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LOFT DIFFERENTIAL PRESSURE UNCERTAINTY ANALYSIS

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LOFT TECHNICAL REPORT

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11-17-77ABSTRACT

A performance analysis of the LOFT differential pressure (ΔP) measurement is presented. Along with completed descriptions of test programs and and theoretical studies that have been conducted on the ΔP , specific sources of measurement uncertainty are identified, quantified, and combined to provide an assessment of the ability of this measurement to satisfy the SDD 1.4.1C (June 1975) requirement of measurement of differential pressure.

The theoretical framework and general methods employed in this supplement are discussed in LTR 141-39, "LOFT Experimental Measurements Uncertainty Analysis".

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SUMMARY

The differential pressure transducers have a good stable slope sensitivity. However, they have significant unwanted line pressure and temperature sensitivities which effect the transducer offset. The following table of uncertainties includes both a temperature and line pressure correction procedure. Without these corrections, the uncertainties would be many times greater.

SUMMARY DIFFERENTIAL PRESSURE TRANSDUCER UNCERTAINTY ANALYSIS

Parameter	Uncertainty (95% Confidence)					
Transducer (Mod. No.)	HLD	HLD	HMD	HMD	HMD	HMD
Range [psid (MPa)]	± 10 (± 0.01)	± 25 (± 0.17)	± 50 (± 0.34)	± 100 (± 0.69)	± 200 (± 1.38)	± 1500 (± 10.38)
Calibration (with temp. offset correction)	± 0.07 (± 0.49)	± 0.17 (± 1.2)	± 0.045 (± 0.31)	± 0.03 (± 0.21)	± 0.06 (± 0.91)	± 0.15 (± 1.0)
Accuracy	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)
Linearity						
Hysteresis	$\pm 0.16\%$ RD	$\pm 0.23\%$ RD	$\pm 0.13\%$ RD	$\pm 0.11\%$ RD	$\pm 0.11\%$ RD	$\pm 0.13\%$ RD
Traceability						
Line Pressure	± 0.02 (± 0.14)	± 0.05 (± 0.34)	± 0.1 (± 0.69)	± 0.2 (± 1.4)	± 0.4 (± 2.8)	± 3.0 (± 21.0)
plus (RSS)	± 0.013	± 0.033	± 0.065	± 0.13	± 0.26	± 1.95
DAVDS (DDAPS)	(± 0.090)	(± 0.224)	(± 0.448)	(± 0.90)	(± 1.79)	(± 13.44)
Total (RSS)	± 0.07 (± 0.49)	± 0.18 (± 1.2)	± 0.13 (± 0.88)	± 0.24 (± 1.7)	± 0.48 (± 3.3)	± 3.6 (± 25)
	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)
	$\pm 0.16\%$ RD	$\pm 0.23\%$ RD	$\pm 0.13\%$ RD	$\pm 0.11\%$ RD	$\pm 0.11\%$ RD	$\pm 0.13\%$ RD

Response (10 to 90% risetime)

35 msec for all these sampled at 50 samples per second.

* These values are in psid with the values below in parentheses are in KPs.

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1.0 PURPOSE

1.1 Core Differential Pressure Measurements

Differential pressure (ΔP) measurement data, obtained during subcooled decompression, supply information used in the determination of the loads acting on the core, core barrel, and core mounting plate. The ΔP data obtained during saturated decompression helps support core flow measurement data.

A measurement of the ΔP between the upper plenum and the upper downcomer is to provide data on the pressure loss across the reactor vessel nozzles in the operating loop. During refill and reflood, this ΔP is the sum of the pressure difference across the core and the downcomer. Since the pressure drop across the core is expected to be small, this measurement should provide an adequate indication of the height of water in the downcomer. Also, the pressure difference between the upper plenum and the downcomer is the driving potential for reflooding the core under steady-state conditions. This measurement, in conjunction with others specified during reflood, will permit an evaluation of the hydraulic behavior throughout the primary system.

The differential pressure across the core mounting plate assembly is required as a potential means of determining the flow direction at the core inlet. The pressure drop across the core mounting plate assembly, which is caused by kinetic losses and momentum effects, is related directly to the flow magnitude and direction through the core.

The differential pressure across the core will provide a check on the core flow and core flow distribution. This measurement is primarily of importance during saturated decompression and reflood because the pressure differential during subcooled decompression can be better obtained as the difference between absolute measurements, which exhibit faster response characteristics.*

1.2 Primary System Coolant Differential Pressure Measurements

Differential pressures are of major importance at two locations in the primary coolant operating loop - across the primary coolant pumps and across the steam generator.

For most flow conditions expected during saturated decompression and reflood, the pressure drop across the pumps is functionally related to the performance and characteristics of the pump. The differential pressure across the pumps, in conjunction with pump speed, velocity, and momentum flux, provides knowledge of pump behavior during transient conditions.

* Abstracted from Page A-83 of MRD-1, February 28, 1975.

The differential pressure measurement across the operating loop steam generator is needed for two reasons. First, the measurement supplies information, used in conjunction with other measurements, to provide an understanding of the complex decompression process in the steam generator. Second, the steam generator contributes a significant resistance to steam flow during reflood. Measurement of the differential pressure, with the inherent effect of heat transfer, will provide an understanding of the decompression processes, particularly, when these measurements are compared with the corresponding measurement across the simulated steam generator in the blowdown loop.

Differential pressure measurements are needed in the blowdown loop to determine the response of the simulated components relative to that of the active components in the operating loop. These measurements will permit an evaluation of the sum of the pressure drops against the driving head, and thus aid assessment of a model for calculating blowdown system behavior during reflood. No flow measurement is made downstream of the simulators. Therefore, the determination of break flow will be strongly dependent on the measurement of differential pressure across the simulators. Further, the ΔP measurements will be used to determine whether the performance of the simulators during the LOCE is the same as that established on the smaller scale versions used in the characterization tests.

During reflood, the pressure drops across the individual components and area changes in the blowdown loop will be quite small. The sum of these drops is a larger, more measurable quantity.

Measurement of the difference between the pressure in the lower plenum and the pressure in the suppression tank is also needed for evaluating the sum of the measured pressure drops across individual components, and for evaluating the measured break flow. This measurement also provides a check on the calculated break flow and ΔP .*

2.0 DESCRIPTION

2.1 Discussion

There are a total of 29 differential pressure measurements to be made in LOFT (see Table 2-1).

See Figure 2-1 for the locations of the differential pressure measurements made with core simulator (nonnuclear testing). See Figure 2-2 for the locations of the differential pressure measurements made with the core (nuclear testing). The locations of the nine operating loop ΔP transducers are shown in Figure 2-3. The locations of the ten broken loop ΔP transducers are shown in Figure 2-4.

*Abstracted from Page A-83 of MRD-1, February 28, 1975.

TABLE 2-1

LOFT DIFFERENTIAL PRESSURE MEASUREMENTS

<u>Measurement I.D.</u>	<u>Test Series</u>	<u>Range</u>	<u>Description</u>
1) Broken Loop			
PdE-BL-1	All	+50 psid (+0.34 MPaD)	ΔP across 14 to 5 inch connection on outlet leg
PdE-BL-2	All	+1500 psid (+10.34 MPaD)	ΔP across 14 to 5 inch connection in inlet leg
PdE-BL-3	All	+1500 psid (+10.34 MPaD)	ΔP across 12 inch joint in break plane
PdE-BL-4	All	+1500 psid (+10.34 MPaD)	ΔP across 12 inch joint in break plane
PdE-BL-5	All	+1500 psid (+10.34 MPaD)	ΔP across pump simulator
PdE-BL-6	All	+50 psid (+0.34 MPaD)	ΔP across steam generator outlet flange
PdE-BL-7	All	+50 psid (+0.34 MPaD)	ΔP across steam generator
PdE-BL-8	All	+50 psid (+0.34 MPaD)	ΔP across steam generator inlet flange
PdE-BL-9	All*	+200 psid (+1.38 MPaD)	ΔP across 14 inch to middle of 5 inch pipe
PdE-BL-10	All*	+200 psid (+1.38 MPaD)	ΔP across middle of 5 inch pipe to break plane
2) Operation Loop			
PdE-PC-1	All	+100 psid (+0.69 MPaD)	ΔP primary coolant pumps
PdE-PC-2	All	+100 psid (+0.69 MPaD)	ΔP across steam generator
PdE-PC-3	All*	+10 psid (+.69 KPaD)	ΔP between reactor vessel outlet to pres. inlet
PdE-PC-4	All*	+10 psid (+.69 KPaD)	ΔP between pres. inlet to steam gen. inlet
PdE-PC-5	All*	+10 psid (+.69 KPaD)	ΔP between primary coolant pump to reactor vessel outlet
PdE-PC-7	All*	+10 psid (+.69 KPaD)	ΔP between reactor vessel inlet to broken loop inlet
PdE-PC-8	All*	+1500 psid (+10.34 MPaD)	ΔP across surge line
PdE-PC-9	All*	+100 psid (+0.69 MPaD)	ΔP across primary coolant pump No. 1
PdE-PC-10	All*	+100 psid (+0.69 MPaD)	ΔP across primary coolant pump No. 2
3) Core			
PdE-CS-1	Nonnuclear only	+25 psid (+0.17 MPaD)	ΔP between core simulator & lower downcomer
PdE-RV-1	All	+1500 psid (+10.34 MPaD)	ΔP between downcomer and suppression tank
PdE-RV-2	Nuclear only	+25 psid (+0.17 MPaD)	ΔP across fuel assembly 1
PdE-RV-3	All*	+10 psid (+.69 KPaD)	ΔP between reactor vessel inlet to lower downcomer
PdE-RV-4	All*	+10 psid (+.69 KPaD)	ΔP between upper plenum and reactor vessel outlet
PdE-2ST-1	Nuclear only	+25 psid (+0.17 MPaD)	ΔP between upper plenum and lower downcomer
PdE-2ST-2	Nonnuclear only	+25 psid (+0.17 MPaD)	ΔP between top and bottom of downcomer
PdE-2ST-3	Nuclear only	+25 psid (+0.17 MPaD)	ΔP between upper plenum and upper downcomer
PdE-2ST-4	Nuclear only	+10 psid (+.69 KPaD)	ΔP across core mounting plots
4) Suppression Tank			
PdE-SV-9	All*	+100in. (+254 cm)	ΔP across vacuum breaker line

*These transducers were added during the nonnuclear test series

FIGURE 2-1

REACTOR VESSEL DIFFERENTIAL PRESSURE MEASUREMENTS WITH THE
 NONNUCLEAR CORE SIMULATOR IN PLACE

FIGURE 2-2
REACTOR VESSEL DIFFERENTIAL PRESSURE MEASUREMENTS
WITH THE NUCLEAR CORE IN PLACE

FIGURE 2-3

OPERATING LOOP DIFFERENTIAL PRESSURE MEASUREMENTS

FIGURE 2-4

BROKEN LOOP DIFFERENTIAL PRESSURE MEASUREMENTS (HOT LEG BREAK CONFIGURATION)

As of this writing 24 ΔP transducers are being used for the nonnuclear tests. The present plan for the nuclear tests include 29 ΔP transducers. A schematic of a typical differential pressure transducer mounting is shown in Figure 2-5.

To make these measurements, bonded strain gage differential pressure transducers were purchased from BLH Electronics, Inc. There are three types of high line pressure differential pressure transducers: HLD (high line, low differential); HMD (high line, medium differential); and HHD (high line, high differential) types.

Transducers were purchased per INEL Specification ANC-60146 in ranges listed below:

<u>Type</u>	<u>Range</u>
HLD	+10 psid (+69 kPaD)
HLD	+25 psid (+0.17 MPaD)
HMD	+50 psid (+0.34 MPaD)
HMD	+100 psid (+0.69 MPaD)
HMD	+200 psid (+1.38 MPaD)
HHD	+1500 psid (+10.34 MPaD)

Vendor calibration data are available for all transducers. All of the transducers use strain gages bonded to a diaphragm which separates the high and low sides of the ΔP sensing element (see Type B transducer description in Supplement No. 9 to LTR 141-39 for additional discussion). The HLD type unit is manufactured with the pressure cavities filled with oil.

2.2 Transducer Specifications

This section consists of a synopsis of performance aspects of INEL Specification ANC-60146, "LOFT Differential Pressure Detector", and a tabulation of vendor's (BLH) transducer performance.

2.2.1 ANC-60146

A. Environment

1. Fluid media is borated water with:

- 500-3000 ppm boron
- 2 ppm lithium
- <10 ppm oxygen

*2. Integrated nuclear irradiation (2000 hrs.)

- 2.0×10^{12} nvt (thermal neutrons)
- 2.0×10^6 R: (gamma)

ANC-A-4751

FIGURE 2-5
DIFFERENTIAL PRESSURE TRANSDUCER MOUNTING SCHEMATIC

B. Electrical

1. Excitation - 10 vdc
2. Full-scale output - nominal 30 mv
3. Bridge resistance - nominal 350 ohms
4. Insulation resistance - $>10^9$ ohms at 50 vdc

C. Functional

1. Response time (10 to 90% rise time) - <10 msec
2. Resolution - infinite
- *3. Compensated temperature range - 40°F to 200°F (4°C to 93°C)
4. Zero Balance - $\pm 2\%$ full scale (FS)
5. Thermal sensitivity shift - $\pm 0.005\%$ FS per degree F ($\pm 0.009\%$ FS per $^{\circ}\text{C}$)
6. Thermal zero shift - $\pm 0.005\%$ FS per degree F (0.009% FS per $^{\circ}\text{C}$)
- *7. Error band - (repeatability, nonlinearity, hysteresis combined) - $\pm 0.5\%$ FS
8. Vibration error - $\pm 0.001\%$ FS for vibration about any three orthogonal axes, for sine wave excitation over the range 20 to 200 Hz at 5g
9. Life at full-scale pressure and temperature - 10^4 hrs. at conditions
- *10. Line pressure - 0 to 2500 psig on either port (0 to 17.24 MPaG)
- *11. Zero shift with line pressure - 0.5% FS
- *12. Zero shift with single port overpressure - 0.5% FS

2.2.2 Vendor Transducer Specification

A listing of published specifications for BLH Models HLD, HMD, and HHD transducers is shown in Table 2-2.

* Significant differences between INEL and vendor specifications are noted

TABLE 2-2

VENDOR TRANSDUCER SPECIFICATIONS

Performance Parameter	HLD	HMD	HHD
Rated pressure (psid) (MPa)	+10.8, +28.8 (+0.0745, +0.199)	+50, +100 (+0.345, +0.689)	+2000, +3000 (+13.8, +20.7)
Excitation, recommended	12 v. ac or dc	10 v. ac or dc	10 v. ac or dc
maximum	18 v. ac or dc	15 v. ac or dc	15 v. ac or dc
Zero balance	1.0% Rated output (R.O.)	2.0% R.O.	2.0% R.O.
Terminal resistance, input	350 $\pm$ 5 ohms	350 $\pm$ 3.5 ohms	350 ohms, min
output	350 $\pm$ 5 ohms	350 $\pm$ 5 ohms	350 $\pm$ 5 ohms
Termination	screw terminal	bendix connector	connector with mating half
Insulation resistance, bridge to ground	5 x 10 ⁹ ohms	5 x 10 ⁹ ohms	5 x 10 ⁹ ohms
Rated output (R.O.)	3.0 mv/v	2.0 mv/v	3.0 mv/v
Calibration accuracy	0.25% R.O.	0.50% R.O.	0.5% R.O.
Nonlinearity	0.5% R.O.	0.25% R.O.	0.25% R.O.
Repeatability	0.1% R.O.	0.10% R.O.	0.10% R.O.
Hysteresis	0.2% R.O.	0.15% R.O.	0.10% R.O.
Temperature range, safe	0 to 200°F (-18 to 93°C)	0 to 200°F (-18 to 93°C)	0 to 200°F (-18 to 93°C)
Compensated	25 to 175°F (-3.9 to 79.4°C)	30 to 130°F (-1 to 54°C)	30 to 130°F (-1 to 54°C)
Temperature effect on zero balance	0.5% R.O. per 100°F (56°C)	0.5% R.O. per 100°F (56°C)	0.5% R.O. per 100°F (56°C)
Temperature effect on R.O.	1.0% R.O. per 100°F (56°C)	0.5% R.O. per 100°F (56°C)	0.5% R.O. per 100°F (56°C)
Overload rating, safe	1500 psi (10.3 MPa)	10 times rated pressure	3000 psi (20.7 MPa)
ultimate	--	---	4000 psi (27.6 MPa)
Max line pressure	5000 psi (34.5 MPa)	5000 psi (34.5 MPa)	5000 psi (34.5 MPa)

TABLE 2-2 (cont'd.)

VENDOR TRANSDUCER SPECIFICATIONS

Performance Parameter	HLD	HMD	HHD
Internal volume at pressure, each cavity	0.7 cu. in. (11.5 cm ³)	--	--
Change in internal volume caused by applied pressure	0.02 cu. in. (0.33 cm ³)	--	--
Material in contact with the pressure medium	300 series S.S.	17-4PH S.S.	17-4PH S.S.
Pressure fitting	3 connections, 90° (1.57 rad.) apart, 1/4-18 MPT pressure connections on 2-1/8 in. (5.4 cm) centers		AND 10050-4 tube fitting 7/16-20 UNF-3B
Line pressure effect on zero balance	--	--	1% R.O. @ 5000 psi (34.5 MPa)
Weight	12 lb. (5.4 kg)	6 1/2 lb. (2.9 kg)	1 lb. (0.45 kg)

3.0 TESTS PERFORMED AND RESULTS

3.1 Transducer Tests

3.1.1 Vendor Acceptance Testing

Tests consisting of three quality control provisions, in addition to an error band test, and two zero shift tests were required of the vendor per ANC-60146.

Traceability - Complete traceability of all manufacturing, testing, and Quality Division records for each transducer were maintained by the manufacturer and submitted to the purchaser.

Calibration - Transducers were furnished with calibration data taken at 20% FS increments over the full-pressure range of transducer. Calibrations were made with the transducers stabilized at 40°F, 120°F, and 200°F (4.4°C, 49°C, and 93°C).

Inspection - All tests required by the specification were made by the manufacturer prior to shipment. The manufacturer submitted an inspection test plan to the purchaser for approval and incorporation of the purchaser's inspection hold point.

A certification that the transducers conform to the requirements of the BLH specification was provided for each lot of transducers shipped. The manufacturer provided all test results.

Error Band Test - Error band tests were as follows:

- a. Stabilize the sensor at a temperature within $\pm 10^{\circ}\text{F}$ ($\pm 18^{\circ}\text{C}$) at the low temperature end of the compensated range. Excite the sensor with 10 ± 0.01 Vdc. Pressurize from 0 to FS psia in 20% FS $\pm 0.05\%$ FS steps. Record the voltage output at each pressure for three complete increasing and decreasing traverses of the FS range.
- b. Repeat (a) at the mid-point of the compensated temperature range and at the high end of the compensated range within $\pm 10^{\circ}\text{F}$ ($\pm 18^{\circ}\text{C}$).
- c. The output values all fall within a band of 0.22% RD plus 0.72% RG at any combination of temperature, pressure and direction of traverse per ANC testing.

Test for Zero Shift with Line Pressure - The test for zero shift with line pressure shall be as follows:

- a. With the sensor stabilized at room temperature, excite the sensor with 10 ± 0.01 Vdc. Connect both inlet pressure ports to a common pressure source so that both ports see the same pressure at all times. Pressurize both ports simultaneously to 3000 psig (20.7 MPa) in 500 ± 10 psig (3.4 ± 0.07 MPa) steps. Record the voltage output at each step for three increasing and decreasing traverses. INEL testing showed errors as high as 10% RG at 2500 psi. (17.2 MPa). Transducers with errors higher than 2% RG and 2500 psi (17.2 MPa) were returned to vendor.

Test for Zero Shift with Single Port Overpressure - The test for zero shift with single port overpressure was be as follows:

- a. With the sensor stabilized at room temperature, excite the sensor with 10 ± 0.01 Vdc. Pressurize the left inlet pressure port to 3000 psig (20.7 MPa). The right pressure port shall be at atmospheric pressure. Depressurize the left inlet port back to atmospheric pressure, and record the voltage output.
- b. Repeat a, but now pressurize the right inlet pressure port, while the left inlet pressure port is at atmospheric pressure.
- c. Vendor certified compliance with specifications.

3.1.2 INEL Qualification Testing Test Plan - DPT-001

This program consists of testing two transducers of each type (HLD, HMD, and HHD) for two electrical and four performance characteristics. This testing is not complete at this time and no data is available.

A. Bridge Resistance (electrical)

At ambient temperature measure and record the input and output resistance.

B. Insulation Resistance (electrical)

Measure and record at ambient temperature the insulation resistance between all terminals, or leads connected in parallel, and the case of the transducer.

C. Ambient Performance Characteristics - High Side

The following tests are to be performed at ambient temperature:

The pressure source is connected to the high side of the transducer. The transducer is seated by rapidly applying and releasing a pressure equal to 100% of the transducers pressure rating.

Two consecutive calibration cycles are run with the applied pressure between 0 and 105% in 20% increments to 100% - then 105%.

A proof pressure is applied to the transducer and released after which zero shifts, transducer performance checks and a calibration cycle are recorded.

D. Performance Characteristics - Low Side

The pressure source is connected to the low side of the transducer and Section 3.1.2C repeated.

E. Performance Characteristics - Reference Pressure

With a reference pressure applied to both sides simultaneously, calibration cycles are run in 20% increments from 0 to 105% of full scale rated pressure. This is done with reference pressures of 2500 psi (17.2 MPa) and 1000 psi, (6.89 MPa) with the calibration measurand applied to the high side and then to the low side.

F. Performance Characteristics - Thermal

Calibration cycles are run at 20% increments between 0 to 105% of rated full scale pressure at 40°F (4°C) and at 200°F (93°C) and data recorded.

3.1.3. ANC Calibration Testing - DPT-002

This test plan provides a measurement of bridge resistance, insulation resistance and ambient performance calibration including response to four calibration resistances for each transducers. The details of this testing are summarized below.

A. Bridge Resistance

At ambient temperature, measure and record the input and output resistance. Both input and output resistance were measured at a nominal 350 ohms.

B. Insulation Resistance

Measure and record at ambient temperature the insulation resistance between all terminals or leads connected in parallel, and the case of the transducer. Insulation resistance was greater than 2×10^9 ohms.

C. Ambient Performance Characteristics

The following calibration was performed at ambient temperature.

1. The pressure source is connected to the high side of the transducer. The transducer is seated by rapidly applying and releasing a pressure equal to 100% of the transducers pressure rating.
2. Two consecutive calibration cycles are run with the applied pressure between 0 to 105% in 20% increments.
3. The pressure source is connected to the low side of the transducer.
4. Two consecutive calibration cycles are run with the applied pressure between 0 and 105% in 20% increments.
5. Calibration equations were calculated for each transducer.

3.1.4 Response Testing of Pressure Standoff Tubes Using the Blowdown Autoclave - R. P. Evans

This material was presented in Section 3.4 of Supplement No. 9 to LTR 141-39 and will not be repeated here.

3.1.5 Standoff Pipe Effects Testing for Time-Varying Transfer- Function Analysis - V. T. Berta

This material was presented in Section 3.5 of Supplement No. 9 of LTR 141-39 and will not be repeated here.

3.1.6 Dynamic Pressure Measurements on Long Transmission Lines - R. H. Meservey

A series of blowdown autoclave tests were run in an attempt to identify the nature and extent of measurement distortion attributable to the fluid filled transmission lines. Both absolute and differential configurations were examined. Preliminary results of this testing were reported in ANCR-1074 and Report of Formal Design Review of R. H. Meservey. Unfortunately, the data tapes were erased precluding a detailed analysis of the results. Figure 3-1 compares the performance of a BLH ΔP transducer on 40 feet (12m) long, $\frac{1}{4}$ inch (0.635 cm) standoffs with the same difference measurement made with a pair of Kistler absolute pressure transducers on 2 feet long, $\frac{1}{4}$ inch OD standoffs.

Figure 3-1 shows good measurement agreement for about the first 2.5 seconds of the 10 second blowdown. Between 2.5 and 5.5 seconds the BLH differs from the measurement made by the Kistlers by about 8%. From 6 to 10 seconds, the difference is greater than the MRD requirement. This may be due to the lines blowing down (steam coming out of the fluid) or a temperature coefficient change between them. This is not an under-damped ringing problem in the same sense as was observed for the absolute pressure measurements made on 40 feet long, $\frac{1}{4}$ inch standoffs.

3.2 LOFT Nonnuclear Test Results

As of this writing four nonnuclear tests have been run on LOFT. Appendix A shows data taken from Test L1-3A. This data has shown good results in verifying uncertainties for the ΔP transducers.

One good method of checking ΔP measurement channel performance is under steady state conditions. Several ΔP transducers have been placed serially around the operating coolant loop. Transducer PdF-PC-1 is placed across the coolant pumps and five others are placed around the loop (PdE-PC-2, PdE-PC-4, PdE-PC-3, PdT-P139-30, and PdE-PC-5). Theoretically, under flow the differential pressure loss across the five transducers should equal the pressure head across the pump. Figure 2-3 has already shown

FIGURE 3-1
STANDOFF ΔP MEASUREMENTS

general location of the ΔP transducers. Data from Test L1-3A is given in Table 3-1 for five different flow levels at a coolant temperature of 540°F (282°C). These data have shown an excellent correlation and help to support the uncertainty values obtained in Section 5.0 of this report.

4.0 THEORETICAL STUDIES

This entire section was presented in Section 4.0 of Supplement No. 9 of LTR 141-39 and will not be repeated here.

5.0 DISCUSSION OF SPECIFIC UNCERTAINTIES

5.1 Temperature - Calibration Equation

The temperature which each transducer will see just prior to and during a LOCE is not known accurately. Since the transducers are mounted at the end of several feet of $\frac{1}{4}$ inch (0.635 cm) tubing, the temperature which the internals of the transducer sees will be that of the stagnant water in the tubing. The transducer, which is mounted on a panel, will see near ambient air temperature.

The HMD and HHD ΔP transducers are internally compensated for a temperature range of 30 to 130°F (-1 to 54°C). The HLD transducers are temperature compensated from 25 to 175°F (-4 to 79°C).

Data taken from the LOFT nonnuclear tests has shown some zero shift in the transducer during the primary coolant heat up sequence of the tests. This is apparently caused by the heatup of the air around the transducer. Several HLD transducers have shown as much as a 6% RG change in offset during the primary coolant heatup from [160°F to 540°F (71°C to 282°C)].

The HMD and HHD transducers have shown the same characteristic but to a lesser degree (<2% RG). These tests have shown little detectable change in the slope sensitivity of the transducer. To keep the temperature uncertainty at a usable level all the nonnuclear tests have had an offset reference point taken with no primary coolant flow. This is taken after the system has reached a stable operating temperature. With this no flow data point, the temperature generated offset can easily be subtracted from the ΔP offset coefficient.

Using data supplied from the manufacture and data obtained from the LOFT nonnuclear tests, the uncertainty for the compensated temperature plus calibration effects on the ΔP transducers are as follows:

TABLE 3-1

DIFFERENTIAL PRESSURE SUMMATION AROUND THE
CLOSED LOOP FOR TEST L1-3A

Pump Freq. (Hz)	<u>Output in psig</u>				
	<u>20</u>	<u>30</u>	<u>40</u>	<u>50</u>	<u>60</u>
Transducer					
PdE-PC-2	5.56	12.37	21.58	33.46	47.02
PdE-PC-4	0.67	0.86	1.45	2.25	3.33
PdE-PC-3	0.22	0.48	0.88	1.37	1.92
P1T-P139-30	4.08	9.18	16.21	25.25	35.57
PdE-PC-5	<u>0.45</u>	<u>1.06</u>	<u>1.86</u>	<u>2.91</u>	<u>4.11</u>
Total Loss	10.98	23.95	41.98	65.24	91.95
PdE-PC-1 Head	10.65	23.92	41.77	65.04	91.45
Difference	+ 0.33	+ 0.03	+ 0.21	+ 0.2	+ 0.5 psid

<u>Transducer Range</u>	<u>Type</u>	<u>Uncertainty (95% Confidence)</u>
<u>+10 psid (+0.069 MPa)</u>	HLD	[<u>+0.07 psid (+0.49 KPa)</u>] + (RSS) <u>+0.16% RD</u>
<u>+25 psid (+0.17 MPa)</u>	HLD	[<u>+0.17 psid (+1.2 KPa)</u>] + (RSS) <u>+0.23% RD</u>
<u>+50 psid (+0.34 MPa)</u>	HMD	[<u>+0.45 psid (+0.31 KPa)</u>] + (RSS) <u>+0.13% RD</u>
<u>+100 psid (+0.69 MPa)</u>	HMD	[<u>+0.03 psid (+0.21 KPa)</u>] + (RSS) <u>+0.11% RD</u>
<u>+200 psid (+1.38 MPa)</u>	HMD	[<u>+0.06 psid (+0.41 KPa)</u>] + (RSS) <u>+0.11% RD</u>
<u>+1500 psid (+10.34 MPa)</u>	HHD	[<u>+0.15 psid (1.0 KPa)</u>] + (RSS) <u>+ 0.13% RD</u>

5.2 Line Pressure Sensitivity

The problem of line pressure sensitivity was discovered to be of significant importance. It was determined that when the same gage pressure is placed on both sides of the differential pressure transducer, the output voltage varies with the gage pressure. Since during the subcooled blowdown the pressure drops from 2250 psig (15.5 MPa) to around 1000 psig (6.89 MPa) within 70 msec, significant uncertainty can be generated.

The line pressure offset is only on the offset of the ΔP transducer. By adding in a separate coefficient to the calibration equation, this uncertainty is reduced to a low level. However, in order to correct for the line pressure effect, data from one of the absolute pressure transducers is required. The calibration equation for the ΔP pressure transducer including line pressure correction is of the following form

$$\Delta P = (A_1 + A_2 V) + A_3 P$$

where:

ΔP is the output measurand in psid (MPa)

A_1 is the offset correction coefficient

A_2 is the slope coefficient

V is the output voltage from the ΔP transducer

A_3 is the line pressure correction coefficient

P is the reference line pressure in psig (MPa)

With this correction, the additional uncertainty generated by the line pressure is considered to be $\pm 0.2\%$ RG.

5.3 Response Limitations

The dynamic response of the differential pressure measurements are defined by three factors:

- a. Transducer response
- b. Fluid filled transmission system (standoff piping, bends, valves, etc.)
- c. DAVDS response

5.3.1 Transducer Response

Uncertainties resulting from response of the transducer are small in comparison with that of the transmission system (see Section 5.2.1 of Supplement No. 9 to LTR 141-39).

5.3.2 Fluid Transmission System

The basic principles of the fluid transmission system are the same as those for the absolute pressure transducers. This material was presented in the absolute pressure uncertainty analysis. In addition to the problems experienced with the absolute pressure measurement system, the ΔP uncertainties are even worse because of longer transmission lines, the difference between the two signals, and the attempt to measure small differential pressures with high line pressures.

Testing described in Section 3.1.6 shows the possibility of uncertainties larger than MRD requirements on measurements with transmission lines within the reactor vessel. However, since the MRD response requirements for the reactor vessel ΔP measurements do not require a rise time (10-90%) faster than 150 ms, proper bandpass filtering should effectively reduce this uncertainty. The data from the nonnuclear LOFT tests have not shown this uncertainty to be a problem (see Appendix A).

The ΔP measurement channels are normally used for steady state pre-LOCE data and saturated blowdown data. For this data, the 35ms rise time of the DDAPS is adequate to meet these requirements.

Some data is used to evaluate the subcooled blowdown transient. Although this is not required by the MRD, this data is used in some of the system pressure analysis. This data is recorded on the MFM analog tape system. For this data the hydraulic transmission effects of the ΔP transducer standoffs

can cause noticeable uncertainty. The primary cause of this uncertainty is generated by the resonant frequency for the length of the standoff. For the standoffs in the LOFT system a rough estimate for the resonant frequency is given as:

$$Hz_R = \frac{5000}{4L}$$

where: Hz_R is the resonant frequency in hertz

L is the length of one side of the standoff in feet

In order to keep the measurement uncertainty insignificant, it is important to filter the data at a frequency below the resonant frequency. At the resonant frequency or higher, the uncertainty becomes large and very difficult to evaluate. From data recorder on the ΔP standoff lengths, a resonant frequency is estimated for each of the ΔP transducers. This data is given in Table 5-1. Since the differential pressure transducers have a standoff on each side of the transducer, two different resonant frequencies may be generated. Because of the two different resonant frequencies, a beat frequency may be generated which lies within the frequency bandwidth of interest. Test data taken on the LOFT nonnuclear test have not shown the beat frequencies to be significant enough to consider them as a source of uncertainty.

5.3.3 DAVDS Response

The differential pressure measurements will be acquired on both the DAVDS multiplexed frequency modulation (MFM) system and the digital data acquisition and processing system (DDAPS). Detailed descriptions of these two systems are provided in Supplement No. 1 to LTR 141-39.

The MFM system is used primarily for redundancy and the usable response of the system will be controlled by the resonant frequency of the standoffs (see Section 5.3.2). The DDAPS generally is set up to record data at 50 samples per second (sps). These data are prefiltered at 10 Hz (this is the -3dB point). For the DDAPS at 50 sps, the 10 to 90% rise time of the system is:

$$T_R = 0.35/f_c = 0.35/10 = 35 \text{ msec}$$

where:

f_c is the -3dB low pass filter point.

Because of the nature of the response some of the differential pressure transducers in the broken loop may be recorded at 500 sps on the DDAPS. These data are prefiltered at 100 Hz. The 10 to 90% rise time for these transducers is:

$$T_R \approx 0.35/f_c = 0.35/100 = 3.5 \text{ msec}$$

The resonant frequency of the standoffs may also become an uncertainty factor in these data; so care must be exercised when using the 500 sps DDAPS data.

5.4 Calibration

There are several calibration factors to consider:

A. BLH/NBS Combined

This includes readout tolerances, environmental, quality control and any other factors associated with BLH as well as traceability to the National Bureau of Standards (NBS). This uncertainty is 0.1% range.

B. INEL Calibration Including Temperature -

The uncertainty for the INEL calibration include temperature is discussed in Section 5.1 of this report.

C. Shunt Calibration Uncertainty -

Shunt calibration can be a significant portion of the uncertainty if it is used as a calibration reference point during the tests. The uncertainty can be broken into two basic parts. The first uncertainty is produced by the fixed tolerance of the shunt resistor and the second is caused by the change in transducer resistance with temperature.

Uncertainty values have been calculated for both the resistor tolerance uncertainty and the temperature effects. As of this writing, the shunt calibration system for the LOFT differential pressure transducers have not been installed. The following data is provided to give the reader an understanding of what the shunt calibrations will be when the system is installed. The shunt calibration uncertainties are not used in calculating the total calibration uncertainties in this report. However when the shunt calibration system is installed and used, the following uncertainties must be root sum squares (RSS) with the other uncertainties.

TABLE 5-1

LOFT DIFFERENTIAL PRESSURE TRANSDUCER RESONANT FREQUENCY

Measurement ID	Line Length (Est.)		Resonant Frequency (Est.)	
	Low Side	High Side	Low Side	High Side
1) Broken Loop				
PdE-BL-1	10 ft	10 ft	125 Hz	125 Hz
PdE-BL-2	7.5	6.5	165	190
PdE-BL-3	4.5	4	275	310
PdE-BL-4	8.5	8	145	155
PdE-BL-5	8	10	155	125
PdE-BL-6	5	5	250	250
PdE-BL-7	10	11	125	110
PdE-BL-8	7	7	175	175
PdE-BL-9	8	8	155	155
PdE-BL-10	8	8	155	155
2) Operating Loop				
PdE-PC-1	7 ft	10 ft	175 Hz	125 Hz
PdE-PC-2	13.5	15	90	80
PdE-PC-3	9	12	135	104
PdE-PC-4	7.5	6.5	165	190
PdE-PC-5	14	14	85	85
PdE-PC-7	20	12.5	60	100
PdE-PC-8	12	12	100	100
PdE-PC-9	15	15	80	80
PdE-PC-10	15	15	80	80
3) Core				
PdE-CS-1	15 ft	25 ft	80 Hz	50 Hz
PdE-RV-1	25	35	50	35
PdE-RV-2	Not Installed		--	--
PdE-RV-3	20	25	60	50
PdE-RV-4	15	20	80	60
PdE-2ST-1	Not Installed		--	--
PdE-2ST-2	15	25	80	50
PdE-2ST-3	Not Installed		--	--
PdE-2ST-4	Not Installed		--	--
4) Suppression Tank				
PdE-SV-9	--	--	--	--

The uncertainty generated by the resistor tolerance is given as 0.1% of reading. Further discussion is given in Supplement No. 2 of this LTR (LTR 141-39). This uncertainty does not include the recording system uncertainty.

When the differential pressure transducers were originally purchased for LOFT, they were purchased without shunt calibration resistors. It was subsequently decided that shunt calibration should be done on these transducers, using external, remotely mounted calibration resistors.

As part of the INEL calibration test plan DPT-002, two transducers of each type were shunt calibrated at three temperatures [40°F, 120°F, and 200°F (4°C, 49°C, and 93°C)] in order to define the temperature dependence of the shunt calibration voltages. These results indicate that the temperature coefficients for all ranges is 0.0125% of range/°F (0.0225% of range/°C).

Because of the temperature uncertainty [70°F to 125°F (21°C to 52°C)] in each of the transducers just prior to a LOCE, the uncertainty in the shunt calibration voltages will be 0.7% of range.

D. Bridge Resistance Changes -

Though the bridge remains very well balanced as temperature varies, the absolute value of the four bridge arms (R) does vary with temperature. The LOFT shunt calibration configuration along with the defining equation is shown in Figure 5-1. Since the cable runs from the transducer to the signal conditioning are nearly identical, the value for cable resistance (R_L) will be the same for each of the seven cables. In any case, it would not be a significant factor because the R_L in the $+V$ leads does not unbalance the bridge. The R_L in $+e_0$ will not cause uncertainty because e_0 is measured with a voltage amplifier with very high input resistance. Because a seven-wire system is used, calibration current is not drawn through the R_L in the $+V$ lead, which would be the case if a four-wire calibration scheme were used.

In Figure 5-1 the excitation voltage (V) is set so that at pre-test conditions (temperature approx. 160°F in the primary coolant), the excitation voltage at the bridge minus the R_L voltage drops is 10 volts. The two switches $S1$ and $S2$ are used to switch in the shunt cal resistors R_{C1} and R_{C2} . The two switches are used one at a time to supply both a positive and negative calibration output voltage (e_0).

$$\frac{e_0}{V} = \frac{R}{4 R_C + 2 R}$$

$$R_C = R_C + 2 R_C$$

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FIGURE 5-1
 SEVEN-WIRE SHUNT

Uncertainty can be generated by the excitation if the bridge resistor values (R) change with temperature. This can change the excitation voltage on the bridge and thus change the sensitivity. The sensitivity of the calibration value to variations in R will be:

$$\frac{\partial(e_o/V)}{\partial R} = \frac{4R'_C}{(4R_C + 2R)^2}$$

which gives rise to percentage errors of:

$$\frac{\partial(e_o/V)}{(e_o/V)} \times 100 = \frac{1}{1 + R/2R'_C} \frac{\partial R}{R} \times 100$$

Numerically $R \approx 350\Omega$

$$29K\Omega < R'_C < 117 K\Omega$$

So,

$$0.994 < \frac{1}{1 + R/2R'_C} < 0.999$$

Therefore, a 10% variation in R would be reflected as a 10% variation in calibration voltage. However, these transducers are temperature compensated and no additional uncertainty is expected outside of that which is already included in Section 5.1.

E. Total Calibration Uncertainty -

The total calibration uncertainty without shunt calibration uncertainty is therefore,

$$\begin{array}{ll} \sqrt{A^2 + B_2^2} & \% \text{ of range} \\ \text{plus (RSS)} \quad B_1^2 & \% \text{ of reading} \end{array}$$

where,

A = BLH/NBS calibration uncertainty

B₁ = calibration uncertainty including temperature (RD)

B₂ = calibration uncertainty including temperature (RG)

Because of the calibration run at the INEL, the total uncertainty listed in Section 5.1 includes all the calibration uncertainties listed.

5.5 DAVDS MFM System

From Supplement No. 1 to LTR 141-39, the uncertainty of the MFM system is 1.0% of range. This uncertainty will be used in place of the 0.13% of range value for the DDAPS if the MFM data are used. The MFM data are considered as backup data for the DDAPS.

6.0 SUMMARY OF UNCERTAINTY

The uncertainty is basically one of calibration. Little change has been noted in the slope sensitivity, however, there is a shift in offset with temperature and line pressure. The present method used to correct the offset effectively reduces the offset to usable uncertainty levels. A summary of the uncertainties with the temperature offset correction is given in Table 6-1.

7.0 CONCLUSIONS

The differential pressure itself is a good measurement if the offset shifts with temperature and line pressure are compensated out. This leaves a good short term transducer. Some problems occur if used over any significant time period particularly if pressure and temperature are likely to change.

8.0 REFERENCES

All of the references listed at the end of this section are located in the LOFT Transducer Reference Catalog (LTRC) maintained by LOFT Experimental Branch and are available for review there. These references have been carefully selected for completion and lack of redundancy. The references listed in this section form the basis for the analysis presented in this supplement.

TABLE 6-1

SUMMARY DIFFERENTIAL PRESSURE TRANSDUCER UNCERTAINTY ANALYSIS

Parameter						
Transducer (Mod. No.)	HLD	HLD	HMD	HMD	HMD	HHD
Range [psid (MPa)]	<u>+10</u> (<u>+0.069</u>)	<u>+25</u> (<u>+0.17</u>)	<u>+50</u> (<u>+0.34</u>)	<u>+100</u> (<u>+0.69</u>)	<u>+200</u> (<u>+1.38</u>)	<u>+1500</u> (<u>+10.38</u>)
Calibration (with temp. offset correction)	<u>+0.07</u> psi (<u>+0.49</u> kPa)	<u>+0.17</u> psi (<u>+1.2</u> kPa)	<u>+0.045</u> psi (<u>+0.31</u> kPa)	<u>+0.03</u> psi (<u>+0.21</u> kPa)	<u>+0.06</u> psi (<u>+0.91</u> kPa)	<u>+0.15</u> psi (<u>+1.0</u> kPa)
Accuracy	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)
Linearity						
Hysteresis	<u>+0.16%</u> RD	<u>+0.23%</u> RD	<u>+0.13%</u> RD	<u>+0.11%</u> RD	<u>+0.11%</u> RD	<u>+ 0.13%</u> RD
Traceability	-----	-----	-----	-----	-----	-----
Line Pressure	<u>+0.02</u> psi (<u>+0.14</u> kPa)	<u>+0.05</u> psi (<u>+0.34</u> kPa)	<u>+0.1</u> psi (<u>+0.69</u> kPa)	<u>+0.2</u> psi (<u>+1.4</u> kPa)	<u>+0.4</u> psi (<u>+2.8</u> kPa)	<u>+3.0*</u> psi (<u>+21.0</u> kPa)
plus (RSS)	<u>+0.013</u> psi	<u>+0.033</u> psi	<u>+0.065</u> psi	<u>+0.13</u> psi	<u>+0.26</u> psi	<u>+1.95*</u> psi
DAVDS (DDAPS)	(<u>+0.090</u> kPa)	(<u>0.224</u> kPa)	(<u>+0.448</u> kPa)	(<u>+0.90</u> kPa)	(<u>+1.79</u> kPa)	(<u>+13.44</u> kPa)
Total (RSS)	<u>+0.07</u> psi (<u>+0.49</u> kPa)	<u>+0.18</u> psi (<u>+1.2</u> kPa)	<u>+0.13</u> psi (<u>+0.86</u> kPa)	<u>+0.24</u> psi (<u>+1.7</u> kPa)	<u>+0.48</u> psi (<u>+3.3</u> kPa)	<u>+3.6*</u> psi (<u>+25</u> kPa)
	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)	plus (RSS)
	<u>+0.16%</u> RD	<u>+0.23%</u> RD	<u>+0.13%</u> RD	<u>+0.11%</u> RD	<u>+0.11%</u> RD	<u>+0.13%</u> RD

Response (10 to 90% risetime)

35 msec for all those sampled at 50 samples per second.

3.5 msec for all those sampled at 500 samples per second.

LOFT TRANSDUCER REFERENCE CATALOG

TITLE/NOMENCLATURE		LTR 141-39 Supp. No. 11, Rev. A	
DIFFERENTIAL PRESSURE TRANSDUCERS			
TYPE Strain gage bonded to diaphragm		MODEL HMD, HLD, HMD	
MFR BLH Electronics, Inc. 42 Fourth Avenue Waltham, MA. 02154		ENG	
		SALES Art. Voehler	
PH/TWX 617-890-6700		P.O. S-5002	
LOFT IDENTIFICATION		LOCATION	QUANTITY L9
PdE-PC-1 PdE-PC-2 PdE-RL-1 PdE-PL-2 PdE-RL-3 PdE-PL-3 PdE-BL-4 PdE-BL-4 PdE-BL-5 PdE-BL-6 PdE-RL-7 PdE-BL-8 PdE-RV-1 PdE-1ST-1 PdE-RV-2		Drawings; 650-P138 650-P139 204024 205050 205184 205193 206183	
PdE-1ST-4 PdE-1ST-3 PdE-2ST-2 PdE-CS-1			

DIFFERENTIAL PRESSURE TRANSDUCERS

LTR 141-39
Supp. No. 11, Rev. A

VOLUME I

ΔP Location	Locations - Identification Numbers - Drawing Numbers - Type & Range	
BLH Data	Diaphragm, Flattened Tube, Diaphragm Beam	3-75
Design Review	Report of Formal Design Review of Absolute and Differential Pressure Measurements	9-71
S-5002	Subcontract S-5002, Aerojet Nuclear Company & BLH Electronics - Purchase Order L006119 - Return to BLH for Recalibration	12-73
S-5002 Mod 2	Return to BLH for Addition of Bleed Ports	1-75
ΔP Performance	Differential Pressure Transducer Detector Only Performance	3-74
HLC-430-74	Quick Look Report on Decompression Testing of LOFT Primary-Coolant Pumps	6-74
WAL-229-74	Return Transducers for Calibration	8-74
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LTR 1113-2	Core Differential Pressure During Non-Nuclear LOCE	7-72
LIP-737	Assembly & Installation of LOFT Pressure Transducer Mounting Panels & Routing & Connecting of Pressure Lines	4-75
MIO 8949	Transducer Calibration	4-75
DPT-001	Qualification Test Plan for LOFT Differential Pressure Transducers	1-75
DPT-002	Calibration Test Plan for LOFT Differential Pressure Transducers	3-75
GF 15.0	Grooming Form	2-75
OMM 141-9	Operation & Maintenance Manual for Differential Pressure Transducer Systems	5-75

DIFFERENTIAL PRESSURE FILE DRAWINGS

405138-3	Section "A-A" Type HMD
423602D	Outline-1000 psid through 3000 psid "HHD"

APPENDIX A
BLOWDOWN PLOTS OF LOFT EXPERIMENTAL
DIFFERENTIAL PRESSURE MEASUREMENTS

Plots of the differential pressure transducers from Test L1-3A for LOFT are provided. The data is given for the blowdown transient beginning ten seconds before rupture and for 70 seconds after.

PdE-BL-1 Differential pressure in broken loop hot leg
across 14-to-5-in. contraction (PdE-BL-1)
(filtered to 4 Hz).

PdE-BL-2 Differential pressure in broken loop cold leg
across 14-to-5-in. contraction (PdE-BL-2).

Figure 3
 PDE-BL-003 DELTA P-BOL COLD LEG BRK PLANE

Figure 4
 PDE-BL-004 DELTA P-BOL HOT LEG BRK PLANE

LOCE LI-3A BLOWDOWN

Figure 5

PDE-BL-005 DELTA P-BOL HOT LEG PUMP SIMULATOR

LI-3A BLOWDOWN PDE-BL-6

Figure 6

PDE-BL-006 DELTA P-BOL HOT LEG SG SIM OUT FLNG

Figure 7
 PDE-BL-007 DELTA P-BOL HOT LEG SG SUMULATOR

Figure 8
 PDE-BL-008 DELTA P-BOL HOT LEG SG SIM IN FLNG

LOCE LI-3A BLOWDOWN

Figure 9

PDE-PC-001 DELTA P-PRIMARY COOLANT PUMP

LOCE LI-3A BLOWDOWN

Figure 10

PDE-PC-002 DELTA P-OPERATING LOOP 50

Figure 11
 PDE-PC-003 DELTA P-OP LOOP HL RV TO VENTURI

Figure 12
 PDE-PC-004 DELTA P-OP LOOP HL VENTURI TO SO

Figure 13
PDE-PC-005 DELTA P-OP LOOP PCP TO RV INLET

Figure 14
PDE-PC-007 DELTA P-OPL RV IN BDL RV IN-CL

LI-3A BLOWDOWN PDE-CS-1 4 HZ FILTER

Figure 15

PDE-CS-001 DELTA P-INSTR STALK 2 LP TO CS

LOCE LI-3A BLOWDOWN

Figure 16

PDE-RV-001 DELTA P-RV DOWNCOMER TO DDST

Figure 17
 PDE-RV-003 DELTA P-OPL CL IN TO BOTTOM OF RV

Figure 18
 PDE-RV-004 DELTA P-RV UP TO OPL HOT LEG RV

Figure 19
PDE-2ST-002 DELTA P-RV INSTR STALK 2 DC TO LP

Figure 20
PDE-SV-009 DELTA P-BOST ACROSS VACUUM BREAKER