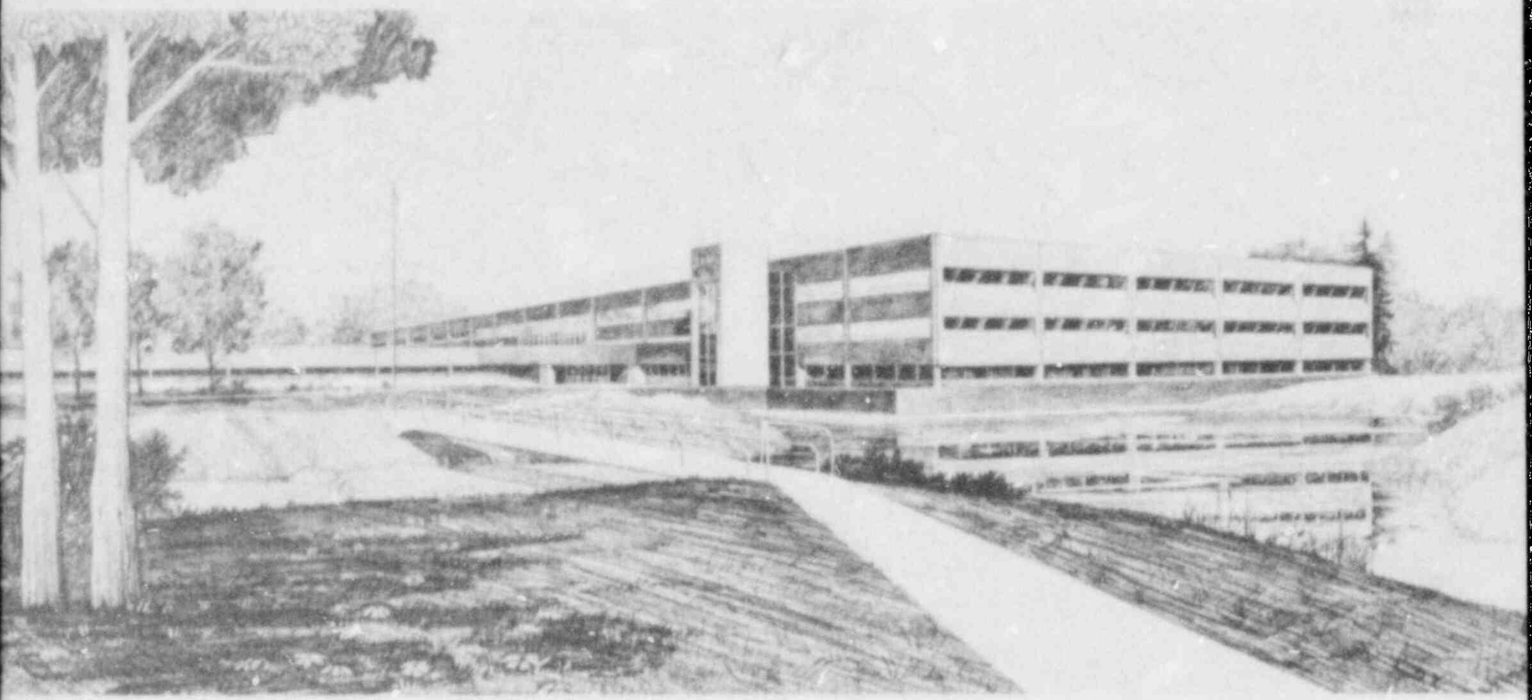
NUREG/CR-0169
EGG-2037
Vol. XI



U.S. Department of Energy
Idaho Operations Office • Idaho National Engineering Laboratory

LOFT Experimental Measurements Uncertainty Analyses
Volume XI
Free-Field Pressure Transducer

Lorenzo D. Goodrich
Gordon D. Lassahn

June 1982

Prepared for the
U.S. Nuclear Regulatory Commission
Under DOE Contract No. DE-AC07-76IDO1570

EG&G Idaho

Available from

GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

and

National Technical Information Service
Springfield, Virginia 22161

NUREG/CR-0169
EGG-2037
Vol. XI
Distribution Category: R2

LOFT EXPERIMENTAL MEASUREMENTS UNCERTAINTY ANALYSES
VOLUME XI
FREE-FIELD PRESSURE TRANSDUCER

Lorenzo D. Goodrich
Gordon D. Lassahn

Published June 1982

EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

Prepared for the
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under DOE Contract No. DE-AC07-76IDO1570
FIN No. A6043

ABSTRACT

Fast pressure transients during the subcooled decompression phase of experiments performed in the Loss-of-Fluid Test (LOFT) system are measured using free-field pressure transducers (FFPTs). This uncertainty analysis estimated the uncertainty for these measurements to be the root-sum-square combination of 0.13 MPa and 1% of reading. Although the FFPTs provide useful pressure measurements during other phases of LOFT experiments, the uncertainty for these measurements may be somewhat larger and is not included in this analysis.

NRC FIN No. A6043—LOFT Experimental Measurements

SUMMARY

Free-field pressure transducers (FFPTs) are used in the Loss-of-Fluid Test (LOFT) system to measure the fast pressure transient associated with the subcooled decompression phase of LOFT experiments. LOFT is a small-scale nuclear pressurized water reactor (PWR) test system designed to provide data from experiments simulating accident conditions in commercial PWR systems.

The FFPTs are immersed in the fluid where the pressure is to be measured. An FFPT consists of two end plates connected by easily compressible bellows and a relatively rigid strain post. A bridge network of four strain gages indicates the compressive strain in the strain post, caused by increasing pressure around the FFPT.

This analysis estimated the measurement uncertainty for FFPTs during the subcooled decompression phase of LOFT experiments to be the root-sum-square combination of 0.31 MPa and 1% of reading. The FFPTs may be used during other phases of LOFT experiments; however, the uncertainty during these phases may be somewhat larger and is not included in this analysis.

FOREWORD

This document (NUREG/CR-0169, EGG-2037, Volume XI[a]) reports results of an uncertainty analysis for the free-field pressure transducer measurements in the Loss-of-Fluid Test (LOFT) system. Measurements uncertainty analyses are performed to evaluate the anticipated performance uncertainty for each experiment measurement in the LOFT system. Results of these analyses are reported in a series of volumes designated NUREG/CR-0169, EGG-2037. Volume I of this series will describe the LOFT experimental measurement systems and the technique used for calculating the uncertainties. The remaining volumes in the series will present detailed results from the uncertainty analysis performed for each experimental measurement system.

The following volumes have preceded Volume XI:

1. P. A. Quinn, G. L. Biladeau, R. Y. Maughan, *LOFT Experimental Measurements Uncertainty Analyses, Volume V, LOFT External Accelerometer Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, October 1978.
2. G. L. Biladeau, *LOFT Experimental Measurements Uncertainty Analyses, Volume VI, LOFT Linear Variable Differential Transformer Displacement Transducer Uncertainty Analysis*, TREE-NUREG-1089, February 1978.
3. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume VII, LOFT Self-Powered Neutron Detector Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, August 1978.
4. G. D. Lassahn and P. A. Quinn, *LOFT Experimental Measurements Uncertainty Analyses, Volume VIII, Traversing In-Core Probe Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, August 1978.
5. G. L. Biladeau, *LOFT Experimental Measurements Uncertainty Analyses, Volume IX, LOFT Strain Gage Uncertainty Analysis*, TREE-NUREG-1089, June 1978.
6. S. Ploger, *LOFT Experimental Measurements Uncertainty Analyses, Volume X, Absolute Pressure Measurement Uncertainty Analysis*, NUREG/CR-0169, EGG-2037, September 1981.
7. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XII, Differential Pressure Measurements*, NUREG/CR-0169, EGG-2037, August 1981.
8. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XIII, Temperature Measurements*, NUREG/CR-0169, EGG-2037, March 1982.
9. S. Silverman, *LOFT Experimental Measurements Uncertainty Analyses, Volume XIV, LOFT Drag Disc-Turbine Transducer Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, November 1978.
10. L. D. Goodrich, *LOFT Experimental Measurements Uncertainty Analyses, Volume XV, LOFT Primary Coolant Pump Speed Measurement Uncertainty Analysis*, TREE-NUREG-1089, April 1978.

---

[a] Volumes VI, IX, XV, and XVI were published prior to implementation of the NUREG/CR numbering system as TREE-NUREG-1089; 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 of uncertainty analyses will be published as NUREG/CR-0169, EGG-2037.

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

12. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XVIII, Radiation-Hardened Gamma Densitometer*, NUREG/CR-0169, EGG-2037, September 1980.

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

ACKNOWLEDGMENTS

The information in this report was extracted from an internal report by G. L. Biladeau and L. D. Goodrich.

CONTENTS

FIGURES

TABLE

LOFT EXPERIMENTAL MEASUREMENTS UNCERTAINTY ANALYSES
VOLUME XI
FREE-FIELD PRESSURE TRANSDUCER

1. INTRODUCTION

The free-field pressure transducer (FFPT) is designed to measure the fast pressure transient that occurs during subcooled depressurization in experiments conducted in the Loss-of-Fluid Test (LOFT) system. The LOFT system [1] includes a small-scale [50 MW(t)] nuclear pressurized water reactor (PWR) and support systems designed to simulate commercial PWR systems during hypothetical accident conditions. The LOFT system is located at the Idaho National Engineering Laboratory (INEL). The LOFT Experimental Program is conducted by EG&G Idaho, Inc., for the U.S. Nuclear Regulatory Commission and is administered by the U.S. Department of Energy. The experiment measurements installed in the LOFT system provide data for evaluating the response of a PWR system during the hypothetical accident conditions.

The rapid response required to measure the fast pressure transient that occurs during subcooled depressurization is accomplished by immersing the FFPT in the fluid where the pressure is to be measured, rather than coupling the fluid to a remote transducer by a long, narrow tube. This is the reason for the name "free field." These transducers were designed and built by EG&G Idaho, Inc., at the INEL.

Section 2 of this report describes the FFPTs. Section 3 gives estimates of the magnitudes of the various recognized uncertainty contributions in the FFPT measurement systems. Conclusions from this analysis are stated in Section 4.

2. DESCRIPTION OF TRANSDUCER

The essential design features of the FFPT are shown in Figure 1. The two end plates are connected by the easily compressible bellows and by the relatively rigid strain post. As the pressure around the transducer increases, the strain post bears most of the compressive load, because it is much stiffer than the bellows. A bridge network of four strain gages gives an indication of the compressive strain in the strain post and, thus, an indication of the pressure around the transducer.

A four-arm bridge of strain gages, instead of a single strain gage, is used to eliminate the effects of temperature sensitivity in the strain gages. If all four gages had the same temperature dependences, the bridge arrangement would eliminate the effects of overall temperature changes, of axial temperature gradients in the transducer, and of thermal expansion of the transducer. Differences in the gages' temperature

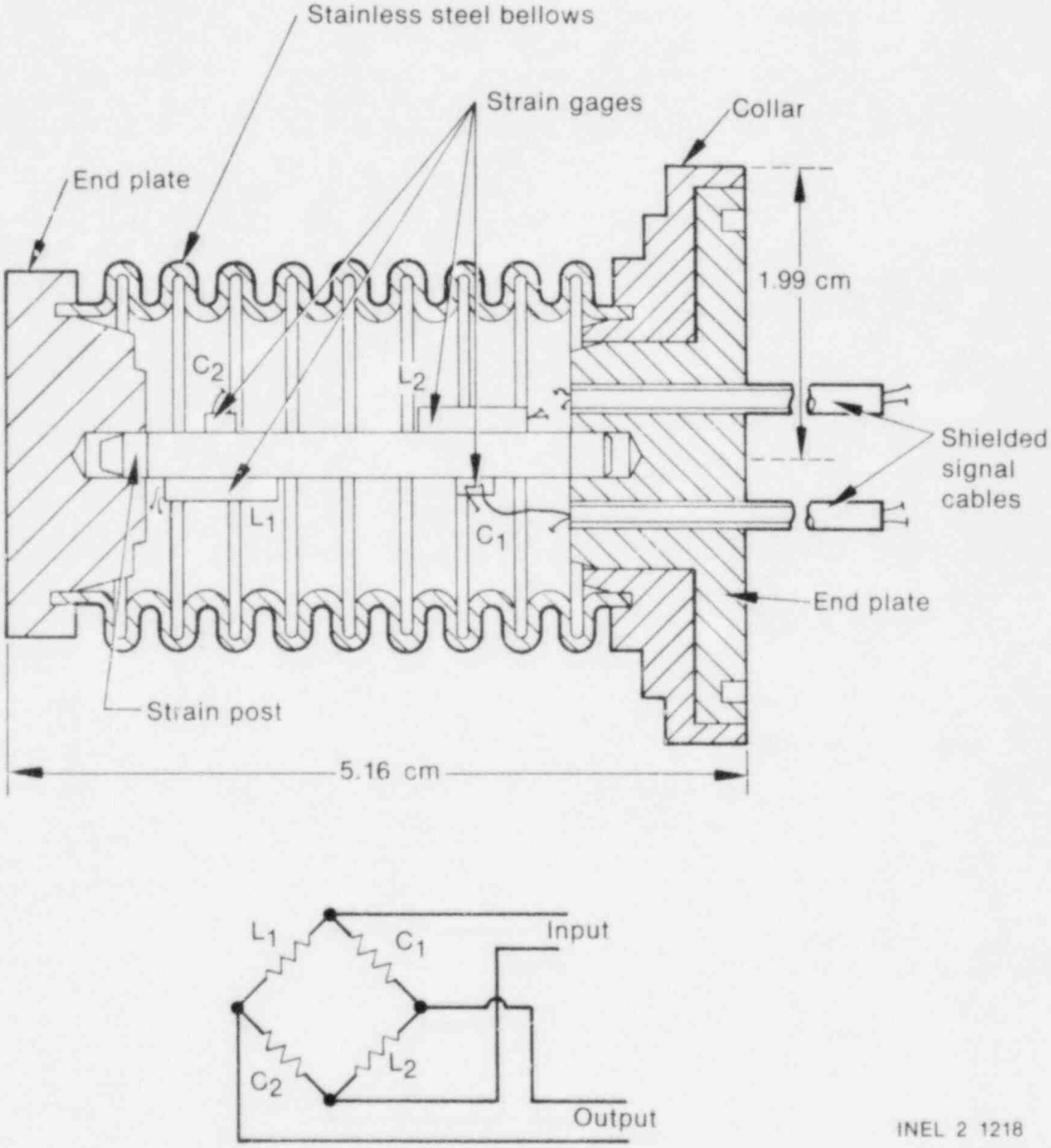


Figure 1. Free-field pressure transducer components.

characteristics, and a temperature dependence in the modulus of elasticity of the strain post, cause the transducer to have some temperature sensitivity. A correction for this temperature sensitivity is applied during the data processing, using a separate measurement for the temperature.

The bellows, strain gages, cables, and electronics are all commercially available components. The bellows is four-ply stainless steel. The cables have stainless steel sheaths and conductors, and magnesia insulation. The strain gages are bonded to the strain post by an alumina flame spray technique. The transducer is useful at temperatures at least as high as 620 K. Various tests have demonstrated that this transducer survives and functions in the required LOFT conditions of temperature, pressure, water chemistry, radiation, and vibration. A shroud is added to the transducer for mechanical protection, as sketched in Figure 2.

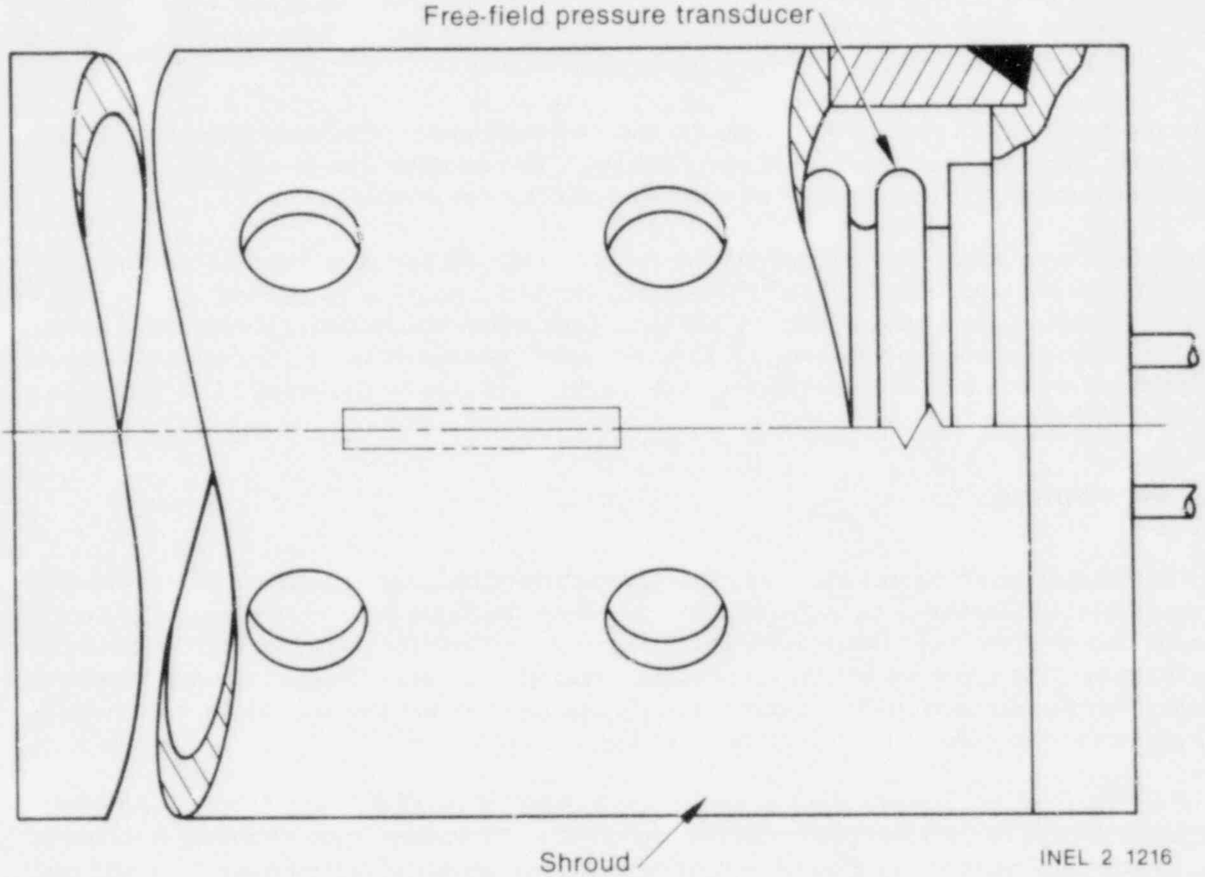


Figure 2. Free-field pressure transducer with shroud.

3. UNCERTAINTY

This section gives estimates of the magnitudes of the various recognized uncertainty contributions in the FFPT measurement systems. Unless otherwise stated, these estimates are based both on laboratory test data and on comparisons with other pressure measurements in the LOFT reactor at various steady temperature and pressure conditions.

3.1 Temperature Sensitivity

The FFPT strain gage locations compensated for temperature offset effects and tended to keep the bridge in balance, but the transducer became more sensitive with temperature. This change was attributed to the change in the modulus of elasticity of the 17-4 Ph stainless steel strain post with temperature (13% of reading from 294 to 589 K). This characteristic was of no consequence during subcooled blowdown, but must be corrected for during saturated blowdown.

A shift in zero offset with temperature has also been observed in some transducers during testing. Some FFPTs exhibited this characteristic and some did not. The reason for this is not clear. Again, this characteristic must be compensated for by calibration and blowdown tests.

For LOFT experiments, only a small uncertainty was contributed by temperature change during subcooled blowdown. Data taken on the FFPTs presently installed in LOFT showed a worst case change in offset of 2.5 kPa/K and change in slope of 0.07%/K. Temperature change during the subcooled portion of a LOFT loss-of-coolant experiment (LOCE) is very small. Assuming a worst case change during subcooled blowdown of 2.8 K, the worst case expected would amount to an uncertainty of 7 kPa + (root sum square) 0.2% of reading.

3.2 Response

To test the response of the transducer, a shock wave was generated and passed through the transducer by means of a set of Hopkinson bars. The test set up is shown in Figure 3. The lower bar is 3.175 cm in diameter and 90.81 cm long. The transducer is placed on its end with the leads extending out through a hole in the bar. The upper bar is 2.858 cm in diameter and 91.4 cm long. The diameters are intended to match closely the diameters of the end pieces of the transducer. The hammer is 2.858 cm in diameter by 10.2 cm long and is guided to the top of the upper bar by a nylon tube.

The results of this test showed that the rise time (10 to 90%) of the FFPT was 85.1 ± 1 μs (95% confidence). Although this test was performed by placing the FFPT under compression only, it should be similar to decompression. This will be true with the very small displacement of the strain post (0.0025 cm), with no yielding of the strain post. The LOFT tests have shown the rise time (10 to 90%) of the subcooled portion of the blowdown to be about 50 to 60 ms. Thus, the relatively fast reponse time of the FFPT should not contribute any significant measurement error. (However, there may be errors caused by response limitations in whatever data recording system is used with the FFPT.)

3.3 Repeatability

The short-term repeatability of the FFPT is very good if the strain post has been correctly seated. Strain gages have an inherent characteristic that when they are attached to a surface, their readings may change considerably until a given number of temperature/pressure cycles have been completed. This was avoided with the FFPT by cycling the strain post prior to assembly, and then cycling the assembly. Data from five FFPTs showed that the short-term repeatability was ±19 kPa (95% confidence). Individual calibrations were used for the FFPT; therefore, the actual short-term repeatability was used.

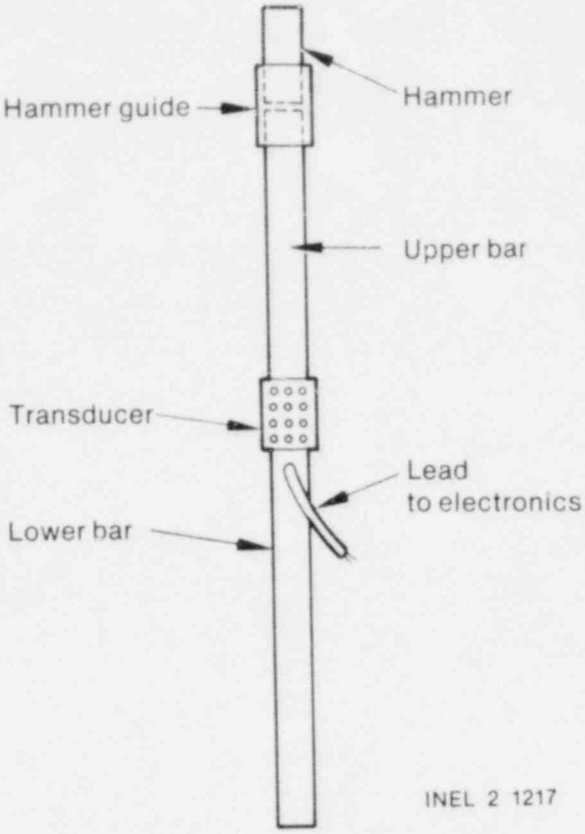


Figure 3. Time response test apparatus.

A long-term drift has been indicated by the LOFT experiments. Because of this drift in the sensitivity and offset, the inplace calibration on the FFPTs was done during the pre-LOCE checkout cycle. A new set of calibration coefficients were calculated prior to each experiment. Because of the temperature sensitivity, this calibration was done at the steady state conditions at 591 K prior to the LOCE. After LOFT Experiment L1-3A,[2] this uncertainty was evaluated to be 0.14 MPa in the offset and ±1% of reading for the sensitivity.

3.4 Hysteresis

Hysteresis of the FFPT was measured on five FFPTs and was found to be ±0.155 MPa (95% confidence).

3.5 Electronics

The specifications for the FFPT electronics showed very small errors for the electronics. The root-sum-square value for these errors was less than 0.10% of reading; therefore, they were considered to be negligible.

3.6 Summary of Specific Uncertainties

The total uncertainty during subcooled blowdown of an FFPT including the data acquisition and visual display system (DAVDS) is indicated in Table 1. The uncertainty for the saturated blowdown will include an additional uncertainty based on the temperature drift. For this table, only the uncertainty in the subcooled portions of the LOCE range is considered.

TABLE 1. Summary of LOFT uncertainties during subcooled blowdown

Parameter	Uncertainty (2σ)
Calibration accuracy	
Offset	0.14 MPa
Sensitivity	1.0%
Hysteresis	0.155 MPa
Repeatability	19 kPa
Temperature drift	7 kPa
	0.2%
Total measurement channel	0.21 MPa and 1% of reading
DAVDS (MFM)	0.23 MPa
Total uncertainty	0.31 MPa and 1% of reading
Maximum system rise time (10 to 90%)	350 μs

4. CONCLUSIONS

The LOFT free-field pressure transducer has a total uncertainty of 0.31 MPa and 1% of reading (root-sum-square combination) for the nearly-constant temperature conditions of subcooled decompression. The FFPT is functional in other LOFT experiment conditions, but the uncertainty may be substantially larger.

5. REFERENCES

1. D. L. Reeder, *Loft System and Test Description (5.5-Ft Nuclear Core 1 LOCEs)*, NUREG/CR-0247, TREE-1208, July 1978.

2. G. M. Miller, *Experiment Data Report for LOFT Nonnuclear Test L1-3A*, TREE-NUREG-1027, December 1976.

EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83415