LOFT TECHNICAL REPORT
LOFT PROGRAM

TITLE

LOFT Primary Coolant Pump Separate-Effects Tests

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SUMMARY

Two pump and motor units, indential to those to be used in the primary-coolant system of the LOFT facility, were subjected to a series of tests to determine their suitability for loss-of-coolant experiments. These tests were mainly decompressions intended to simulate the various loadings which will occur in LOFT experiments. Additionally, performance tests, cavitation tests, and tests of the water injection to the motor and bearings were made.

Various checks and measurements were made before and after each test to assess the effects on the pump of the environments to which they were exposed. Each of these requalifications indicated a normal condition. A complete disassembly and inspection of both pumps and motors will be made and reported upon later. This report contains plots of the pertinent data acquired as well as descriptions of the instrumentation used, system configuration, and test conditions. Such information should enable all interested parties to make independent evaluations of the environments to which the pumps were subjected and the performance of the pumps under those conditions; neither interpretations nor evaluations are offered in this report.

1.0 INTRODUCTION

System decompressions in water-cooled reactors impose loads which could damage components. Rapid blowdowns cause the pumped fluid to cool quickly, producing thermal stresses. Although slower blowdowns impose less severe thermal gradients across the walls, large differences in the mean wall temperature of various regions of a component can occur leading to potential displacement problems. Isothermal (subcooled) decompressions can cause problems due to the over-pressure effect which may occur as the pressure waves propagate through the system. Conditions similar to those expected in the LOFT facility were imposed on the primary-coolant pumps to insure their capability to survive blowdown experiments.

Canned-rotor pumps, such as the LOFT pumps, are more subject to severe subcooled loading than conventional shaft-sealed units, since waves can enter the motor-cooling passages among which large phase shifts and extensive wave reflections can occur. These phenomena can produce overpressures of several hundred pounds per square inch. A further aspect of canned-rotor pumps is that the pumped fluid is used to lubricate the rotor bearings as well as to remove motor-loss heat. The two-phase fluid in the volute during a blowdown must be prevented from entering the motor cavity if adequate lubrication is to be maintained. Even if the pumped fluid remains at zero, or very low, quality, the small auxiliary impeller which circulates fluid through the motor and bearings could degrade enough during blowdowns to prevent proper circulation. A positive flow of water to the motor was therefore provided in the LOFT pumps by injecting external water into the vent port at the top of the motor. A test of this system was desired.

Other considerations were steady performance of the pumps and their susceptibility to cavitate.

2.0 TEST DESCRIPTIONS

The various tests which were performed are tabulated in Table 1. Two pump units were tested during the program, designated here simply as no. 3 (Serial no. 332476) and no. 4 (Serial no. 332478). The particular tests on each pump are indicated in Table 1.

2.1 Cavitation Tests

The cavitation tests were done by obtaining the desired initial conditions and then slowly reducing the system pressure. In both cavitation tests performed, saturation conditions were reached in the system (this probably occurred first at the top of the drum since the higher elevation fluid near blowdown port A must have remained cooler than the bulk fluid), cf. Figure 1. Data of interest was pump head and circulation rate as a function of the inlet pressure.

TABLE 1. TEST CONDITIONS

No.	Test Type	Test Objective	Initial Inlet Conditions					Remarks
			Temperature F	Pressure psig	Saturation Pressure psig	Power-Supply Frequency Hz	Flow Rate gpm	
1	Cavitation	To determine cavitation data	384.	~250.	190.	59.7	~5000.	Pump head degraded about 10% at 38 ft. suction head
2			367.	~200.	142.	34.9	2345.	No head degradation at 38 ft. suction head
3	Slow Blowdown	To subject pump to volute-distorting conditions	544.	1119.	980.	34.9	1994.	Pump shut down at 7 min. (fluid temperature = 410 F)
4			540.	1180.	948.	34.8	2189.	Pump remained energized; momentarily tripped at 7 minutes
5	Fast Blowdown	To subject pump to fast-decompression loading	565.	1775.	1164.	35.0	2100.	
6	Steam Test	To verify cooling and lubrication capability of the injection water	327.	12.	84.1	34.9	—	3.5 gpm injection flow; pump on 2.75 min; no vibration or heatup detected
7			282.	5.7	36.3	34.5	—	2.1 gpm injection flow; pump on 10 min; no vibration or heatup detected
8	Subcooled Decompression	To subject pump to the over-pressure loading of the LOFT system	263.	555.	22.5	34.4	1891.	1.16-inch orifice used
9			273.	635.	29.2	34.6	1878.	2.0-inch orifice used
10			253.	1515.	16.6	34.3	2146.	

NOTE: Tests no. 1, 2, 3, 5, and 6 were made on pump unit no. 3.

Figure 1. System Configuration For LOFT Pump-Tests

2.2 Slow Blowdown

A 1-inch-diameter orifice was placed just upstream of the rupture-disc assembly at blowdown port A for the slow system blowdowns. When the system had stabilized at the initial conditions desired, an injection-water flow of 2.5 gpm was started and the blowdown was begun. In both of the slow blowdowns a considerable subcooling was present. Just prior to the blowdown, the system was isolated by closing off both feed and bleed lines. During the first test, the pump was shut down seven minutes after the start. The test was terminated at 15 minutes by closing off the shutoff valve ahead of the rupture disc. In the second test the pump remained energized for 25 minutes until the fluid temperature had decreased to about 310°F. The pump was inadvertently shut down by a low-pressure trip about 7 minutes after the test began, but power was quickly restored.

2.3 Fast Blowdown

One fast blowdown was done from port A by removing the orifice plate. About 600 psi subcooling, as indicated in Table 1, existed. The pump was shut down after 45 seconds when the inlet pressure had dropped to about 75 psig. Test procedure was as described for the slow blowdown.

2.4 Steam Test

The steam test involved a running of the pump with a superheated-steam-filled system. This simulated the high-quality environment expected to occur toward the end of a blowdown experiment in the LOFT system. The CE system could not, because of geometric and component dissimilarities, achieve a high-quality condition at the pump during a blowdown. The test was run with an injection flow of 3.5 gpm and later repeated at 2.1 gpm.

2.5 Subcooled Decompressions

Subcooled decompressions were performed by using the expansion volume at port B. Analyses with the WHAM^[3] code had shown that port B was far more suitable than port A as regards generating subcooled pressure histories at the pump akin to those which will occur during the LOFT tests. Tests using increasingly severe initial conditions were performed until overpressure loads (volute to injection port) typical of the 200-300 psid expected in the LOFT system were obtained; this was achieved during the third of these tests, test no. 10.

3.0 FACILITIES DESCRIPTION

The experimental system was a modified steam-water-separator-test facility located in the KDL laboratory of Combustion Engineering, Inc. (CE), Windsor, Connecticut.

The main system with pertinent information and dimensions is shown on Figures 1, 2, and 3. Decompressions were initiated by bursting a rupture disc. The rupture-disc assembly could be located at either port A or B, and the unused port was closed off with a blank flange.

An expansion volume, shown in detail on Figure 4, was used for purely subcooled decompressions and could be attached to either decompression port. The purpose of using the expansion volume, in lieu of venting to the atmosphere was to prevent a system blowdown following a subcooled decompression and/or the outflow of large volumes (~1500 gal) of water during tests from port B. Furthermore, reaction loads on the system were considerably reduced by using such a device.

Pressurization was effected by an auxiliary feed pump; the fluid temperature as well was regulated by a feed/bleed system whereby either cool water or steam up to 635°F could be fed. Miscellaneous systems included pump-coolant supply, pump-injection-water supply, boiler, demineralizer, generator, power supply, and data-acquisition systems. The instrumentation is discussed in detail in the following section.

Pump Description

Manufacturer: Byron-Jackson Div. of Borg-Warner Corporation

Size: 10 in. x 10 in. x 11-1/2 in. Double Volute, Single Suction

Motor: Canned Rotor, 500 hp, 2 pole, 440 volt, 3 phase, 60 cps, Kingsbury Thrust Bearing

Rating: Specific Speed 3300, 5000 gpm @ 320 ft. head, 2500 psig, 650°F Fluid Temperature

4.0 INSTRUMENTATION

ANC and CE each furnished and operated instrumentation for this test series. CE instrumentation was of a systems-control nature, measuring steady-state values of flow rate, power-supply frequency, temperatures, and pressures. ANC provided high-speed data-acquisition systems for transient-test data.

Primary ANC measurements were pressures in the lower portion of the loop near the pump inlet, outlet, and water-injection port. Secondary measurements were volute strains, various temperatures, pump-motor vibration, differential pressures, flow rate, and fluid momentum. Transducer locations are shown on Figure 2. Data records were made on magnetic tape (analogue) and on an oscillograph; most signals were recorded on both systems. Details of the measurements are listed in Table A1, and additional information on the electronics is given in the Appendix.

Instrument Legend

- A. Drag disc; turbine meter, 2-ft. standoff pressure cell; 180° spaced
- B. Flush-mounted pressure cell
- C. Penetration for 2.5-ft. standoff pressure cell and ΔP cell
- D. Strain-gage rosette
- E. Turbine meter, 10-in. standoff pressure cell
- F. Flush-mounted pressure cell
- G. Drag disc, 20-ft. standoff pressure cell
- H. Temperature; penetration for 2-ft. standoff pressure cell and P cells; 90° spaced
- I. Injection-port pressure
- J. Outer volute temperature
- K. Motor-cavity temperature
- L, M. Accelerometers
- N. Strain-gage rosette

Note: All dimensions in feet and along centerline.

Figure 2. Dimensions of Lower Portion of Pump-Test System And Instrumentation Locations

Note: All dimensions
in feet and to inner
surface of drum.

Figure 3. Dimensions of Upper Portion
of Pump-Test System

Figure 4. Blowdown Port B With Expansion Volume

A particular emphasis during the subcooled tests was the comparisons of pressure-transducer responses as a function of standoff lengths. These varied from zero (flush-mounted transducers) to 20 feet.

5.0 TEST DATA

This section contains plots of most of the data which had been recorded on magnetic tape. Selected performance data (steady running) are also included. Comments on the cavitation and steam tests, for which no permanent records were made, are given in Table 1.

Figure 5a. Pump Performance at 550°F

Figure 5b. Pump Performance at 550°F

Figure 6: Pressure at Pump Inlet, Station H, Test No. 3

Figure 7: Pressure at Pump Inlet During Subcooled Decompression, Station H, Test No. 3

Figure 8: Pump Head Generated, Station C/II, Test No. 3

Figure 9: Pump Head During Subcooled Decompression, Station C/II, Test No. 3

Figure 10: Differential Pressure Across Pump Motor,
Station H/I, Test No. 3

Figure 11: Pump Motor ΔP During Subcooled Decompression,
Station H/I, Test No. 3

Figure 12: Vibration at Pump Base, Station L, Test No. 3

Figure 13: Fluid Temperature at Pump Inlet, Station H, Test No. 3

Figure 14*: Fluid Momentum at Pump Inlet, Station G,
Test No. 3

* cf. Appendix Fig. A1

Figure 15*: Fluid Velocity at Pump Inlet, Station E,
Test No. 3

*cf. Appendix Fig. A2

Figure 16: Inlet Pressure During Subcooled Decompression,
Station E, Test No. 4

Figure 17: Pump-Inlet Pressure, Station E, Test No. 4

Figure 18: Pressure at Injection Port During Subcooled Decompression, Station I, Test No. 4

Figure 19: Pump-Outlet Pressure (2-ft. Standoff), Station A, Test No. 4

Figure 20: Inlet Pressure (20-ft. Standoff) During Subcooled Decompression, Station 6, Test No. 4

Figure 21: Pump Head During Blowdown, Station C/II, Test No. 4

Figure 22: Fluid Temperature at Pump Inlet, Station H, Test No. 4

Figure 23: Outer-Volute Temperature, Station J, Test No. 4

Figure 24: Vibration at Motor Base (Filtered above 60 Hz),
Station L, Test No. 4

Figure 25: Vibration at Motor Base During Restart of
Pump (Filtered above 200 Hz), Station L, Test No. 4

Figure 26: Strain at Volute Discharge (parallel), Station N, Test No. 4

Figure 27: Pressure at Pump Inlet, Station II, Test No. 5

Figure 28: Pressure at Pump Inlet During Subcooled Decompression, Station H, Test No. 5

Figure 29: Pressure at Injection Port, Station I, Test No. 5

Figure 30: Pressure at Injection Port During Subcooled Decompression, Station I, Test No. 5

Figure 31: Pump-Motor AP, Station H/I, Test No. 5

Figure 32: Pump-Motor ΔP During Subcooled Decompression,
Station II/1, Test No. 5

Figure 33A: Fluid Momentum at Pump Outlet, Station A, Test
No. 5

*cf. Appendix Fig. A1

Figure 34*: Fluid Velocity at Pump Outlet, Station A, Test No. 5

*cf. Appendix Fig. A2

Figure 35*: Fluid Velocity at Pump Inlet, Station E, Test No. 5

*cf. Appendix Fig. A2

Figure 36: Fluid Temperature at Pump Inlet, Station H,
Test No. 5

Figure 37: Vibration at Motor Base (Filtered above 2000 Hz),
Station L, Test No. 5

Figure 38: Vibration at Motor Base (Filtered above 200 Hz),
Station L, Test No. 5

Figure 39: Pump Head Generated, Station C/II, Test No. 5

Figure 40: Pump Head During Subcooled Decompression,
Station C/H, Test No. 5

Figure 41: Pump Head Generated, Station C/H, Test No. 5

Figure 42: Pressure at Pump Outlet (Flush Mounted), Station B, Test No. 8

Figure 43: Outlet Pressure (Flush Mounted), Station B, Test No. 8

Figure 44: Pressure at Injection Port, Station I, Test No. 8

Figure 45: Pressure at Injection Port, Station I, Test No. 8

Figure 46: Pressure at Pump Inlet (Flush Mounted), Station F, Test No. 8

Figure 47: Pressure at Pump Inlet (Flush Mounted), Station F, Test No. 8

Figure 48: Inlet Pressure (20-ft. Standoff), Station G,
Test No. 8

Figure 49: Inlet Pressure (20-ft. Standoff), Station G,
Test No. 8

Figure 50: Outlet Pressure (2-ft. Standoff), Station A,
Test No. 8

Figure 51: Outlet Pressure (2-ft. Standoff), Station A,
Test No. 8

Figure 52: Inlet Pressure (10-in. Standoff), Station E,
Test No. 8

Figure 53: Inlet Pressure (10-in. Standoff), Station E,
Test No. 8

Figure 54: Vibration at Motor Base (Filtered above 2000 Hz),
Station L, Test No. 8

Figure 55: Vibration at Motor Base (Filtered above 200 Hz),
Station L, Test No. 8

Figure 56: Strain at Volute Discharge (Parallel to Inlet), Station N, Test No. 8

Figure 57: Strain at Volute Inlet (45° to axis), Station N, Test No. 8

Figure 58: Strain at Volute Discharge (Parallel to Discharge), Station N, Test No. 8

Figure 59: Outer-Volute Temperature, Station J, Test No. 8

Figure 60: Pump Head Generated, Station C/H, Test No. 8

Figure 61: Inlet Pressure (10-in. Standoff), Station E, Test No. 9

Figure 62: Inlet Pressure (10-in. Standoff), Station E,
Test No. 9

Figure 63: Outlet Pressure (2-ft. Standoff), Station C,
Test No. 9

Figure 64: Outlet Pressure (2-ft. Standoff), Station C,
Test No. 9

Figure 65: Outlet Pressure (Flush Mounted), Station B,
Test No. 9

Figure 66: Outlet Pressure (Flush Mounted), Station B,
Test No. 9

Figure 67: Inlet Pressure (Flush Mounted), Station F,
Test No. 9

Figure 68: Inlet Pressure (Flush Mounted), Station F,
Test No. 9

Figure 69: Inlet Pressure (20-ft. Standoff), Station G,
Test No. 9

Figure 70: Inlet Pressure (20-ft. Standoff), Station G, Test No. 9

Figure 71: Injection Pressure, Station I, Test No. 9

Figure 72: Injection Pressure, Station I, Test No. 9

Figure 73: Strain at Volute Discharge (Parallel to Inlet), Station N, Test No. 9

Figure 74: Strain at Volute Discharge (45° to axis), Station H, Test No. 9

Figure 75: Strain at Volute Discharge (Parallel to Discharge), Station N, Test No. 9

Figure 76: Pump Head Generated, Station C/R, Test No. 9

Figure 77: Vibration at Motor Base (Filtered above 5000 Hz), Station L, Test No. 9

Figure 78: Vibration at Motor Base (Filtered above 200 Hz),
Station L, Test No. 9

Figure 79: Vibration at Pump base (Filtered above 50 Hz),
Station L, Test No. 9

Figure 80: Outlet Pressure (Flush Mounted), Station B,
Test No. 10

Figure 81: Outlet Pressure (Flush Mounted), Station B,
Test No. 10

Figure 82: Inlet Pressure (Flush Mounted), Station F,
Test No. 10

Figure 83: Inlet Pressure (Flush Mounted), Station F,
Test No. 10

Figure 84: Inlet Pressure (10-in. Standoff), Station E, Test No. 10

Figure 85: Inlet Pressure (10-in. Standoff), Station E, Test No. 10

Figure 86: Outlet Pressure (2-ft. Standoff), Station A, Test No. 10

Figure 87: Outlet Pressure (2-ft. Standoff), Station A, Test No. 10

Figure 88: Inlet Pressure (20-ft. Standoff), Station G, Test No. 10

Figure 89: Inlet Pressure (20-ft. Standoff), Station G, Test No. 10

Figure 90: Pressure at Injection Port, Station 1, Test No. 10

Figure 91: Pressure at Injection Port, Station 1, Test No. 10

Figure 92: Strain at Volute Discharge (Parallel to Suction),
Station N, Test No. 10

Figure 93: Strain at Volute Discharge (45° to Axia),
Station N, Test No. 10

Figure 94: Strain at Volute Discharge (Parallel to Discharge), Station N, Test No. 10

Figure 95: Pump Head, Station C/H, Test No. 10

Figure 96: Vibration at Motor Base (Filtered above 5000 Hz),
Station L, Test No. 10

Figure 97: Vibration at Motor Base (Filtered above 50 Hz),
Station L, Test No. 10

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2. H. L. Coplen Ltr. to R. E. Swanson, Quick-Look Report on LOFT Pump Tests, HLC-430-74, June 12, 1974
3. S. Fabric, Report 67-49-R, Kaiser Engineers, 1967

APPENDIX

Instrumentation

TABLE A1 -. ANC TRANSDUCERS

Parameter	Location	Transducer Specification	Station	Test No.	Remarks
Pressure	Injection Port	Consolidated Controls, 0-3000 psig, nat. freq. 31kc, SN/1568	I	3, 5	2-1/2 foot standoff
				4,8,9,10	2-foot standoff
	Pump inlet	Kistler 406, 0-2500 psig, nat. freq. 31 kc, SN/1317	H	3, 5	2-foot standoff
			E	4,8,9,10	10-inch standoff
		Kistler 406, 0-2500 psig, nat. freq. 31 kc, SN/1316	G	4, 8 9, 10	20-foot standoff
		Norwood 111, 0-3000 psig, gas cooled, nat. freq. 45 kc, SN/10807	F	8,9,10	Flush Mounted
	Pump outlet	Norwood 111, 0-3000 psig, gas cooled, nat. freq. 45 kc, SN/10801	B	8,9,10	
		Consolidated Controls, 0-3000 psig, nat. freq. 31 kc, SN/1566	C	3, 5	2-foot standoff, branched
			A	4,8,9,10	2-ft. straight, isolated standoff
Temperature	Pump inlet	Chromel - Alumel TC, grounded sheath	H	3,4,5 8,9,10	
	Pump volute	Chromel - Alumel TC, grounded sheath	J	4,8,9,10	
	Motor cavity	Iron - constantan TC	K	4, 7	no permanent record made during test no. 7

TABLE A1 (Cont.)

Parameter	Location	Transducer Specification	Station	Test No.	Remarks
Vibration	Motor top	Columbia 302-7, SN/3016, freq. res. 7kc	M	3,4,5 8,9,10	Mounted horizontally; Acceleration signal on Magnetic tape; oscillograph record converted to DC average from 50-1000 Hz
	Motor base	Columbia 302-7, SN/3017, freq. res. 7kc	L	3,4,5,7 8,9,10	
Strain	Volute inlet	Ailtech SG428, 3-gage rosettes, $\pm 6000 \mu\text{-in/in}$	D	3,4,5 8,9,10	
	Volute outlet		N	3,4,5 8,9,10	
Differential Pressure	Inlet/Outlet	BLH HMD, 0-200 psid, nat. freq. 1.8 kc, SN/69883	C/H	3,4,5	
		BLH HLD, 0-100 inches H_2O , SN/74274, time constant 0.01 sec	C/H	3,4,5	
	Inlet/Injection	BLH HMD, 0-200 psid, nat. freq. 1.8 kc, SN/69879	I/H	3,5	
Flow Velocity	Pump inlet	Flow Technology FTD-10-LB turbine meter, SN/0630337	E	3,5	
	Pump outlet	Flow Technology FTD-10-LB turbine meter, SN/0630340	A	3,5	failed during test No. 5

TABLE A1 (Cont.)

Parameter	Location	Transducer Specification	Station	Test No.	Remarks
Fluid Momentum	Pump inlet	Ramapo V-5300-3RD drag disc, 200-2000 lbm/ft-sec ² SN/2924	G	3	
	Pump outlet	Ramapo V-5300-3RD drag disc, 200-2000 lbm/ft-sec ² , SN/2927	A	3	failed prior to test
		Ramapo V-5300-3RD drag disc, 200-2000 lbm/ft-sec ² , SN/2924	A	5	

SEMI-LOGARITHMIC 46 6290
5 CYCLES X 72 DIVISIONS
MADE IN U.S.A.
KEUFFEL & ESSER CO.

Appendix Figure A1

Appendix Figure A2

LOFT PUMP TESTS AT CE, MAY-JUNE, 1974 INSTRUMENT
RECORDING SYSTEM

Instrument Manufacturer & Model No.	Description	Function Remarks
Ampex FR-1300	Magnetic Tape Recorder	14 data channels plus voice channel - used at 7½ ips (Response 0-2500 Hz) and 30 ips (Response 0-10000 Hz)
Ampex TC-10	Tape Recorder Calibrator	Used to adjust and calibrate tape recorder amplifier to within 1% of 1.00 volt.
Honeywell Visicorder Model 1912	Direct-write, 36 channel oscilloscope	Used M-1650 Galvanometers, response 0-1000 Hz
Honeywell Accudata 120	Low Level DC Differential Amplifiers	Switched-step gains; 10, 20, 50, 100, 200, 500, 1000 Amplifiers calibrated with above oscilloscope; used to drive galvos and tape recorder
Gen. Resistance Co. (Dial-a-source) DAS-46AL	DC Voltage Calibration Source	This instrument was primary calibration source and was used in conjunction with the digital voltmeter to calibrate and test recording instrumentation. This instrument was returned to NRTS between trips to update calibration through the NRTS Standards Lab. Stated accuracy $\pm .0015\%$ of voltage setting
Fluke Model 8100A	Digital Multimeter	Used for digital voltmeter in monitor and calibration functions (see above)
Kistler Model 504-M4	Charge Amplifier 2 each	Used with accelerometers (charge to voltage converter)

I&CE Fabricated

Amplifier, Monitor-
Calibration/Control
Cabinet Assembly

Used to control and switch input to DC amplifiers,
monitor output of amplifiers, for calibration and
monitor purposes.

B&F Model
2471/15-200F

Adjustable DC Power
Supplies and Bridge
Completion Units
(12 channels)

Used for strain gages and pressure transducers

I&CE Fabricated
(with video int.
SR 200 EM and
SRC-3569 Adjustable
Power Supplies

Same as above
except 4 channels

Used for drag disc flowmeters and Norwood flush
mount transducers

I&CE Fabricated

10 channel
Operational
Amplifier
Manifold

Used for circuitry to provide filter and averaging
of accelerometer signals, and for attenuator cir-
cuit for accelerometer signals.

Gulton Model
108

IRIG Time
Code Generator

Kronhite Model
4200

Sine Wave
Oscillator

These units used to provide timing and speed control
information record on tape recorder

ATEG 6B86

Frequency
Counter

Flow Technology
Model PRI-102FR

Flow Rate Monitor
(For Turbine
Flowmeters)

Conditions the pulse signal from turbine transducers
to equivalent DC signal (digital to analog converter)

Transducers

Turbine Flow Meter, Typical of 2

Acceleration, Typical of 2

Transducers

Pressure Transducers and Drag Disc Flowmeters (Typical of All)

Strain Gages, Typical of All

Thermocouple, Typical of All

Instrumentation Block Diagram,
 LOFT Pump Tests at CE