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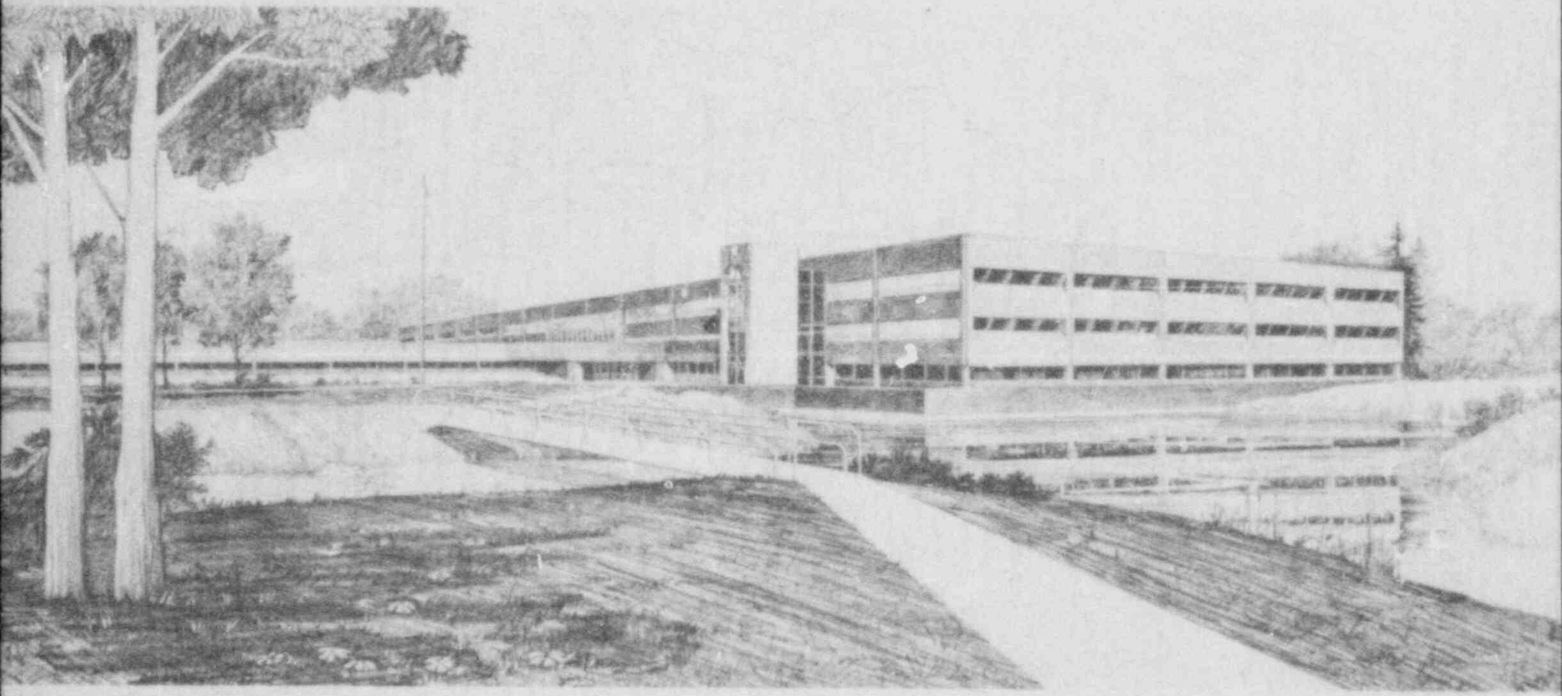

Idaho National Engineering Laboratory
Operated by the U.S. Department of Energy

LOFT Experimental Measurements Uncertainty Analysis
Volume XXII
Fission Product Detection System Instruments Recorded on the DAVDS

Robert P. Evans

November 1984

Prepared for the
U.S. Nuclear Regulatory Commission
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LOFT EXPERIMENTAL MEASUREMENTS UNCERTAINTY ANALYSIS
VOLUME XXII
FISSION PRODUCT DETECTION SYSTEM INSTRUMENTS RECORDED ON THE DAVDS

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Idaho Falls, Idaho 83415

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ABSTRACT

An uncertainty analysis was performed for the Loss-of-Fluid Test Fission Product Instruments recorded on the Data Acquisition and Visual Display System in order to document the accuracy of these channels under steady state operating conditions. In addition, an uncertainty analysis was performed for certain temperature and pressure measurement channels excluding their recording system.

FIN No. A6043—LOFT Instrumentation

SUMMARY

Uncertainty analyses are presented to quantify the uncertainty bounds for the instruments of the Loss-of-Fluid Test (LOFT) Fission Product Measurement System (FPMS) that are recorded on the Data Acquisition and Visual Display System (DAVDS). The FPMS instruments are specialized instruments for measuring the gap release during fission product release tests. The uncertainties presented are basically of two types: objective and subjective. Objective uncertainties (basically random) are those for which there are data and can be duplicated in the laboratory. Subjective uncertainties (basically systematic) are those for which there are no specific data and must be based on engineering judgment.

Actual measurements are made in a high-pressure, high-temperature steam environment, as well as under moderate-to-high radiation levels. The analysis is valid only during steady-state, normal operating conditions.

The objective uncertainties are derived, in most cases, for a measurement channel by the root-sum-square total of all manufactures' specifications. These specifications are summarized in Appendix A. It is assumed that the manufacturers' specifications have been normalized to the measurand "percent of range" (RG) and are statistically 2σ values. This is a conservative assumption, as most suppliers quote a 3σ value.

The subjective uncertainties, those derived from engineering experience and judgement when there are no objective data on which to base an uncertainty in a specific area, could include such parameters as radiation effects or vibration sensitivity. No attempt will be made to break down such an uncertainty into its parameters; rather, it will merely be listed as a single number with the types of uncertainties that went into the estimate.

The uncertainty listed is the uncertainty on what is actually being measured, not necessarily on what was intended to be measured.

The total uncertainty for a measurement channel is given as the RSS sum of the objective and subjective uncertainties. These uncertainties, along with a diagram of the measurement channel components, are documented in Appendix A, Figures A-1 through A-3. The uncertainties quoted include a DAVDS uncertainty of +0.13% of range[1], where applicable.

The uncertainties covered in this analysis are summarized in the table below.

Table S.1. LOFT steam sample system measurements list

Measurement Identification	Measurement Description	Measurement Range	Measurement Accuracy*	Measurement Location Figure	Measurement Schematic Figure
FT-P165-S1-26	S1 Sample Flow	0 - 12 l/m	±5% RG	2	A-1
FT-P165-S2-26	S2 Sample Flow	0 - 12 l/m	±5% RG	2	A-1
FT-P165-S3-26	S3 Sample Flow	0 - 12 l/m	±5% RG	2	A-1
FT-P165-S4-26	S4 Sample Flow	0 - 12 l/m	±5% RG	2	A-1
TT-P165-S1-22	S1 Line Temperature	273 - 478 K	±[4.1K + 0.5%(RG-255) + 0.9%(RD-255)]	2	A-2
TT-P165-S2-22	S2 Line Temperature	273 - 478 K	±[4.1K + 0.5%(RG-255) + 0.9%(RD-255)]	2	A-2
TT-P165-S3-22	S3 Line Temperature	273 - 478 K	±[4.1K + 0.5%(RG-255) + 0.9%(RD-255)]	2	A-2
TT-P165-S4-22	S4 Line Temperature	273 - 478 K	±[4.1K + 0.5%(RG-255) + 0.9%(RD-255)]	2	A-2
PT-P165-S1-14	S1 Sample Pressure	0 - 103 kPa	±1.2% RG	2	A-3
PT-P165-S2-14	S2 Sample Pressure	0 - 103 kPa	±1.2% RG	2	A-3
PT-P165-S3-14	S3 Sample Pressure	0 - 103 kPa	±1.2% RG	2	A-3
PT-P165-S4-14	S4 Sample Pressure	0 - 103 kPa	±1.2% RG	2	A-3

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*Measurement accuracy is the RSS sum of the objective and subjective uncertainties.

FOREWORD

Analyses are performed to evaluate the anticipated performance uncertainty for each experimental measurement in the LOFT system. Results of these analyses are reported in a series of volumes designated NUREG/CR-0169, EGG-2037.[a] Volume I of this series describes the LOFT experimental measurement systems and the techniques used for calculating the uncertainties. The remaining volumes in the series present detailed results from the uncertainty analysis performed for each experimental measurement system. The following volumes were previously published.

1. G. L. Biladeau, *LOFT Experimental Measurements Uncertainty Analyses, Volume VI, LOFT Linear Variable Differential.*

2. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XVI, LOFT Three-Beam Gamma Densitometer System*, TREE-NUREG-1089, February, 1978.

3. L. D. Goodrich, *LOFT Experimental Measurements Uncertainty Analyses, Volume XV, LOFT Primary Coolant Pump Speed Measurement Uncertainty Analysis*, TREE-NUREG-1089, April 1978.

4. G. L. Biladeau, *LOFT Experimental Measurement Uncertainty Analyses, Volume IX, LOFT Strain Gage Uncertainty Analysis*, TREE-NUREG-1089, June 1978.

5. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume VII, LOFT Self-Powered Neutron Detector Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, August 1978.

6. G. D. Lassahn and P. A. Quinn, *LOFT Experimental Measurements Uncertainty Analyses, Volume VIII, LOFT Traversing In-Core Probe Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, August 1978.

7. P. A. Quinn, G. L. Biladeau, and R. Y. Maughan, *LOFT Experimental Measurements Uncertainty Analyses, Volume V, LOFT External Accelerometer Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, October 1978.

8. S. Silverman, *LOFT Experimental Measurements Uncertainty Analyses, Volume XIV, LOFT Drag-Disc Turbine Transducer Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, November 1978.

9. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XVIII, Radiation-Hardened Gamma Densitometer System*, TREE-NUREG-1089, February 1978.

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[a] Volumes VI, IX, XV, and XVI were published prior to implementation of the NUREG/CR numbering system. Volumes V, VII, VIII, and XIV were published as NUREG/CR-0169, TREE-1089 (TREE was the former designation for formal reports prepared by EG&G Idaho, Inc.). The remaining volumes in this series will be published as NUREG/CR-0169, EGG-2037.

10. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XII, Differential Pressure Measurements*, NUREG/CR-0169, EGG-0237, March 1982.

11. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XIX, Small-Pipe MCA Densitometer*, NUREG/CR-0169, EGG-2037, August 1981.

12. S. Ploger, *LOFT Experimental Measurements Uncertainty Analyses, Volume X, Absolute Pressure Measurement Uncertainty Analysis*, NUREG/CR-0169, EGG-2037, September 1981.

13. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XIII, Temperature Measurements*, NUREG/CR-0169, EGG-2037, March 1982.

14. L. D. Goodrich and G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XI, Free-Field Pressure Transducer*, NUREG/CR-0169, EGG-2037, June 1982.

15. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume III, Data Acquisition and Recording System*, NUREG/CR-1069 EGG-2037, August 1982.

16. T. R. Meachum, *LOFT Experimental Measurements Uncertainty Analyses, Volume IV, Liquid Level Transducer*, NUREG/CR-1069, EGG-2037, August 1982.

17. G. D. Lassahn and D. J. N. Taylor, *LOFT Experimental Measurements Uncertainty Analyses, Volume XX, Fluid Velocity Measurement Using Pulsed Neutron Activation*, NUREG/CR-1069, EGG-2037, August 1982.

18. G. C. Cheever, *LOFT Experimental Measurements Uncertainty Analyses, Volume XXI, Modular Drag-Disc Turbine Transducer*, NUREG/CR-1069, EGG-2037, February 1983.

19. R. P. Evans and K. D. McKnight, *LOFT Experimental Measurements Uncertainty Analysis, Volume XVII, Process Instruments Recorded on DAVDS*, NUREG/CR-1069, EGG-2037, September 1984.

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LOFT EXPERIMENTAL MEASUREMENTS UNCERTAINTY ANALYSIS
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INTRODUCTION

Some of the flow measurements for the Fission Product Measurement System (FPMS) in the Loss-of-Fluid Test (LOFT) system are recorded on the Data Acquisition and Visual Display System (DAVDS) to measure steam flow in the FPMS. These flow measurements and certain of the temperature and pressure measurements on the Steam Sample System (SSS) of the FPMS are analyzed excluding their recording systems. The measurements are intended to supply information about the temperature, pressure, and flow of the steam through the sampling system.

INSTRUMENT CHANNEL DESCRIPTION

The FPMS consists of several different systems. The only one considered in this document is the steam sampling system. This system is designed to sample the steam that carries the fission products from the fuel rod gap release. The following instruments are considered in this analysis:

- Turbine flowmeters
- Pressure transmitters
- Thermocouples.

Of these measurements, only flowmeters are recorded on DAVDS. The other two are presented in this document for information and completeness. The uncertainty reported is the root-sum-square total of the objective uncertainty (that derived from the manufacturers' specifications) and the subjective uncertainty (that derived through engineering experience and judgement). In many cases the subjective portion is much larger than the objective portion of the uncertainty, since the unknowns of the measurement installation and environment are very large. Such factors as the effect of ambient pressure, temperature, radiation, vibration, etc., are virtually unknown for most of the channels. Figures 1 and 2 indicate the approximate location of each measurement and Figures A-1 through A-3 show the connection of the various components and specific component uncertainties.

Turbine Flowmeters

There are four gas-flow turbine flowmeters on the SSS that are recorded on DAVDS. The four flowmeters, one on each line, are located just upstream of the condenser. The turbine flowmeter measurement channel consists of a turbine flowmeter, a pulse rate converter, an isolation amplifier, and DAVDS. The turbine is designed for gas flow measurements and is mounted so as to turn parallel to the flow. The pulse rate converter accepts the low-level input frequency signals from the flowmeter and provides analog output signals that are proportional to the flow rate. Both the turbine flowmeter and the pulse rate converter are manufactured by Flow Technology, Inc. The isolation amplifier, manufactured by ACROMAG, provides electrical isolation between input and output signals. The signals are recorded on DAVDS. The measurement channel interconnections, along with the manufacturers' uncertainties for each component, are shown in Figure A-1.

Temperature

The temperature measurements considered for this analysis are located on the SSS. Four Type K thermocouples, one on each line, are on the outer wall of the species sampler. The measurement channel consists of (a) the thermocouple, manufactured by Omega Engineering, Inc., (b) a temperature transmitter, which gives a 4- to 20-mA dc output for a thermocouple input, manufactured by Rosemount, Inc., and (c) a data recording system, not covered by this analysis. Figure A-2 shows the measurement channel interconnections and the manufacturers' uncertainties for each component.

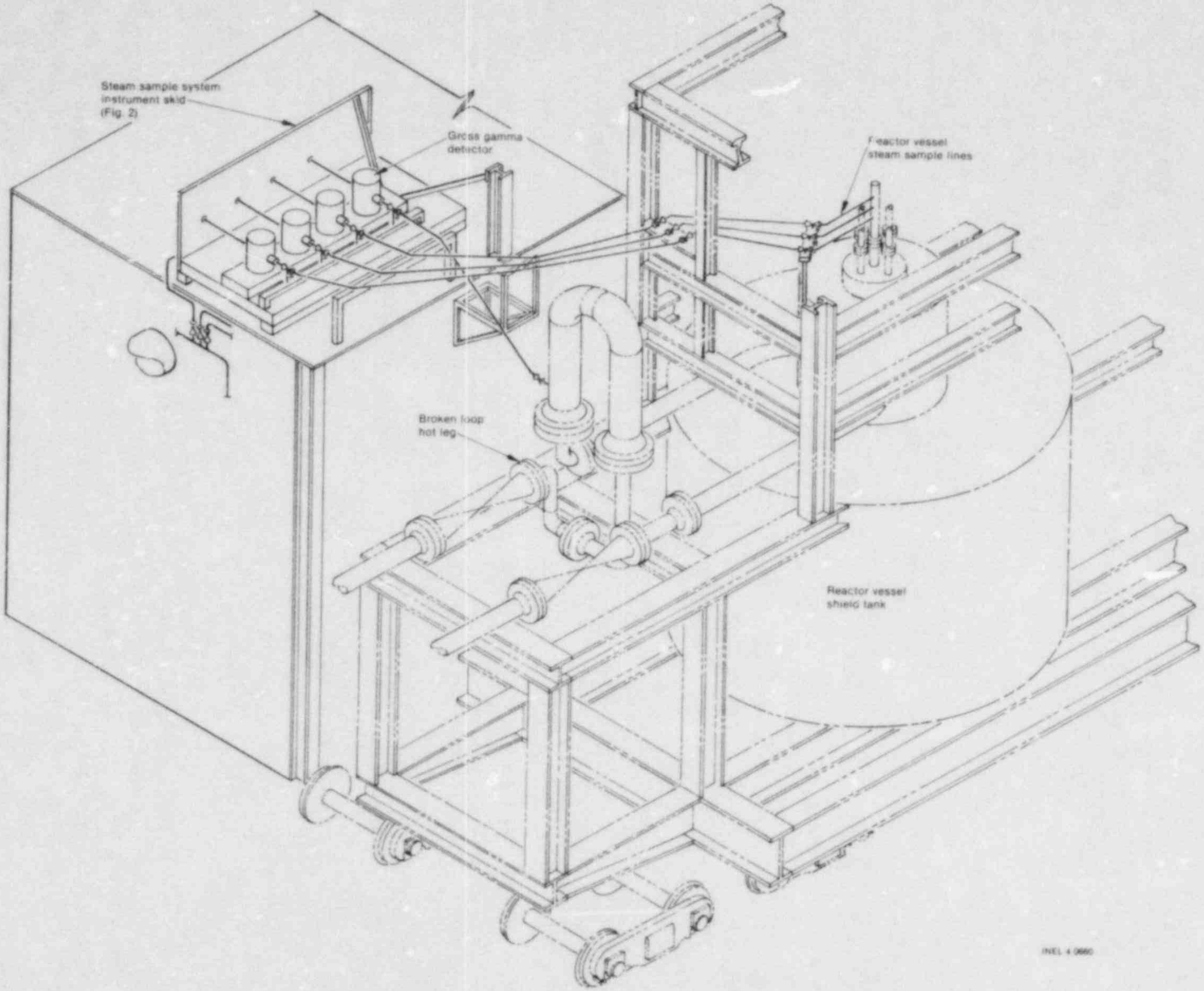

Figure 1. FPMS measurement locations.

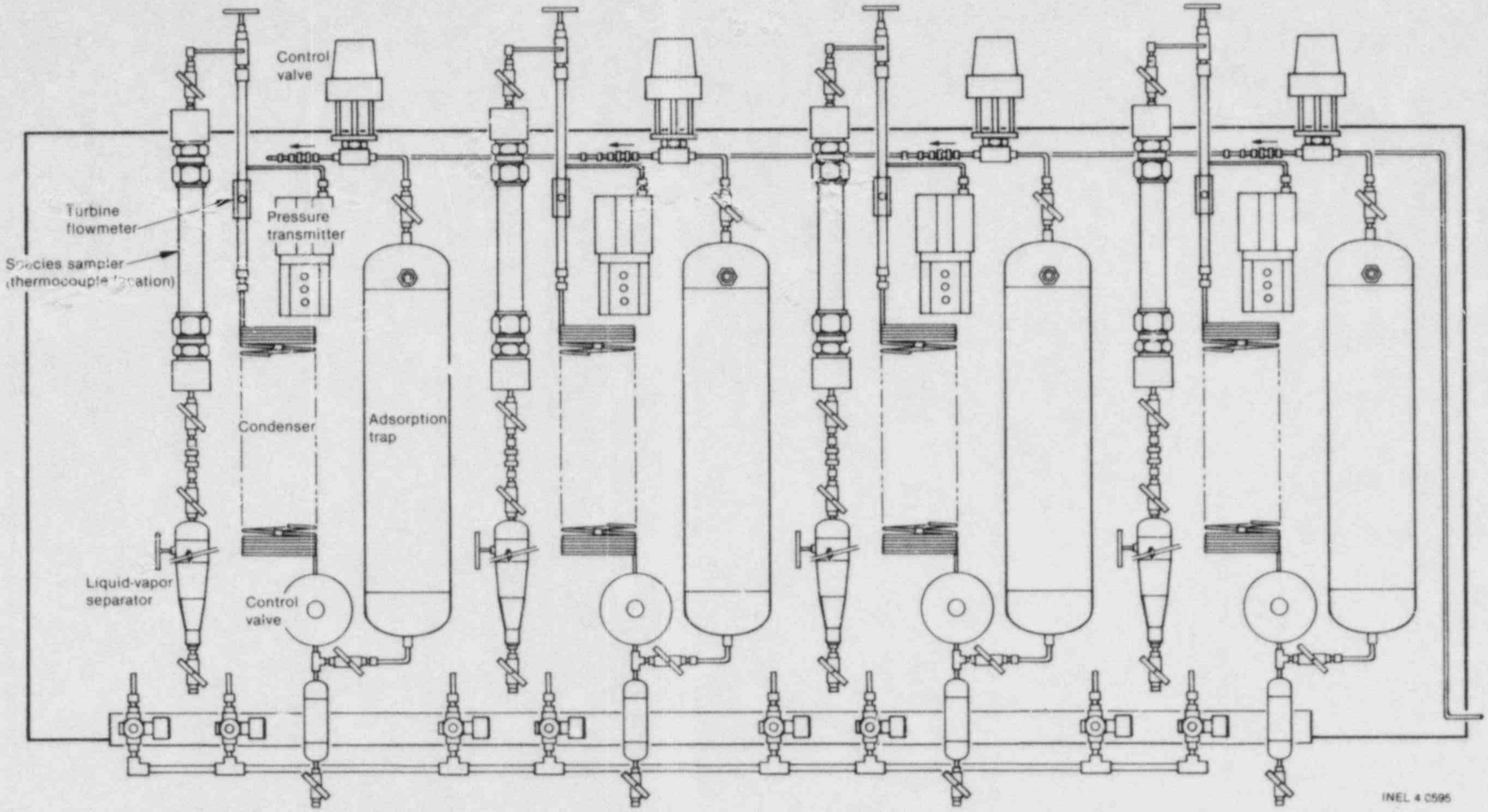

Figure 2. FPMS instrument panel layout.

Pressure

The four absolute pressure measurements considered in this analysis are located between the temperature and flow measurements, considered previously, on each of the SSS lines. Each measurement channel consists of (a) a pressure transmitter, manufactured by Rosemount, Inc., and (b) a recording system, which is not covered in this analysis. Figure A-3 shows the measurement channel interconnections, and the manufacturer's uncertainties for each component.

DISCUSSION OF UNCERTAINTIES

The uncertainties documented in this section are those specific to the measurement channel for which information is available. The reported objective (random) errors are based on manufacturers' specifications, calibrations, or testing. Subjective (bias) uncertainty estimates are also presented, with some basis for the estimates.

Flow

In addition to the manufacturer's stated uncertainties, shown in Appendix B, several other variables affect the output of the turbine during calibrations and LOFT fission product testing. Although some of these variables may have been considered by the manufacturer, they have been included here for completeness. These variables include the following.[2]

- State of knowledge of the measurement principles
- Temperature
- Pressure
- Irradiation
- Mounting misalignment
- Hysteresis
- Pipe dynamics
- Fluid transients
- Electronics
- Fluid kinematic viscosity
- Flow pattern within the meter
- Entrance flow pattern
- Orientation of the meter
- Position of the pickup
- Retarding forces
- Dynamic resonse and vibration of the turbine blades.

All of these variables can affect the transducer's output, and though in most cases the effect is small or negligible, all variables should be considered.

Theory of Operation. The validity of the flow measurement depends largely on flow conditions. With homogeneous, single-phase flow, the flowmeter measures flow with minimal uncertainty. In the steam sampling system, the flow should be homogeneous, single-phase steam.

In single-phase flow, the flowmeter measures volumetric flow.[3,4,5,6] The output of the turbine pickoff is a series of pulses with a frequency (ω) that is six times the rotational rate of the rotor (six blades are on the rotor). The pulse rate converter then converts the frequency into a voltage proportional to the rotation rate of the rotor and thus the volumetric flow rate.

Calibration data for the turbines and pulse rate converters are fit to the following equations:

Q_T (m^3/s) = $C_0 + C_1\ \omega$ (Hz) Turbine

ω(Hz) = $C_0 + C_1$ ET (V) Pulse Rate Converter

where

C_0 and C_1 = volumetric flow rate

ω = turbine blade frequency

C_0 and C_1 = calibration coefficients

ET = pulse rate converter output voltage.

Combining the preceding equations produces the volumetric flow in terms of the voltage output of the pulse rate converter. Dividing the volumetric flow rate by the cross-sectional area of the flow path gives the velocity of the fluid.

Hardware. The hardware for the flow measurement channel was discussed under "Instrument Channel Description" on page 1. The uncertainties, based on manufactures' specifications, are given in Appendixes A and B.

Measurement Channel Testing. Testing of the measurement channel components was conducted by the manufacturer to determine calibration constants, but no in-place testing has been performed on the measurement channel. Hence, the effect of the other system components on measurement channel uncertainty, specifically the heaters, is unknown and must be assumed to be large. For this analysis, the uncertainty is assumed to be ±5% RG.

Variables Affecting Measurement Channel Uncertainty.

State of Knowledge of the Measurement Principles. Since the measurement is made in single-phase steam, the measurement principles are relatively well known. The uncertainty attributed to this factor is less than 0.1% of range.

Temperature. The effects of temperature on the measurement should be minimal since both the transducer and electronics will remain at a relatively constant temperature during the time of measurement and will be within the manufacturer's stated temperature range. No additional uncertainty will be assigned to this component.

Pressure. Testing of similar flowmeters has indicated a pressure sensitivity of 0.05% of range per MPa.[7] During the time of the measurement, the pressure should remain fairly constant; therefore, the pressure sensitivity effect should be negligible.

Irradiation. The radiation environment of the FPMS consists of neutrons of widely varying energy levels, charged particles, intense gamma radiation, and intense electromagnetic fields. Separation of the effects of each of these phenomena is difficult, if not impossible; hence, they are treated as a conglomerate.

Although the actual effect of the radiation on the flowmeter is unknown, it should be small owing to the short duration of operation in the radiation environment.

Mounting Misalignment. There are no data available on the effects of mounting misalignment for a turbine flowmeter, but allowing for only small misalignments that might be found in actual installation, the uncertainty is considered small.

Hysteresis. The effects of hysteresis should be minimal and within manufacturer's stated uncertainty. It will not be considered further.

Pipe Dynamics. There are no data on the effects of pipe dynamics (vibration and acceleration) on the turbine output. The forces that the turbine and pick-off will experience are unknown but could be potentially large and may have a significant effect on the flowmeter output.

Fluid Transients. The turbine should only be measuring single-phase steam; hence, transients should be small. The uncertainty contributions are considered minimal.

Electronics. The uncertainty caused by the electronics while operating within the manufacturer's requirements should be within stated specifications.

Remaining Variables. In general, the effect of each of the remaining variables on uncertainty appears to be small, but since none of them has been investigated, the uncertainty cannot be estimated accurately.

Although individually most of the variables discussed above may be small or negligible, combined the estimated effect is 0.5% of range.

The manufacturer states no response time for the transducer in gas flow. It can only be assumed that the response is much slower than the 10-ms response for liquid operation.

Table 1 presents the uncertainty factors for the flow measurement.

Table 1. Uncertainty factors for the flow measurement

Uncertainty Factors	Objective Uncertainty	Subjective Uncertainty
Mounting	—	±0.5% RG
Measurement principles	—	±0.1% RG
Flowmeter	±(0.2% RD + 0.3% RG)	—
Pulse rate converter	±0.2% RG	—
Isolation amplifier	±0.08% RG	—
Data acquisition system	±0.13% RG	—
Other factors	—	±0.5% RG
Total	±(0.2% RD + 0.4% RG)	±5% RG

Temperature

Although temperature measurements are generally considered one of the easiest to make, they are in fact one of the most difficult because of the number of small effects on the measurement that can go undetected.

Theory of Operation. A thermocouple is formed by joining both ends of any pair of different material wires, of different materials, to form a thermoelement and then inserting an appropriate voltage measuring device in the measurement loop. When the two junctions are at different temperatures, a net electromotive force (emf), E_{net}, is generated proportional to the temperature difference between the two junctions and related to physical (thermoelectric) properties of the materials along the thermoelement.[8]

$$E_{net} = \int_{0}^{L} \mathcal{E}_1 \frac{dt}{dx} dx + \int_{L}^{0} \mathcal{E}_2 \frac{dt}{dx} dx$$

where

$\mathcal{E}_1, \mathcal{E}_2$ = total thermoelectric power of the materials

T = temperature

x = distance along the wire

L = length of the wires.

When the wires are homogeneous (that is, when thermoelectric coefficients are not a function of position along the wire) and each wire begins at temperature T_0 and ends at temperature T_L, the expression for E_{net} can be simplified.

$$E_{net} = \int_{T_0}^{T_L} (\mathcal{E}_1 - \mathcal{E}_2)\, dT \ .$$

Thermal energy is converted to electrical energy when a thermocouple circuit is placed in a temperature gradient field wherein the junction contacts are not at the same temperature. This relationship between the potential developed in such a circuit and the temperature difference between the circuit junctions is a proportionality defined by the Seebeck coefficient, α_{AB}, according to the equation

$$\alpha_{AB} = \frac{dE}{dT}$$

where

dE = potential developed in the circuit

dT = temperature difference between the junctions.

The magnitude of these potentials for most metal pairs is in the range of 10 to 100 mV for temperature differences of up to several hundred kelvin.

A reversible heating or cooling effect occurs when an electric current passes through a junction formed by different metals. The Peltier coefficient, π_{AB}, is relative to the absorbed or lost heat, Q, and the transmitted charge, q, by the following equation:

$$\pi_{AB} = \frac{Q}{q} .$$

A third thermoelectric effect is evidenced by the reversible heat absorbed that occurs when a current flows in a homogeneous conductor in which a temperature gradient exists. This effect, characterized by the Thompson coefficient, σ_{TA}, depends on the material and absolute temperature. The Thompson coefficient relates the heat absorbed to the product of the charge and thermal gradient, as follows:

$$\sigma_{TA} = \frac{Q}{q(dT/dx)}$$

where

dT/dx = temperature gradient.

The effects defined by the above equations are related by the laws of thermodynamics, and knowing one enables derivation of the remaining two.

The thermoelectric properties of materials are nonlinear with respect to temperature. Such properties can be neither calculated nor measured except with reference to a selected standard. When accurate determination is made of the voltage produced at known temperatures with respect to a selected standard, a wire of a certain material may be related to one of another material in an absolute sense.

Measurements of unknown temperatures are made by maintaining one junction of a thermocouple transducer at a known, constant temperature and placing the other junction in the measurement location. The emf of the circuit represents the difference between the known reference temperature and the temperature at the measurement location. The circuit emf can be equated to a temperature, when the reference temperature is known, through reference to tabulated thermoelement outputs (or by application of a polynomial representing such a tabulation) for the specific wire pair.[8]

Hardware. The thermocouple measurement channels used on the SSS of the LOFT FPMS consist of a standard grade thermocouple element, a temperature transmitter, and a recording system (not covered in this analysis). The thermocouple is attached to the outside of the pipe wall under insulation and near the heat tape that heats the pipe. The thermocouple is therefore measuring the temperature of the heated outer pipe wall. Detailed descriptions of the hardware and the interconnections are given in Appendixes A and B.

Measurement Channel Testing. No testing has been performed on this measurement channel to determine the effects of the other system components; hence, their effects are unknown.

General Uncertainties. Thermocouples are sensitive to a wide range of environmental conditions, and their output is affected thereby. The effects are discussed in detail in this section. Testing activities, current literature, and manufacturers' specifications are used to evolve the uncertainty bounds.

Inhomogeneity. In actual practice, no such thing as a homogeneous thermocouple exists. Since thermocouple response depends on thermal gradients, an ideal calibration sequence would be to first ascertain the exact operating temperature profile along the length of the wire and then calibrate the measurement channel on the basis of that known profile. Such an ideal approach is not possible for most experimental applications; therefore, the assumption must be made that the thermocouple wires are homogeneous, and an uncertainty to account for the error of this assumption assigned. This uncertainty is included in the thermocouple uncertainty.

Thermocouple Wire Uncertainty. The limits of error[9] for thermocouples are generally, in current literature, published in English units and based on a temperature scale related to the ice point in °F. The SI temperature units (kelvin) used in this document are based on absolute zero. Care must be taken, therefore, in computing temperature and thermocouple uncertainties for readings and ranges in kelvin units.

The thermocouple wire error limits for applicable temperature ranges are given in the manufacturer's literature[9] as a percent of the thermocouple reading in °F (these limits include the inhomogeneity errors mentioned in the preceeding subsection). The following conversion equation is derived to enable the use of any percentage error value based on °F, along with the thermocouple reading recorded in kelvin, to calculate the thermocouple limits of error in terms of kelvin:

(% error)(RD-255) = error in kelvin

where

RD = thermocouple reading in kelvin.

Standard grade thermocouple wire is used for the LOFT FPMS thermocouple measurements. The limits of error for the Type K thermocouples, converted to kelvin equivalent of the °F value published in Reference 9, is 2.2 K for temperature ranges of 273 to 550 K, or 0.75% (RD-255) for temperature ranges 550 to 1589 K. The error limits are applicable only over the specified thermocouple ranges.

Extension Wire Uncertainty. The limits of error for the Type K extension wire is given as ±2.2 K for a temperature range of 273 to 478 K.

Thermocouple Equation Uncertainty. The use of an equation to represent the thermocouple calibration table produces an error in the engineering-unit thermocouple reading. The thermocouple output, in millivolts, cannot be exactly matched to the temperature scale by a mathematical equation. On the basis of engineering judgement, an error limit of ±1.6 K is attributed to the equation used to represent the calibration table.

Cold Working-Produced Uncertainty. An error of ±0.5% (RD-255) is assumed to account for cold working effects. The uncertainty is estimated on the basis of engineering experience and judgement.

Reference Junction Uncertainty. The reference junction for each of the LOFT FPMS SSS temperature measurements is electronic and is contained within the temperature transmitter. The uncertainty for this junction is included in that for the transmitter and is based on the manufacturer's specification.

Aging and Radiation. Although no test data have been found on the effects of aging and radiation on thermocouples, an uncertainty of ±0.5% (RD-255) is assigned on the basis of engineering judgement.

ANSI Type K thermocouples are virtually insensitive to transmutation. Ionization or electron production, or both, caused by gamma and neutron interactions are not considered significant. An estimate of the upper bound for error caused by radiation in an ANSI Type K thermocouple was obtained from current literature, and an immediate rise of 2 to 4 K caused by gamma heating of the measurement junction has been identified.[10,11] In the temperature range of 500 to 930 K, the calibration shift for Type K thermocouples caused by radiation fields of magnitudes less than 10^{16} n/cm^2*s (fast and thermal neutrons) and 10^{10} R/h (gamma) is, at most, ±0.5% of range.[11] Sandefur et al.[12] provide evidence that Type K thermocouples remain within 1% of range after a neutron radiation exposure of 2 x 10^{23} n/cm^2 (thermal) and 4 x 10^{21} n/cm^2 (fast) for 2960 h at 1200 K. This should be significantly higher than will be experienced in the LOFT application. A conservative estimate of the radiation error for the Type K thermocouple is ±(2 K + 0.5% of reading). This error is in addition to the error assigned earlier in this subsection.

The uncertainty factors for the temperature measurement are presented in Table 2.

Pressure

The steam pressure in the SSS is measured by means of a pressure transmitter on the end of a gas-filled transmission tube. The mounting effects are the greatest contributor to the uncertainty in this measurement.

Theory of Operation. The pressure transmitter used on the SSS of the LOFT FPMS uses a capacitance sensing element to measure pressure. In this transmitter, a diaphragm positioned between two fixed plates is deflected by the pressure that changes the capacitance of the sensing circuit.[13] The process pressure is transmitted through an isolating diaphragm and oil fill fluid to a sensing diaphragm. The atmospheric reference pressure is transmitted in like manner to the other side of the sensing diaphragm. The displacement of the diaphragm is proportional to the difference in the atmospheric pressure and the process pressure. The differential capacitance between the sensing diaphragm and the capacitor plates is converted electronically to a 2-wire, 4-20 mA dc signal.

Hardware. The hardware for the pressure measurement channel is discussed on page 7. The uncertainties, based on manufacturer's specifications, are given in Appendixes A and B.

Table 2. Uncertainty factors for the temperature measurement

Uncertainty Factors	Objective Uncertainty	Subjective Uncertainty
Thermocouple	±2.2K	—
Extension wire	—	±2.2K
Equation	—	±1.6K
Cold work	—	±0.5%(RD-255)
Transmitter	±0.2%(RG-255)	—
Aging	—	±0.5%(RD-255)
Radiation	—	±[2K + 0.5%(RL-255)]
DAS	±0.5%(RG-255)	—
Total	±[2.2K + 0.5%(RG-255)]	±[3.4K + 0.9%(RD-255)]

Measurement Channel Testing. No measurement channel testing has been performed on the pressure measurements to determine the effects of other system components. The uncertainties caused by the other components are unknown.

Variables Affecting Measurement Channel Uncertainty. Transmitters using capacitance sensing elements are quite stable for long-term process measurements. Some of the variables that affect the transmitter output are listed below. No additional uncertainty estimate is assigned for variables considered by the manufacturer. Note that the transducer range, the range used in computing the measurement uncertainty, is 0 to 3000 psig. The measurement range is 0 to 15 psig. Therefore, even a 1% of range error in the transducer translates into a 200% error in the measurement.

Repeatability, Linearity, and Hysteresis. The manufacturer quotes an uncertainty of ±0.25% of calibrated range for the combined effects of nonlinearity, nonrepeatability, and hysteresis.

Temperature Effects. Capacitance type pressure transmitters are very sensitive to temperature changes.[13] The manufacturer quotes an uncertainty of ±3.5% of range per 55 K at minimum span, which will be the range in which the transmitter is used. Assuming a temperature change of about 10 K, the resulting uncertainty is about ±0.6% of range. This includes both span and zero errors.

Shock, Vibration and Acceleration. Capacitance type pressure transmitters are fairly insensitive to this type of an environment. The manufacturer quotes an uncertainty of ±0.05% of range per g to 200 Hz. This translates to about ±0.1% of range for the transducer location.

Radiation and Aging. No data are available on the effects of radiation and aging on this transducer. The uncertainty is considered minimal owing to the short time the transmitter has been installed.

Stray Pickup in the Leads. The capacitance type pressure transmitter is susceptible to pickup of noise in the leads between the capacitor and the electronics. No information is available on the magnitude of this effect in the LOFT environment, but it is estimated as ±0.05% of range.

Mounting Effects. The transmitter is connected to the pressure source using gas-filled tubing. The length of the tubing, the presence of valves, and the possibility of the steam condensing in the transmission line all contribute to the uncertainty of the measurement. Based on engineering judgement, the uncertainty caused by mounting effects is estimated at ±1.0% of range.

The uncertainty factors for the pressure measurements are presented in Table 3.

Table 3. Uncertainty factors for the pressure measurements

Uncertainty Factors	Objective Uncertainty	Subjective Uncertainty
Linearity, hysteresis, repeatability	±0.25% RG	—
Temperature effects	±0.6% RG	—
Shock, vibration, acceleration	±0.1% RG	—
Stray electrical pickup	—	±0.05% RG
Mounting effects	—	±1.0% RG
Total	±0.7% RG	±1.0% RG

CONCLUSIONS

The uncertainties derived in this analysis are estimates based on manufacturers' specifications, LOFT testing, and engineering judgement. The largest source of uncertainty in all of the analyzed measurements is attributed to the mounting and environmental factors, largely owing to the many unknowns in these areas.

The steam sample system measurements recorded on the DAVDS are intended only for steady state operation. Data obtained during transient conditions must be carefully considered for response limitations.

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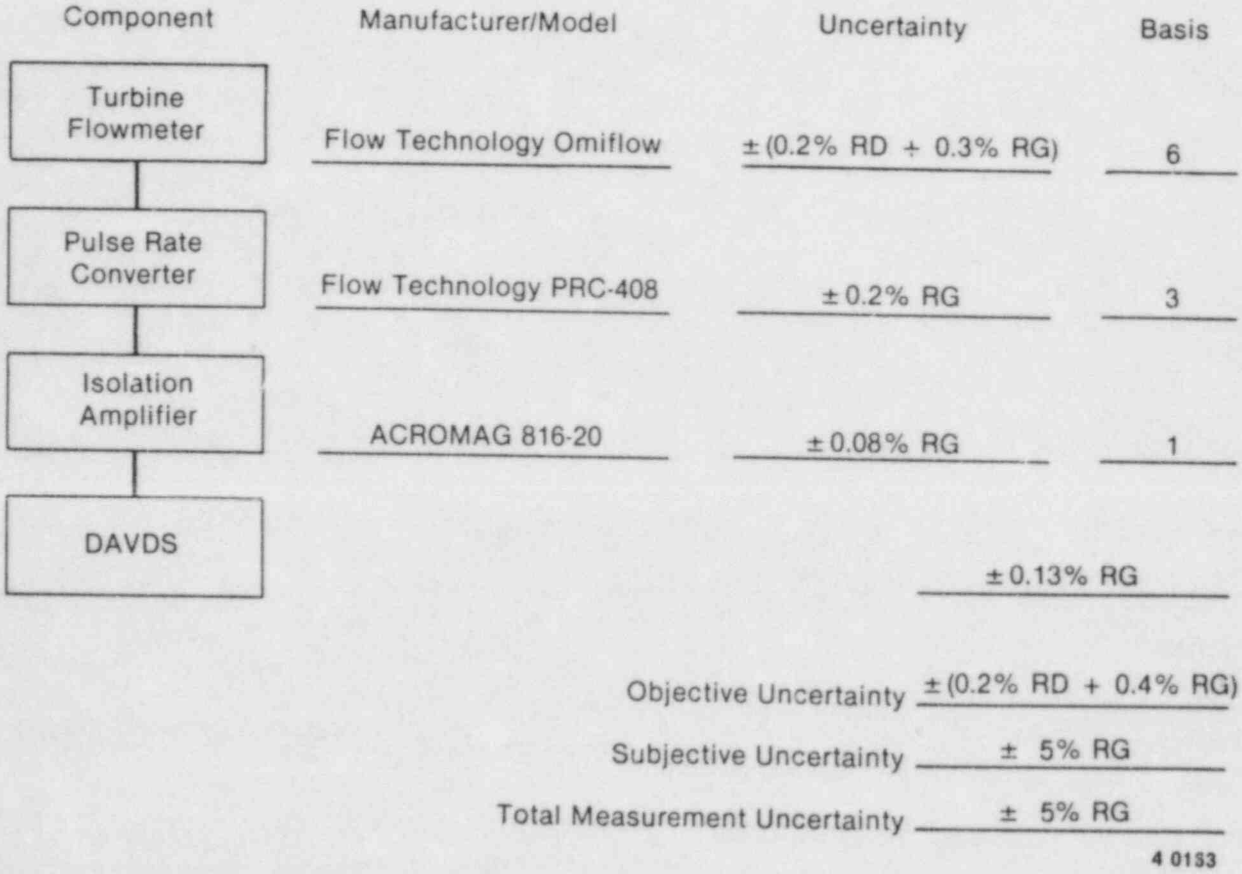
APPENDIX A
MEASUREMENT CHANNEL INTERCONNECTIONS

APPENDIX A
MEASUREMENT CHANNEL INTERCONNECTIONS

This appendix presents Figures A-1, A-2, and A-3, which list the measurement channel interconnections, along with the components, their manufacturers, and uncertainties. Where in the specification the uncertainty is given by the manufacturer, the number to the side refers to the summary in Appendix B where backup information can be found. In cases where no manufacturer's uncertainty is given, an "E" is placed next to the uncertainty indicating that it is an engineering estimate based on the best available information.



Component	Manufacturer/Model	Uncertainty	Basis
Turbine Flowmeter	Flow Technology Omiflow	±(0.2% RD + 0.3% RG)	6
Pulse Rate Converter	Flow Technology PRC-408	±0.2% RG	3
Isolation Amplifier	ACROMAG 816-20	±0.08% RG	1
DAVDS			
		±0.13% RG	

Objective Uncertainty ±(0.2% RD + 0.4% RG)

Subjective Uncertainty ± 5% RG

Total Measurement Uncertainty ± 5% RG

4 0133

Figure A-1. Flowmeter measurement channel.

Component	Manufacturer/Model	Uncertainty	Basis
Type K Thermocouple	Omega Engineering TJ72-CASS	± 2.2 K	5
Temperature Transmitter	Rosemount Inc. 444-TKI-UIA2	± 0.2% (RG-255)	4
Data Acquisition System		± 0.5% (RG-255)	E

Objective Uncertainty ± [2.2 K + 0.5% (RG-255)]

Subjective Uncertainty ± [3.4 K + 0.9% (RD-255)]

Total Measurement Uncertainty ± [4.1 K + 0.5% (RG-255) + 0.9% (RD-255)]

4 0161

Figure A-2 Temperature measurement channel.

Component	Manufacturer/Model	Uncertainty	Basis
Pressure Transmitter	Rosemount 1151GP	± 0.48% RG	2
Data Acquisition System		± 0.5% RG	E

Objective Uncertainty ± 0.7% RG

Subjective Uncertainty ± 1.0% RG

Total Measurement Uncertainty ± 1.2% RG

Note: The transducer range is 3000 psia, the measurement range is 15 psia. The 1.2% of range uncertainty is therefore equivalent to 36 psi or 240% of the measurement range.

4 0162

Figure A-3. Pressure measurement channel.

APPENDIX B
MANUFACTURERS' SPECIFICATION SUMMARY

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MANUFACTURERS' SPECIFICATION SUMMARY

This appendix contains a summary of the specifications for the components used in the Steam Sample System of the LOFT FPMS measurements that are recorded on DAVDS. The uncertainties for each component are calculated using the root-sum-square technique.

The manufacturers' estimates of uncertainty are assumed to be 2σ values. Although no justification is published for the manufacturers' uncertainty estimates, they are the only estimates available in many cases. An estimate may be biased, but the manufacturer, as manufacturer, is still the best source for the estimate. Where no uncertainty estimate is available from the manufacturer or any other source, an estimate is assigned based on similar types of instruments.

Summary of Manufacturers' Specifications

Isolation Amplifier

Manufacturer	Acromag
Model	816-20
Input range = Output range	4-20 mA
Accuracy	±0.05% RG
Line change	±0.05% RG
Temperature	±0.03% RG
Uncertainty	±0.08% RG

Pressure Transmitter

Manufacturer	Rosemount, Inc.
Model	Model 1151 GP Alphaline
Description	Model 1151 gage type pressure transmitter converts pressure (transmitted through an isolation diaphragm and silicone oil to a sensing diaphragm) to a 4 to 20 mA dc signal. The position of the sensing diaphragm is detected by capacitor plates on both sides of the sensing diaphragm.
Range	0 - 3000 psig
Temperature limits	-20 to 200°F
Overpressure limits	4500 psi
Accuracy (linearity, hysteresis, repeatability)	±0.25% RG
Stability	±0.25% RG for 6 months ±0.08% RG for 2 months

Temperature sensitivity	±1.0 % RG per 100°F ±0.4 % RG per 40°F
Uncertainty	±0.5% RG

Pulse Rate Converter

Manufacturer	Flow Technology, Inc.
Model	PRC-408 Pulse Converter
Description	Model PRC-408 pulse converter interfaces the turbine flowmeter with readout equipment. It provides an analog output signal proportional to the fluid flow rate.
Linearity	±0.2% RG
Temperature effect	±0.03% RG
Uncertainty	±0.2% RG

Temperature Transmitter

Manufacturer	Rosemount, Inc.
Model	Model 444-TK1-U1A2 Alphaline
Description	Model 444 temperature transmitter gives a 4 to 20 mA dc output for a thermocouple input.
Temperature limits	-25 to 85°C
Accuracy (linearity, repeatability, hysteresis)	±0.2% RG
Stability	±0.2% RG for 6 months ±0.07% RG for 2 months
Temperature sensitivity	
Zero	±2.5°C per 50°C ±1.0°C per 20°C
Span	±0.5% RG per 50°C ±0.2% RG per 20°C
Uncertainty	±(0.3% RG + 1°C)

Thermocouple

Manufacturer	Omega Engineering, Inc.
Model	TJ72-CASS-18U-12BX-LUG

Description	ANSI Type K (nickel-chromium vs. nickel-aluminum) ungrounded thermocouple.
Uncertainty	Standard limits of error: ±2.2°C or ±0.75% RD, whichever is greater.

Turbine Flowmeter

Manufacturer	Flow Technology, Inc.
Model	Omniflo Series II
Description	Omniflo, an in-line turbine flowmeter, uses the rotor to generate digital flow information. The fluid is directed past the underside of the rotor which turns in a plane in line with the fluid motion. Rotor motion is sensed by the modulated carrier pickoff.
Operating range	To be determined.
Operating temperature	-60 to 400°F
Accuracy (Gas)	
Repeatability	±0.2% RD
Calibration	±0.3% RG
Uncertainty	±(0.2% RD + 0.3% RG)

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An uncertainty analysis was performed for the Loss-of-Fluid Test Fission Product Instruments recorded on the Data Acquisition and Visual Display System in order to document the accuracy of these channels under steady state operating conditions. In addition, an uncertainty analysis was performed for certain temperature and pressure measurement channels excluding their recording system.

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