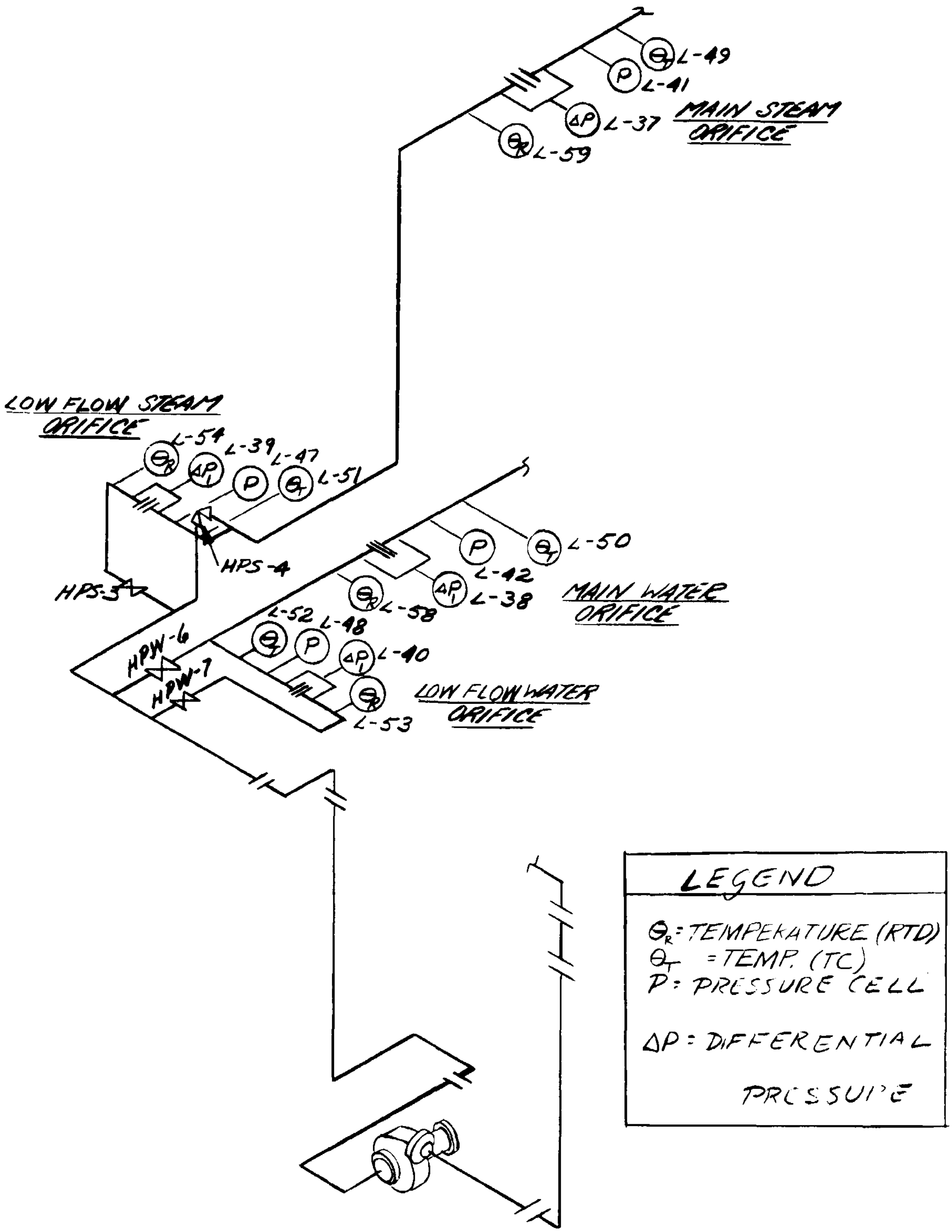
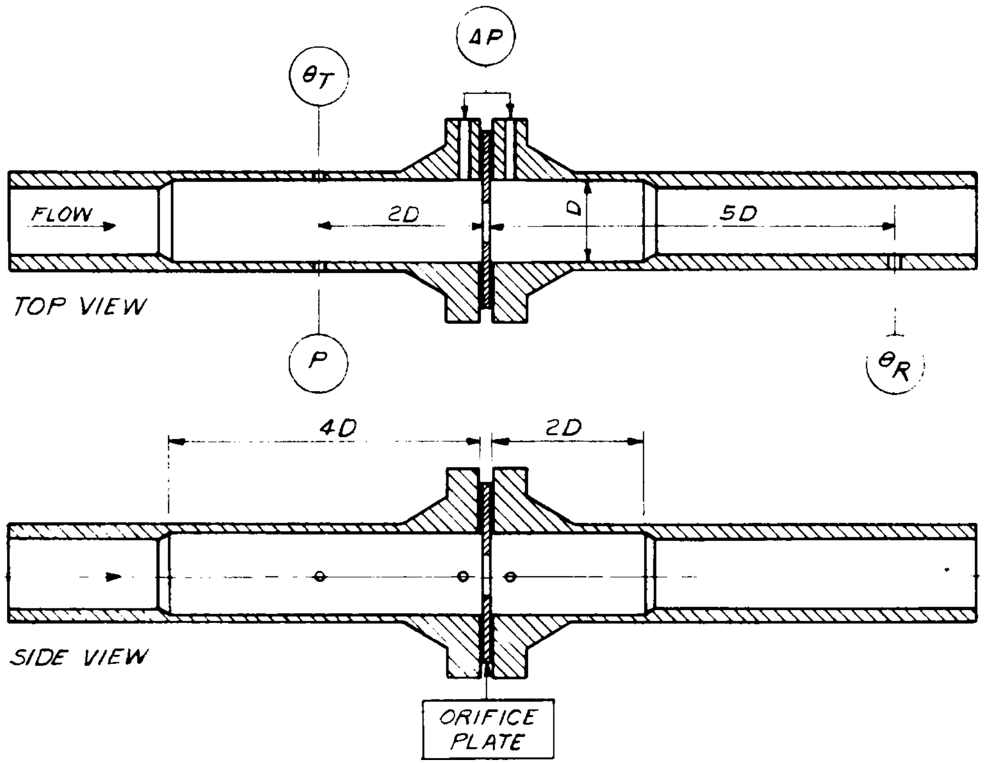
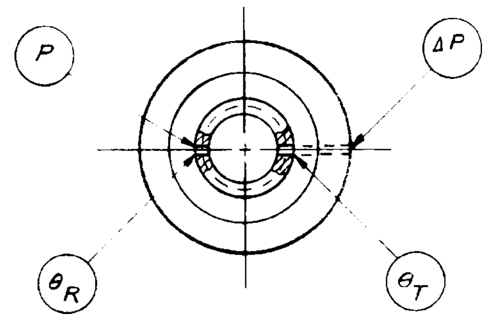


FIGURE 4-2 ORIFICE LOCATIONS

NOTES:

1. ALL INSTRUMENT TAPS LOCATED HORIZONTALLY.





ORIFICE	LOCATION NO. ΔP LOW	ΔP MED	ΔP HIGH	P	θ_{RTD}	θ_{TC}
MAIN WATER	L-38L	L-38M	L-38H	L-42	L-58	L-50
LOW FLOW WATER	L-40L		L-40H	L-48	L-53	L-52
MAIN STEAM	L-37L		L-37H	L-41	L-59	L-49
LOW FLOW STEAM	L-39L		L-39H	L-47	L-54	L-51
TEST PUMP INJECTION			L-9	L-10		L-21

LEGEND

θ_T = THERMOCOUPLE

θ_R = RESISTANCE TEMPERATURE DEVICE

P = PRESSURE CELL

ΔP = DIFFERENTIAL PRESSURE CELL

FIGURE 4-3

ORIFICE INSTRUMENTATION

ASME procedures. Pressure and temperature measurements determine the density of the liquid or vapor. Flow rate was determined by the differential pressure cell, connected to the flange orifice taps. Primarily the resistance temperature devices (RTD's) were used for temperature. Thermocouples were used for backups for the RTD's.

4.1.2 Test Pump Instrumentation

Test instrumentation in the vicinity of the pump is shown isometrically in Figures 4-4 and 4-5. Detailed locations of instruments for the pump suction and discharge legs are shown in Figures 4-6 and 4-7, respectively.

Basically the test pump instrumentation can be divided into four subgroups: (1) suction instrument section, (2) discharge instrument section, (3) pump speed, torque, head and related differential pressure cells, and (4) injection flow measurement instrumentation. Each is considered below. Section 4.2 discusses each instrument type in detail.

4.1.2.1 Suction Instrument Section. Figure 4-6 shows the location of instruments for the suction instrument section. Starting at the normal inlet side (opposite the pump suction) the first two devices were a thermocouple (TC, L-13) followed by a resistance temperature device (RTD, L-55). The RTD was the primary temperature sensing device for the suction side instrumentation for steady-state tests. The TC was provided for backup. For transient tests the TC served as the primary temperature sensor due to its faster response time. It was calibrated in situ against the RTD prior to each transient. The next instrument was a pressure transducer (L-5) which served as the primary pressure sensing device for the suction side instrumentation. Directly opposite L-5 was the tap for one side of differential pressure cells L-7 and L-61 discussed below. The next two groups of instruments consisted of one drag disc and one turbine meter per group. Two drag disc (L-1, L-26) and two turbine meter (L-3, L-28) locations were provided to allow two different ranges of instrument to be used simultaneously and also for backup. Thermocouple L-30 was provided to sense local temperature at the drag discs to allow correction of drag disc output for temperature sensitivity. Drag disc and turbine meter penetrations were arranged at 30° from the horizontal to prevent the masking or shadowing of one instrument by another or by the temperature and pressure probes.

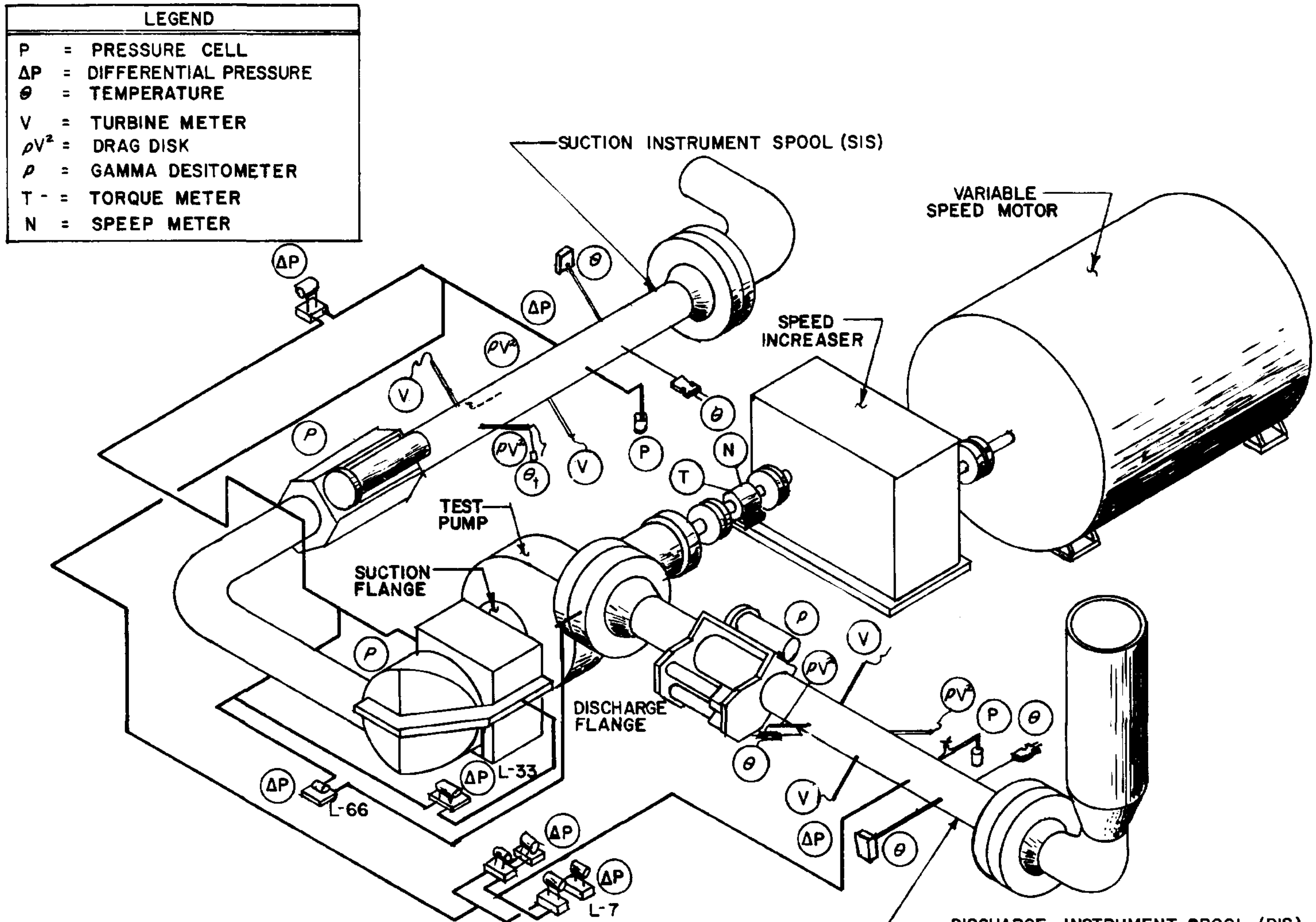


FIGURE 4-4
TEST PUMP INSTRUMENTATION

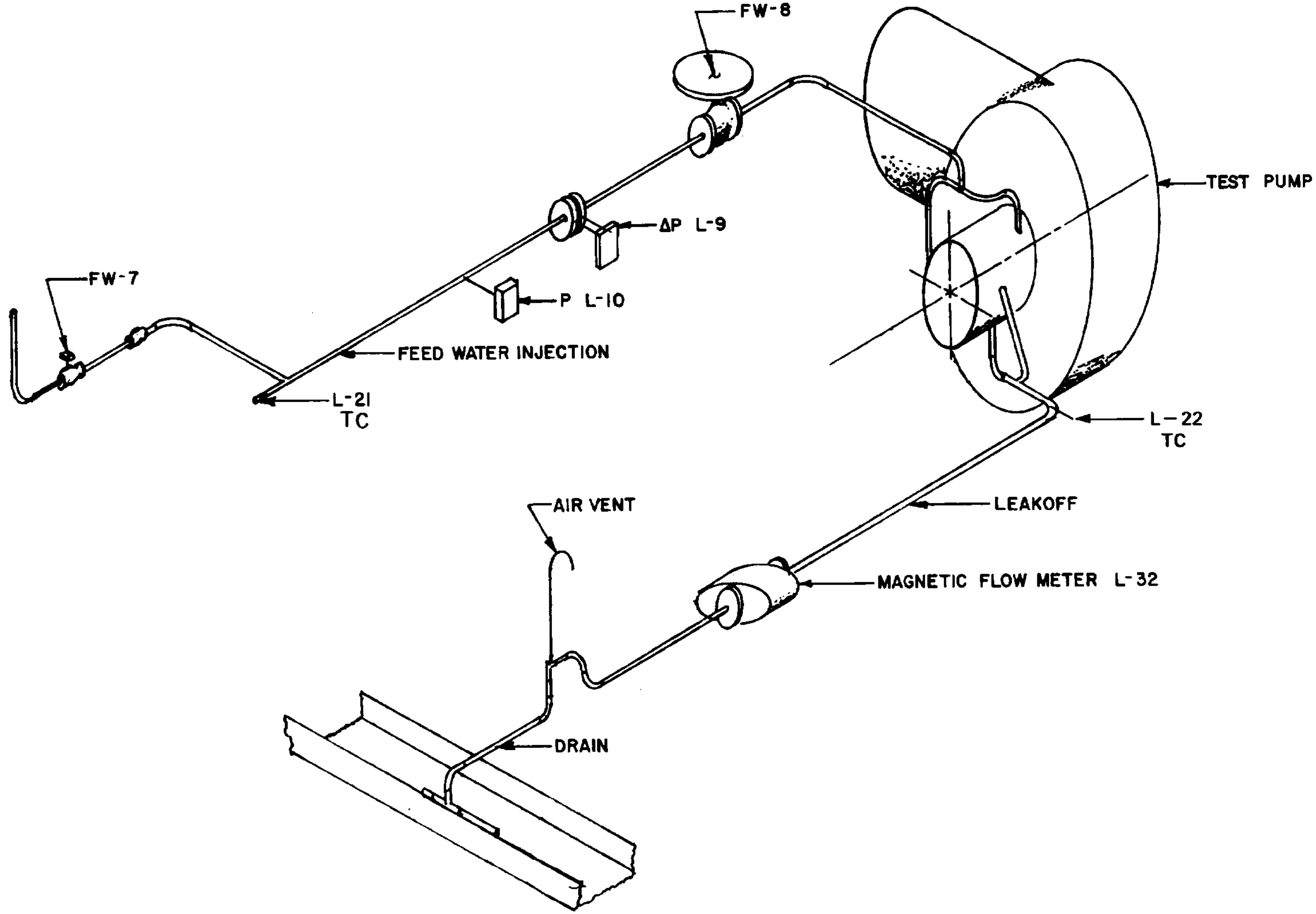


FIGURE 4-5

TEST PUMP INJECTION & LEAKOFF INSTRUMENTATION

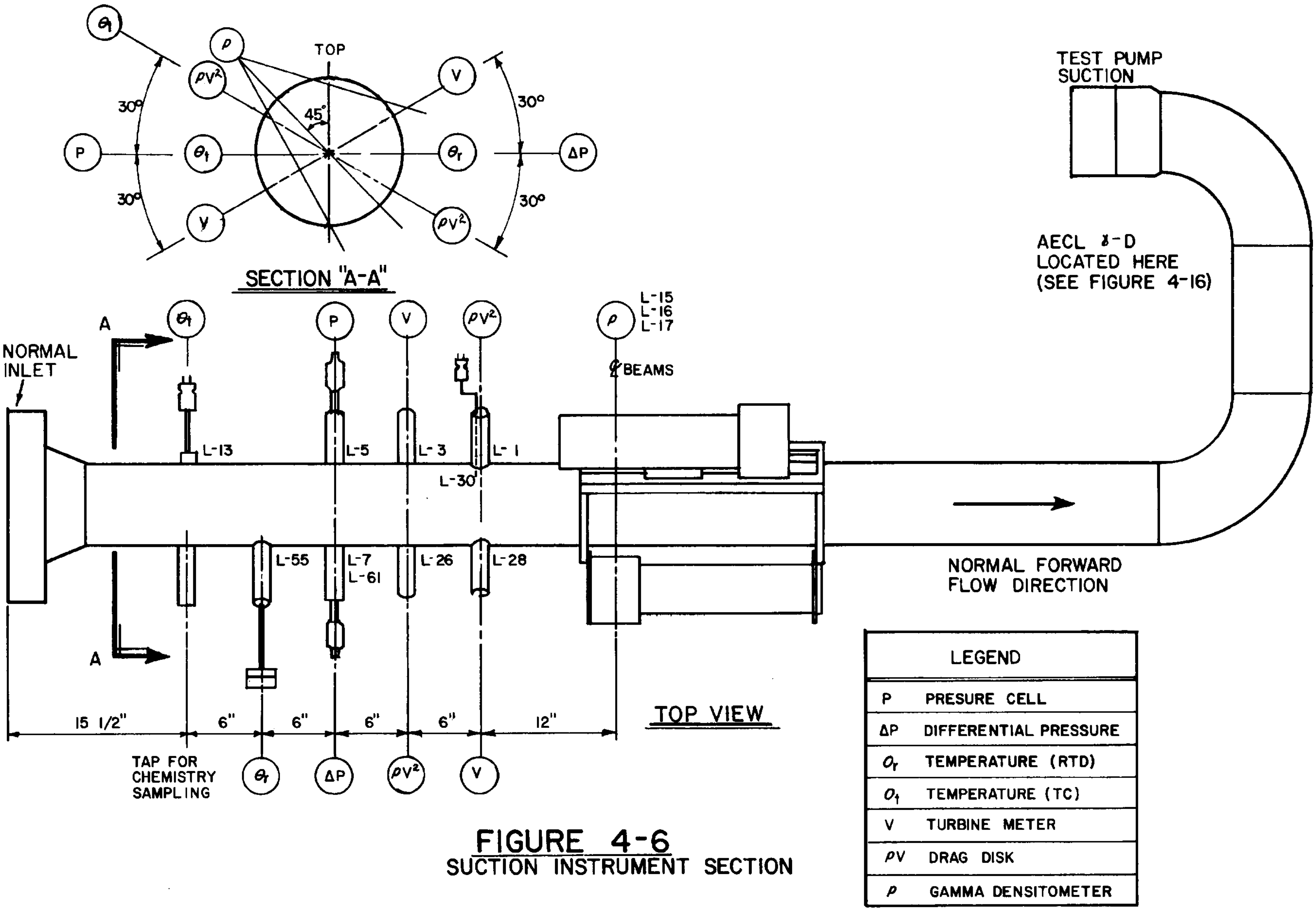


FIGURE 4-6
SUCTION INSTRUMENT SECTION

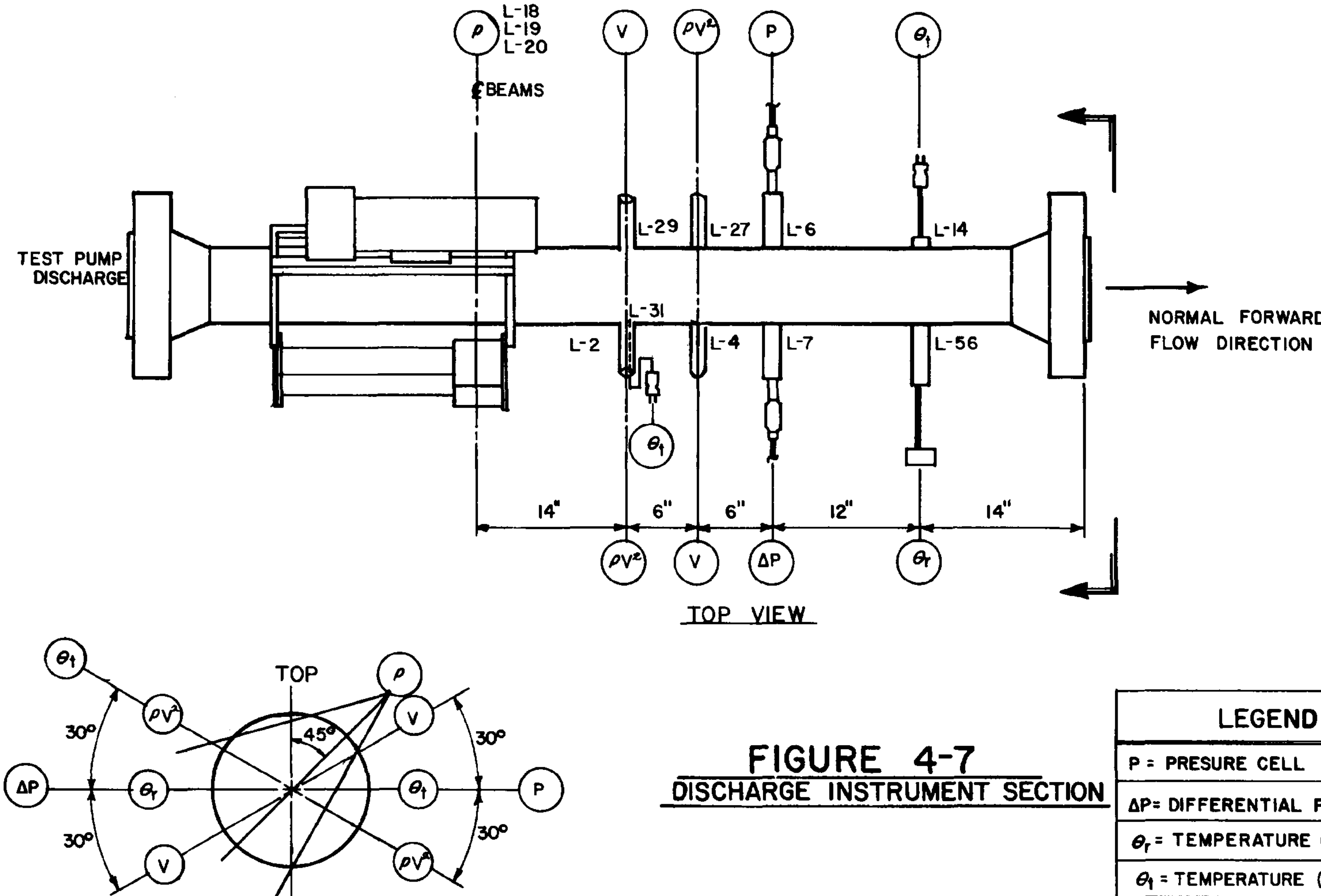


FIGURE 4-7
DISCHARGE INSTRUMENT SECTION

LEGEND
P = PRESURE CELL
ΔP = DIFFERENTIAL PRESURE
θ_r = TEMPERATURE (RTD)
θ_t = TEMPERATURE (TC)
V = TURBINE METER
ρV = DRAG DISK
ρ = GAMMA DENSITOMETER

Various insertion lengths were also used to prevent interference (see below). The next instrument on the suction instrument section was the Measurements Inc. (MI) three-beam gamma densitometer (L-15, L-16, L-17). This instrument provided information of fluid density and flow regime. Adjacent to the test pump suction was a second three-beam gamma densitometer (L-34, L-35, L-36). This instrument was supplied by Atomic Energy of Canada Limited. Density and flow regime information at the test pump suction were provided by this instrument.

4.1.2.2 Discharge Instrument Section. Instrument locations for the discharge instrument section are shown in Figure 4-7. Starting at the normal outlet of this section (opposite the test pump discharge) the instrument locations were similar to those of the suction instrument section with the exception of the AECL gamma densitometer.

4.1.2.3 Pump Speed, Torque and Head. Figure 4-4 shows the location of the torque (L-11)/speed (L-12) transducer and various differential pressure cells decribed below:

- Test Pump Leg-To-Leg Differential Pressure (L-7): Consisted of four transducers of which only two were used at a time. Each pair was made up of a low and high range cell hydraulically connected in parallel. One pair of cells (made by Rosemount) was used for steady-state tests. The other pair (made by BLH) was used for transient tests. Valves were provided so that only one pair of cells was on line at a time.

- Test Pump Flange-To-Flange Differential Pressure (L-66): Provided data on Δp across test pump for comparison with L-7. The latter included effects of pressure drop in the instrument sections.

- Suction Instrument Leg To Test Pump Inlet Flange Differential Pressure (L-61): Measured ΔP due to pressure drop in the suction instrument section.

- Differential Pressure Across Test Pump Suction Pipe Cross-Section (L-33): This ΔP cell in conjunction with the AECL gamma densitometer provided data which could be used to interpret flow regime (for two-phase flow) adjacent to the test pump suction. A BLH cell was at this location.

- Test Pump Volute To Impeller Back Differential Pressure (L-68): This instrument was originally provided for control purposes. The intent was to use its output to govern the rate of seal injection flow so that cold injection water did not enter the pump cavity. When this was found to be unfeasible the instrument was left in place to provide information which might prove useful in understanding conditions inside the test pump. Figure 3-2 shows the location of the taps. One is directly behind the impeller 2 1/2 inches from the center of the shaft (labeled "A" in the Figure). The other is located just outside the impeller circumference 4 inches from the shaft center (labeled "B").

4.1.2.4 Injection Flow. Figure 4-5 shows the locations of the injection flow instruments. These instruments were provided to measure test pump seal injection and leakoff flows.

The injection flow was measured with a standard ASME square edged orifice plate. Dimensions for this run are shown in Figure 2-14. Differential pressure (L-9), pressure (L-10) and temperature (TC, L-21) were measured.

Leakoff flow was measured by a magnetic flow meter (L-32). A thermocouple was provided (L-22) for temperature measurement.

4.1.3 Miscellaneous Instrumentation

In addition to the instrumentation located at the orifice runs and test pump, certain auxiliary instruments were provided. Each is discussed below. Reference should be made to Figure 4-1 for instrument locations.

Water level in the high pressure drum was measured with a differential pressure cell (L-25). Location of the taps for this cell are shown in Figure 2-8 (Penetrations H and J). Drum pressure was measured at L-65. Thermocouples were placed on the inside (L-23) and outside (L-24) of the drum to monitor the temperature gradient across the drum shell during transient operation.

Continuing in the normal flow direction from the high pressure drum the next instrument encountered was at location L-62. Differential pressure across the second booster pump (PAC 16) was measured at this location. Beyond the test pump discharge instrument section there were two instrument locations. Differential pressure across the loop flow control valve was measured at L-60 and fluid pressure just beneath the rupture disc assembly was measured at L-64 (See Figure 2-18 for the location of this pressure tap).

Finally, L-57 was the location of the ambient temperature thermocouple.

4.2 DESCRIPTION OF MEASUREMENT SYSTEMS

Instrumentation for the test pump can be classified into parameter groups as shown in Table 4-1. While some instrumentation was intended only for the measurement of single-phase conditions (e.g., orifice run instrumentation), the bulk of the test instrumentation were used to measure both single- and two-phase flow parameters. Additionally, test instrumentation was further divided into groups of steady-state and transient data measuring devices. Instruments which were intended primarily for transient data were the gamma densitometers, drag discs, turbine meters, and certain thermocouples.

The sections which follow contain a brief description of measurement accuracies and a detailed treatment of each instrument type.

4.2.1 Measurement Accuracy

A summary of manufacturer specified and measured accuracies is shown in Table 4-1. Also shown in this table are manufacturer specified time constants and actually measured time constants (where available). Time constants shown reflect the speed of response for these instruments.

The standard ASME flatplate orifice meters used achieve an overall error of less that $\pm 1.0\%$ of their reading plus the $\pm 0.2\%$ error of the differential pressure cell used to read their output. The use of two ranges of dp-cells enables flow ranges of up to two orders of magnitude to be measured accurately with these meters. Response times of orifice meters are determined by the dp-cells used in them, and includes allowance for the acceleration of fluid in the dp-cell pressure transmission lines.

4.2.2 Instrumentation Description

A general description of each instrument type is given below. Included in the description is a detailed line drawing showing its connection at the locations specified in Figure 4-1. Included on the line drawings are the instrument wiring schematics, showing how its output signal was connected to the terminal strips in the control panel and ultimately to the data scanner and FM recording system. Also indicated in these wiring schematics are power supplies, signal conditioners, and other equipment necessary to obtain the instrument output. All instruments were installed according to these line drawings and wiring schematics.

4.2.2.1 Pressure Cells. Pressure cells consisted of Rosemount Model 1104 pressure cells having a specified total static error of ± 0.15% of the full calibrated span (Manufacturer's data). The response time of the Model 1104 cell is 0.025 seconds.

Pressure cells were utilized for single-phase measurements for the orifices and also for two-phase, steady-state and transient flow measurements. Water cooling of the pressure transmission line for the pump discharge pressure cell (L-6) was provided for, to minimize the amount of liquid flashing during transient testing. Installation of water cooling was not possible on L-5. Burring on the inside of the pipe was minimized by following ASME installation procedure as shown in Figure 4-8.

4.2.2.2 Differential Pressure Cells. Differential pressure cells were either Rosemount Model 1151 or the BLH series HMD differential pressure cell (L-33, two of the L-7 cells). The model 1151 cell has a total static error of ±0.2% of full calibrated span and a response time of 0.17 seconds. The BLH differential pressure cell has a calibration accuracy of 0.5% of rated output and a total system response time of less than 5 milliseconds. The BLH cell was selected for its fast response time and bidirectional measuring capability to measure the differential pressure across the pump during blowdown tests. Differential pressure cell hook-up is schematically shown in Figure 4-9. Hook-up for orifice differential pressure cells are shown in Figure 4-10.

To minimize any chance of error due to flashing during transient tests, water cooled probes were provided for certain differential pressure cells across the pump (L-7, L-33, L-61, L-66) (See Figure 4-8). As in the case of the pressure cells precautions were taken to avoid burring on the inside of the pipe/pressure tap junction.

4.2.2.3 Resistance Temperature Devices. The resistance temperature devices (RTD) used to measure fluid temperatures were Rosemount Engineering Company Model 108 MB platinum resistance types mounted in a 316 SS thermowell. The long-term stability, or error of this RTD-bridge assembly is ±0.18°F of the calibrated values when periodic ice point checks are made. The response time of the RTD-thermowell is not specified but is on the order of minutes, making

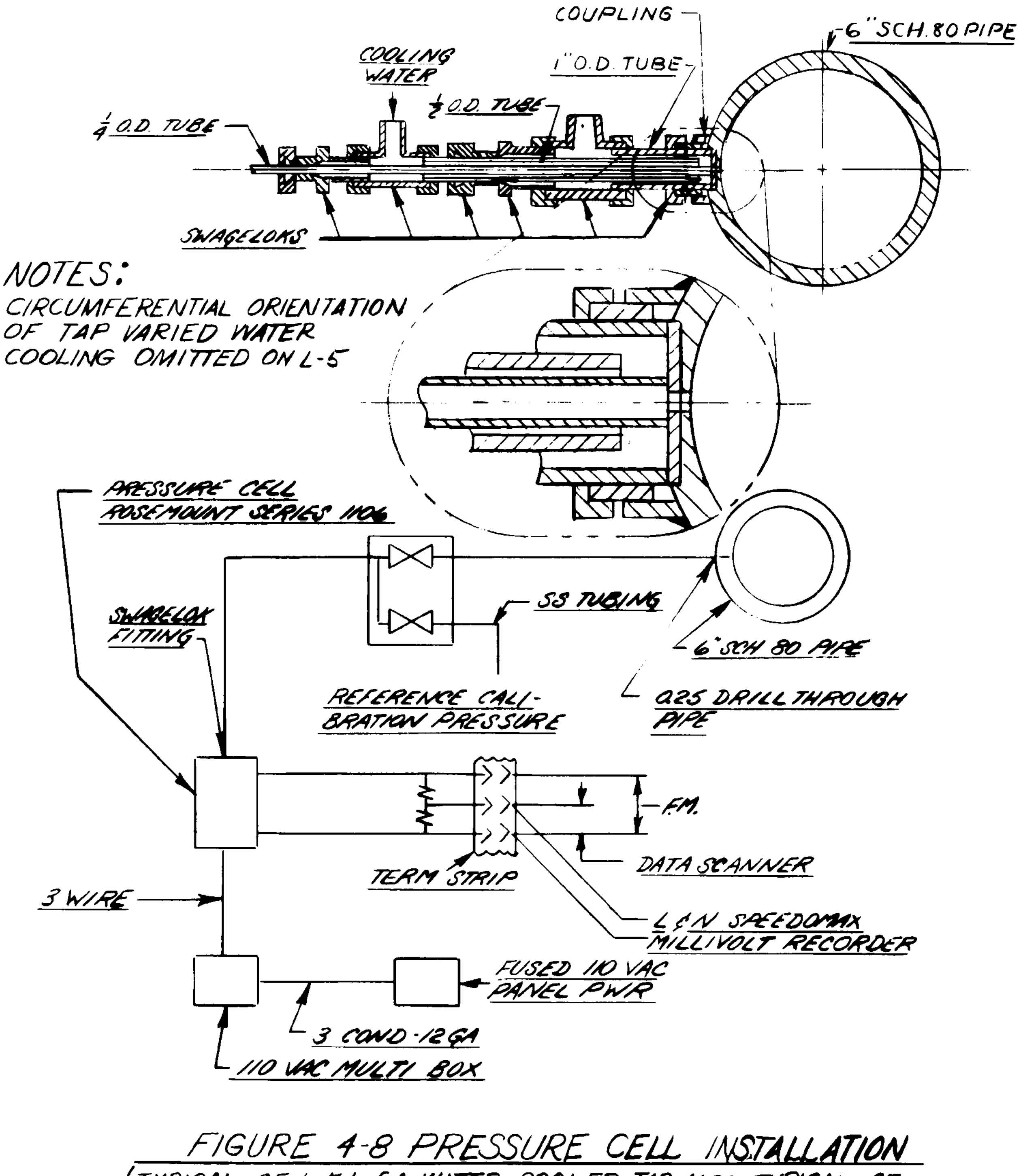


FIGURE 4-8 PRESSURE CELL INSTALLATION
(TYPICAL OF L-5 L-6; WATER COOLED TAP ALSO TYPICAL OF DIFFERENTIAL PRESSURE CELLS L-7, L-33, L-61, L-66)

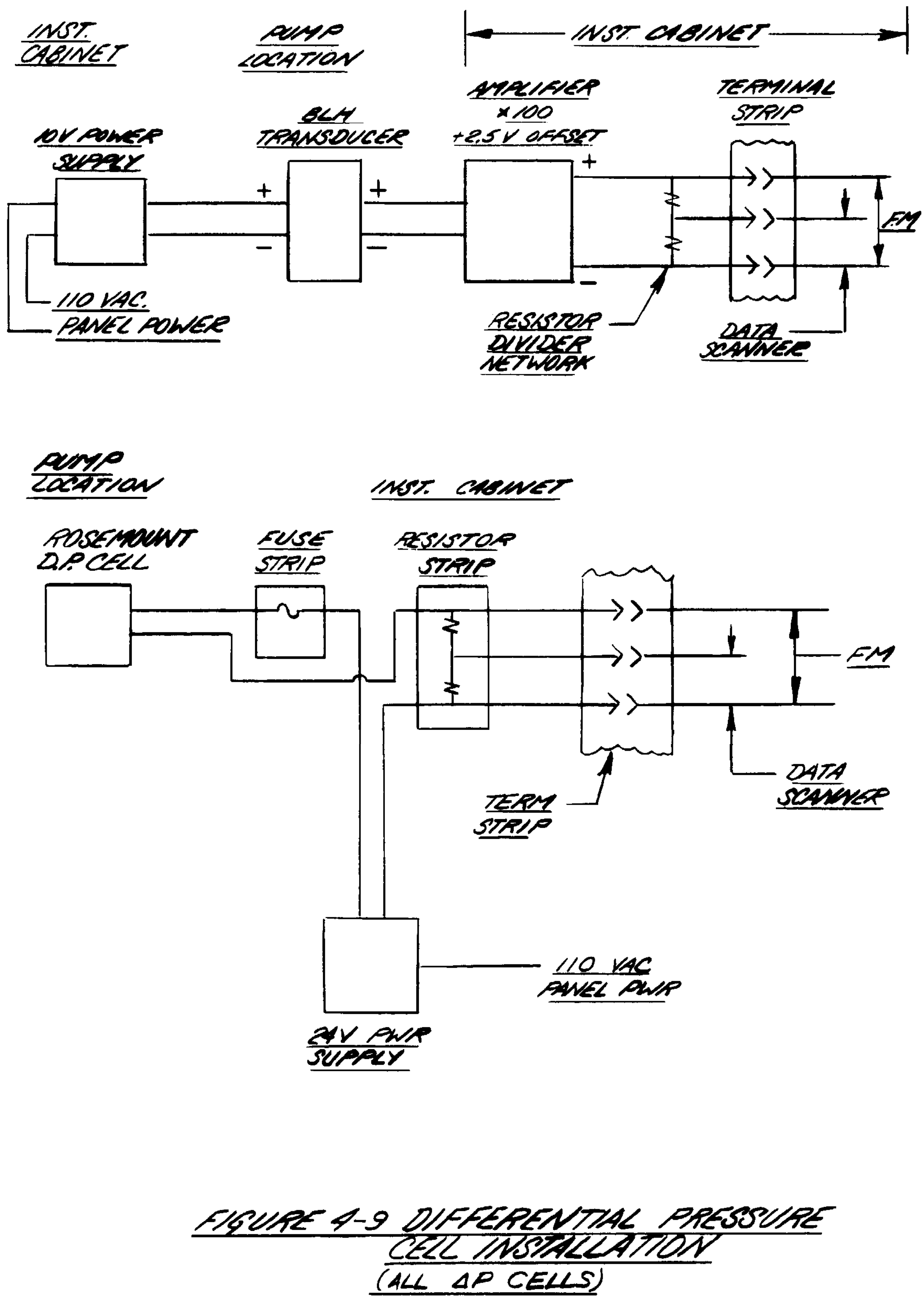


FIGURE 4-9 DIFFERENTIAL PRESSURE CELL INSTALLATION
(ALL ΔP CELLS)

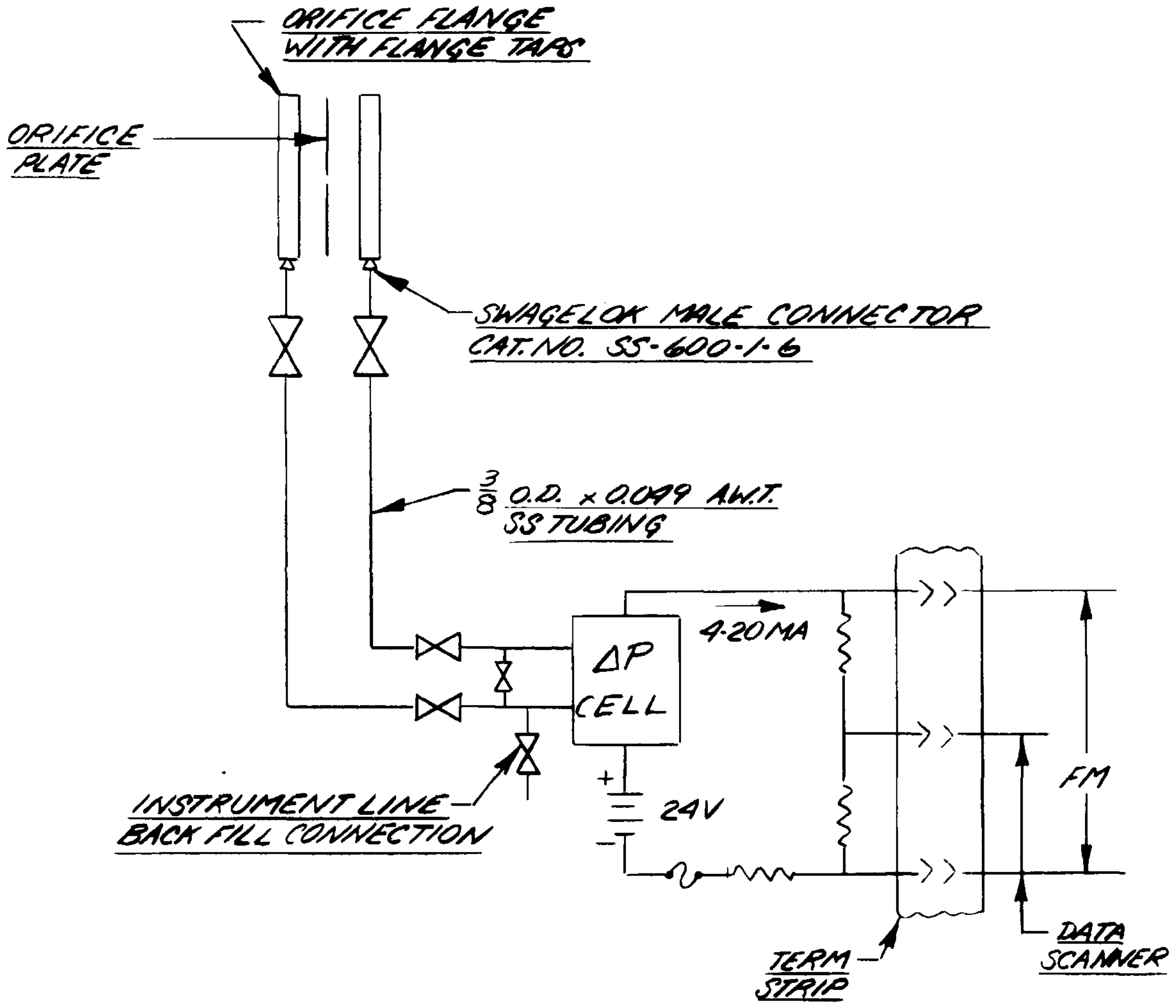


FIGURE 4-10 ORIFICE DIFFERENTIAL PRESSURE CELL INSTALLATION
(TYPICAL OF L-9, L-37, L-38, L-39, L-40)

these devices unsatisfactory for transient tests. However, they were used for steady-state tests and to calibrate the faster response thermocouples in place before transient tests. A typical installation is shown in Figure 4-11.

4.2.2.4 Thermocouples. Loop thermocouples were Conax, 0.040" diameter, metal sheathed, Type K thermocouples. The thermocouples were of the grounded junction type and were spot welded to a support tube as shown in Figure 4-12.

Thermocouples of this type possess an uncalibrated error of ±2°F to 530°F and ±0.375% of its reading above 530°F (according to manufacturer's data). The suction and discharge thermocouples (L-13, L-14) were calibrated in place in the test loop against the more accurate resistance temperature devices prior to each transient.

The response time of the above thermocouples was 90 milliseconds in stagnant water. Response times change with the conductivity and velocity of the fluid in contact with the thermocouple. However, this response time was adequate for the temperature change rates encountered.

4.2.2.5 Turbine Meters. The velocities of the fluid flowing in the pump suction and discharge pipes were measured with Flow Technology Model FTP turbine meter probes with a flow sensing area 3/4 inches in diameter. The frequency output of the turbine meters was converted to a direct current (dc) voltage by means of a frequency to dc converter.

The error of the turbine meter is less than 1% of full scale as calibrated against a standard orifice for single phase (manufacturer's data). The transient response time was about 110 milliseconds.

The insertion depth of the turbine meters was adjustable. Normally they were installed so that the insertion depth, measured from turbine center line to pipe inside diameter, was equal to 1/3 of the pipe radius (see Figure 4-13). However in some instances certain turbine meters were installed so that the turbine meter and pipe center lines coincided.

4.2.2.6 Drag Discs. The momentum flux of the fluid flowing in the pump suction and discharge pipes during transient tests was measured by Ramapo drag

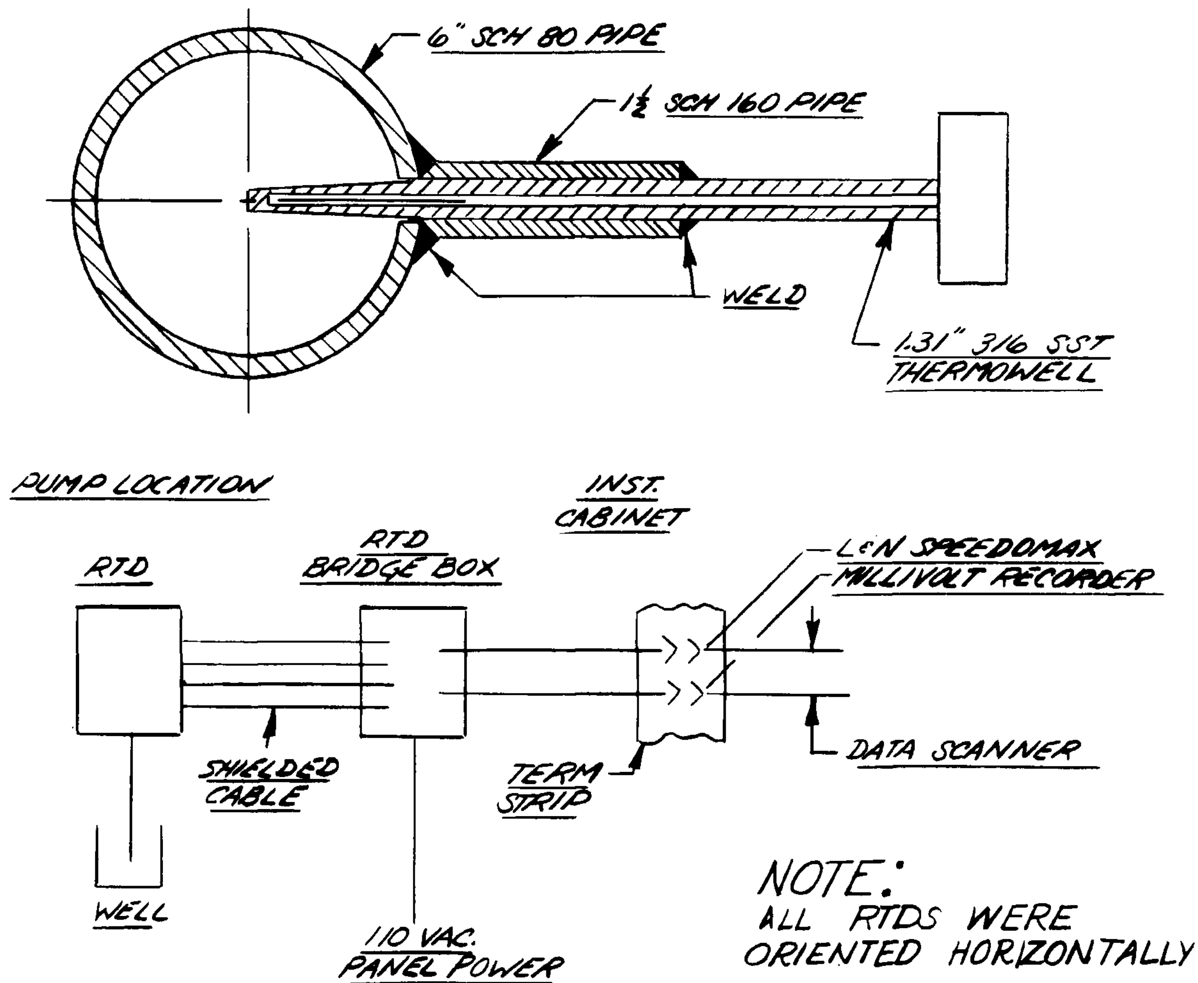
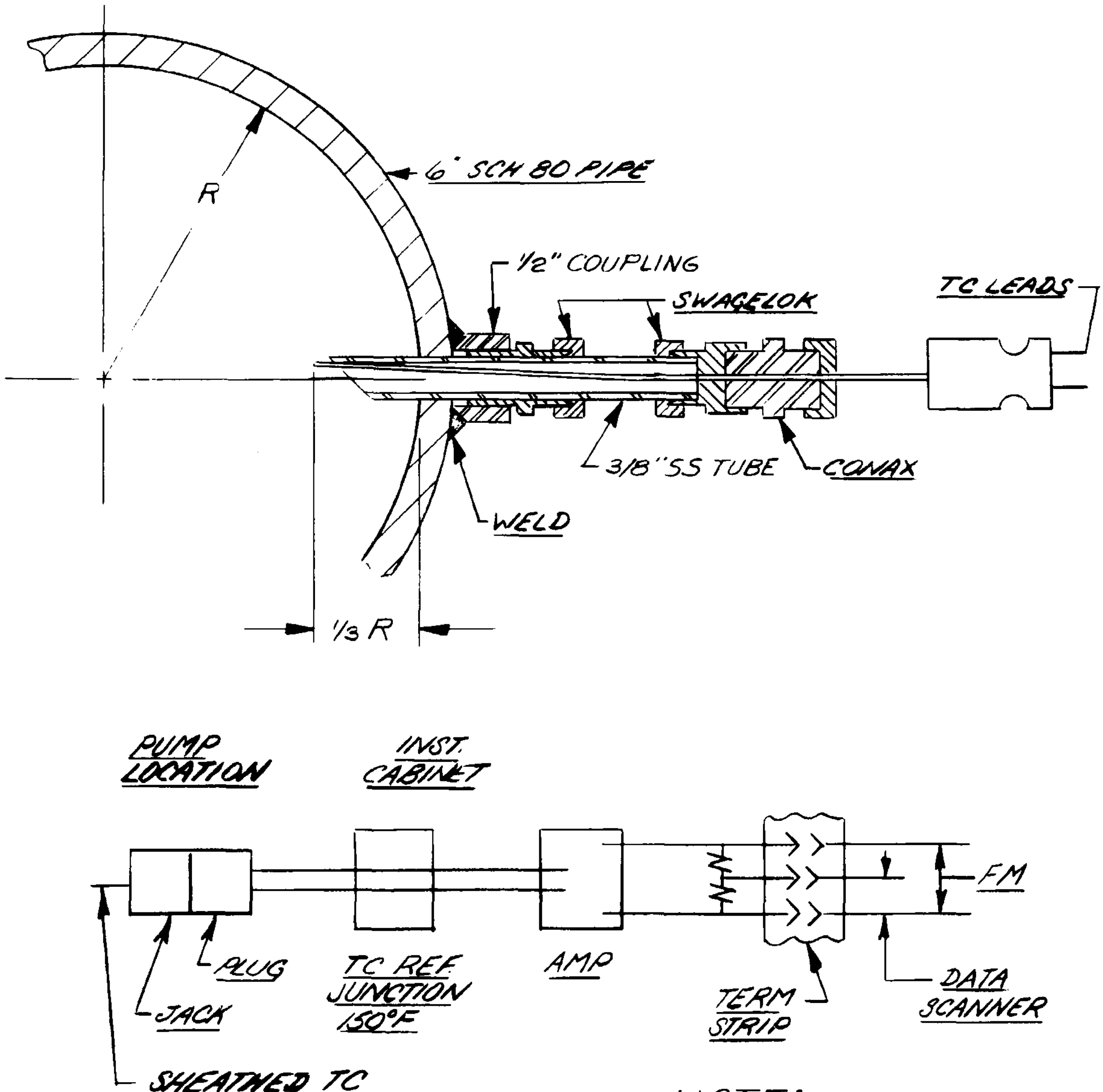


FIGURE 4-11 RESISTANCE TEMPERATURE DEVICE INSTALLATION
(TYPICAL OF L-53, L-54, L-55, L-56, L-58, L-59)



NOTE:
L-13 AND L-14
ORIENTED HORIZONTALLY

FIGURE 4-12 FLUID TEMPERATURE THERMOCOUPLE INSTALLATION
(TYPICAL OF L-13, L-14)

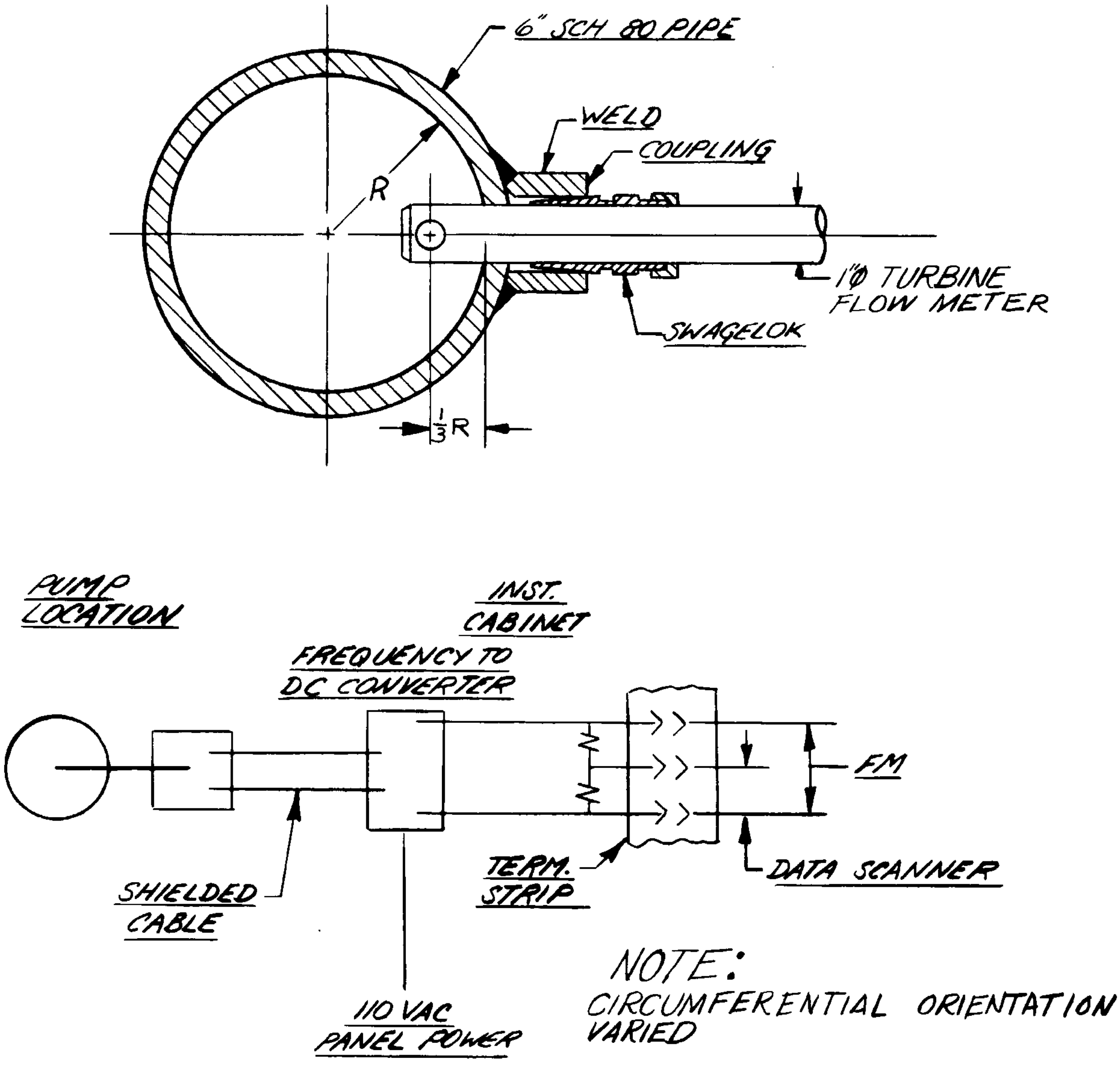


FIGURE 4-13 TURBINE METER INSTALLATION
(TYPICAL OF L-3, L-4, L-28, L-29)

discs. The accuracy of these devices, calibrated against a standard orifice and with density interpretation from pressure and density relationship, was better than 2% of full scale for single-phase flow. The measured response time of this device was about 30 milliseconds for the 120,000 $lb/ft\text{-}sec^2$ range meter and about 60 milliseconds for the 200,000 $lb/ft\text{-}sec^2$ meter. All of the drag discs used were for bi-directional flow. Figure 4-14 shows a typical installation of a drag disc.

This type of meter is known to exhibit a temperature sensitivity. To correct for this effect thermocouples were installed in one suction (L-1) and one discharge (L-2) drag disc to monitor sensor temperature. Temperature effect on zero was calibrated in situ.

4.2.2.7 Gamma Densitometers. A total of three gamma densitometer systems with three beams each were used. The suction (L-15, L-16, L-17) and discharge (L-18, L-19, L-20) gamma densitometers were made by Measurements Inc. (MI). The test pump suction inlet gamma densitometer (L-34, L-35, L-36) was made by Atomic Energy of Canada Limited (AECL). Figure 4-15 shows the arrangement for the MI gamma densitometer. The AECL is shown in Figure 4-16.

The three-beam gamma densitometer systems measured the average density or void fraction and provided some information on flow regime in the test section. Accuracy was about 0.5% of reading at the saturated liquid density and about 1% of reading at the saturate vapor density (see Figure 4-17). Response time was about 1 millisecond.

Each system consisted of a 30 Curie Cs-137 source (20 Curie for AECL) encapsulated in a cask. The emergent beam was collimated at both the source and the detectors to reduce measurement interference between beams. Detectors were of the NaI scintillation crystal type (CsF for the AECL), which are sensitive only to the high energy (0.65 MeV) gamma rays. Light emitted from the scintillation crystals was amplified electronically by a photomultiplier/preamplifier set. Stability of the detector system under severe temperature conditions was provided for by watercooled detector housings. Stability of better than 0.1%/hour was obtainable (manufacturer's data).

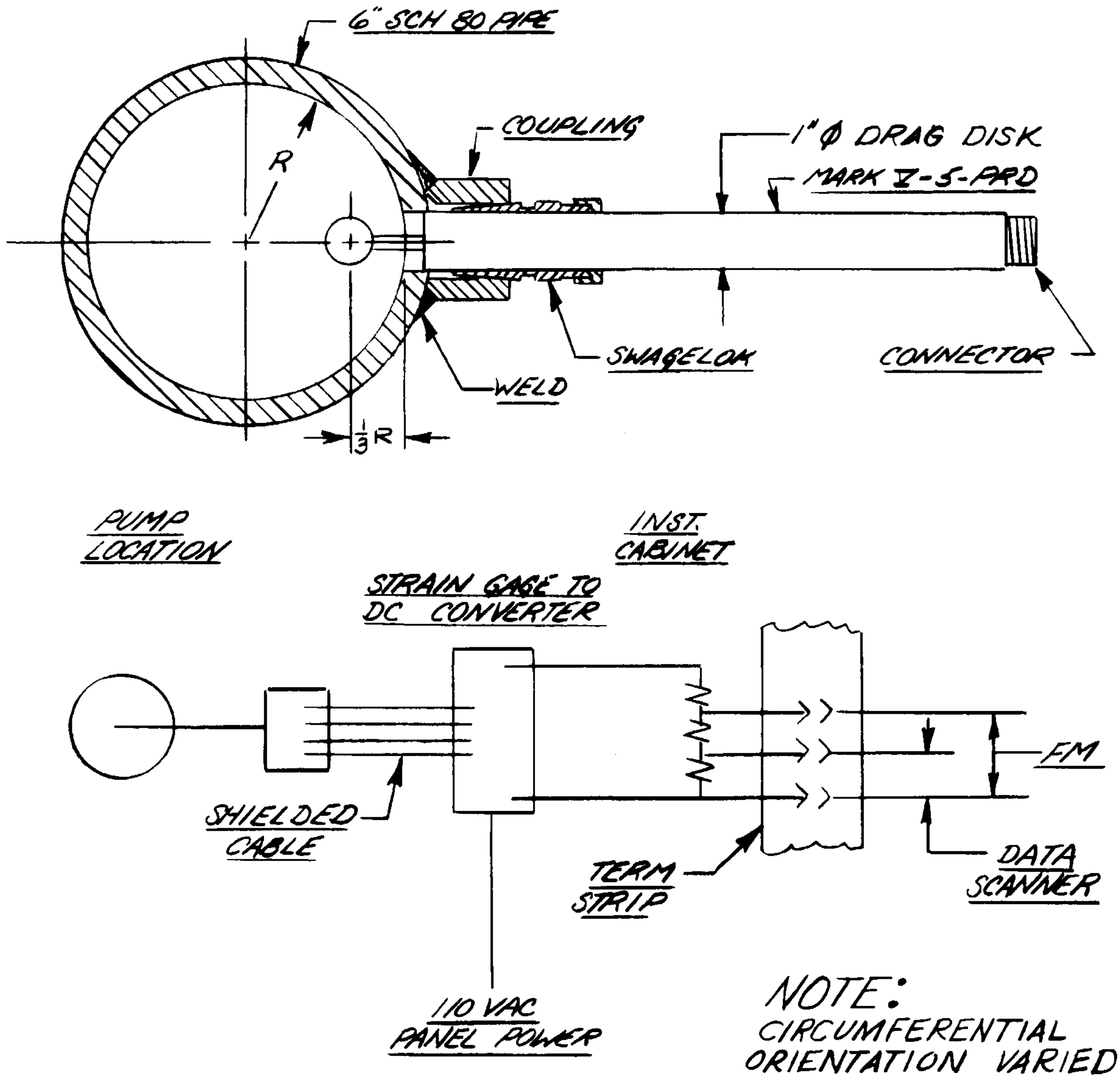


FIGURE 4-14 DRAG DISC INSTALLATION
(TYPICAL OF L-1, L-2, L-26, L-27)

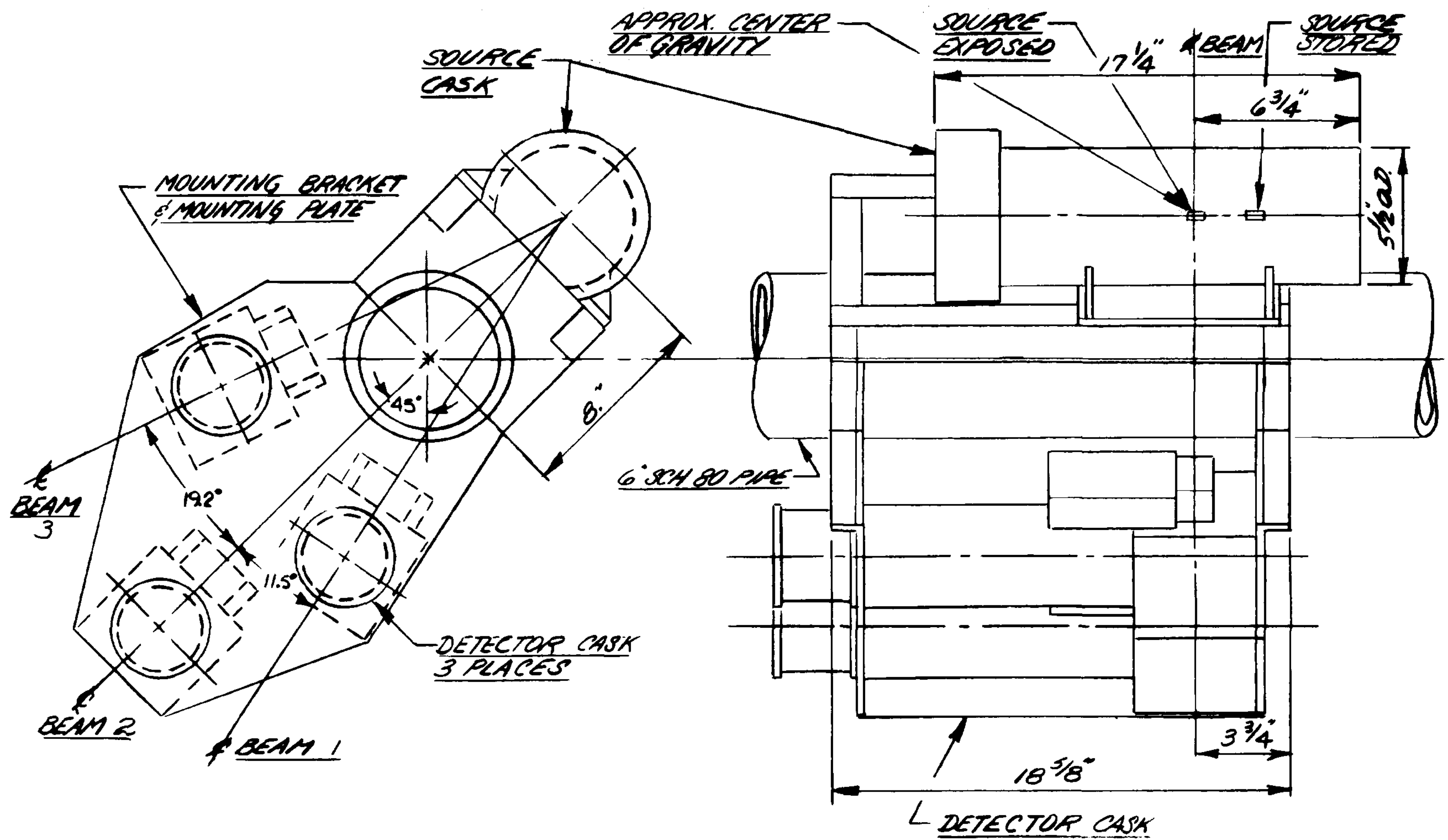


FIGURE 4-15 THREE-BEAM GAMMA DENSITOMETER ARRANGEMENT (M I)

	BEAM		
	1	2	3
SUCTION	L-15	L-16	L-17
DISCHARGE	L-18	L-19	L-20

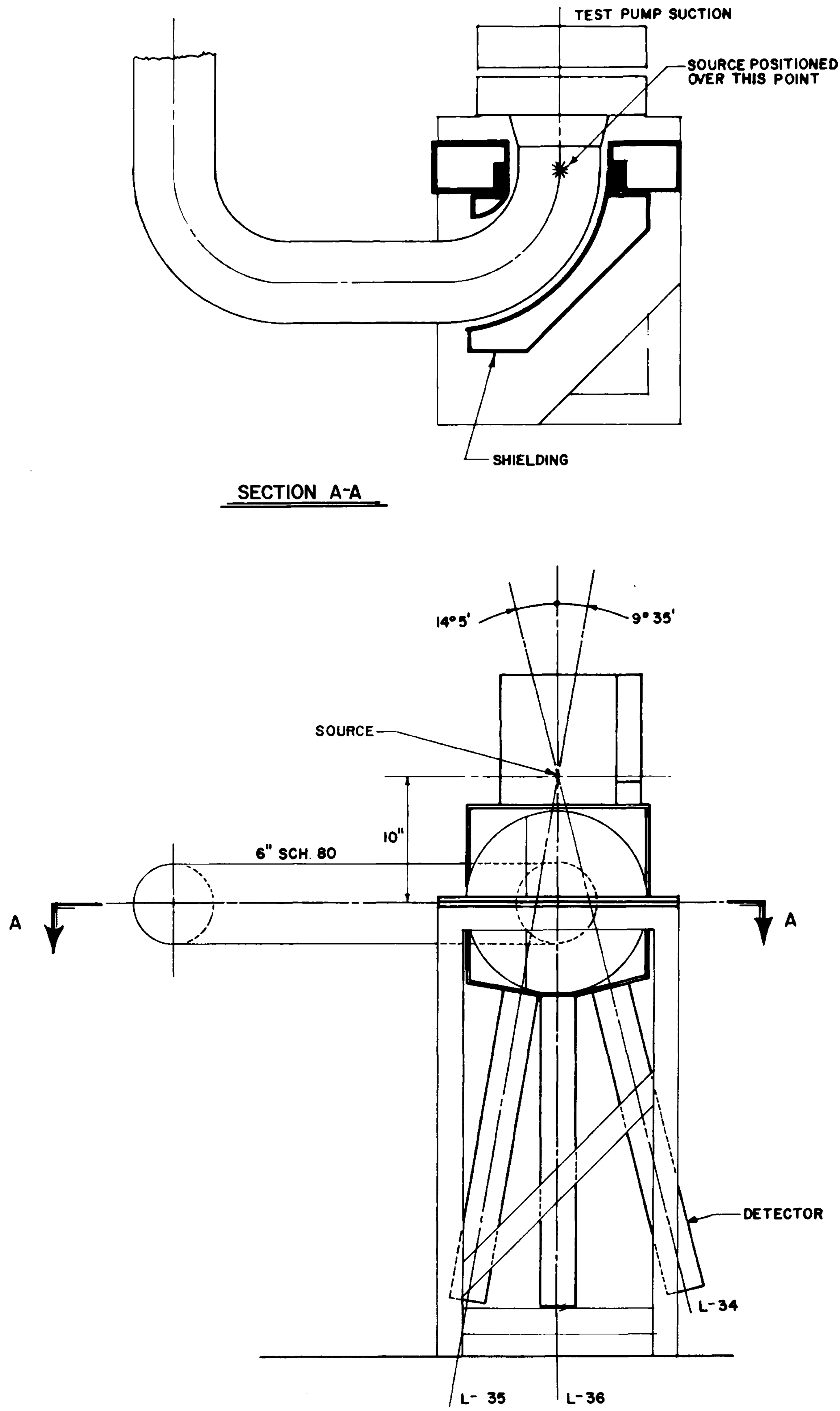


FIGURE 4-16
THREE BEAM AECL GAMA DESITOMETER ARRANGEMENT

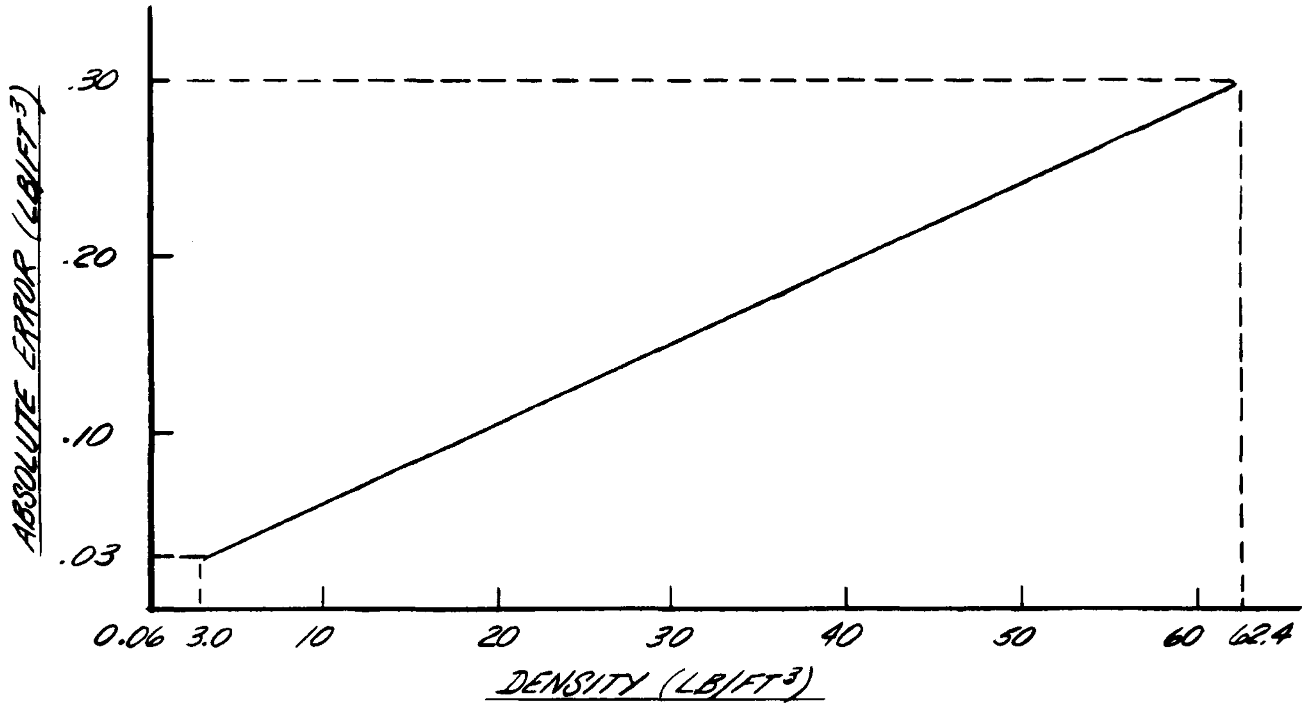


FIGURE 4-17 GAMMA DENSITOMETER UNCERTAINTIES

Final calibration of the units was done in-situ with known fluid density in the pipe. Calibration shims were provided, for additional calibration information.

As indicated in Figure 4-15, the beams of the MI system were of such orientation that each passed through the vertical axis of the pipe. One through the top, and others through the center and bottom of the pipe. This arrangement had the greatest potential to provide useful information in regard to flow regime determination.

The three beams of the AECL gamma densitometer passed through the pump suction inlet pipe in a vertical plane, as shown in Figure 4-16. This arrangement of beams provided information on two-phase flow separation due to the elbows on the suction side of the test pump.

4.2.2.8 Torque-Speed Transducers. The torque-speed transducers for these tests were Lebow Associates Model 160 rotating torque sensors with integral speed sensors. The Lebow Model 1605-10K measured torque in the range 0-10,000 in-lb and could be manually changed to the Lebow Model 1605-2K which measured torque in the range 0-2000 in-lb. The output of this transducer was conditioned by a Daytronic Model 878A strain gage conditioner/amplifier and a Model 840 frequency to voltage conditioning amplifier. The static error of the torque sensor-conditioner was calibrated and was less the ±0.1% of full scale. The static error of the speed sensor-conditioner was less than ±0.05% full scale (manufacturer's data). The response time of the torque sensor was less than 5 milliseconds and that of the speed sensor about 22 milliseconds.

4.2.2.9 Magnetic Flow Meter. The magnetic flow meter (L-32) used to measure test pump leakoff was a Foxboro model 281H flow tube and 696A converter. Nominal pipe size was 1.5-inch. Accuracy was 1% of full scale. Range was adjustable to a maximum of 0-100 GPM.

4.3 CALIBRATION METHODS

4.3.1 Bench Calibration

Calibrations were performed before, during and after the conclusion of the testing phases. These calibrations were performed in accordance with standard

KDL procedures. In general the calibration was done by removing the transducer or cell (the part of the instrument which converted the physical quantity into an electrical signal) from the loop and placing it in a calibration rig. Electrical leads, converters, amplifiers and so on were not changed. Data was read out on the same data scanner as used during testing. Therefore a complete instrument system calibration was performed.

Certain instruments were calibrated in situ and are discussed later. Reference should also be made to Volume VIII for a further discussion of calibration methods.

4.3.1.1 Instrument Calibration Traceability. Every effort was made to achieve high quality instrument calibrations. Each instrument was calibrated against a laboratory standard. These standards were sent to a commercial measurement standards laboratory for calibration, certified traceable to the National Bureau of Standards. In certain cases, test instruments themselves were calibrated by an outside facility. Examples were the Dana Digital Voltmeter (for the data scanner) and the Magnetic Flow Meter. These calibrations were also certified traceable to N.B.S.

4.3.1.2 Calibration Data. Calibration data for each instrument was processed by a curve fitting computer program to arrive at a set of conversion constants between millivolts and engineering units. The program used a regression analysis that applied a least-square fit of an equation to the calibration data. The standard error of the calibration data was also determined.

The standard calibration procedure for this project was to obtain at least five points going up in the instrument output and at least five points going down in the instrument output. If a sensitivity to some second possible variable was also present, or anticipated, then this process was repeated three or four times at different levels of that variable. For example, the differential pressure cells were calibrated at three different static line pressures in the range 70 psi to 1500 psi.

4.3.2 In Situ Calibrations

4.3.2.1 In Situ Flow Calibration. The drag disks and turbine meters were calibrated under actual loop, steady-state, single-phase operating conditions.

A curve was established relating flow (based on single-phase orifice measurements) to the instrument's output signal. Calibration conversion constants were determined for drag disks and turbine meters from these curves. These constants related flow rate to instrument output. For drag discs, temperature sensitivity calibrations were performed in situ to determine the relationship between output and temperature.

4.3.2.2 In Situ Thermocouple Calibration. Suction (L-13) and discharge (L-14) thermocouples were the primary temperature measuring devices during transient tests and also received an in situ comparison calibration. The thermocouples were compared, under actual steady-state loop operating conditions, to closely located platinum resistance temperature detectors. A difference equation was generated by the computer program to provide, for each thermocouple, the variation from standard thermocouple tables. Each thermocouple was calibrated over a range of 200°F to 500°F.

4.3.2.3 In Situ Gamma Densitometer Calibration. The manufacturer performed a water level calibration to establish the densitometer's linearity and variability. In addition, in situ calibrations were performed in the loop using single-phase conditions. Seven points were used for this purpose. They included two air points, four subcooled water points (two at 180°F and two at 525°F) and a saturated steam point. This effectively established the end points of the densitometer's calibration curve. A calibration shim was used for one each of the air, cold water and hot water calibration points (MI gamma densitometers only). Furthermore, known flow regime models were tested in the MI gamma densitometers and then checked against predicted values to permit identification of flow regimes (Reference 5). Figure 4-17 provides a graph of the uncertainities of the gamma densitometer system as a function of density.

4.3.3 Calibration Standards

Laboratory Standards used by KDL to calibrate the instrumentation were as follows:

1. Pressure cells were calibrated using a Mansfied and Green Model R30 Deadweight Tester. The limits of error for the tester are ±0.1% of the indicated reading.

2. Differential Pressure Cells were calibrated at three levels of static (casing) operating pressure with a Miriam Instrument Model #30FA350

single-leg high pressure mercury manometer. The resolution of this standard is ±0.025 psid over the range of 0-25 psid. Calibration of differential pressure cells in the 0-5 psid range was accomplished by using an identical manometer except that it is filled with red dyed tetrabromoethane. This provides a resolution of ±0.01 psid.

Differential pressure cells having a range greater than 0-25 psid were calibrated using two portable deadweight testers, providing an accuracy to ±0.4 psig, for cells in the 0-200 psid range.

3. Temperature standards used were as follows:

   a. Ice Point Calibration Standard, Joseph Kay & Co., Inc. Model RC54, Calibration Temperature 32.0°F ±0.04°F.

   b. Tin Freezing Point Standard, Consolidated Controls Corp., Model 601, Calibration Temperature 449.44°F ±0.02°F.

   c. Lead Freezing Point Standard, Consolidated Controls Corp., Model 602, Calibration Temperature 621.32°F to ±0.009°F.

   d. Fluidized Solids Constant Temperature Bath, Procedyne Thermocal Model TH-060, stability and uniformity ±0.25°F, with Rosemount Model 162C Standard RTD, accuracy ±0.02°F with a Mueller Bridge. This equipment provides a calibration range of 0-1000°F with accuracy to ±0.25°F.

4. The Pump Speed Meter was calibrated using a Hewlett Packard Model 5233L Electronic Counter accurate to ±1 count ± time base accuracy. The time base accuracy was ± 1 part per 10 million and ages at ±2 parts per 10 million per month.

4.4 DATA ACQUISITION

A data scanner was utilized to obtain steady-state information and for supplementary transient data. The primary data acquisition for transient tests was an FM magnetic tape recording system.

4.4.1 Data Scanner

The data scanner used for collecting steady-state data was a Control Module, Model 275 Scanner. Its operation was basically as follows:

Analog signals from the instruments listed in Table 4-2 were brought into the scanner by means of leads from the control console. The scanner sequentially connected these signals to a digital voltmeter which converted the signal to a digital form. Digital data was then stored on magnetic tape. The instruments were scanned in sequence over and over until the scanner was manually stopped.

After the scanning was stopped, the data stored on magnetic tape was punched on a paper tape for submittal to a computer for data reduction. The data submitted to the computer was stored in a data file for access by the data reduction program as described in Volume VIII. The paper tape was also placed in storage for future reference if required.

There were three basic variable functions which determined scanner operation. One, was the "Sample Rate", which was the time between sets of data. Second, the "Dwell Time", which was the time for a single channel to be read and stored. Third, was the "Write Time", which was the time for the data to be written on magnetic tape. No data can be acquired during the "Write Time" and the scanner module was inoperative during this time (see Figure 4-18).

The scanner had a 100-channel capacity (of which 69 were used) and could scan 17.5 channels per second at an accuracy of ±0.005% of full scale in the filtered mode. In the superfast mode, it could scan up to 87 channels per second (69 used) at an accuracy of 0.01% of full scale. This was an unfiltered mode of operation. During steady-state tests the scanner was operated in the filtered mode with a sample rate of 30 seconds and a dwell of 0.1 seconds. When used as a backup on transient tests the unfiltered mode with a sample rate of 5 seconds and a dwell of 0.05 seconds was used.

Instrument signals from some of the instruments were also read by the following additional systems: Data was recorded on 24-point recorders, primarily for operator control purposes. Furthermore, selected instruments were connected to a digital panel meter for access by operators when making adjustments to operating conditions. All readouts are indicated in the instrumentation list of Table 4-2. The recorders were switched off when the data scanner was used to avoid interference.

4.4.2 FM Multiplex System

This system consisted of a Honeywell 5600 Magnetic Tape system. In the frequence modulation record mode, the system could accept up to 39 channels of input data. Variable amplitude signals from the sensors were converted to five distinct frequency ranges that did not overlap, permitting five channels to share one tape track. The basic data acquisition system is shown in Figure 4-19.

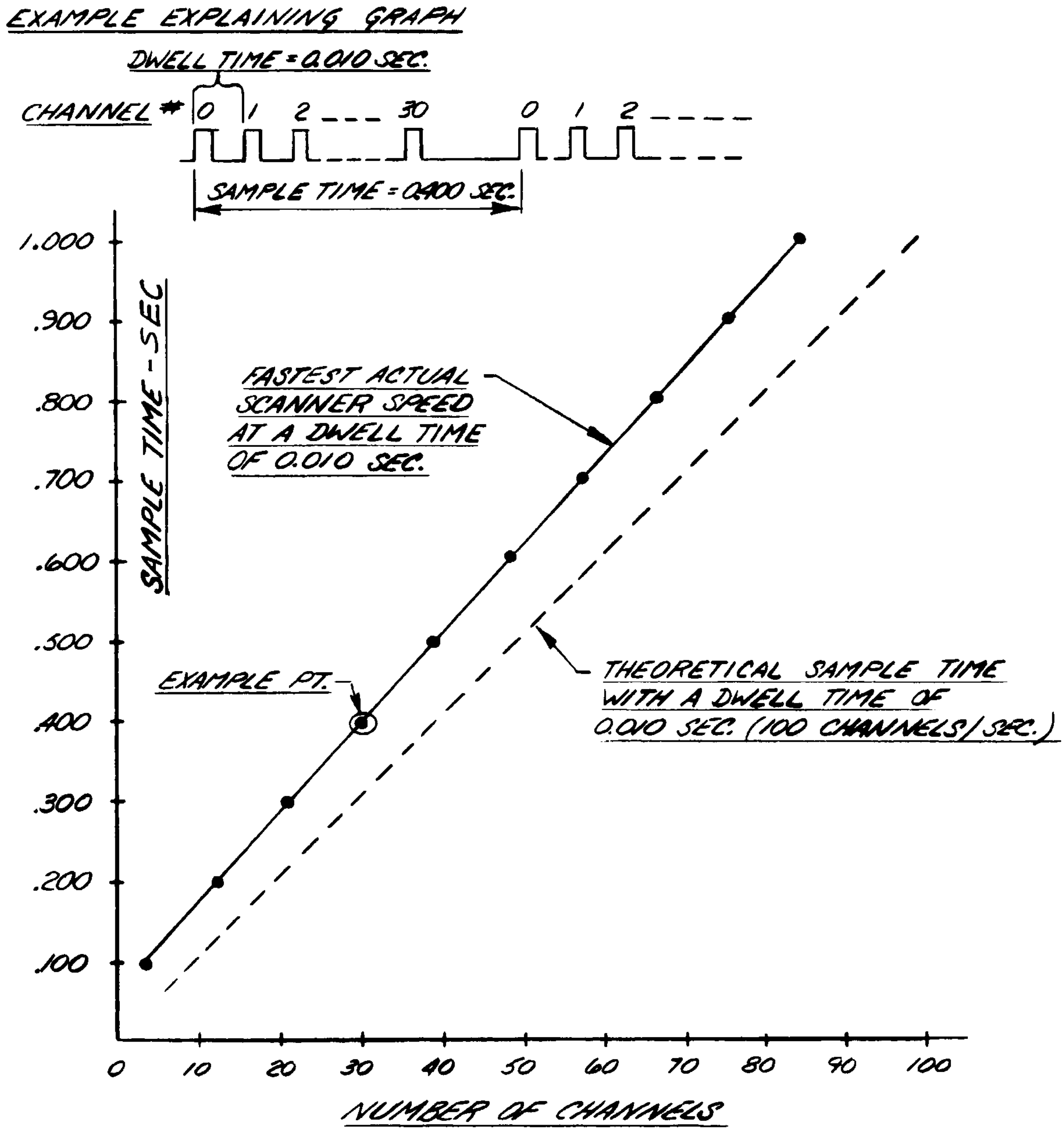


FIGURE 4-18 DATA SCANNER OPERATION, SAMPLE RATE

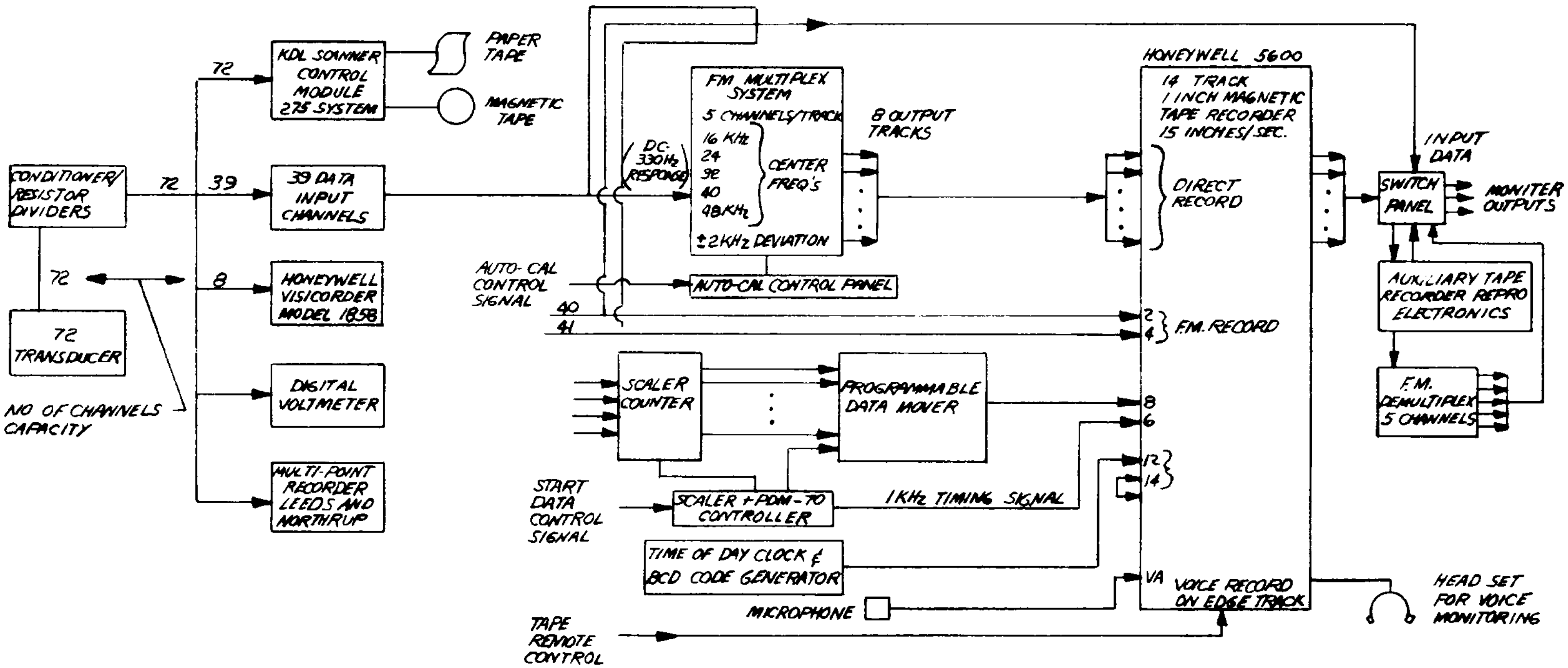


FIGURE 4-19

FM DATA ACQUISITION SYSTEM

This system was capable of resolving frequency information up to 5 Hz. Time resolution was maintained within $\pm .100$ second. The accuracy of the system was primarily determined by the analog to frequency converters. Their accuracy was specified to be 1%, but they were actually considerably better in an automatic calibration mode. In this mode their accuracy was within $\pm 0.2\%$.

After recording transient data with the system described, the tape was played back and the analog data digitized at selected time intervals. Digitization rates of 200 and 20 samples per second were selected. Once digitized, the data was in a form ready for reduction. Additional details on the FM system and the transient data reduction process may be found in Volume VIII.

Section 5

TEST LOOP OPERATION

5.1 LOOP OPERATING MODES

The Pump Test Facility schematic is included as a piping and instrumentation diagram in Figure 4-1. This diagram shows all major components, instruments, and valves pertinent to the operation of the pump test facility. Also included in Figure 4-1 are valve and instrumentation listing by numbers and identifying descriptions.

Referral to this figure from time to time will help to increase the readers familiarity with the test facility and produce a more meaningful understanding of the operating modes described below.

Based on the particular group of test points to be run the loop was set up for one of three basic operating modes. These modes are as follows:

a. Single-phase water flow with piping in forward or reverse flow configuration

b. Single-phase steam flow with piping in forward or reverse flow configuration.

c. Two-phase flow with piping in forward or reverse configuration.

Single-phase water tests and transient tests were set up in the same manner. Water was circulated by the booster pumps around the test loop and steam was fed into the high pressure drum to obtain the specific temperature of loop water called for by the test point parameters. Specified fluid conditions were maintained by controlling the loop pressure with the high-pressure drum vent valve (HPS-6). The boiler firing rate was adjusted so that a minimum of steam was vented while loop conditions were maintained, thereby conserving fuel. With the loop stable in this condition steady-state single-phase water point data was taken.

Single-phase steam points were obtained by admitting steam to the mixing tee while the loop water was bypassed back to the drum. The steam flowed through the test pump to the high-pressure drum. In this case the main water shut off valve (HPW-6) was closed to prevent steam from short circuiting back to the drum without passing through the test pump (see Figure 4-1). The booster pumps were used to maintain uniform loop water temperature and to supply boiler cross feed. System pressure and steam flow rate were maintained with the drum vent valve and boiler firing rate.

Two-phase test points were achieved by admitting steam to the mixing tee while saturated water was circulated in the loop by the booster pumps (PAC-12 & PAC-16). The steam and water mixture flowed through the test pump and back to the drum. No steam was fed to the drum directly except in cases of very low void fractions where insufficient steam flow existed to maintain loop conditions. Pressure and temperature were maintained by controlling boiler firing rate and adjusting the drum vent valve. During most two-phase flow operations large quantities of steam were necessary to achieve the void fractions required by the test point parameters. To minimize venting any excess steam, a cross feed system was incorporated. utilization of the cross feed system allowed boiler feedwater to be taken from the test loop. Makeup feedwater was injected into the loop at the high-pressure drum and was heated to saturation by the excess steam returning to the high pressure drum. In this manner nearly 100% feed heating was obtained utilizing steam which otherwise would have been lost to atmosphere. Use of this system resulted in a significant fuel savings and it was used during most steady-state two-phase flow conditions.

A steam saver system was also utilized whenever possible. This system allowed steam venting from the high pressure drum, to flow into the house steam supply header. Thus whenever sufficient waste steam was available it would flow into this header and supply low pressure steam for functions that would normally be supplied by the boiler. This system also reduced fuel costs.

5.2 GENERAL START-UP PROCEDURES

With the test loop facility in a particular configuration for obtaining a specified test group sequence start-up could begin. The start-up procedure is independent of the loop operating mode. General start-up for single-phase water or steam and two-phase flow is the same. The procedure is as follows:

1. Verify that the valve alignment is correct.

2. Check that all required equipment is operational, and that all required instrumentation is calibrated and operational.

3. Fire the boiler to insure a steam supply for deaeration of boiler feed and loop water.

4. Fill loop with dearated water.

5. Circulate water in the loop and check water chemistry for compliance with water chemistry specifications. Drain and refill or feed and bleed until "crud" levels are acceptable. Follow chemical procedures for frequency and type of sampling and analysis.

6. Bleed all P and DP cells. Record zeros on P and DP cells at least once every 24 hours.

7. Fire the test boiler and raise loop temperature to the desired level required for testing. Maximum rate of rise is 100°F/hr, based on drum inside metal temperature.

8. Make periodic operational checks on all pumps and auxiliary equipment.

This procedure brought the loop to the single-phase water flow mode. Two-phase flow testing was achieved by switching steam supplied to the high-pressure drum to the mixing tee. This was accomplished by opening either the main (HPS-3) or low flow (HPS-4) steam supply valve, depending on the steam demand required to achieve the desired test conditions, and closing the main steam stop (HPS-1) to the high-pressure drum.

The single-phase steam mode was reached after a normal single-phase water startup had been accomplished. Once the loop temperature and pressure conditions had been reached steam flow was switched over from the drum to the mixing tee (this maneuver was the same as that done to obtain the two-phase flow mode). Water flow to the mixing tee was now cut back by diverting the water back to the drum through bypass valve HPW-1 (see Figure 4-1) and closing the main water stop valve HPW-6. Saturated water flow was maintained through the 12-inch booster pump through the main water bypass valve HPW-1 and water flow through the 16-inch booster pump was maintained to supply cross feed to the boiler. Steam flowing to the mixing tee passed through the test pump and back to the drum where it heated the loop water and boiler feed. Excess steam was vented through the drum vent valve (HPS-6).

5.3 STEADY-STATE TEST PROCEDURE (TWO-PHASE)

To achieve two-phase flow conditions after the loop had been started up and had reached the specified temperature and pressure for a particular test point, steam flow was switched from the drum to the mixing tee. Once this was done two-phase flow existed in the pump since loop water was almost saturated at the mixing tee. The steam injected at the mixing tee remained in the steam phase until it returned to the drum where it mixed with and reheated loop, boiler feed and loop make-up water.

Two-phase flow test points were specified in terms of total volumetric flow and void fraction, for a specific pump speed and pressure at the pump upstream instrument section location. These specifications were translated into individual water and steam flows. The operator then adjusted these flows by throttling water flow from the booster pumps and adjusting boiler firing rate to achieve steam flow rates. This operation was complicated by a number of factors. The interaction of the boiler and loop under these conditions was such that any adjustment to steam flow also caused a change in loop water flow and vice versa. To increase steam flow the operator increased the boiler firing rate. This increased boiler pressure allowing steam flow to increase. The increase in steam flow raised the pressure at the mixing tee and caused a decrease in water flow from the booster pumps. In addition, the water coming from the drum through the booster pumps was subcooled to some degree. This subcooling was due to feed, make-up and booster pump injection water flow into the loop. All flows were dependent on loop pressure. Thus, any change made by the operator produced changes in all variables. In order to obtain a particular test condition upstream of the pump a tedious iterative process was required, which was obviously time consuming. To aid the operator in this task and reduce the time required to achieve test conditions a setpoint program was developed. This program called SETACT enabled the operator to achieve the test point parameters to within a specified tolerance with a minimum of iterations.

The operator first established approximate steam and water flow rates at the proper pressure and temperature for the test point required. The loop operator then input, into the computer, the required setpoints and also the actual millivolt readings for the water orifice pressure, differential pressure and temperature and the steam orifice temperature and differential pressure. The program then calculated a new set of millivolt settings for these instruments based on the actual existing conditions at the orifices. The operator then adjusted the system until he had attained the new values output from SETACT and repeated this process until the program output was the same as the input indicating that the test conditions had been satisfied within established tolerances. With the system stable the operator recorded the test data with the data scanner and continued to the next test point in the matrix group, where this entire process was repeated. Using this method test points could be attained within four or five iterations.

When all test points in a particular group had been completed, or if it became necessary to shutdown for any reason, a general shutdown procedure was followed.

To shut down from the two-phase flow mode, it was first necessary to switch back to the single-phase water mode. This was done by switching steam flow from the mixing tee to the HP drum. Once in the single-phase mode cooldown could begin by reducing boiler firing rate such that the boiler and loop cooldown rate did not exceed 100°F/hour, based on the drum internal surface temperature. When loop pressure reached approximately 150 psi the loop was isolated from the boiler by closing HPS-1. The boiler was maintained at a minimum firing rate to supply steam for deaerating loop makeup water until the loop temperature was below 200°F. At this time the boiler was secured. The loop was then drained or placed in wet layup in preparation for the next test sequence group.

5.4 TRANSIENT OPERATION

Transient test operation differed from other test modes in that during the actual transient, when data was being recorded, very little operator action was required. Once the blowdown was initiated the loop was essentially independent of the loop operator. The events leading up to the actual transient, however, were quite involved.

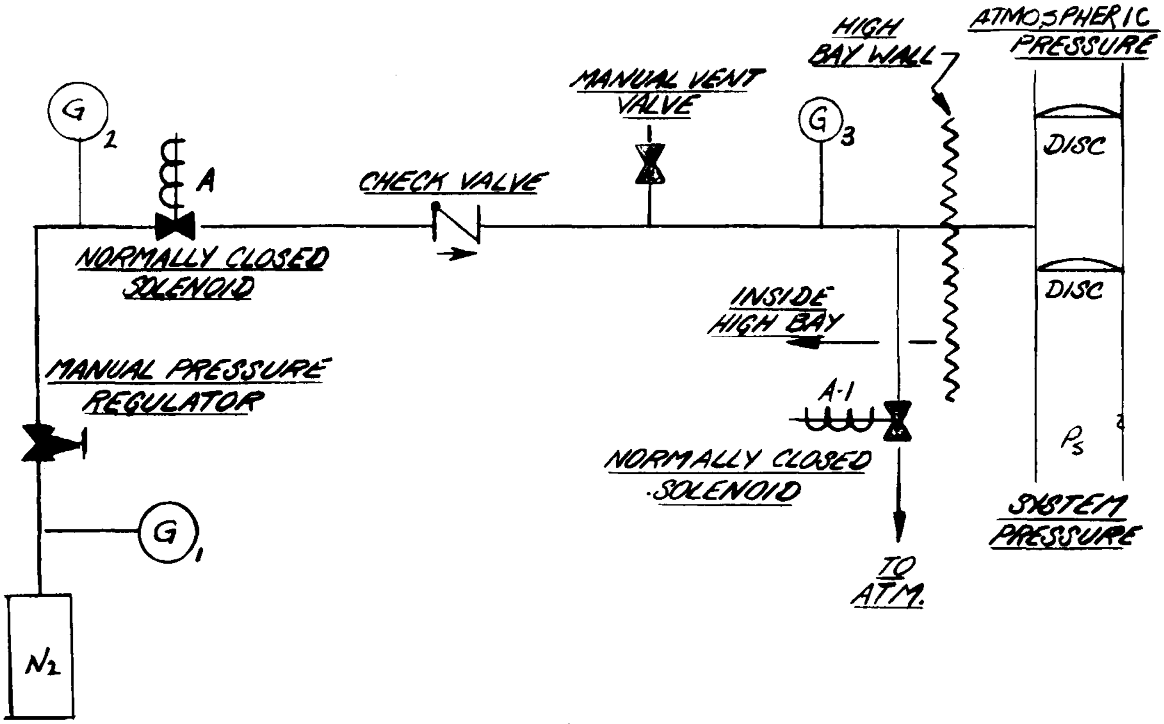
Due to the time required and cost of completing a blowdown or transient test it was essential that all system components and instrumentation be constantly checked during the preparatory stages of the test to insure that the required data was recorded accurately during the actual blowdown.

Transient tests were specified according to 1) the initial steady-state test conditions, 2) drum water level, 3) the orifice size in the blowdown line, and 4) post rupture conditions, namely whether pump power was to be tripped and whether the flow control valve (HPSW-1) was to be closed. The blowdown orifice size was selected to control the rate of loop de-pressurization during the transient. Figure 2-18 shows the location of the orifice in the blowdown leg of the test loop.

The first step in preparation for the transient mode of operation involved assembly of the rupture disk holder with the specified rupture disks and blowdown orifice. The specified loop pressure governed the rupture disk rating. Each of the rupture disks had a burst pressure rating less than final loop operating pressure. When the loop was filled and heated up in the liquid phase mode, according to the steady-state procedures, the pressure in the intermediate chamber between the two disks was maintained at approximately one-half of the loop pressure, with nitrogen (see Figure 5-1). In this manner, each disk was safely loaded below its burst pressure until the transient was initiated. The blowdown valve (HPSW-2) was cracked open and the drain on the blowdown leg was partially opened to maintain circulation in the blowdown pipe during the preparatory stages of the test. With the loop configured for the specific transient, initial instrumentation checkout prior to start-up was accomplished.

The high range torque meter was used for all but one blowdown. The torque meter received a calibration check prior to start-up for each test. It was checked at zero, 20%, 40% 60%, 80% and 100% of it's span by hanging calibrated weights at known distances from the torque meter shaft center. Scanner millivolt readings were recorded at each torque value and these values were checked against pre-test calibration data. Once the torque meter calibration check was complete it was aligned and recoupled to the test pump. A documented channel calibration check of the FM Data Acquisition System was then performed.

The timing of events following the initiation of blowdown was governed by the settings of the time delay relays in the blowdown sequence timing system. Based on pre-determined valve reaction times, time delay relays in the electrical control unit were set to time the sequence of events as follows:



METHOD OF OPERATION

1. WHENEVER CONTROL POWER IS ON, P AT N_2 RESERVOIR WILL FEED STRAIGHT THRU TO DISC'S POCKET. SOLENOID A WILL BE ENERGIZED.

2. MAINTAIN PRESSURE IN CHAMBER, READ AT GAUGE 3, TO ABOUT $\frac{1}{2}$ OF SYSTEM PRESSURE, P_S.

3. AT START OF BLOWDOWN, SOLENOID A WILL DE-ENERGIZE, CLOSING, AND SOLENOID A-1 WILL ENERGIZE, OPENING. THE DISC WILL RUPTURE. THE TIME AT WHICH SOLENOID A WILL CLOSE & SOLENOID A-1 WILL OPEN, WILL BE A FUNCTION OF THE SETTING ON T.D. RELAY 13.

ALL TUBING ~ SS-ASA-316 OR 304

FIGURE 5-1 AUTOMATIC BLOWDOWN SYSTEM.

1. FM data acquisition system is started.
2. The flow control valve (HPSW-1) closes.
3. N_2 is vented bursting rupture discs.
4. Pump is tripped.

In addition, time delay relays allowed programming of these events in a different sequence, if specified. A review and setting of the blowdown sequence timing was done and a number of dry runs were made with one dry run recorded on visicarder tape.

A gamma densitometer air point was accomplished during preparation for a transient test. The instrument pipe sections upstream and downstream of the test pump were opened at the flow homogenizer locations and dried for eight hours with warm dry air before an air point was taken. The air point was recorded on the data acquisition system and on FM System magnetic tape. All piping was then reconnected.

Turbine meters and drag discs were then installed. In general, only high range instruments were used during transients.

The loop operator could now begin start-up procedures. The test loop was filled with deaerated water and all pressure differential pressure cells were bled to remove any air in the sensing lines.

The loop was heated with steam to 175°F. Flow through the test pump was established at 30% rated flow (1050 gpm). A gamma densitometer water point was recorded on the data scanner and FM system.

An FM system span check was accomplished, and all pressure and differential pressure cells were zeroed. P and DP cell zero values were recorded on the data scanner and FM tape.

Data reduction personnel updated the steady-state and transient constant files (TAPE 4) with the latest gamma densitometer constants (C_1, C_2 and C_3) obtained from the air and water points taken. P and DP cell zero data were also updated.

Drag disc and turbine meter cold calibration was done by obtaining seven different flow points spanning from zero to maximum flow. Flow points were established with the water flow orifice and checked against the outputs of the drag discs and turbine meters. All data was then reviewed for consistency before proceding further.

The loop was heated at 100°F/hr to 300°F as indicated by the test pump upstream RTD. Water flow was controlled with HPSW-1, downstream of the test pump, to maintain the fluid in a subcooled condition. At 300°F drag disc temperature dependency checks were made with zero flow in the loop. A slight flow was then attained in order to calibrate the system thermocouples (L-13 and L-14) against the slower but more accurate resistance temperature devices. Flow was increased to 100% rated flow to verify that all systems were functioning properly. All data taken was recorded on the data scanner and on the FM Tape System. If all data checked satisfactorily the loop was brought to 425°F. At 425°F the same instrument checks were made for drag discs, thermocouples and other components as was done at 300°F.

When review of this data was complete the loop was brought to 850 psi or approximately 525°F. At this condition a drag disc temperature dependency check was made with zero loop flow. Loop flow was raised to 30% of rated flow to record a gamma densitometer water data point. All pressure and differential pressure cells were put into their zero position and their millivolt output signals recorded. Calibration constant files were updated with gamma densitometer and P and DP cell zero data obtained at 850 psi. At this time the FM data acquisition system was checked against the KDL Data Scanner.

Drag disc and turbine meter hot calibrations were done at this time using the same seven flow rate increments used for the cold calibrations taken at 175°F. A plot of drag disc and turbine meter millivolt output versus mixing tee flows for both cold and hot flow calibrations was derived.

If all mechanical, instrumentation and data acquisition systems were functioning properly at this time the operator could proceed to the specified pre-blowdown condition. This condition was specified in the test matrix. Once in the pre-blowdown condition, a complete set of five data scans was taken, reduced and reviewed as a final check.

Prior to the actuation of the blowdown sequence timer a number of actions were taken by the operator. The actions were taken to protect the test boiler and certain system components from damage during the transient. In addition, steps were taken to minimize inflow of injection and feedwater into the test loop during the blowdown. The actions taken were as follows:

1. Open HPS-2 to full open position
2. Install remote blowdown actuation and termination cables
3. Reduce injection flows to the booster pumps and test pump to the minimum allowable.
4. Establish water level in H.P. drum in accordance with test instructions.

   NOTE: The remaining actions were accomplished in the minimum time possible prior to initiation of blowdown sequence timer.

5. Secure centrifugal feed pump.
6. Isolate crossfeed system.
7. Close HPS-1 to isolate loop from boiler and secure boiler fires and forced draft fan.
8. Close all loop vents and drains still in operation.
9. Secure booster pumps and engage mechanical brakes on each.
10. Turn off speedomax recorders to eliminate any interference with the scanner and FM Data Acquisition Systems.
11. Turn on scanner (FM system was started automatically by sequence timer)
12. Put feed and injection system in automatic mode.
13. Initiate blowdown sequence timer. The rupture disc's will rupture when nitrogen is automatically released from the space in between these two discs. (See Figure 5-1).

During the actual blowdown the operator could terminate the blowdown remotely.

Termination of blowdown was governed by one or more of the following:

1. Pre-set time closure of the blowdown stop valve (HPSW-2).
2. Overspeed of the test pump.
3. Manually, by the "terminate" push button.

All of the above actions closed valve HPSW-2, thus terminating the blowdown.

The previous procedure was typical when the pump was running at initiation of blowdown. Some tests required that the pump rotor be locked for blowdown.

Normal termination of blowdown was done when system pressure reached 50 psig. At that time the data acquisition systems were stopped.

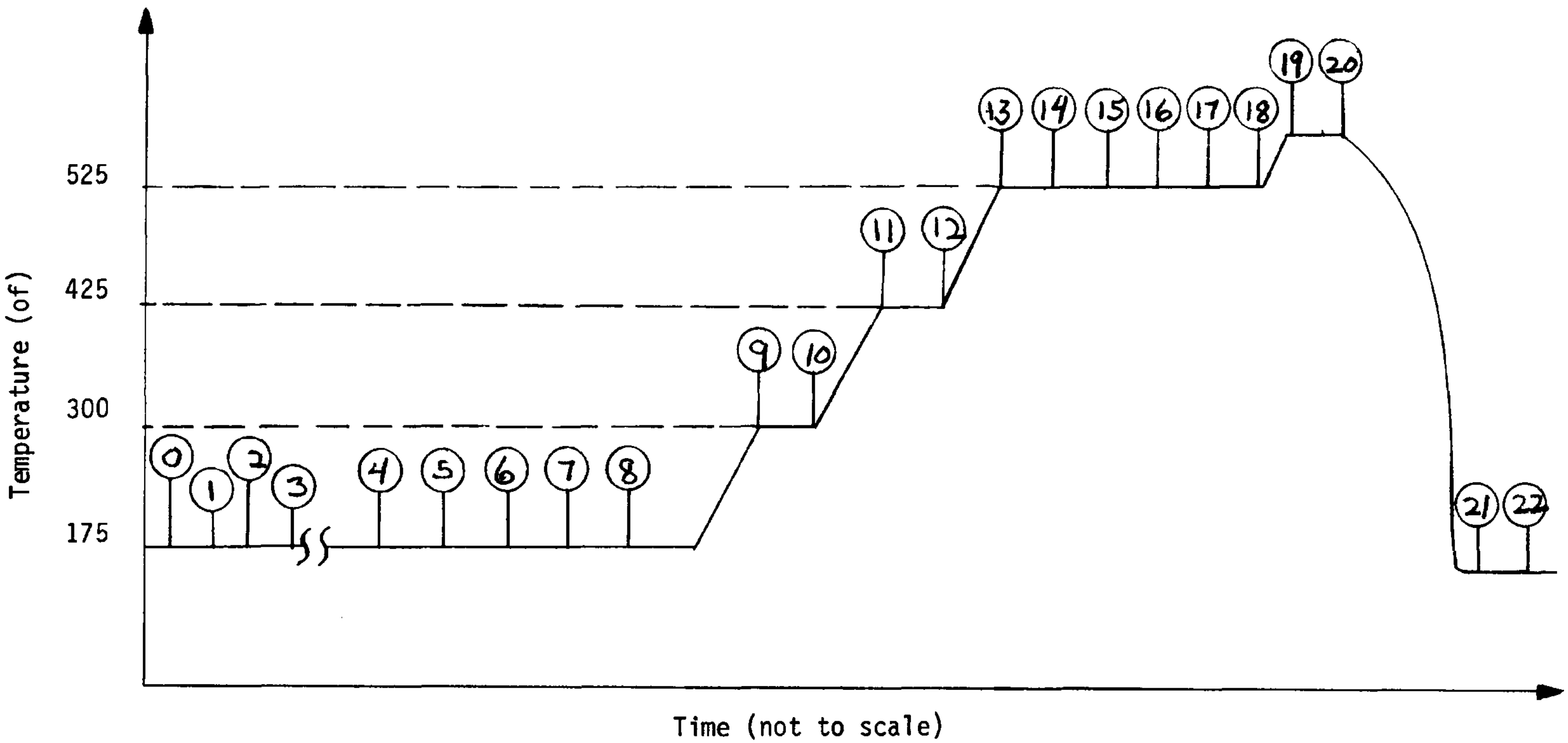
All injection water was secured when the loop temperature was below 212°F, as measured on the test pump upstream thermocouple.

The FM system was turned on for 30 seconds to record post-blowdown FM calibration voltages, FM clock reading and tape footage.

With atmospheric pressure in the loop five data scans were taken to record a gamma densitometer air point.

With all the loop water exhausted the high-pressure metal temperature was still at approximately 500°F. This was due to the fact that the water in the drum was lost very early in the blowdown leaving the thick metal shell at temperatures near the pre-blowdown condition. Because of the high metal temperatures, cool deaerated water could not be put into the drum. To cool the system in a timely manner the boiler was fired up until steam temperatures matched those of the drum metal. The boiler steam was then admitted to the HP drum. With steam going to the HP drum loop feed water was slowly injected into the drum through the drum spray heater connection. The feed water rate was controlled to limit the ΔT across the drum shell to 200°F. When sufficient heated water had been added to the loop to attain a level in the drum the PAC 12 booster pump was started to circulate loop water. From this point single-phase water mode normal cooldown was initiated. After cooldown the torque meter was uncoupled from the pump and, after insuring that it rotated freely, five data scans were taken to record torque meter, drag disc, and turbine meter post-blowdown zero values. From this condition preparation for the next test sequence could be started.

Figure 5-2 is a blowdown data acquisition chart which summarizes the pre-blowdown preparatory sequence described above.



0. Torque Meter Calibration Check
1. FM Calibration
2. γ-D Air Point
3. Fill Loop
4. γ-D Water Point 175° (30% Rated Flow)
5. Pressure & Differential Pressure Cell Zeros
6. 175°F Zero Flow (16 mv on SN 69)
7. 175°F Intermediate Flow Points (22,28,34,40,46 mv on SN 69)
8. 175°F Max Flow Point (52 mv on SN 69)
9. 300°F Zero Flow
10. 300°F Rated Flow
11. 425°F Zero Flow
12. 425°F Rated Flow
13. 850 psia Zero Flow
14. 850 psia γ-D Water Point (30% Rated Flow)
15. FM vs Scanner Check
16. 850 psia Zero Flow Point (16 mv on SN 69)
17. 850 psia intermediate Flow Points (22,28,34,40,46, mv on SN 69)
18. 850 psia Max Flow Point (52 mv on SN 69)
19. Preblowdown Condition
20. Blowdown Initiated
21. γ-D Air Point
22. Post Blowdown Zeros (TM., D.D., Torque Meter)

Figure 5-2 Blowdown Data Acquisition Chart

Section 6

REFERENCES

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2. ANSI B 31.3 - 1973 - Power Piping, with ANSI B31.1e-1974, Winter, 1974 Addenda.

3. MEC-21, "Piping Flexibility Analyses Program for IBM 7000". J. H. Griffin, University of California, Los Alamos, N.M. July 4, 1964.

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5. Gamma - Densitometer Systems Acceptance Test Data Report. Measurements Incorporated, January 1976, For Combustion Engineering, Inc.

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Appendix A

PROCEDURE FOR MEASUREMENT OF TEST LOOP VOLUMES

PROCEDURE

PURPOSE

The purpose of this procedure is to determine the fluid volume present in the test loop prior to a blowdown sequence.

METHOD

Three methods will be employed in this procedure. A combination of more than one method is required due to the complexity of piping and component configurations.

Method 1

This will be a direct displacement of loop volume with water. A totalizer will be utilized to measure the water volume required to fill the loop.

Method 2

A calculation of unfilled volumes will be made for parts of the loop which will not completely filled using Method 1. These volumes would normally be full of fluid prior to a blowdown, however, venting of these specific portions of the system is not possible during this procedure. Pressure and temperature effects during the filling of the loop will be accounted for with this method.

Method 3

Direct calculation of certain portions of the loop which will be isolated from the filled portion of the loop. These piping sections are of simple geometry and thus accurate volumes can be determined.

Procedure: (Method 1)

A) Weight Scale Calibration:

To calibrate the weight scale that will be used to calibrate the totalizer, traceable weights will be used.

1. Place scale on level platform.
2. Record scale reading on Data Sheet 1.

3. Place a number of small weights on the scale and record the scale reading and the weight numbers on Data Sheet 1.

4. Repeat Step 3 until a weight of approximately 450 lbs. is on the scale. Select the weight increase increments such that at least 10 points are recorded between 0 and 450 lbs.

5. Remove the weights in reverse order and record scale readings on Data Sheet 1 until all weights are removed from scale.

6. Record scale reading with no weights added, on Data Sheet 1.

7. Plot curve of actual weight vs. scale reading.

   Note: Scale reading should be corrected by adding or subtracting as applicable, the average scale reading without weights added from each test point.

B) Totalizer Calibration: (Method 1)

The loop volume measuring instrument will be a water totalizer. This instrument will be calibrated by weighing a volume of water which has passed through the totalizer with a calibrated scale. The temperature of the water flowed and the measured weight will determine the actual volume which passed through the totalizer. Figure A-1 shows the totalizer calibration setup.

1. Set up scale, tank, and totalizer.

2. Reset totalizer to read zero (0) gallons.

3. Close V-2 (Tank outlet stop valve).

4. Record scale reading on Data Sheet 2.

5. Open valve V-1 (Tank inlet stop valve).

6. Fill tank then close V-1.

7. Record scale reading, totalizer reading and fluid temperature on Data Sheet 2.

8. Open V-2 and drain tank.

9. Repeat Steps 3 thru 8 until totalizer reads approximately 2000 gals.

   Note: The tank will hold approximately 50 gal. thus approximately 40 test points should be taken.

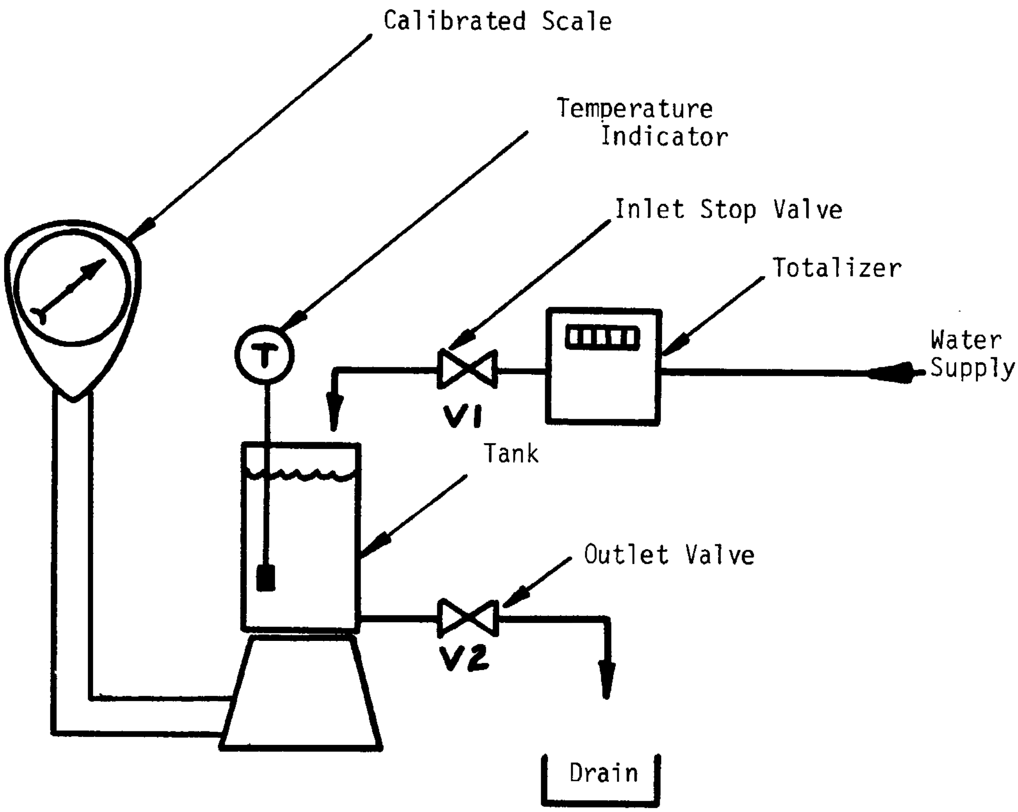

Figure A-1
Totalizer Calibration Setup

10. Subtract scale before fill reading from scale after fill reading for each point to obtain differential scale readings and record on Data Sheet 2.

11. Using test point water temperature and differential scale readings, calculate actual water flowed for each point.

12. Calculate and record on Data Sheet 2 the increase in totalizer reading for each point.

13. Plot a curve of actual water flowed vs. totalizer indicated volumes.

C) Measurement of Loop Volume: (Method 1)

The test loop volume will be measured with the water totalizer calibrated in Section B of this procedure. Prior to measuring loop volumes the system will be set up as shown in Figure A-2.

To accomplish this setup, the following must be done:

1. Open all vents and drains on loop.

2. Remove flow homogenizer spacer pieces from pump discharge and suction pipes. (This is at Points (A) and (C) in Figure A-2).

3. Install totalizer adapter flange at Point (A) Figure A-2. This flange is piped to the totalizer and provides a path for water to enter the loop through the totalizer.

4. Install blank flange at Point (C) Figure A-2.

5. Install gage glass and drum level DP cell at the HP drum.

6. Remove HP drum access door.

7. Install rupture disc blank flange.

Test Procedure:

1. Open the following valves:

HPSW-1	HPW-2	HP Drum vent valves
HPSW-3	HPW-6	
HPSW-2	HPW-7	

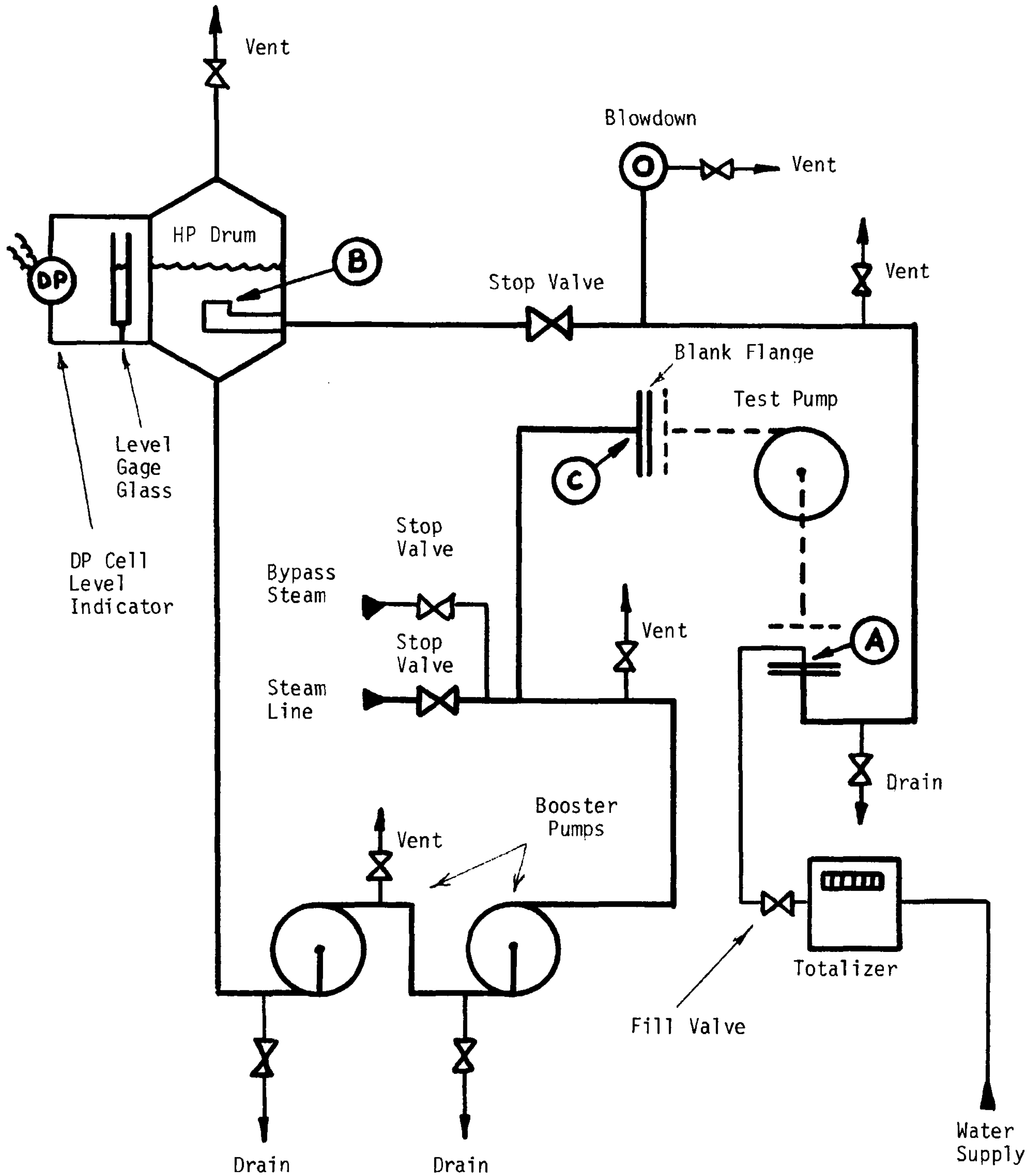

Figure A-2
Loop Volume Measurement Setup

Close the following valves:

HPW-1	HPW-5	PAC 16 Injection and leakoff
HPW-3	HPW-8	PAC 12 Injection and leakoff
HPS-4	HPS-1	Feed water to drum stop valve
HPW-4	HPS-2	

Insure all instrumentation line root valves on loop are shut and all penetrations sealed.

2. Close all loop drains and vents.

3. Reset totalizer to read zero gallons.

4. Open totalizer fill valve to begin filling loop from Point (A) to Point (B) on Figure A-2.

5. Observe separator support pipes in HP drum and stop filling loop when water reaches the top of these pipes.

6. Very carefully vent all pipes between Points (A) and (B) Figure A-2. Close vent immediately when water issues from vent pipes.

7. If level of water in separator support pipe drops during venting, refill to top of pipes by carefully opening fill valve until level is reestablished, then close fill valve. Level should not drop.

8. Record totalizer valve and water temperature at totalizer on Data Sheet 3.

9. Record water temperature of water in drum.

10. Install HP drum access door.

11. Open fill valve to fill loop from Point (B) to (C) on Figure 3 and until DP cell reads 40m V.

12. With DP cell reading 40 mV, carefully vent all piping between Points (B) and (C) on Figure A-2.

13. Refill loop to 40 mV through totalizer.

14. Record totalizer reading on Data Sheet 3, mark water level on sight glass and stop accumulating leakage from PAC 16 and PAC 12.

15. Record distance from lower pressure tap to water level mark in sight glass with DP cell at 40m V.

16. Record water temperature at totalizer.

17. Measure weight and temperature of any leakage accumulated before totalizer reading was taken. Use calibrated scale and temperature indicator for this purpose.

18. Fill loop to 30 mV on DP cell and measure water level on sight glass and record on data sheet along with totalizer reading.

19. Fill loop to 25 mV on DP cell and measure water level on sight glass and record on data sheet along with totalizer reading.

20. Drain water from loop until DP cell reads 40 mV. Measure water level and record on data sheet.

21. Hold water level from 15 minutes to determine if any loop leakage is occurring. Water level will change if leaks are present.

22. Drain water from loop until DP cell reads 50 mV. Measure water level and record on data sheet.

23. Drain water from loop until DP cell reads 60 mV. Measure water level and record on data sheet.

24. Test complete - drain loop.

Method 2 - Calculation of loop volume not completely filled during Method 1 testing.

1. Steam Supply Line

A portion of the vertical pipe from the main steam supply valve to the mixing tee could not be vented during the Method 1 test. This pipe is represented by Item 33F in Table 2-3 which is a compilation of calculated volumes of the loop piping.

The volume of Item 33F is .29 ft^3. The pressure exerted on this volume with the DP cell at 40 mV is approximately 14.5 ft. of water. Thus

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

neglecting temperature effects

$$P_1V_1 = P_2V_2$$

$$1(.29) = (1 + \frac{14.5}{33})\ (V_2)$$

$$V_2 = .2\ ft^3$$

2. Volume of PAC 16 booster pump plus discharge piping:

From Table 2-3, Items 22A, 22B, 22C, 22F, 22E and 1/2 of 22G were not vented. In addition, the pump casing was also full of air.

The volumes associated with these items are:

$$
\begin{aligned}
22A &= 1.49\ ft^3 \\
22B &= 1.49\ ft^3 \\
22C &= 3.47\ ft^3 \\
22F &= 2.21\ ft^3 \\
22E &= 1.49\ ft^3 \\
1/2\ 22G &= .375\ ft^3 \\
\text{Pump Casing} &= \underline{2.00\ ft^3}\ \text{(estimated)} \\
& \quad 12.525\ ft^3
\end{aligned}
$$

The pressure exerted on the air in this volume is approximately 29.5 ft. of water. Thus

$$P_1V_1 = P_2V_2$$

$$1(12.525) = (1 + \frac{29.5}{33})\ (V_2)$$

$$V_2 = 6.6\ ft^3$$

3. Items 24A, 24B, 24C, 24D, and 24E in Table 2-3:

$$
\begin{aligned}
24A &= .19\ ft^3 \\
24B &= .72\ ft^3 \\
24C &= .38\ ft^3 \\
24D &= .91\ ft^3 \\
24E &= \underline{.18\ ft^3} \\
& \quad 2.38\ ft^3
\end{aligned}
$$

$$P_1V_1 = P_2V_2$$

$$1(2.38) = (1 + \frac{29.5}{33})\ (V_2)$$

$$V_2 = 1.26\ ft^3$$

4. Items 67F and 1/2 67E in Table 2-3:

$$\begin{array}{rl} 67F = & .99\ ft^3 \\ 1/2\ 67E = & .075\ ft^3 \\ \hline & 1.065\ ft^3 \end{array}$$

Pressure exerted on this volume is approximately atmospheric. Thus V = 1.065 ft^3.

Total additional volume not included in totalizer reading is:

$$\begin{array}{r} .2\ ft^3 \\ 6.6\ ft^3 \\ 1.26\ ft^3 \\ 1.065\ ft^3 \\ \hline 9.125\ ft^3 \end{array}$$

Method 3 - Excluded Volumes:

The only excluded volumes from Method 1 testing are those from the pump suction mixing plate flange to the test pump suction and from the pump discharge flange to the discharge mixing plate flange. From Table 2-3 these volumes are:

	Item No.	Volume Ft^3
Pump Suction:	48	.19
	47	.18
	46	.19
	45	1.54
		2.1 ft^3
Pump Discharge:	49	1.45 ft^3