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LOFT TECHNICAL REPORT

Title A COMPARISON OF COMPUTED DENSITY PROFILES FROM THE TRANSIENT FLOW CALIBRATION FACILITY, USING THREE OR SIX BEAM MEASUREMENTS	LTR No. LO-87-80-137
Author T. R. Meachum, J. L. Wambach	Released By LOFT CDCS
Performing Organization LOFT Measurements Division	Date August 14, 1980
LOFT Review and Approval	Project System Engineer

LMAB Mgr. LDAB Mgr. LMD Mgr.

Abstract

An analysis of computed pipe average density, as calculated by using a three beam and a six beam densitometer computer model, is presented. Data taken at the Transient Flow Calibration Facility was used as input to density and flow regime modeling computer algorithms. The affect of the number of beams and/or their placement, when calculating an average density, was found to be minimal. However, when modeling the flow regime, many differences were found in the output from the three beam and in that from the six beam densitometer.

DISPOSITION OF RECOMMENDATIONS

There are no specific plans for further study (recommended on page 9) at this time. No other action is required.

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SUMMARY

This report presents the results of an analysis of the effects of densitometer beam number on calculating an average whole pipe density. Density, pressure, and temperature data taken as part of the Transient Test Program performed at Wyle Laboratories in Norco, California were used as input to a computer model, which calculated both average density and flow regime as a function of time. Runs were made using two three beam densitometers and the two combined as a six beam densitometer in order to identify the differences in the model output due to beam number. The effects of upstream geometry were also investigated by comparing tests of varying configurations.

The analysis revealed that there is little difference in the computed average density regardless of the number of beams used. There was, however, a marked difference in the flow regime modeled by the computer program depending on the number of beams, the beam orientation and the upstream geometry.

CONTENTS

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1. INTRODUCTION

One of the phenomena encountered in the Loss-of-Coolant Experiments (LOCEs), modeled in the Loss-of-Fluid Test (LOFT) program, is the presence of two-phase fluid flow during portions of the tests. In order to identify the various flow regimes and flow geometry, the fluid density must be known. Chordal density measurements are obtained using three beam gamma densitometers at various locations in the LOFT system. In an effort to establish the accuracy and validity of these three beam measurements, a system was constructed by Wyle Laboratories in Norco, California to duplicate full scale LOFT geometry blowdown transients (Figure 1). The densitometer system installed at Wyle in the Transient Flow Calibration Facility included two LOFT three beam gamma densitometers located at the same axial position on the facility test spool. Chordal density measurements were obtained during the transient tests using the two three beam densitometers individually and together, thus providing a six beam densitometer unit along with the pair of three beam densitometers.

The densitometer data were used as input into two computer algorithms, each of which calculates an average cross-sectional fluid density. This paper presents a comparison of the calculated density profiles using both three and six beam measurements. The differences and/or agreements between the currently used three beam densitometer system and the proposed six beam system are detailed.

2. DENSITOMETER DESCRIPTION

The gamma densitometer system installed in the Transient Flow Calibration Facility included six separate gamma ray detectors, and two gamma sources. Each of the three beam densitometer units were defined by one source, three detectors, a collimator cask, and a photomultiplier tube housing (Figure 2). The pair of three beam units were mounted on a common clamp, one on each side of the pipe, with both positioned at the same axial location on the test spool. This arrangement provided one six beam gamma densitometer measurement. The densitometer beams were all mounted upstream of the drag-disk turbine transducer (DTT) penetration (Figure 3). Looking upstream, DE-1 is located on the left side of the pipe and DE-2 on the right, making DE-1 on the inside of the piping during tests when the elbow is installed.

The shielded radiation source casks contained approximately 30 curies of cesium 137. Air lines were provided to the casks to move the sources to the collimators, to expose the sources for operation. The photomultiplier tube housings were water cooled to make the densitometer system readings more uniform and repeatable.

The uncertainity of the densitometer system was ± 58 kg/m^3, less an unaccountable bias. The uncertainity, however, is believed to be closer to ± 20 kg/m^3 if the bias were removed.

3. COMPUTER ANALYSIS

Chordal density measurements, taken from the densitometer beams were used as input into two existing average density and density profile modeling algorithms. The algorithm currently used by LOFT limits the number of beams to be processed to three. All of the three beam densitometer data were processed through the algorithm currently used for LOFT, as well as a n-beam density profile modeling algorithm proposed for LOFT. The six beam densitometer data was processed solely through the n-beam algorithm.

Comparisons were made between the 3-beam algorithm and the n-beam algorithm on the data obtained from the pair of three beam densitometers. Figure 4 shows the correlation, for a specific test, between the two algorithms when computing a whole pipe average density. During the 5 to 25 second time interval, a maximum 89 kg/m^3 variation was found in the calculated average densities. That is less than 4.5% variation of reading for the time interval during which the density was decreasing in the pipe. The differences in the density profiles modeled by the two algorithms were attributed to a larger number of models incorporated in the 3-beam algorithm. Certain restrictions were made on the profile models supplied within the n-beam algorithm, since the algorithm allows for a greater number of beams to be processed.

The density profiles allowed within the n-beam algorithm include homogeneous, tilted stratified, and eccentric annular. The algorithm returned the profile to be homogeneous if the individual beam readings were equal, or nearly equal. A direct average of the individual beams were taken during homogeneous flow to calculate average density. If the selected profile was either tilted stratified or eccentric annular then the average density was given by

$$\overline{\rho} = 1/A \int \rho(\overline{r})\, dA$$

where

A = cross-sectional area of the pipe

$\rho(\overline{r})$ = chordal profile.

If none of the above mentioned profile models represent the data, then the average density was calculated by a weighted average of the chordal density readings.

4. AVERAGE DENSITY COMPARISONS

During the course of the transient, the value of the calculated average density varied from the density of saturated water at the specified initial conditions to zero, indicating an empty pipe. The calculated averge density was used when calculating mass flow rate, therefore it is critical that a model accurately indicates a single, reasonable value for fluid density at any time during that transient. The densitometer beam data obtained from all tests performed at the Transient Flow Calibration Facility, after being processed through both the 3-beam and the n-beam algorithms, were first compared with the individual beam input to assure reasonable results. Engineering judgement was used to warrant the models as functioning correctly for each test. As stated previously, the n-beam algorithm is the only algorithm of the two that can process both six and three beam input. Because of this, the following comparisons are based on the output from the n-beam algorithm only.

Calculated average density from the transient tests produced evidence that the three beam densitometer was as accurate as the six beam densitometer when determining an average cross-sectional fluid density. A study of the data from any one test showed almost a direct overlay of the calculated average density from all three densitometer units. Figures 7 and 8 show the absolute difference in the average densities between the six beam densitometer and DE-1, and the six beam and DE-2, respectively (DE-1 and DE-2 being the pair of three beam densitometers). The test which produced the data for the two figures was a broken loop, cold leg test, with a six inch diameter orifice, a nozzle installed, and an elbow installed upstream of the densitometer units. This test, of fairly complicated upstream geometry, showed during the 5 to 25 second time interval, a maximum of 100 kg/m^3 variation (or a 10.28% of reading over the time interval) between DE-1 and the six beam, and a 90 kg/m^3 variation between DE-2 and the six beam when comparing the calculated average densities. For the remaining time interval, a difference of less than 1.0% of range was found between the six beam and either of the three beam densitometers. Figure 9 is the calculated average density from the six beam densitometers for the same test. The calculated average densities from all of the tests in Table I were compared on a per test basis, and a maximum of 5.0% of range variation was found over the time interval between the six beam and either of the three beam densitometers. These correlations were based on the relative values of each output at the same point in time after blowdown initiation.

5. FLOW PROFILE COMPARISONS

Fluid conditions within a pipe during a transient test are also an important consideration. By calculating local void fraction in combination with the associated geometry factors during a test, the distribution of the different phases of fluid across the pipe cross-section can be modeled. The n-beam algorithm performs such calculations and produces information as to the density profile and conditions during any point in time of a test. This information can be plotted and the variety of density profiles during a test can be seen.

Figures 10 - 12 show the different density profiles modeled from both three beam and six beam data from a test of fairly complex upstream geometry (nozzle installed and an elbow upstream of the densitometers). Differences in the density profile between the six beam and pair of three beams were found. Also, a noticeable difference was seen between the two three beam densitometer profile outputs. These variations in modeled profiles, between the six and three beam densitometers and between the pair of three beam densitometers were seen in all transient tests performed at the facility. Less severe variations were found during test with straight piping installed, as seen in Figure 13. After comparing all test profiles, DE-2 was found to agree closer with the six beam during test with the elbow installed, than did the DE-1; DE-2 being on the outside of the elbow piping and DE-1 on the inside. The agreement between the six beam unit and DE-2 for tests with an elbow installed denote the importance of proper beam placement, along with the effect of upstream pipe geometry, on modeling density profiles when two-phase conditions exist within a pipe.

Hydraulic conditions resulting from piping configuration create different density profiles. During tests with an elbow installed in the piping upstream of the densitometers, the density profile modeled with the n-beam algorithm showed eccentric annular and tilted stratified flow existing during the time interval the fluid density decreased in the pipe. For tests with straight piping the most frequent flows were homogeneous and tilted stratifed. The n-beam algorithm calculated the tilt angle of the fluid inside the pipe when eccentric annular or tilted stratified flow existed. When a straight pipe was installed upstream of the densitometer units a minimal, between ± 0.5 radians, tilt angle was seen (Figure 16). This was seen during the same time interval for all three densitometer units. Spikes existing in the data that reached 3.14 radians, or π, were ignored. When the readings reached π, the tilt angle was 180°, the physical equivalent of zero degrees. Density profiles resulting from tests when the elbow was installed show more severe tilt angles when calculated from the six beam densitometer, than from either of the three beam units. Figure 17 shows an example of the tilt angle calculated from the six beam densitometer unit during eccentric annular flow. Figures 18 and 19 show the tilt angles as seen by DE-1 and DE-2, respectively, during the same time interval. The figures show a disagreement in the tilt angle calculations from the three different densitometer units.

6. CONCLUSION

One result was evident from the data taken with the six and three-beam densitometers tested at the Transient Flow Calibration Facility. The basic densitometer system, currently used in the LOFT program, was as capable of determining an accurate measure of average density as was a six-beam densitometer system. No evidence was produced to merit the installation of a greater number of beams when interested in calculating average cross-sectional fluid density.

Accurate fluid density profile modeling, however, requires a more detailed study. Despite the differences in density profiles modeled from the densitometer units, numerous time periods of non-homogeneous flow were identified. This, in itself, is the first step in the characterization of two-phase flow regimes. Further study into proper beam placement and broader knowledge of the effects of piping geometry are needed to better depict the existance of two-phase flow regimes during transient tests.

Schematic of Transient Flow Calibration Facility

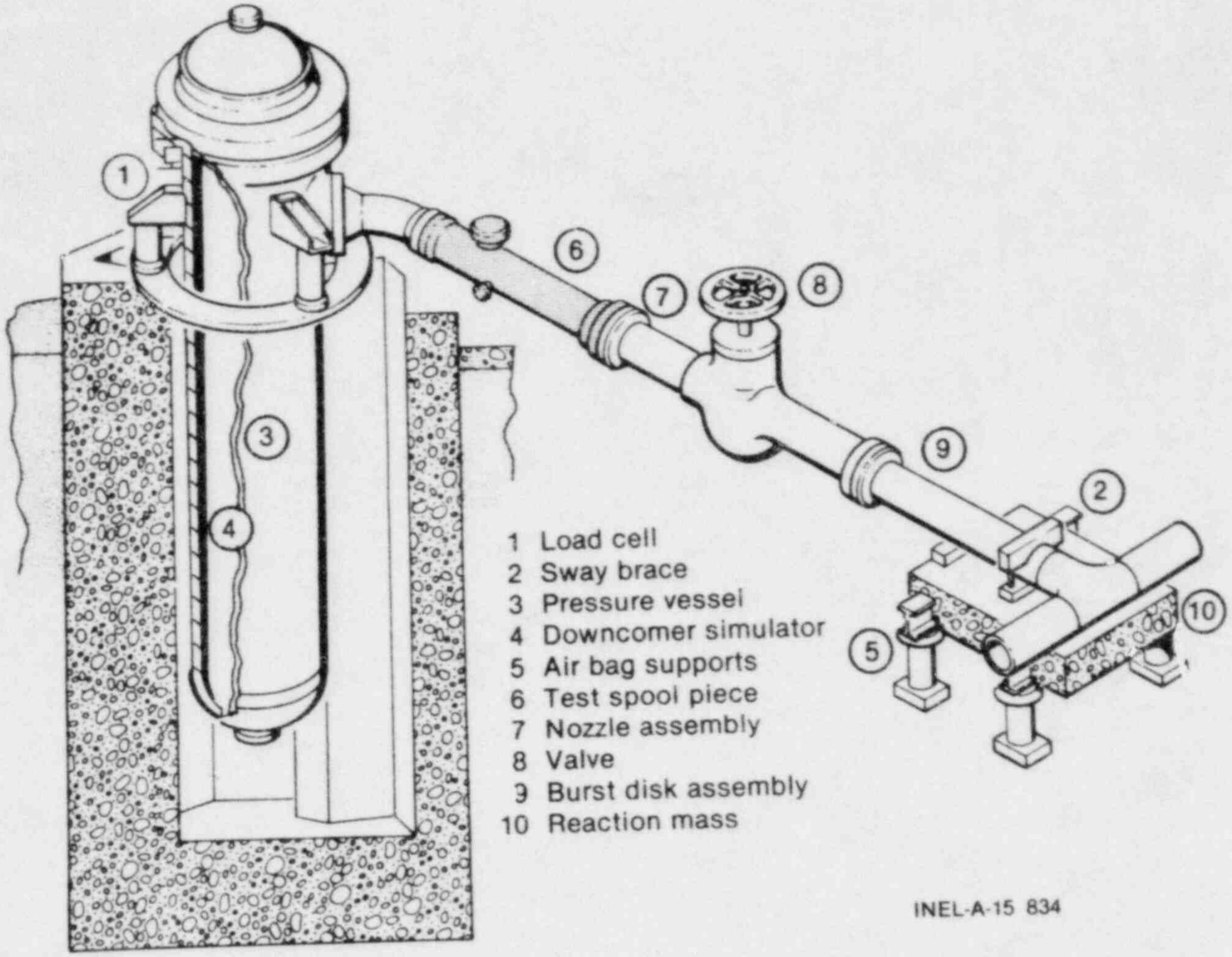

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Figure 1

Densitometer cross-section of installation

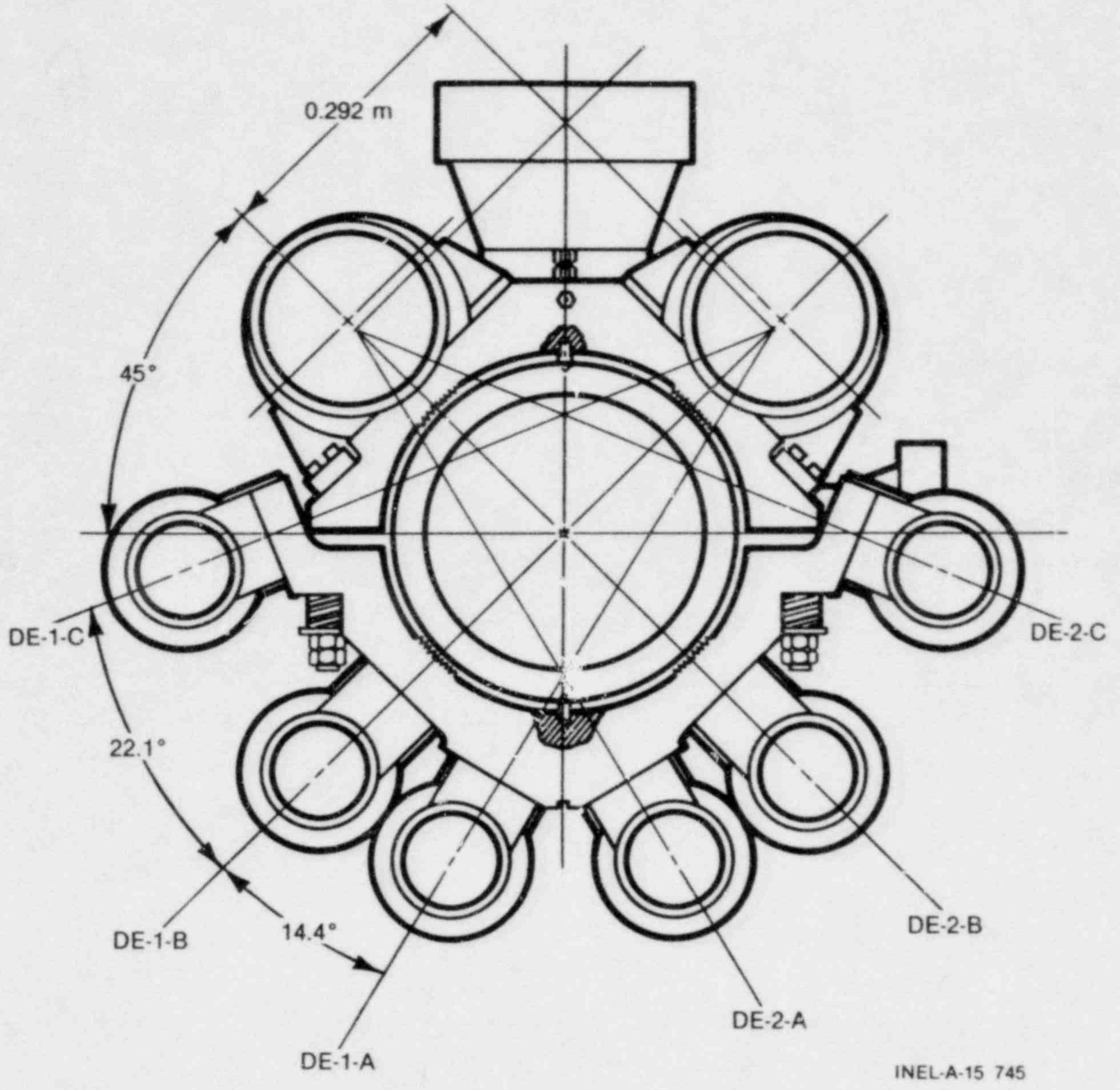

Figure 2

Schematic of transient test spool piece

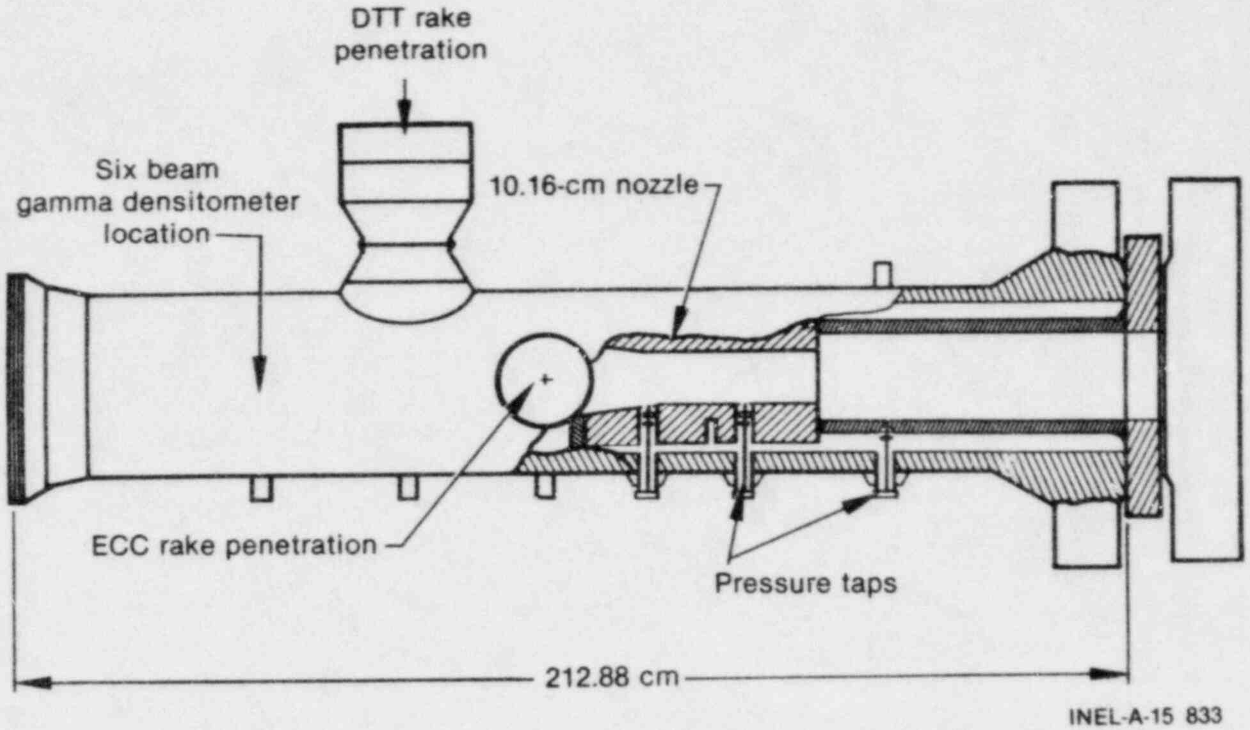

Figure 3

Algorithm correlation for average density

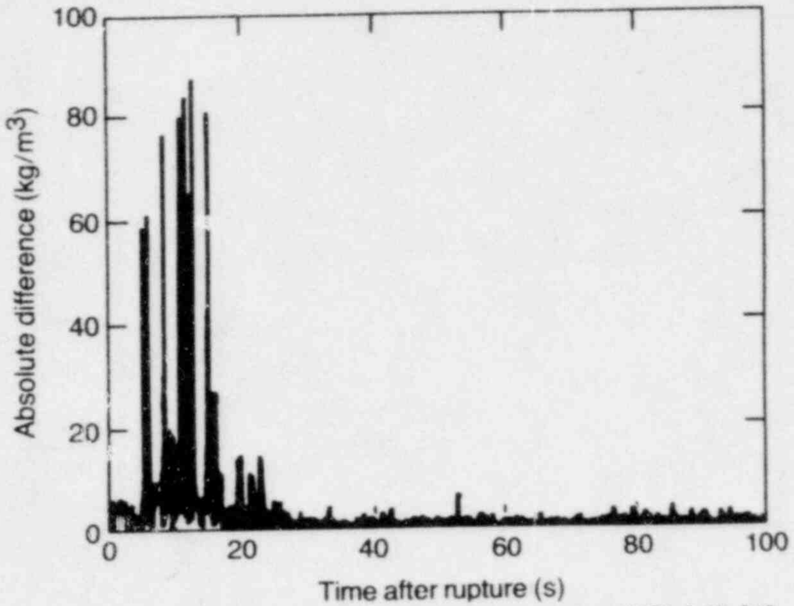

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Figure 4

Absolute difference between six beam and DE-1 (Test IA1)

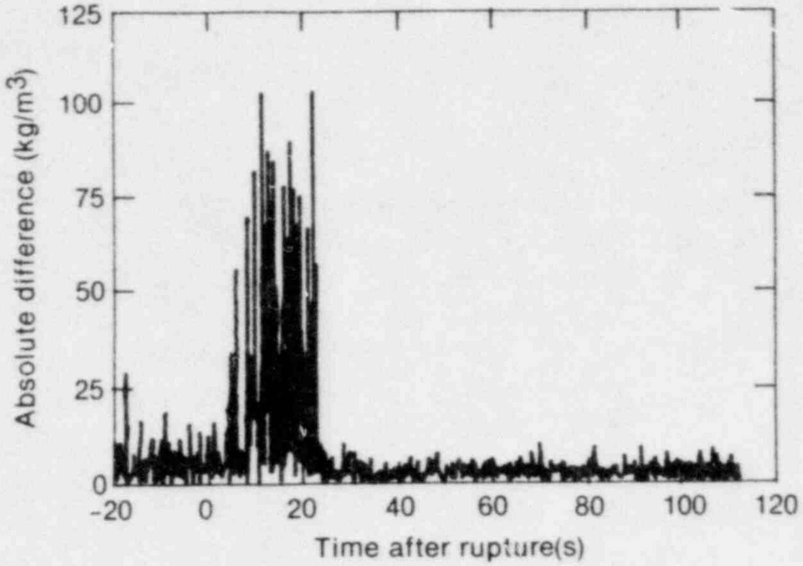

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Figure 5

Absolute difference between six beam and DE-2 (Test IA1)

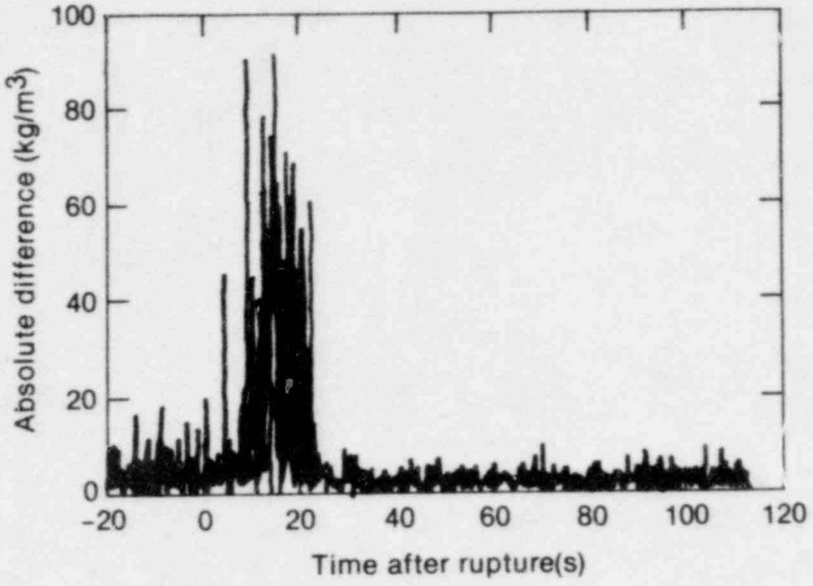

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Figure 6

Average density from six beam densitometer (Test IA1)

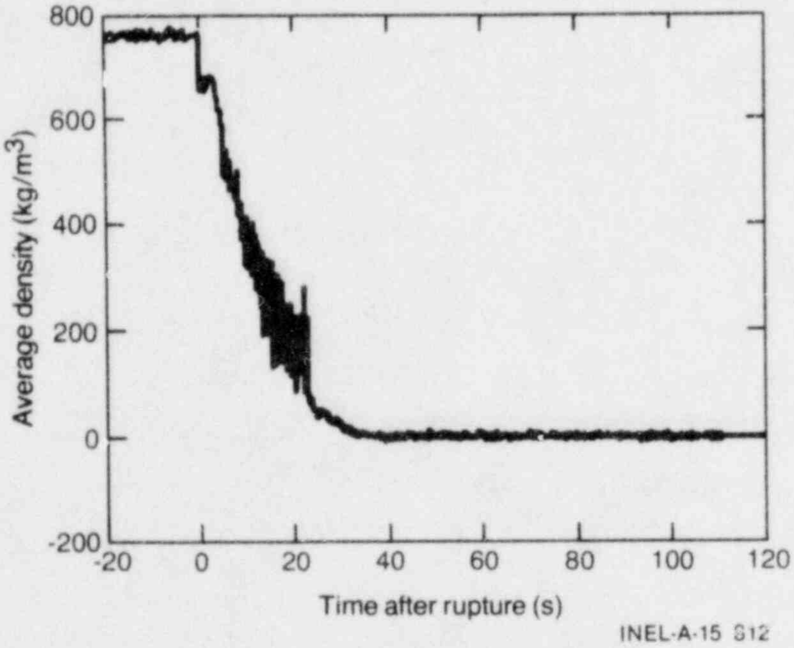

Figure 7

Density profile from six beam densitometer (Test IIIA1)

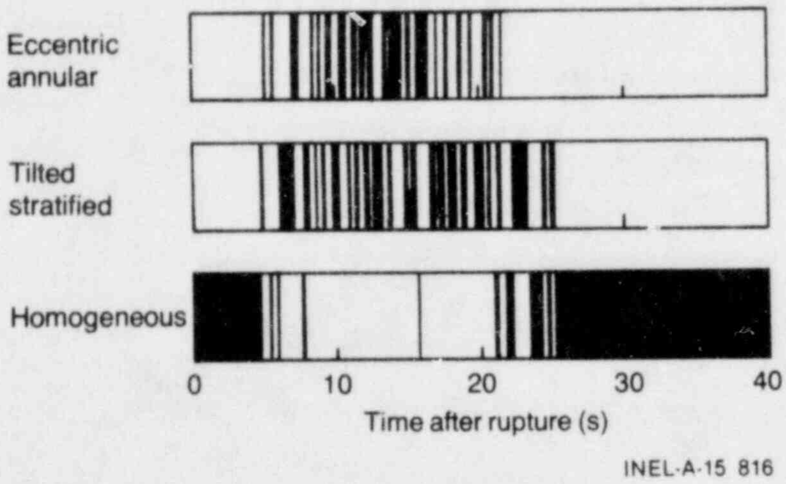

Figure 8

Density profile from DE-1 (Test IIIA1)

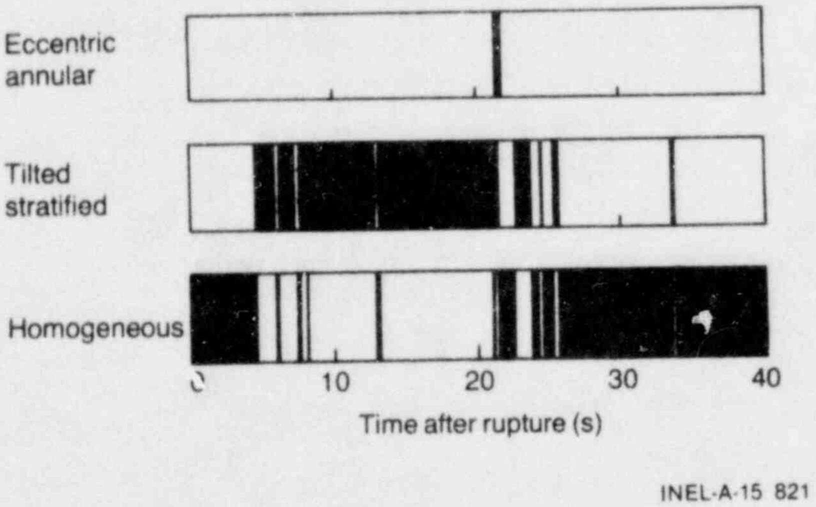

Figure 9

Density profile from DE-2 (Test IIIA1)

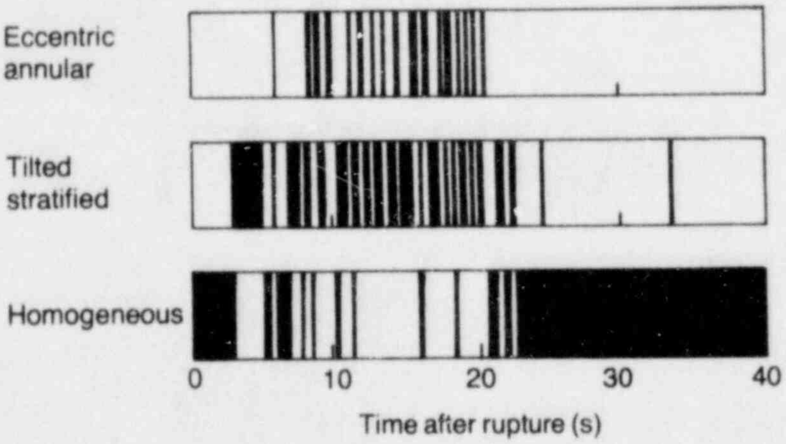

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Figure 10

Density profile from six beam densitometer (Test IIB1)

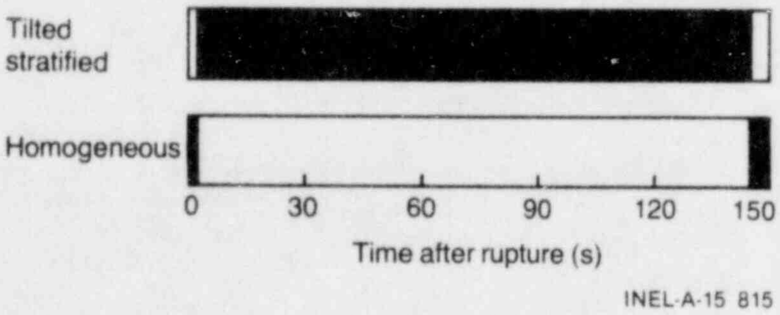

Figure 11

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Calculated tilt angle - six beam densitometer (Test IIB1)

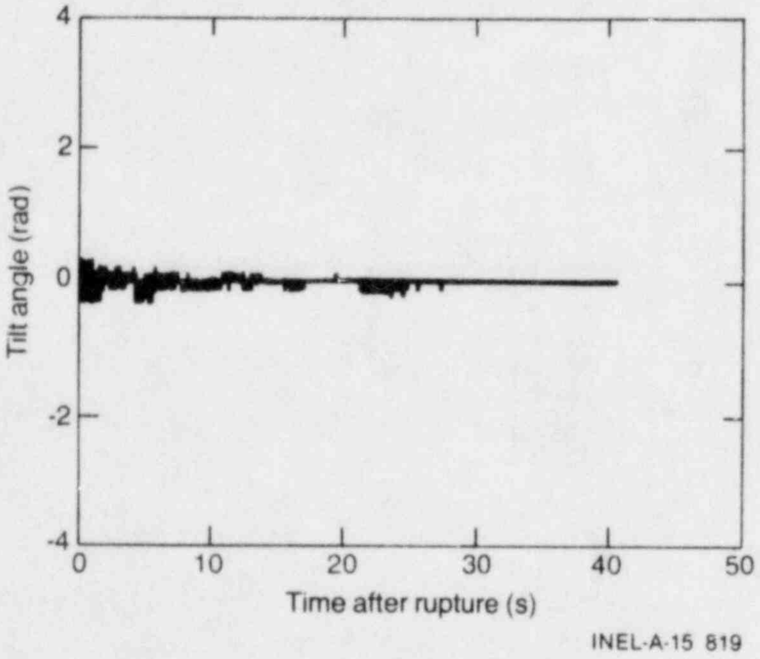

Figure 12

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Calculated tilt angle - six beam densitometer (Test IA1)

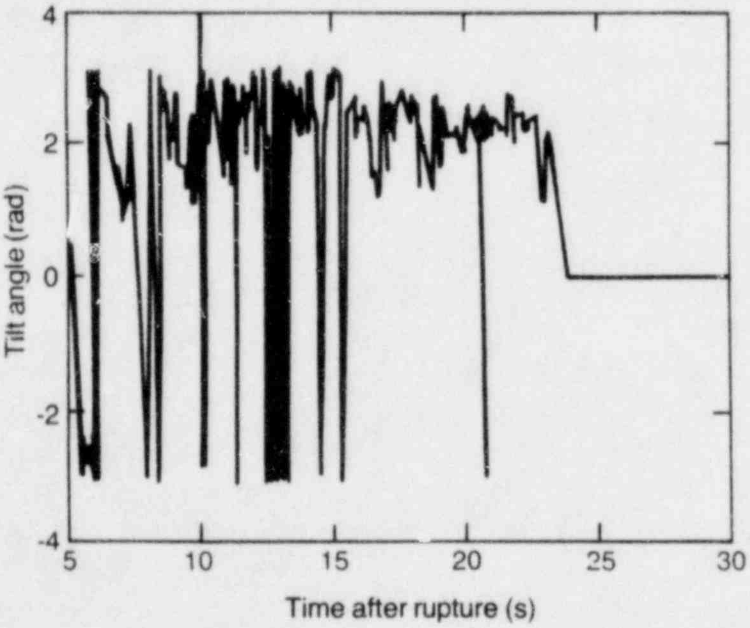

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Figure 13

Calculated tilt angle - DE-1 (Test IA1)

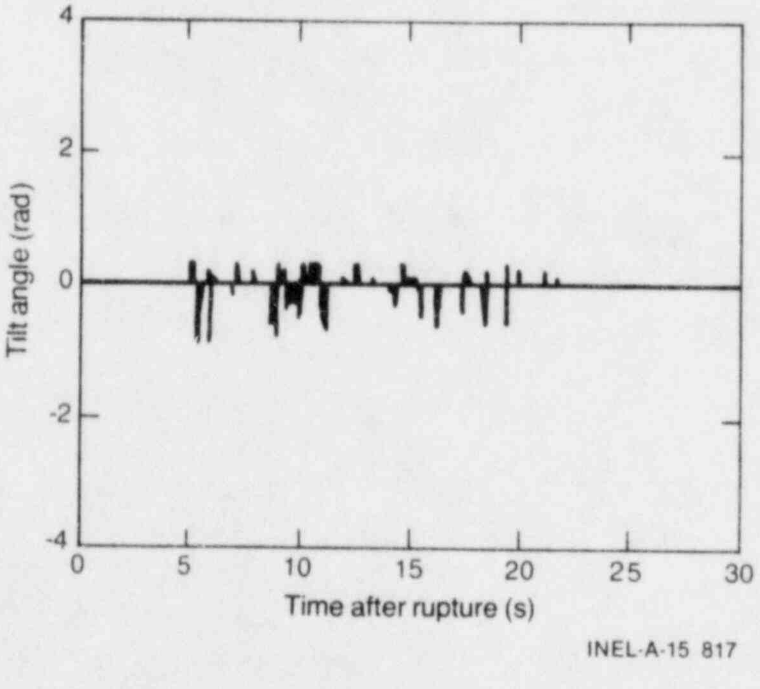

Figure 14

Calculated tilt angle - DE-2 (Test IA1)

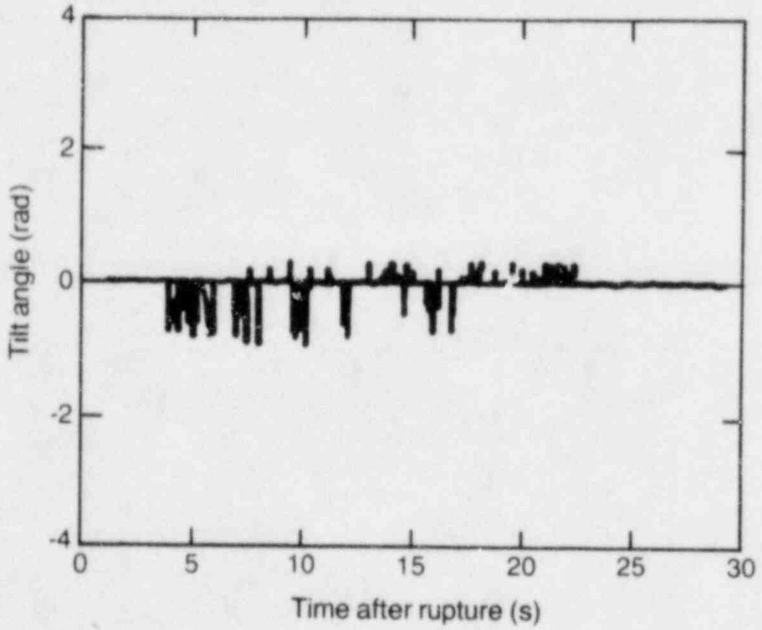

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Figure 15

TABLE I. TRANSIENT FLOW CALIBRATION FACILITY

TEST MATRIX

Test Description	Test Id	SPOOL ORIENT	PIPE GEOMETRY	NOZZLE	PRIMARY FLOW INSTRUMENT	ORIFICE DIAMETER
- Broken Loop Cold Leg	IA1	0°	Elbow	Yes	DTT	6"
- Broken Loop Cold Leg	IA2	0°	Elbow	Yes	Pitot	6"
- Broken Loop Hot Leg	IIA1	0°	Elbow	Yes	DTT	2"
- Broken Loop Hot Leg	IIA2	0°	Elbow	Yes	Pitot	2"
- Intact Loop Cold Leg	IIIA1	90°	Elbow	No	DTT	4"
- Intact Loop Hot Leg	IVA1	90°	Elbow	No	DTT (Reversed)	2"
- Broken Loop Cold Leg	IB1	0°	Straight	Yes	DTT	6"
- Broken Loop Hot Leg	IIB1	0°	Straight	Yes	DTT	2"
- Broken Loop Hot Leg	IIB2	0°	Straight	Yes	Pitot	2"