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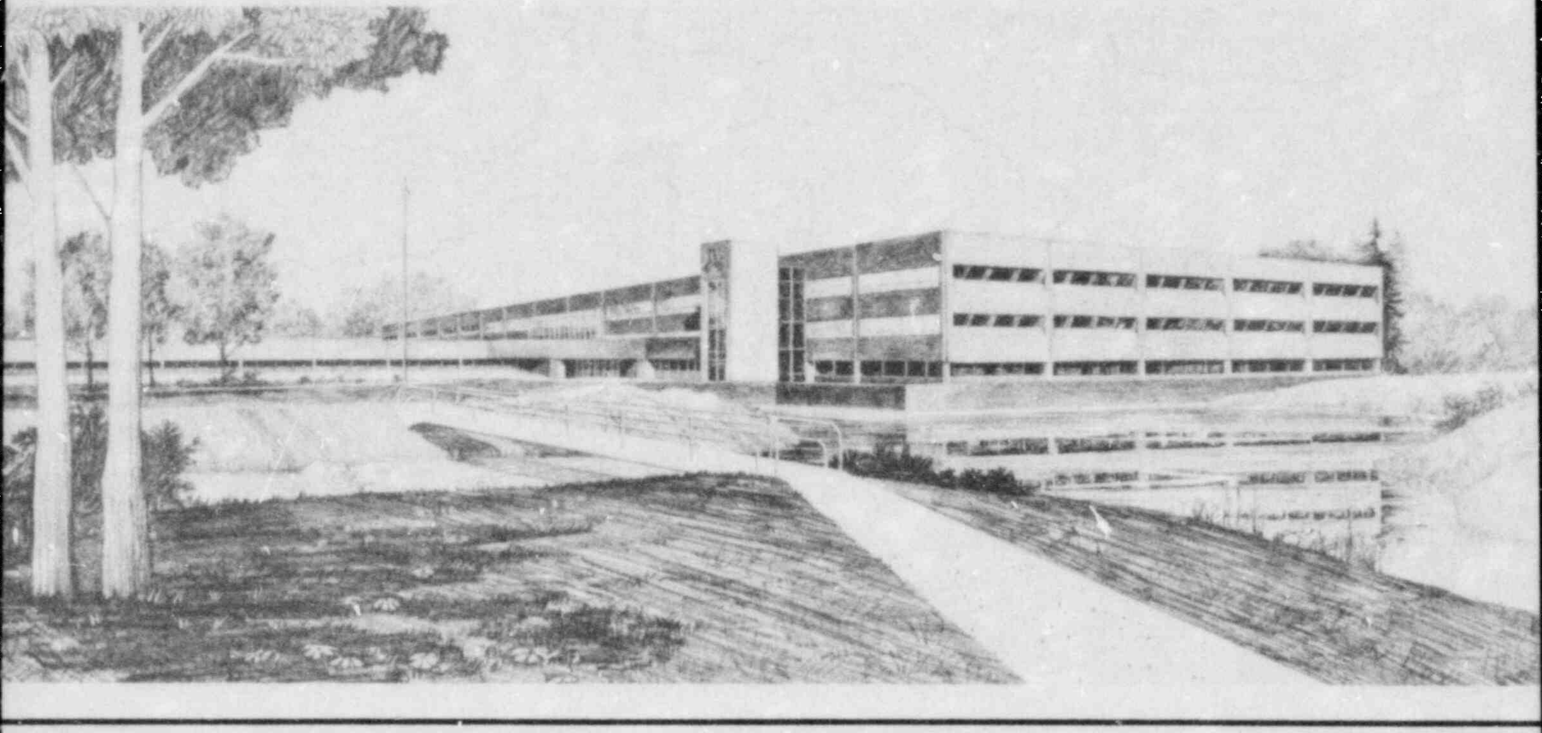

Idaho National Engineering Laboratory
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LOFT Experimental Measurements Uncertainty Analyses
Volume IV
Liquid Level Transducers

Teresa R. Meachum

October 1982

Prepared for the
U.S. Nuclear Regulatory Commission
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LOFT EXPERIMENTAL MEASUREMENTS UNCERTAINTY ANALYSES
VOLUME IV
LIQUID LEVEL TRANSDUCERS

Teresa R. Meachum

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ABSTRACT

The uncertainties of the measurements from the liquid level transducers (LLTs) installed in the Loss-of-Fluid Test (LOFT) reactor system have been computed and documented herein. The LLT is a conductivity-sensitive device designed to detect the presence or absence of liquid. Four types of LLTs are installed at various locations in the reactor core, downcomer, lower plenum, and upper plenum to provide information pertaining to the liquid level during LOFT transient experiments. This analysis determined that the in-core, downcomer, lower plenum, and upper plenum LLTs have 2 σ uncertainties of 2.78, 4.5, 8.33, and 6.25% of range, respectively.

FIN No. A6043—LOFT Experimental Instrumentation

SUMMARY

The Loss-of-Fluid Test (LOFT) reactor system is equipped with conductivity-sensitive liquid level transducers (LLTs) to indicate the presence or absence of liquid. The LLTs are used to establish the liquid level in the reactor system under transient conditions.

The LLTs are located in the reactor core, downcomer, and the upper and lower plenums. A typical LLT contains up to 19 independent conductivity-sensitive electrodes equally spaced over the expected water level. The design of a particular LLT, however, depends on its specific location. The output of the LLT is a binary decision of "covered" or "not covered," thus few factors contribute to the uncertainty.

In determining the uncertainty for the LLT measurements it is important to consider the temperature of the surrounding liquid, the aging of the ceramic seal of the electrodes, and the response time of the LLT. The contributions of these factors are small, but should be considered. The mounting tolerances of the electrodes in the LLT are also small contributors to the uncertainty. The largest contributor to the uncertainty is the spacing of the electrodes on the LLT.

The 2 σ uncertainties for the various LLTs are:

LLT Type	2 σ Uncertainty (percent of range)
In-core	2.78
Downcomer	4.5
Lower plenum	8.33
Upper plenum	6.25

FOREWORD

This document (NUREG/CR-0169, EGG-2037, Volume IV[a]) reports results of an uncertainty analysis for the liquid level transducer measurements in the Loss-of-Fluid Test (LOFT) system, and it supersedes LOFT Technical Report (LTR) 141-39, Supplement 3. 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 IV:

1. G D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume III, Data Acquisition and Recording System*, NUREG/CR-0169, EGG-2037, August 1982.
2. 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.
3. G. L. Biladeau, *LOFT Experimental Measurements Uncertainty Analyses, Volume VI, LOFT Linear Variable Differential Transformer Displacement Transducer Uncertainty Analysis*, TREE-NUREG-1089, February 1978.
4. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume VII, LOFT Self-Powered Neutron Detector Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, August 1978.
5. 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.
6. G. L. Biladeau, *LOFT Experimental Measurements Uncertainty Analyses Volume IX, LOFT Strain Gage Uncertainty Analysis*, TREE-NUREG-1089, June 1978.
7. S. Ploger, *LOFT Experimental Measurements Uncertainty Analyses, Volume X, Absolute Pressure Measurement Uncertainty Analysis*, NUREG/CR-0169, EGG-2037, September 1981.
8. 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.
9. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XII, Differential Pressure Measurements*, NUREG/CR-0169, EGG-2037, August 1981.
10. G. D. Lassahn, *LOFT Experimental Measurements Uncertainty Analyses, Volume XIII, Temperature Measurements*, NUREG/CR-0169, EGG-2037, March 1982.
11. S. Silverman, *LOFT Experimental Measurements Uncertainty Analyses, Volume XIV, LOFT Drag Disc-Turbine Transducer Uncertainty Analysis*, NUREG/CR-0169, TREE-1089, November 1978.

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[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.

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

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

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

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

16. G. D. Lassahn and D. J. N. Taylor, *LOFT Experimental Measurements Uncertainty Analyses, Volume XX, Fluid Velocity Measurement Using Pulsed Neutron Activation*, NUREG/CR-0169, EGG-2037, August 1982.

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LOFT EXPERIMENTAL MEASUREMENTS
UNCERTAINTY ANALYSES
VOLUME IV
LIQUID LEVEL TRANSDUCERS

1. INTRODUCTION

Liquid level conductivity measurements are located in the reactor core, the downcomer, and the upper and lower plenums of the Loss-of-Fluid Test (LOFT) reactor system. The measurements are designed to indicate the presence or absence of liquid and are used to establish the liquid level in the LOFT system under transient conditions.

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.

This report presents the estimated uncertainties for the LLT measurements. Section 2 describes the LLTs. The factors that cause the uncertainties and the estimated uncertainty values are presented in Section 3. Section 4 states the conclusions from this uncertainty analysis.

2. TRANSDUCER DESCRIPTION

An LLT system comprises a conductivity-sensitive transducer, electronic signal conditioning equipment, and data recording equipment (refer to Figure 1). Each transducer consists of a support tube; up to 19 equally spaced, independent, conductivity-sensitivity electrodes; and a common ground plane (refer to Figure 2). For each transducer, the electrodes are spaced equally over the expected water level. The presence or absence of liquid is determined by the voltage across the media between an electrode and the ground plane. The impedance between the electrode and the ground plane varies from 0.25 to 1.5 kilohms with a boric acid, lithium hydroxide, water mixture, and is >5 kilohms in steam.

The design of each transducer differs, depending on where the transducer is located. The differences in design are in the spacing of the electrodes, the types of ports (either slotted or circular), and the presence of and/or type of splash shielding. The differences are shown in Table 1.

Splash shields are installed on the transducers in the downcomer and lower plenum to prevent splashing of the primary coolant that could cause erroneous liquid level measurements. No shields are required for the in-core and upper plenum LLTs because the liquid rises from the lower plenum and does not flow down over either of these locations.

Measurement identifiers and the location of each LLT measurement are listed in Table 2. The design criteria and performance specifications for the LLT measurements are summarized in Table 3.

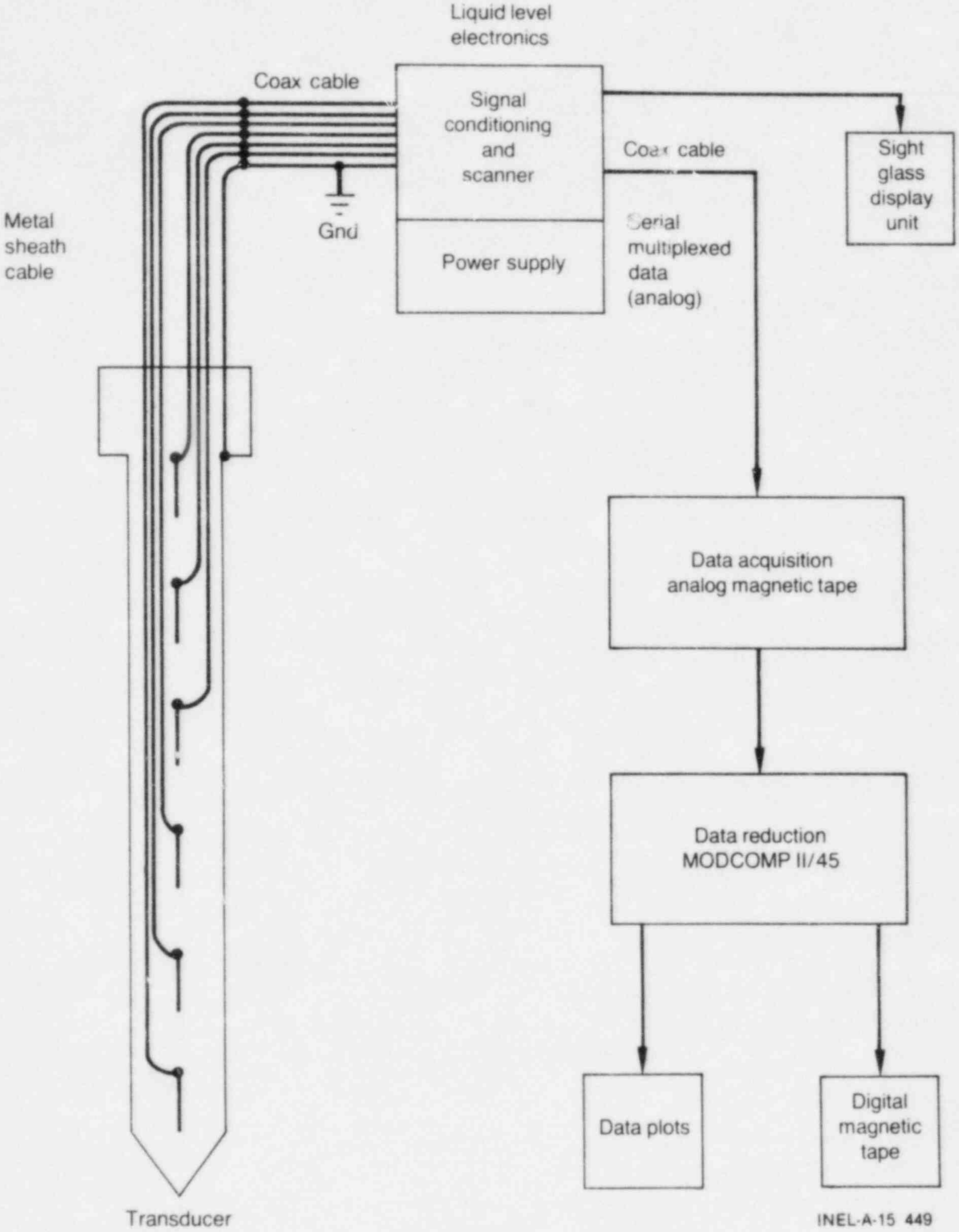

Figure 1. Liquid level transducer system.

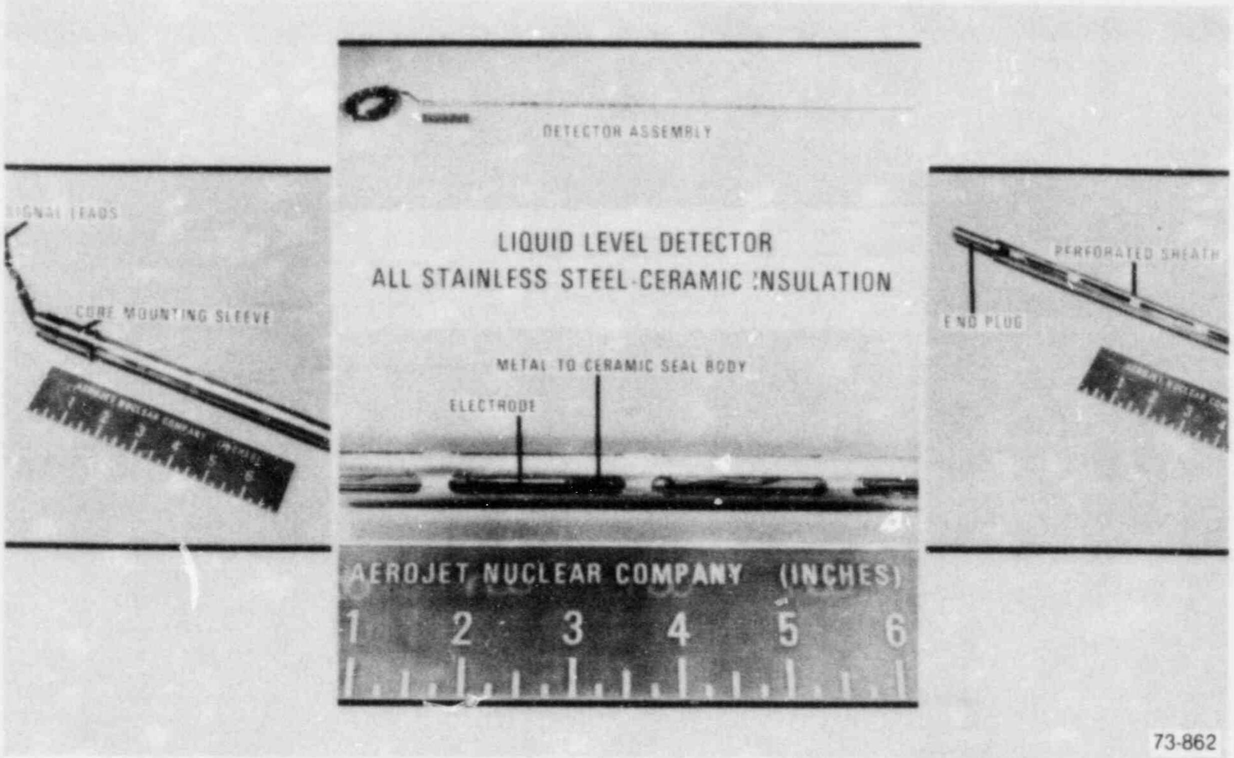

Figure 2. Typical LLT.

Table 1. Comparison of different types of LLTs

	LLT Type			
Characteristic	In-core	Downcomer	Lower Plenum	Upper Plenum
Number of electrodes	19	12	7	9
Electrode spacing [m (in.)]	0.0978 (3.85)	0.305 (12.0)	0.102 (4.0)	0.203 (8.0)
Port:				
Configuration	Slotted	Circular	Slotted[a]	Slotted
Spacing [m (in.)]	--	0.086 to 0.102 (3.375 to 4.0)	0.0175 (0.69)	--
Splash shield configuration	--[b]	Slotted[c]	Circular	--[b]

---

[a] Also has six 0.002-m (0.09-in.) diameter holes in bottom of LLT.

[b] None required.

[c] Also has port splash shields.

Table 2. LLT identifiers and locations

Measurement	Location
1F10	Core support tube; Fuel Assembly 1, Column F, Row 10
3F10	Core support tube; Fuel Assembly 3, Column F, Row 10
5E11 (A1 fuel bundle)	Core support tube; Fuel Assembly 5, Column E, Row 11
5K11 (F2 and F1 fuel bundles)	Core support tube; Fuel Assembly 5, Column K, Row 11
1ST-1	Lower plenum, Downcomer Stalk 1
2ST-1	Lower plenum, Downcomer Stalk 2
1ST-2	Downcomer Stalk 1
2ST-2	Downcomer Stalk 2
3UP	Upper plenum above Fuel Assembly 3

Table 3. Design requirements and specifications for the LLTs

Characteristic	Value
Environment	
Pressure [MPa (psi)]	
Normal	15.51 (2250)
Maximum (hot)	17.24 (2500)
Maximum (cold)	25.79 (3740)
Temperature [K (°F)]	
Normal	588.7 (600)
Maximum	922.0 (1200)
Radiation	
Normal operation	1.0×10^{14} nv
Total exposure (2000 efph)[a]	7.2×10^{20} nvt
Gamma flux	1×10^{11} R/h
Total exposure (2000 efph)	2×10^{12} R
Response time	Less than 500 ms
Lifetime (efph)	
Normal	2000
Maximum	10,000 at temperature and pressure
Transducer spacing [m (in.)]	
In-core	0.0978 (3.85)
Downcomer	0.305 (12.00)
Lower plenum	0.102 (4.00)
Upper plenum	0.203 (8.00)
Transducer range [m (in.)]	
In-core	1.76 (69.3)
Downcomer	3.35 (132.0)
Lower plenum	0.61 (24.0)
Upper plenum	1.63 (64.0)

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[a] Effective full power hours.

3. UNCERTAINTY ESTIMATION

The LLT measurement system was not designed to provide local void fraction or fluid conductivity information accurately. It was intended to provide liquid level measurements by sensing the presence or absence of liquid. The output of the LLT is basically a binary decision of "covered" or "not covered." Because the LLT is a discrete measurement, few factors contribute to the uncertainty. However, the following factors should be considered.

3.1 Temperature

The temperature of the fluid does have a large effect on the fluid conductivity, thus inducing an uncertainty on the "covered" impedance. However, this temperature dependence has virtually no effect on the "covered" versus "not covered" decision.

3.2 Aging

The most serious aging problem of the LLT is the degradation of the ceramic seal which can affect the resistance of the electrode. Testing has shown that the "uncovered" resistance can register as low as 2 kilohms due to degradation of the seals. However, as long as the difference between the "covered" resistance of <1 kilohm and the degraded "uncovered" resistance can be distinquished, the LLT will operate as designed.

3.3 Response Time Limitations

Tests have indicated a response time for the LLT of <330.4 ms, with 95% confidence limits. Because of a multiplexing rate of 200 Hz, a given electrode impedance can only be reviewed every 5 ms per electrode. The worst case response time would cause an additional 100-ms (5 ms for each of 20 electrodes) delay in overall response time.

3.4 Mounting Errors

The major contribution to the uncertainty of the LLT measurements is due to the finite spacing of the electrodes. The spatial error limits for each of the different types of LLTs are:

1.	In-core	±0.049 m (1.93 in.)
2.	Downcomer	±0.152 m (6.0 in.)
3.	Lower plenum	±0.051 m (2.0 in.)
4.	Upper plenum	±0.102 m (4.0 in.).

Several mounting tolerances associated with the installation of the transducers should be considered. In calculating these tolerances for the lower plenum LLT, the bottom of the vessel should be used as the reference. For the in-core and downcomer LLTs, the bottom of the fuel should be used as the reference; for the upper plenum LLT, the top of the fuel should be used as the reference. The mounting relationships are shown in Figure 3.

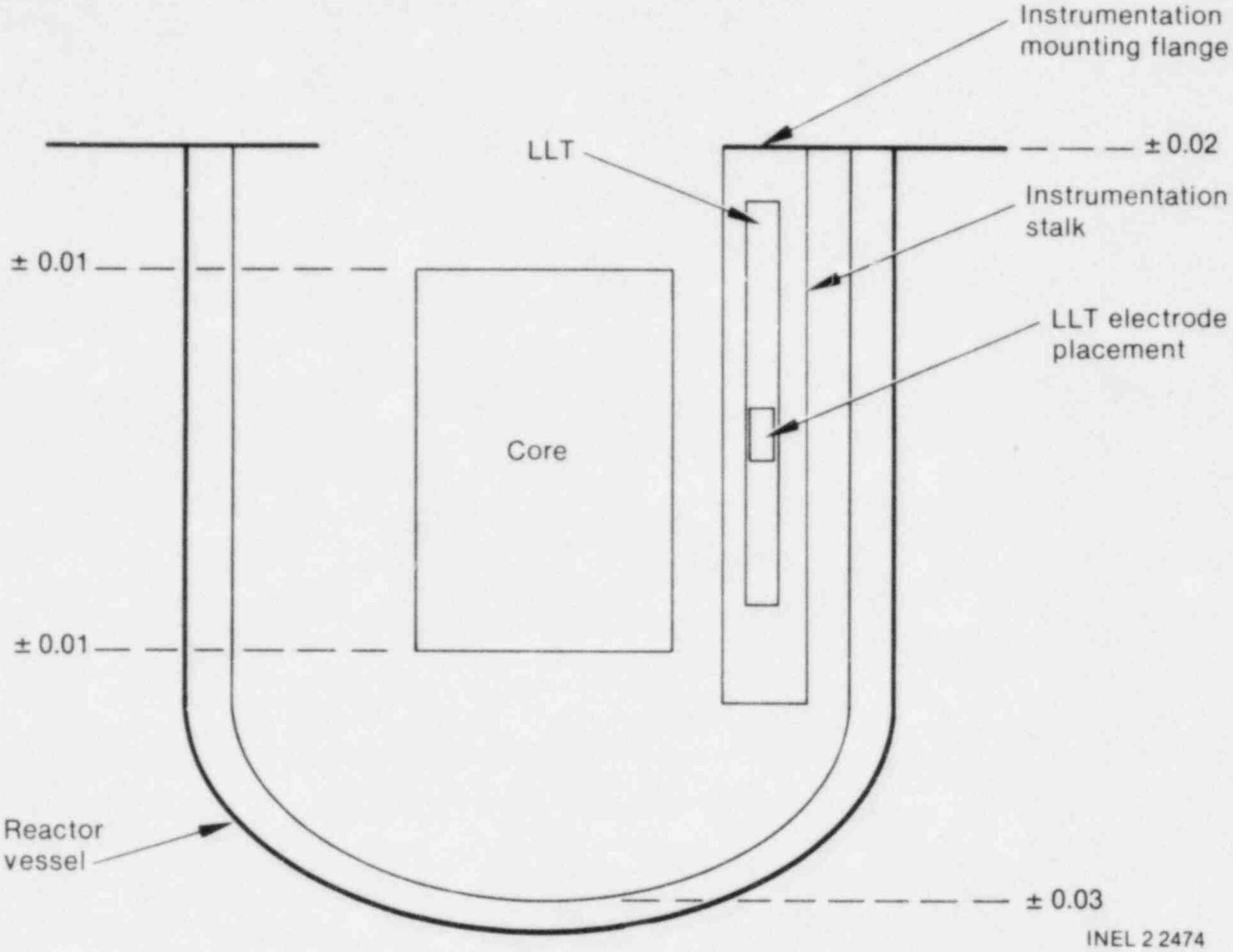

Figure 3. Mounting relationships of the LLT.

All of the contributing factors to the mounting errors are independent 3 σ, specification limit, errors. In order to calculate the mounting error, a 2/3 root sum square should be computed on the contributing errors. The total mounting tolerances and contributing errors for the different types of LLTs are as follows:

1. For the in-core LLTs,

   a. The mounting tolerances are:

Electrode placement on LLT	±7.620E-4 m (0.03 in.)
Attachment of LLT to fuel rod assembly	±1.524E-3 m (0.06 in.)
Mounting of fuel rod assembly in reactor vessel	±2.540E-4 m (0.01 in.)
Placement of bottom of core	±2.540E-4 m (0.01 in.)

   b. The mounting error is $2/3\sqrt{(7.62\text{E-}4)^2 + (1.524\text{E-}3)^2 + (2.54\text{E-}4)^2 + (2.54\text{E-}4)^2}$ $= \pm 1.159\text{E-}3$ m (0.046 in.)

2. For the downcomer LLTs,

   a. The mounting tolerances are:

Electrode placement on LLT	±7.620E-4 m (0.03 in.)
Attachment of LLT to downcomer	±1.524E-3 m (0.06 in.)
Mounting downcomer stalk to reactor vessel	±5.080E-4 m (0.02 in.)
Placement of bottom of core	±2.540E-4 m (0.01 in.)

   b. The mounting error is $2/3\sqrt{(7.62\text{E-}4)^2 + (1.524\text{E-}3)^2 + (5.08\text{E-}4)^2 + (2.54\text{E-}4)^2}$ $= \pm 1.197\text{E-}3$ m (0.047 in.)

3. For the lower plenum LLTs,

   a. The mounting tolerances are:

Electrode placement on LLT	±7.620E-4 m (0.03 in.)
Attachment of LLT to downcomer	±1.524E-3 m (0.06 in.)
Mounting downcomer stalk to reactor vessel	±5.080E-4 m (0.02 in.)
Relative location to bottom of vessel	±7.620E-4 m (0.03 in.)

   b. The mounting error is $2/3\sqrt{(7.62\text{E-}4)^2 + (1.524\text{E-}3)^2 + (5.08\text{E-}4)^2 + (7.62\text{E-}4)^2}$ $= \pm 1.295\text{E-}3$ m (0.051 in.)

4. For the upper plenum LLTs,

   a. The mounting tolerances are:

Electrode placement on LLT	±7.620E-4 m (0.03 in.)
Attachment of LLT above fuel rod assembly	±1.524E-3 m (0.06 in.)
Mounting of fuel rod assembly in reactor vessel	±2.540E-4 m (0.01 in.)
Placement of core	±2.540E-4 m (0.01 in.)

   b. The mounting error is $2/3\sqrt{(7.62\text{E-}4)^2 + (1.524\text{E-}3)^2 + (2.54\text{E-}4)^2 + 2.54\text{E-}4)^2}$ $= \pm 1.159\text{E-}3$ m (0.046 in.).

The total placement error would be the root sum square of the spatial and the mounting errors. Because the mounting errors are small, they are concealed in the spatial errors when the root sum square is computed. The total placement errors for the LLTs, therefore, are equal to the spatial errors.

4. CONCLUSIONS

Because of the discrete nature of the LLT, very few factors contribute to the uncertainty of the measurement. The spacing of the electrodes of the LLT was found to be the largest contributor to the uncertainty. The temperature of the liquid, the aging of the material used in the LLT ceramic seal, and the response time are all limiting factors in the interpretation of the LLT output. But none of the three severely affect the uncertainty of an operating LLT measurement.

The uncertainties of the four different types of LLTs are listed below. The response time (10 to 90% rise time) was determined to be 330.4 ms for all LLTs.

LLT Type	Total Placement Error [m (in.)]	2σ Uncertainty (percent of range)
In-core	±0.049 (1.93)	2.78
Downcomer	±0.152 (6.00)	4.5
Lower plenum	±0.051 (2.00)	8.33
Upper plenum	±0.102 (4.00)	6.25

5. REFERENCE

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

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