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Idaho National Engineering Laboratory

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Abstract

For many experiments which investigate the Loss-of-Coolant Accident (LOCA) in nuclear reactors, proper measurement of the two-phase mass flow rate is of great importance. This report presents the experimental description and the data of experiments designed to understand the behaviour of a free field drag disc turbine transducer (DTT) and a three beam gamma densitometer in steady-state horizontal steam-water and air-water flow. The pressure was varied between 2 and 75 bars, the experiments were made at a mass flow rate and void fraction range where various quite separated flow regimes occurred. Two different test sections with 103 mm ID (5" pipe) and 66 mm ID (3" pipe) were used.
Information on flow regime and phase distribution in the cross section was obtained with local impedance probes, measurements of the axial distribution of phase velocities in the test section piping were made with the radiotracer technique. These techniques are of great help for the physical interpretation of the single instrument readings. The results of detailed data analyses are given in another report.

Zusammenfassung

Test der EG&G-Zweiphasenmassenstrom-Instrumentierung im Kernforschungszentrum Karlsruhe

Analysebericht Nr. 1: Ergebnisse der Tests des LOFT-DTT-und eines LOFT-Gamma-Densitometers

In vielen Experimenten zum Kühlmittelverlustunfall von Kernreaktoren ist die genaue Messung des zweiphasigen Massenstromes von großer Bedeutung. Dieser Bericht enthält eine Beschreibung der Instrumentierung und die Daten von Experimenten zur Untersuchung des Verhaltens eines lokal messenden Drag Disc-Turbine-Transducers (DTT) und eines Dreistrahl-Gamma-Densitometers in stationärer, horizontaler Dampf-Wasser sowie Luft-Wasser-Strömung. Der Druck wurde variiert zwischen 2 und 75 bar, die Experimente wurden in einem Massenstrom- und Dampfvolumenanteils-Bereich durchgeführt, bei denen verschiedene, recht stark separierte Strömungsformen vorhanden waren. Zwei verschiedene Teststrecken mit Innendurchmessern von 103 mm (5" Teststrecke) sowie 66 mm (3" Teststrecke) wurden verwendet.
Lokale Impedanz-Sonden dienten zur Bestimmung der Strömungsform sowie zur Messung der Phasenverteilung im Strömungsquerschnitt, die Verteilung der Phasengeschwindigkeiten längs der Rohrachse wurde mit Radiotracer-Verfahren gemessen. Diese Meßtechniken sind sehr hilfreich für die physikalische Interpretation der einzelnen Meßsignale. Die Ergebnisse einer detaillierten Datenanalyse sind in einem weiteren Bericht enthalten.

ACKNOWLEDGEMENT

The authors wish to acknowledge the loop operators L. Pawlak and E. Wanner, the investigators who obtained the data D.J. Barnum, J. Colson, R.L. Crumley, A. Demski, V.W. Hansen, H.J. Helbert, R.D. Meininger and A. Stephens and R.L. Hoskinson who contributed in compiling and reviewing the experimental data.

Last but not least, the support given to this project by the US NRC and the German BMFT and the coordination by J.P. Hosemann from the KfK Project Nuclear Safety is gratefully acknowledged.

Nomenclature

A	pipe cross-sectional area
D	pipe diameter
G	mass flux
H	height of water
h	enthalpy
$\dot{m}$	mass flow rate
p	pressure
p_3, p_5	percent of DTT height covered by liquid for the three-inch, five inch pipe
S	slip
s	entropy
T	temperature
V	velocity
V_s	superficial velocity
x	quality
α	void fraction
ρ	density
ρV^2	momentum flux
Θ	angle for water level determination

Subscripts

A	A-Beam of LOFT-Gamma Densitometer
B	B-Beam of LOFT-Gamma Densitometer
C	c-Beam of LOFT-Gamma Densitometer
DD	Drag Disk
H	homogeneous flow
l	liquid
R	Radiotracer Technique
ref	reference instrumentation
T	Turbine Meter
t	test section
γ	LOFT Gamma Densitometer

1. INTRODUCTION

As part of the United States Nuclear Regulatory Commission (NRC) sponsored research efforts in pressurized water reactor safety, EG&G Idaho, Inc. is conducting loss-of-coolant experiments (LOCE) in the Loss-of-Fluid Test (LOFT) facility at the Idaho National Engineering Laboratory (INEL). One of the basic variables measured during the LOFT-LOCE is the two-phase mass flow rate. The flow measurement transducers used in LOFT were designed to measure the mass flow rates at discrete points in a transient two-phase flow field (free field measurement configuration) and were calibrated in steady state single phase water in full flow configuration. The single-phase full-flow calibrations are used with two-phase free field measurement models to compute two-phase mass flow rates.

In LOFT, two-phase flow is measured with an array of three drag disk turbine transducers (DTTs) and a three-beam gamma densitometer (GD). The DTT is a combination of a drag disk, a turbine and a thermocouple in a single unit. The drag disk measures momentum flux, the turbine measures velocity and the gamma densitometer measures fluid density. The mass flow rates will than be evaluated from the combined measurements of DTT and densitometer by using a measurement model. A proper measurement model should correlate the transducer outputs to the pipe flow rates via the physical behavior of the transducer. the local flow quantities measured by the transducers and the overall flow field.

To evaluate and understand the DTT behavior in a known two-phase flow field, a LOFT test program consisting of two-phase calibrations in two different test sections, one a five-inch pipe, and the other a three-inch pipe, was conducted in Germany during 1977. The instruments intended for calibration were the LOFT production Drag Disc Turbine Transducer (DTT) and a three-beam gamma densitometer. The DTT is representative of the type used in the LOFT L1 (nonnuclear) series. Both test sections provide free field calibrations. That is, the DTT is smaller than the inside diameter of both test sections. The gamma densitometer is a three-beam unit representative of the configuration used in LOFT, but modified to fit on a smaller pipe.

All testing was done in the Two-Phase Flow Instrumentation Test Facility of the Institut für Reaktorbauelemente (IRB) of the Kernforschungszentrum Karlsruhe (KfK) West Germany. The major objectives of this work are:

1. Provide calibration data for the LOFT drag disk turbine transducer (DTT) and the LOFT gamma densitometer for future instrument improvement.

2. Determine if air-water calibration data can be used to predict steam-water calibration.
3. Provide data for future analysis development.
4. Correlate LOFT gamma densitometer data to flow regime determination.
5. Determine the effect of pipe size, pressure, and vapor fraction on mass flow rate determination.
6. Determine any other parametric effects upon the calibration.
7. Determine if there is any method of calculating flow rates better than the current method used by LOFT or if one method currently used is better than others.
8. Determine the accuracy of the LOFT mass flow determination.

The work reported on in this volume was conducted to supply horizontal performance calibration data for LOFT instruments used to measure two-phase mass flow in pipes.

The instruments tested in this phase of the experiments included a DTT of the plenum type used primarily in the L1 series and a three-beam gamma densitometer of the LOFT type which was built to fit on three or five inch schedule 160 pipe.

This report presents the experimental description and the data obtained. Also included are brief sections on data obtained with the Radiotracer Measurement System, the Transversing Impedance Probe and the Scanning Densitometer Instruments. This report is the summarized version of the report /1/ which additionally contains operation log and setup sheets, IRB computer listings of reference values, instrument calibration data, EG&G strip chart recordings (voltages), EG&G time averaged digitized analog data (voltages), EG&G reference densitometer data (scanning densitometer) and more advanced instruments results.

A detailed analysis of data is given in another report /2/.

2. TEST PROGRAM SUMMARY, TEST LOOP DESCRIPTION, INSTRUMENTATION AND DATA ACQUISITION

To achieve the test objectives within the facility capabilities, tests were specified by the following independent variables:

1. The size of the test section relative to that of the DTT. The flow area ratio of the 5-inch test section to the DTT is 4.24 and that of the

3-inch test section 1.77.

2. The superficial gas velocity
3. The superficial liquid velocity
4. The test section pressure.

Six test series were conducted; four in the five-inch pipe and two in the three-inch pipe. In the five-inch pipe, an air-water series at a nominal pressure of 2 bars and three steam-water series at nominal pressures of 4 bar, 40 bar, and 70 bar, respectively, were conducted. In the three-inch pipe, two steam-water series were run at 40 bar and 70 bar nominal pressures. The reference mass flow rates were measured with orifices in single phase flow before mixing. In some experiments, radiotracer measurements were available which were able to measure the velocity of each phase, and, in combination with the reference mass flow data, are capable of providing an estimate of the void fraction. A vertically traversing impedance probe was used to provide void fraction distribution data on the five-inch pipe and a traversing reference gamma densitometer was used for this information on the three-inch pipe.

2.1 Test Program Summary

The five-inch test section was installed and initial instrument calibration was accomplished on October 18, 1977. The final day of testing was November 4, 1977. In addition to the single-phase calibrations the following nominal test points were run during this period: superficial gas velocity, V_{sg}=1; 5; 10 m/s; superficial liquid velocity, V_{sl}=0.05; 0.1; 0.5 m/s; test section pressure = 2 bar for air water, 4; 40; 70 bar for steam-water; the maximum mass flux was 600 kg/m^{2}s.

The three-inch test section was installed and tests were run from November 9 through November 18, 1977. The turbine stuck during the first test point on November 17. A second DTT was installed on November 18, and the new turbine again stuck when the DTT was operated at high velocity (12 m/s) in slightly superheated steam. Testing was continued that day (November 18) with only the drag disk and densitometer operable since radioactive tracer information was also being obtained. The final day of loop utilization was Monday, November 21, 1977, when the replaced drag disk was calibrated.

During the three-inch pipe testing, radioactive tracer data was taken on November 10, 15 and 18, 1977. A part of the desired steam-water points in the low pressure (4 bar) region were not performed due to the unfavorable loop operating range. In addition to the single phase calibrations, the nominal test points were conducted at V_{sg} between 1 and 10 m/s, V_{sl} between 0.5 and 1.7 m/s and at pressures of 40 and 75 bar. The maximum mass flux was 1500 kg/m^{2}s. Most of the tests were at 1000 kg/m^{2}s.

2.2 Test Loop Description

A schematic of the facility is shown in Figure 2.1 and Figure 2.2. The facility is capable of either air water (low pressure and temperature) operation or steam-water (high pressure, high temperature) operation. Different supply lines are used for the air-water system but the same mixer and test sections (described later) are used for both. The air-water system is supplied by a high volume water pump and four air compressors. After the air-water mixture goes through the test section, the individual phases are seperated with the air being exhausted to the atmosphere and the liquid being recirculated. The steam-water mixture is supplied by two boilers. Two methods of operation are available. In the first, termed mixing runs, either boiler may be used to supply the steam. In the second method, either one or both boilers may be used to supply high pressure saturated liquidwhich is then flashed to a steam-water mixture. The mass flow rate through the test section can be controlled by the pump speed and air compressor control system in the air-water operation and by the boilers in the steam-water operation. Additional control is achieved in the steam-water operation by use of the boiler bypass. Details of the facility is given in /3/.

For air-water flow testing, the published maximum loop capability is 30 kg/s water and 1.0 kg/s air at a pressure of 4 bar. Operating pressure can be increased to 10 bar at reduced maximum flow. For steam-water testing, two steam generators are used. The lower limits of flow are approximately 0.164 kg/s for water and 0.024 kg/s for steam at 25 bar pressure. At lower pressures and flows, accuracy of flow measurement decreases. With both steam generators producing steam, the upper flow limit is 3.75 kg/s. With both steam generators producing hot water, the upper flow limit is 5.5 kg/s. Throttling of the hot liquid alone can be used to produce qualities up to 20 %. The flow rate capabilities versus quality are shown in Figure 2.3.

The two-phase loop consists of air-water and steam-water supply sections, mixing section and test sections. The reference flow measurement orifices are installed in the supply sections before the phase mixing.

Both the air input section and the water input section of the air-water loop have three orifices with different measuring ranges. Both "NW 100" orifices remain fixed, but the "NW 50 " orifices are interchanged.

The steam water-loop uses two boilers, the Henschel Boiler and the Benson Boiler. For mixing runs, either of two combinations may be used: NW 65 (steam line from Henschel) and NW 50 (water line from Benson) or NW 100 (steam line from Benson) and NW 32 (water line from Henschel). For throttling runs, the water lines from both boilers, NW 50 and NW 32, are combined.

Figure 2.4 shows the mixing section. Mixing of the phases is accomplished by means of a perforated tube. This tube has a wall thickness of 3 mm and contains about 600 drilled holes (diameter 2mm) which are inclined slightly in the direction of the flow. For some tests, these holes are partly closed by a sleeve to make sure that even at low volumetric flows the pressure drop across the holes was big enough to ensure stable behaviour of the mixing chamber. There are two methods of operating the mixing chambers. In the first method, steam flows through the center pipe and water is injected from the outher annulus into steam. In the second method, the mixing chamber is revolved by 180^{o} so that water flows through the center pipe and steam is injected into the water from the outher annulus. The first method of operation may be used with other inserts for special purposes. For example, another insert is available to help promote a well developed annular mist flow in the test section. For the testing reported here, the second method of operation was used where steam is dispersed into water. This method of operation allows a closer approach to steam-water thermal equilibrium at the mixing chamber outlet.

There are two mixing chamber inserts available with outlet diameters of 50 or 80 mm. Between the mixing chamber outlet and the test section entrance, a connecting pipe (length 1.36 m; diameter 50 or 80 mm) was positioned which contained the junction to the bypass. In all the tests reported on in this volume, the 50 mm insert with the 50 mm connecting pipe was used.

2.3 Test Sections

The loop test sections are 6.50 meters in length including adapters. For the five inch test section, 0.65 m was used to diverge from the 50 mm I.D. piping to the five inch (103.2 mm I.D.) test pipe and 0.65 m to converge back to the 50 mm loop piping. A schematic of the five inch test section is shown in Figure 2.5. The first two sections consist of two adapters, one from 50 mm pipe to three inch pipe, and the other from three inch to five inch pipe. The third section is 384 cm long and contains the radiotracer injectors and detectors and the LOFT three beam gamma densitometer. The next pipe section is 69 cm long and houses the traversing impedance probe. The fifth section contains the DTT. The DTT is mounted in a spool piece which has an insert which has the same internal diameter as the rest of the five inch pipe. The gamma densitometer is 125.3 cm upstream of the DTT. It could not be mounted closer because of the interference with the traversing impedance probe. The entrance length from the adapters up to the DTT is 453 cm, corresponding to 43.9 diameters. The remaining three sections consist of a 50.8 cm length of five inch pipe and two adapters which reduce to the 50 mm outlet pipe. The inlet and outlet adapters were made so that the bottom of the pipes were in line to prevent damming. The entire test section (as well as the rest of the loop) was well insulated whereever possible to minimize heat loss. Those parts of the test section which were not insulated were at the four radioactive tracer detectors, the LOFT gamma densitometer, and the top of the pipe at the traversing impedance probe.

The three inch test section is shown in Figure 2.6. The total length including adapters is 649 cm. The 50 mm pipe to three inch pipe adapters are the same as those used in the five inch test section. The second and third pipe sections contain the radiotracer injectors and detectors and two fixed impedance probes. The fourth pipe section contains two gamma densitometers. The first is the LOFT three beam system. Because of support interference, the densitometer was mounted upside down on the three inch test section. This is discussed later in the instrumentation section. The second is a scanning reference densitometer which was intended to supply the same density distribution information on the three inch pipe that the traversing impedance probe supplied on the five inch pipe. The next three sections house the DTT and consist of the same three inch to five inch adapters used on the five inch pipe and the DTT spool piece. A pipe insert has been added which keeps the internal diameter through these test sections the same as the rest of the three inch pipe. A radiotracer detector is placed on the last section of three inch pipe. Another is placed on the 50 mm pipe which should give further information on change in void fraction through a contraction.

Figure 2.7 shows a photograph of a part of the test loop containing the 3" test section.

2.4 Experimental Instruments

The advanced instruments which were used in these experiments were supplied by LOFT, Semiscale, Institut für Reaktor Bauelemente (IRB), and Laboratorium für Isotopentechnik (LIT). The advanced instruments supplied by LOFT, the drag disk turbine transducer (DTT) and the three beam gamma densitometer (γ), were being calibrated in these tests. The other advanced instruments were used as supplementary measurements of the two-phase flow in the test section.

Schematics of the DTT installed in the test spool for both the five inch and the three test sections are shown in Figure 2.8. The drag disk is installed upstream of the turbine for all of the tests reported here. The same test spool was used for both test sections. A sleeve was inserted in each installation so that no pipe diameter changes occurred in the test spool.

Most of the DTT data was taken by a DTT of the plenum type used primarily in the LOFT L1 test series. The diameter of the drag disc is 1.52 cm (0.6 in.) and that of the turbine 3.05 cm (1.2 in.). The drag disc is located approximately 3.56 cm (1.4 in.) upstream of the turbine. Both of the drag disc and turbine are housed in a 3.56 cm diameter housing and enclosed in the upstream and downstream by 0.56 cm square grids. The ridge of the grids is in approximately tapered rectangular shape (0.02 in. x 0.25 in.). The leading and tailing edges are of 0.18 mm in thickness. The drag disk (DD) force is measured by a linear variable differential transformer mechanically coupled to the drag disk. The turbine (T) rotation rate is measured by an induction coil pick-up which senses passage of the blade. Detail drawings of the DTT are shown in Figure 2.9.

The LOFT three-beam gamma densitometer beam orientations for the five-inch and three-inch test sections are shown in Figures 2.10 and 2.11, respectively. The methods of averaging the beams to obtain an average density are also indicated in these figures. Both a beam length weighting method and a vertical beam span weighting method are used. Both methods usually produce similar averages. The beam orientation desired includes one beam through the bottom of the pipe, one beam through the center, and one beam near the top of the pipe which would measure the water film thickness in annular flow. The beam size is approximately 1.27 cm in diameter. The source is located above the pipe in LOFT installations. It was necessary to mount the source below the three-inch test section because of interference between the detectors and the support structure.

To detect the flow regimes impedance probes supplied by IRB were used. Two fixed probes were installed upstream of the gamma densitometer on the three-inch pipe test section. One of these probes was installed 10 mm from the top of the pipe flow channel and the other 15 mm from the bottom of the pipe flow channel. In the five inch-test section a traversing impedance probe was used (shown in Figure 2.12) which additionally enabled measurements of the vertical void distribution. Details of this equipment are described in Appendix 1.

The scanning reference densitometer supplied by Semiscale was used on some of the experiments in the three-inch section to supply void fraction information.

This system uses a single source and a single detector (also shown in Figure 2.13). The source detector combination rates about a fixed point at the source location. In actual operation, diskrete readings are taken at 68 different radial positions to cover the pipe cross section. Details of this equipment are described in Appendix 2.

The radioactive tracer injection technique which was used to measure the individual vapor and liquid velocities was supplied by the LIT. Figure 2.14 shows the radioisotope injection ports and some radiotracer detectors to detect the passage of the radioisotope clouds. Details of this technique are described in Appendix 3.

2.5 Data Acquisition

All reference values such as pressures and temperatures in the test section and upstream of the single phase orifices, and the pressure differences of the orifices are recorded analog by two H.u.B. (Hartmann und Brown) 12 point printers and digitally by the KFK PDP11/40 computer. The PDP11 also reports the calculated single-phase mass flow rates and the total flow, and the temperature differences between the single phase and the saturation temperature. The quality (χ), the homogeneous void fraction (α), and the superficial steam and water velocities are calculated for the condition of the test section.

The LOFT data aquisition system consisted of Bay Laboratories signal conditioners and amplifiers, Ampex FR 1300 analog tape recorders, and Honeywell Strip Chart Recorders as well as all the peripheral specialized signal conditioning and monitoring and calibration equipment required for data aquisition. The outputs of the Bay Lab amplifiers were also input to a Hewlett-Packard 2100 computer with data printed out on a type 33 teletype printer.

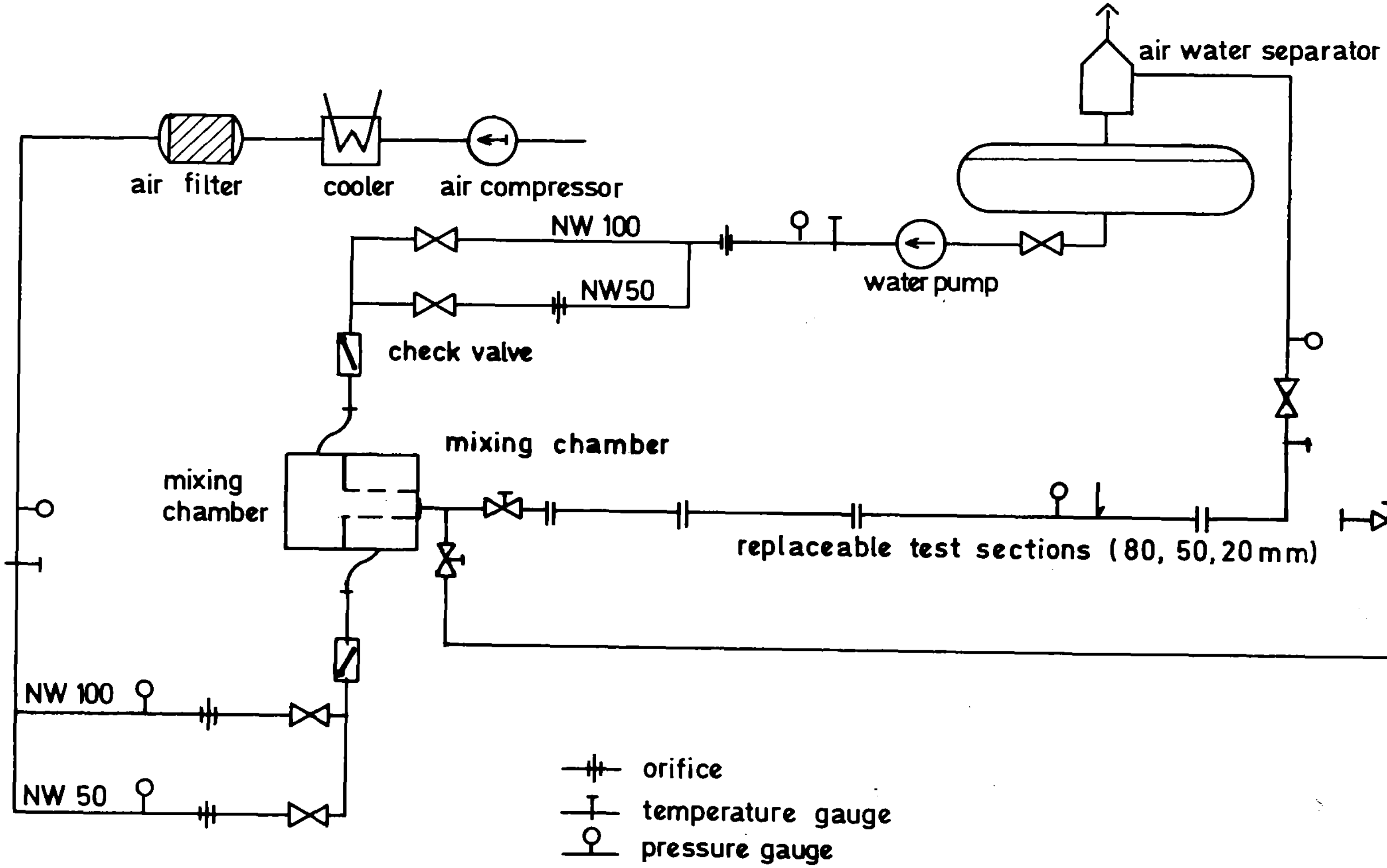

FIGURE 2.1: TWO-PHASE AIR-WATER LOOP

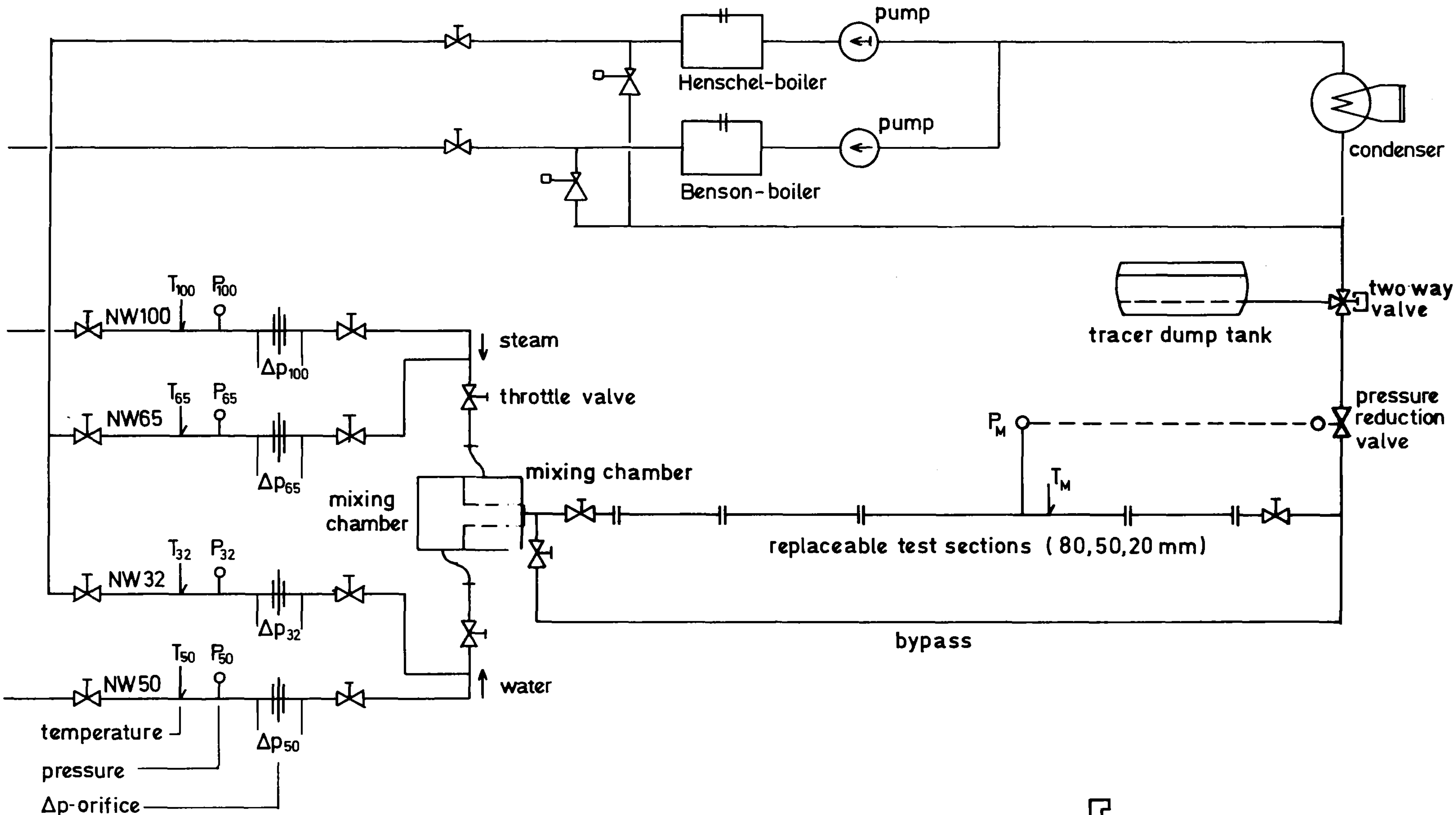

FIGURE 2.2 TWO-PHASE STEAM-WATER LOOP

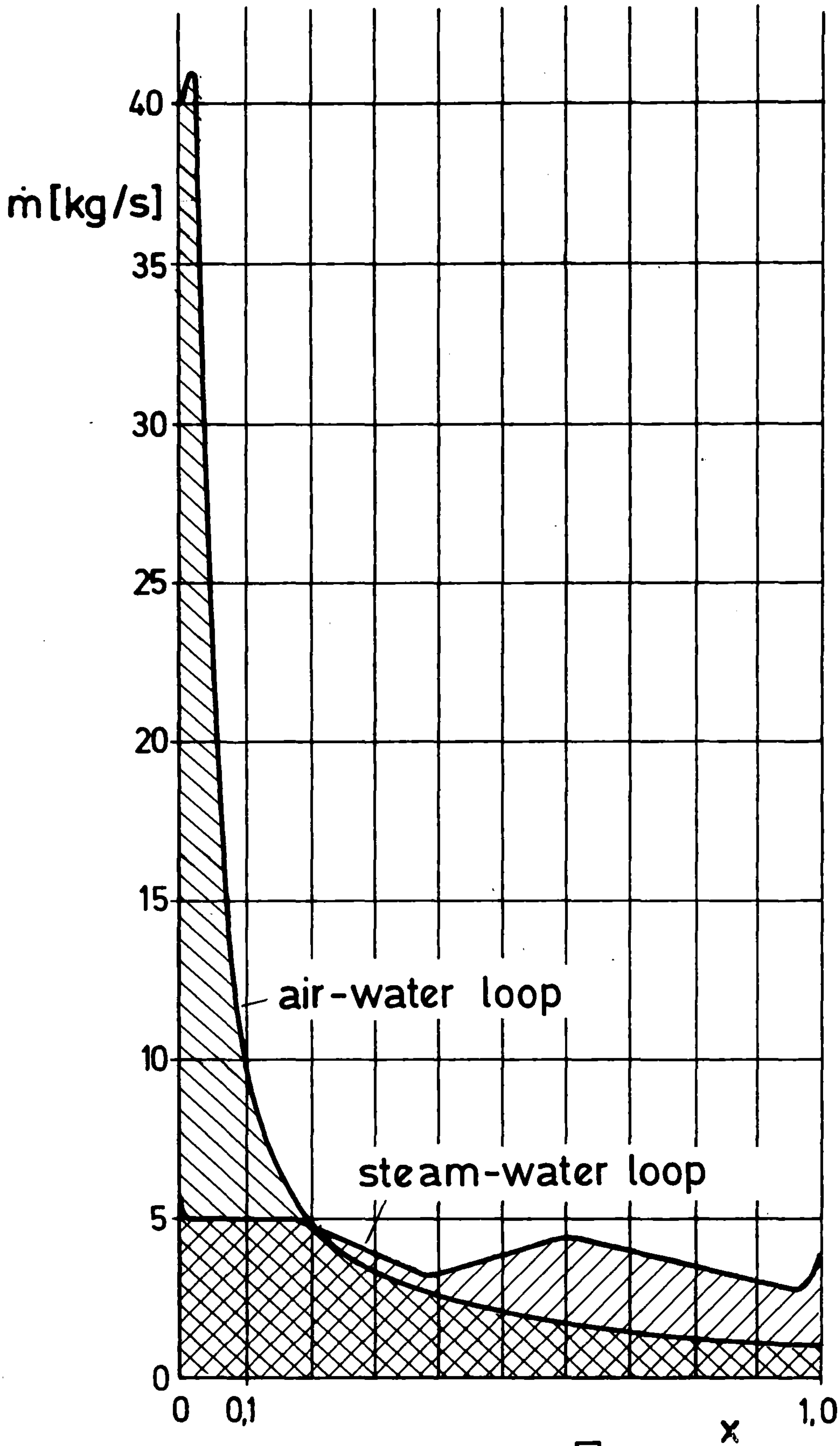

FIGURE 2.3 FLOW RATE CAPABILITIES

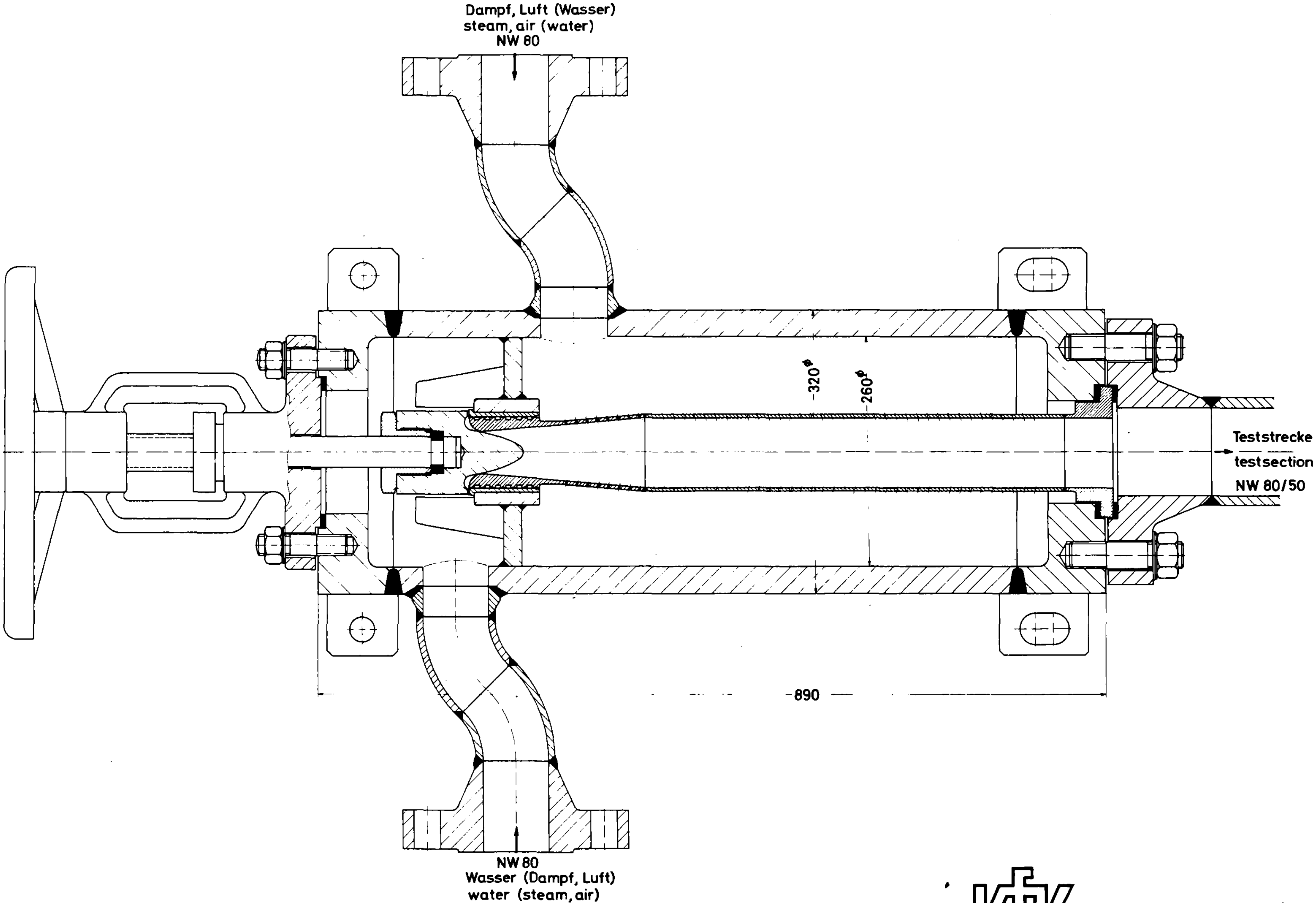

FIGURE 2.4: MIXING SECTION

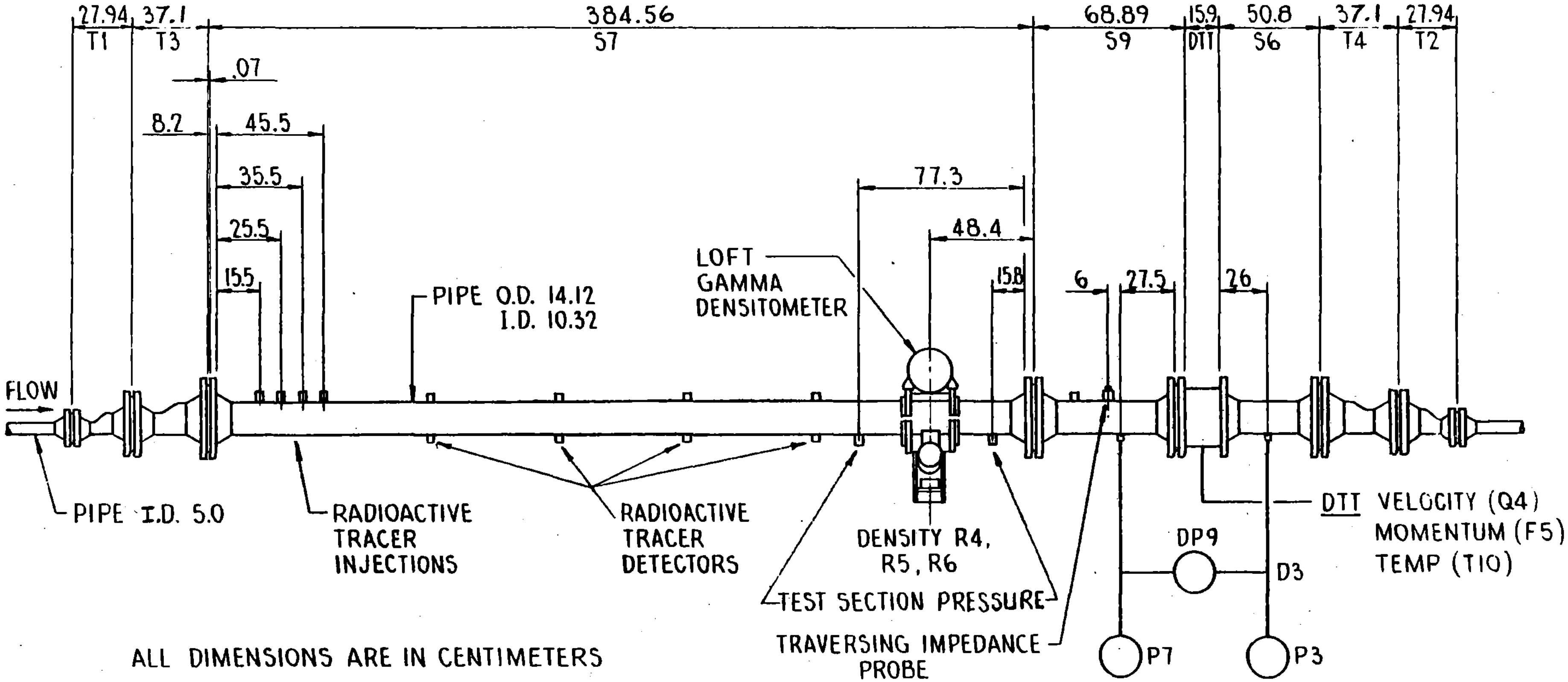

FIGURE 2.5: LOFT FIVE INCH TEST SECTION

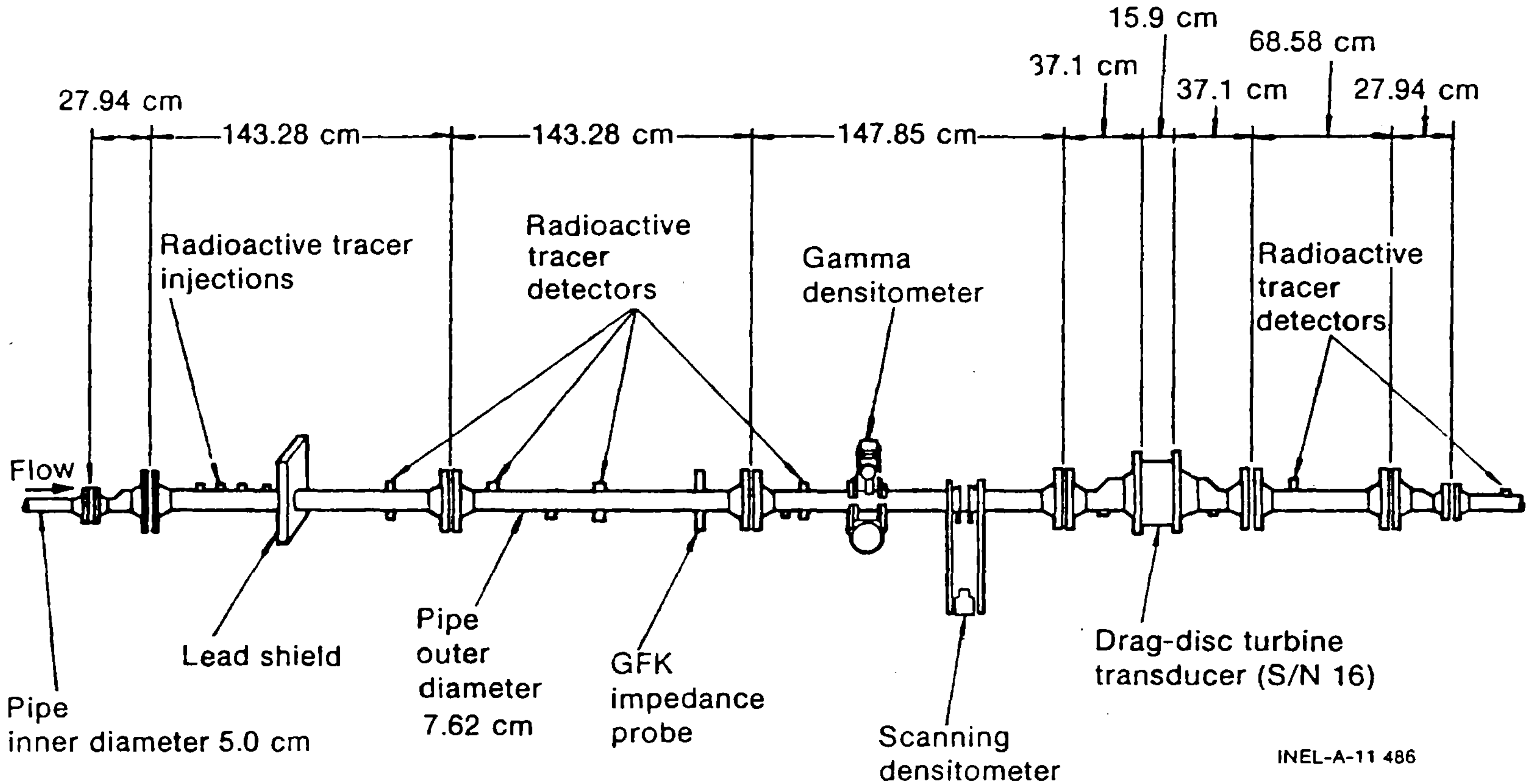

FIGURE 2.6: LOFT THREE INCH TEST SECTION

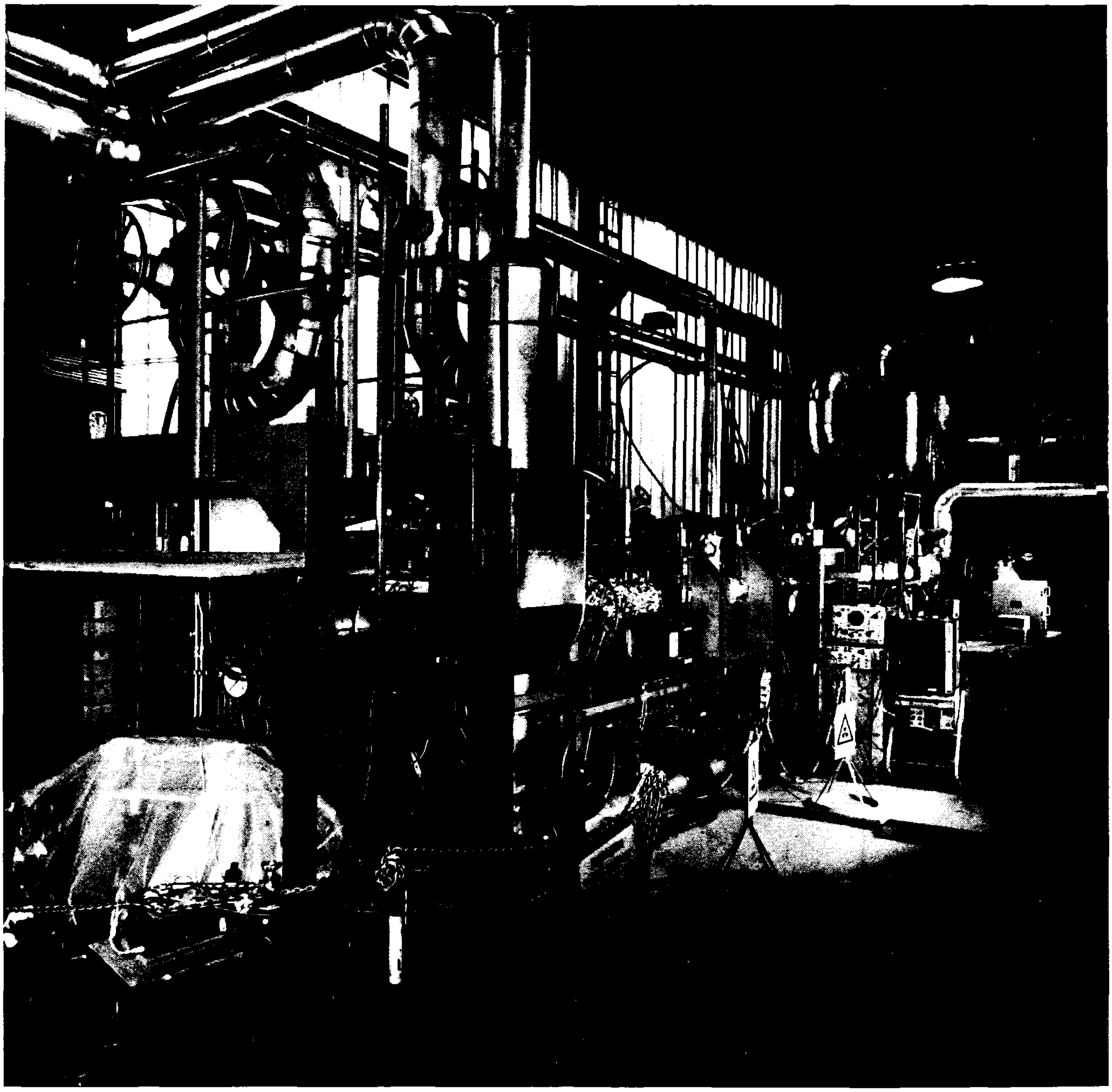

FIGURE 2.7: PHOTOGRAPH OF INSTRUMENTED TEST-SECTION

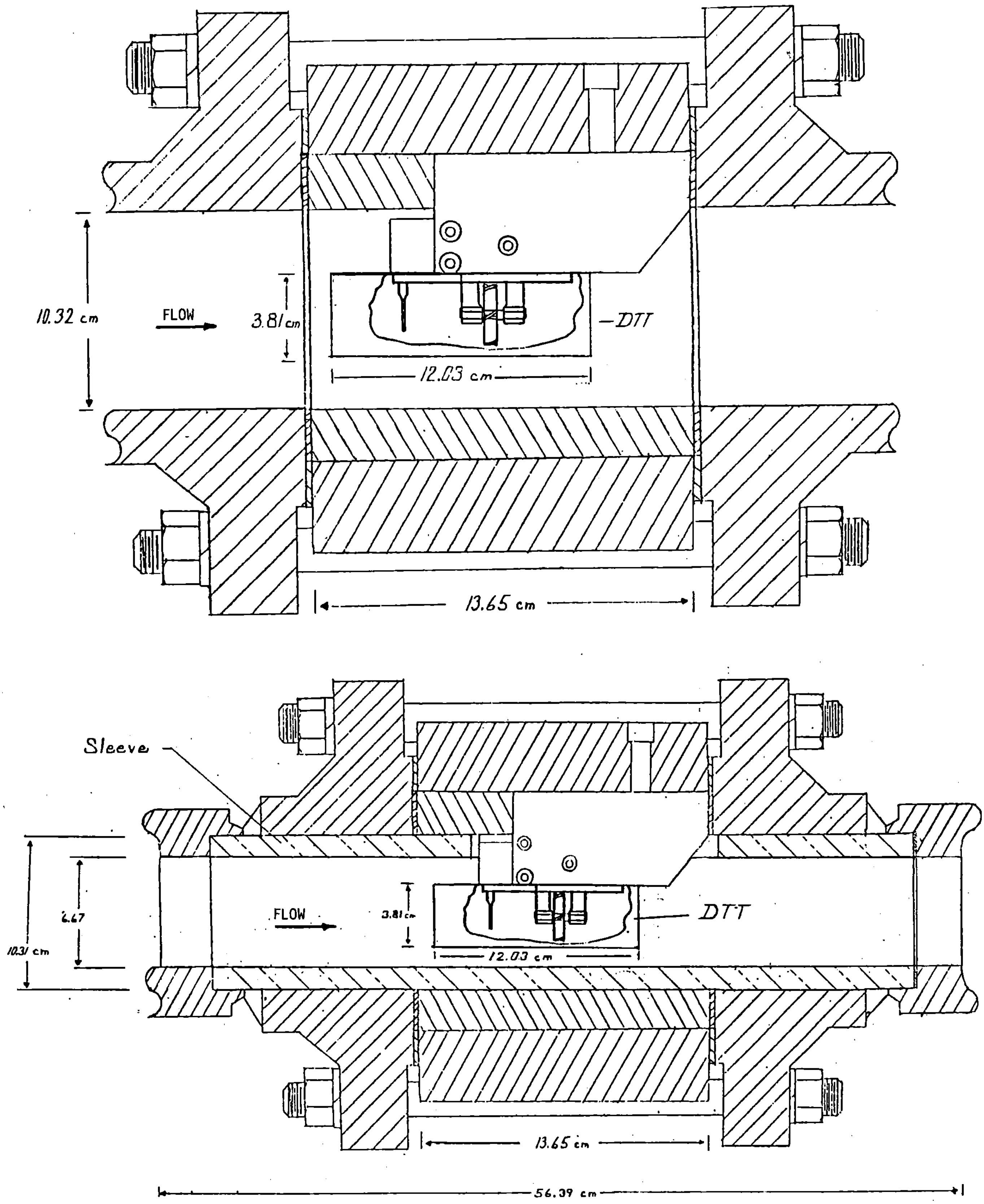

FIGURE 2.8: DTT IN FIVE AND THREE INCH PIPE

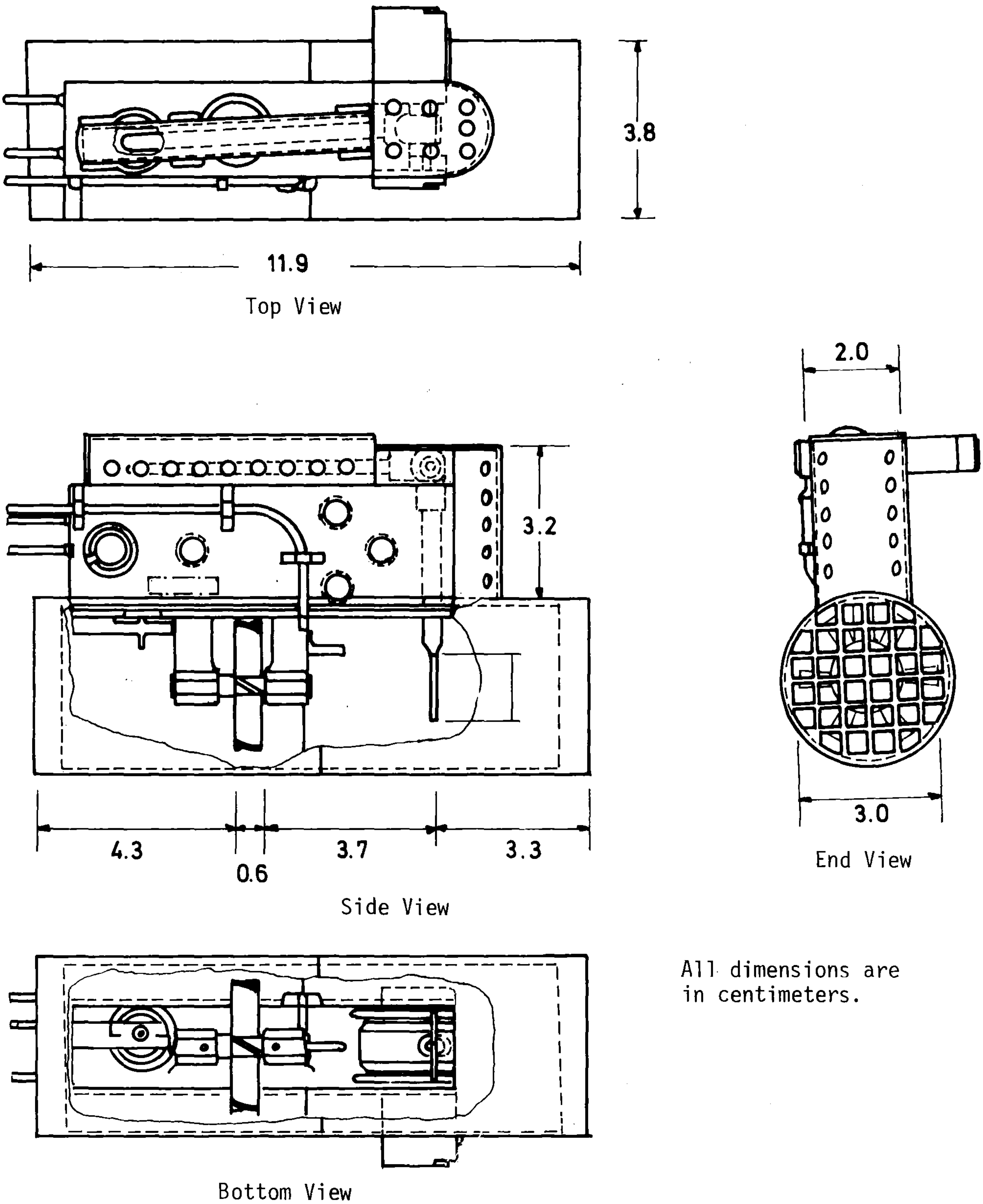

FIGURE 2.9: LOFT DRAG DISK, TURBINE FLOW METER ASSEMBLY

LOFT 3-Beam Densitometer

Pipe ID = 10.32cm
Pipe OD = 14.13cm

A Beam - Length = 8.75cm Vert. Span = 7.62cm

B Beam - Length - 10.236cm Vert. Span = 8.065cm

C Beam - Length - 6.553cm Vert. Span = 4.511cm

If $\rho_A > \rho_B > \rho_C$

Vertical $\bar{\rho} = .377\rho_A + .399\rho_B + .224\rho_C$

If not:

Length $\bar{\rho} = .343\rho_A + .401\rho_B + .257\rho_C$

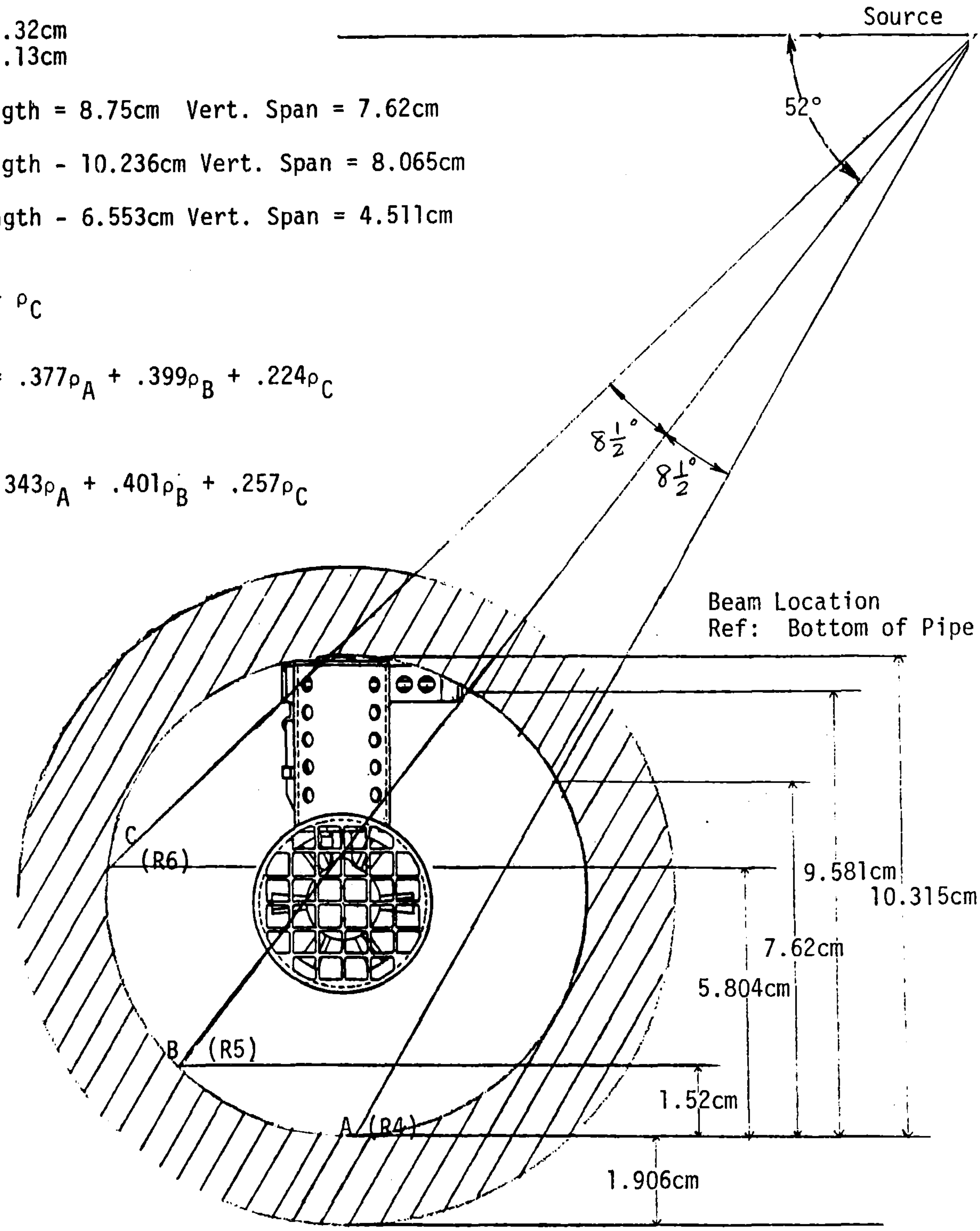

FIGURE 2.10: BEAM ORIENTATION ON THE FIVE INCH TEST SECTION

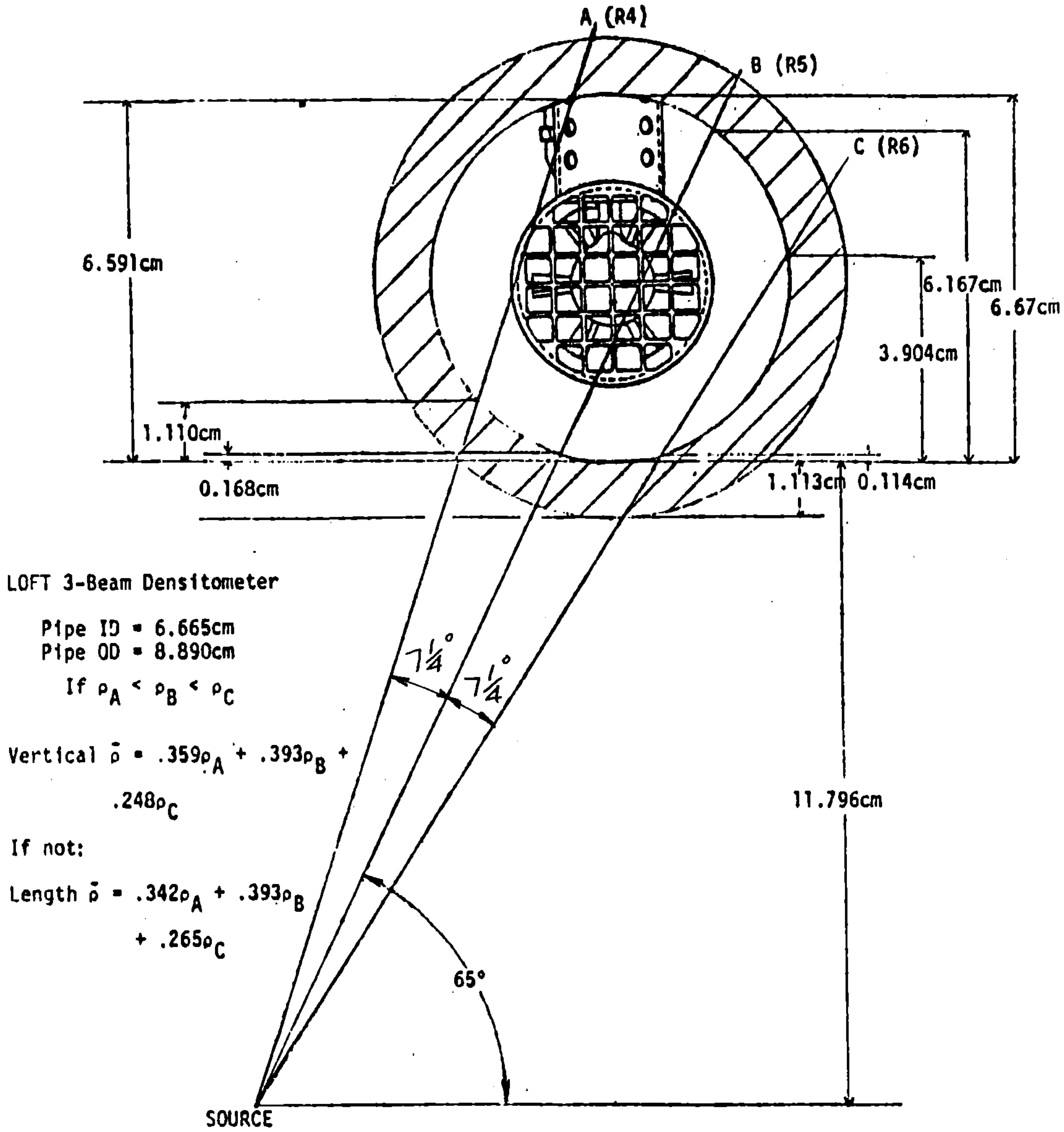

FIGURE 2.11: BEAM ORIENTATION ON THE THREE INCH TEST SECTION

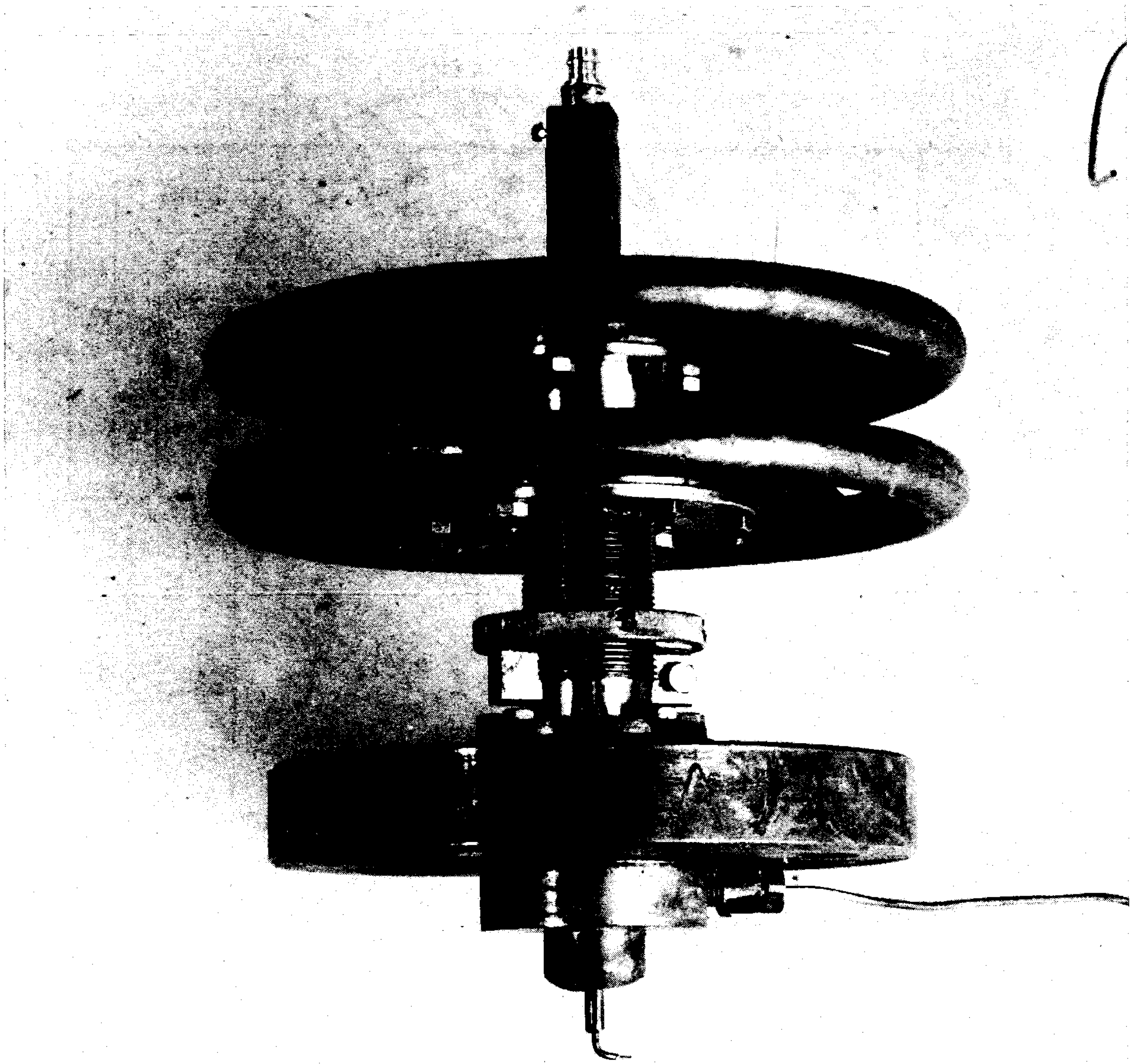

FIGURE 2.12: PHOTOGRAPH OF TRAVERSING IMPEDANCE PROBE

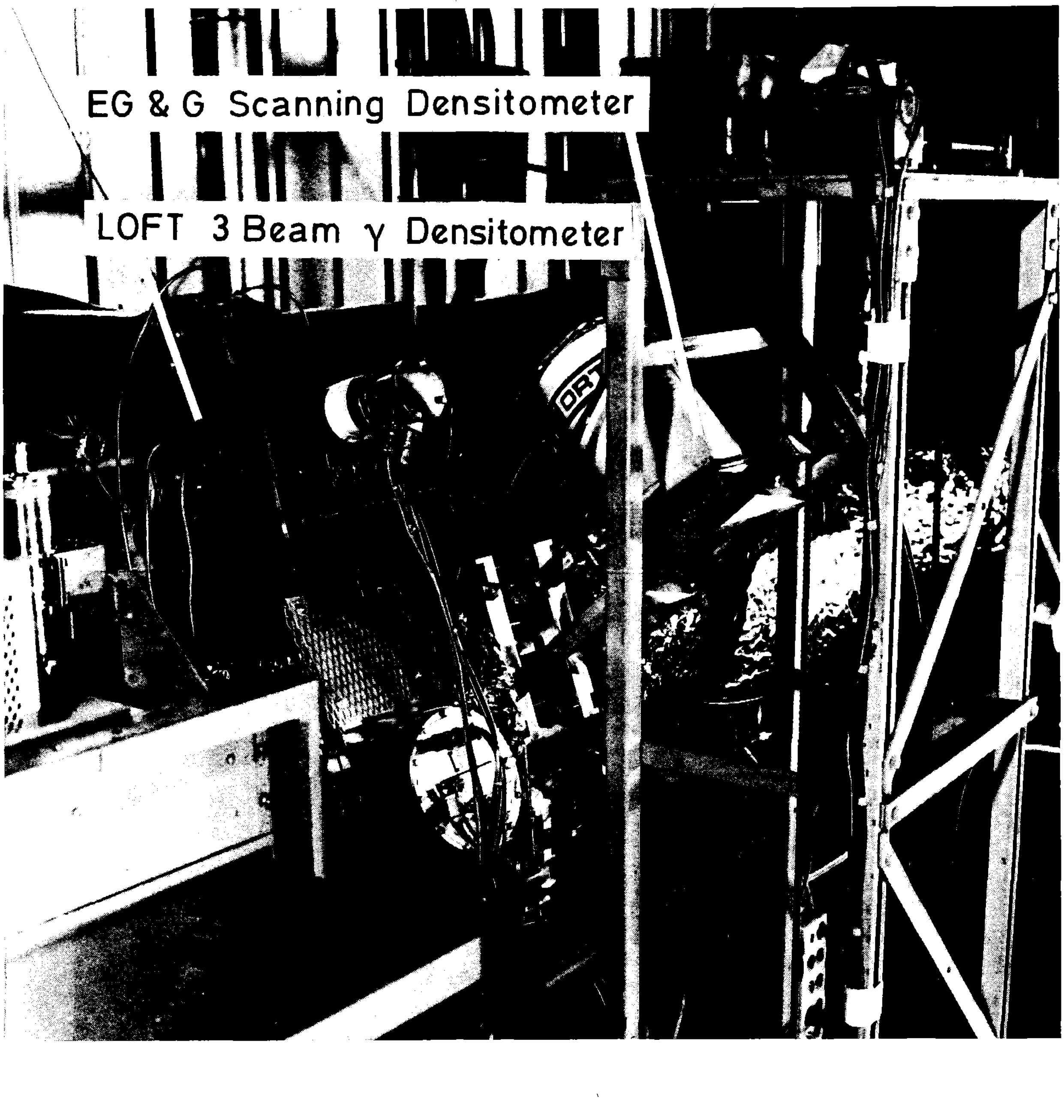

FIGURE 2.13: PHOTOGRAPH OF THREE BEAM DENSITOMETER AND SCANNING DENSITOMETER

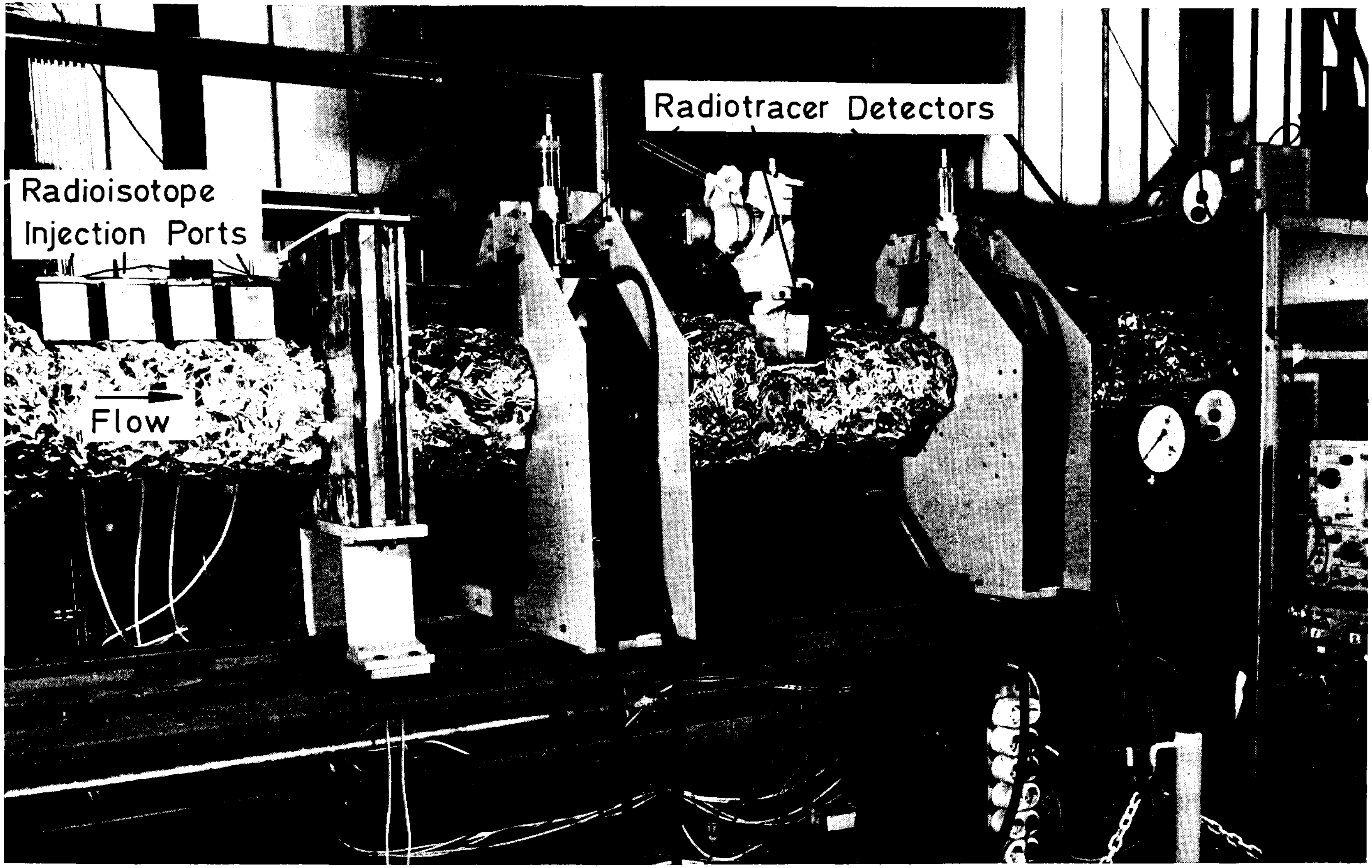

FIGURE 2.14: PHOTOGRAPH OF RADIOTRACER INCECTION PORTS AND DETECTORS

3. EQUATIONS FOR THE PRIMARY DATA AND THE COMPUTED VARIABLES

The data in terms of computed variables are included in Sections 5 to 10 inclusive. The first sheet of each section presents all of the primary time average data in engineering units. That is, calibration equations have been applied to all the voltage readings to produce engineering units. All data manipulations such as calculation of average density from the three line average density values are referred to as computed variables and are included in all the pages other than the first. This section describes the computation procedures used for both the primary engineering unit data and the computed variables data.

3.1 Primary Engineering Unit Data

The first portion of these data sheets consists of the pressure, temperature, and reference flow rates. The second consists of advanced instrumentation data.

3.1.1 Reference Flow Rates

The reference mass flow rates for the air-water runs are calculated as described in Section 3.2.1 with no other corrections required. On the other hand, the steam-water mass flow rates of each phase must be corrected for phase change effects. Although the total mass flow is unchanged by these corrections, the total volumetric flow rate (or superficial velocity), the quality χ, and the homogeneous void fraction α are affected by them. The method of correcting these mass flow rates includes the following:

(1) The flow rate and thermodynamik conditions are given at the metering section for each stream. The liquid supply is subcooled and the vapor supply is superheated enough to insure that each stream is single phase through the measuring orifice. A check is made to ascertain that two-phase conditions are not encountered in the orifice.

(2) Each stream is throttled isenthalpically to the test section pressure

$$\overset{o}{m}_1 \, h_1 \, (P_1, s_1) = \overset{o}{m}_1 \, h_1 \, (P_t, s_1^t)$$

$$\overset{o}{m}_2 \, h_2 \, (P_2, s_2) = \overset{o}{m}_2 \, h_2 \, (P_t, s_2^t)$$

where $\overset{o}{m}$ = mass flow rate

h = enthalpy

P = pressure

s = entropy

1 = conditions at metering section in stream 1

2 = conditions at metering section in stream 2

t = test section conditions

(3) The two streams are mixed assuming infinite heat transfer rate

$$\overset{\circ}{m}_t\, h_t = \overset{\circ}{m}_1\, h_1 + \overset{\circ}{m}_2\, h_2$$

where h_t is the mixture enthalpy neglecting the heat loss.

(4) The heat loss is subtraced from the mixture at constant pressure

$$\overset{\circ}{m}_t\, h_t = \overset{\circ}{m}_t\, h_t - (0.1\ T_t - 7^{\circ}C)\frac{860}{3600}$$

where T = saturation temperature corresponding to P_t, h is in Kcal/Kg, and $\overset{\circ}{m}$ is in Kg/s.

The heat loss calibration is often a small correction.

(5) The resultant quality, χ, can be calculated for the test section since h_t is related to χ by

$$\overset{\circ}{m}_t\, h_t = \overset{\circ}{m}_t\, \chi\, h_g\, (P_t) + \overset{\circ}{m}_t\, (1-\chi)\, h_\ell\, (P_t)$$

where h_g and h_ℓ refer to saturation properties of the gas and liquid phases at pressure P_t.

Solving for χ yields

$$\chi = \frac{h_t - h_\ell}{h_g - h_\ell}$$

The mass flow rate of each phase in the test section can be calculated from the quality with the following equations except when χ is outside of the range 0 to 1

$$\overset{\circ}{m}_g = \overset{\circ}{m}_t\, \chi$$

$$\overset{\circ}{m}_\ell = \overset{\circ}{m}_t (1-\chi)$$

A quality outside of the range of 0 to 1 means that the flow was single phase, in which case the total mass flow, $\overset{\circ}{m}_t$ would represent the single phase flow rate.

The superficial velocities, V_s, which represent the volumetric velocity divided by the full pipe area, are obtained by the equations

$$V_{s_g} = \frac{\overset{\circ}{m}_g}{\rho_g\, A}$$

and

$$V_{s_\ell} = \frac{\overset{o}{m}_\ell}{\rho_\ell A}$$

where ρ_g and ρ_ℓ are the saturation densities of gas and liquid respectively corresponding to the test section pressure, and A is the pipe cross-sectional area.

The homogeneous void fraction referring to a two-phase mixture without slip is:

$$\alpha = \frac{\chi \cdot \rho_g}{(1-\chi) \cdot \rho_\ell + \chi \cdot \rho_g}$$

If both boilers are delivering saturated water and steam is produced in the throttle valves before the mixing section by flashing, the same equations are used to calculate the superficial velocities, the steam quality and the homogeneous void fraction in the test section.

3.1.2 Advanced Instrumentation Data

The equation used to relate turbine velocity (V_T) values to output voltages (T) is given by the equation

$$V_T = 0.1547 \text{ m/s} + 1.337 \frac{\text{m}}{\text{s} \cdot \text{volts}} \cdot \text{Volts Turbine}$$

Two different equations were used to relate the momentum flux measured by the drag disk ($(\rho V^2)_{DD}$) to output voltages.

Air-water (ambient temperature)

$$(\rho V^2)_{DD} = -449.649 \text{ kg/ms}^2 + 591.307 \frac{\text{kg}}{\text{m s}^2 \cdot \text{volts}} \cdot \text{Volts}_{DD}$$

steam-water (higher temperature)

$$(\rho V^2)_{DD} = -396.58 \text{ kg/ms}^2 + 458.15 \frac{\text{kg}}{\text{m/s}^2 \cdot \text{volts}} \cdot \text{Volts}_{DD}$$

The calibration of these instruments in single phase flow is described in Section 5. The air-water coefficients were based on a cold water calibration. The selection of the coefficients used for the steam-water was based upon the single phase steam calibration.

The calibration equations for each gamma densitometer beam in the five-inch pipe are related to the output voltage by

$$\rho_A = 81.103 \ln (10.02/\text{volts}_{A\ \text{beam}}) \cdot 16.01846$$

$$\rho_B = 69.881 \ln (10.02/\text{volts}_{B\ \text{beam}}) \cdot 16.01846$$

$$\rho_C = 106.42 \ln (10.02/\text{volts}_{C\ \text{beam}}) \cdot 16.01846$$

The calibration equations for the gamma densitometer beams in the three-inch pipe are related to the output voltage by

$$\rho_A = 124.82 \ln (10.01/\text{volts}_{A\ \text{beam}}) \cdot 16.01846$$

$$\rho_B = 107.09 \ln (10.01/\text{volts}_{B\ \text{beam}}) \cdot 16.01846$$

$$\rho_C = 180.71 \ln (10.01/\text{colts}_{C}\ \text{beam}) \cdot 16.01846$$

The radiotracer technique is based upon measurement of the time that it takes a radiotracer to traverse a known distance. Thus, the velocity of a phase i, V_i, is estimated as where D_n-D_{n-1} = distance between two detectors n and n-1 and t_i = time required for the radiotracer of phase "i" to traverse the distance between the two detectors.

The primary data in engineering units extrapolated for the gamma densitometer location are shown in Table 1 for each series. These velocities are used for further calculations.

The radiotracers may be injected at a rate of 10 injections per second so it is possible to determine the change in velocity with time. The phase velocities at different axial locations of the test section are shown in Appendix III.

3.2 Computed Variables

Most of the computed variables fall into four categories: the mass fluxes, the superficial velocities (volumetric flow rates), the vapor fraction, and the phase velocities. Other parameters are also calculated.

3.2.1 Mass Fluxes

The mass flux (G) can be calculated in three different ways by combining three instrument readings of density (ρ_γ), turbine celocity (V_T), and drag disk momentum flux ($(\rho V^2)_{DD}$).

$$G_{\gamma\text{-DD}} = \frac{M_{\gamma\text{-DD}}}{A} = (\rho_\gamma \cdot (\rho V^2)_{DD})^{0.5}$$

$$G_{\gamma\text{-T}} = \frac{M_{\gamma\text{-T}}}{A} = \rho_\gamma \cdot V_T$$

and

$$G_{T\text{-DD}} = \frac{M_{T\text{-DD}}}{A} = \frac{(\rho V^2)_{DD}}{V_T}$$

Each of these methods depends upon two of the measurements and not the third. The total reference mass flux is calculated by adding the mass flow rates of the two phases and dividing by the pipe area.

The average density calculation is described in Section 3.2.3. The beam length averaged density is used in these calculations since it is negligibly different from the vertical beam span average.

The tabular values of the mass fluxes are given in Table 2 of each series. Comparisons of each of these mass fluxes to the reference mass flux is given in Figures 2 to 4 of each series. The numbers plotted on these figures and all others are the last two digits of the Test ID.

3.2.2 Superficial Velocity or Volumetric Flux

The total volumetric flux is calculated by adding the volumetric flow rates of each phase together and dividing by the pipe area. This is equivalent to adding the superficial velocities of both phases.

Two velocities are measured by the LOFT advanced instruments. The first is measured directly by the turbine (V_T). This is the only measurement which can be compared directly to a reference measurement. The second velocity is calculated from a combination of the drag disk and gamma densitometer as

$$V_{DD\text{-}\gamma} = \left(\frac{(\rho V^2)_{DD}}{\rho_\gamma} \right)^{0.5}$$

The tabular values of these velocities are with reference values in Table 3 for each series. Figures 5 and 6 compare these velocities to the reference volumetric flux.

3.2.3 Pipe Averaged Density and Void Fraction Calculations.

The average density is calculated by weighted average of the densities calculated for each beam. The procedure recommended in the L1 series consists of selecting between two different averages. If the density of the upper beam is less than the middle beam and if the middle beam is also less than the lower beam, then stratified flow is assumed. The average to be used in this instance is based upon weighting the vertical component of the beam length passing through the pipe (vertical beam span averaging). The average for homogeneous flow regimes is recommended as a weighting of the length of each beam (beam length averaging). Both of the beam averages are included in Section 2.3 for each test section. Both of these averages are included in Table 4 of each series for all data points. Since these averages are very close, the beam length averaged density is used in all the following calculations of computed variables. The densities measured by gamma densitometer vs reference densities are shown in Figure 10.

The vapor fraction in the test section may be calculated from the densities measured by the gamma densitometer:

$$\alpha_\gamma = \frac{\rho_\gamma - \rho_\ell}{\rho_g - \rho_\ell}$$

where ρ_g and ρ_ℓ are the saturated densities of the gass and liquid respectively.

The homogeneous void fraction, in the following called thermodynamic vapor fraction (or vapor volumetric flow ratio, a flow quantity), α_T, can be calculated by the equation

$$\alpha_T = \frac{V_{sg}}{(V_{sg} + V_{s\ell})} = \frac{\alpha_\gamma V_g}{(\alpha_\gamma V_g + (1-\alpha_\gamma)V_\ell)} = \frac{\alpha_\gamma S}{\alpha_\gamma S + (1-\alpha_\gamma)}$$

where V_g and V_ℓ are the phase velocity of the gas and liquid phase. The ratio of α_γ and α_T is a measure of the slip between phases. As the slip ratio increases, the vapor fraction α_γ decreases.

The vapor fraction can also be calculated from the radiotracer velocities measured for each phase and the superficial velocity of each phase. The vapor fraction calculated from the vapor phase is

$$\alpha_{Rg} = 1 - \frac{V_{sg}}{V_g}$$

The vapor fraction calculated from the liquid phase is

$$\alpha_{R\ell} = 1 - \frac{V_{s\ell}}{V_\ell}$$

Agreement between α_{Rg} and $\alpha_{R\ell}$ provides a measure of the accuray of the radiotracer velocities and the reference flow rates. If these two values agree, then the agreement between α_R and α_γ provides a measure of the accuracy of the gamma densitometer vapor fraction.

Table 4 of each test series presents the comparison between these vapor fractions. A comparison of the radiotracer vapor fractions are presented in Figure 7.

3.2.4 Phase Velocity Comparisons

The velocity of each phase can be calculated from the superficial velocities and the gamma densitometer vapor fractions as

$$V_{\gamma_g} = \frac{V_{sg}}{\alpha_\gamma}$$

and

$$V_{\gamma_\ell} = \frac{V_{s\ell}}{1-\alpha_\gamma}.$$

A comparison of these velocities to the radiotracer velocities are presented in Table 5.

The slip ratio is calculated for sets of velocities by the equations

$$S_\gamma = \frac{V_{\gamma g}}{V_{\gamma_\ell}}$$

and

$$S_R = \frac{V_g}{V_\ell}$$

3.2.5 Comparisons to Single Instruments

Three quantities were calculated to attempt to evaluate individual instruments. The turbine is evaluated directly by comparing it to the total superficial velocity shown in Figure 5.

A reference density can be calculated from reference values assuming equal phase velocities by the equation

$$\rho_H = \frac{G_{ref}}{V_{s\ell} + V_{sg}}$$

The value of the length averaged gamma densitometer density is plotted versus ρ_H in Figure 10.

Two different reference momentum fluxes can be calculated. The first is obtained using only reference measurements assuming that the velocities are equal.

$$(\rho V^2)_H = (G)_{ref}\,(V_{s\ell} + V_{sg})$$

The other momentum flux which can be calculated depends upon the densitometer measured void fraction (α_γ) by using the definition

$$(\rho\ V^2)_\gamma = (\alpha_\gamma \rho_g V_g)\ V_g + ((1-\alpha_\gamma)\rho_\ell V_\ell)V_\ell$$

or

$$(\rho V^2)_\gamma = G_g \cdot \frac{V_{sg}}{\alpha_\gamma} + G_\ell \cdot \frac{V_{s\ell}}{(1-\alpha_\gamma)}$$

The drag disk value is evaluated by comparing the drag disk outputs with $(\rho V^2)_H$ in Figure 11 and with ρV_γ^2 in Figure 12. These values are presented in Table 8.

3.2.6 The Dependence of Measurement Error On Void Fraction

The interested measurement quantities, mass flux and velocity, is thought to be dependent on void fraction. The deviations of the measured mass flux and velocity plotted versus void fraction are shown in Figure 8 and 9 respectively for the turbine and gamma densitometer.

3.3 Flow Regime Determination

The flow regime can be estimated from three techniques; (1) a standard flow regime map, (2) the LOFT three-beam gamma densitometer, and (3) the IRB impedance probe and the Semiscale reference gamma densitometer on the three-inch test section.

3.3.1 Standard Flow Regime Map

The flow regime map used was taken from Govier and Aziz /4/ and converted to metric units. This flow regime map requires knowledge of the superficial velocities of each phase. The coordinates of each data point are plotted on a flow regime map in Figure 1 a in each series and the flow regime indicated is listed in Table 6.

3.3.2 LOFT Three Beam Gamma Densitometer Technique

The gamma densitometer used in these tests provided three beams, from which three chordal average densities were calculated. These values can be processed with the three-beam densitometer reduction model /5/ to obtain flow regime and pipe cross-sectional average density. This model was applied for those three-inch pipe tests where reference densitometer measurements were made (see Appendix 2). In those tests the model /5/ always predicted stratified flow.

The frequency response of the densitometer is limited only by count rate statistics. The densitometer, as used in these tests, was capable of a minimum frequency response of 100 Hz. The accuracy of the densitometer is also a function of count rate statistics, as well as other factors. A 2σ accuracy of $\pm 20\ kg/m^3$ should be applied to the data obtained with the three beam densitometer in these tests.

3.3.3 Impedance Probe Technique

The impedance probe data on the five-inch tests were obtained with the traversing impedance probe which was able to give experimental data as a function of vertical position over the whole pipe. At a given location in the pipe, the probe gives the vapor fraction versus time. This allows the determination of an average vapor volume fraction at that location as well as an indication of the size of the bubbles, droplets, or slugs passing by a point. Combining the data at all vertical positions yields a good idea of the flow structure details as well as the average void fraction over the pipe. In the three-inch tests two fixed impedance probes were used with a distance of 5mm above the bottom and below the top of the pipe, respectively. Because two measuring positions do not give the same amount of information as a traversable probe, for flow regime determination the time dependent signals of the gamma densitometer and the DTT were sometimes also used. The flow regime map obtained from this technique as well as the definition of the flow regimes are also described in Appendix 1. Figure 1b in each data section presents the data on the revised flow regime map based on the data of the 40 and 75 bar experiments.

3.3.4 Reference Gamma Densitometer Technique

The reference densitometer is characterized by a fixed source, a small exposed detector area, and a traversing mechanism to move the detector in an arc about the source point to obtain the density at many chordal positions over the flow field. These densities also can be processed with a special data reduction model /8/ to give flow regime and pipe cross-sectional average density. Appendix 2 contains the results of the density distribution in the vertical direction.

3.3.5 Water Level Estimation

The assumption can be made that there is a collapsed water level to estimate whether single-phase or two-phase is flowing through the DTT. The location of the water level can be determined by knowing the vapor fraction α_γ. The value of α_γ can be determined as

$$\alpha_\gamma = \frac{\text{vapor area}}{\text{total area}}$$

or (compare Fig. 3.1)

$$\alpha_\gamma = 1 - \frac{1}{2\pi}(\theta - \sin\theta)$$

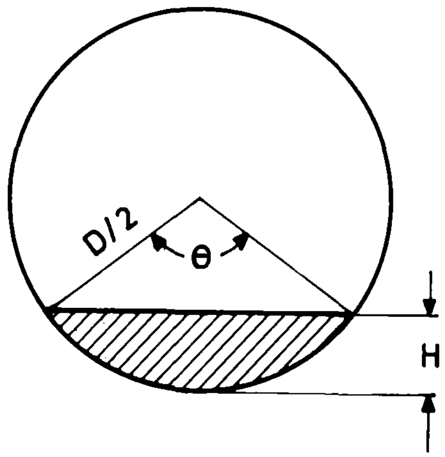

Fig. 3.1 : Water Level Determination

The height of the water level with respect to the bottom of the pipe is

$$H = \frac{D}{2}\left(1 - \cos\left(\frac{\theta}{2}\right)\right)$$

The percent of the DTT height covered by the liquid can be calculated by

$$P_3 = \frac{H - 1.427\ \text{cm}}{3.81\ \text{cm}} \times 100\ \%$$

for the three-inch pipe, and

$$P_5 = \frac{H-3.255\ cm}{3.81\ cm} \times 100\ \%$$

for the five-inch pipe. These values are included in Table 6.

4. CALIBRATION

The majority of the data in this report were taken with DTT Serial Number 16. The specified limits of this instrument are turbine from 0.46 to 9.15 m/s and drag disc from 373 to 5215 kg/ms^2. The calibration of the instruments in this device in single-phase flow are reported in this section. There were eight series of calibrations performed. These were:

(1) The calibration performed at ARA in all water in a pipe of the same area as the DTT (referred to here as full flow).

(2) An all water calibration in the five-inch test section (cold).

(3) An all steam calibration at 75 bar in the five-inch pipe.

(4) An all steam calibration at 40 bar in the five inch pipe. (The accuracy of this run is suspect.)

(5) Repeat of all steam 40 bar in the five-inch pipe.

(6) An all steam calibration at 40 bar in the three-inch pipe.

(7) An all water calibration under hot conditions at 70 bars in the three inch-pipe.

(8) An all water calibration under hot conditions at 40 bars in the three-inch pipe.

There were no calibrations performed in single-phase air flow or steam flow at low pressure.

Turbine data are plotted in Figure 4.1 and the drag disk data are plotted in Figure 4.2. Continuous lines were drawn visually through the test points for each of the series. The coefficients which were used to obtain turbine velocities and drag disk momentum fluxes from voltage outputs were given in Section 3.1.2. These equations are shown as dashed lines in Figure 4.1 and 4.2, resepectively.

The turbine calibrations show that although each data set appears to be self consistent within each series, there is a difference between each series. However, the difference does not seem to be significant (except for the 40 bar five inch pipe points which are suspect) and the single curve fits all of the data well within the two-phase data variation. Consequently, the error in calculations made with the turbine output should be close to zero for vapor fractions of both zero and one. There is no clear variation of the data with pipe size, pressure, or fluid. The drag disk calibrations show a large variation in the momentum flux output versus voltage output from the drag disc. The curve which appears to deviate the most from the other data is the all water calibration in full flow done at ARA before taking the unit to Karlsruhe. It has been discovered that there is a large installation factor associated with the drag disc and that variation in length of leads to the unit will cause a difference in calibration. Hence, the data obtained at ARA for this unit are not usefull and are not considered part of the relevant calibration for the Karlsruhe data. The rest of the calibration curves show an interesting variation. Each one of the calibrations is different from each other, but again, the variation between them is small. Each of the data sets seem quite consistent within each other and most of them fall on a straight line. The calibration which shows the greatest variation from a straight line is the all water calibration which was done at low temperature. This variation may be due to a greater amount of friction at low temperature. This calibration also seems to show the greatest deviation from the other curves particulary at high flow rates. There is no clear variation between the all steam calibrations with either pipe size or pressure. In fact, the four calibration points which were taken at high temperature in all water also fall in this same general area. Hence, it is concluded that the drag disk is not sensitive to calibrations in all steam or all liquid, but it appears to be sensitive to the temperature at which it is calibrated. Hence, one calibration line was used for the air-water data reduction which, of course, is done at low temperature and a different curve (as shown in Figure 4.2) was used for the calibration coefficients for all of the data taken in steam-water at the higher temperatures.

Reference instrumentation at KfK supplied by INEL consisted of pressure, temperature, differential pressure and density instruments. Table 4.1 summarizes the uncertainties associated with this instrumentation. Calibrations for the pressure, temperature and differential pressure instrumentation were conducted at INEL facilities prior to shipment to the KfK test facility. The gamma densitometers were calibrated prior to each day of testing. The calibration of the densitometer consisted of setting the gain and zero offset of each beam such that a predetermined calibration equation was correct. The reference conditions for the densitometer calibration were obtained by filling the test section with steam and then water. Shim calibrations were not used. No calibrations of other reference instrumentation were conducted at the KfK facility.

TABLE 4.1

INEL REFERENCE INSTRUMENTATION AT GFK TWO PHASE TESTS

Instrument Type	Serial Number	Uncertainty*
Pressure		
CEC 1000	2611	
	2613	
CEC 2500	2353	± · 1% RD RSS 11 psi
	2734	
Differential Pressure		
BLH 50"	42694	± · 16% RD RSS.07 psid
BLH 20"	39192	
Temperature		
Type K TC	none	± 4.2% RD
Density		
3-beam	none	± 23.9 kg/m^3 single beam
gamma densitometer		± 78.0 kg/m^3 pipe average density
Scanning Gamma Densitometer	none	about 1%

* Uncertainty is 2 limits from LOFT Experimental Measurements Uncertainty Analysis TREE-NUREG-1089

RD - Reading

RSS- Root Sum Square

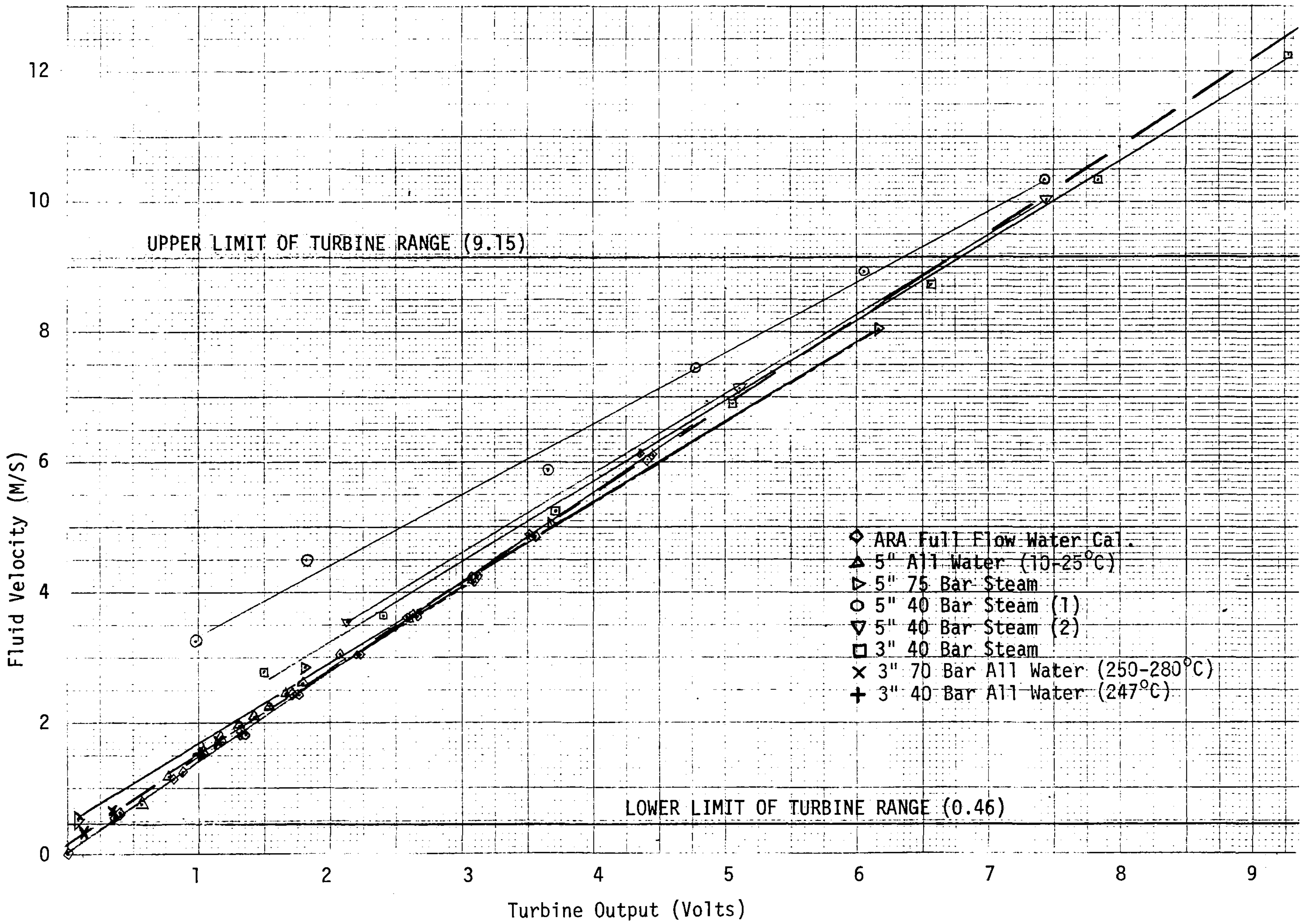

Figure 4.1. Turbine Calibration in Single Phase

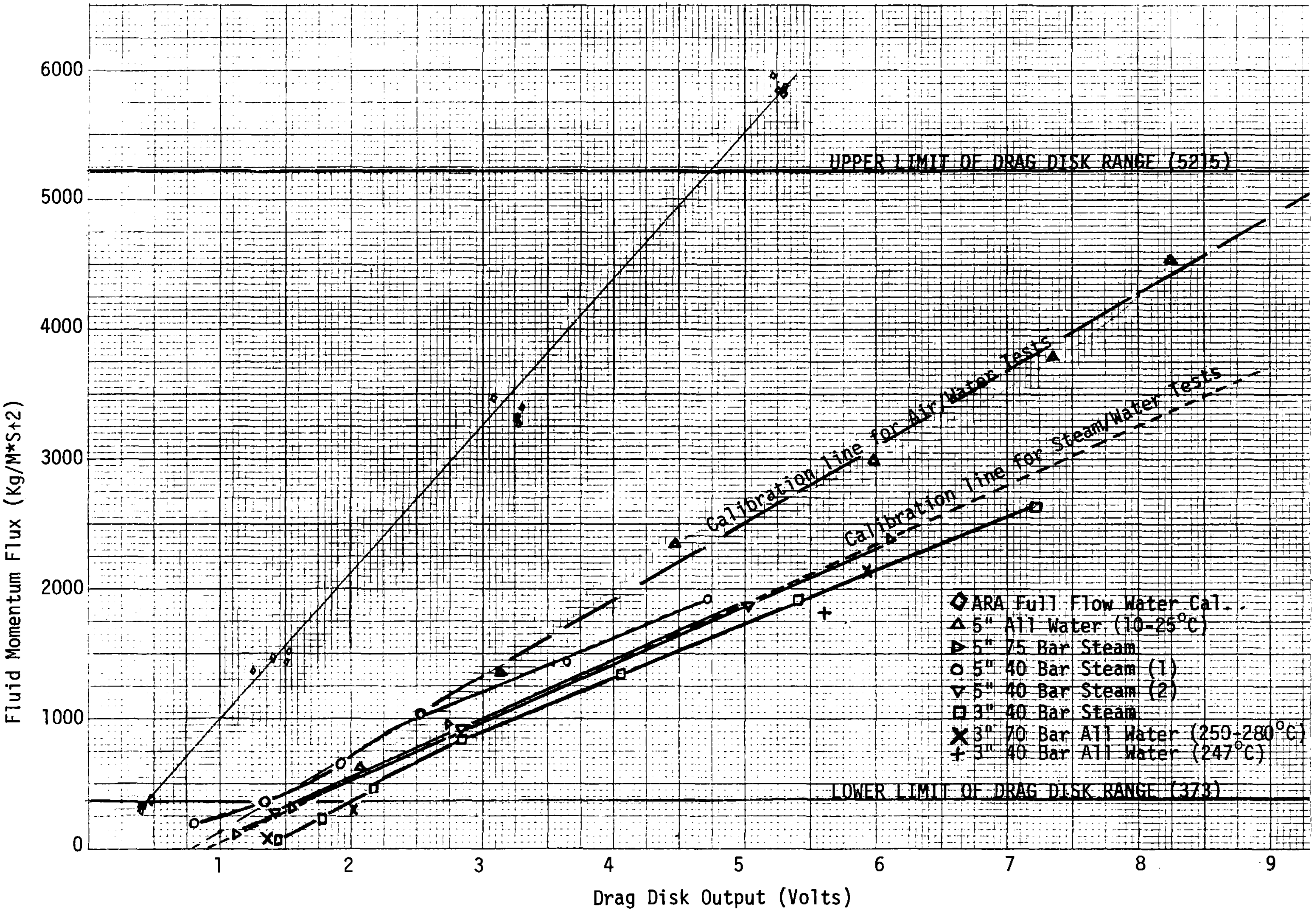

Figure 4.2. Drag Disk Calibration in Single Phase

5.

FIVE-INCH AIR-WATER 2 BAR

FLUID: AIR - WATER
PIPE SIZE= 5 INCH DOUBLE EXTRA STRONG
NOMINAL PRESSURE= 2 BARS

INSIDE DIAMETER= 0.10320 M
TURB. DIA.= 0.0381 M
PIPE AREA= 0.0083647 M↑2

RUN ID TSN	PRESS. (BARS)	TEMP. (DEG C)	FLOW RATES AIR SUP-VEL (M/S)	FLOW RATES AIR MASS (KG/S)	FLOW RATES WATER SUP-VEL (M/S)	FLOW RATES WATER MASS (KG/S)	TURB. VEL (M/S)	DRAG DISK (KG/M*S↑2)	GAMMA DENSITOMETER A BEAM LOWER (KG/M↑3)	GAMMA DENSITOMETER B BEAM MIDDLE (KG/M↑3)	GAMMA DENSITOMETER C BEAM UPPER (KG/M↑3)	IMPEDANCE PROBE INSERTION (MM)	RADIOTRACER VELOCITIES AIR (M/S) (AT GAMMA DENS)	RADIOTRACER VELOCITIES WATER (M/S) (AT GAMMA DENS)	Comments
4206	2.0	20.1	4.55	0.076	0.050	0.415	3.21	-	260	45	33	0			DD below range
4207	1.9	21.3	0.59	0.010	0.050	0.415	0.31	-	474	232	32	0			T, DD below range
4208	6.2	20.9	1.36	0.023	0.225	1.868	0.39	582	361	134	45	0			T below range
4209	2.1	22.1	9.73	0.163	0.125	1.038	6.87	934	176	36	39	20			
4209	2.1	22.1	9.73	0.163	0.125	1.038	7.07	935	170	36	38	60			
4209	2.0	22.2	9.73	0.163	0.125	1.038	6.43	720	165	34	38	95			
4209	2.0	22.2	9.73	0.163	0.125	1.038	6.61	720	164	32	37	95			
4210	2.0	22.5	10.39	0.174	0.050	0.415	7.01	600	145	31	41	0			
4210	2.0	22.7	10.39	0.174	0.050	0.415	7.17	591	142	29	40	0			
4211	2.0	21.6	10.39	0.174	0.250	2.075	7.10	1879	127	42	47	20			
4211	2.0	21.5	10.39	0.174	0.250	2.075	7.15	1931	132	43	51	40			
4211	2.1	21.6	10.39	0.174	0.250	2.075	7.20	1340	123	37	34	30			
4211	2.0	21.5	10.39	0.174	0.250	2.075	6.44	553	131	42	48	70			
4211	2.0	21.6	10.39	0.174	0.250	2.075	7.02	1653	128	37	33	50			
4211	2.1	21.5	10.39	0.174	0.250	2.075	6.73	952	128	38	37	90			
4211	2.1	21.4	10.39	0.174	0.250	2.075	6.56	929	138	41	38	95			
4211	2.1	21.4	10.39	0.174	0.250	2.075	6.64	882	134	41	38	90			
4212	6.0	21.5	6.25	0.104	0.230	1.909	4.92	634	-	-	-	90			
4212	6.0	21.5	6.25	0.104	0.230	1.909	4.82	707	137	44	39	95			
4212	6.0	21.7	6.25	0.104	0.230	1.909	5.09	676	142	42	28	40			
4212	6.1	21.7	6.25	0.104	0.230	1.909	5.23	684	140	46	41	60			
4212	6.2	21.8	6.25	0.104	0.230	1.909	5.32	760	145	45	46	10			
4212	6.1	21.8	6.25	0.104	0.230	1.909	5.19	691	145	45	46	20			
4213	1.9	20.9	10.29	0.172	0.500	4.151	8.36	3261	82	39	26	10			
4213	2.0	20.9	10.29	0.172	0.500	4.151	5.62	1039	83	41	28	95			
4213	1.9	20.9	10.29	0.172	0.500	4.151	8.65	2328	84	45	39	50			
4214	2.0	21.4	3.90	0.065	0.515	4.275	2.84	536	101	58	32	10			
4214	2.0	21.2	3.90	0.065	0.515	4.275	2.41	900	104	61	40	30			
4214	1.9	21.3	3.90	0.065	0.515	4.275	2.36	826	111	59	34	95			
4214	2.0	21.1	3.90	0.065	0.515	4.275	2.91	1155	111	61	40	50			
4214	1.9	21.1	3.90	0.065	0.515	4.275	2.71	957	112	62	40	70			
4215	2.0	22.6	1.12	0.019	0.515	4.275	0.72	1023	356	183	43	20			
4215	2.0	22.7	1.12	0.019	0.515	4.275	0.71	991	362	189	35	10			
4215	2.0	22.4	1.12	0.019	0.515	4.275	0.82	1083	353	178	28	50			
4215	2.0	22.4	1.12	0.019	0.515	4.275	0.73	969	349	179	28	40			
4215	2.0	22.1	1.12	0.019	0.515	4.275	0.76	1030	350	174	29	70			
4215	2.0	22.3	1.12	0.019	0.515	4.275	0.76	903	356	173	31	60			
4215	2.0	22.0	1.12	0.019	0.515	4.275	0.86	1069	378	191	24	90			
4215	2.0	22.1	1.12	0.019	0.515	4.275	0.83	1047	360	180	37	80			
4216	2.0	22.9	0.62	0.010	0.515	4.275	0.88	1116	380	199	26	10			
4216	2.0	23.0	0.62	0.010	0.515	4.275	0.91	1124	376	198	27	30			
4216	2.0	23.2	0.62	0.010	0.515	4.275	0.88	1121	370	191	6	40			
4216	2.0	23.2	0.62	0.010	0.515	4.275	0.85	1122	381	206	49	50			
4216	2.0	23.3	0.62	0.010	0.515	4.275	0.84	1140	376	204	46	60			
4216	2.0	23.4	0.62	0.010	0.515	4.275	0.90	1243	372	198	39	70			
4216	2.0	23.6	0.62	0.010	0.515	4.275	0.94	1399	372	199	32	80			
4216	2.0	23.6	0.62	0.010	0.515	4.275	0.93	1477	377	202	29	90			

Dash indicates error in data.
Blank indicates no data.

TABLE 5.1: PRIMARY ENGINEERING UNIT DATA

5 INCH 2 BAR

RUN ID TSN	GDOT REF (KG/M↑2*S)	GDOT G-T (KG/M↑2*S)	GDOT G-DD (KG/M↑2*S)	GDOT T-DD (KG/M↑2*S)
4206	58.699	372.386		
4207	50.799	81.817		
4208	226.012	74.416	331.637	1477.939
4209	143.485	581.727	281.252	135.979
4209	143.485	580.898	277.216	132.293
4209	143.485	514.871	240.160	112.022
4209	143.485	518.472	237.730	109.004
4210	70.369	510.247	208.887	85.515
4210	70.369	507.737	204.599	82.446
4211	268.857	513.027	368.440	264.602
4211	268.857	539.121	371.534	256.042
4211	268.857	471.620	347.050	255.383
4211	268.857	477.509	203.378	86.622
4211	268.857	472.073	333.402	235.466
4211	268.857	464.044	256.109	141.348
4211	268.857	484.033	261.733	141.528
4211	268.857	479.703	252.476	132.882
4212	240.730			141.129
4212	240.730	358.899	229.379	146.600
4212	240.730	369.819	221.706	132.913
4212	240.730	403.325	229.625	130.733
4212	240.730	423.864	245.975	142.744
4212	240.730	413.347	234.538	133.080
4213	516.768	421.025	405.293	390.149
4213	516.768	293.105	232.910	185.077
4213	516.768	488.937	362.738	269.112
4214	518.888	187.911	188.512	189.114
4214	518.888	169.664	251.505	372.822
4214	518.888	166.042	241.084	350.041
4214	518.888	212.505	290.506	397.136
4214	518.888	198.895	265.180	353.555
4215	513.342	148.167	459.706	1426.290
4215	513.342	149.171	454.850	1386.921
4215	513.342	164.442	464.763	1313.564
4215	513.342	145.243	443.039	1351.416
4215	513.342	150.248	450.932	1353.358
4215	513.342	151.521	424.673	1190.248
4215	513.342	182.611	476.506	1243.398
4215	513.342	170.294	463.776	1263.038
4216	512.338	191.709	492.045	1262.892
4216	512.338	196.712	491.798	1229.543
4216	512.338	180.547	479.197	1271.856
4216	512.338	191.409	503.319	1323.501
4216	512.338	187.124	504.097	1357.995
4216	512.338	195.758	519.834	1380.413
4216	512.338	202.210	549.013	1490.603
4216	512.338	202.324	567.076	1589.404

TABLE 5.2: MASS FLOW RATE COMPARISON

5 INCH 2 BAR

RUN ID TSN	VSL+VSG (M/S)	TURB. VEL (M/S)	VEL. DD-G (M/S)
4206	4.597	3.213	
4207	0.640	0.310	
4208	1.584	0.394	1.755
4209	9.859	6.868	3.321
4209	9.859	7.068	3.373
4209	9.859	6.428	2.998
4209	9.859	6.605	3.029
4210	10.444	7.014	2.871
4210	10.444	7.169	2.889
4211	10.644	7.101	5.100
4211	10.644	7.152	4.929
4211	10.644	7.204	5.301
4211	10.644	6.443	2.744
4211	10.644	7.020	4.958
4211	10.644	6.734	3.717
4211	10.644	6.564	3.550
4211	10.644	6.640	3.495
4212	6.476	4.918	
4212	6.476	4.825	3.084
4212	6.476	5.089	3.051
4212	6.476	5.232	2.979
4212	6.476	5.325	3.090
4212	6.476	5.193	2.946
4213	10.794	8.359	8.047
4213	10.794	5.615	4.462
4213	10.794	8.650	6.418
4214	4.413	2.835	2.844
4214	4.413	2.413	3.577
4214	4.413	2:360	3.427
4214	4.413	2.907	3.974
4214	4.413	2.706	3.608
4215	1.634	0.717	2.225
4215	1.634	0.715	2.180
4215	1.634	0.824	2.330
4215	1.634	0.732	2.233
4215	1.634	0.761	2.284
4215	1.634	0.759	2.127
4215	1.634	0.860	2.244
4215	1.634	0.829	2.258
4216	1.131	0.884	2.269
4216	1.131	0.914	2.285
4216	1.131	0.882	2.340
4216	1.131	0.848	2.230
4216	1.131	0.839	2.261
4216	1.131	0.900	2.391
4216	1.131	0.938	2.547
4216	1.131	0.929	2.604

TABLE 5.3: TOTAL VELOCITY COMPARISON

5 INCH 2 BAR

DENSITIES (KG/M↑3) VA[illegible] [illegible]CTIONS

RUN ID TSN	VERT AVG GAMMA	LEN AVG GAMMA	ALPHA GAMMA (LEN)	ALPHA THERMO
4206	123.56	115.90	0.88	0.99
4207	278.30	263.70	0.72	0.92
4208	199.54	189.01	0.80	0.86
4209	89.33	84.70	0.91	0.99
4209	86.63	82.19	0.91	0.99
4209	84.39	80.10	0.92	0.99
4209	82.79	78.50	0.92	0.99
4210	76.26	72.75	0.92	1.00
4210	74.27	70.83	0.93	1.00
4211	74.92	72.25	0.92	0.98
4211	78.11	75.38	0.92	0.98
4211	68.46	65.47	0.93	0.98
4211	76.88	74.11	0.92	0.98
4211	70.44	67.25	0.93	0.98
4211	71.97	68.91	0.93	0.98
4211	77.09	73.74	0.92	0.98
4211	75.47	72.24	0.92	0.98
4212				0.96
4212	77.68	74.38	0.92	0.96
4212	76.50	72.68	0.92	0.96
4212	80.40	77.08	0.92	0.96
4212	82.93	79.60	0.92	0.96
4212	82.92	79.60	0.92	0.96
4213	52.20	50.37	0.95	0.95
4213	54.01	52.20	0.95	0.95
4213	58.00	56.52	0.94	0.95
4214	68.53	66.28	0.93	0.88
4214	72.40	70.32	0.93	0.88
4214	72.88	70.35	0.93	0.88
4214	75.43	73.10	0.92	0.88
4214	75.84	73.49	0.92	0.88
4215	216.89	206.58	0.78	0.69
4215	219.46	208.69	0.78	0.69
4215	210.17	199.47	0.79	0.69
4215	208.96	198.38	0.79	0.69
4215	207.98	197.40	0.79	0.69
4215	210.43	199.69	0.79	0.69
4215	223.99	212.32	0.77	0.69
4215	216.06	205.39	0.78	0.69
4216	228.53	216.90	0.77	0.55
4216	226.69	215.20	0.77	0.55
4216	216.79	204.80	0.78	0.55
4216	236.69	225.74	0.76	0.55
4216	233.76	222.91	0.76	0.55
4216	228.37	217.40	0.77	0.55
4216	226.71	215.51	0.77	0.55
4216	229.23	217.77	0.77	0.55

TABLE 5.4: VOID FRACTION COMPARISON

5 INCH

RUN ID TSN	V GAS G DENS (M/S)	V LIQ. G DENS (M/S)	SLIP G DENS
4206	5.181	0.409	12.675
4207	0.820	0.178	4.607
4208	1.711	1.094	1.564
4209	10.683	1.407	7.595
4209	10.652	1.451	7.343
4209	10.625	1.491	7.128
4209	10.606	1.521	6.972
4210	11.248	0.658	17.095
4210	11.224	0.676	16.598
4211	11.242	3.314	3.393
4211	11.283	3.172	3.557
4211	11.154	3.666	3.043
4211	11.266	3.227	3.491
4211	11.177	3.568	3.133
4211	11.199	3.477	3.221
4211	11.262	3.243	3.472
4211	11.242	3.312	3.394
4212			
4212	6.786	2.891	2.348
4212	6.772	2.961	2.287
4212	6.808	2.786	2.443
4212	6.829	2.694	2.535
4212	6.829	2.696	2.533
4213	10.858	9.628	1.128
4213	10.880	9.277	1.173
4213	10.934	8.543	1.280
4214	4.187	7.462	0.561
4214	4.206	7.019	0.599
4214	4.206	7.018	0.599
4214	4.220	6.746	0.626
4214	4.222	6.711	0.629
4215	1.434	2.344	0.612
4215	1.438	2.320	0.620
4215	1.420	2.428	0.585
4215	1.418	2.442	0.581
4215	1.416	2.454	0.577
4215	1.421	2.426	0.586
4215	1.446	2.281	0.634
4215	1.432	2.358	0.607
4216	0.802	2.231	0.359
4216	0.800	2.249	0.355
4216	0.788	2.365	0.333
4216	0.812	2.143	0.379
4216	0.808	2.171	0.372
4216	0.802	2.226	0.360
4216	0.800	2.246	0.356
4216	0.803	2.223	0.361

TABLE 5.5: PHASE VELOCITY COMPARISON

RUN ID TSN	From Govier & Aziz Flow Regime Map	From Gamma Densitometer: Flow Regime	From Gamma Densitometer: Interface Location(%)*
4206	Wave Flow		-36.81
4207	Stratified Flow		2.19
4208	Slug Flow		-16.80
4209	Annular Mist		-46.28
4210	Annular Mist		-52.26
4211	Slug Flow		-52.26
4212	Slug Flow		-49.09
4213	Slug Flow		-59.83
4214	Slug Flow		-50.47
4215	Slug Flow		-11.43
4216	Slug Flow		- 9.01

*Pipe Empty: 0.0 cm liquid level is -85.43%

Pipe Full: 10.32 cm liquid level is 185.43%

Bottom of DTT Housing: 3.255 cm liquid level is 0.0%

Top of DTT Housing: 7.07 cm liquid level is 100.0%

TABLE 5.6: FLOW REGIME COMPARISON

5 INCH 2 BAR

RUN ID TSN	ALPHA GAMMA	GDOT-GDOT G-T REF (KG/M↑2*S)	VI-(VSL+VSG) (M/S)
4206	0.88	313.69	-1.38
4207	0.72	31.02	-0.33
4208	0.80	-151.60	-1.19
4209	0.91	438.24	-2.99
4209	0.91	437.41	-2.79
4209	0.92	371.39	-3.43
4209	0.92	374.99	-3.25
4210	0.92	439.88	-3.43
4210	0.93	437.37	-3.28
4211	0.92	244.17	-3.54
4211	0.92	270.26	-3.49
4211	0.93	202.76	-3.44
4211	0.92	208.65	-4.20
4211	0.93	203.22	-3.62
4211	0.93	195.19	-3.91
4211	0.92	215.18	-4.08
4211	0.92	210.85	-4.00
4212			-1.56
4212	0.92	118.17	-1.65
4212	0.92	129.09	-1.39
4212	0.92	162.60	-1.24
4212	0.92	183.13	-1.15
4212	0.92	172.62	-1.28
4213	0.95	-95.74	-2.44
4213	0.95	-223.66	-5.18
4213	0.94	-27.83	-2.14
4214	0.93	-330.98	-1.58
4214	0.93	-349.22	-2.00
4214	0.93	-352.85	-2.05
4214	0.92	-306.38	-1.51
4214	0.92	-319.99	-1.71
4215	0.78	-365.17	-0.92
4215	0.78	-364.17	-0.92
4215	0.79	-348.90	-0.81
4215	0.79	-368.10	-0.90
4215	0.79	-363.09	-0.87
4215	0.79	-361.82	-0.88
4215	0.77	-330.73	-0.77
4215	0.78	-343.05	-0.80
4216	0.77	-320.63	-0.25
4216	0.77	-315.63	-0.22
4216	0.78	-331.79	-0.25
4216	0.76	-320.93	-0.28
4216	0.76	-325.21	-0.29
4216	0.77	-316.58	-0.23
4216	0.77	-310.13	-0.19
4216	0.77	-310.01	-0.20

TABLE 5.7: ERROR CALCULATIONS

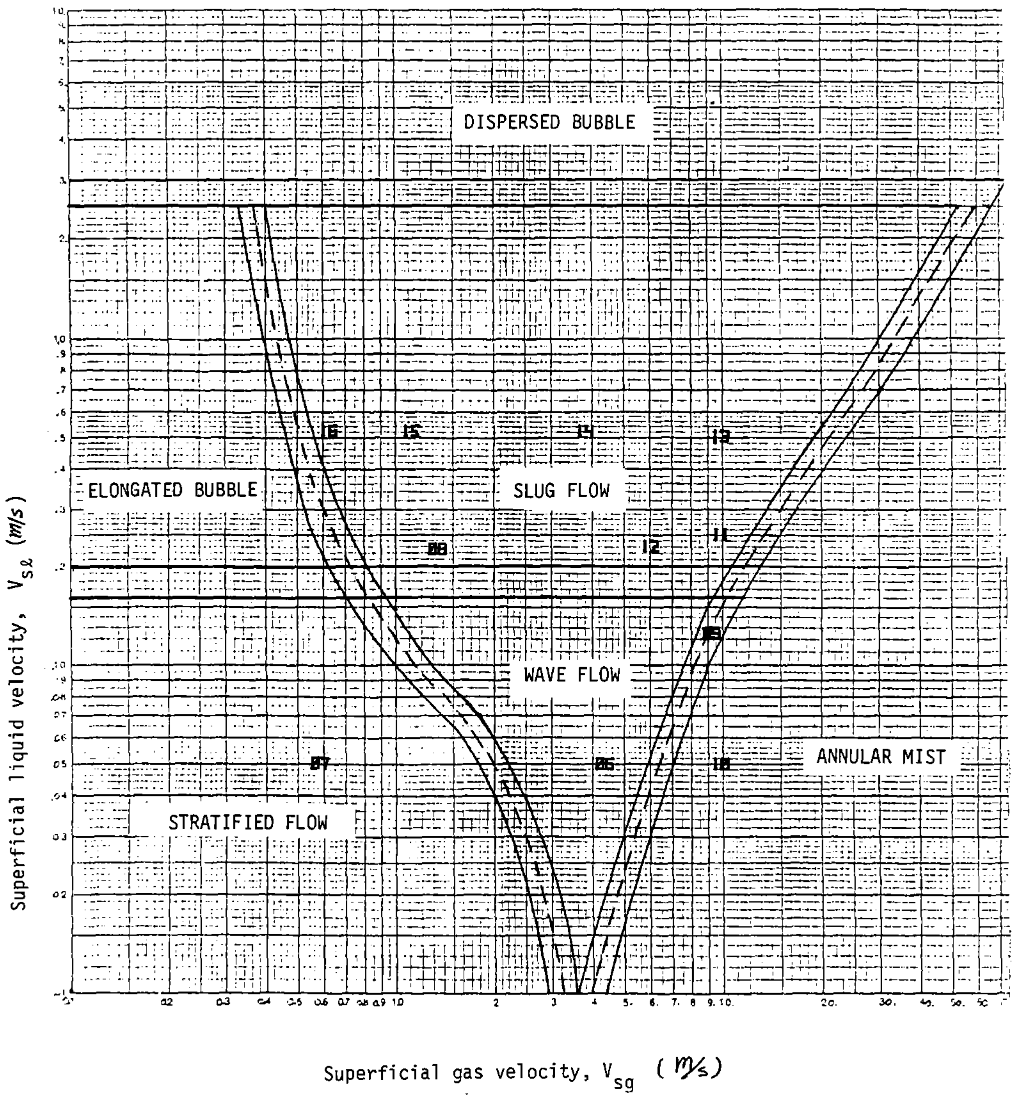

FIGURE 5.1A: GOVIER AND AZIZ FLOW REGIME MAP

LTR LO 00 79-109
KFK 2784

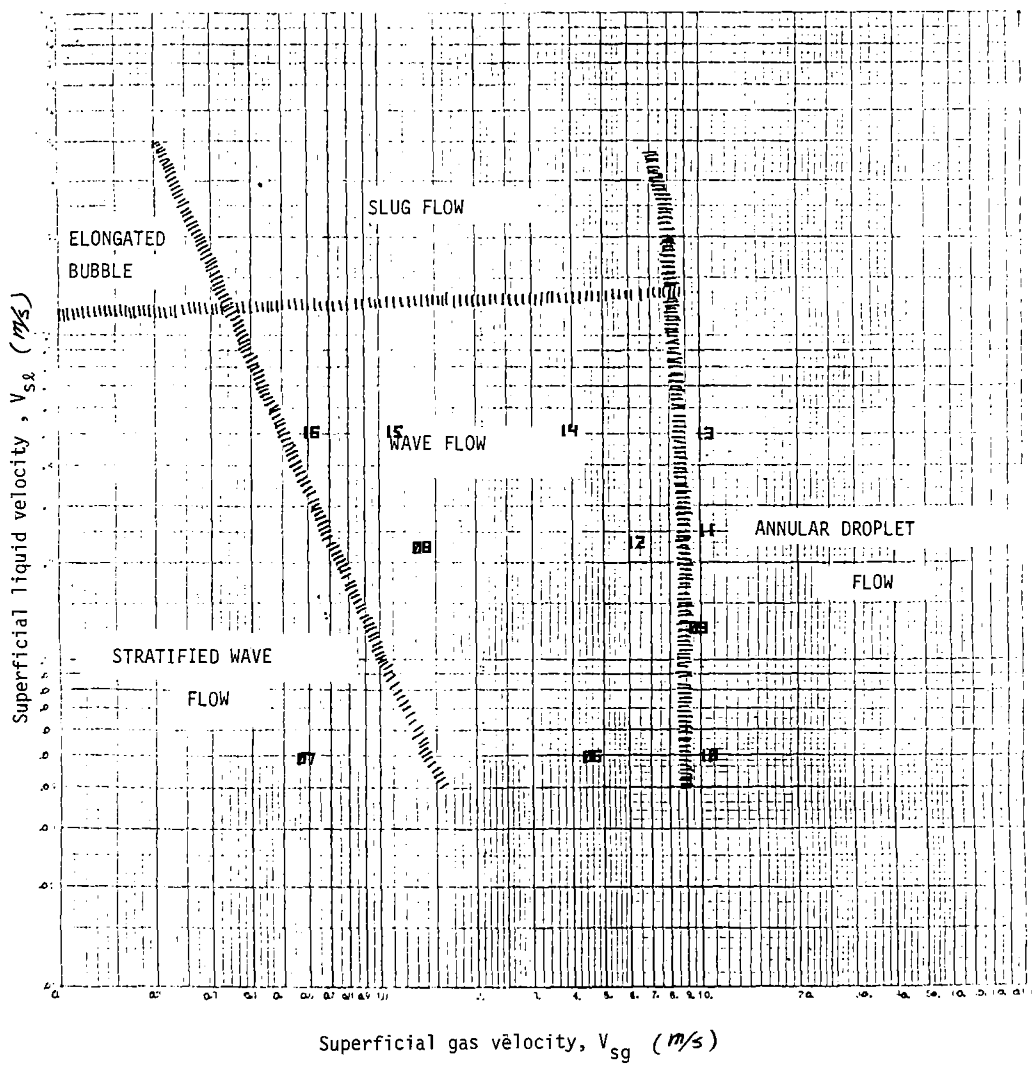

FIGURE 5.1B: IMPEDANCE PROBE FLOW REGIME MAP

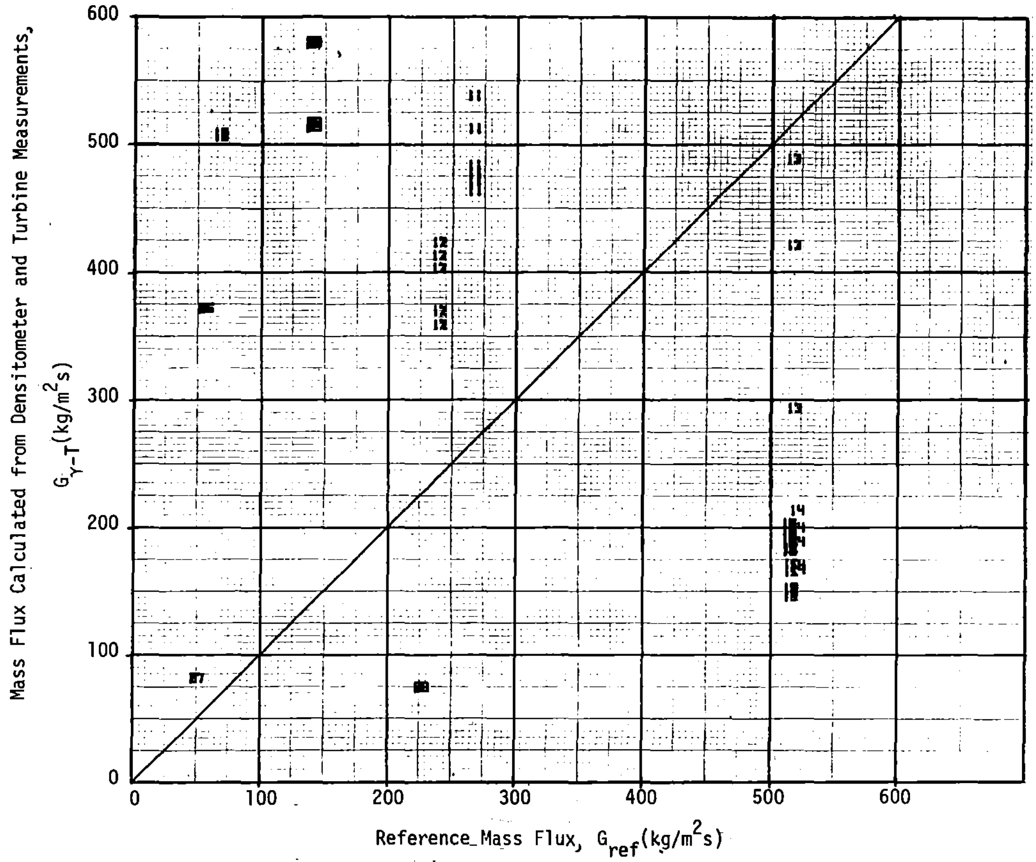

FIGURE 5.2: MASS FLUXES CALCULATED FROM GAMMA-DENSITOMETER AND TURBINE MEASUREMENTS AT DIFFERENT REFERENCE VALUES

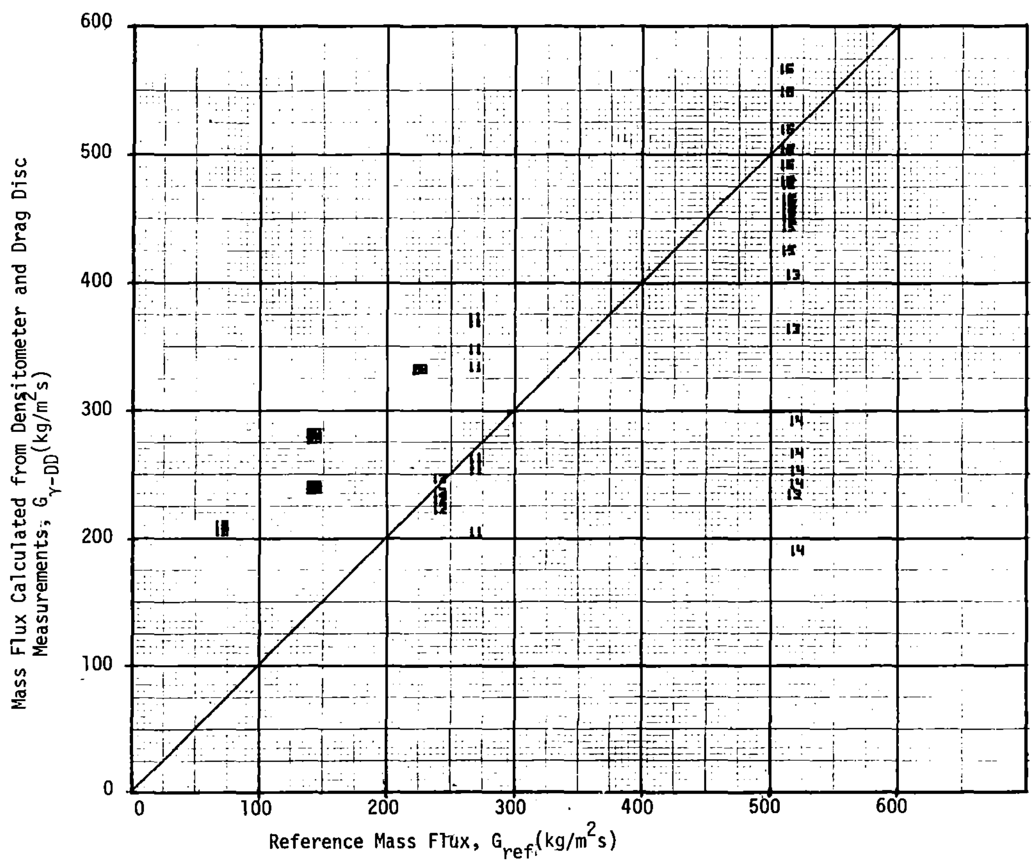

FIGURE 5.3: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

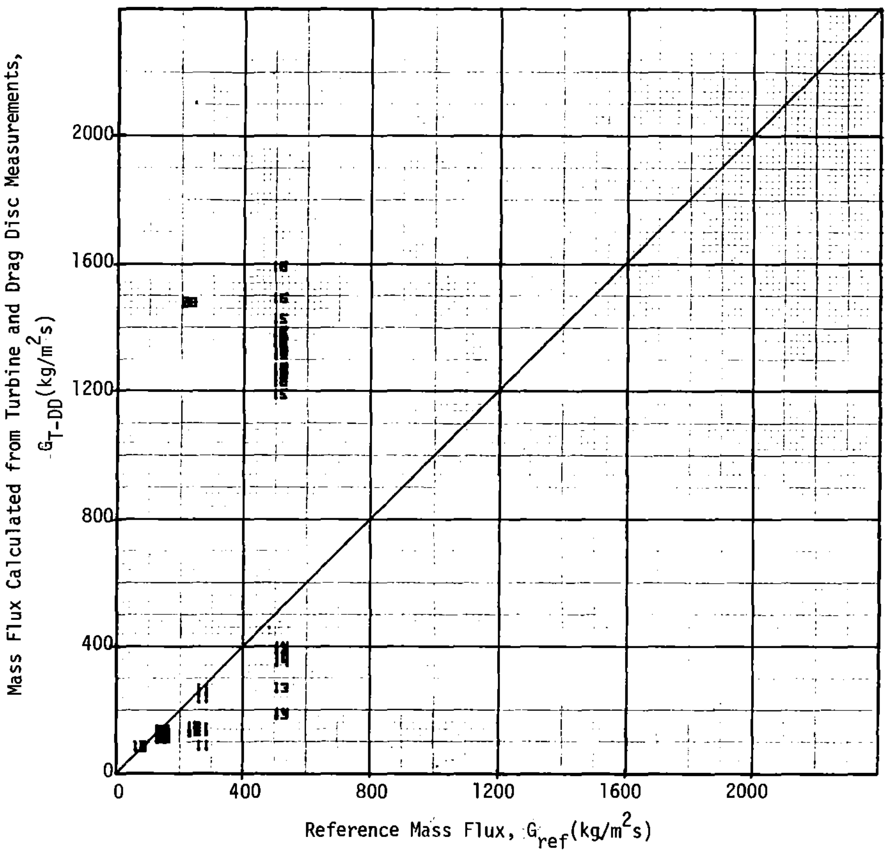

FIGURE 5.4: MASS FLUXES CALCULATED FROM TURBINE AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

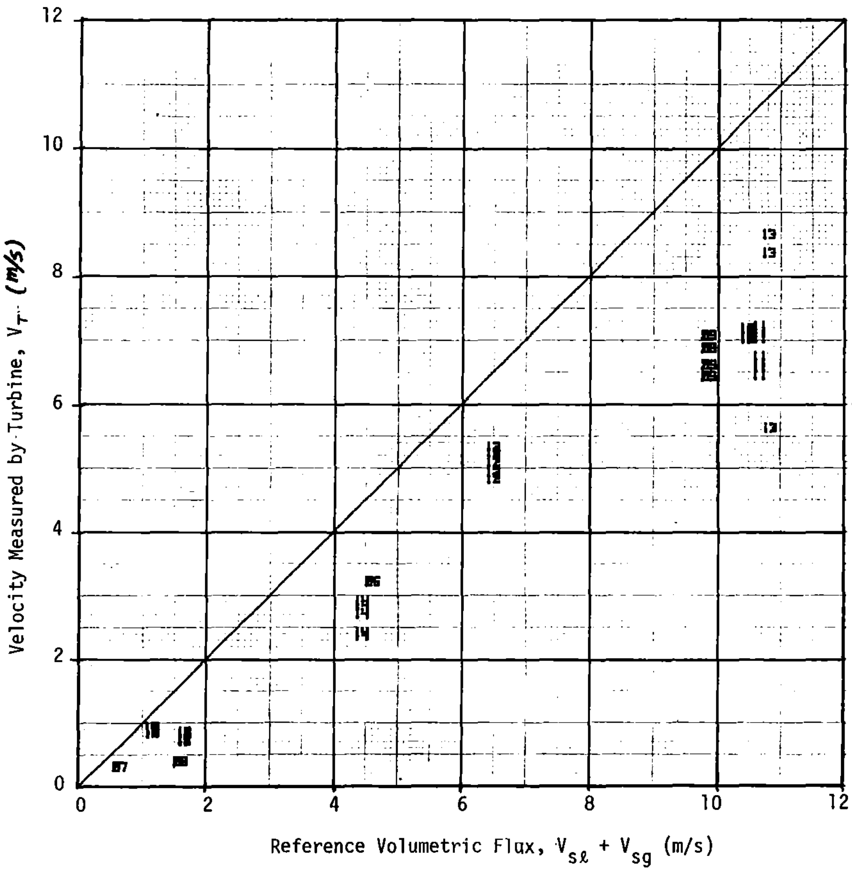

FIGURE 5.5: THE VELOCITIES MEASURED BY TURBINE AT VARIOUS VOLUMETRIC FLUXES

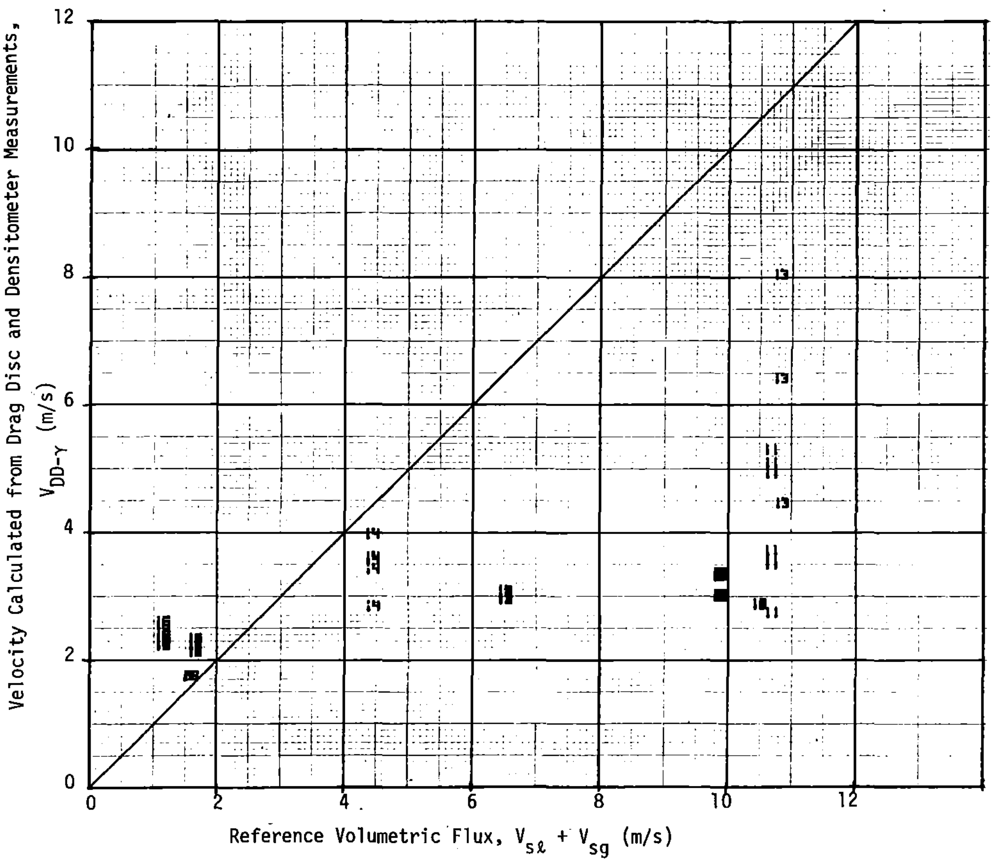

FIGURE 5.6: THE VELOCITIES CALCULATED FROM DRAG DISC AND DENSITOMETER MEASUREMENTS AT DIFFERENT REFERENCE VOLUMETRIC FLUXES

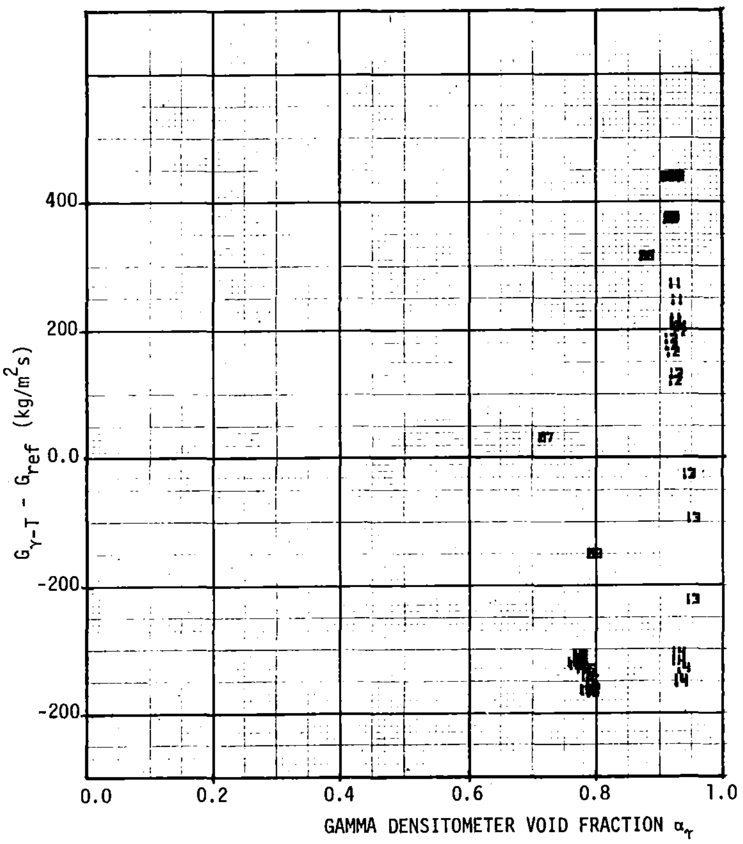

FIGURE 5.8: ERROR IN GAMMA-DENSITOMETER - TURBINE MASS FLOW CALCULATION

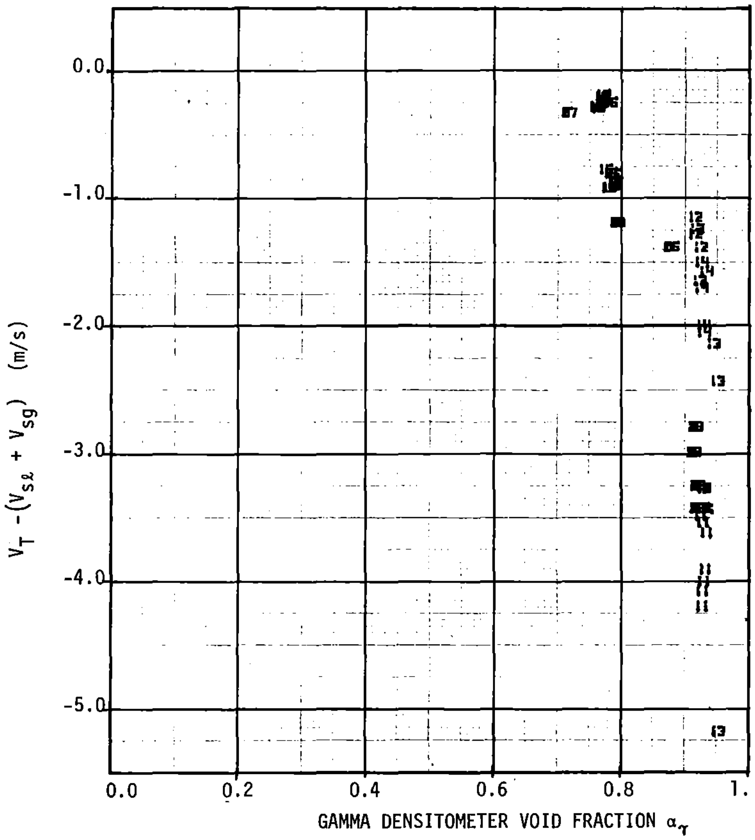

FIGURE 5.9: ERROR IN TURBINE VELOCITY

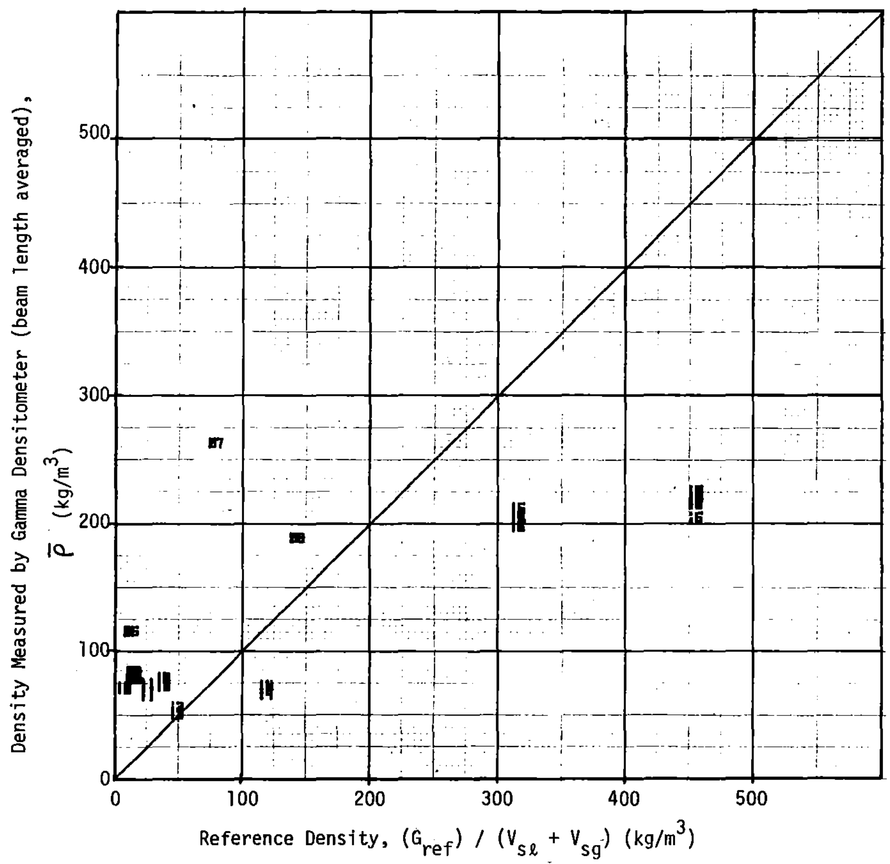

FIGURE 5.10: DENSITY COMPARISONS

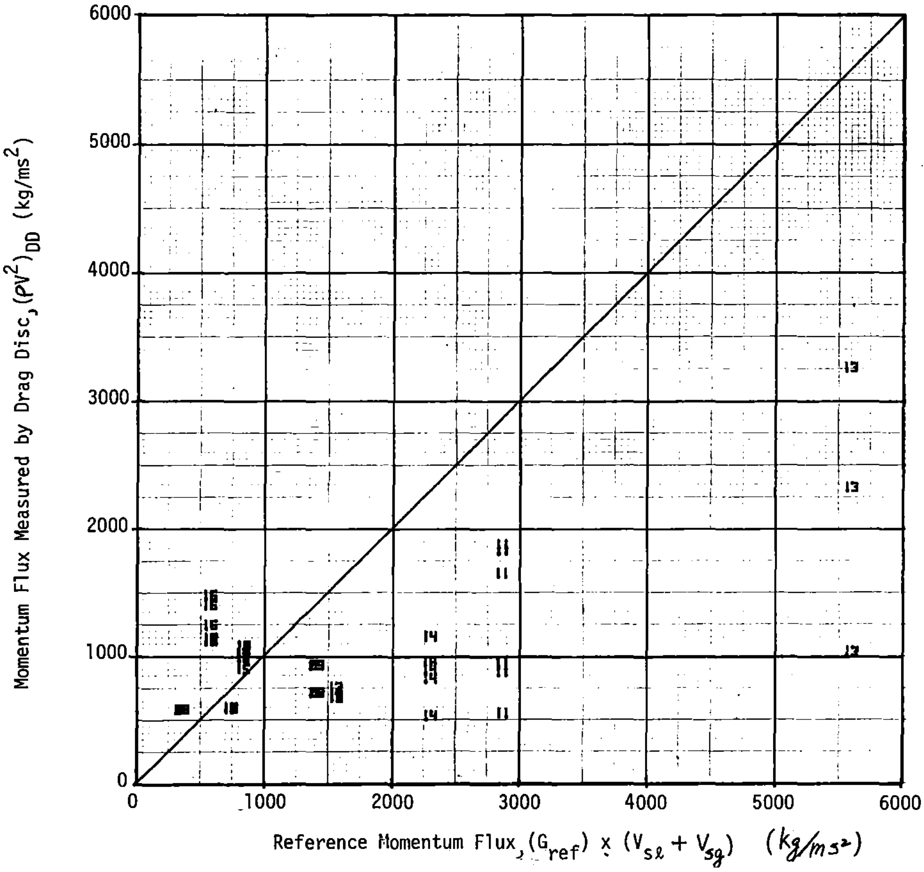

FIGURE 5.11: MOMENTUM FLUX COMPARISONS

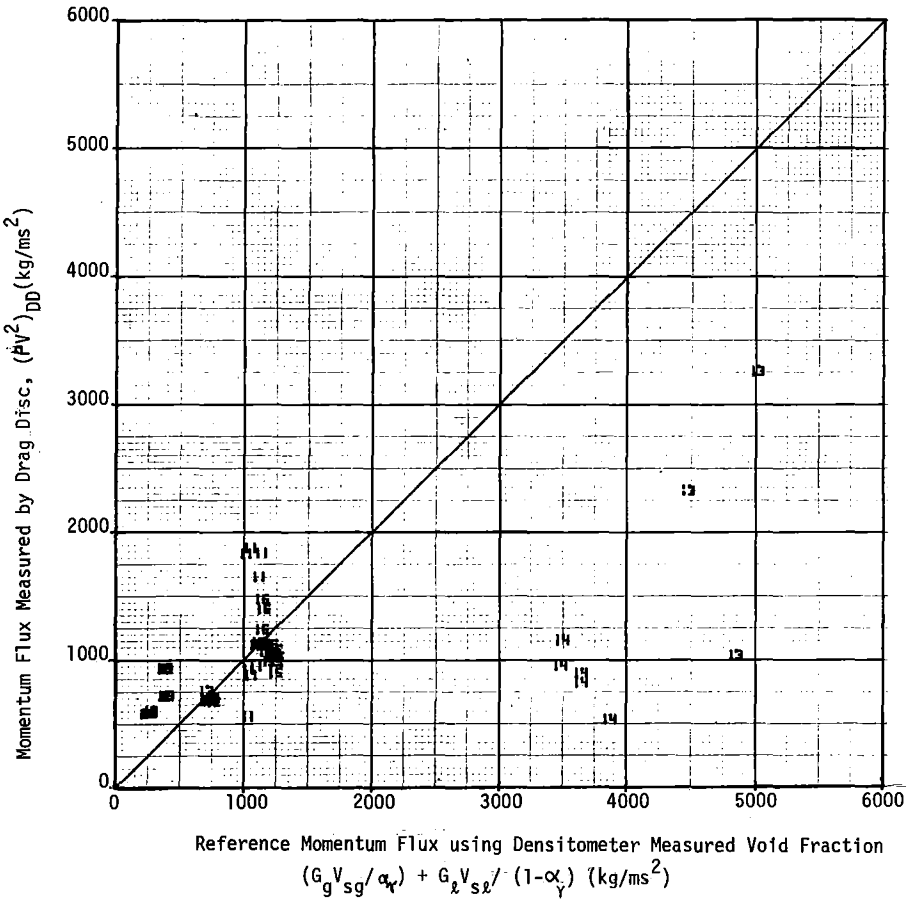

FIGURE 5.12: DRAG DISC MOMENTUM FLUX COMPARISON

6.

FIVE-INCH STEAM-WATER 4 BAR

FLUID: STEAM - WATER
PIPE SIZE= 5 INCH DOUBLE EXTRA STRONG
NOMINAL PRESSURE= 4 BARS

INSIDE DIAMETER= 0.10320 M
TURB. DIA.= 0.0381 M
PIPE AREA= 0.0083647 M↑2

RUN ID TSN	PRESS. (BARS)	TEMP. (DEG C)	FLOW RATES: STEAM SUP-VEL (M/S)	FLOW RATES: STEAM MASS (KG/S)	FLOW RATES: WATER SUP-VEL (M/S)	FLOW RATES: WATER MASS (KG/S)	TURB. VEL (M/S)	DRAG DISK (KG/ M*S↑2)	GAMMA DENSITOMETER A BEAM LOWER (KG/ M↑3)	GAMMA DENSITOMETER B BEAM MIDDLE (KG/ M↑3)	GAMMA DENSITOMETER C BEAM UPPER (KG/ M↑3)	IMPED PROBE (KG/ M↑3)	RADIOTRACER VELOCITIES STEAM (M/S) (AT GAMMA DENS)	RADIOTRACER VELOCITIES WATER (M/S) (AT GAMMA DENS)	Comments
5031	4.4	121.8	5.84	0.115	0.478	3.681	1.13	494	172	56	42	122			
5032	5.6	121.0	10.42	0.257	0.238	1.822	3.74	603	59	19	39	49			
5033	5.6	155.7	0.83	0.020	0.227	1.736	0.16	69	285	132	25	222			T, DD below range
5034	4.2	142.9	0.82	0.015	0.484	3.734	0.45	283	-	-	-				T, DD below range
5035	4.4	146.0	4.49	0.089	0.090	0.693	0.15	133	150	32	38	113			T, DD below range
5050	4.6	144.7	9.90	0.202	0.119	0.915	4.65	784	104	30	47	76			
5051	4.3	145.8	4.53	0.088	0.246	1.899	0.29	206	175	43	39	140			T, DD below range
5052	4.9	154.2	0.76	0.017	0.109	0.837	0.14	288	527	351	54	360			T, DD below range

Dash indicates error in data
Blank indicates no data

TABLE 6.1: PRIMARY ENGINEERING UNIT DATA

5 INCH 4 BAR

RUN ID TSN	GDOT REF (KG/M↑2*S)	GDOT G-T (KG/M↑2*S)	GDOT G-DD (KG/M↑2*S)	GDOT T-DD (KG/M↑2*S)
5031	453.812	104.562	213.510	435.974
5032	248.544	142.268	151.397	161.112
5033	209.930	25.875	104.377	421.052
5034	448.193			634.409
5035	93.488	11.199	99.523	884.409
5050	133.537	277.072	216.045	168.459
5051	237.546	25.483	134.177	706.502
5052	102.096	48.503	310.679	1989.987

TABLE 6.2: MASS FLOW RATE COMPARISON

5 INCH 4 BAR

RUN ID TSN	VSL+VSG (M/S)	TURB. VEL (M/S)	VEL. DD-G (M/S)
5031	6.316	1.133	2.313
5032	10.659	3.741	3.981
5033	1.057	0.165	0.665
5034	1.301	0.445	
5035	4.583	0.151	1.339
5050	10.021	4.654	3.629
5051	4.772	0.292	1.536
5052	0.869	0.145	0.927

TABLE 6.3: TOTAL VELOCITY COMPARISON

5 INCH 4 BAR

RUN ID TSN	DENSITIES (KG/M↑3) VERT AVG GAMMA	LEN AVG GAMMA	IMPED PROBE	VAPOR FRACTIONS ALPHA [illegible]	ALPHA IMPD PROBE	ALPHA THERMO
5031	96.68	92.31	121.75	0.[illegible]	0.87	0.92
5032	38.73	38.03	48.53	0.56	0.95	0.93
5033	165.68	157.08	221.73	0.83	0.76	0.79
5034						0.63
5035	78.13	74.32	112.57	0.92	0.88	0.98
5050	61.44	59.53	75.85	0.94	0.92	0.9[illegible]
5051	91.90	87.35	140.12	0.91	0.85	0.95
5052	350.70	335.26	359.66	0.64	0.61	0.87

TABLE 6.4: VOID FRACTION COMPARISON

5 INCH 4 BAR

RUN ID TSN	V GAS G DENS (M/S)	V LIQ. G DENS (M/S)	SLIP G DENS
5031	6.472	4.879	1.326
5032	10.838	6.188	1.752
5033	0.999	1.342	0.744
5034			
5035	4.875	1.149	4.243
5050	10.559	1.911	5.526
5051	4.988	2.664	1.872
5052	1.194	0.300	3.977

TABLE 6.5: PHASE VELOCITY COMPARISON

RUN ID TSN	From Govier & Aziz Flow Regime Map	From Gamma Densitometer: Flow Regime	From Gamma Densitometer: Interface Location(%)*	From Impedance Probe: Flow Regime	From Impedance Probe: Interface Location(%)*
5031	Slug Flow		-43.38		
5032	Slug Flow		-63.28		
5033	Slug Flow		-23.74		
5034	Slug Flow		-		
5035	Wave Flow		-49.09		
5050	Annular Mist		-55.73		
5051	Slug Flow		-46.28		
5052	Stratified		19.68		

*Pipe Empty: 0.0 cm liquid level is -85.43%

Pipe Full: 10.32 liquid level is 185.43%

Bottom of DTT Housing: 3.255 cm liquid level is 0.0%

Top of DTT Housing: 7.07 cm liquid level is 100.0%

TABLE 6.6: FLOW REGIME COMPARISON

5 INCH 4 BAR

RUN ID TSN	ALPHA GAMMA	GDOT-GDOT G-T REF (KG/M↑2*S)	VT-(VSL+VSG) (M/S)
5031	0.90	-349.25	-5.18
5032	0.96	-106.28	-6.92
5033	0.83	-184.06	-0.89
5034			-0.86
5035	0.92	-82.29	-4.43
5050	0.94	143.53	-5.37
5051	0.91	-212.06	-4.48
5052	0.64	-53.59	-0.72

TABLE 6.7: ERROR CALCULATIONS

5 INCH 4 BAR

RUN ID TSN	LEN AVG GAMMA (KG/M↑3)	GDOT/(VSL+VSG) REF (KG/M↑3)	DRAG DISK (KG/M*S↑2)	(GDOT)X(VSL+VSG) REF (KG/M*S↑2)	(SUM MV/ ALPHA)/AREA (KG/M*S↑2)
5031	92.31	71.85	494	2866.19	2236.26
5032	38.03	23.32	603	2649.27	1681.01
5033	157.08	198.69	69	221.81	280.85
5034		344.38	283	583.31	
5035	74.32	20.40	133	428.42	146.91
5050	59.53	13.33	784	1338.19	464.04
5051	87.35	49.77	206	1133.69	657.13
5052	335.26	117.49	288	88.72	32.40

TABLE 6.8: SINGLE INSTRUMENT CALCULATION

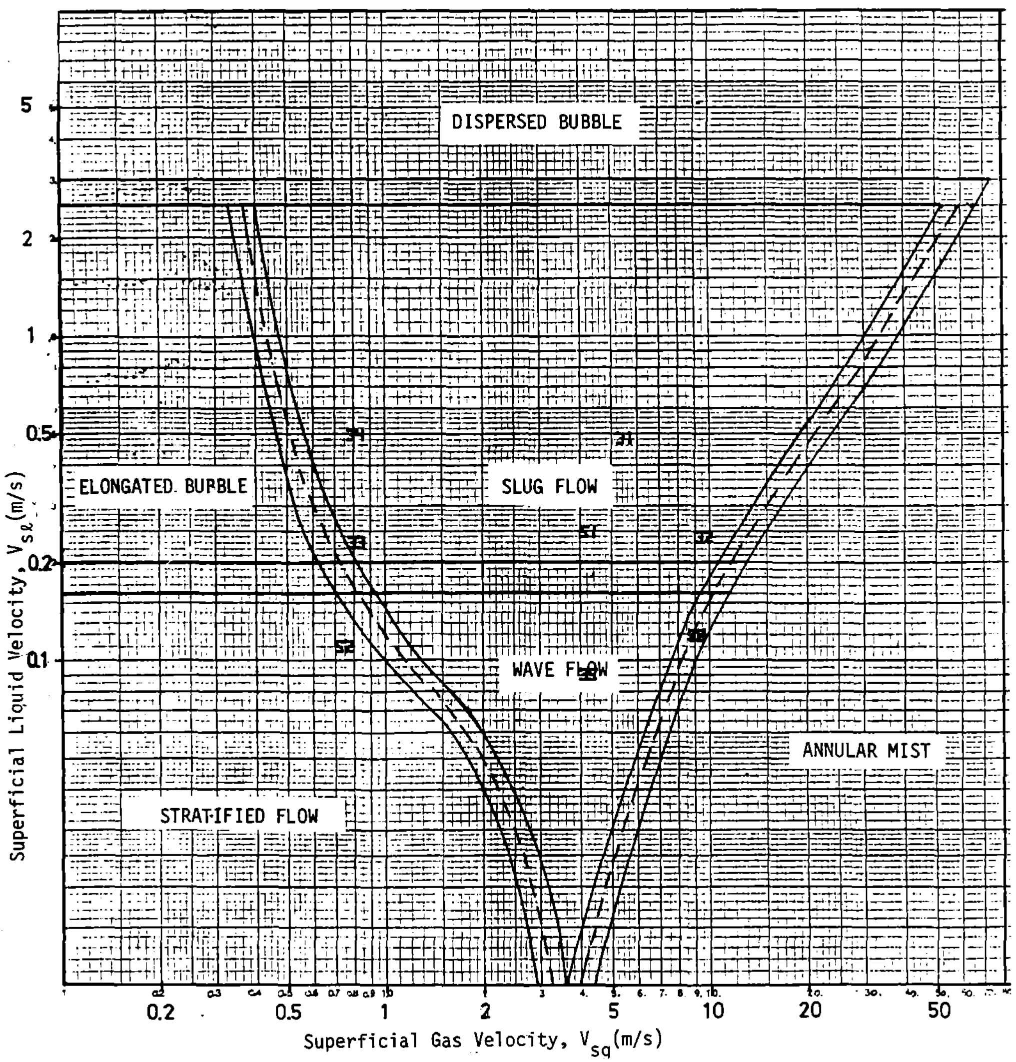

FIGURE 6.1A: GOVIER AND AZIZ FLOW REGIME MAP

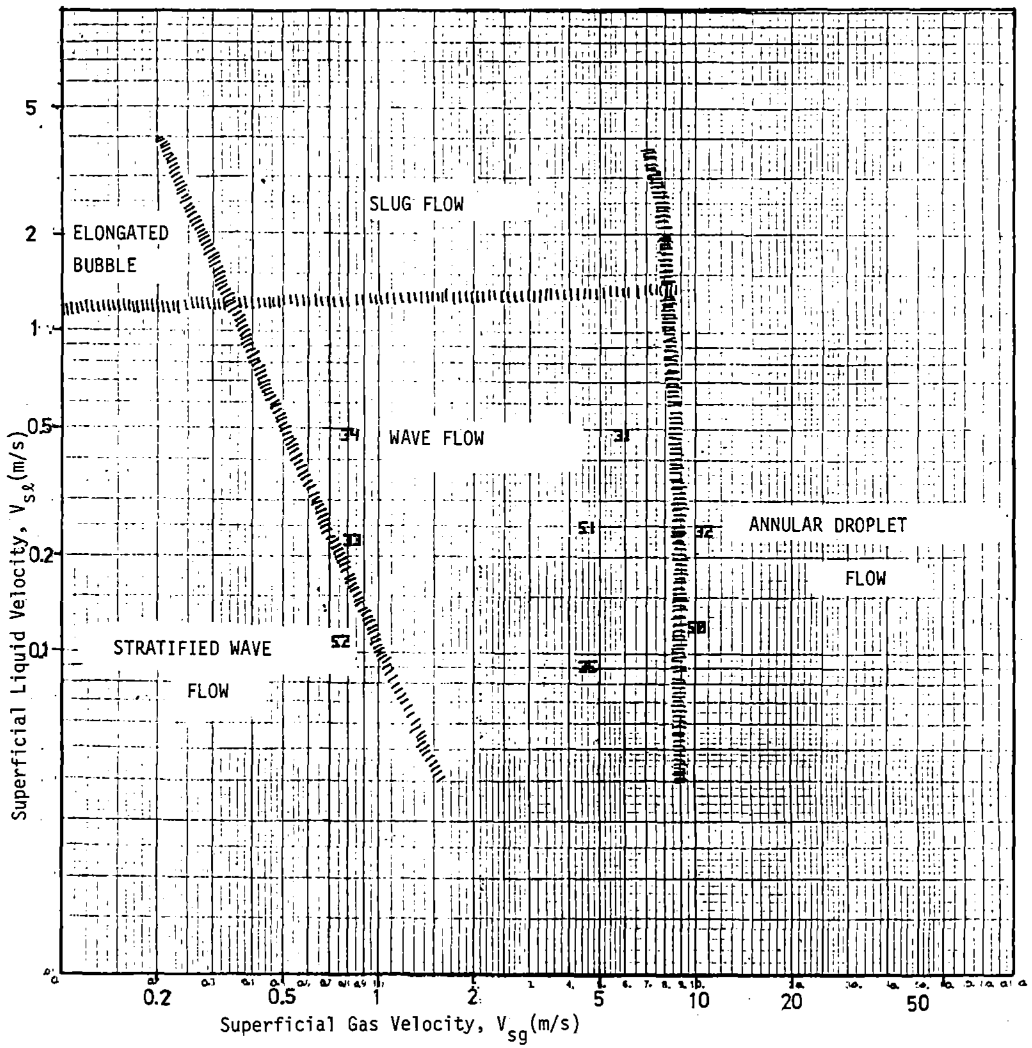

FIGURE 6.1B: IMPEDANCE PROBE FLOW REGIME MAP

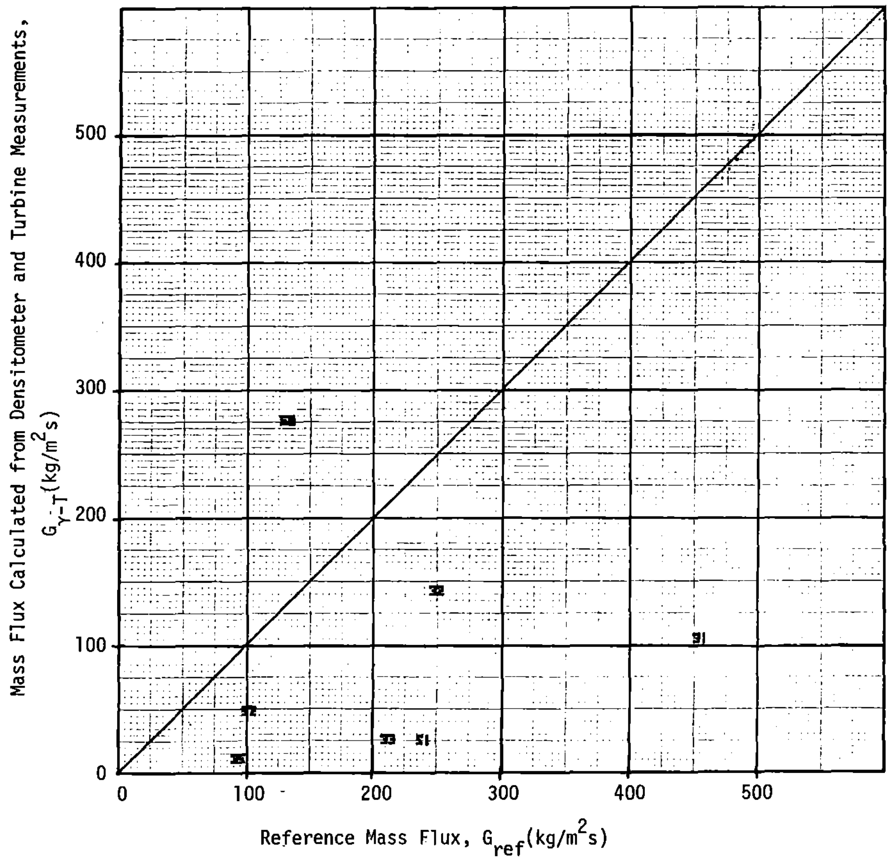

FIGURE 6.2: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND TURBINE MEASUREMENTS AT DIFFERENT REFERENCE VALUES

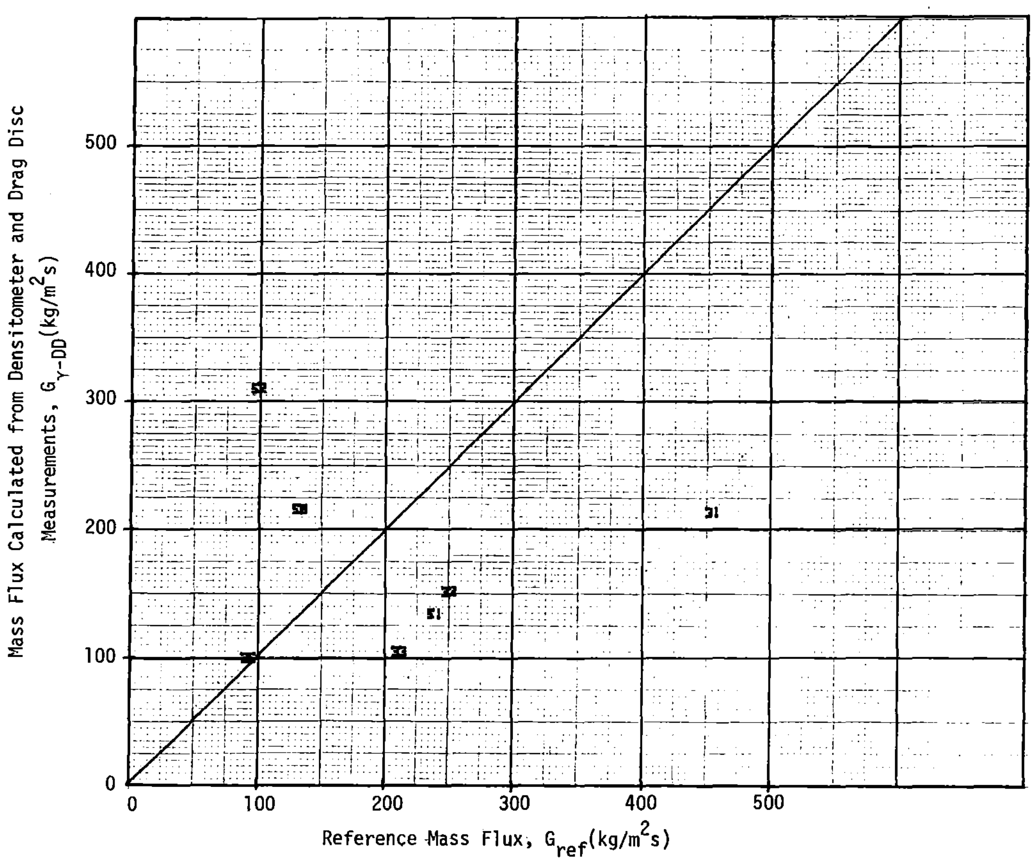

FIGURE 6.3: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

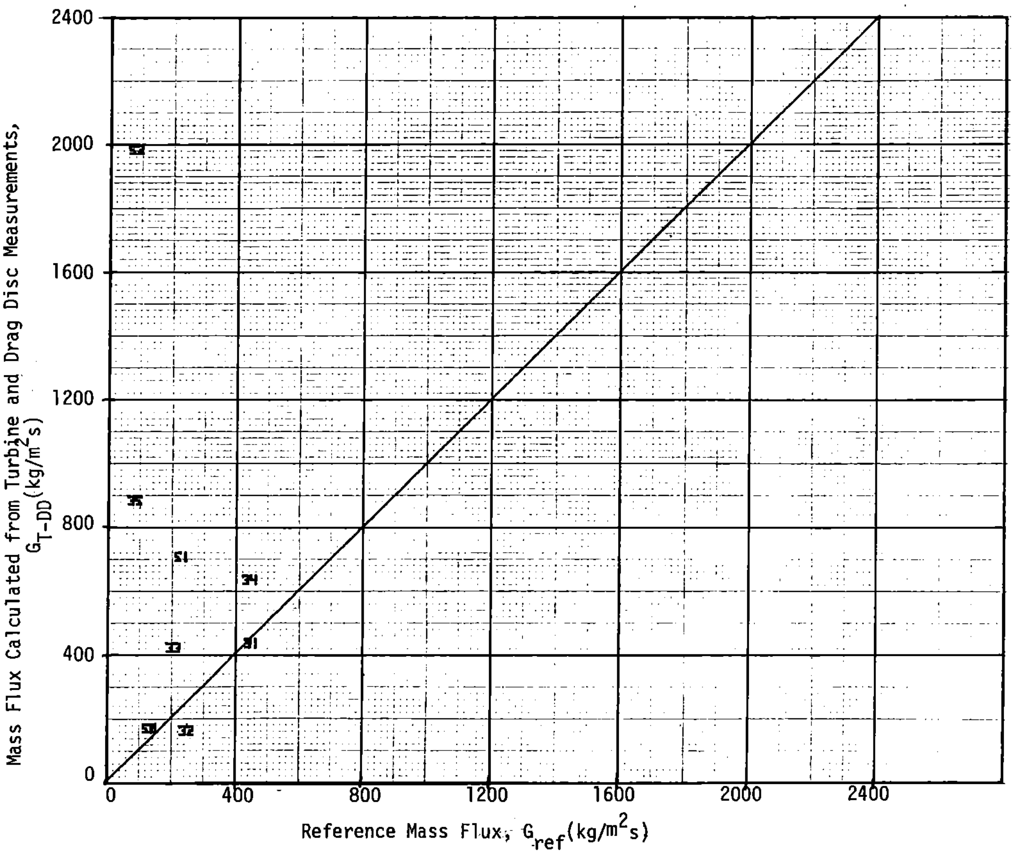

FIGURE 6.4: MASS FLUXES CALCULATED FROM TURBINEAND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

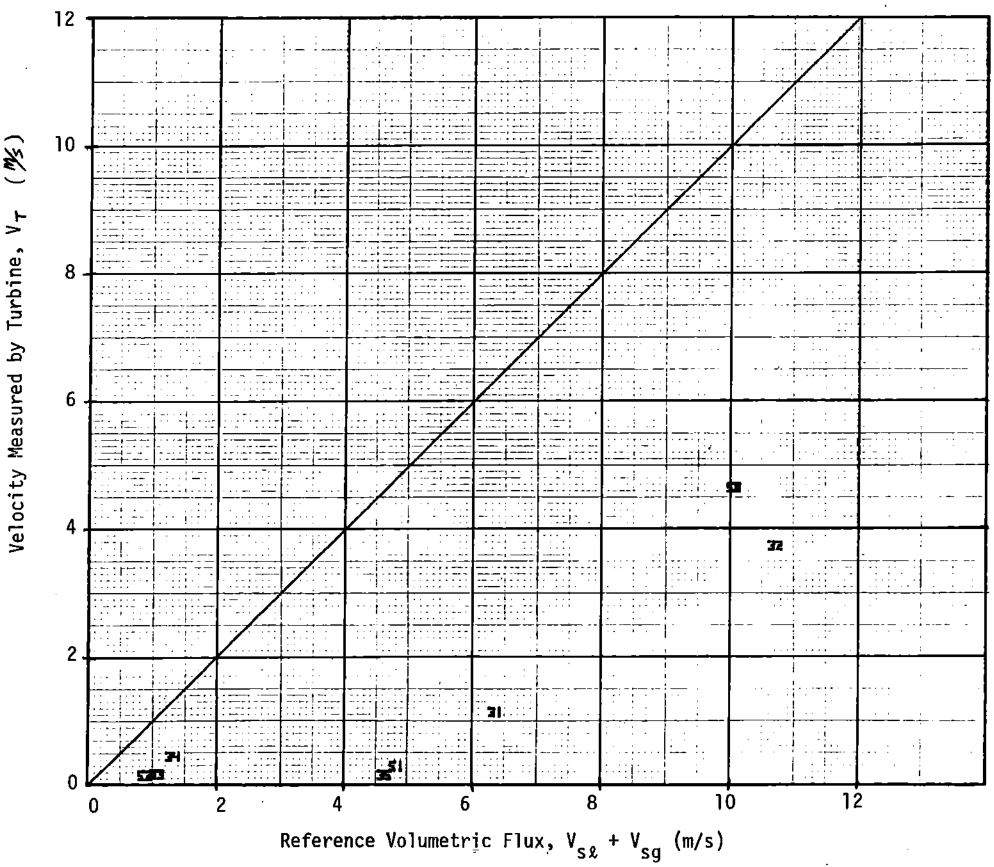

FIGURE 6.5: THE VELOCITIES MEASURED BY TURBINE AT VARIOUS VOLUMETRIC FLUXES

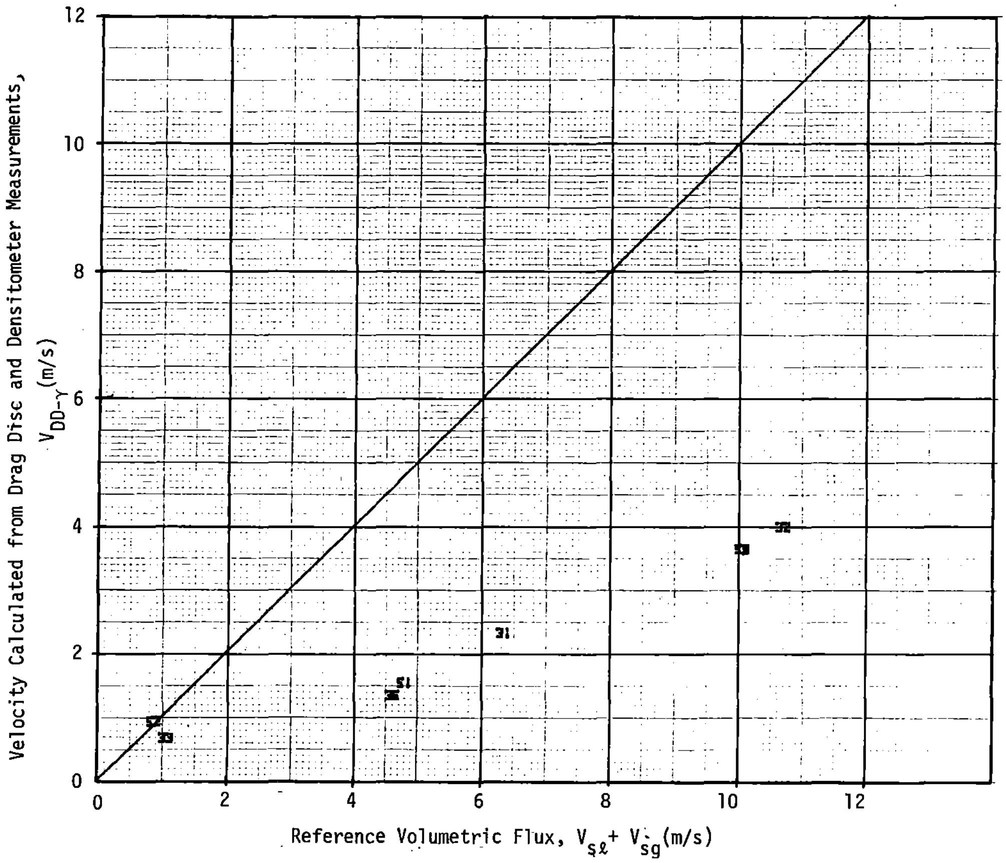

FIGURE 6.6: THE VELOCITIES CALCULATED FROM DRAG DISC AND DENSITOMETER MEASUREMENTS AT DIFFERENT REFERENCE VOLUMETRIC FLUXES

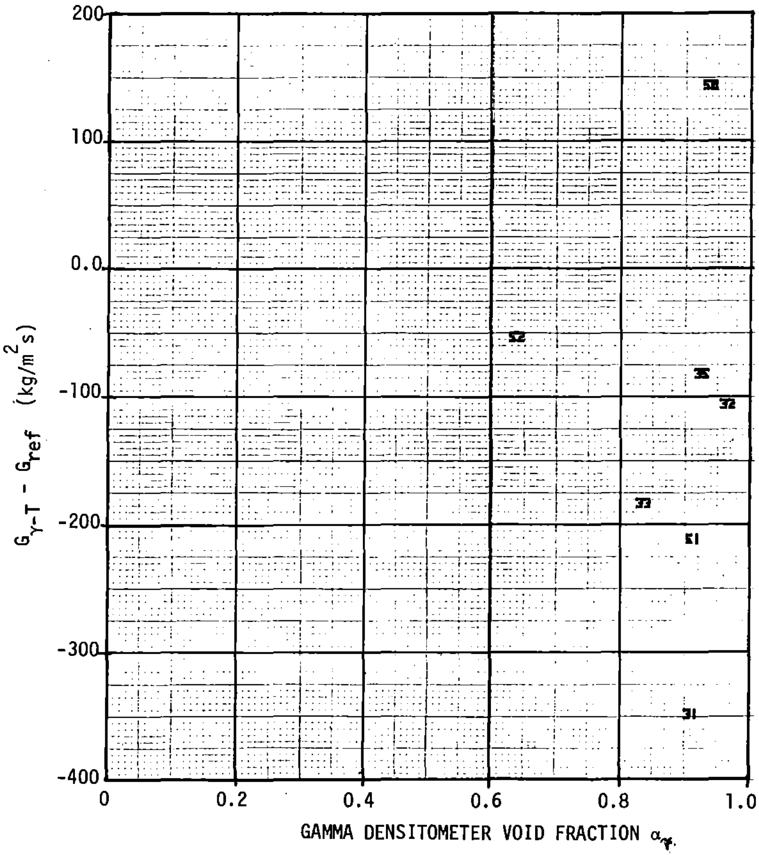

FIGURE 6.8: ERROR IN GAMMA DENSITOMETER - TURBINE MASS FLOW CALCULATION

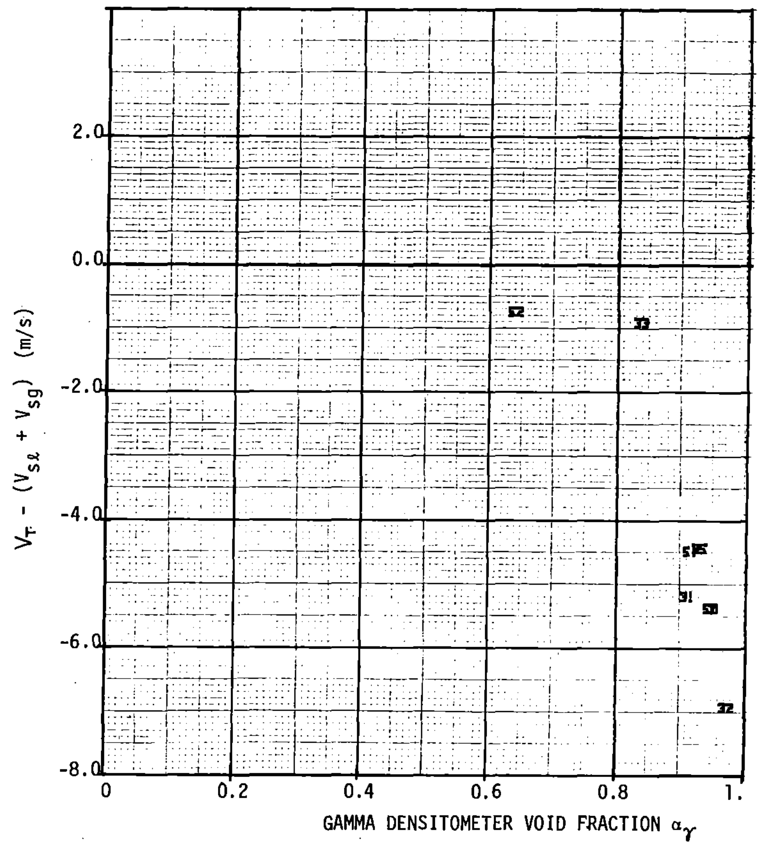

FIGURE 6.9: ERROR IN TURBINE VELOCITY

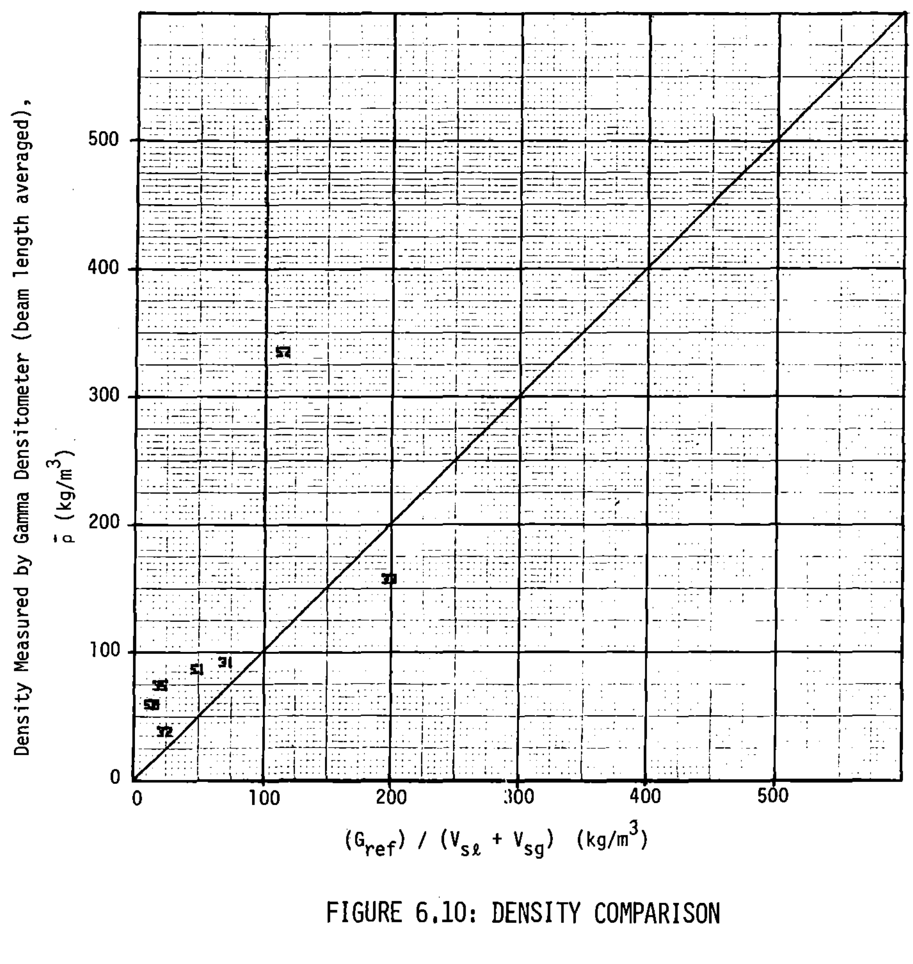

FIGURE 6.10: DENSITY COMPARISON

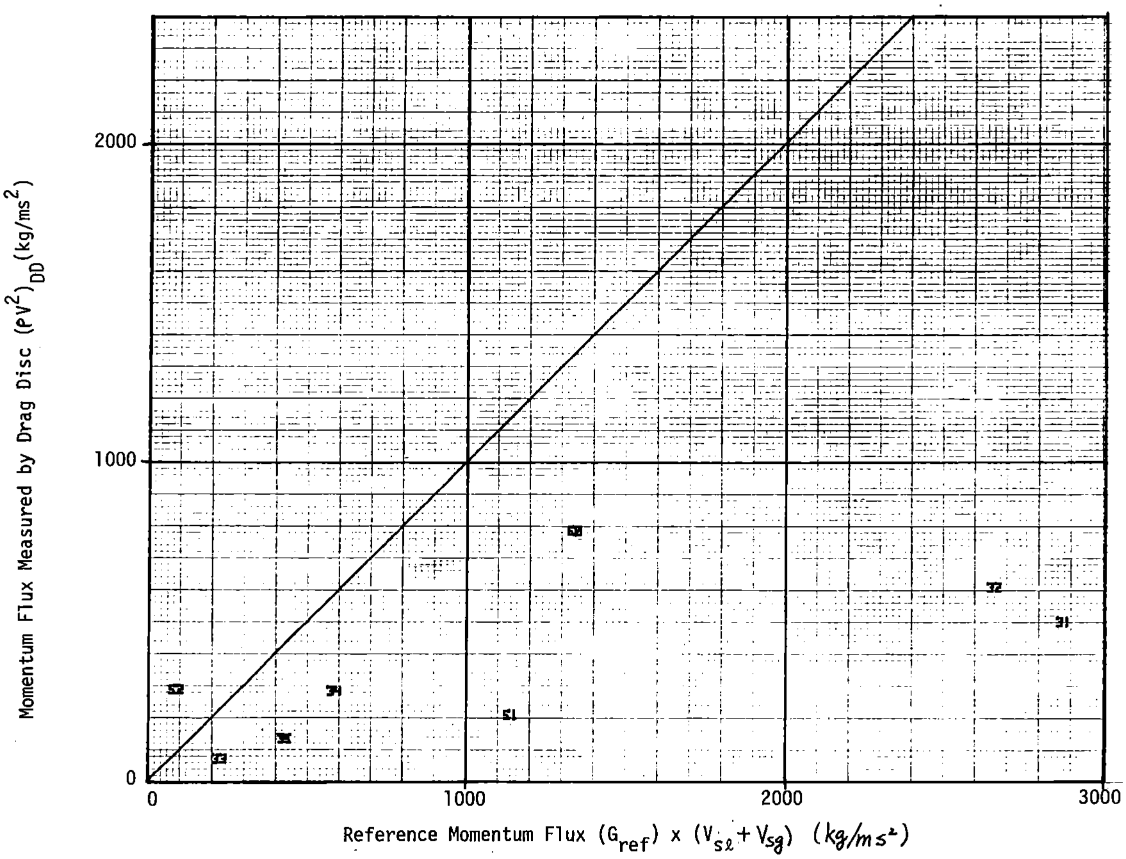

FIGURE 6.11:MOMENTUM FLUX COMPARISONS

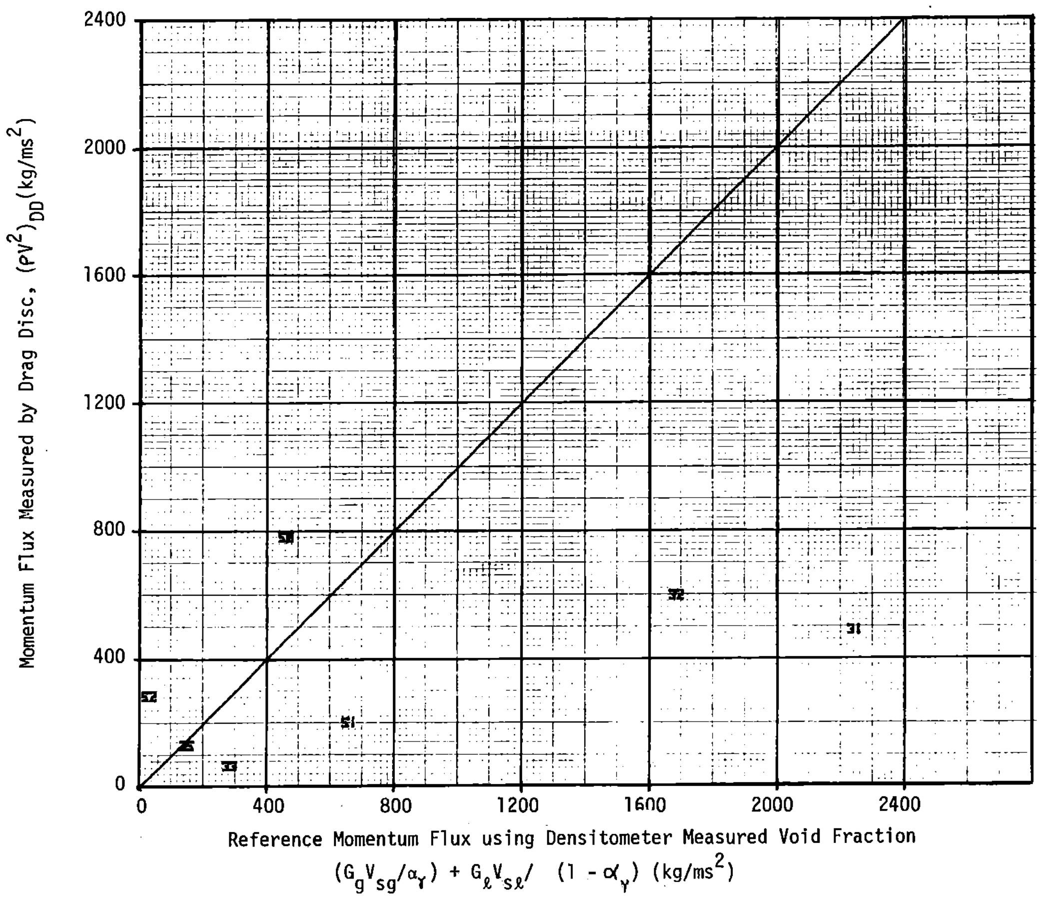

FIGURE 6.12: DRAG DISC MOMENTUM FLUX COMPARISON

7.

FIVE-INCH STEAM-WATER 40 BAR

FLUID: STEAM - WATER
PIPE SIZE= 5 INCH DOUBLE EXTRA STRONG
NOMINAL PRESSURE= 40 BARS

INSIDE DIAMETER= 0.10320 M
TURB. DIA.= 0.0381 M
PIPE AREA= 0.0083647 M↑2

RUN ID TSN	PRESS. (BARS)	TEMP. (DEG C)	FLOW RATES STEAM SUP-VEL (M/S)	FLOW RATES STEAM MASS (KG/S)	FLOW RATES WATER SUP-VEL (M/S)	FLOW RATES WATER MASS (KG/S)	TURB. VEL (M/S)	DRAG DISK (KG/M*S↑2)	GAMMA DENSITOMETER A BEAM LOWER (KG/M↑3)	GAMMA DENSITOMETER B BEAM MIDDLE (KG/M↑3)	GAMMA DENSITOMETER C BEAM UPPER (KG/M↑3)	IMPED PROBE (KG/M↑3)	RADIOTRACER VELOCITIES STEAM (M/S) (AT GAMMA DENS)	RADIOTRACER VELOCITIES WATER (M/S) (AT GAMMA DENS)	Comments
5001	42.1	244.5	9.81	1.742	0.229	1.509	11.13	2533	146	46	33	98			T above range
5002	41.9	247.4	4.91	0.868	0.232	1.531	5.29	607	197	65	40	144			
5004	41.3	244.9	9.83	1.709	0.110	0.730	10.68	2348	96	45	42	59			T above range
5005	41.4	246.0	9.75	1.703	0.054	0.359	10.84	2384	54	37	44				T above range
5037	40.0	247.7	4.77	0.803	0.125	0.833	5.19	577	152	33	8	98			
5038	40.7	248.8	4.83	0.828	0.057	0.377	5.05	571	107	25	10	67			
5039	40.1	247.0	5.07	0.856	0.031	0.208	5.21	514	73	12	2	43			
5040	39.9	247.7	0.99	0.166	0.057	0.377	0.37	126	272	134	10				T, DD below range
5041	40.8	248.8	0.72	0.124	0.135	0.892	0.36	178	226	95	21	98			T, DD below range
5042	40.3	248.8	1.00	0.170	0.244	1.619	0.23	181	238	114	37				T, DD below range
5043	40.1	247.4	9.61	1.625	0.057	0.381	10.60	2065	72	31	41				T above range
5044	40.5	248.5	4.82	0.823	0.498	3.304	5.74	690	225	92	2	160			
5045	40.7	250.6	0.89	0.153	0.503	3.331	0.36	217	293	153	24	206			T, DD below range
5046	39.8	248.8	0.47	0.079	0.505	3.358	0.15	183	350	182	25	229			T, DD below range
5054	40.6	247.0	9.48	1.621	0.223	1.481	10.27	2121	124	36	15	98	11.10	3.30	T above range
5055	40.1	248.1	4.80	0.811	0.228	1.516	4.92	537	179	48	28	136			
5056	40.8	250.3	4.57	0.785	0.122	0.809	4.70	516	163	35	13		4.60	1.40	
5057	40.8	251.7	4.78	0.821	0.054	0.356	4.48	519	122	31	20	67	5.10	1.30	
5058	40.2	248.1	9.54	1.616	0.063	0.417	10.31	2169	91	32	24	51	10.00	2.30	T above range
5059	40.0	246.7	9.44	1.588	0.116	0.769	10.20	2106	112	32	27	74	10.00	2.80	T above range
5060	40.0	247.0	1.08	0.182	0.127	0.842	0.19	107	247	79	3	183	1.30	0.90	T, DD below range
5061	40.0	248.5	0.91	0.153	0.057	0.377	0.18	92	298	153	24	214	1.20	0.30	T, DD below range
5062	40.8	248.5	1.08	0.186	0.232	1.536	0.24	85	242	106	40	183	1.40	1.90	T, DD below range

Dash indicates error in data.
Blank indicates no data.

TABLE 7.1: PRIMARY ENGINEERING UNIT DATA

5 INCH 40 BAR

RUN ID TSN	GDOT REF (KG/M↑2*S)	GDOT G-T (KG/M↑2*S)	GDOT G-DD (KG/M↑2*S)	GDOT T-DD (KG/M↑2*S)
5001	388.657	857.165	441.670	227.579
5002	286.800	550.693	251.356	114.728
5004	291.582	662.674	381.607	219.752
5005	246.512	484.071	326.349	220.016
5037	195.584	350.428	197.472	111.279
5038	144.058	248.849	167.744	113.073
5039	127.201	158.730	125.243	98.821
5040	64.916	55.746	137.136	337.361
5041	121.463	43.890	146.894	491.636
5042	213.875	31.110	157.267	795.013
5043	239.817	505.155	313.703	194.810
5044	493.383	659.954	281.609	120.165
5045	416.512	60.913	190.775	597.496
5046	410.893	30.069	191.203	1215.809
5054	370.844	624.354	359.208	206.663
5055	278.193	433.072	217.371	109.104
5056	190.563	345.032	194.630	109.789
5057	140.710	267.532	176.081	115.891
5058	243.045	518.259	330.251	210.446
5059	281.779	592.189	349.637	206.431
5060	122.419	22.043	111.812	567.166
5061	63.362	29.805	125.360	527.269
5062	205.865	33.114	107.304	347.714

TABLE 7.2: MASS FLOW RATE COMPARISON

5 INCH 40 BAR

RUN ID TSN	VSL+VSG (M/S)	TURB. VEL (M/S)	VEL. DD-G (M/S)
5001	10.043	11.131	5.736
5002	5.139	5.289	2.414
5004	9.937	10.684	6.152
5005	9.806	10.837	7.306
5037	4.896	5.189	2.924
5038	4.887	5.050	3.404
5039	5.106	5.206	4.108
5040	1.046	0.373	0.917
5041	0.854	0.362	1.211
5042	1.247	0.228	1.150
5043	9.671	10.598	6.581
5044	5.319	5.743	2.451
5045	1.396	0.363	1.136
5046	0.976	0.151	0.958
5054	9.699	10.265	5.906
5055	5.028	4.920	2.469
5056	4.690	4.703	2.653
5057	4.835	4.483	2.950
5058	9.606	10.306	6.567
5059	9.551	10.202	6.024
5060	1.209	0.188	0.954
5061	0.965	0.175	0.738
5062	1.314	0.244	0.789

TABLE 7.3: TOTAL VELOCITY COMPARISON

5 INCH 40 BAR

RUN ID TSN	DENSITIES (KG/M↑3) VERT AVG GAMMA	LEN AVG GAMMA	IMPED PROBE	VAPOR FRACTIONS ALPHA GAMMA (LEN)	ALPHA IMPD PROBE	T...	RADIOTRACER APOR FRACTION TEAM	WATER
5001	80.80	77.00	98.15	0.93	0.90	[illegible]		
5002	109.36	104.12	144.28	0.89	0.84	0.95		
5004	63.81	62.03	59.37	0.95	0.95	0.99		
5005	44.98	44.67		0.97		0.99		
5037	72.34	67.53	97.62	0.94	0.90	0.97		
5038	52.55	49.28	66.87	0.96	0.94	0.95		
5039	32.86	30.49	43.38	0.99	0.97	0.99		
5040	158.25	149.60		0.83		0.95		
5041	128.07	121.27	97.81	0.87	0.90	0.64		
5042	143.36	136.71		0.85		0.60		
5043	48.70	47.67		0.96		0.99		
5044	122.31	114.91	159.62	0.88	0.82	0.91		
5045	176.86	167.99	206.00	0.81	0.76	0.64		
5046	210.24	199.55	229.38	0.77	0.73	0.48		
5054	64.47	60.82	97.76	0.95	0.90	0.99	0.85	0.93
5055	93.10	88.02	136.37	0.91	0.85	0.95		
5056	78.42	73.37		0.93		0.97	0.99	0.91
5057	63.10	59.68	66.91	0.95	0.94	0.99	0.94	0.96
5058	52.52	50.29	51.21	0.96	0.96	0.99	0.95	0.97
5059	60.89	58.04	74.37	0.95	0.93	0.99	0.94	0.96
5060	125.31	117.17	182.85	0.87	0.79	0.90	0.83	0.86
5061	178.93	169.90	213.84	0.81	0.75	0.94	0.76	0.81
5062	142.65	135.93	182.81	0.85	0.79	0.82	0.77	0.88

TABLE 7.4: VOID FRACTION COMPARISON

5 INCH 40 BAR

RUN ID TSN	V GAS G DENS (M/S)	V GAS RADIO (M/S)	V LIQ. G DENS (M/S)	V LIQ. RADIO (M/S)	SLIP G DENS	SLIP RADIO
5001	10.583		3.147		3.363	
5002	5.502		2.147		2.562	
5004	10.382		2.060		5.039	
5005	10.063		1.756		5.731	
5037	5.082		2.048		2.481	
5038	5.017		1.525		3.291	
5039	5.143		2.349		2.190	
5040	1.188		0.339		3.504	
5041	0.828		1.032		0.802	
5042	1.181		1.620		0.729	
5043	9.969		1.618		6.159	
5044	5.493		4.072		1.349	
5045	1.104		2.630		0.420	
5046	0.613		2.180		0.281	
5054	9.998	11.10	4.272	3.30	2.340	3.364
5055	5.261		2.604		2.020	
5056	4.904	4.60	1.784	1.40	2.749	3.286
5057	5.037	5.10	1.058	1.30	4.762	3.923
5058	9.929	10.00	1.617	2.30	6.140	4.348
5059	9.922	10.00	2.363	2.80	4.198	3.571
5060	1.238	1.30	1.011	0.90	1.225	1.444
5061	1.126	1.20	0.293	0.30	3.838	4.000
5062	1.272	1.40	1.550	1.90	0.820	0.737

TABLE 7.5: PHASE VELOCITY COMPARISON

RUN ID TSN	From Govier & Aziz Flow Regime Map	From Gamma Densitometer: Flow Regime	Interface Location(%)*	From Impedance Probe: Flow Regime	Interface Location(%)*
5001	Slug Flow		-52.26	Strat. Mist	-64
5002	Slug Flow		-40.40	Wave	-42
5004	Annular Mist		-59.83	Strat. Mist	-66
5005	Annular Mist		-67.53	Strat. Mist	-75
5037	Wave Flow		-55.73	Wave	-53
5038	Wave Flow		-63.65	Wave	-72
5039	Wave Flow		-77.22	Wave	-79
5040	Stratified Flow		-23.17		
5041	Stratified Flow		-34.72	Strat.→ Wave	-35
5042	Slug Flow		-29.33		
5043	Annular Mist		-63.65	Strat. Mist	-75
5044	Slug Flow		-37.33	Wave	-37
5045	Slug Flow		-19.14	Wave	-18
5046	Elongated Bubble		- 9.01	Strat.→ Wave	-13
5054	Slug Flow		-59.83	Strat. Mist	-64
5055	Slug Flow		-46.28	Wave	-42
5056	Wave Flow		-52.26	Wave	-56
5057	Wave Flow		-59.83	Wave	-66
5058	Annular Mist		-63.65	Strat. Mist	-77
5059	Annular Mist		-59.83	Strat. Mist	-66
5060	Wave Flow		-34.72	Strat.→ Wave	-31
5061	Stratified Flow		-19.14	Wave	-18
5062	Slug Flow		-29.33	Wave	-66

TABLE 7.6: FLOW REGIME COMPARISON

5 INCH 40 BAR

RUN ID TSN	ALPHA GAMMA	GDOT-GDOT G-T REF (KG/M↑2*S)	VT-(VSL+VSG) (M/S)
5001	0.93	468.51	1.09
5002	0.89	263.89	0.15
5004	0.95	371.09	0.75
5005	0.97	237.56	1.03
5037	0.94	154.84	0.29
5038	0.96	104.79	0.16
5039	0.99	31.53	0.10
5040	0.83	-9.17	-0.67
5041	0.87	-77.57	-0.49
5042	0.85	-182.76	-1.02
5043	0.96	265.34	0.93
5044	0.88	166.57	0.42
5045	0.81	-355.60	-1.03
5046	0.77	-380.82	-0.83
5054	0.95	253.51	0.57
5055	0.91	154.88	-0.11
5056	0.93	154.47	0.01
5057	0.95	126.82	-0.35
5058	0.96	275.21	0.70
5059	0.95	310.41	0.65
5060	0.87	-100.38	-1.02
5061	0.81	-33.56	-0.79
5062	0.85	-172.75	-1.07

TABLE 7.7: ERROR CALCULATIONS

5 INCH 40 BAR

RUN ID TSN	LEN AVG GAMMA (KG/M↑3)	GDOT/(VSL+VSG) REF (KG/M↑3)	DRAG DISK (KG/M*S↑2)	(GDOT)X(VSL+VSG) REF (KG/M*S↑2)	(SUM MV/ ALPHA)/AREA (KG/M*S↑2)
5001	77.00	38.70	2533	3903.15	2771.62
5002	104.12	55.80	607	1473.98	963.70
5004	62.03	29.34	2348	2897.32	2301.18
5005	44.67	25.14	2384	2417.32	2124.25
5037	67.53	39.95	577	957.53	691.66
5038	49.28	29.48	571	704.04	565.47
5039	30.49	24.91	514	649.51	584.68
5040	149.60	62.07	126	67.90	38.87
5041	121.27	142.18	178	103.76	122.29
5042	136.71	171.49	181	266.74	337.50
5043	47.67	24.80	2065	2319.33	2009.65
5044	114.91	92.75	690	2624.49	2149.00
5045	167.99	298.39	217	581.39	1067.50
5046	199.55	420.82	183	401.20	880.95
5054	60.82	38.24	2121	3596.72	2694.11
5055	88.02	55.33	537	1398.73	982.06
5056	73.37	40.63	516	893.75	632.63
5057	59.68	29.10	519	680.32	539.61
5058	50.29	25.30	2169	2334.70	1998.82
5059	58.04	29.50	2106	2691.33	2100.60
5060	117.17	101.22	107	148.05	128.67
5061	169.90	65.66	92	61.14	33.81
5062	135.93	156.73	85	270.41	312.96

TABLE 7.8: SINGLE INSTRUMENT CALCULATION

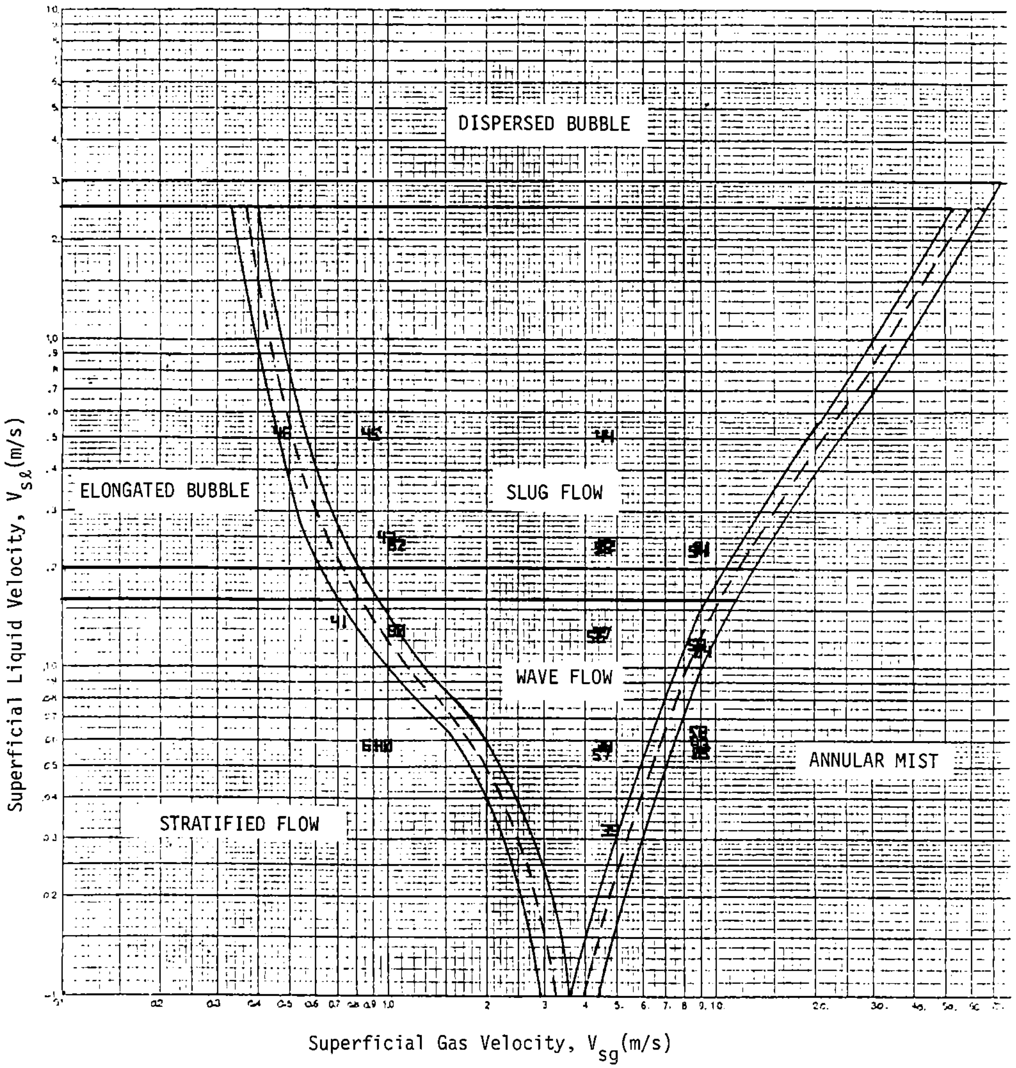

FIGURE 7.1A: GOVIER AND AZIZ FLOW REGIME MAP

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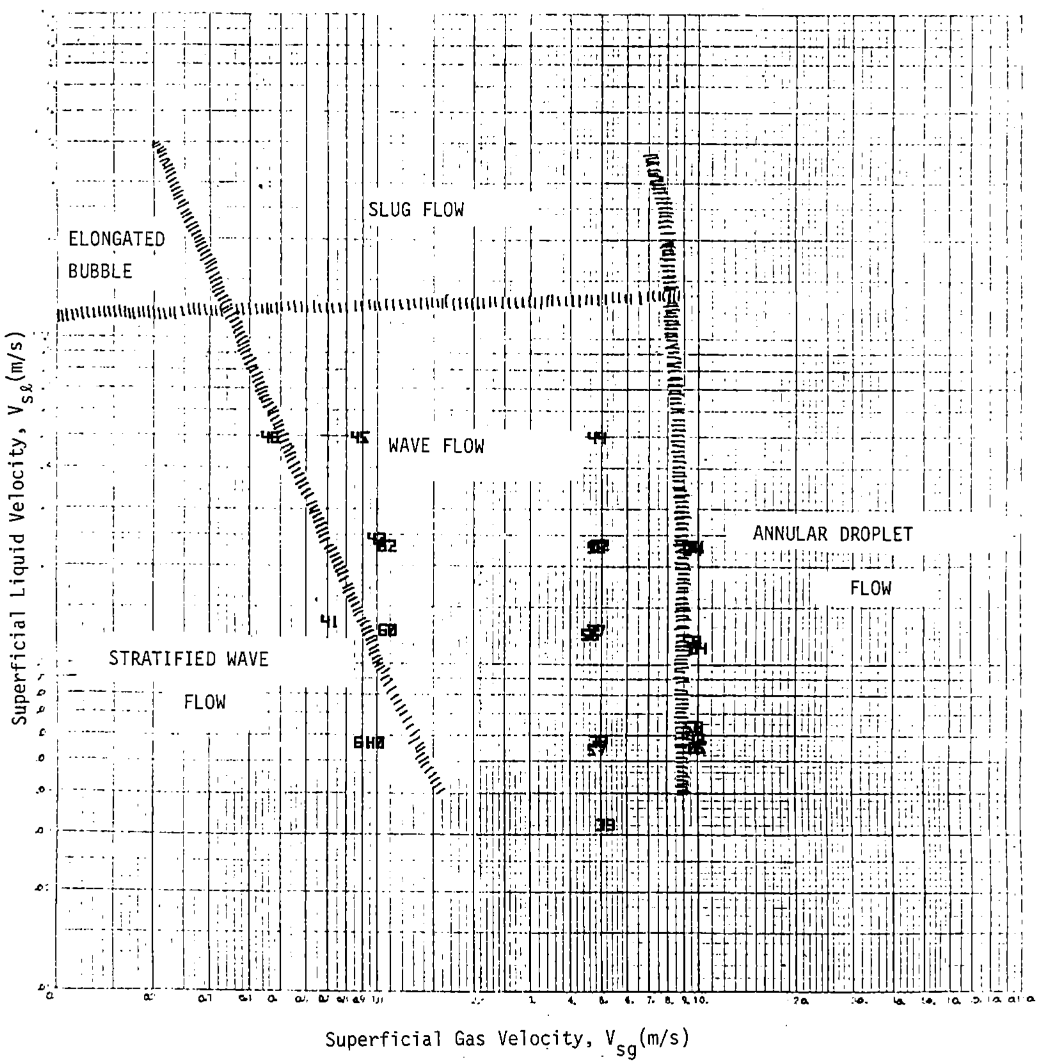

FIGURE 7.1B: IMPEDANCE PROBE FLOW REGIME MAP

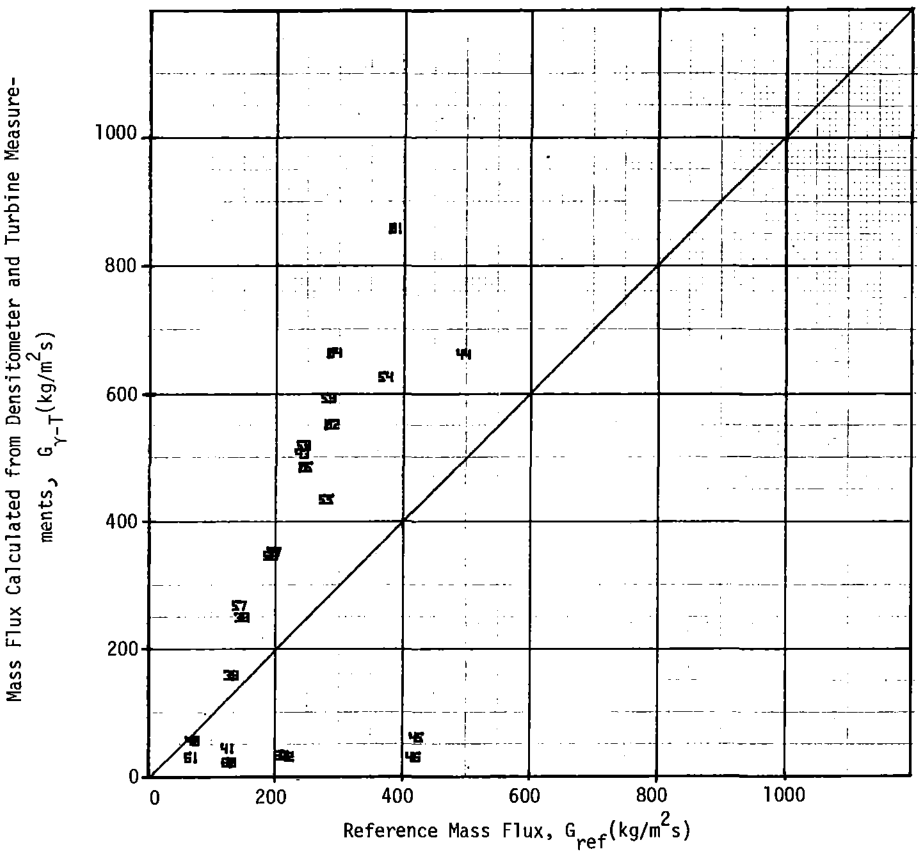

FIGURE 7.2: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND TURBINE MEASUREMENTS AT DIFFERENT REFERENCE VALUES

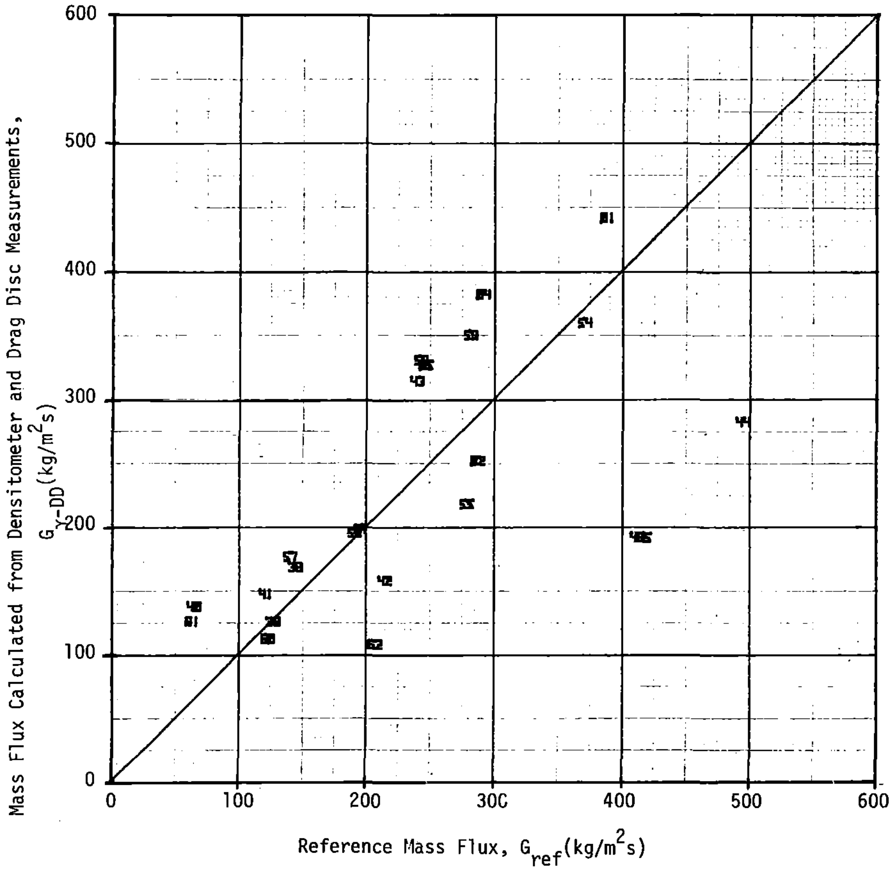

FIGURE 7.3: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

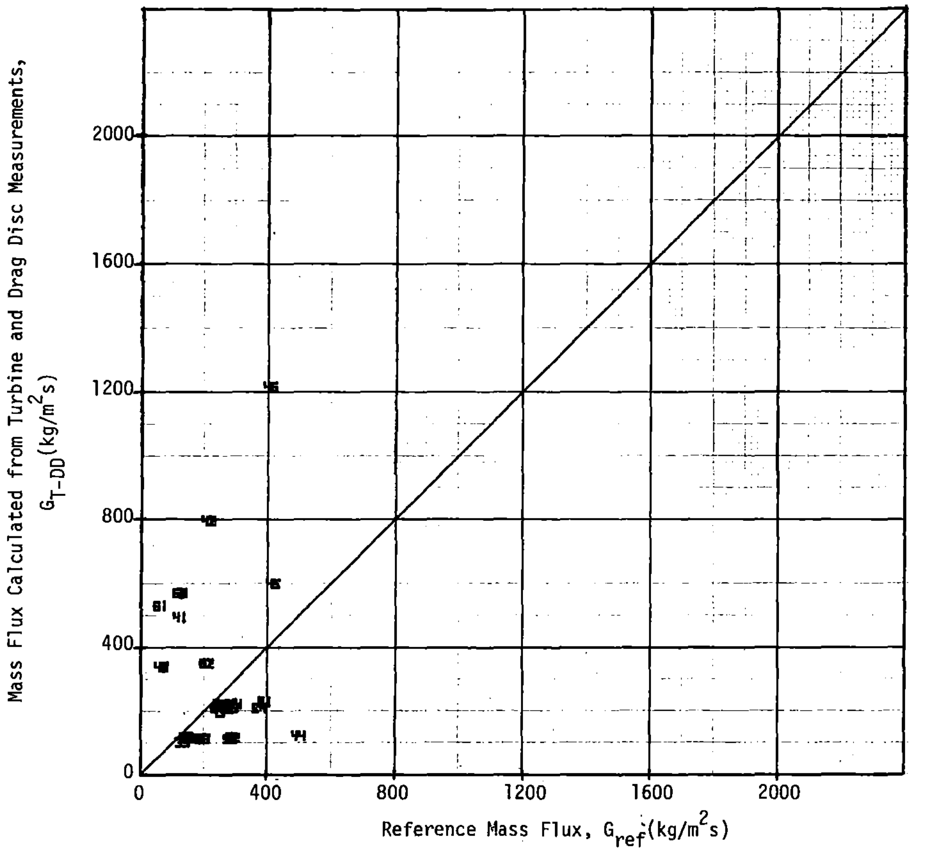

FIGURE 7.4: MASS FLUXES CALCULATED FROM TURBINE AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

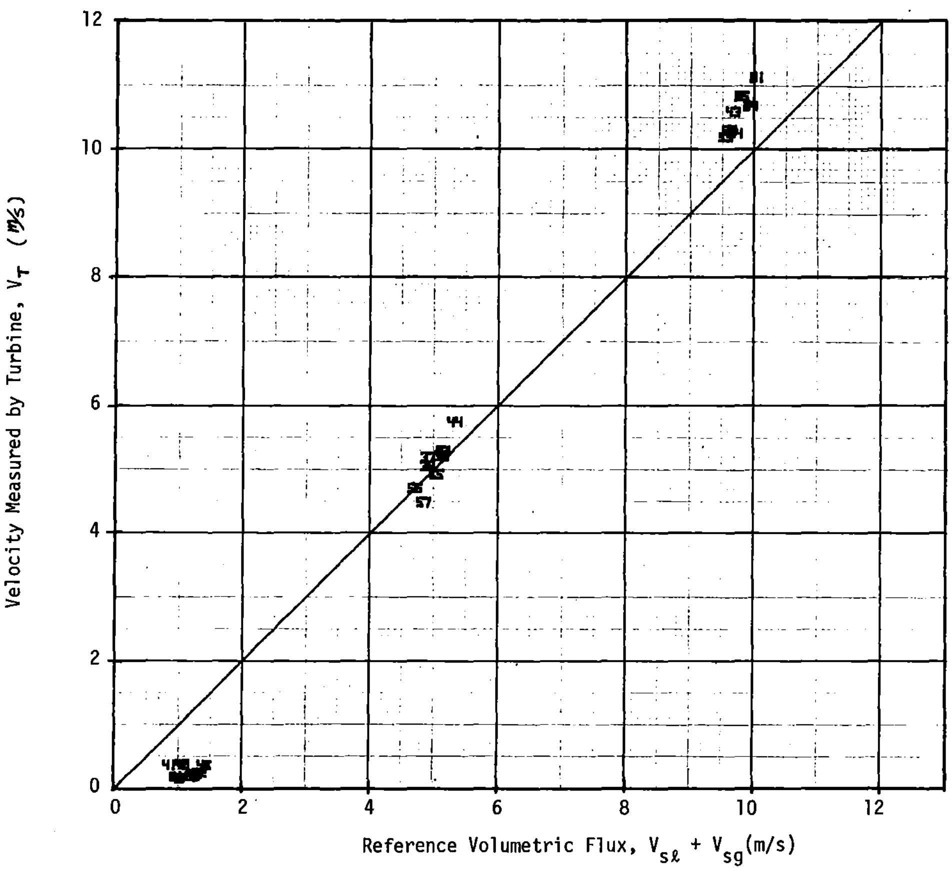

FIGURE 7.5: THE VELOCITIES MEASURED BY TURBINE AT VARIOUS VOLUMETRIC FLUXES

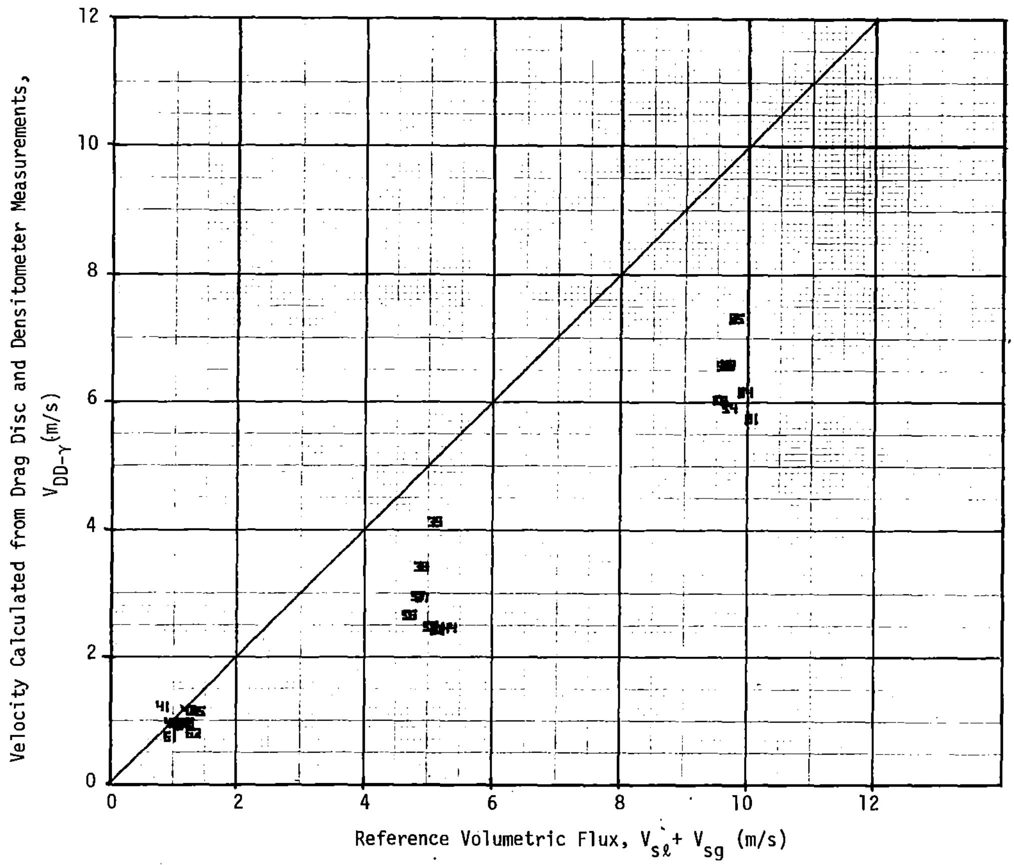

FIGURE 7.6: THE VELOCITIES CALCULATED FROM DRAG DISC AND DENSITOMETER MEASUREMENTS AT DIFFERENT REFERENCE VOLUMETRIC FLUXES

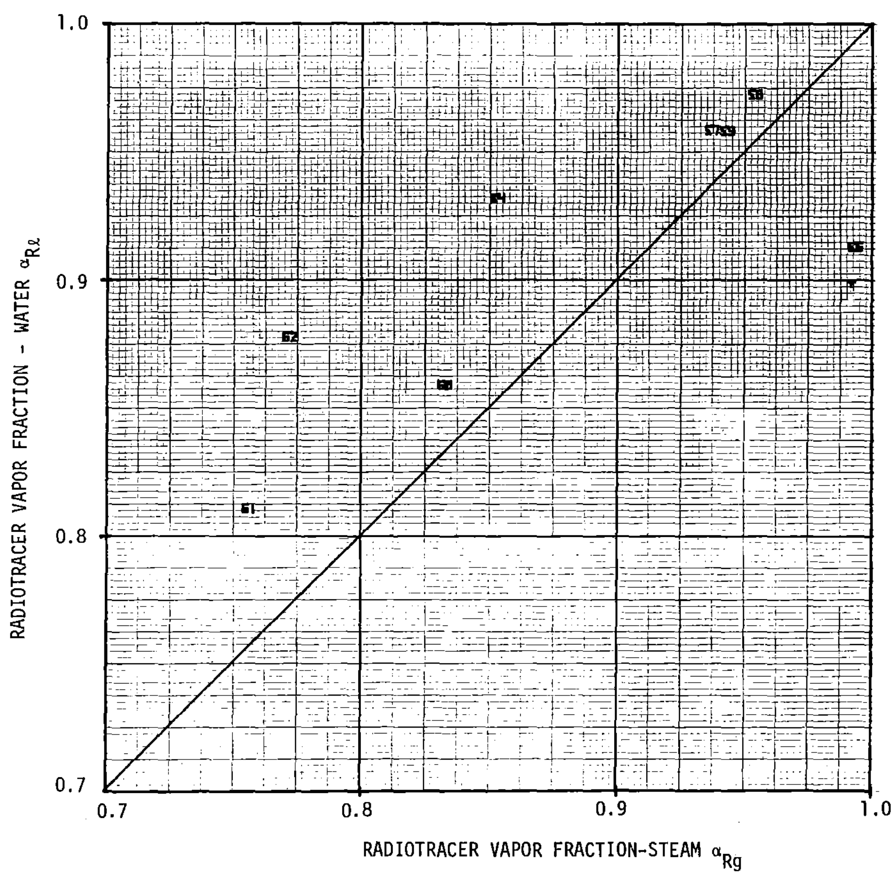

FIGURE 7.7: COMPARISON OF RADIOTRACER VAPOR FRACTIONS

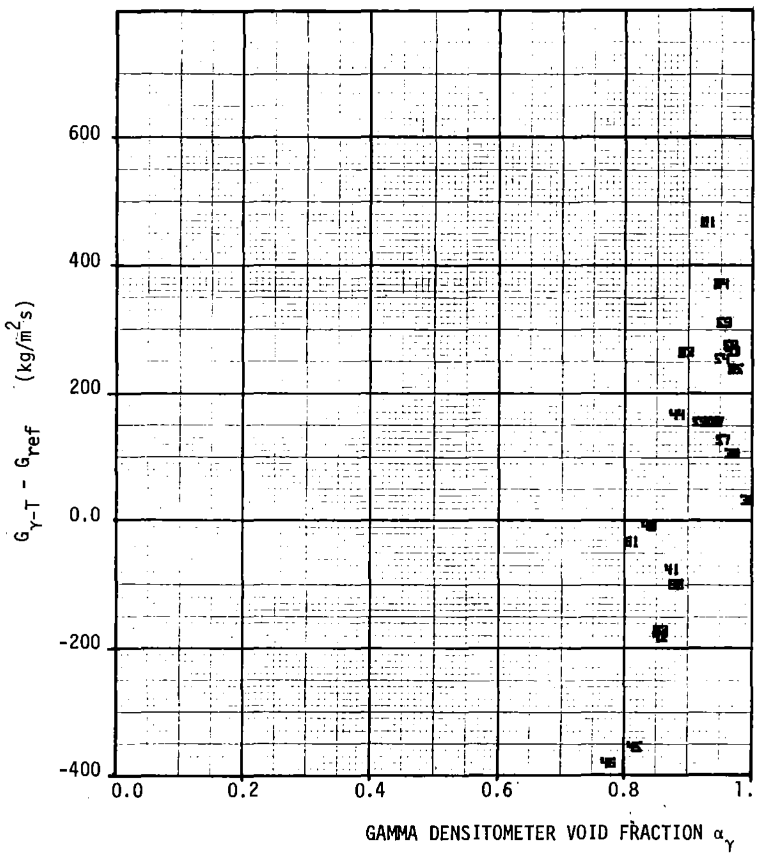

FIGURE 7.8: ERROR IN GAMMA DENSITOMETER - TURBINE MASS FLOW CALCULATION

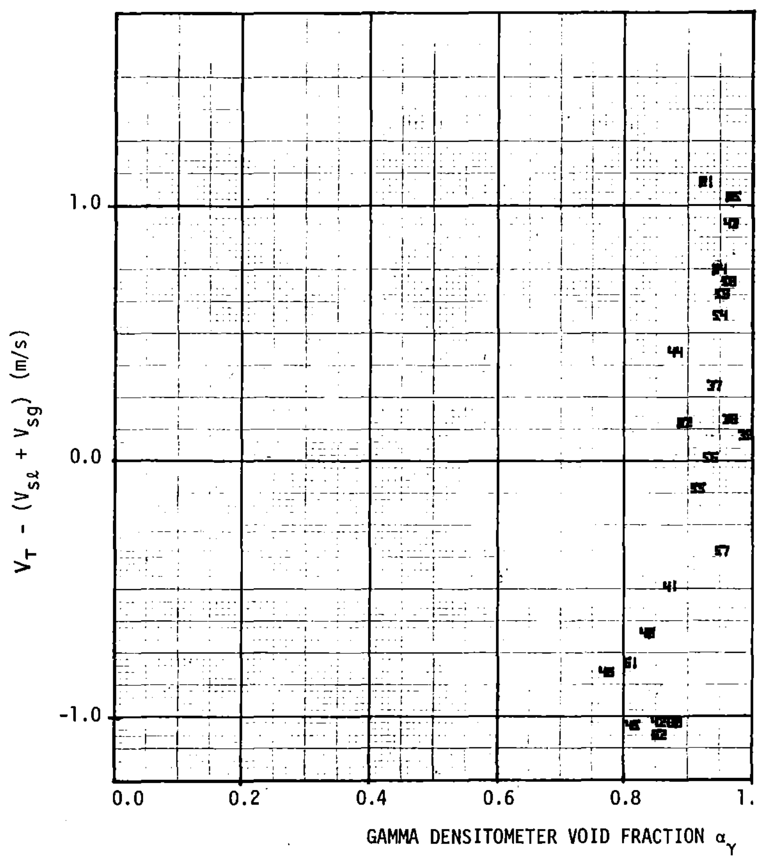

FIGURE 7.9: ERROR IN TURBINE VELOCITY

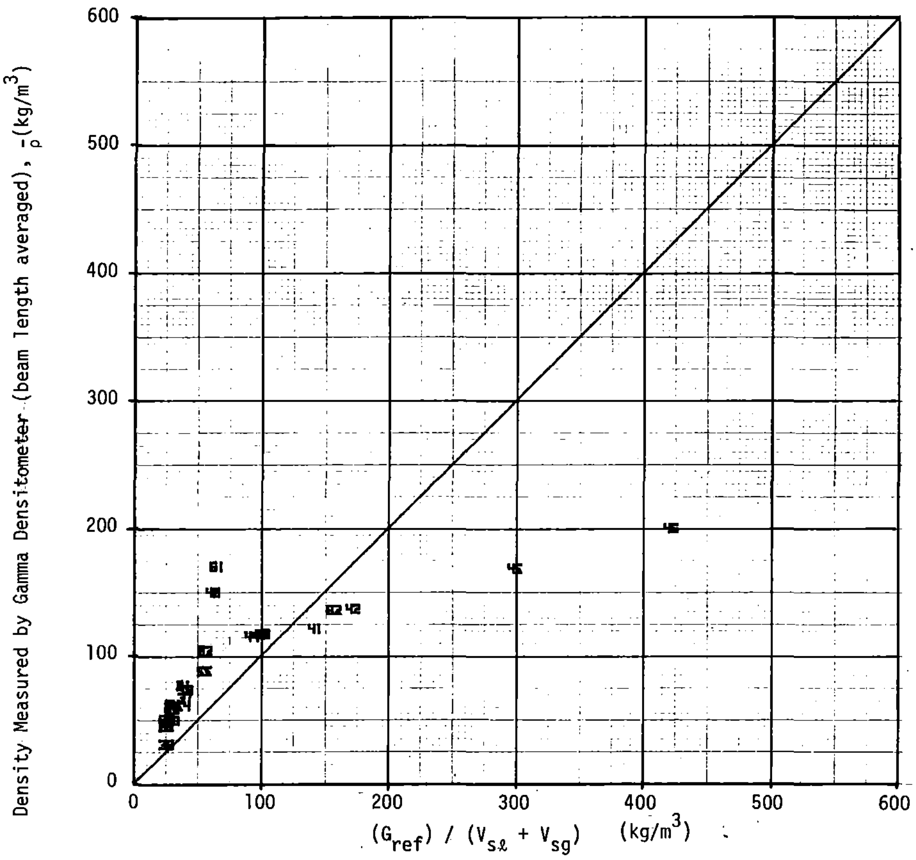

FIGURE 7.10: DENSITY COMPARISONS

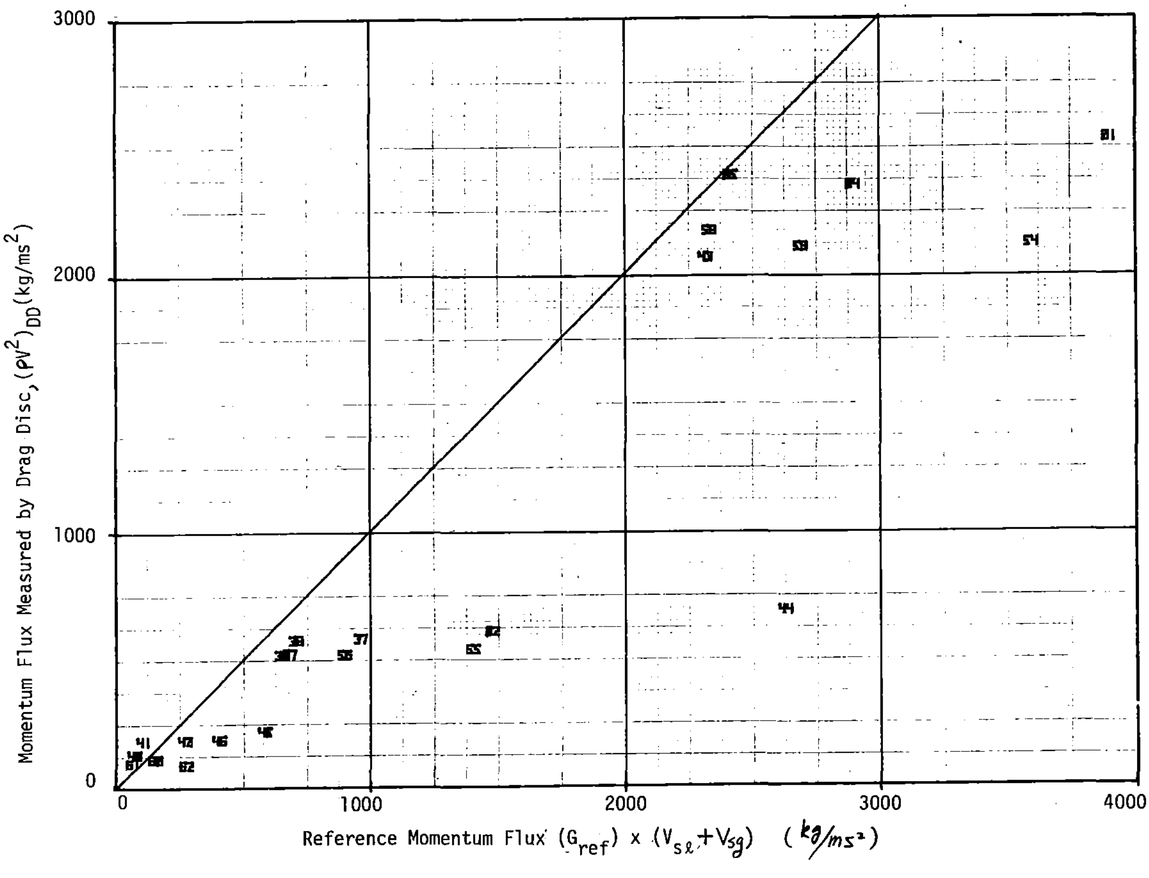

FIGURE 7.11: MOMENTUM FLUX COMPARISONS

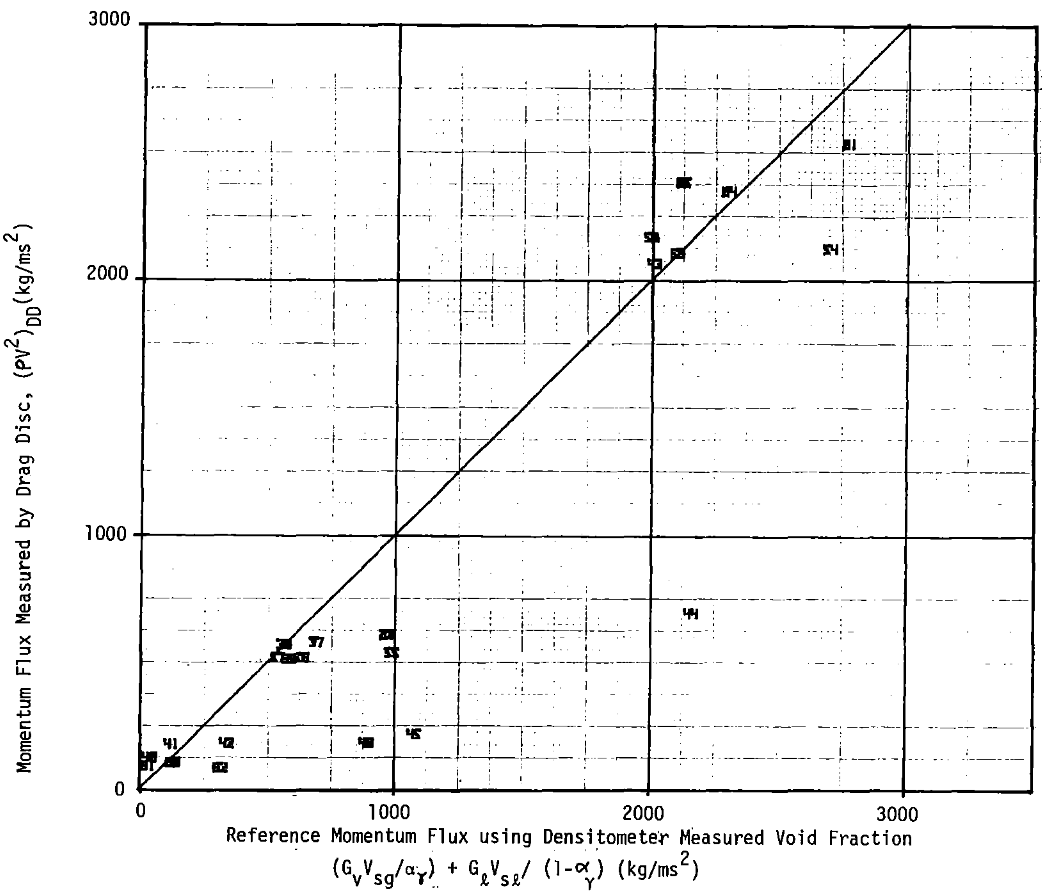

FIGURE 7.12: DRAG DISC MOMENTUM FLUX COMPARISON

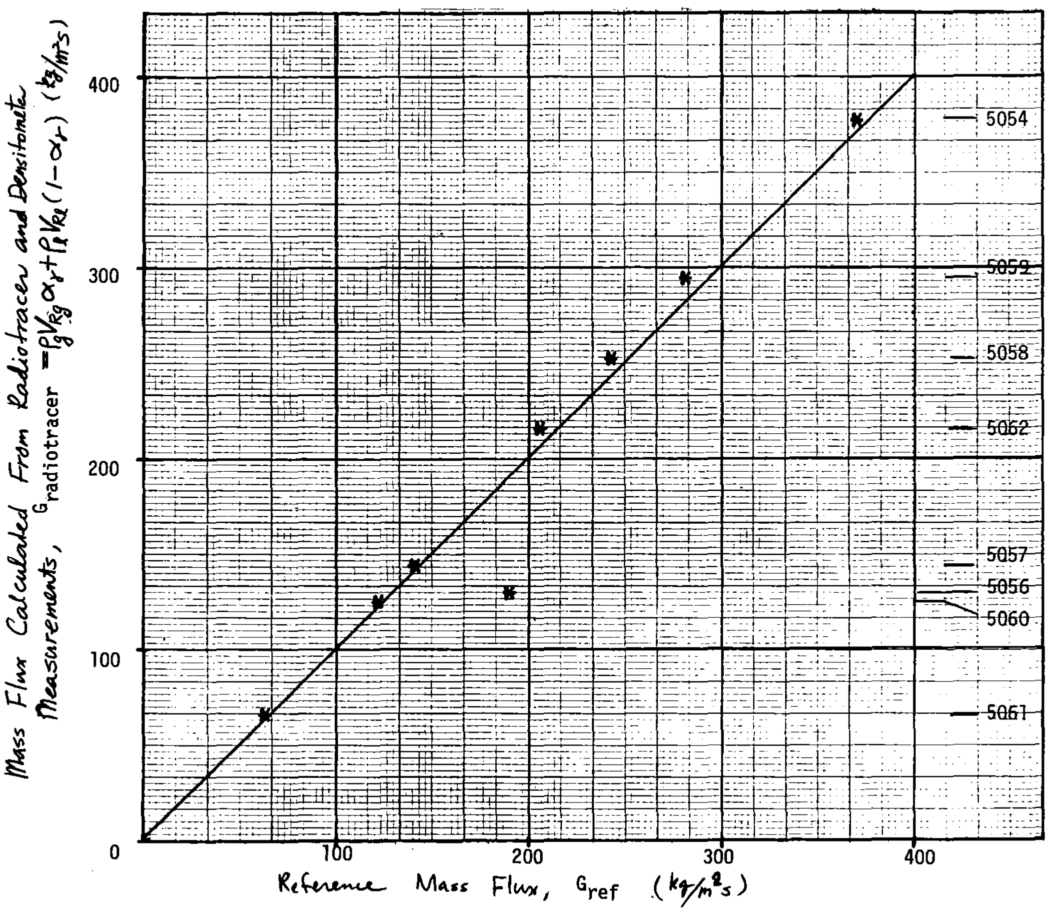

FIGURE 7.13: MASS FLUX CALCULATION FROM RADIOTRACER AND DENSITOMETER MEASUREMENTS AT DIFFERENT REVERENCE VALUES

8.

FIVE-INCH STEAM-WATER 70 BAR

FLUID: STEAM - WATER
PIPE SIZE= 5 INCH DOUBLE EXTRA STRONG
NOMINAL PRESSURE= 70 BARS

INSIDE DIAMETER= 0.10320 M
TURB. DIA.= 0.0381 M
PIPE AREA= 0.0083647 M↑2

RUN ID TSN	PRESS. (BARS)	TEMP. (DEG C)	FLOW RATES STEAM SUP-VEL (M/S)	FLOW RATES STEAM MASS (KG/S)	FLOW RATES WATER SUP-VEL (M/S)	FLOW RATES WATER MASS (KG/S)	TURB. VEL (M/S)	DRAG DISK (KG/ M*S↑2)	GAMMA DENSITOMETER A BEAM LOWER (KG/ M↑3)	GAMMA DENSITOMETER B BEAM MIDDLE (KG/ M↑3)	GAMMA DENSITOMETER C BEAM UPPER (KG/ M↑3)	IMPED PROBE (KG/ M↑3)	RADIOTRACER VELOCITIES STEAM (M/S) (AT GAMMA DENS)	RADIOTRACER VELOCITIES WATER (M/S) (AT GAMMA DENS)	Comments
5014	74.8	288.3	5.76	1.895	0.033	0.201	6.19	1334	76	27	29	60			
5015	75.0	288.0	5.12	1.689	0.063	0.389	5.61	1104	109	32	37	81			
5016	75.3	287.6	5.12	1.696	0.135	0.828	5,83	1183	136	41	37	109			
5017	75.2	288.7	0.97	0.323	0.127	0.780	0.68	61	223	101	37				
5019	75.7	288.3	0.83	0.277	0.243	1.490	0.52	99	247	118	39				DD below range
5021	74.8	287.6	7.60	2.499	0.233	1.435	8.73	2777	113	48	39				DD below range
5022	74.8	286.2	7.72	2.539	0.126	0.773	8.58	2689	90	44	46				Rerun of 5020
5023	74.6	288.0	7.69	2.524	0.054	0.332	8.36	2523	65	39	39				
5024	75.0	288.0	7.67	2.533	0.035	0.212	8.21	2475	50	37	44				
5025	75.3	288.0	4.82	1.596	0.243	1.490	5.59	1155	165	66	48				
5047	74.2	288.7	2.07	0.675	0.497	3.060	1.87	350	309	183	43				
5048	74.9	289.4	0.89	0.292	0.496	3.049	0.47	192	310	173	43				DD below range
5049	74.4	289.0	0.47	0.154	0.492	3.025	0.26	152	328	196	44				DD below range
5066	75.5	288.7	4.79	1.594	0.229	1.407	5.35	1106	181	76	51	144	5.30	2.40	T, DD below range
5067	76.0	289.4	4.76	1.595	0.124	0.762	5.23	1102	147	51	43	110	5.10	2.70	
5068	75.9	290.1	1.05	0.351	0.129	0.793	0.53	86	232	105	47	186	1.00	1.00	
5069	75.5	288.3	1.18	0.393	0.241	1.479	0.31	110	244	116	40	179	1.10	1.70	T, DD below range
5070	76.1	290.1	1.20	0.402	0.055	0.334	0.72	147	206	90	38	165	1.30	0.60	T, DD below range
5071	76.1	288.0	5.36	1.797	0.055	0.340	5.59	1291	109	51	55	82	5.70	2.10	DD below range

Dash indicates error in data
Blank indicates no data

TABLE 8.1: PRIMARY ENGINEERING UNIT DATA

5 INCH 70 BAR

RUN ID TSN	GDOT REF (KG/M↑2*S)	GDOT G-T (KG/M↑2*S)	GDOT G-DD (KG/M↑2*S)	GDOT T-DD (KG/M↑2*S)
5014	250.577	274.481	243.103	215.311
5015	248.425	334.535	256.599	196.820
5016	301.744	422.364	292.683	202.819
5017	131.864	85.479	87.568	89.708
5019	211.245	73.344	118.606	191.800
5021	470.310	595.414	435.147	318.019
5022	395.950	517.882	402.787	313.271
5023	341.435	400.285	347.594	301.839
5024	328.165	353.318	326.362	301.463
5025	368.931	533.323	331.906	206.558
5047	446.519	356.736	258.075	186.700
5048	399.417	87.430	189.415	410.363
5049	380.049	52.495	175.294	585.347
5066	358.770	566.340	342.154	206.713
5067	281.779	429.696	300.974	210.813
5068	136.765	70.520	107.321	163.325
5069	223.798	43.168	124.420	358.605
5070	87.989	83.856	130.808	204.049
5071	255.478	400.856	304.241	230.912

TABLE 8.2: MASS FLOW RATE COMPARISON

5 INCH 70 BAR

RUN ID TSN	VSL+VSG (M/S)	TURB. VEL (M/S)	VEL. DD-G (M/S)
5014	5.792	6.194	5.486
5015	5.180	5.610	4.303
5016	5.255	5.832	4.042
5017	1.102	0.676	0.693
5019	1.073	0.516	0.834
5021	7.830	8.732	6.381
5022	7.844	8.584	6.676
5023	7.746	8.357	7.257
5024	7.705	8.209	7.583
5025	5.060	5.594	3.481
5047	2.568	1.872	1.354
5048	1.384	0.468	1.014
5049	0.962	0.259	0.865
5066	5.022	5.349	3.232
5067	4.886	5.229	3.662
5068	1.179	0.527	0.802
5069	1.423	0.307	0.885
5070	1.251	0.718	1.120
5071	5.415	5.591	4.243

TABLE 8.3: TOTAL VELOCITY COMPARISON

5 INCH 70 BAR

RUN ID TSN	DENSITIES (KG/M↑3) VERT AVG GAMMA	LEN AVG GAMMA	IMPED PROBE	VAPOR F…TIONS ALPHA GAMMA /LEN	ALPHA IMPD PROBE	TH…	…ADIOTRACER …R FRACTION …AM	WATER
5014	45.88	44.31	60.42	0.99	0.97	0.99		
5015	62.05	59.64	81.38	0.97	0.94	0.99		
5016	75.75	72.42	109.44	0.95	0.90	0.97		
5017	132.58	126.42		0.87		0.88		
5019	149.09	142.22		0.85		0.77		
5021	70.63	68.19		0.96		0.97		
5022	61.80	60.33		0.97		0.98		
5023	48.72	47.90		0.99		0.99		
5024	43.19	43.04		0.99		1.00		
5025	99.23	95.34		0.92		0.95		
5047	199.27	190.56		0.78		0.81		
5048	195.50	186.72		0.79		0.64		
5049	212.01	202.70		0.77		0.49		
5066	110.21	105.88	144.40	0.90	0.85	0.95	0.90	0.90
5067	85.64	82.18	109.72	0.94	0.90	0.97	0.93	0.95
5068	139.90	133.80	186.32	0.86	0.79	0.89	1.05	0.87
5069	147.33	140.56	179.28	0.85	0.80	0.83	1.08	0.86
5070	122.33	116.75	165.44	0.89	0.82	0.96	0.92	0.91
5071	73.47	71.70	81.90	0.95	0.94	0.99	0.94	0.97

TABLE 8.4: VOID FRACTION COMPARISON

5 INCH 70 BAR

RUN ID TSN	V GAS G DENS (M/S)	V GAS RADIO (M/S)	V LIQ. G DENS (M/S)	V LIQ. RADIO (M/S)	SLIP G DENS	SLIP RADIO
5014	5.801		4.568		1.270	
5015	5.269		2.181		2.416	
5016	5.374		2.853		1.884	
5017	1.114		1.016		1.097	
5019	0.974		1.646		0.592	
5021	7.926		5.625		1.409	
5022	7.958		4.165		1.911	
5023	7.789		4.334		1.797	
5024	7.710		6.729		1.146	
5025	5.237		3.024		1.732	
5047	2.646		2.285		1.158	
5048	1.127		2.341		0.481	
5049	0.614		2.093		0.293	
5066	5.297	5.30	2.407	2.40	2.201	2.208
5067	5.070	5.10	2.044	2.70	2.481	1.889
5068	1.214	1.00	0.955	1.00	1.270	1.000
5069	1.383	1.10	1.659	1.70	0.834	0.647
5070	1.345	1.30	0.493	0.60	2.726	2.167
5071	5.616	5.70	1.214	2.10	4.624	2.714

TABLE 8.5: PHASE VELOCITY COMPARISON

RUN ID TSN	From Govier & Aziz Flow Regime Map	From Gamma Densitometer Flow Regime	Interface Location(%)*	From Impedance Probe Flow Regime	Interface Location(%)*
5014	Annular Mist		-77.22	Wave	-77
5015	Wave Flow		-67.19	Wave	
5016	Wave Flow		-59.83	Wave	-66
5017	Wave Flow		-34.72	Wave	-32
5019	Slug Flow		-29.33	Wave	-29
5021	Slug Flow		-63.65		
5022	Wave Flow		-67.19		
5023	Annular Mist		-77.22		
5024	Annular Mist		-77.22		
5025	Slug Flow		-49.09		
5047	Slug Flow		-11.43		
5048	Slug Flow		-13.83		
5049	Elongated Bubble		-9.61		
5066	Slug Flow		-43.38	Wave	-46
5067	Wave Flow		-55.73	Wave	-58
5068	Wave Flow		-32.59	Strat → Wave	-29
5069	Slug Flow		-29.33	Wave	-29
5070	Stratified		-40.40	Wave	-37
5071	Wave Flow		-59.83	Wave	-66

*Pipe Empty: 0.0 cm liquid level is -85.43%

Pipe Full: 10.32 cm liquid level is 185.43%

Bottom of DTT Housing 3.255 cm liquid level is 0.0%

Top of DTT Housing 7.07 cm liquid level is 100.0%

TABLE 8.6: FLOW REGIME COMPARISON

5 INCH 70 BAR

RUN ID TSN	LEN AVG GAMMA (KG/M↑3)	GDOT/(VSL+VSG) REF (KG/M↑3)	DRAG DISK (KG/M*S↑2)	(GDOT)X(VSL+VSG) REF (KG/M*S↑2)	(SUM MV/ ALPHA)/AREA (KG/M*S↑2)
5014	44.31	43.26	1334	1451.40	1423.94
5015	59.64	47.96	1104	1286.73	1165.45
5016	72.42	57.42	1183	1585.60	1372.13
5017	126.42	119.66	61	145.31	137.78
5019	142.22	196.89	99	226.65	325.44
5021	68.19	60.06	2777	3682.64	3332.91
5022	60.33	50.48	2689	3105.69	2800.43
5023	47.90	44.08	2523	2644.67	2522.31
5024	43.04	42.59	2475	2528.65	2505.38
5025	95.34	72.92	1155	1866.65	1537.87
5047	190.56	173.89	350	1146.57	1049.64
5048	186.72	288.59	192	552.80	892.52
5049	202.70	395.21	152	365.47	768.35
5066	105.88	71.44	1106	1801.63	1414.11
5067	82.18	57.67	1102	1376.82	1152.94
5068	133.80	116.03	86	161.21	141.51
5069	140.56	157.22	110	318.56	358.28
5070	116.75	70.35	147	110.04	84.28
5071	71.70	47.18	1291	1383.49	1256.04

TABLE 8.8: SINGLE INSTRUMENT CALCULATION

5 INCH 70 BAR

RUN ID TSN	ALPHA GAMMA	GDOT-GDOT G-T REF (KG/M↑2*S)	VT-(VSL+VSG) (M/S)
5014	0.99	23.90	0.40
5015	0.97	86.11	0.43
5016	0.95	120.62	0.58
5017	0.87	-46.38	-0.43
5019	0.85	-137.90	-0.56
5021	0.96	125.10	0.90
5022	0.97	121.93	0.74
5023	0.99	58.85	0.61
5024	0.99	25.15	0.50
5025	0.92	164.39	0.53
5047	0.78	-89.78	-0.70
5048	0.79	-311.99	-0.92
5049	0.77	-327.55	-0.70
5066	0.90	207.57	0.33
5067	0.94	147.92	0.34
5068	0.86	-66.25	-0.65
5069	0.85	-180.63	-1.12
5070	0.89	-4.13	-0.53
5071	0.95	145.38	0.18

TABLE 8.7: ERROR CALCULATIONS

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2784

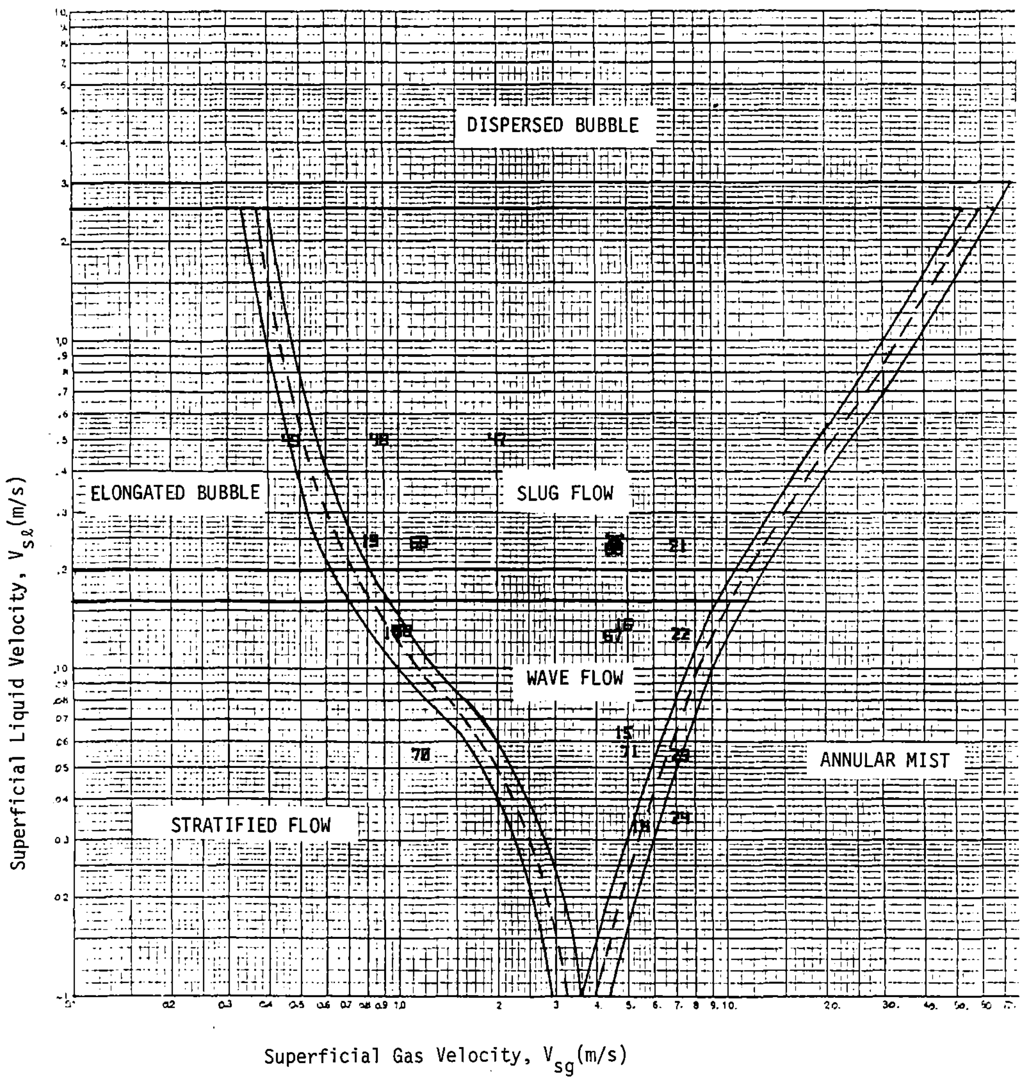

FIGURE 8.1A: GOVIER AND AZIZ FLOW REGIME MAP

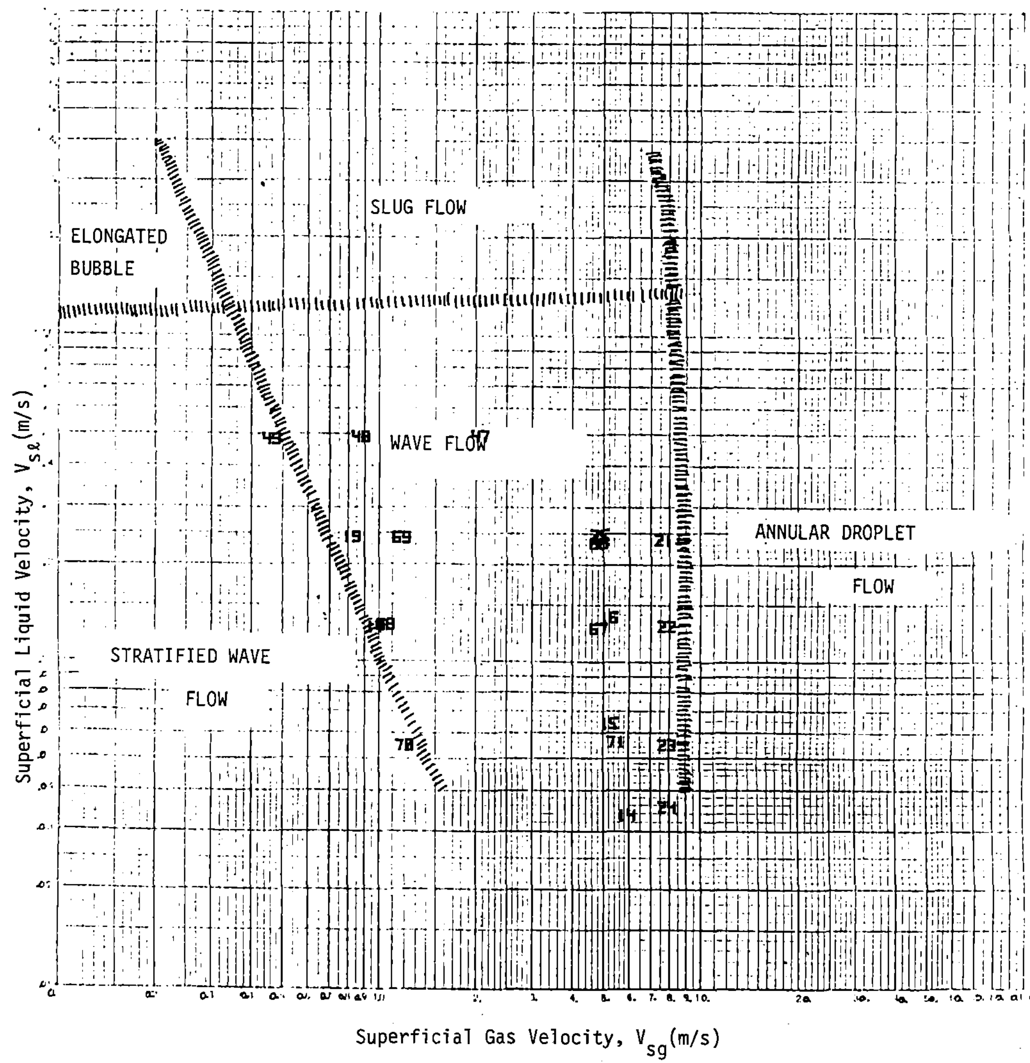

FIGURE 8.1B: IMPEDANCE PROBE FLOW REGIME MAP

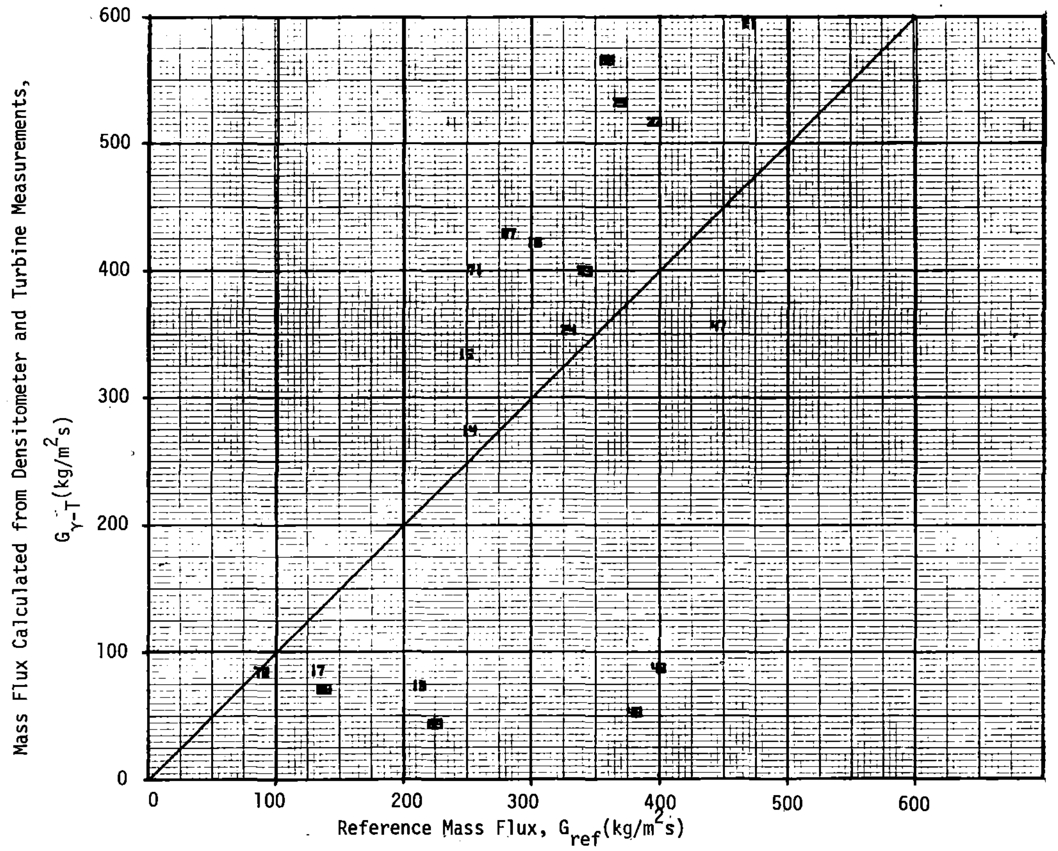

FIGURE 8.2: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND TURBINE MEASUREMENTS AT DIFFERENT REFERENCE VALUES

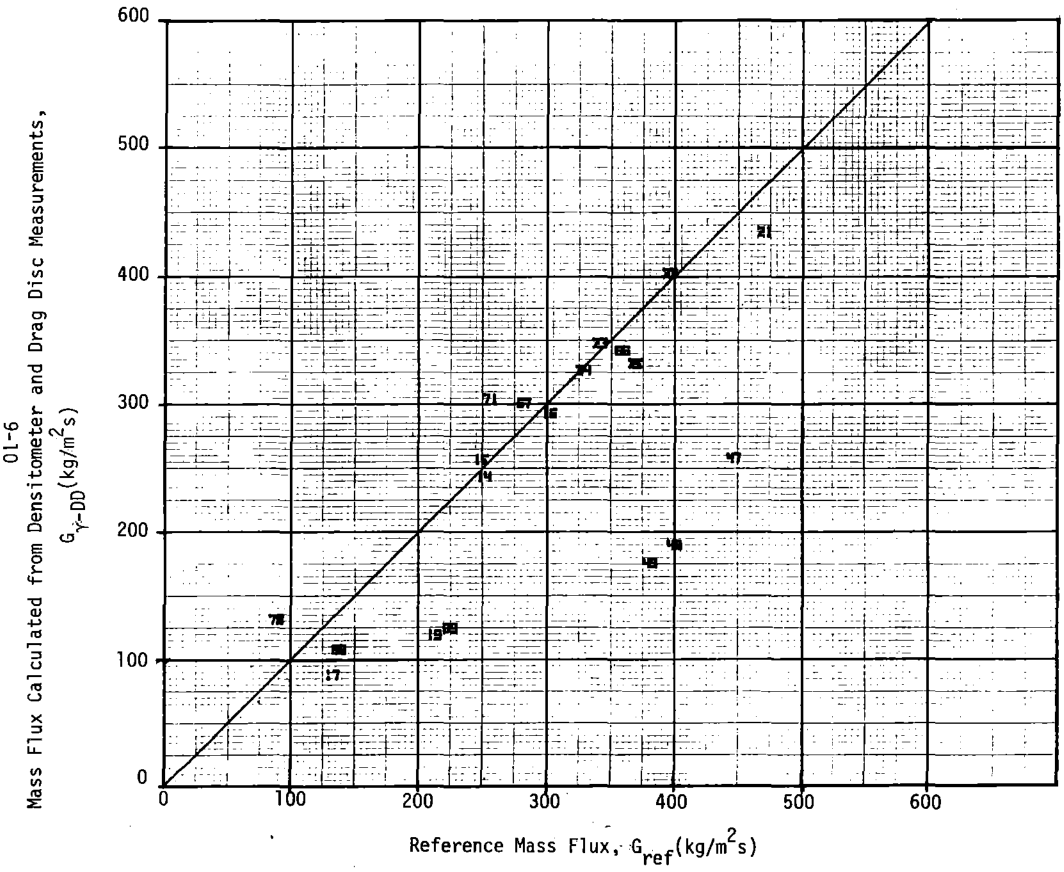

FIGURE 8.3: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

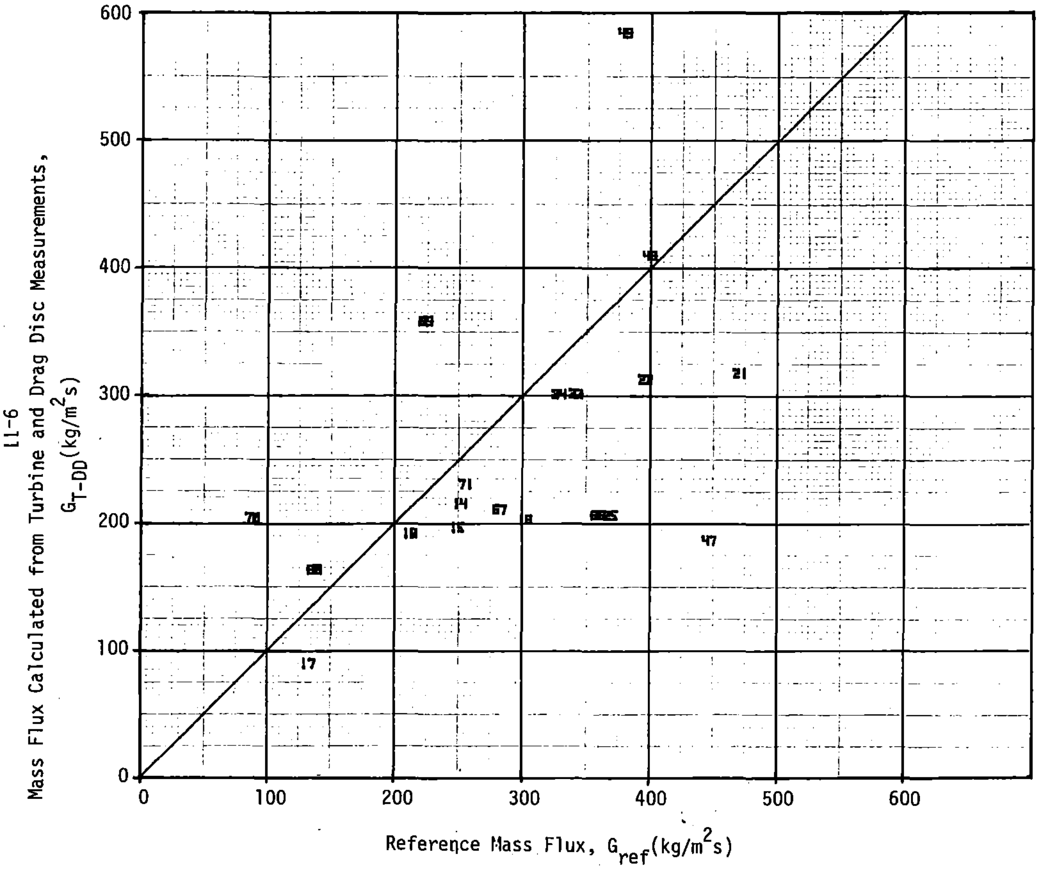

FIGURE 8.4: MASS FLUXES CALCULATED FROM TURBINE AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

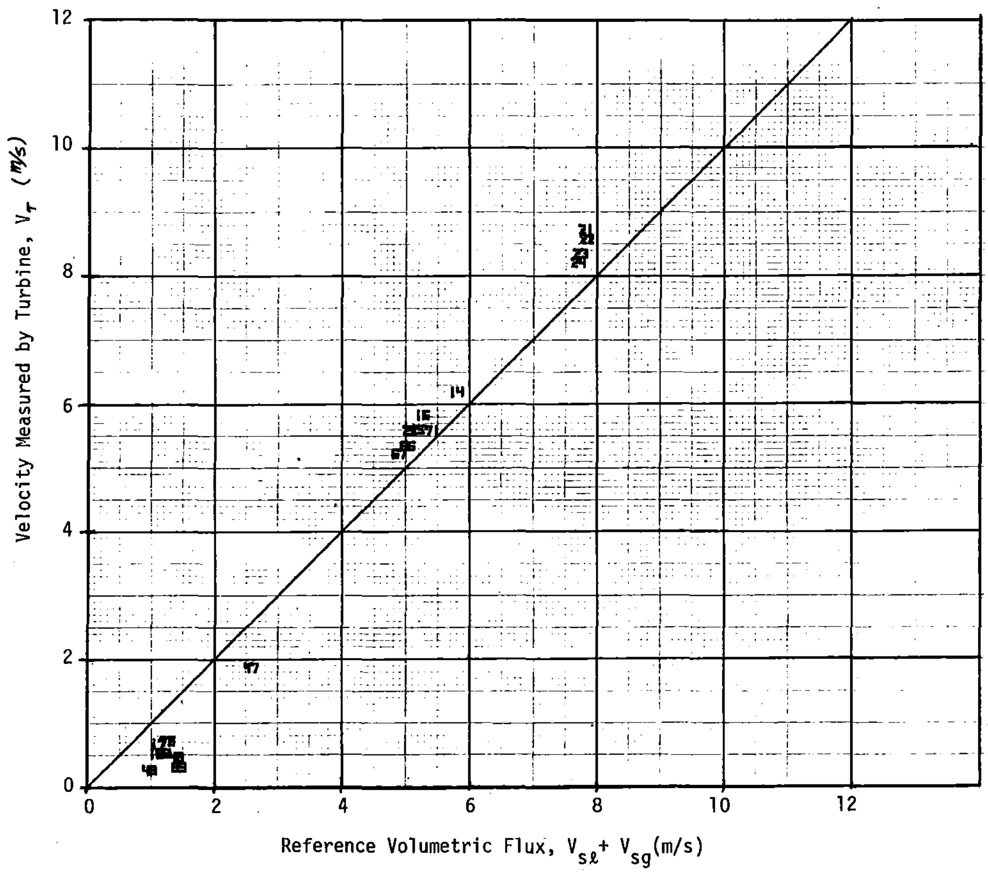

FIGURE 8.5: THE VELOCITIES MEASURED BY TURBINE AT VARIOUS VOLUMETRIC FLUXES

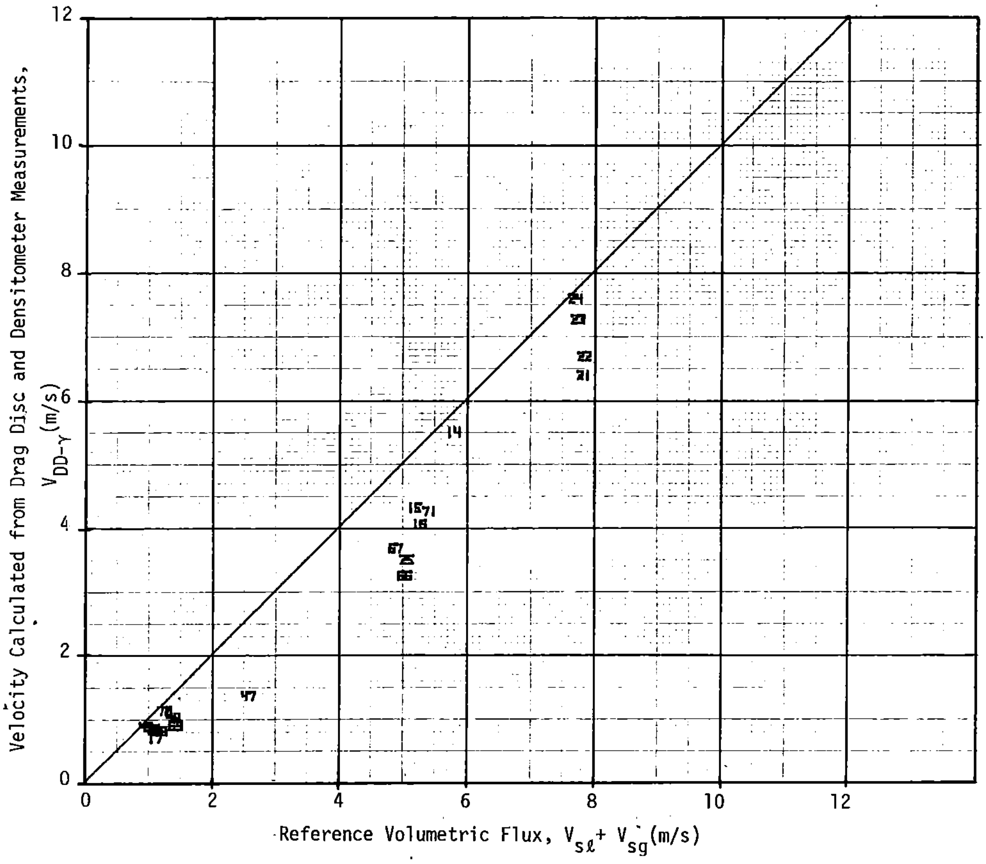

FIGURE 8.6: THE VELOCITY CALCULATED FROM DRAG DISC AND DENSITOMETER MEASUREMENTS AT DIFFERENT REFERENCE VOLUMETRIC FLUXES

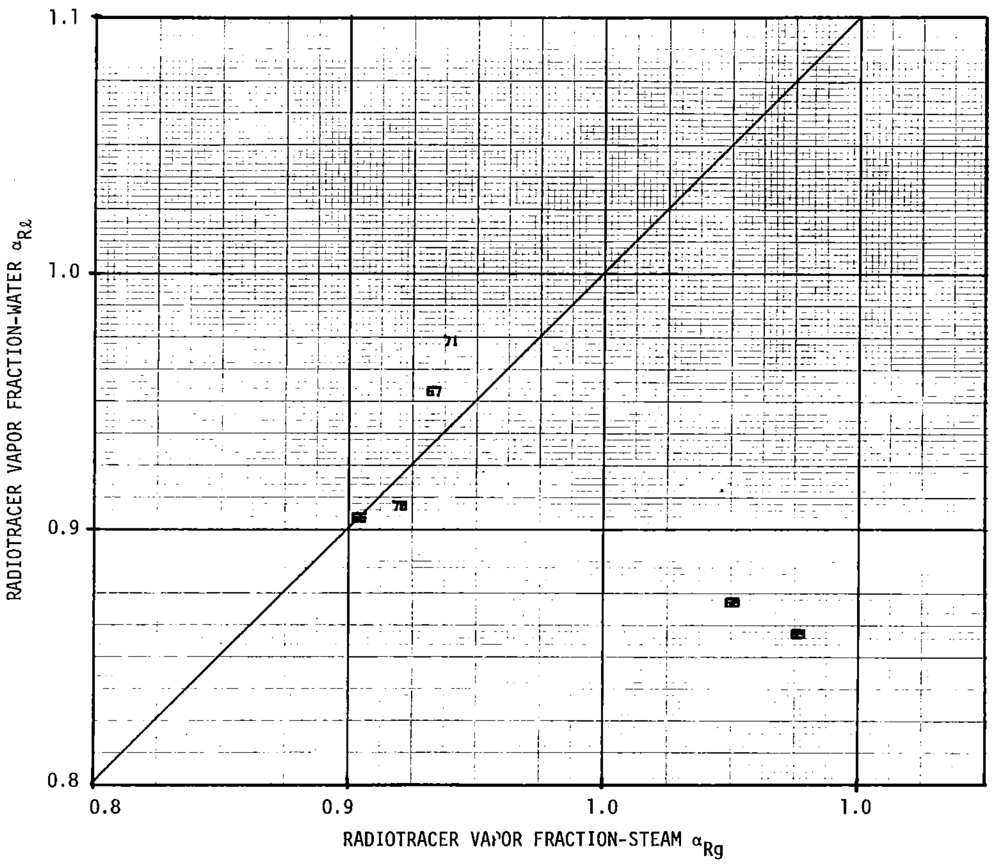

FIGURE 8.7: COMPARISON OF RADIOTRACER VAPOR FRACTIONS

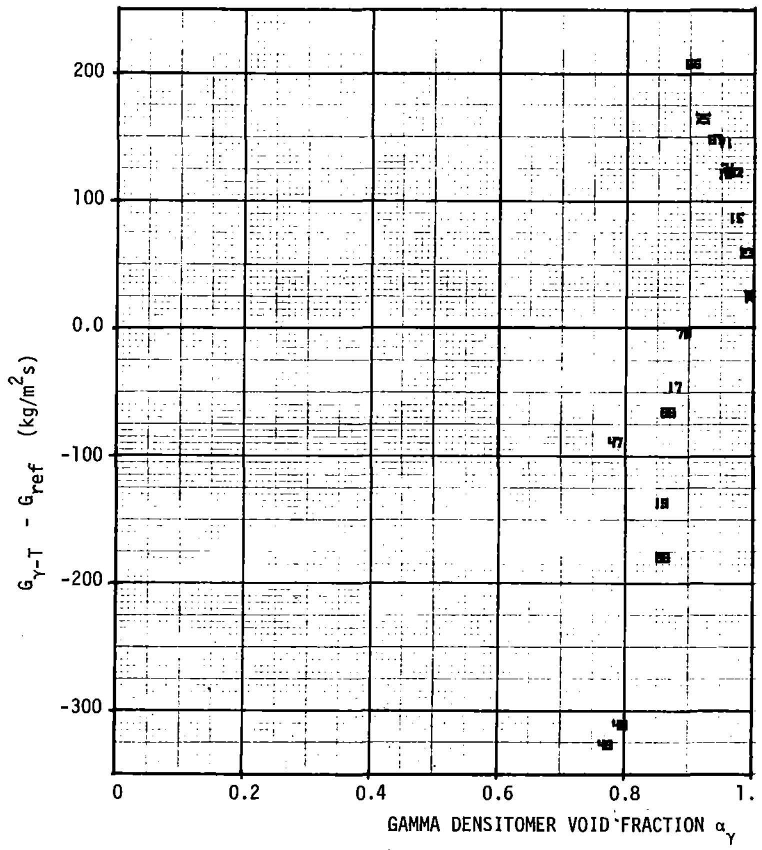

FIGURE 8.8: ERROR IN GAMMA DENSITOMETER - TURBINE MASS FLOW CALCULATION

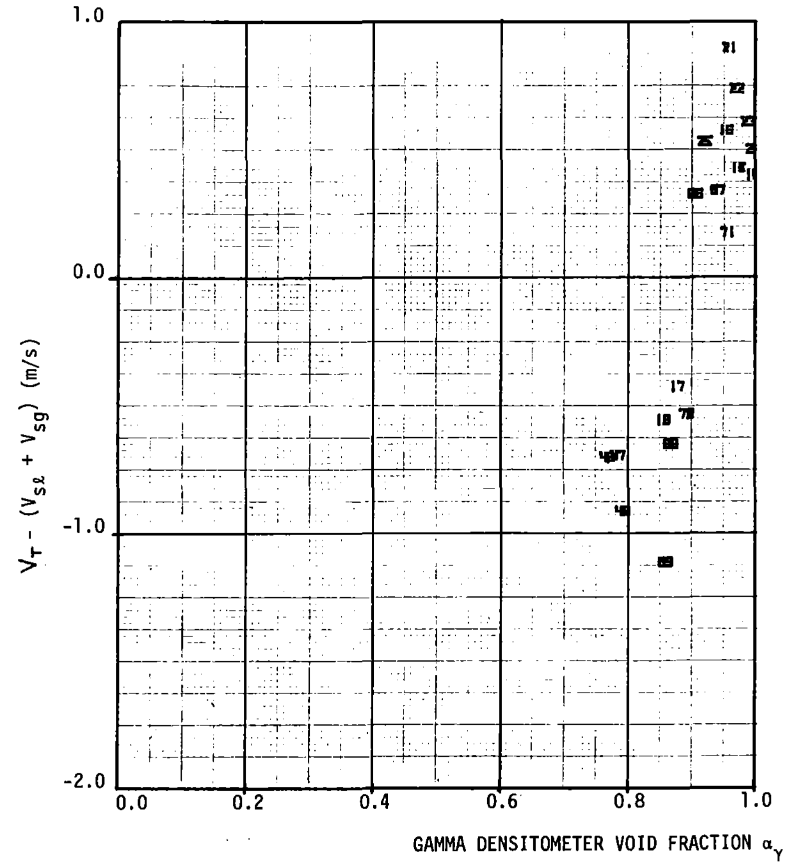

FIGURE 8.9: ERROR IN TURBINE VELOCITY

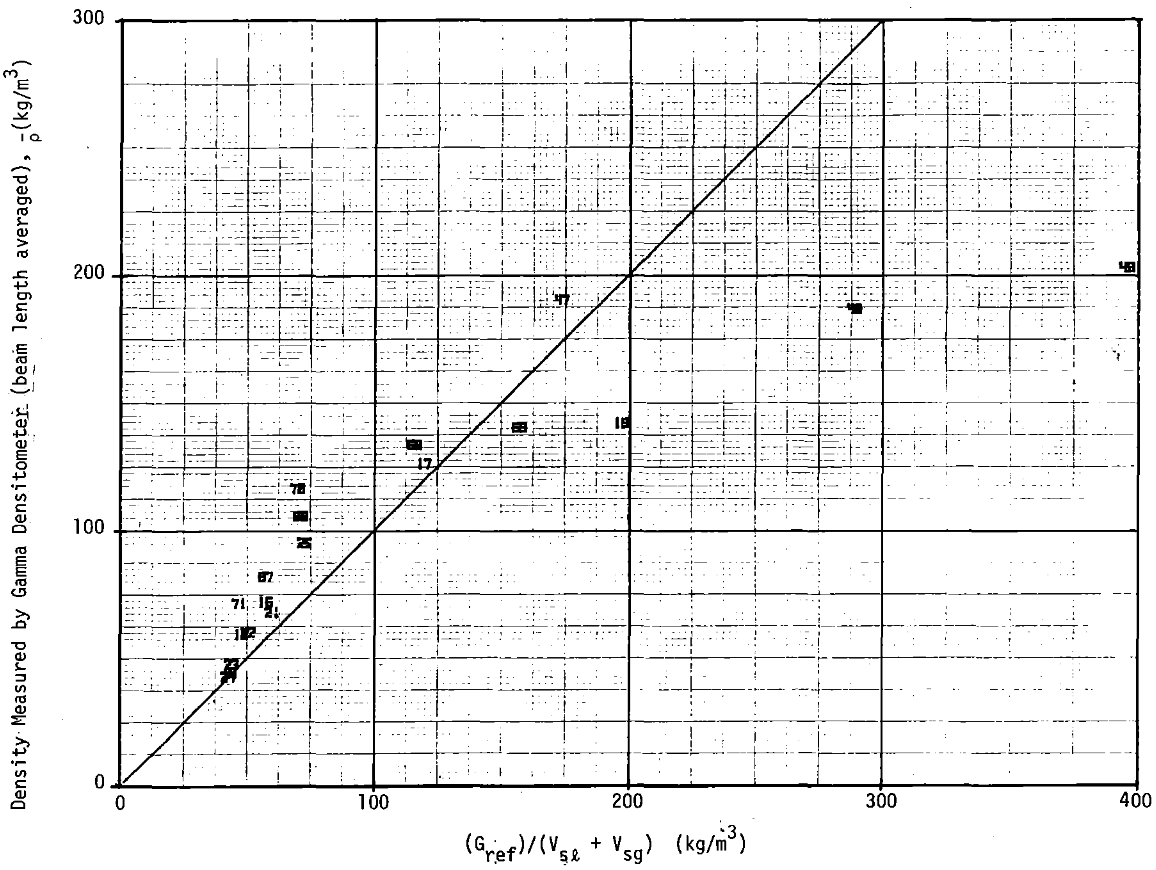

FIGURE 8.10: DENSITY COMPARISON

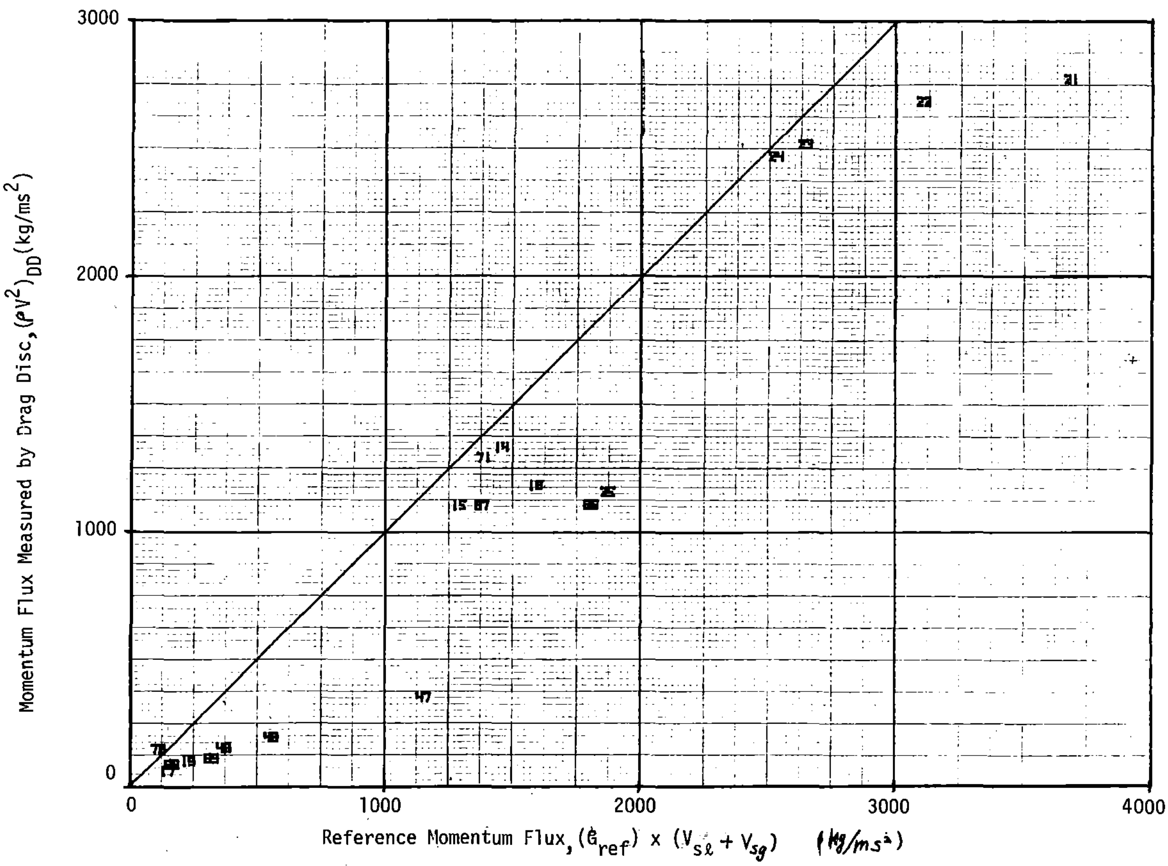

FIGURE 8.11: MOMENTUM FLUX COMPARISON

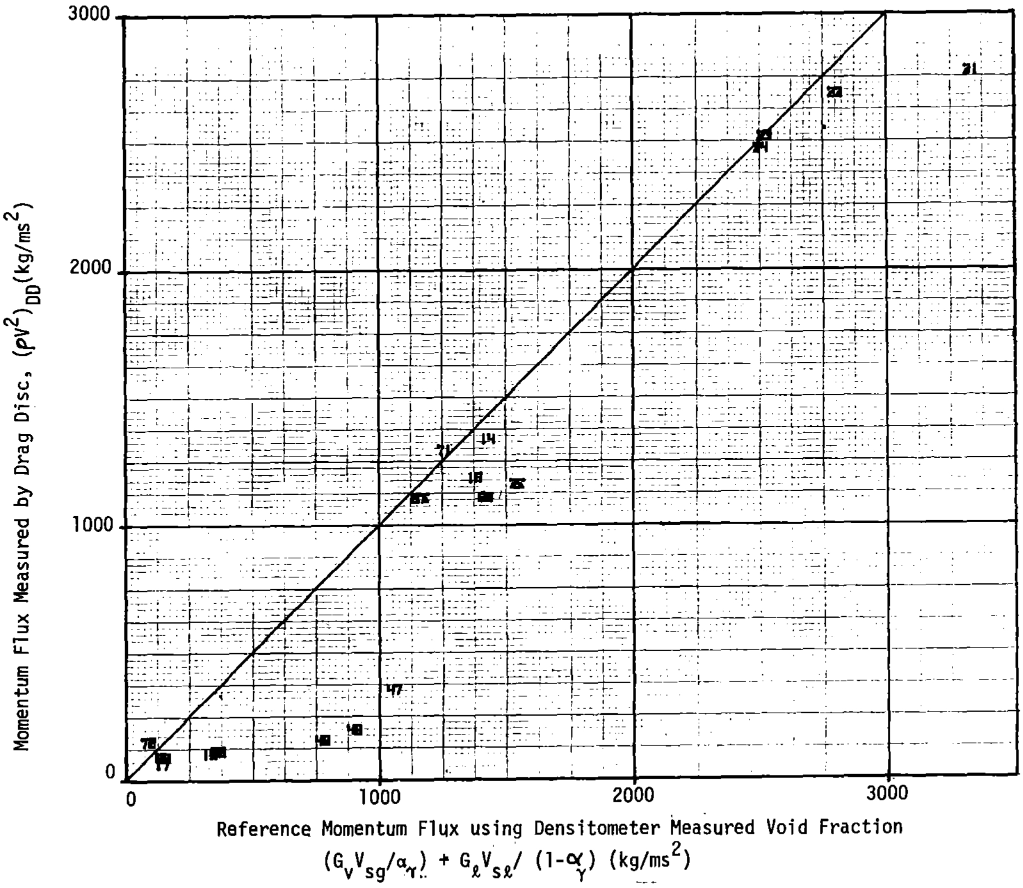

FIGURE 8.12: DRAG DISC MOMENTUM FLUX COMPARISON

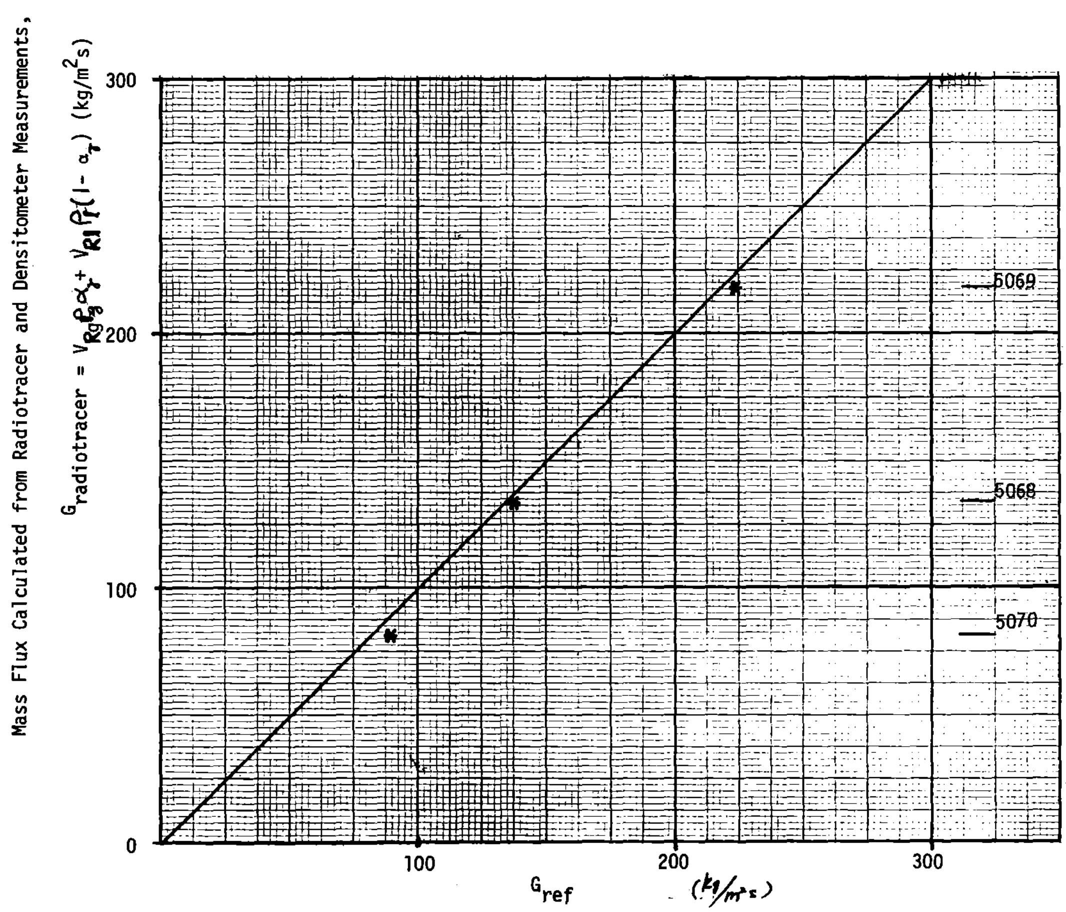

FIGURE 8.13: MASS FLUX CALCULATION FROM RADIOTRACER AND DENSITOMETER MEASUREMENTS AT DIFFERENCE REFERENCE VALUES

9.

THREE-INCH STEAM-WATER 40 BAR

FLUID: STEAM - WATER
PIPE SIZE= 3 INCH SCHEDULE 160
NOMINAL PRESSURE= 40 BARS

INSIDE DIAMETER= 0.06665 M
TURB. DIA.= 0.0381 M
PIPE AREA= 0.0034889 M↑2

RUN ID TSN	PRESS. (BARS)	TEMP. (DEG C)	FLOW RATES STEAM SUP-VEL (M/S)	FLOW RATES STEAM MASS (KG/S)	FLOW RATES WATER SUP-VEL (M/S)	FLOW RATES WATER MASS (KG/S)	TURB. VEL (M/S)	DRAG DISK (KG/ M*S↑2)	GAMMA DENSITOMETER A BEAM UPPER (KG/ M↑3)	GAMMA DENSITOMETER B BEAM MIDDLE (KG/ M↑3)	GAMMA DENSITOMETER C BEAM LOWER (KG/ M↑3)	SCAN DENS (KG/ M↑3)	RADIOTRACER VELOCITIES STEAM (M/S) (AT GAMMA DENS)	RADIOTRACER VELOCITIES WATER (M/S) (AT GAMMA DENS)	Comments
6003	40.5	247.7	4.73	0.336	1.210	3.348	3.67	2125	208	310	499				
6004	40.7	247.0	9.15	0.654	1.212	3.350	6.55	3484	123	188	300				
6005	40.5	246.7	8.97	0.639	1.274	3.523	7.72	3716	122	166	265				
6013	40.2	248.5	10.15	0.717	1.017	2.815	9.61	3755	46	126	198	137	12.70	9.80	T above range
6014	41.0	248.8	4.11	0.296	1.048	2.896	4.18	1713	143	267	439	265	6.20	3.20	
6015	40.0	247.4	0.79	0.055	1.008	2.792	1.40	1459	369	507	746		1.80	1.70	
6016	40.2	248.5	0.83	0.058	0.508	1.407	0.93	565	295	421	648	370	1.70	0.90	
6017	40.4	248.5	5.23	0.371	0.516	1.427	6.33	1189	99	229	315	188	7.00	2.20	
6018	40.2	247.4	9.56	0.675	0.527	1.460	11.55	3281	18	117	163		10.60	4.80	T above range
6019	40.6	248.8	1.16	0.083	1.321	3.653	1.75	2524	386	515	752	476	2.20	2.10	
6020	40.0	248.1	1.32	0.093	1.251	3.465	1.83	2697	340	486	727	463	2.40	2.20	
6021	40.1	248.5	5.71	0.402	1.261	3.491	5.36	2618	91	257	400		8.50	4.70	
6022	40.2	248.5	2.72	0.192	1.235	3.419	2.82	2257	200	368	584		4.40	3.00	
6023	40.0	246.7	4.69	0.329	1.228	3.403	4.55	2250	119	279	448		6.90	3.70	
6024	40.4	248.5	6.96	0.494	1.223	3.383	6.38	3209	54	209	344		8.90	5.70	
6025	39.9	246.7	8.79	0.615	1.235	3.422	8.03	3721	34	165	261	173	11.00	7.90	
6026	40.1	247.7	6.05	0.426	1.331	3.687	5.40	2874	89	241	391		7.80	5.30	
6027	40.5	248.5	2.84	0.202	1.323	3.660	3.10	2360	201	356	571		5.10	3.30	
6048	39.2	246.3	5.09	0.350	1.649	4.579	4.79	2966	212	308	527				
6066	40.1	249.9	0.93	0.066	0.103	0.285	–	377	137	223	316				T failed
6067	39.9	249.5	0.91	0.064	0.256	0.708	–	463	272	350	522				T failed
6068	40.7	250.6	4.91	0.351	0.247	0.682	–	901	91	177	-				T failed
6069	40.1	249.5	10.29	0.725	0.262	0.726	–	4749	-	62	84	69			T failed
6070	40.1	249.5	5.31	0.375	0.268	0.741	–	1744	35	145	180	113			T failed
6071	40.1	249.5	4.95	0.348	0.131	0.363	–	1401	-	119	91				T failed

Dash indicates error in data.
Blank indicates no data.

TABLE 9.1: PRIMARY ENGINEERING UNIT DATA

3 INCH 40 BAR

RUN ID TSN	GDOT REF (KG/M↑2*S)	GDOT G-T (KG/M↑2*S)	GDOT G-DD (KG/M↑2*S)	GDOT T-DD (KG/M↑2*S)
6003	1055.920	1194.940	831.550	578.670
6004	1147.640	1280.426	625.513	532.223
6005	1192.926	1366.188	810.846	481.245
6013	1012.353	1133.544	665.565	390.789
6014	914.902	1130.161	680.767	410.068
6015	816.017	733.589	873.676	1040.515
6016	419.903	408.097	497.560	606.633
6017	515.349	1312.844	496.522	187.786
6018	611.941	1101.594	559.349	284.017
6019	1070.825	934.597	1160.360	1440.659
6020	1019.806	916.190	1160.655	1470.349
6021	1115.824	1275.975	789.708	488.755
6022	1034.997	1037.366	911.020	800.063
6023	1069.678	1225.208	778.282	494.384
6024	1111.238	1224.026	784.591	502.917
6025	1157.098	1169.471	736.256	463.520
6026	1178.882	1235.789	810.886	532.078
6027	1106.939	1114.234	921.564	762.211
6048	1412.766	1595.518	994.200	619.506
6066	100.605		286.903	
6067	221.273		413.366	
6068	296.082			
6069	415.890			
6070	319.872		451.043	
6071	203.789			

TABLE 9.2: MASS FLOW RATE COMPARISON

3 INCH 40 BAR

RUN ID TSN	VSL+VSG (M/S)	TURB. VEL (M/S)	VEL. DD-G (M/S)
6003	5.936	3.672	2.556
6004	10.361	6.547	4.221
6005	10.245	7.722	4.583
6013	11.171	9.609	5.642
6014	5.161	4.178	2.517
6015	1.793	1.402	1.670
6016	1.335	0.931	1.136
6017	5.743	6.333	2.354
6018	10.084	11.551	5.865
6019	2.483	1.752	2.175
6020	2.573	1.834	2.323
6021	6.968	5.356	3.315
6022	3.951	2.821	2.478
6023	5.920	4.551	2.891
6024	8.182	6.380	4.090
6025	10.022	8.028	5.054
6026	7.382	5.402	3.544
6027	4.159	3.096	2.561
6048	6.736	4.788	2.984
6066	1.037		1.315
6067	1.164		1.121
6068	5.154		
6069	10.551		
6070	5.582		3.866
6071	5.077		

TABLE 9.3: TOTAL VELOCITY COMPARISON

3 INCH 40 BAR

RUN ID TSN	DENSITIES (KG/M↑3) VERT AVG GAMMA	LEN AVG GAMMA	SCAN DENS	[illegible] FRACTIONS [illegible]	[illegible]	[illegible]	RADIOTRACER FOR FRACTION [illegible]	WATER
6003	320.46	325.39						
6004	192.57	195.58						
6005	174.49	176.92						
6013	115.40	117.97	137.10	[illegible]	[illegible]	[illegible]	0.80	0.90
6014	265.44	270.48	264.55	[illegible]	[illegible]	[illegible]	0.66	0.67
6015	516.79	523.20		0.35		[illegible]	0.44	0.41
6016	432.12	438.11	369.96	0.46	0.55	0.62	0.49	0.44
6017	203.73	207.41	187.96	0.76	0.78	0.91	0.75	0.77
6018	92.89	95.37		0.90		0.95	0.90	0.89
6019	527.29	533.52	475.98	0.34	0.41	0.47	0.53	0.37
6020	492.98	499.56	463.49	0.38	0.43	0.51	0.55	0.43
6021	232.99	238.25		0.72		0.82	0.67	0.73
6022	361.15	367.68		0.55		0.69	0.62	0.59
6023	263.61	269.19		0.68		0.79	0.68	0.67
6024	186.91	191.84		0.78		0.85	0.78	0.79
6025	141.82	145.67	172.86	0.84	0.80	0.88	0.80	0.84
6026	223.66	228.78		0.73		0.82	0.78	0.75
6027	353.60	359.88		0.56		0.68	0.56	0.60
6048	327.87	333.23		0.60		0.76		
6066	215.19	218.23		0.74		0.90		
6067	364.65	368.90		0.55		0.78		
6068						0.95		
6069			69.43		0.94	0.98		
6070	114.19	116.66	112.87	0.88	0.88	0.95		
6071						0.97		

TABLE 9.4: VOID FRACTION COMPARISON

3 INCH 40 BAR

RUN ID TSN	V GAS G DENS (M/S)	V GAS RADIO (M/S)	V LIQ. G DENS (M/S)	V LIQ. RADIO (M/S)	SLIP G DENS	SLIP RADIO
6003	7.809		3.065		2.548	
6004	11.833		5.342		2.215	
6005	11.251		6.286		1.790	
6013	11.623	12.70	8.045	9.80	1.445	1.296
6014	6.084	6.20	3.236	3.20	1.880	1.938
6015	2.244	1.80	1.550	1.70	1.448	1.059
6016	1.800	1.70	0.940	0.90	1.914	1.889
6017	6.897	7.00	2.131	2.20	3.237	3.182
6018	10.585	10.60	5.429	4.80	1.950	2.208
6019	3.463	2.20	1.988	2.10	1.742	1.048
6020	3.474	2.40	2.019	2.20	1.721	1.091
6021	7.947	8.50	4.472	4.70	1.777	1.809
6022	4.931	4.40	2.749	3.00	1.794	1.467
6023	6.918	6.90	3.816	3.70	1.813	1.865
6024	8.944	8.90	5.509	5.70	1.623	1.561
6025	10.488	11.00	7.611	7.90	1.378	1.392
6026	8.285	7.80	4.938	5.30	1.678	1.472
6027	5.060	5.10	3.011	3.30	1.681	1.545
6048	8.535		4.083		2.090	
6066	1.255		0.402		3.118	
6067	1.654		0.567		2.915	
6068						
6069						
6070	6.071		2.147		2.827	
6071						

TABLE 9.5: PHASE VELOCITY COMPARISON

RUN ID TSN	From Govier & Aziz Flow Regime Map	From Gamma Densitometer: Flow Regime	From Gamma Densitometer: Interface Location(%)*	From Reference Densitometer: Flow Regime	From Reference Densitometer: Interface Location(%)*
6003	Slug Flow		34.72		
6004	Slug Flow		11.91		
6005	Slug Flow		7.25		
6013	Slug Flow		-5.04		2
6014	Slug Flow		24.93		28
6015	Slug Flow		70.74		
6016	Slug Flow		54.75		41
6017	Slug Flow		13.49		15
6018	Slug Flow		-9.98		
6019	Slug Flow		72.43		54
6020	Slug Flow		66.46		54
6021	Slug Flow		19.14		
6022	Slug Flow		43.39		
6023	Slug Flow		24.93		
6024	Slug Flow		10.73		
6025	Slug Flow		0.93		2
6026	Slug Flow		15.89		
6027	Slug Flow		42.08		
6048	Slug Flow		36.87		
6066	Stratified Flow		16.29		
6067	Slug Flow		42.95		
6068	Slug Flow				
6069	Slug Flow				
6070	Slug Flow		-6.72		
6071	Wave Flow				

TABLE 9.6: FLOW REGIME COMPARISON

3 INCH 40 BAR

RUN ID TSN	ALPHA GAMMA	GDOT-GDOT G-T REF (KG/M↑2*S)	VT-(VSL+VSG) (M/S)
6003	0.61	139.02	-2.26
6004	0.77	132.79	-3.81
6005	0.80	173.26	-2.52
6013	0.87	121.19	-1.56
6014	0.68	215.26	-0.98
6015	0.35	-82.43	-0.39
6016	0.46	-11.81	-0.40
6017	0.76	797.50	0.59
6018	0.90	489.65	1.47
6019	0.34	-136.23	-0.73
6020	0.38	-103.62	-0.74
6021	0.72	160.15	-1.61
6022	0.55	2.37	-1.13
6023	0.68	155.53	-1.37
6024	0.78	112.79	-1.80
6025	0.84	12.37	-1.99
6026	0.73	56.91	-1.98
6027	0.56	7.29	-1.06
6048	0.60	182.75	-1.95
6066	0.74		
6067	0.55		
6068			
6069			
6070	0.88		
6071			

TABLE 9.7: ERROR CALCULATIONS

3 INCH 40 BAR

RUN ID TSN	LEN AVG GAMMA (KG/M↑3)	GDOT/(VSL+VSG) REF (KG/M↑3)	DRAG DISK (KG/M*S↑2)	(GDOT)X(VSL+VSG) REF (KG/M*S↑2)	(SUM MV/ ALPHA)/AREA (KG/M*S↑2)
6003	325.39	177.87	2125	6268.30	3693.50
6004	195.58	110.77	3484	11890.28	7347.93
6005	176.92	116.44	3716	12221.66	8408.01
6013	117.97	90.63	3755	11308.73	8879.82
6014	270.48	177.27	1713	4721.84	3201.96
6015	523.20	455.06	1459	1463.30	1276.06
6016	438.11	314.45	565	560.71	409.19
6017	207.41	89.73	1189	2959.66	1604.48
6018	95.37	60.68	3281	6170.78	4319.51
6019	533.52	431.24	2524	2658.98	2163.98
6020	499.56	396.38	2697	2623.78	2097.81
6021	238.25	160.14	2618	7774.64	5390.46
6022	367.68	261.99	2257	4088.77	2964.90
6023	269.19	180.69	2250	6332.52	4375.15
6024	191.84	135.82	3209	9091.95	6608.09
6025	145.67	115.46	3721	11596.08	9314.40
6026	228.78	159.69	2874	8702.96	6229.15
6027	359.88	266.15	2360	4603.90	3451.27
6048	333.23	209.72	2966	9517.01	6214.09
6066	218.23	97.05	377	104.29	56.53
6067	368.90	190.06	463	257.62	145.35
6068		57.44	901	1526.11	
6069		39.42	4749	4388.06	
6070	116.66	57.31	1744	1785.44	1108.07
6071		40.14	1401	1034.62	

TABLE 9.8: SINGLE INSTRUMENT CALCULATION

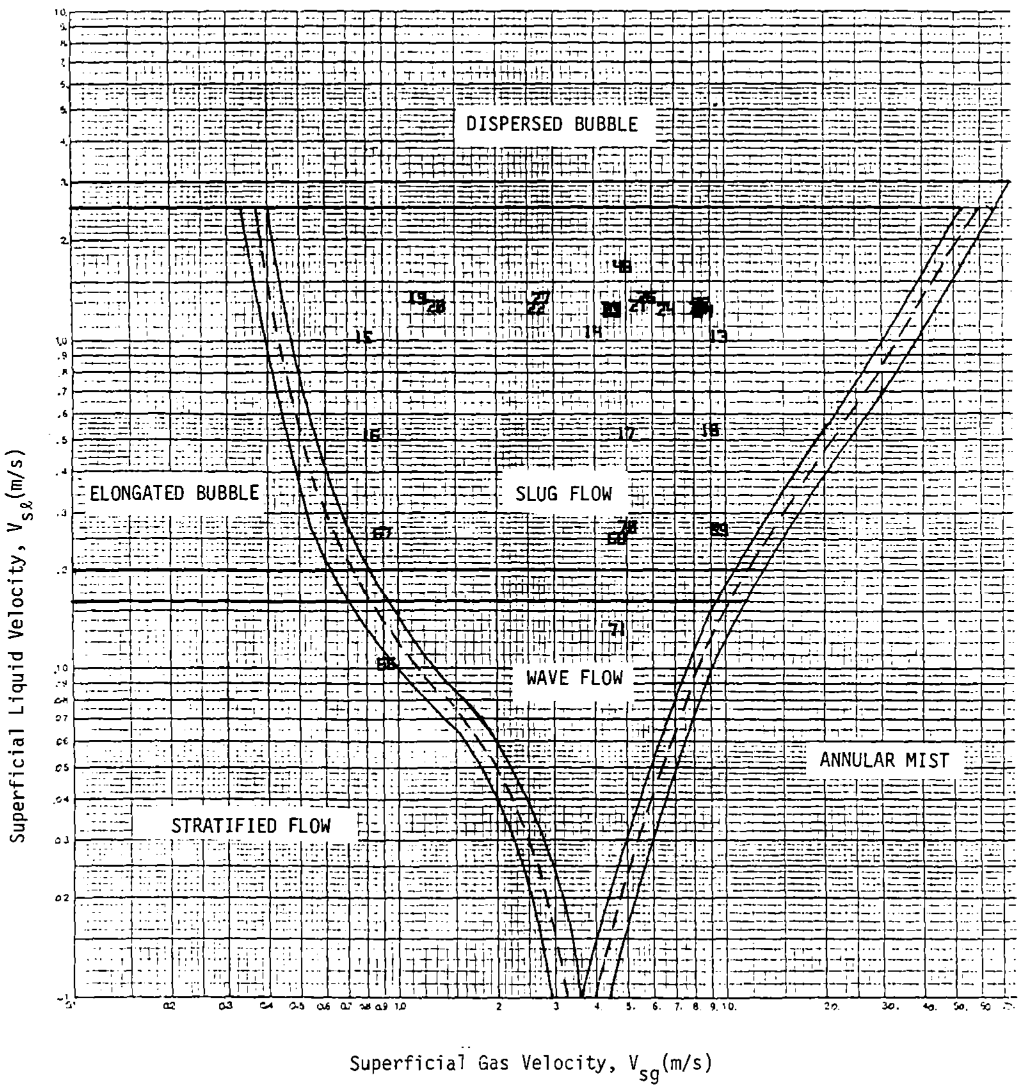

FIGURE 9.1A: GOVIER AND AZIZ FLOW REGIME MAP

LTR LO 00 79-109
2784

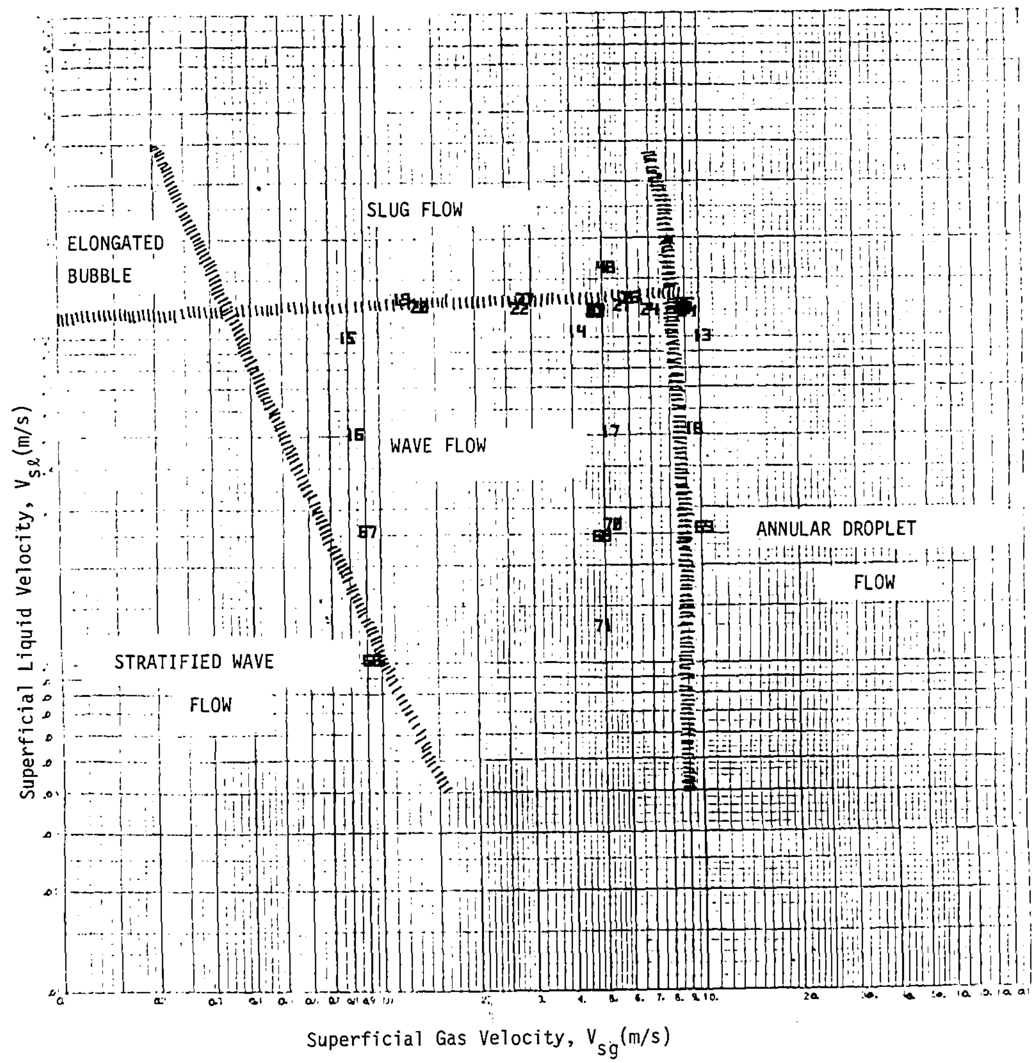

FIGURE 9.1B: IMPEDANCE PROBE FLOW REGIME MAP

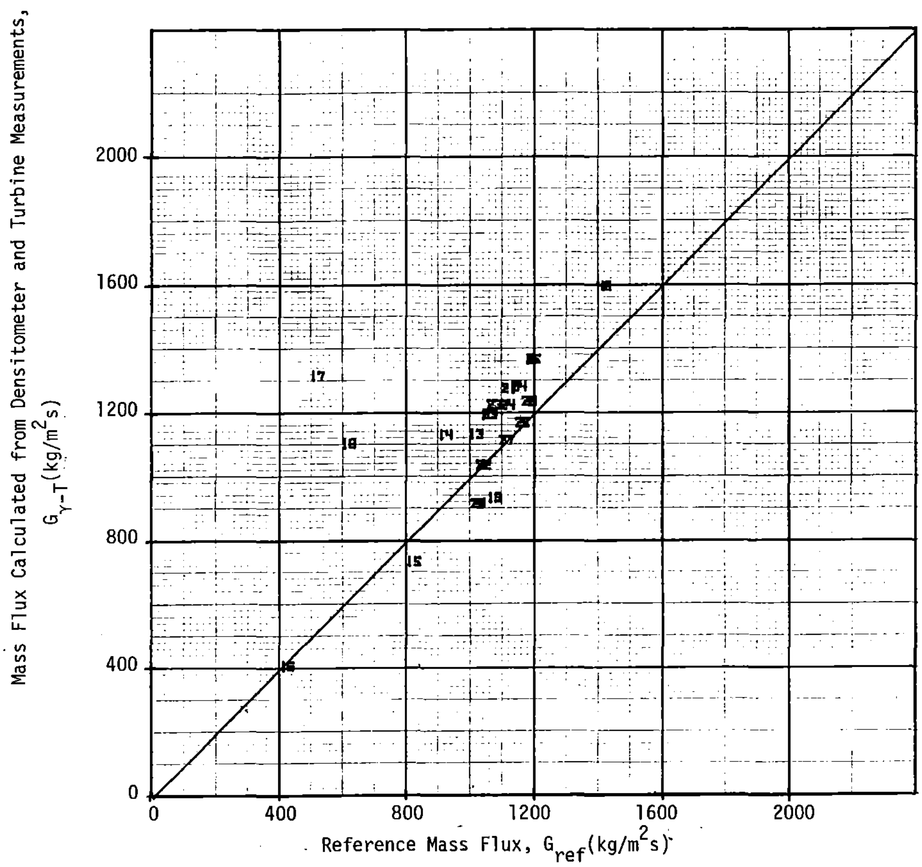

FIGURE 9.2: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND TURBINE MEASUREMENTS AT DIFFERENT REFERENCE VALUES

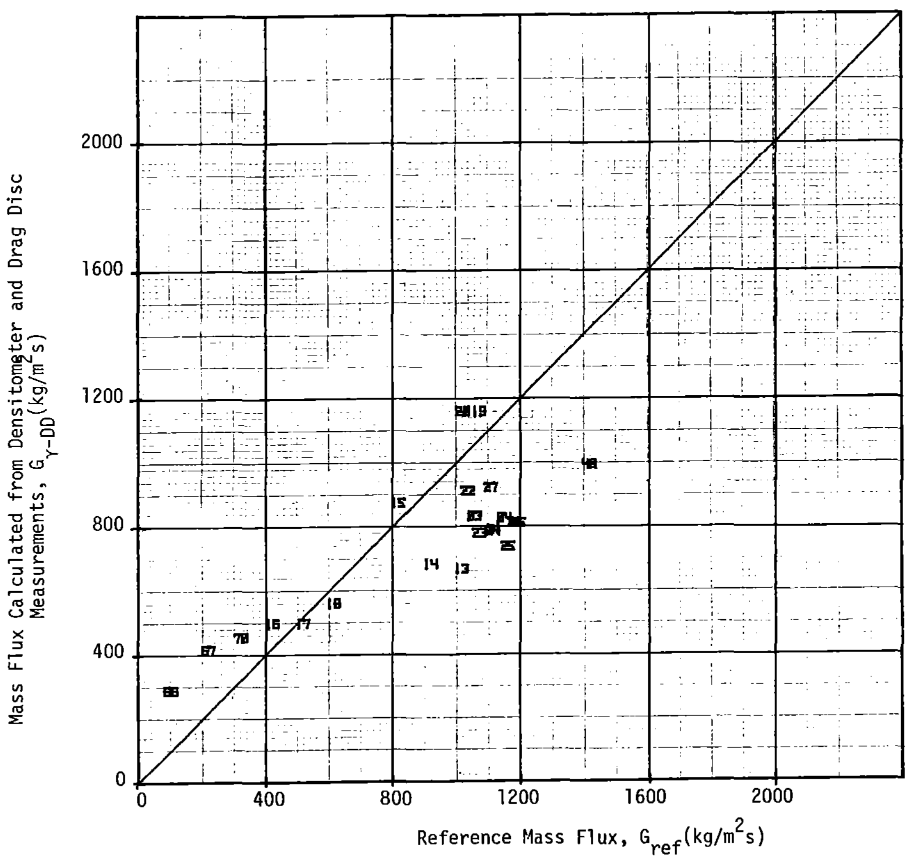

FIGURE 9.3: MASS FLUXES CALCULATED FROM GAMMA DENSITOMETER AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

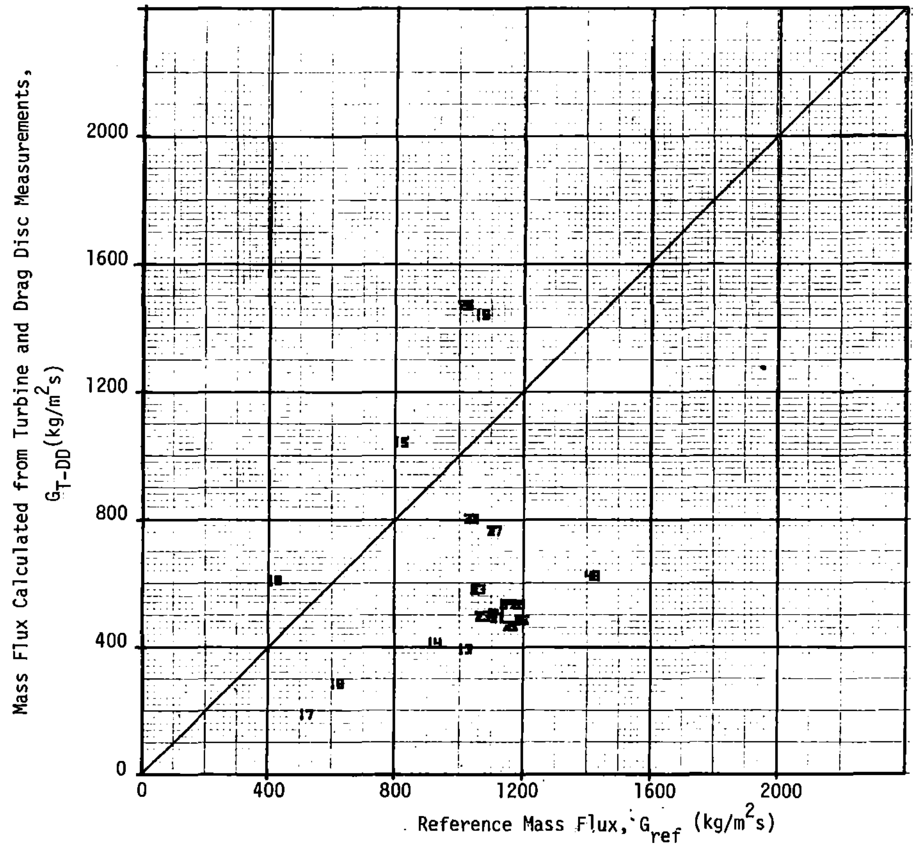

FIGURE 9.4: MASS FLUXES CALCULATED TURBINE AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

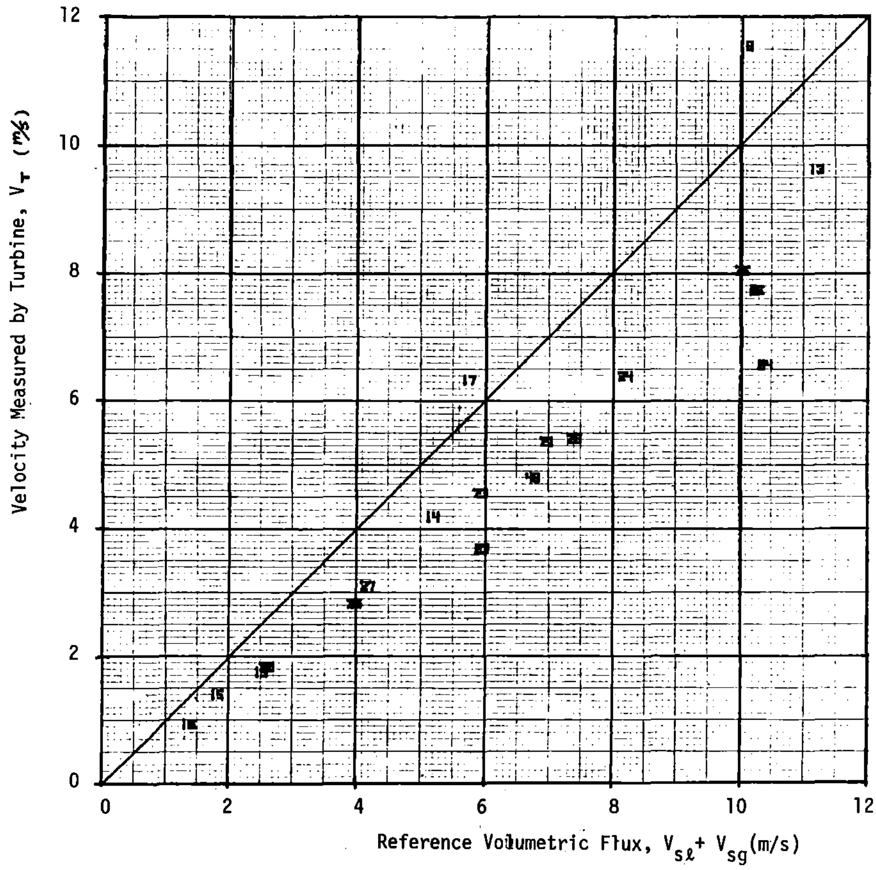

FIGURE 9.5: THE VELOCITIES MEASURED BY TURBINE AT VARIOUS VOLUMETRIC FLUXES

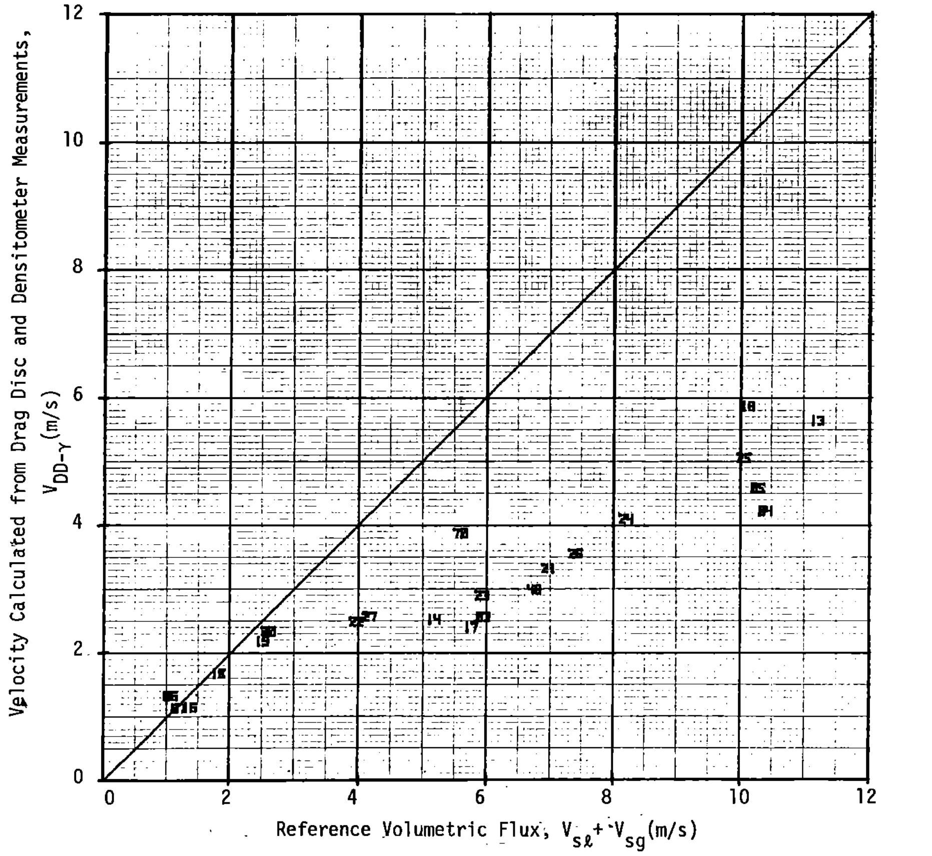

FIGURE 9.6: THE VELOCITIES CALCULATED FROM DRAG DISC AND DENSITOMETER MEASUREMENTS AT DIFFERENT REFERENCE VOLUMETRIC FLUXES

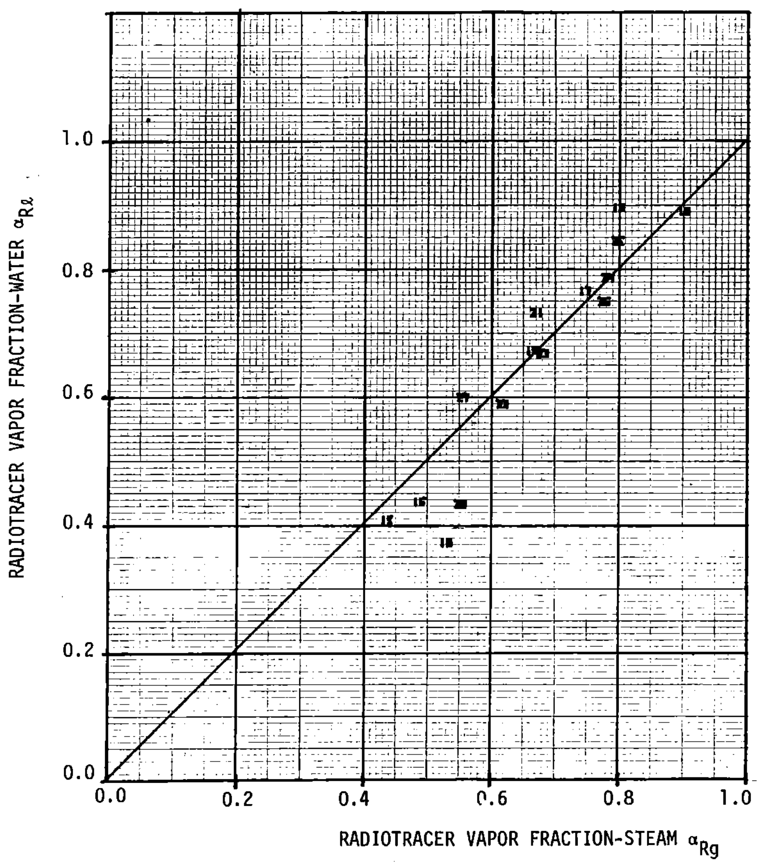

FIGURE 9.7: COMPARISON OF RADIOTRACER VAPOR FRACTION

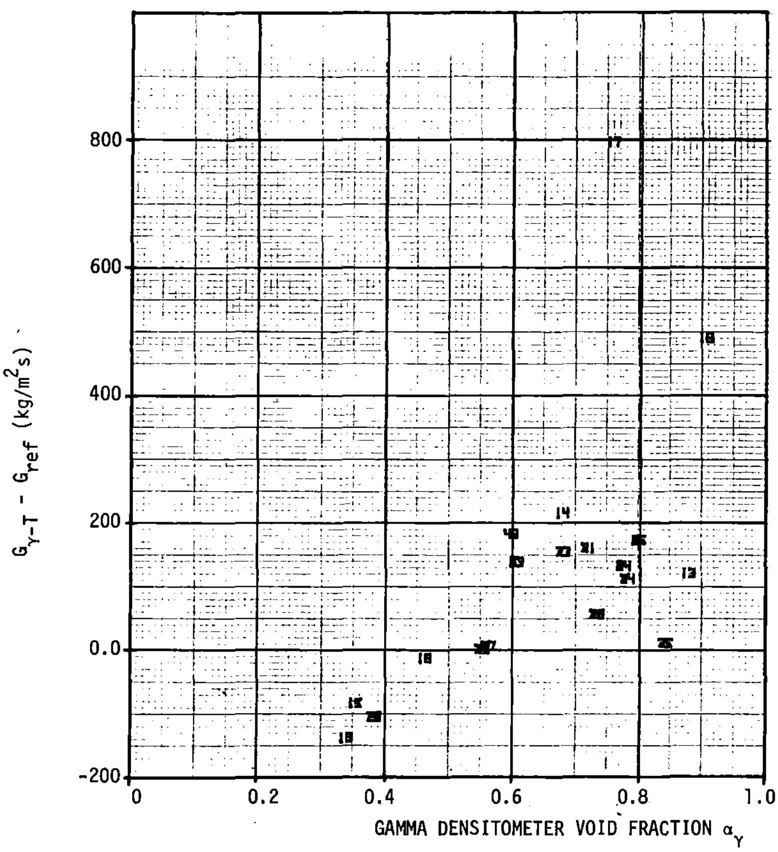

FIGURE 9.8: ERROR IN GAMMA DENSITOMETER - TURBINE MASS FLOW CALCULATION

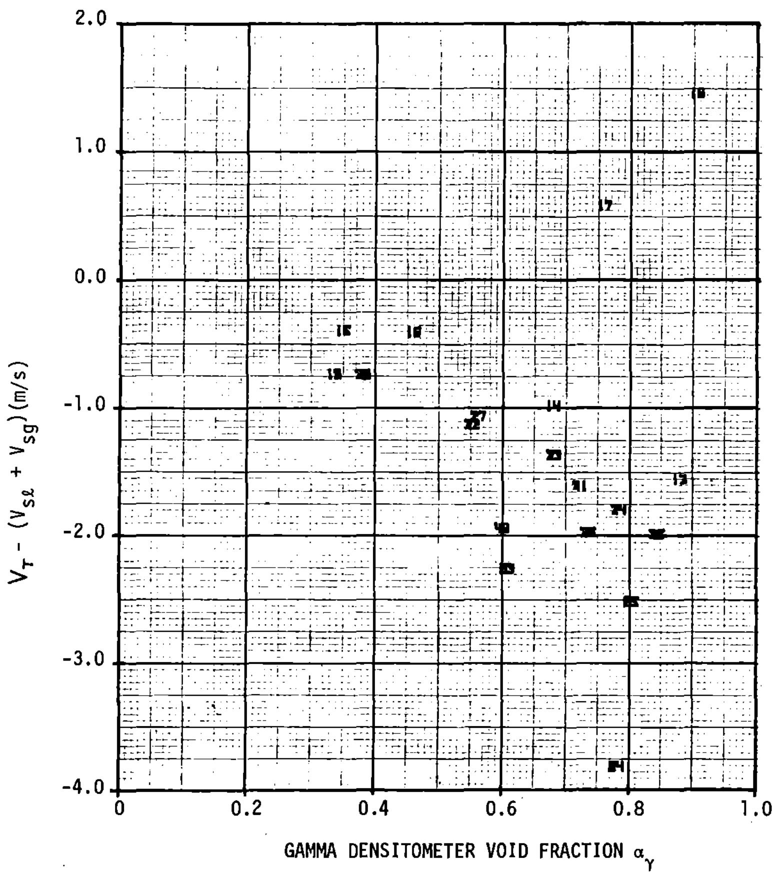

FIGURE 9.9: ERROR IN TURBINE VELOCITY

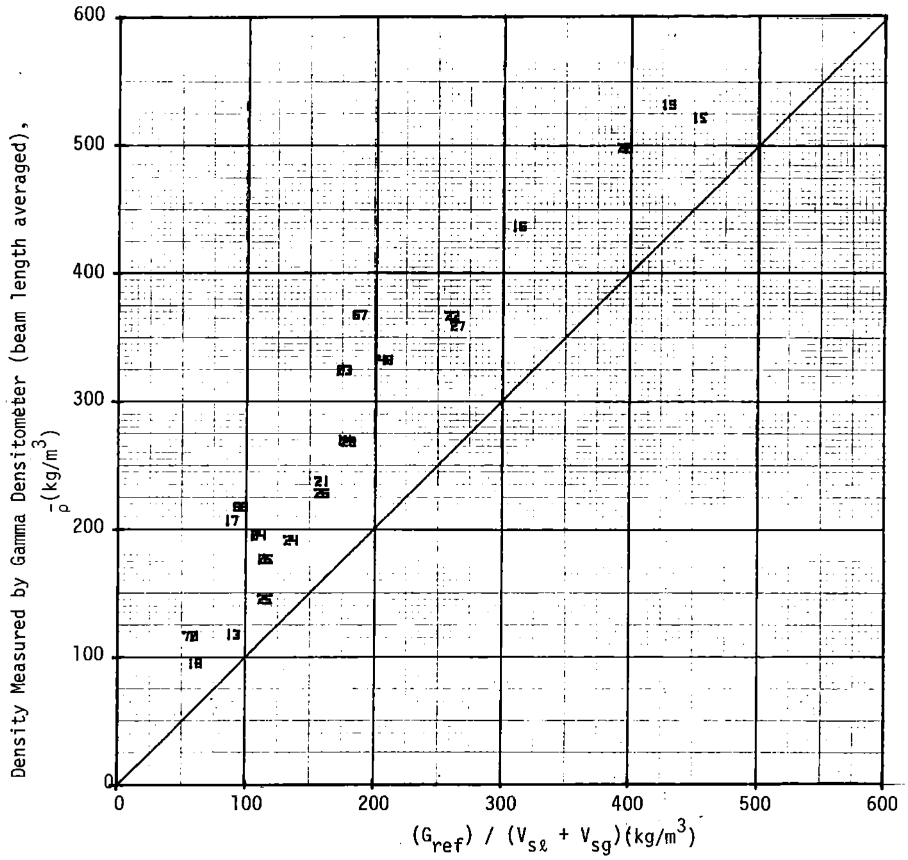

FIGURE 9.10: DENSITY COMPARISONS

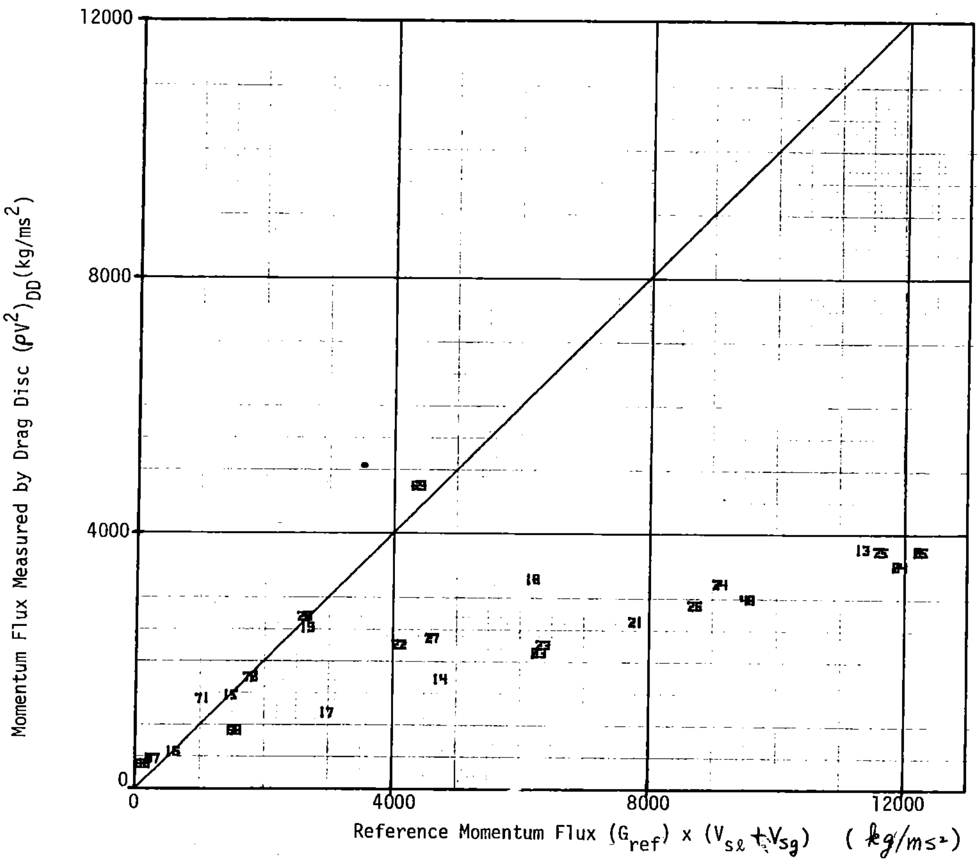

FIGURE 9.11: MOMENTUM FLUX COMPARISONS

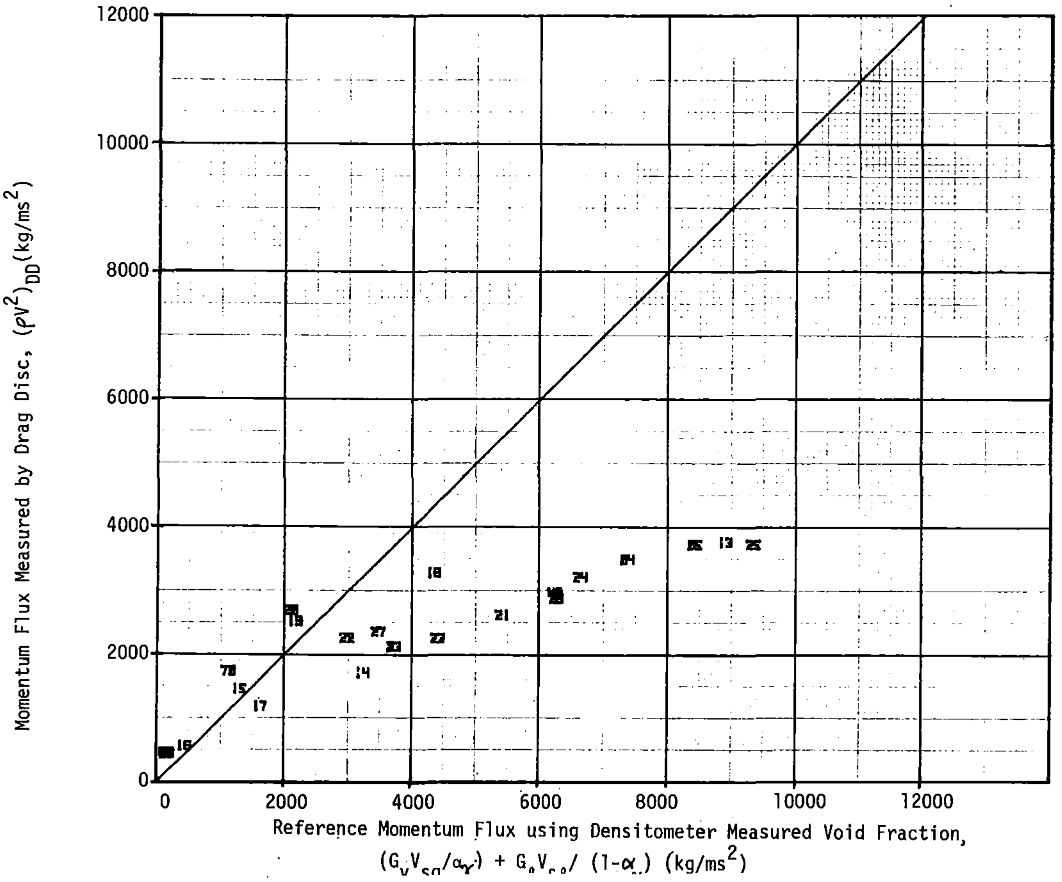

FIGURE 9.12: DRAC DISC MOMENTUM FLUX COMPARISON

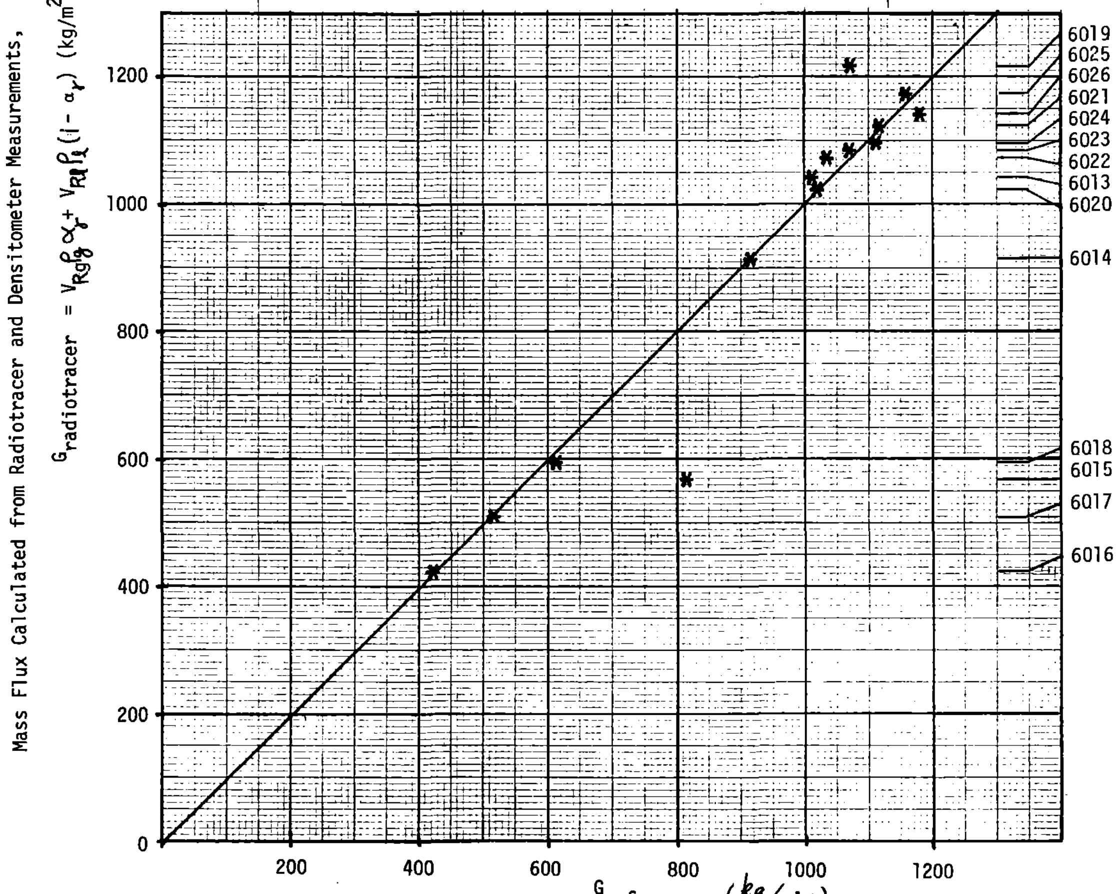

FIGURE 9.13: MASS FLUX CALCULATION FROM RADIOTRACERAND DENSTIO-METER MEASUREMENTS AT DIFFERENT REFERENCE VALUES

10.

THREE-INCH STEAM-WATER 70 BAR

FLUID: STEAM - WATER
PIPE SIZE= 3 INCH SCHEDULE 160
NOMINAL PRESSURE= 70 BARS

INSIDE DIAMETER= 0.06665 M
TURB. DIA.= 0.0381 M
PIPE AREA= 0.0034889 M↑2

RUN			FLOW RATES					DRAG	GAMMA DENSITOMETER			SCAN	RADIOTRACER VELOCITIES		
			STEAM		WATER		TURB.	DISK	A BEAM	B BEAM	C BEAM	DENS	STEAM	WATER	Comments
ID TSN	PRESS. (BARS)	TEMP. (DEG C)	SUP-VEL (M/S)	MASS (KG/S)	SUP-VEL (M/S)	MASS (KG/S)	VEL (M/S)	(KG/ M*S↑2)	UPPER (KG/ M↑3)	MIDDLE (KG/ M↑3)	LOWER (KG/ M↑3)	(KG/ M↑3)	(M/S) (AT GAMMA DENS)	(M/S)	
6035	78.1	291.2	0.21	0.030	1.779	4.530	1.86	2943	651	723	765	665			
6036	78.7	291.5	0.86	0.126	1.630	4.144	1.93	3150	485	550	740	537			
6037	78.4	292.3	1.48	0.215	1.589	4.042	2.36	3402	389	469	704	428			
6051	75.7	288.7	5.29	0.737	0.995	2.546	6.37	2866	139	223	334	178			
6052	75.5	289.0	7.36	1.021	1.188	3.042	7.04	3851	139	192	296		9.40	6.20	
6053	76.2	290.1	1.61	0.226	1.219	3.117	2.12	2507	318	407	608	357	3.10	2.70	
6054	75.6	287.6	0.91	0.126	0.507	1.299	0.99	536	290	379	556		1.80	1.00	
6055	75.4	290.1	0.96	0.134	1.064	2.723	1.59	1649	358	428	634	437	2.10	2.00	
6056	75.8	290.5	5.10	0.711	0.510	1.305	6.55	2070	108	202	289		6.30	2.90	
6057	76.1	290.5	3.11	0.435	1.205	3.082	3.30	2222	236	329	508		5.00	3.20	
6058	75.8	290.1	4.51	0.628	1.216	3.111	4.60	2626	189	280	428	262	6.50	3.90	
6059	75.3	289.0	5.95	0.822	1.214	3.109	6.44	3762	146	205	315		8.00	5.00	
6060	75.7	289.4	3.31	0.460	1.491	3.815	3.62	2995	251	340	536		5.40	3.70	
6061	75.8	289.8	1.45	0.202	1.491	3.815	2.24	3434	362	455	682		3.20	2.60	
6062	75.3	288.3	5.52	0.763	1.613	4.132	5.74	3863	181	246	396		7.10	5.30	
6063	75.9	288.7	10.11	1.410	1.331	3.404	10.79	4162	89	125	167		12.60	10.30	T above range
6074	75.6	290.1	4.96	0.689	0.137	0.351	—	2772	28	104	63				T failed
6075	74.8	289.0	10.03	1.376	0.139	0.356	—	5360	3	60	2				T failed, DD above range
6076	74.9	289.0	9.80	1.347	0.259	0.665	—	5456	9	70	41				T failed, DD above range
6077	74.9	289,4	4.96	0.682	0.264	0.676	—	2544	39	143	153	111			T failed
6078	74.6	288.7	0.77	0.105	0.235	0.604	—	585	191	287	390	235			T failed
6079	75.8	290.1	0.85	0.119	0.156	0.398	—	559	145	252	333	242			T failed
6080	75.3	289.0	9.43	1.303	0.537	1.375	—	5465	41	107	108				T failed, DD above range

Dash indicates error in data.
Blank indicates no data.

TABLE 10.1: PRIMARY ENGINEERING UNIT DATA

3 INCH 70 BAR

RUN ID TSN	GDOT REF (KG/M↑2*S)	GDOT G-T (KG/M↑2*S)	GDOT G-DD (KG/M↑2*S)	GDOT T-DD (KG/M↑2*S)
6035	1307.002	1316.303	1444.622	1585.450
6036	1223.881	1114.773	1349.528	1633.720
6037	1220.155	1190.108	1309.667	1441.237
6051	940.984	1425.268	800.873	450.019
6052	1164.550	1419.600	880.970	546.709
6053	958.182	913.292	1038.010	1179.760
6054	408.438	391.597	460.271	540.990
6055	818.883	727.331	869.821	1040.226
6056	577.833	1262.659	631.535	315.870
6057	1008.054	1138.403	875.113	672.716
6058	1071.684	1324.421	869.918	571.387
6059	1126.716	1376.959	896.549	583.751
6060	1225.315	1309.382	1040.293	826.504
6061	1151.366	1081.786	1288.725	1535.249
6062	1403.021	1512.884	1009.402	673.477
6063	1379.805	1334.984	717.488	385.614
6074	298.088		431.426	
6075	496.432		367.054	
6076	576.686		475.573	
6077	389.234		529.230	
6078	203.216		405.719	
6079	148.184		363.968	
6080	767.577		680.303	

TABLE 10.2: MASS FLOW RATE COMPARISON

3 INCH 70 BAR

RUN ID TSN	VSL+VSG (M/S)	TURB. VEL (M/S)	VEL. DD-G (M/S)
6035	1.990	1.856	2.037
6036	2.494	1.928	2.334
6037	3.070	2.361	2.598
6051	6.289	6.368	3.578
6052	8.550	7.044	4.371
6053	2.829	2.125	2.415
6054	1.417	0.990	1.164
6055	2.028	1.585	1.896
6056	5.610	6.553	3.278
6057	4.316	3.303	2.539
6058	5.723	4.596	3.018
6059	7.164	6.445	4.196
6060	4.796	3.624	2.879
6061	2.940	2.237	2.665
6062	7.131	5.736	3.827
6063	11.436	10.793	5.801
6074	5.099		6.425
6075	10.167		14.603
6076	10.055		11.473
6077	5.227		4.808
6078	1.003		1.441
6079	1.009		1.537
6080	9.963		8.033

TABLE 10.3: TOTAL VELOCITY COMPARISON

3 INCH 70 BAR

RUN ID TSN	DENSITIES (KG/M↑3) VERT AVG GAMMA	LEN AVG GAMMA	SCAN DENS	VAPOR FRACTIONS ALPHA GAMMA (LEN)	ALPHA SCAN DENS	AL THEF	ADIOTRACER OR FRACTION AM	WATER
6035	707.25	709.20	664.71	0.03	0.09	0.11		
6036	573.80	578.13	537.11	0.22	0.28	0.35		
6037	498.76	504.12	427.58	0.33	0.44	0.48		
6051	220.50	223.80	177.88	0.73	0.80	0.84		
6052	198.86	201.53		0.77		0.86	0.78	0.81
6053	424.90	429.83	357.48	0.44	0.54	0.57	0.52	0.55
6054	390.90	395.42		0.49		0.64	0.51	0.49
6055	454.11	458.80	436.73	0.40	0.43	0.48	0.46	0.47
6056	189.61	192.69		0.78		0.91	0.81	0.82
6057	340.00	344.62		0.56		0.72	0.62	0.62
6058	284.14	288.20	262.09	0.64	0.68	0.79	0.69	0.69
6059	210.79	213.66		0.75		0.83	0.74	0.76
6060	356.51	361.35		0.54		0.69	0.61	0.60
6061	478.13	483.57		0.36		0.49	0.45	0.43
6062	260.10	263.75		0.68		0.77	0.78	0.70
6063	122.35	123.69		0.88		0.88	0.80	0.87
6074	66.55	67.14		0.96		0.97		
6075	25.15	25.14		1.02		0.99		
6076	40.91	41.45		1.00		0.97		
6077	108.14	110.08	110.97	0.90	0.90	0.95		
6078	278.08	281.46	235.35	0.65	0.72	0.77		
6079	233.68	236.87	242.26	0.72	0.71	0.85		
6080	83.55	84.69		0.94		0.95		

TABLE 10.4: VOID FRACTION COMPARISON

3 INCH 70 BAR

RUN ID TSN	V GAS G DENS (M/S)	V GAS RADIO (M/S)	V LIQ. G DENS (M/S)	V LIQ. RADIO (M/S)	SLIP G DENS	SLIP RADIO
6035	7.032		1.834		3.835	
6036	3.937		2.088		1.886	
6037	4.523		2.362		1.915	
6051	7.204		3.752		1.920	
6052	9.600	9.40	5.098	6.20	1.883	1.516
6053	3.680	3.10	2.167	2.70	1.698	1.148
6054	1.865	1.80	0.990	1.00	1.884	1.800
6055	2.433	2.10	1.762	2.00	1.381	1.050
6056	6.541	6.30	2.316	2.90	2.824	2.172
6057	5.551	5.00	2.742	3.20	2.024	1.563
6058	7.020	6.50	3.396	3.90	2.067	1.667
6059	7.940	8.00	4.843	5.00	1.640	1.600
6060	6.161	5.40	3.217	3.70	1.915	1.459
6061	4.022	3.20	2.331	2.60	1.726	1.231
6062	8.146	7.10	4.999	5.30	1.630	1.340
6063	11.493	12.60	11.022	10.30	1.043	1.223
6074	5.166		3.479		1.485	
6075						
6076	9.824		88.782		0.111	
6077	5.524		2.594		2.129	
6078	1.177		0.677		1.739	
6079	1.192		0.548		2.175	
6080	10.080		8.272		1.219	

TABLE 10.5: PHASE VELOCITY COMPARISON

RUN ID TSN	From Govier & Aziz Flow Regime Map	From Gamma Densitometer: Flow Regime	From Gamma Densitometer: Interface Location(%)*	From Reference Densitometer: Flow Regime	From Reference Densitometer: Interface Location(%)*
6035	Elongated Bubble		125.41		94
6036	Slug Flow		90.34		81
6037	Slug Flow		74.12		54
6051	Slug Flow		17.91		15
6052	Slug Flow		11.91		
6053	Slug Flow		57.81		54
6054	Slug Flow		51.26		
6055	Slug Flow		63.02		54
6056	Slug Flow		10.34		
6057	Slug Flow		42.08		
6058	Slug Flow		30.43		28
6059	Slug Flow		15.08		
6060	Slug Flow		44.70		
6061	Slug Flow		69.46		
6062	Slug Flow		24.93		
6063	Slug Flow		-6.72		
6074	Wave Flow		-23.15		
6075	Wave Flow		-		
6076	Slug Flow		-37.47		
6077	Slug Flow		-10.30		
6078	Slug Flow		29.15		
6079	Wave Flow		19.14		
6080	Slug Flow		-8.37		

TABLE 10.6: FLOW REGIME COMPARISON

3 INCH 70 BAR

RUN ID TSN	ALPHA GAMMA	GDOT-GDOT G-T REF (KG/M↑2*S)	VT-(VSL+VSG) (M/S)
6035	0.03	9.30	-0.13
6036	0.22	-109.11	-0.57
6037	0.33	-30.05	-0.71
6051	0.73	484.28	0.08
6052	0.77	255.05	-1.51
6053	0.44	-44.89	-0.70
6054	0.49	-16.84	-0.43
6055	0.40	-91.55	-0.44
6056	0.78	684.83	0.94
6057	0.56	130.35	-1.01
6058	0.64	252.74	-1.13
6059	0.75	250.24	-0.72
6060	0.54	84.07	-1.17
6061	0.36	-69.58	-0.70
6062	0.68	109.86	-1.39
6063	0.88	-44.82	-0.64
6074	0.96		
6075	1.02		
6076	1.00		
6077	0.90		
6078	0.65		
6079	0.72		
6080	0.94		

TABLE 10.7: ERROR CALCULATIONS

3 INCH 70 BAR

RUN ID TSN	LEN AVG GAMMA (KG/M↑3)	GDOT/(VSL+VSG) REF (KG/M↑3)	DRAG DISK (KG/M*S↑2)	(GDOT)X(VSL+VSG) REF (KG/M*S↑2)	(SUM MV/ ALPHA)/AREA (KG/M*S↑2)
6035	709.20	656.93	2943	2600.35	2442.09
6036	578.13	490.80	3150	3051.90	2621.70
6037	504.12	397.50	3402	3745.36	3014.98
6051	223.80	149.63	2866	5917.72	4259.95
6052	201.53	136.20	3851	9957.38	7254.06
6053	429.83	338.70	2507	2710.73	2174.56
6054	395.42	288.33	536	578.58	436.01
6055	458.80	403.82	1649	1660.56	1468.42
6056	192.69	103.00	2070	3241.63	2198.84
6057	344.62	233.55	2222	4350.99	3114.35
6058	288.20	187.27	2626	6133.02	4292.01
6059	213.66	157.27	3762	8072.18	6186.86
6060	361.35	255.47	2995	5876.97	4329.26
6061	483.57	391.61	3434	3385.10	2781.32
6062	263.75	196.76	3863	10004.53	7702.33
6063	123.69	120.65	4162	15779.60	15398.11
6074	67.14	58.46	2772	1520.05	1370.22
6075	25.14	48.83	5360	5047.16	
6076	41.45	57.35	5456	5798.41	20709.41
6077	110.08	74.47	2544	2034.36	1582.38
6078	281.46	202.70	585	203.73	152.54
6079	236.87	146.89	559	149.48	103.12
6080	84.69	77.04	5465	7647.26	7024.70

TABLE 10.8: SINGLE INSTRUMENT CALCULATION

LTR LO 00 79-109
2784

LTR LO 00 79-109
2784

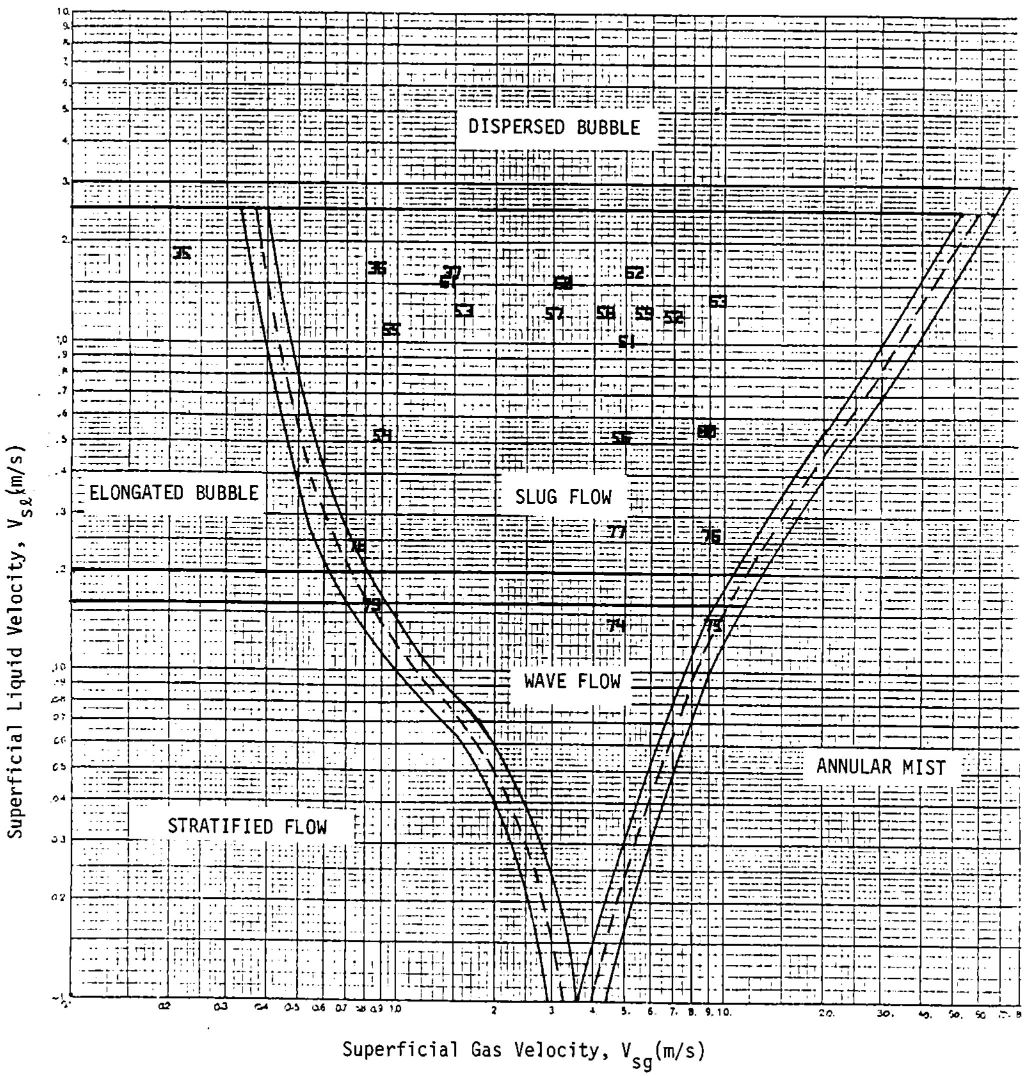

FIGURE 10.1A: GOVIER AND AZIZ FLOW REGIME MAP

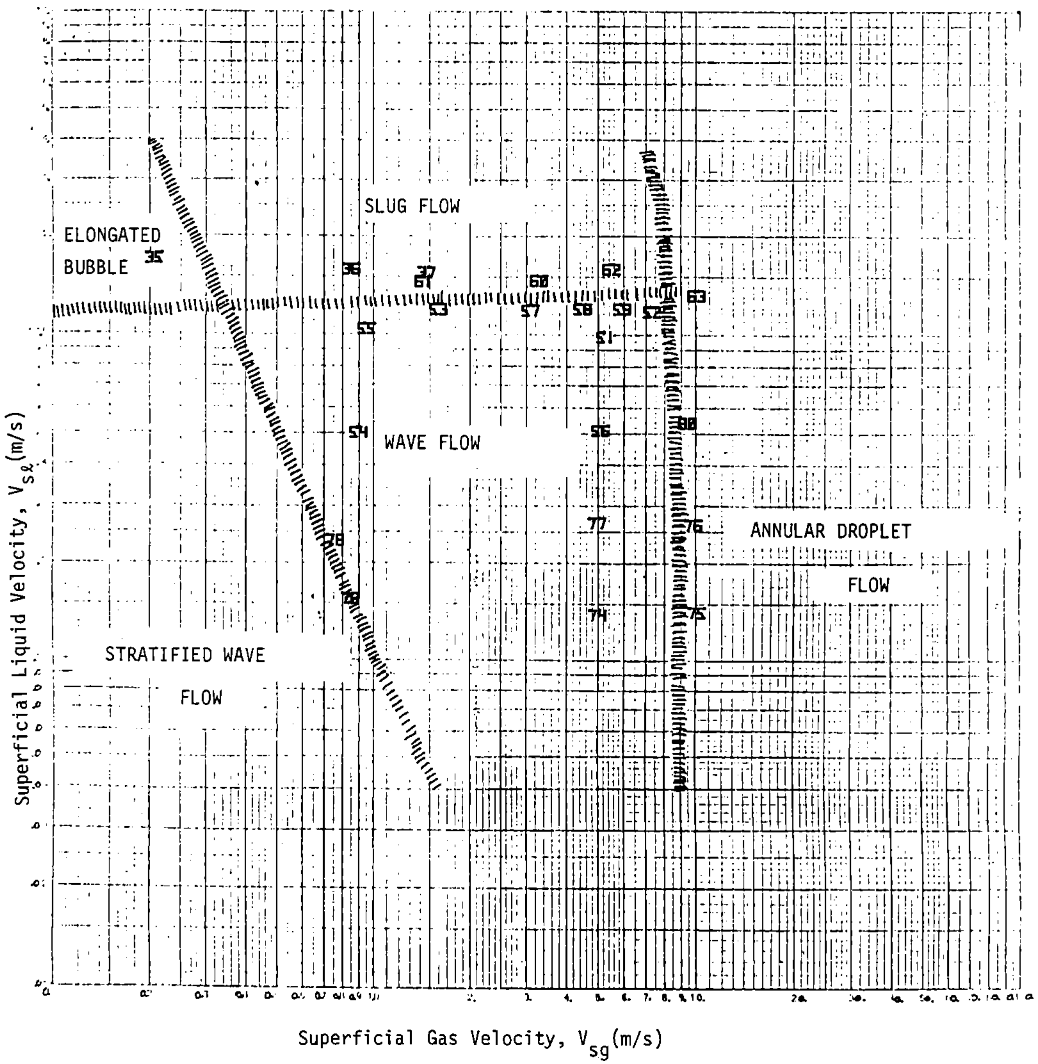

FIGURE 10.1B: IMPEDANCE PROBE FLOW REGIME MAP

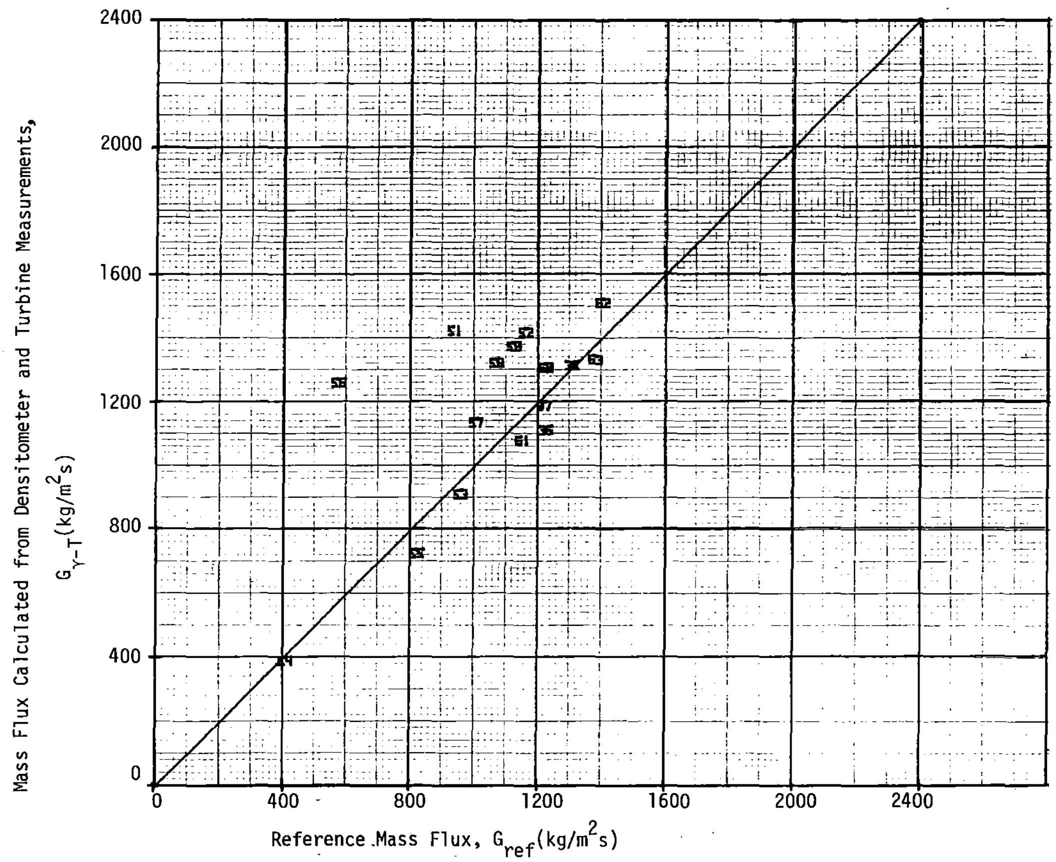

FIGURE 10.2: MASS FLUXES CALCULATED FROM GAMMA-DENSITOMETER AND TURBINE MEASUREMENTS AT DIFFERENT REFERENCE VALUES

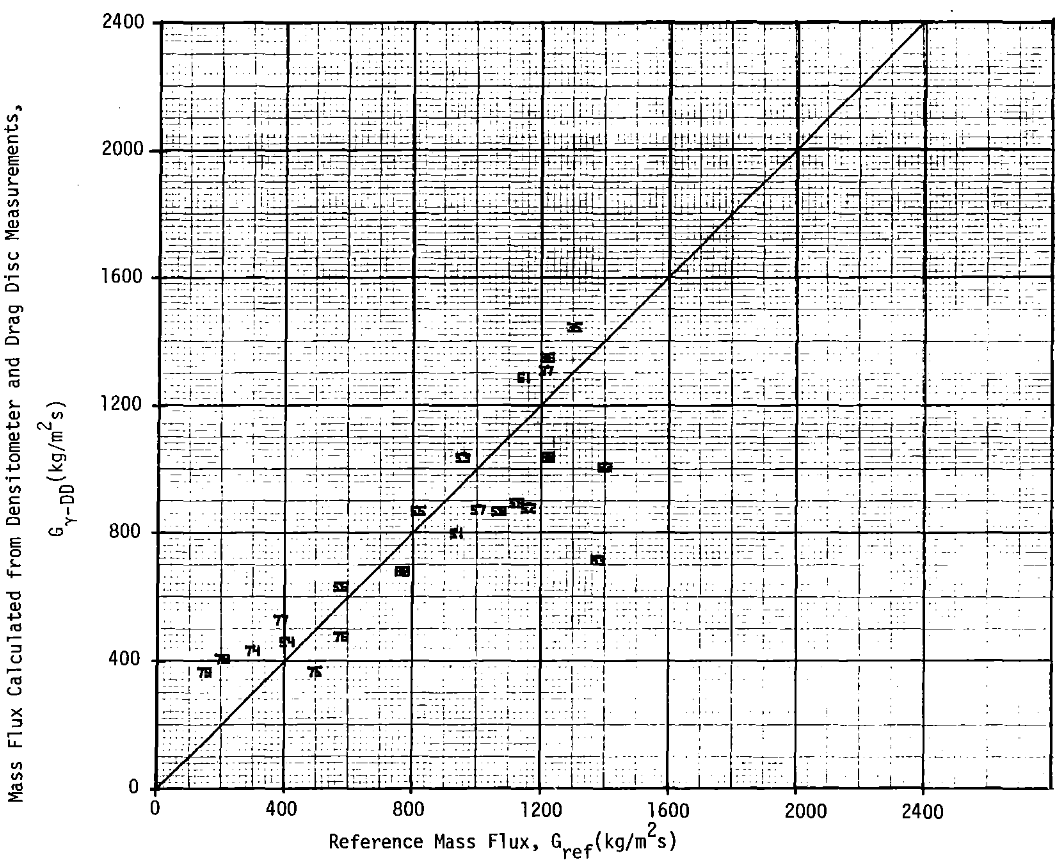

FIGURE 10.3: MASS FLUXES CLACULATED FROM GAMMA-DENSITOMETER AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

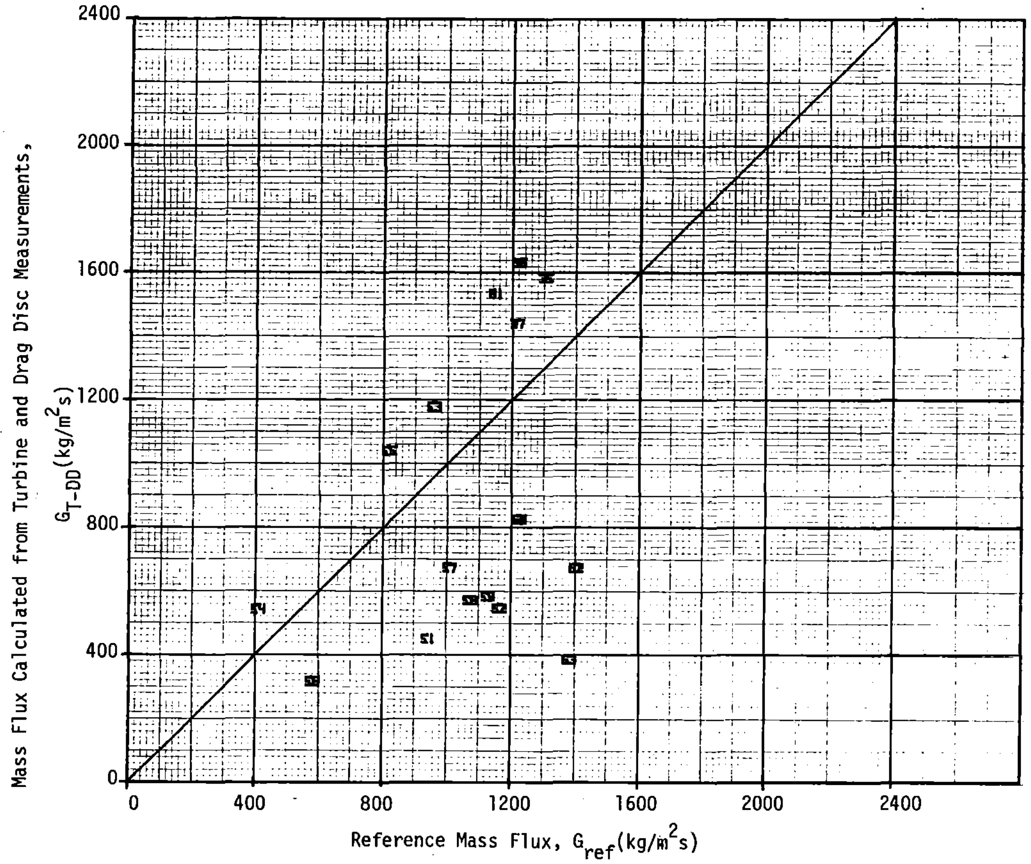

FIGURE 10.4: MASS FLUXES CALCULATED FROM TURBINE AND DRAG DISC MEASUREMENTS AT DIFFERENT REFERENCE VALUES

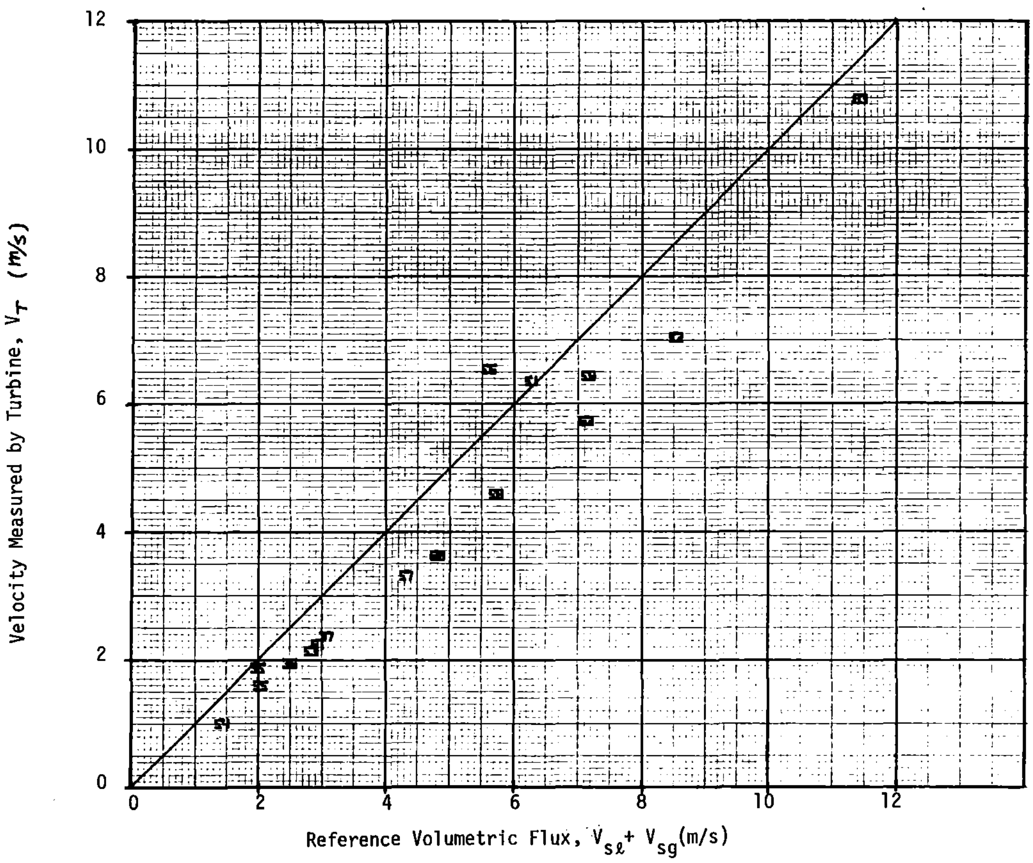

FIGURE 10.5: THE VELOCITIES MEASURED BY TURBINE AT VARIOUS VOLUMETRIC FLUXES

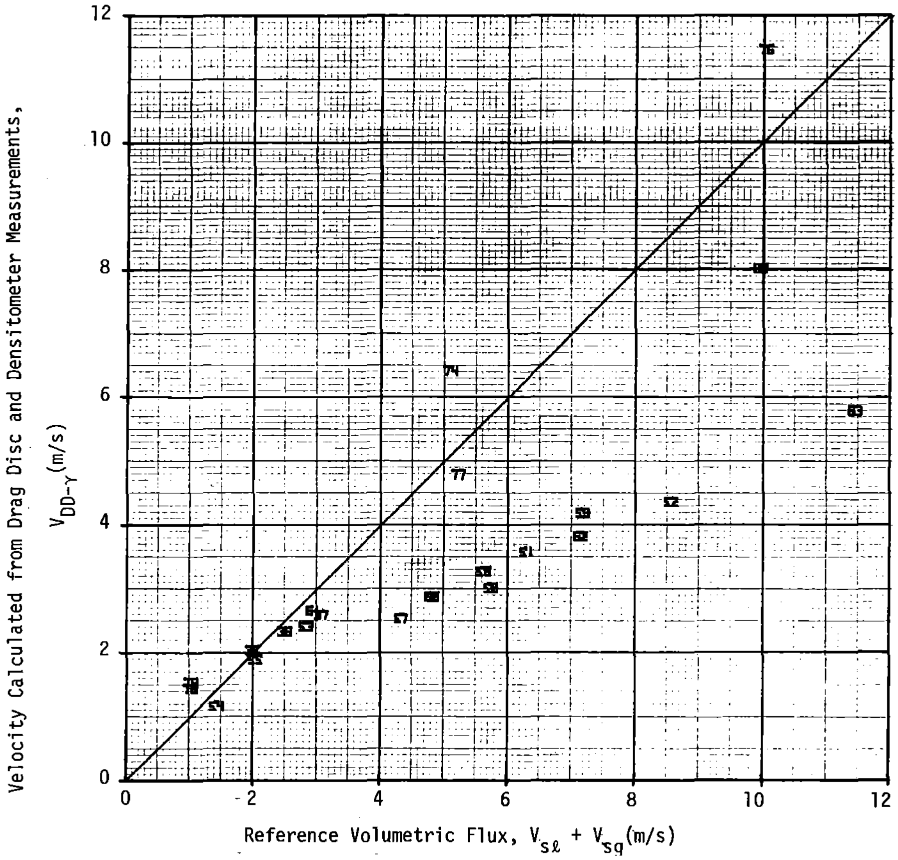

FIGURE 10.6: THE VELOCITIES CALCULATED FROM DRAG DISC AND DENSITOMETER MEASUREMENTS AT DIFFERENT REFERENCE VOLUMETRIC FLUXES

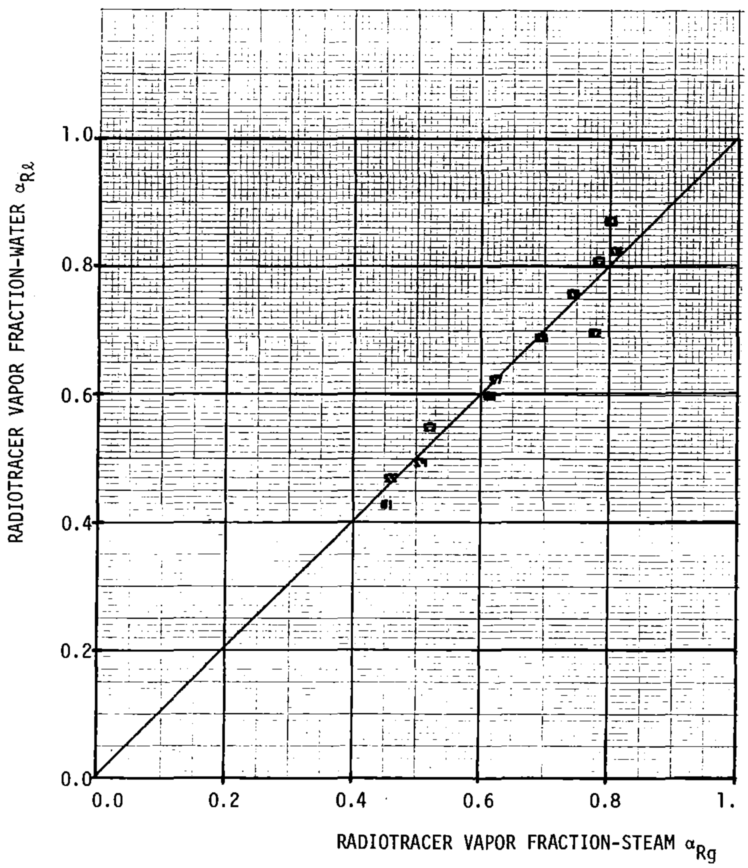

FIGURE 10.7: COMPARISON OF RADIOTRACER VAPOR FRACTION

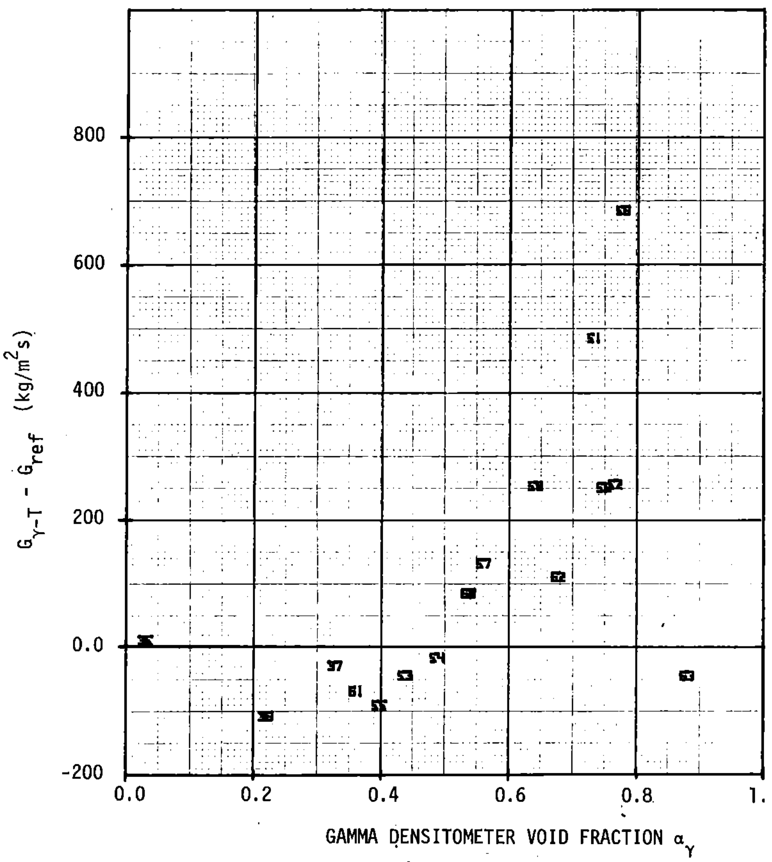

FIGURE 10.8: ERROR IN GAMMA DENSITOMETER - TUBINE MASS FLOW CALCULATION

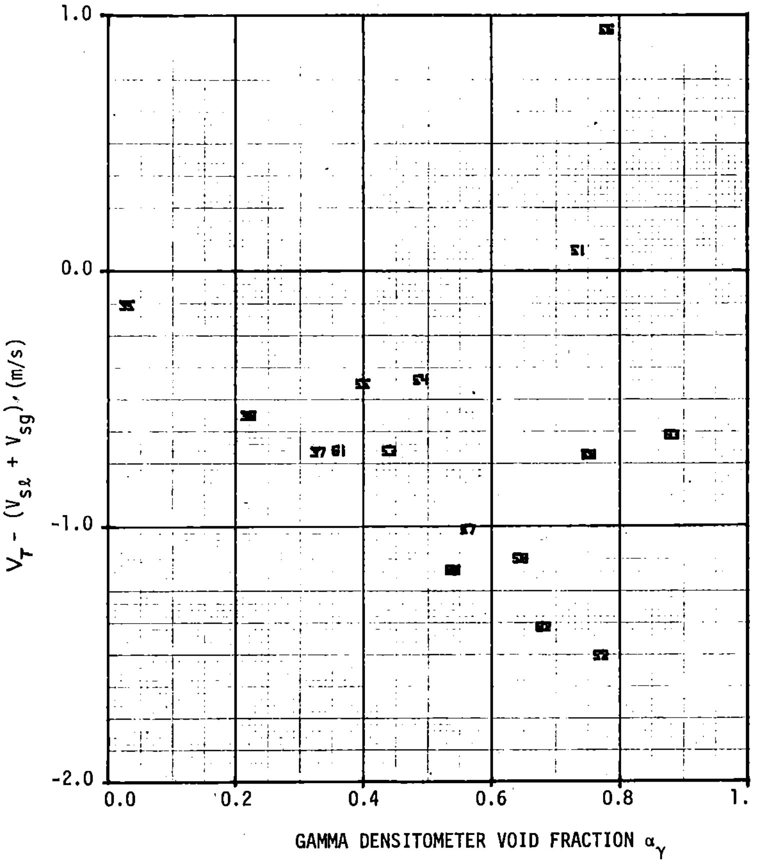

FIGURE 10.9 ERROR IN TURBINE VELOCITY

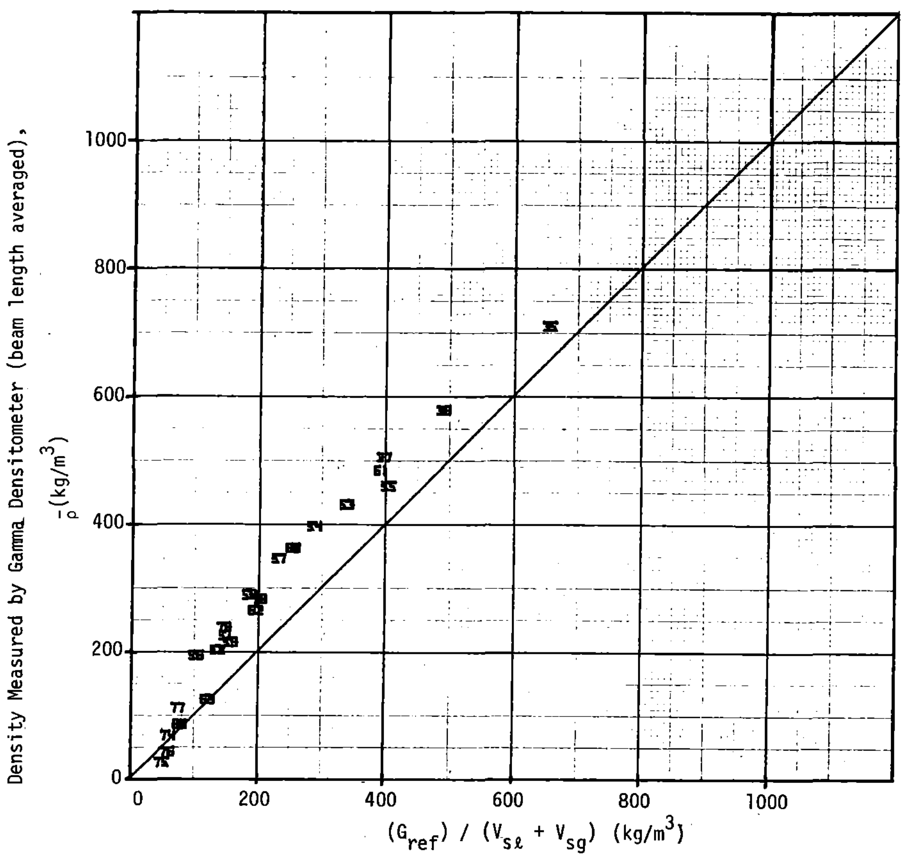

FIGURE 10.10: DENSITY COMPARISONS

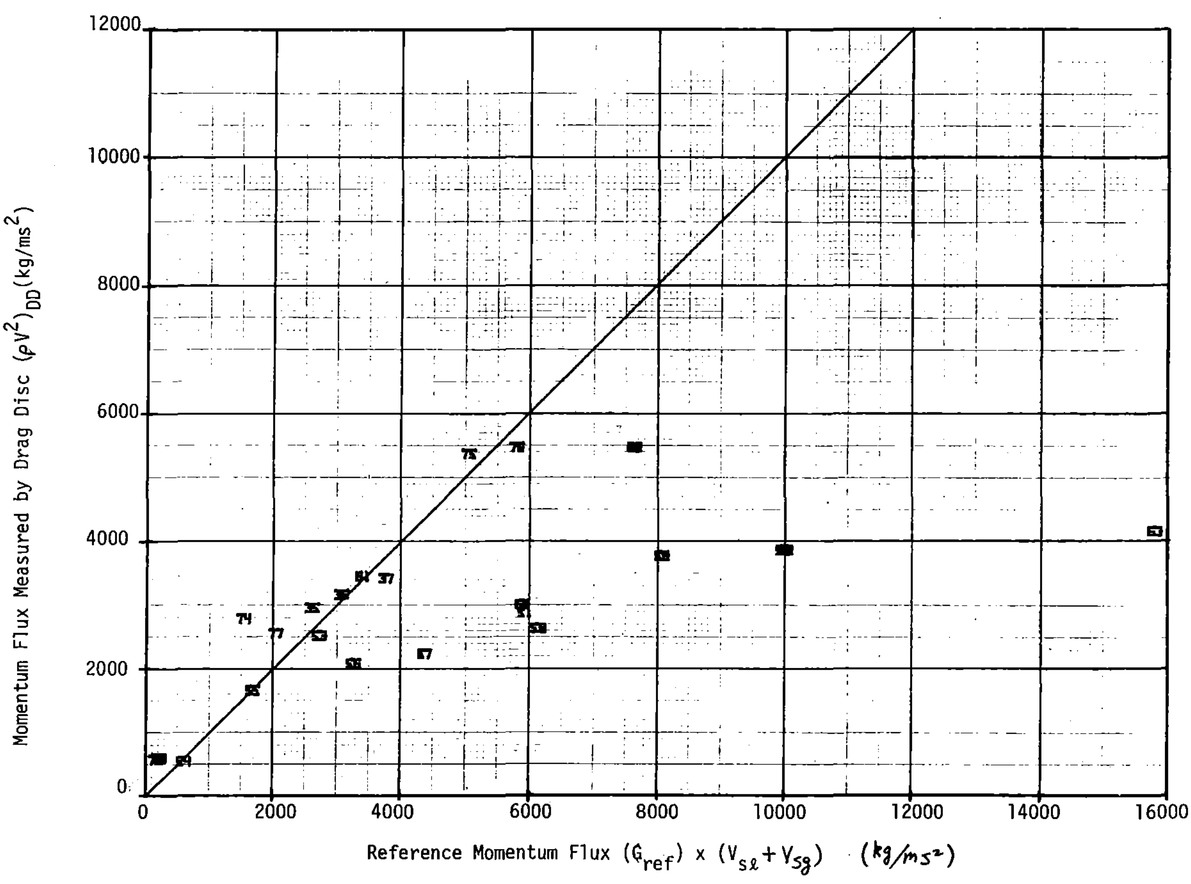

FIGURE 10.11: MOMENTRUM FLUX COMPARISONS

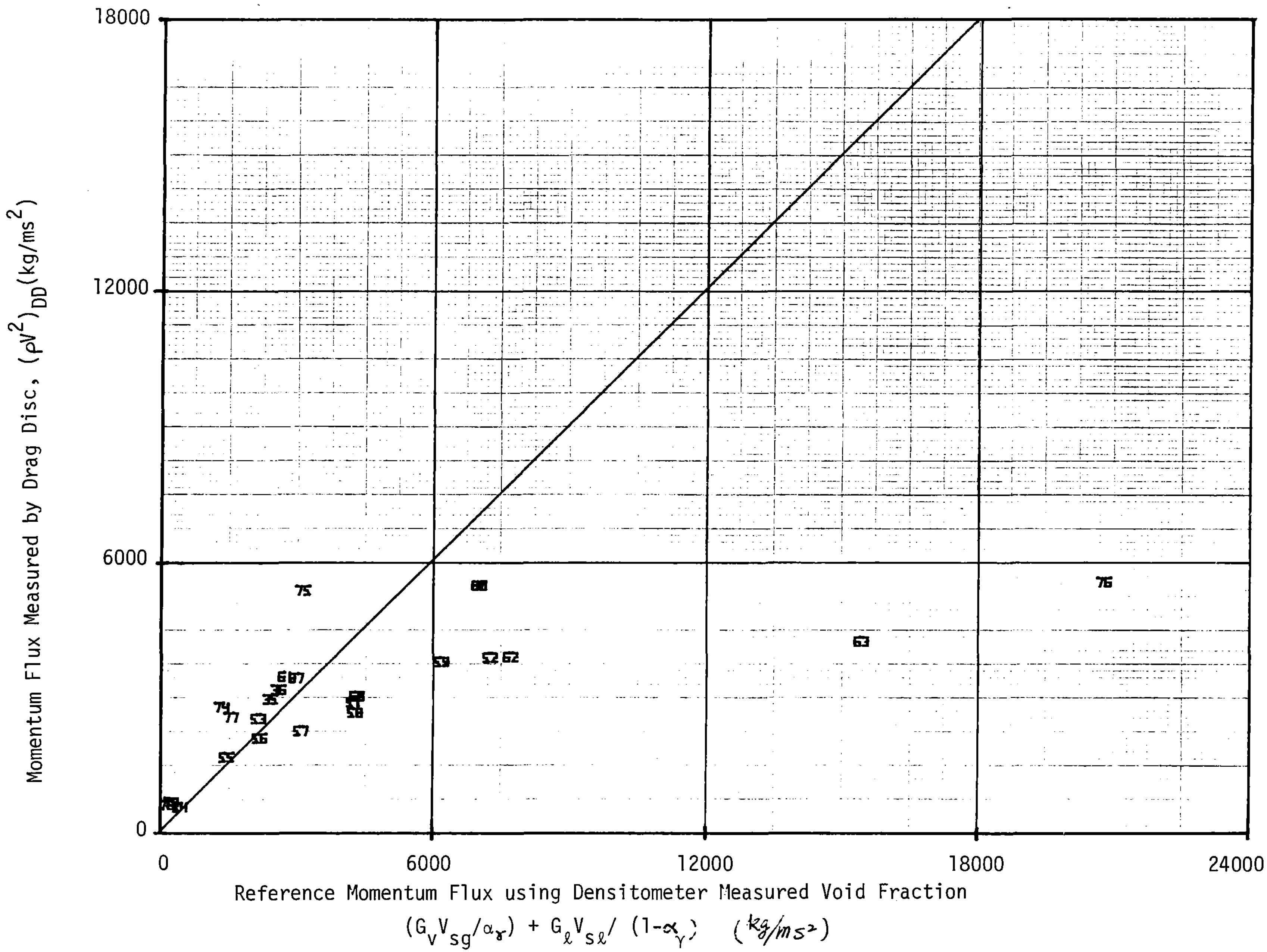

FIGURE 10.12: DRAG DISC MOMENTUM FLUX COMPARISONS

11. Conclusions

The behavior of a LOFT DTT mounted in free field configuration and a LOFT type Gamma-Densitometer installed in a five inch pipe and a three inch pipe test section in horizontal two-phase flow were investigated. This report presents the experimental description and the data obtained. Also included are data obtained with the Radiotracer Measurement System, Impedance Probes and the Scanning Densitometer.

Basing on these data, analyses are performed

- to interprete physically the data as a function of the phase distribution
- to calculate mass flux with other models
- to develop a calibration relationship

The results of these analyses are presented in another report /2/.

12. References

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Appendix I

Impedance Probe Data

Whereas a gamma beam gives information on void fraction integrated over the beam length, for local void fraction measurement often electrical probes are used. A special development of such a probe is the impedance probe used in these experiments which is applicable also in liquids with negligible electrical conductivity such as steam-water at high pressure or freon. The measuring principle is described in detail in /6/; examples for steam-water measurements are reported in /7/. Figure I.1 shows schematically typical probe signals for a dispersed bubble flow (upper part) and a dispersed droplet flow (lower part). These two phase configurations can exist at the same time in the cross section of a pipe when in the upper part droplets exist in the gas core and in the lower part the liquid is concentrated (eccentrical annular flow).

In the figure the lower level belongs to the liquid phase and the upper level to the gas phase. By selection of a convenient trigger level the time averaged void fraction is obtained.

The analysis of impedance probe data allows both a density determination and a flow regime determination when data are obtained with a traversing impedance probe. When data are obtained with a fixed impedance probe, it is possible to estimate only the flow regime and not the entire density over the cross section. Impedance probe data with a traversable impedance probe were taken on the five-inch pipe and were taken with two fixed impedance probes on the three-inch pipe. The flow regimes which have been postulated to occur from the traversing impedance probe data in the five-inch pipe are summarized in Figure I.2 and a flow regime map obtained from analysis of the 40 and 75 bar data is given in Figure I.3. Figures I.4 to I.8 indicate how the flow regimes were determined from the data obtained. Figure I.4 shows a summary of four different test points. It includes in it the flow regime definitions and the time average density at each point in the vertical direction. Point 5052 shows a sharp decrease in the density as the vertical relative distance (y/d) increased beyond 0.35. The other points show this decrease to be slower and to occur lower in the pipe. Figure I.5 shows the impedance probe data obtained at the different elevations where significant changes in the density were occurring. Three-beam gamma densitometer outputs as a function of time corresponding to these data are also shown. The densitometer outputs are synchronized with that impedance probe output whose dimensionsless distance is underlined. The top curve, the impedance probe data at elevation (y/d) 0.53, shows almost all steam. At elevation 0.48, the data shows more liquid, at elevation 0.43 almost 50 %.liquid and at elevation 0.38, almost all liquid. The three beams of the gamma densitometer are consistent with the above described impedance probe data. The top beam, γ_3 , shows mostly steam in the top part of the pipe. The second beam which nearly goes through the center of the pipe at a 52^0 angle from horizontal direction shows much more liquid and the beam which goes through the bottom of the pipe shows almost all liquid. Figures I.6a and I.6b show the same type of information for test No. 5051. Figures I.7 and I.8 also show this same information for the remaining two points. It is observed in all these cases that the structure of the signal is considerably different from run to run. The considerably different oscillations associated with each experimental condition indicate differenct wave structures, bubble and droplet sizes between the various runs. This type of measurements has been done for all of the five-inch test points, all profiles of the density versus vertical distance and the associated flow regime are shown in /2/.

A different method is used to estimate the flow regime in the three-inch pipe where only two positions were measured with fixed impedance probes.,The two impedance probes were approximately 5 mm above the bottom and below the top of the pipe flow channel respectively. Since two measuring positions do not give the same amount of information as a traversable probe, the time dependent signals of the gamma densitometer and the DTT were also used in the flow regime determination.

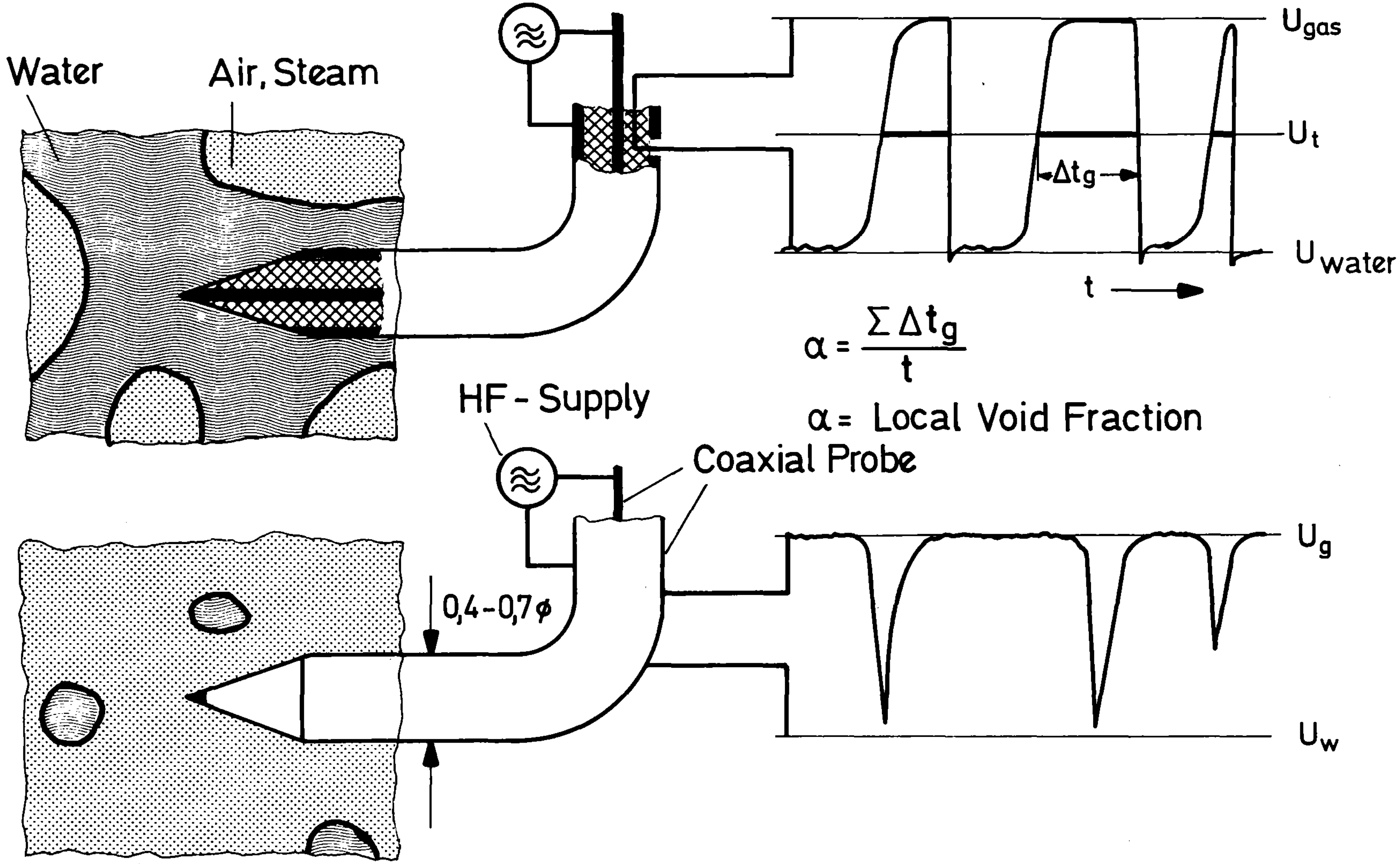
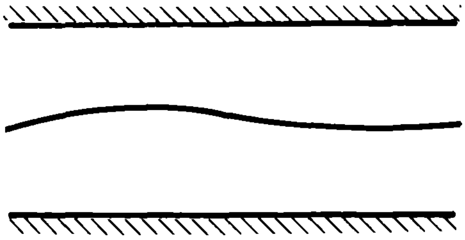
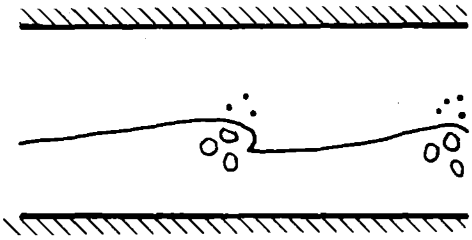


FIGURE I.1: SCHEMATIC DIAGRAM OF THE IMPEDANCE PROBE



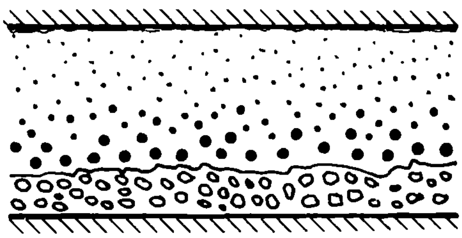
NO WAVES OR LOW FREQUENT WAVES, NO BUBBLE ENTRAINMENT, NO DROPLET ENTRAINMENT

STRATIFIED FLOW



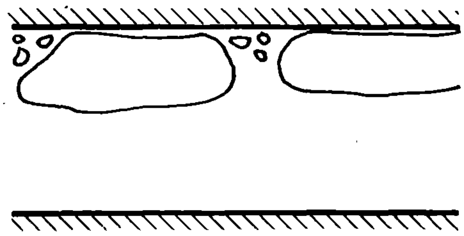
HIGHER FREQUENT WAVES, PERIODIC BUBBLE ENTRAINMENT, FEW DROPLETS ABOVE INTERFACE

WAVE FLOW



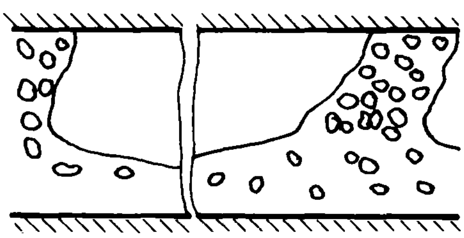
NO DISTINCT WAVES, HIGH BUBBLE ENTRAINMENT IN LIQUID AT PIPE BOTTOM, CONSIDERABLE DROPLET ENTRAINMENT IN GAS CORE, DROPLET DEPOSITION AT UPPER PIPE WALL CAUSES THIN LIQUID FILM: ECCENTRICAL ANNULAR DROPLET FLOW

STRATIFIED MIST FLOW
(ECCENTRICAL ANNULAR FLOW)



LONG AND SMALL BUBBLES IN THE UPPER POSITION OF THE PIPE

ELONGATED BUBBLE FLOW



LARGE GAS PLUGS SEPARATED BY SLUGS WITH CONSIDERABLE BUBBLE ENTRAINMENT IN BOTTOM LAYER ALSO BUBBLE ENTRAINMENT

SLUG FLOW

FIGURE I.2: DEFINITIONS OF FLOW REGIMES

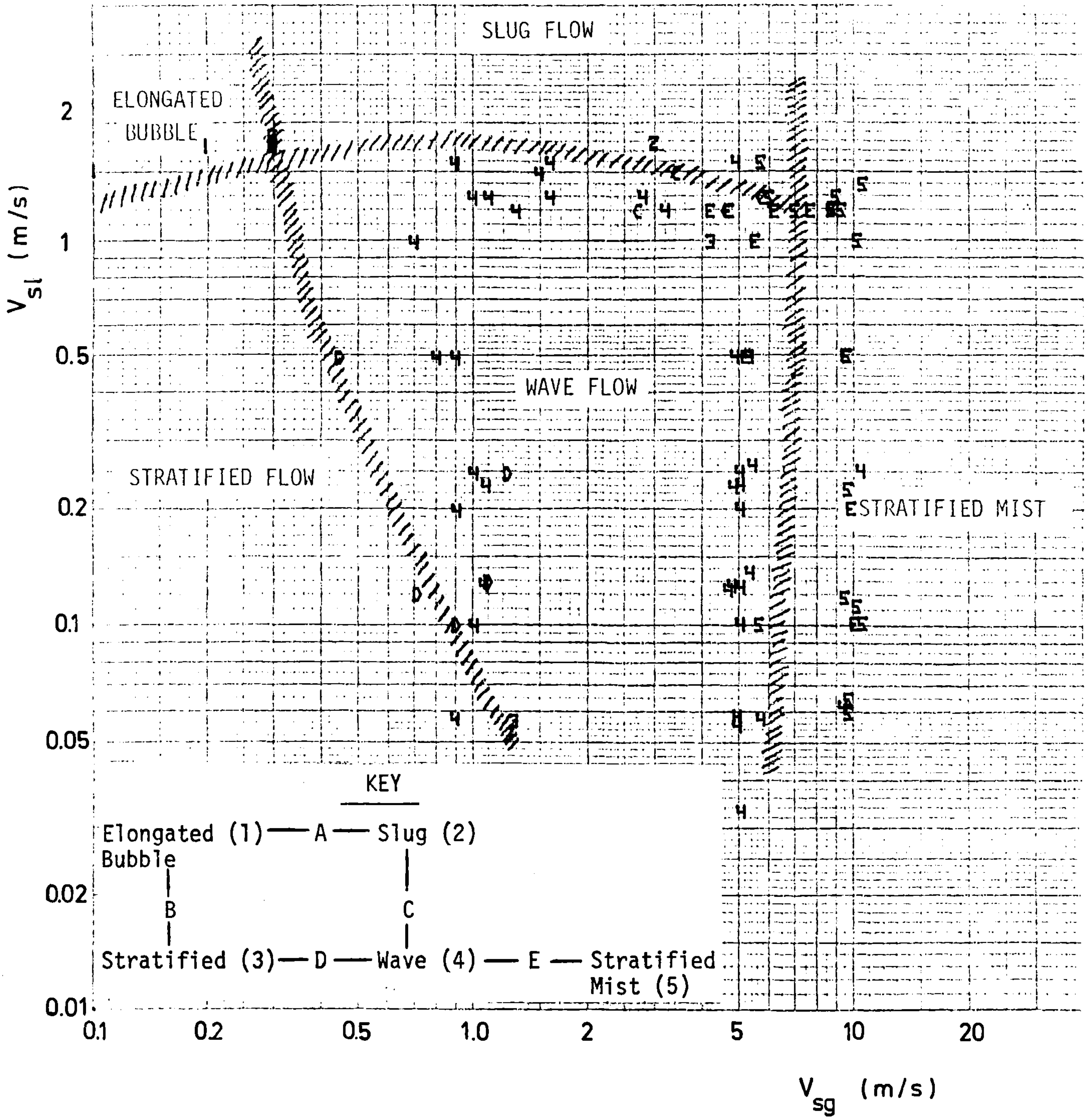
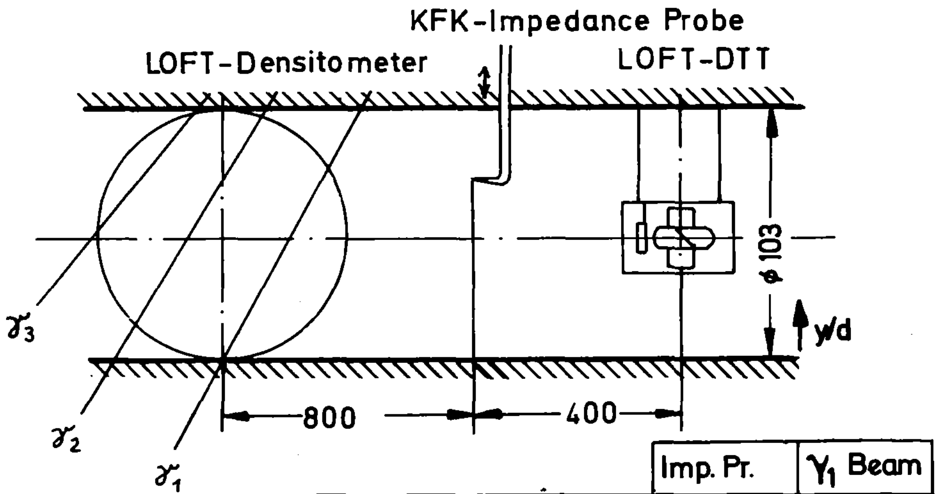
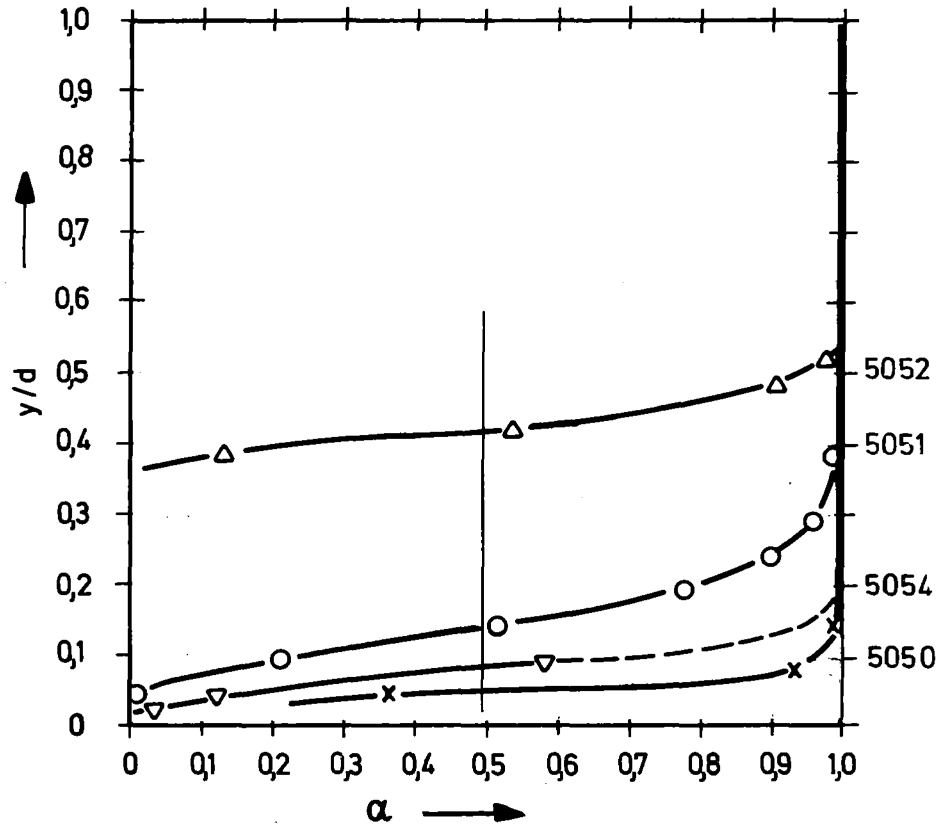


FIGURE I.3: FLOW REGIME MAP FROM TRAVERSING IMPEDANCE PROBE DATA (40 AND 70 BAR EXPERIMENTS



Test Nr.	Symbol	p (bar)	c_{sl} (m/s)	c_{sg} (m/s)	Imp. Pr. $(y/d)_{IF}$	γ_1 Beam $(y/d)_{IF}$
5050	x	4,5	0,12	10,4	0,05	0,08
5051	o	4,3	0,25	4,5	0,13	0,13
5052	△	4,9	0,08	0,99	0,40	0,41
5054	▽	40	0,22	9,93	0,08	-



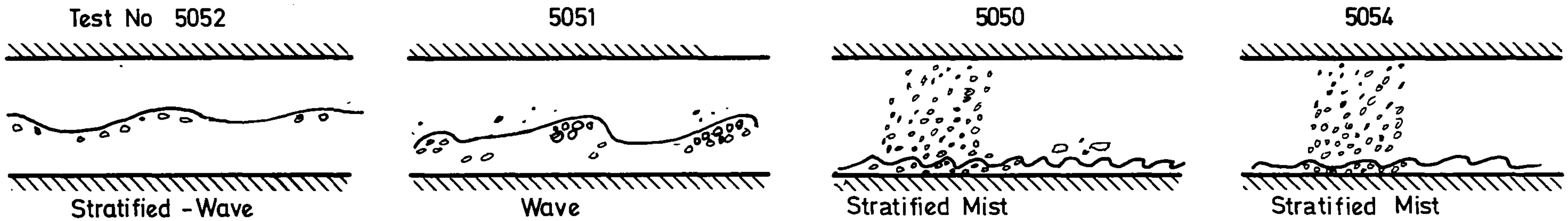


FIGURE I.4: VOID FRACTION IMPEDANCE PROBE ANALYSIS

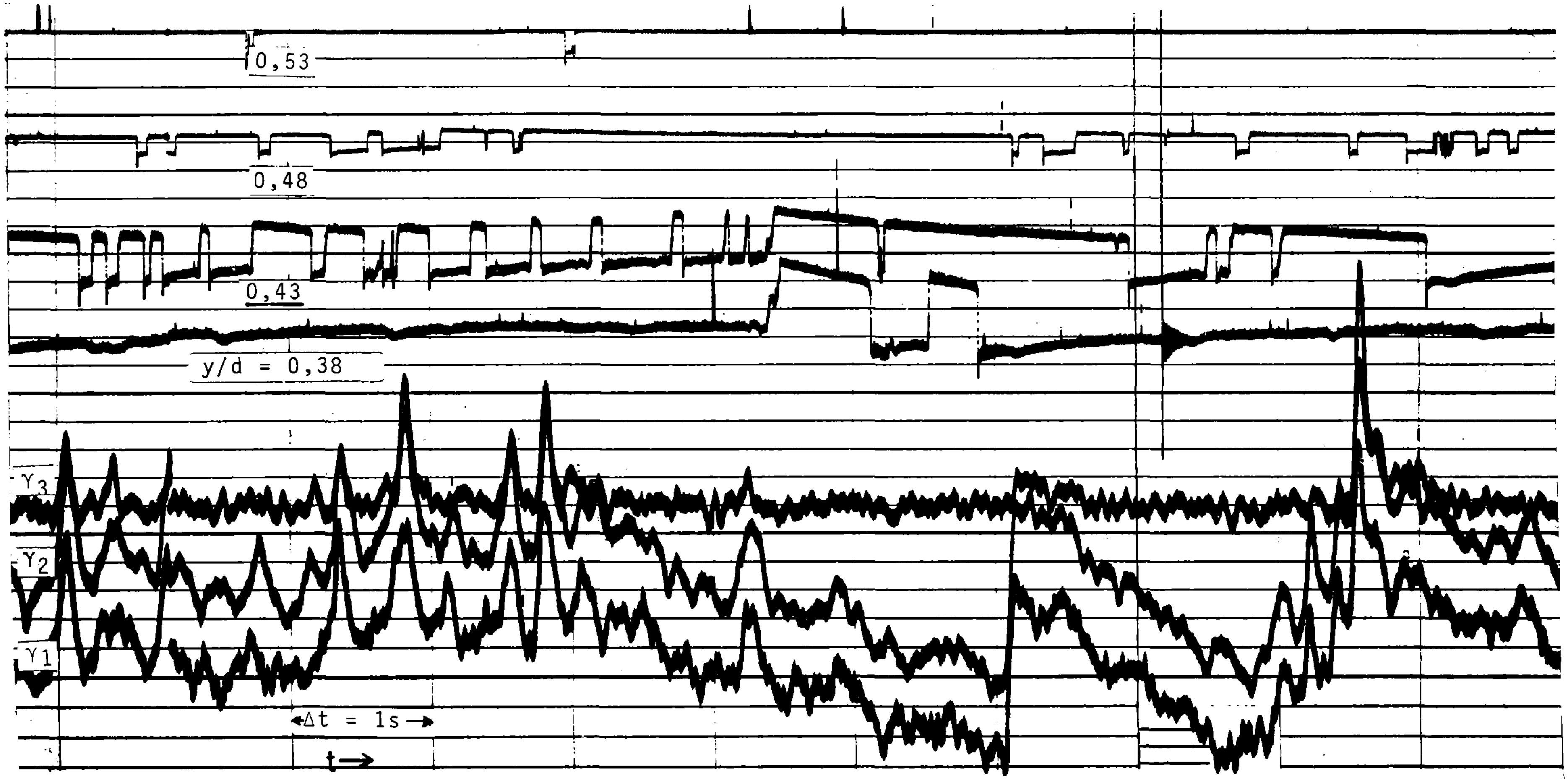


FIGURE I.5: SIGNALS OF IMPEDANCE PROBE AND γ-BEAMS FOR TEST NR. 5052: P = 4,9 BAR, c_W = 0,08 M/S, c_S = 0,985 M/S

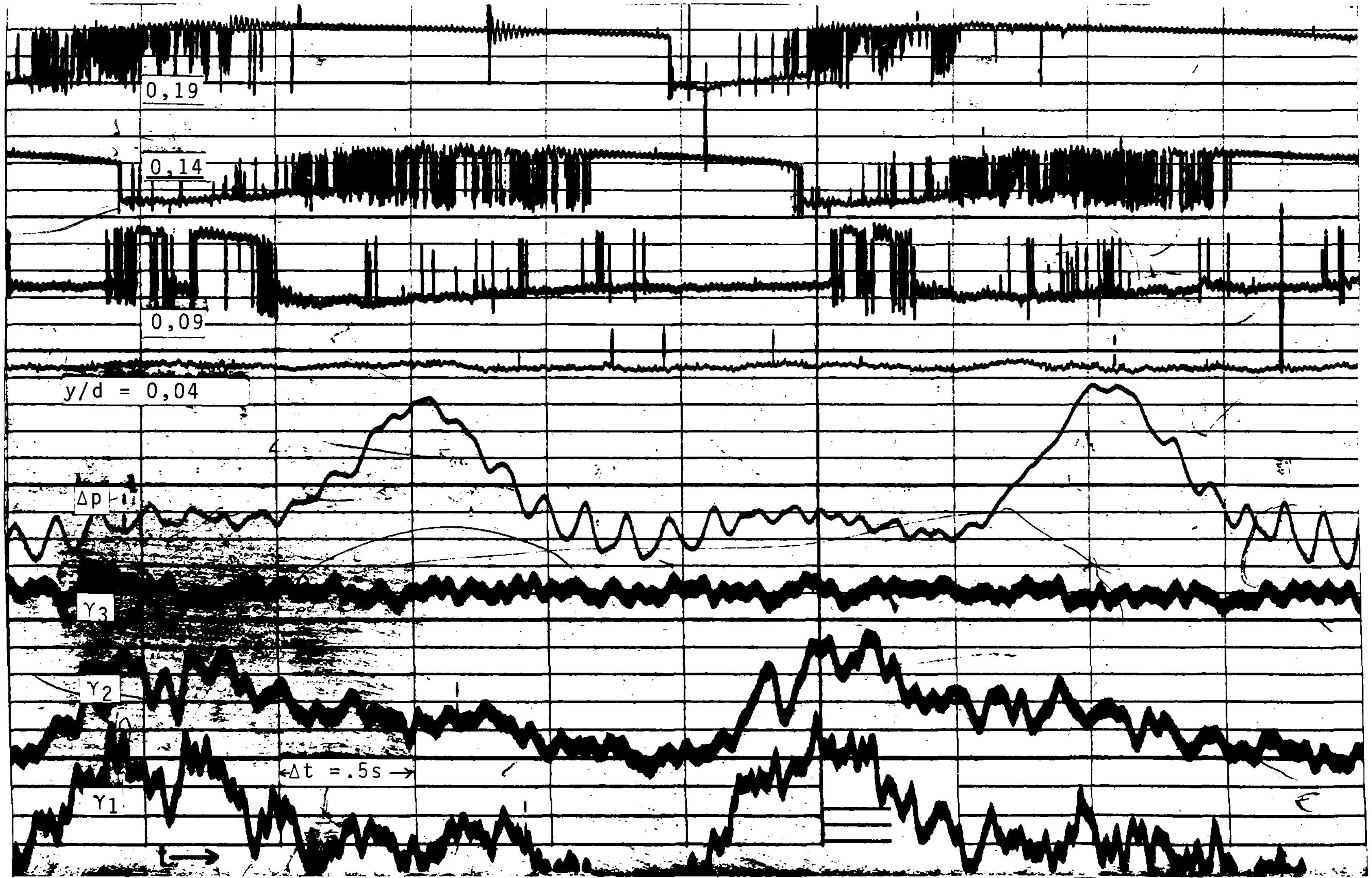


FIGURE I,6A: SIGNALS OF IMPEDANCE PROBE AND γ-BEAMS FOR TEST NR. 5051: p = 4,3 BAR, c_W = 0,246 M/S, c_S = 4,86 M/S

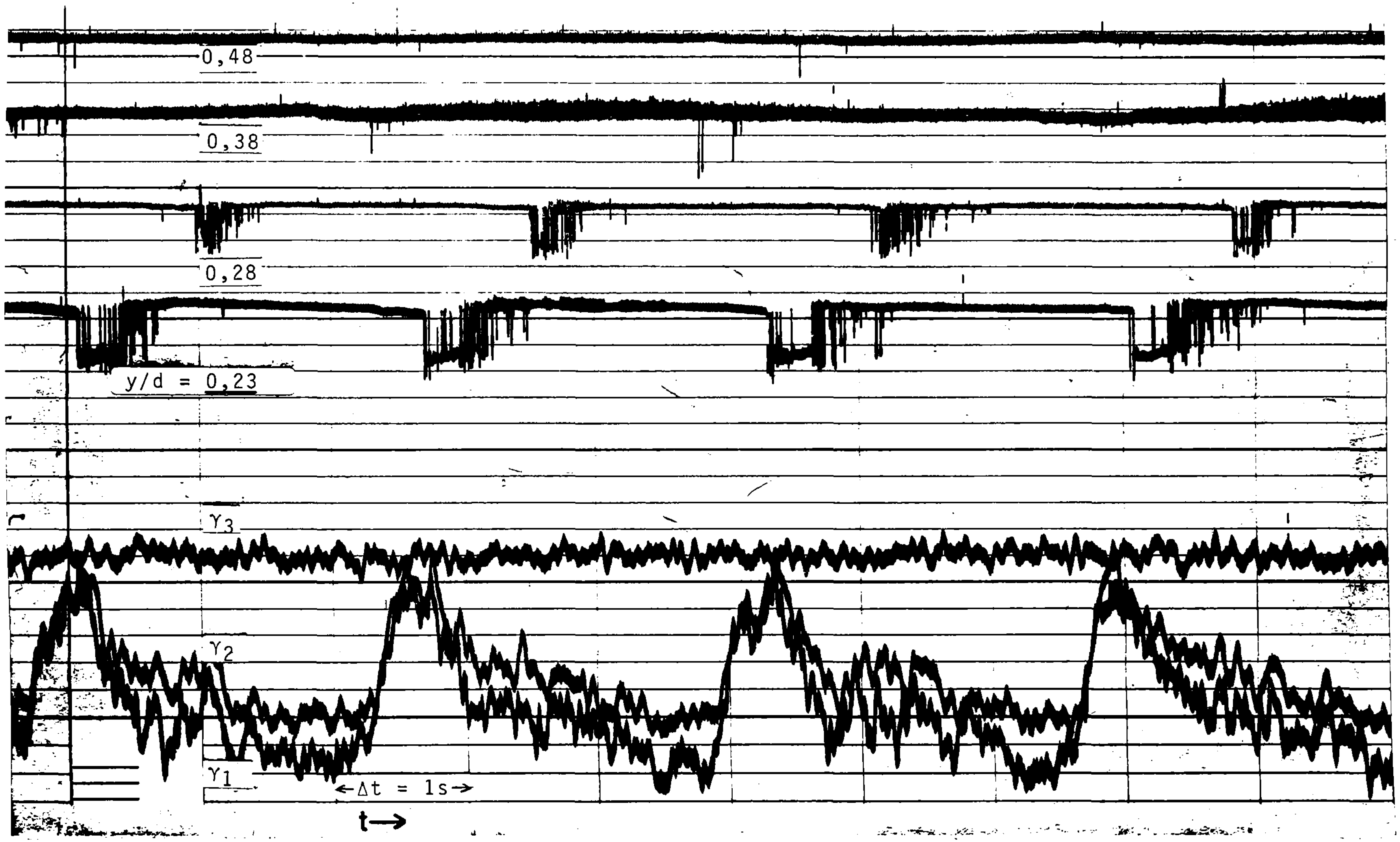


FIGURE I.6B: SIGNALS OF IMPEDENCE PROBE AND γ-BEAMS FOR TEST NR. 5051: P = 4,3 BAR, c_W = 0,246 M/S, c_S = 4,86 M/S

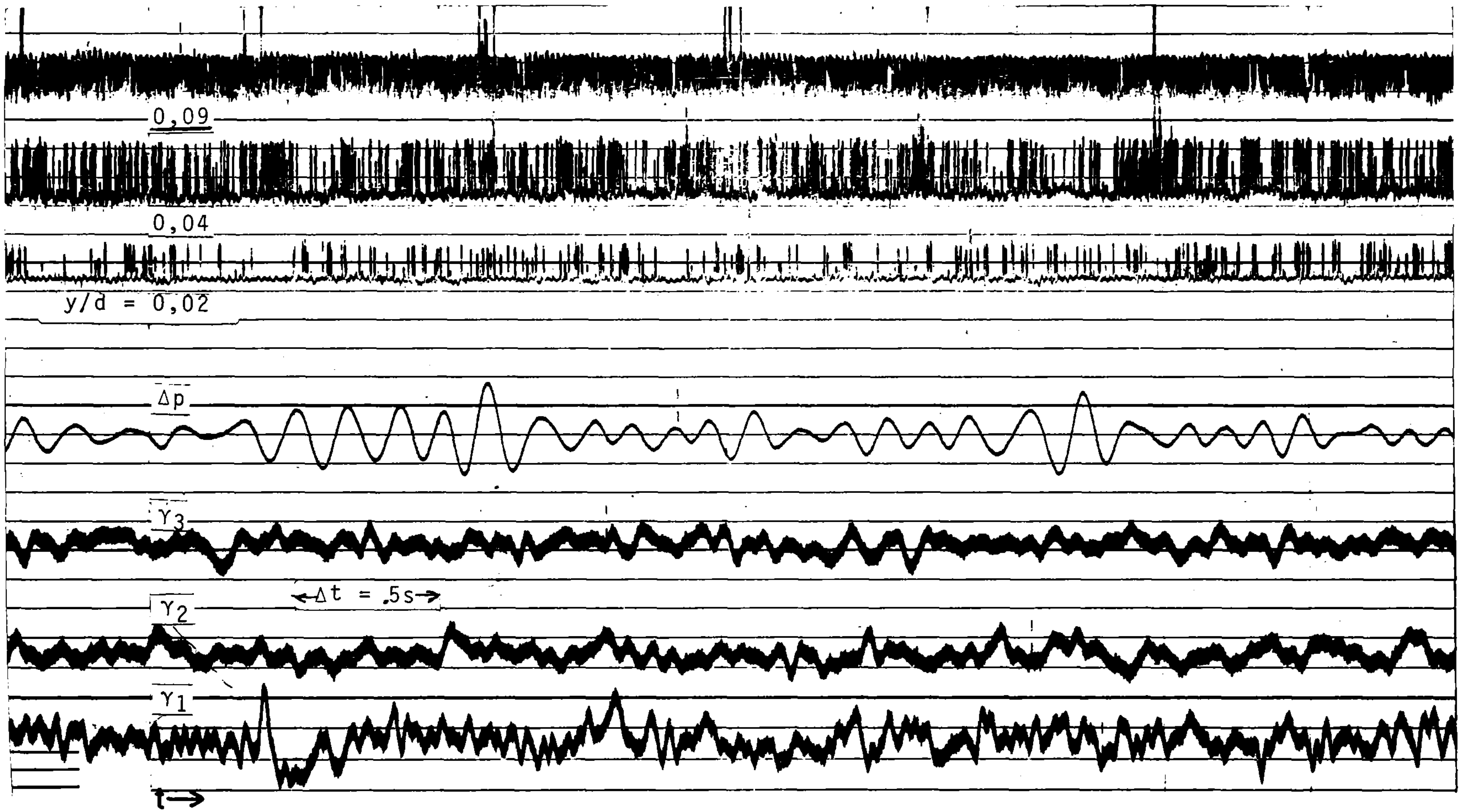


FIGURE I.7: SIGNALS OF IMPEDANCE PROBE AND γ-BEAMS FOR TEST NR. 5054: P = 40 BAR, c_W = 0,22 M/S, c_S = 9,93 M/S

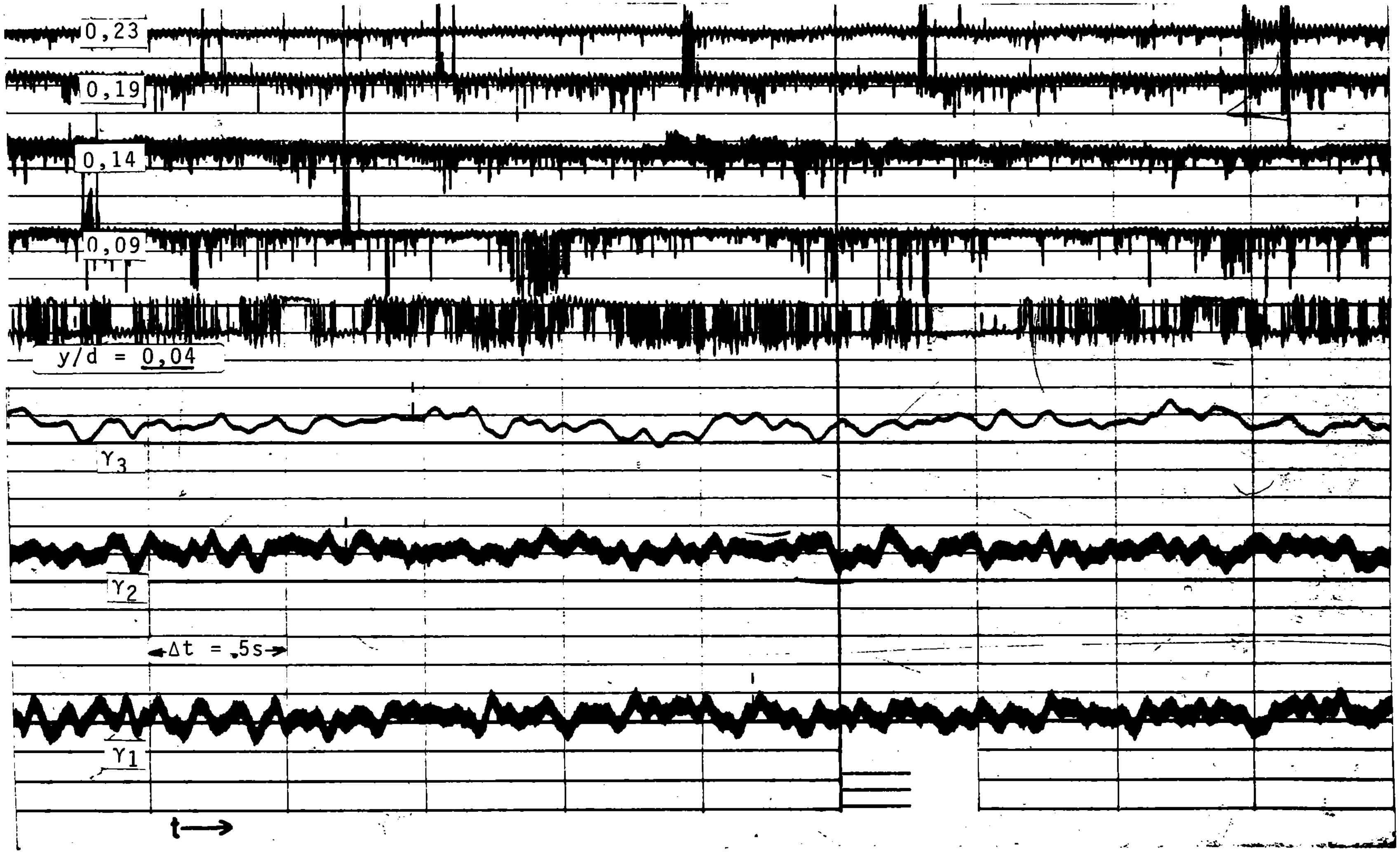


FIGURE I.8A: SIGNALS OF IMPEDANCE PROBE AND γ-BEAMS FOR TEST NR. 5050: P = 4,5 BAR, c_W = 0,118 M/S, c_S = 10,4 M/S

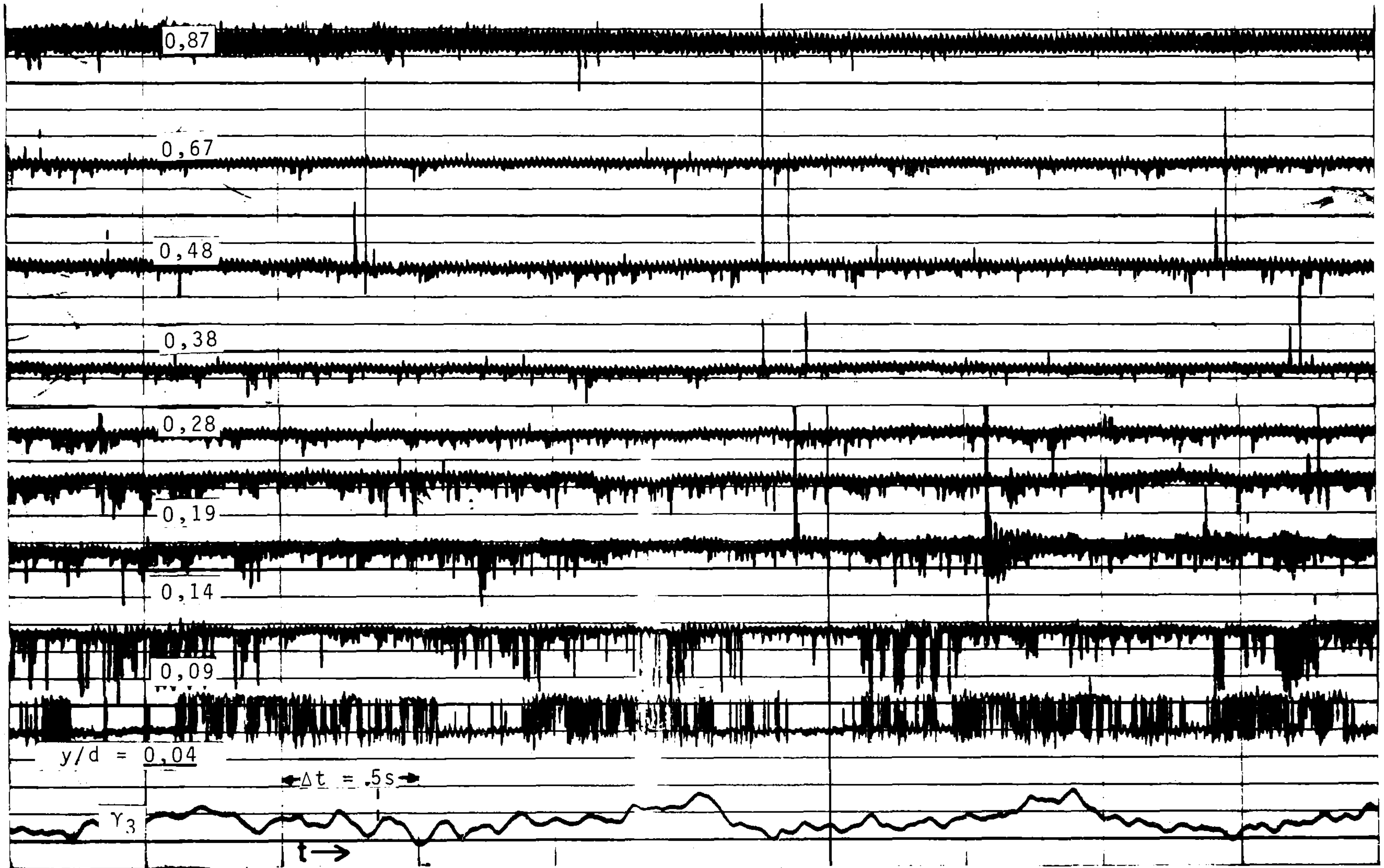


FIGURE I.8B: SIGNALS OF IMPEDANCE PROBE AND γ-BEAMS FOR TEST NR. 5050: P = 4,5 BAR, c_W = 0,118 M/S, c_S = 10,4 M/S

Appendix II

The EG & G Reference Densitometer (Scanning Densitometer)

The scanning densitometer was a low photon energy, moving-detector system (Figure II.1)assembled and checked out at EG & G Idaho, Inc. Significant portions of the system were purchased from Westinghouse Nuclear Energy Systems where it had been used previously /8/. In the Karlsruhe testing, a new spool piece and traversing framework were built, a new source was supplied, and these were combined with the Westinghouse detector, electronics, and traversing motor and control to form the new system.

The spool piece was a 1.48 m length of 3 inch. Schedule 160, Type 304 stainless steel pipe with Grayloc hubs at both ends and a flanged joint about 23 cm from the downstream end. A beryllium ring was mounted between these flanges and the joint sealed with silver-plated Inconel 600 O-rings. The nominal beryllium ring inside diameter was 66.7 mm with an outside diameter of 101.6 mm, was 19.05 mm thick, and fabricated of Brush-Wellman alloy S-200 E. The flanges were specially fabricated with an 8 bolt pattern and with taps for pressure, temperature, and Storz lens connections. Three of the flange bolts were replaced by a pair of flange clamps in order to permit the detector an unobstructed view of the entire flow cross section. The clamp bolts were at locations outside the traversing range of the detector. At the spool horizontal centerline, a 19.18 mm diameter hole was drilled in each flange at a distance of 7.620 cm from the center of the flange bore. A 19.05 mm diameter shaft aligned like a flange bolt, was mounted through and between these holes, and served two functions: (1) it was the axle about which the detector rotated, and (2) it housed the radioactive source.

The liquid nitrogen dewar and X-ray detector were mounted on a traversing frame constructed of rectangular aluminium tubing. At one end of the frame, vertical arms connected it to the axle/source tube. Sealed ball bearings were pressed into the arms and provided low frictional resistance between the stationary axle and rotating arms and frame. At the frame's outer end, a vertical circular arc segment was attached to the frame. A chain from the drive motor sprocket was attached to the bottom of the arc, so that pulling upward on the chain raised the detector. The chain unwrapped from the circular segment causing a detector movement linearly related to the rotation of the drive motor.

The radioactive source consisted of approximately 45 mCi of accelerator-grade Cd-109, prepared in May 1977 by New England Nuclear Company. The active material was electroplated on a silver disc which was housed in a hermetically sealed short cylinder. The primary radiation is the 22.1 keV silver k_α X-ray with a yield of better than 95 % per disintegration. k_β X-rays are also present at 24.9 and 25.4 keV, as is an 88 keV gamma. The electron capture decaying isotope has a half life of about 453 days.

The detector was a 1.0 cm diameter by 5 mm active depth Si (Li) crystal, cooled to near liquid nitrogen temperature in a common vacuum 5 liter dewar, Ortec Model 78916-10300. The 3.81 cm diamter evaculated cryostat snout was sealed against the atmosphere with a 0.001 inch thick beryllium window. A detector shield was mounted on the front of the cryostat. It consisted of a lead sleeve and 25.4 mm thick shield. A rectangular collimating hole was machined in the shild and had a cross section 10 mm wide by 3.17 mm high. Thus, the collimating hole length-to-height ratio was approximately 8 to 1.

With the source/detector of 24.58 cm, the 3.17 mm collimating slot height corresponded to an angular beam height of 0.739 degrees, and constituted 1/20 of the flow diameter. Photon energy resolution of the detector was 274 eV full width half maximum at 15,00 of the 22.1 keV X-rays per second with a main amplifier shaping time constant of μs.

A traverse is started by moving the detector to its initial position. The 22.1 keV pulses are counted for 10 s and the number counted is typed on the teletype. While the typing is prceeding, the detector is moved by the stepping motor to position 2. The counter is reset and counting reinitiated at the new position. This procedure is repeated automatically for the 65 azimuthal detector positions, at which time the operator stops the process and returns the detector to its initial position for the next data run.

Densitometer calibration was accomplished by obtaining count rate traverse data for known density, all-liquid and all-dry vapor conditions. Data were reduced using the scanning densitometer data reduction computer program, PATDR. Chordal average densities are calculated using Equation (4) and cross sectional average fluid density is calculated using Equation (5). The weighting factor used in the latter equation accounts for the angular segment beam area associated with the polar coordinate setup of source and detector.

$$\rho_c(\theta) = \rho_f - \left(\rho_f - \rho_g\right) \frac{\ln \frac{I(\theta)}{I_f(\theta)}}{\ln \frac{I_g(\theta)}{I_f(\theta)}} \qquad (4)$$

$$\bar{\rho} = \frac{\sum_{i=1}^{47} \left[\rho_c(\theta_i)\ 0.5\ (D_o+D_s)(\cos\ \theta_i)\ X_f(\theta_i)_{\Delta\theta}\right]}{\sum_{i=1}^{47} 0.5(D_o+D_s)(\cos\ \theta_i)\ X_f\ (\theta_i)_{\Delta\theta}} \qquad (5)$$

where ρ_f = the density of the subcooled water giving rise to traverse count rates $I_f(\theta)$.

ρ_g = the superheated steam density yielding count rates $I_g(\theta)$.

ρ_c = the chordal average density determined from the two phase flow count rates $I(\theta)$.

D_o = beryllium ring outer diameter.

D_s = twice the distance from source center to nearest outer surface of beryllium ring.

= traverse angle (Figure).

X_f = fluid chordal path length = $(D_i^2 - (D_o + D_s)^2 \sin^2 \theta)^{1/2}$.

D_i = beryllium ring innter diameter.

The Figures II.2 to II.8 show how the scanning densitometer is used to verify the correctness of the three beam densitometer data reduction model. Three beam and scanning densitometers were mounted side by side and used to monitor a stratified flow regime. Three chordal average density readings were obtained, one from each of the three beams of the three beam densitometer. Forty-seven chordal average density values were obtained by the scanning densitometer monitoring the same flow. The three values from the three beam densitometer and the information that the flow regime was stratified were used in Lassahn's stratified three-beam densitometer data reduction model /5/. The output from that model is the other density distribution shown in the figures.

The good agreement between the scanning densitometer data distribution and that calculated from the multibeam densitometer data gives a high level of confidence in the three beam densitometer data reduction model. Although this result is encouraging, in practical application the appropriate type of flow regime must still be determined in order to apply the appropriate data reduction model to the three-beam densitometer data.

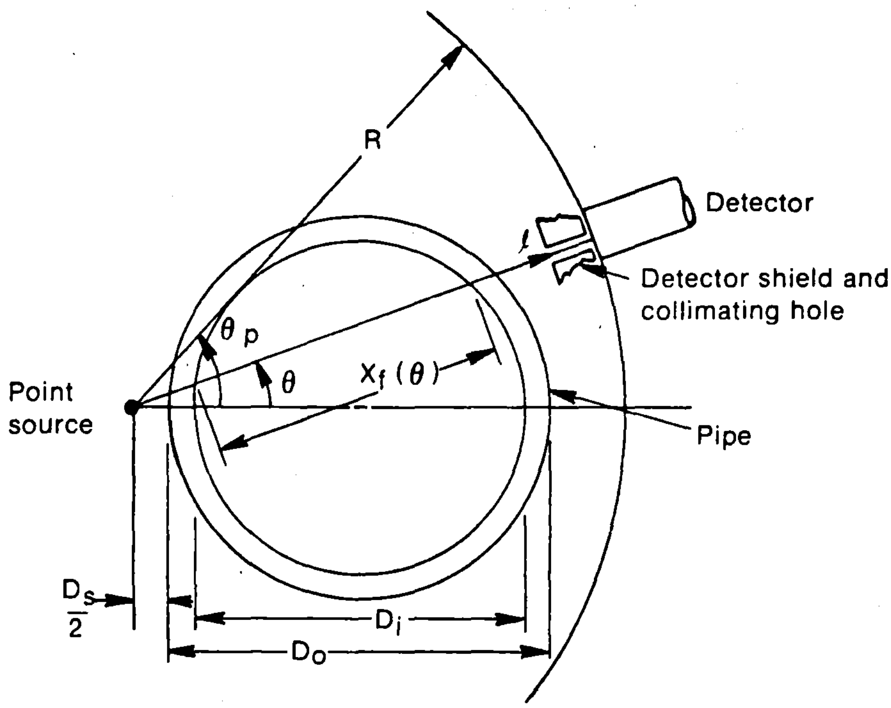
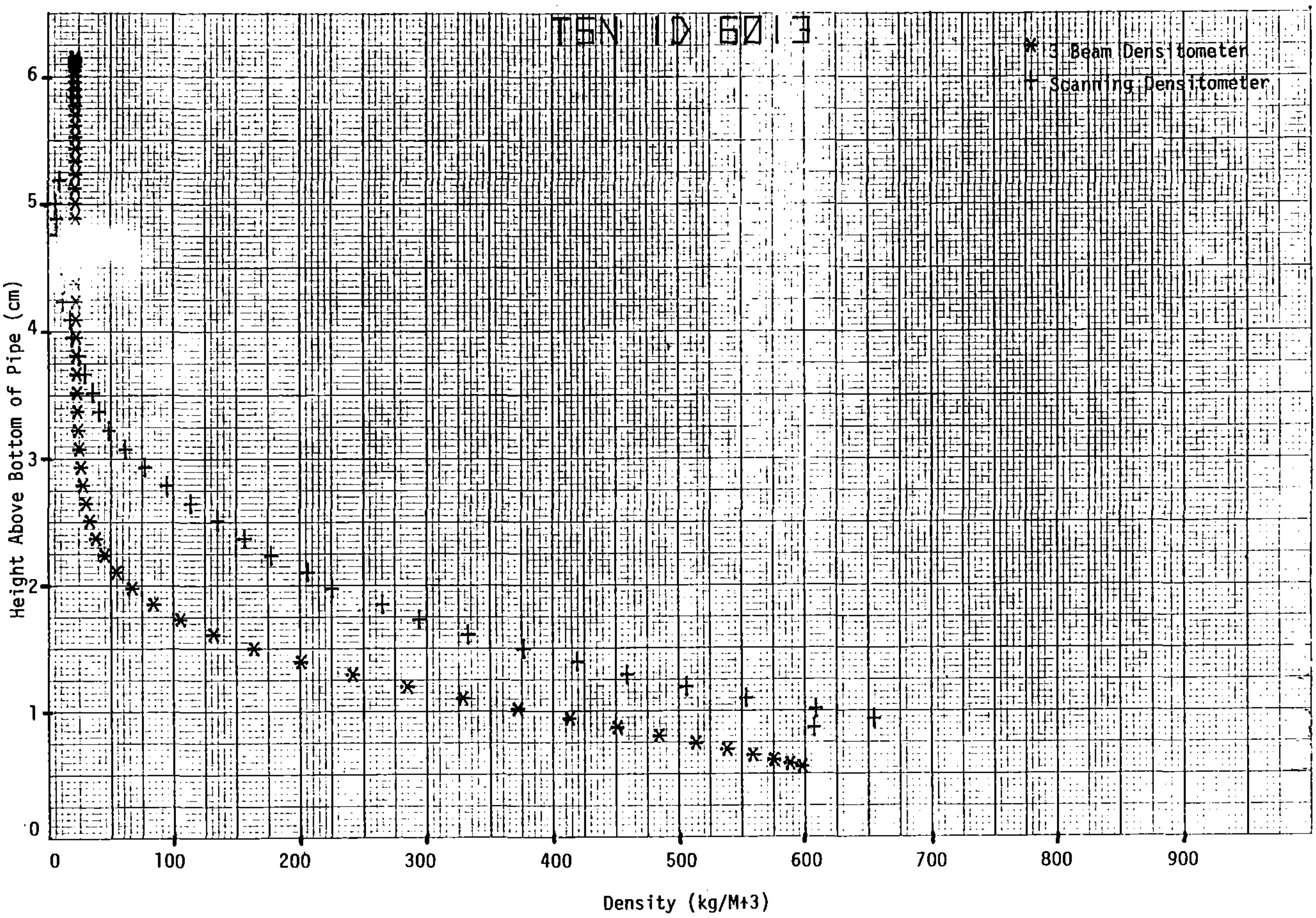


FIGURE II.1: DENSITOMETER SOURCE, PIPE, DETECTOR GEOMETRY



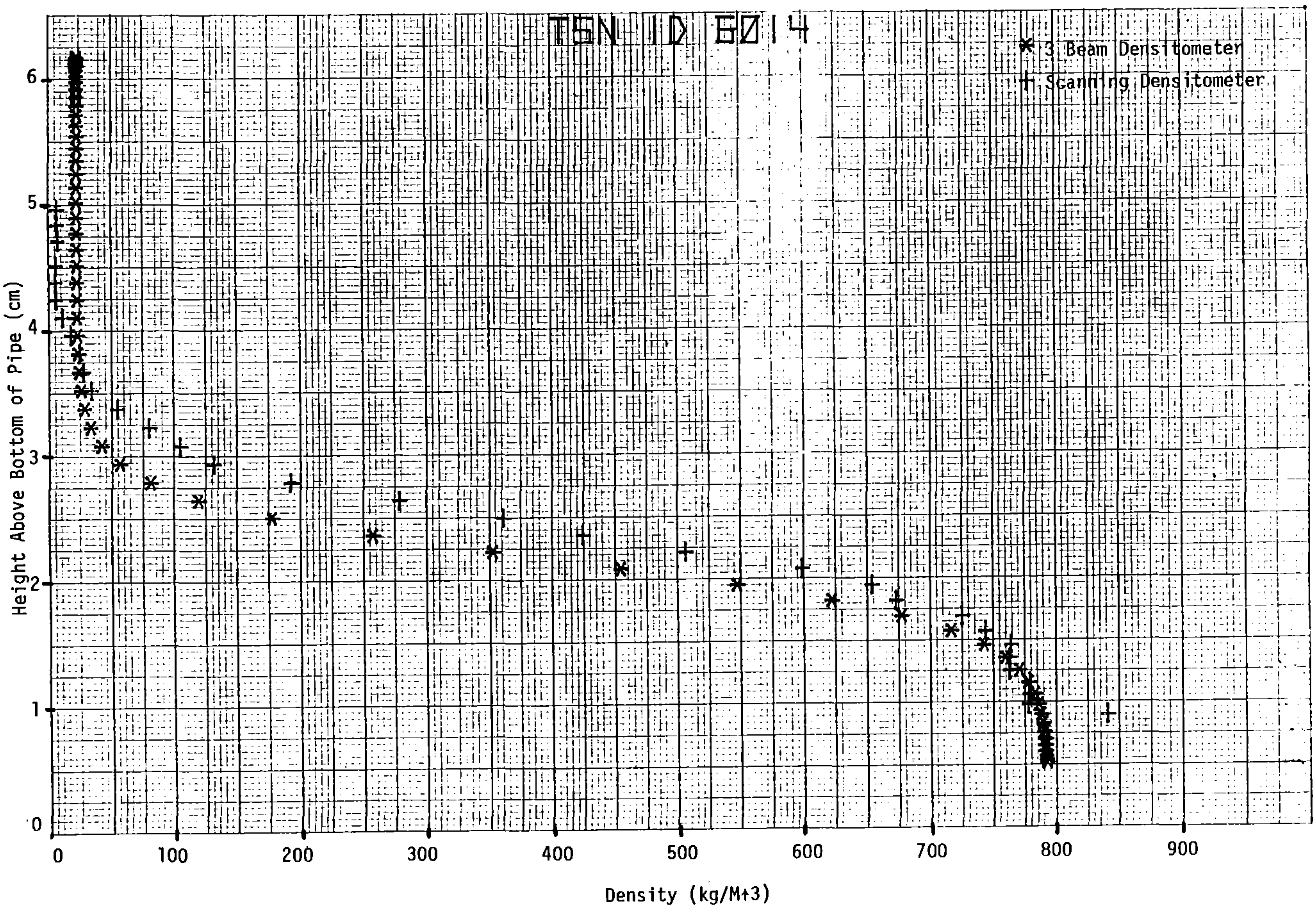
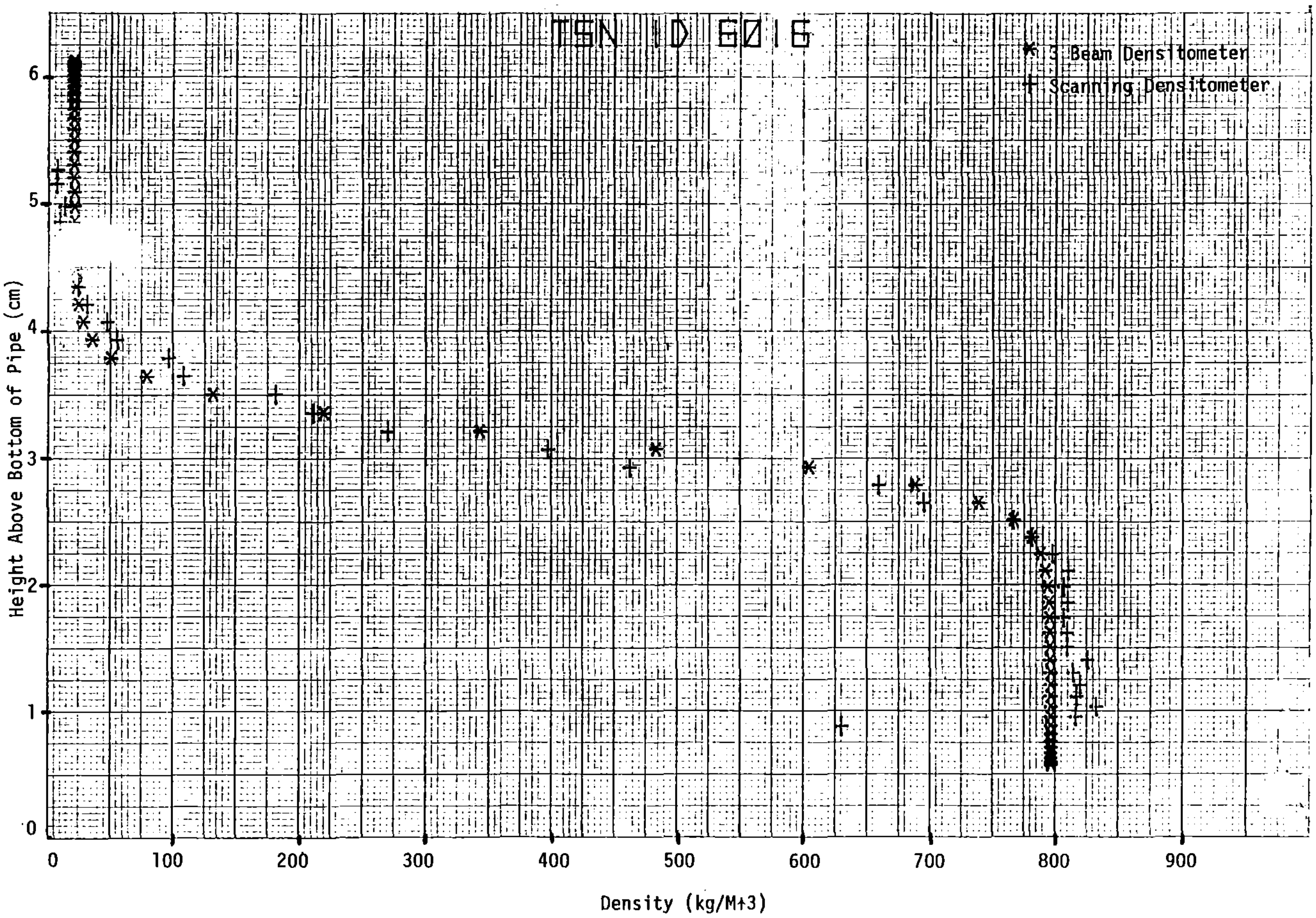


FIGURE II.2: COMPARISON OF DENSITY PROFILES (TSN 6013 AND 6014)



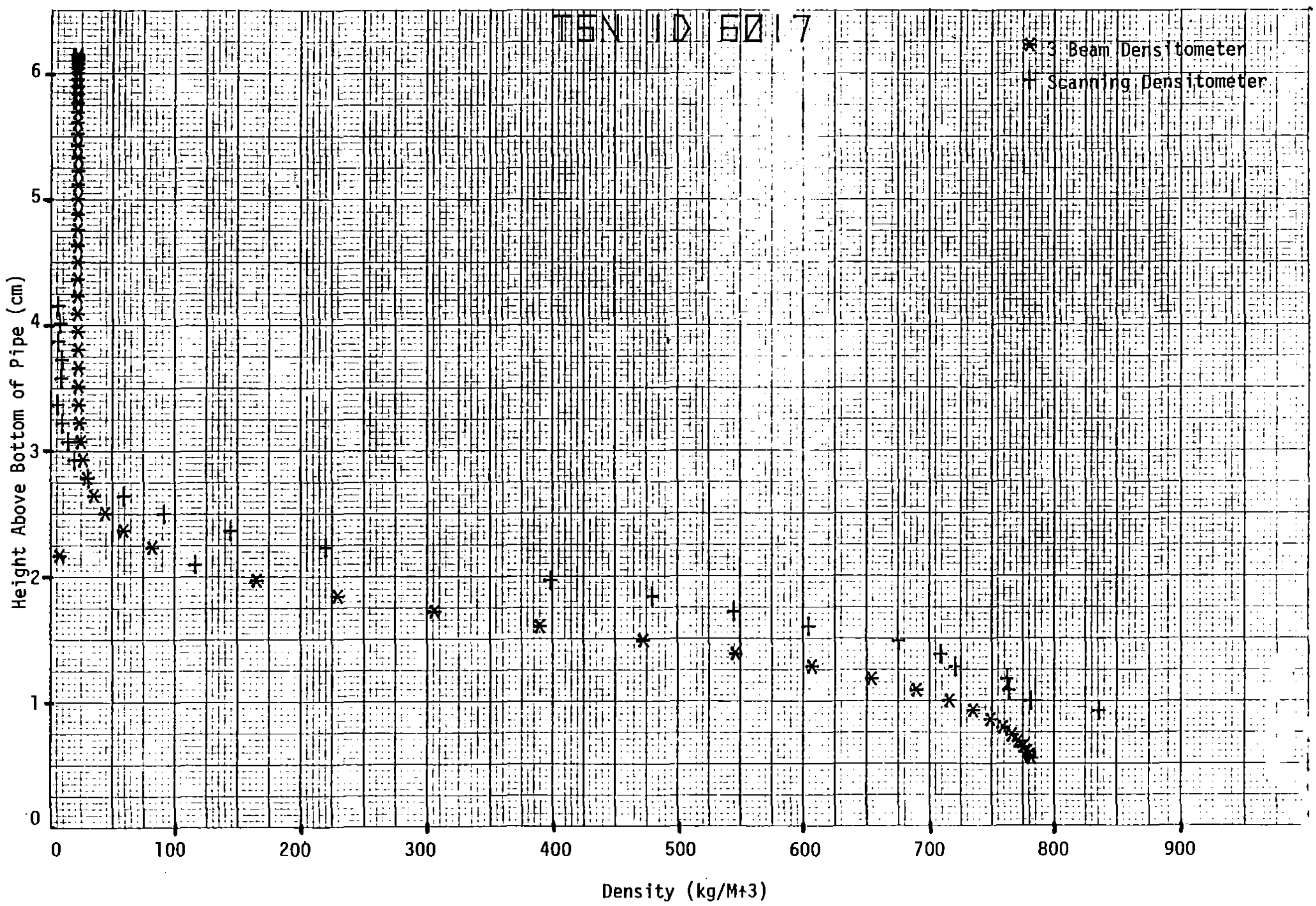
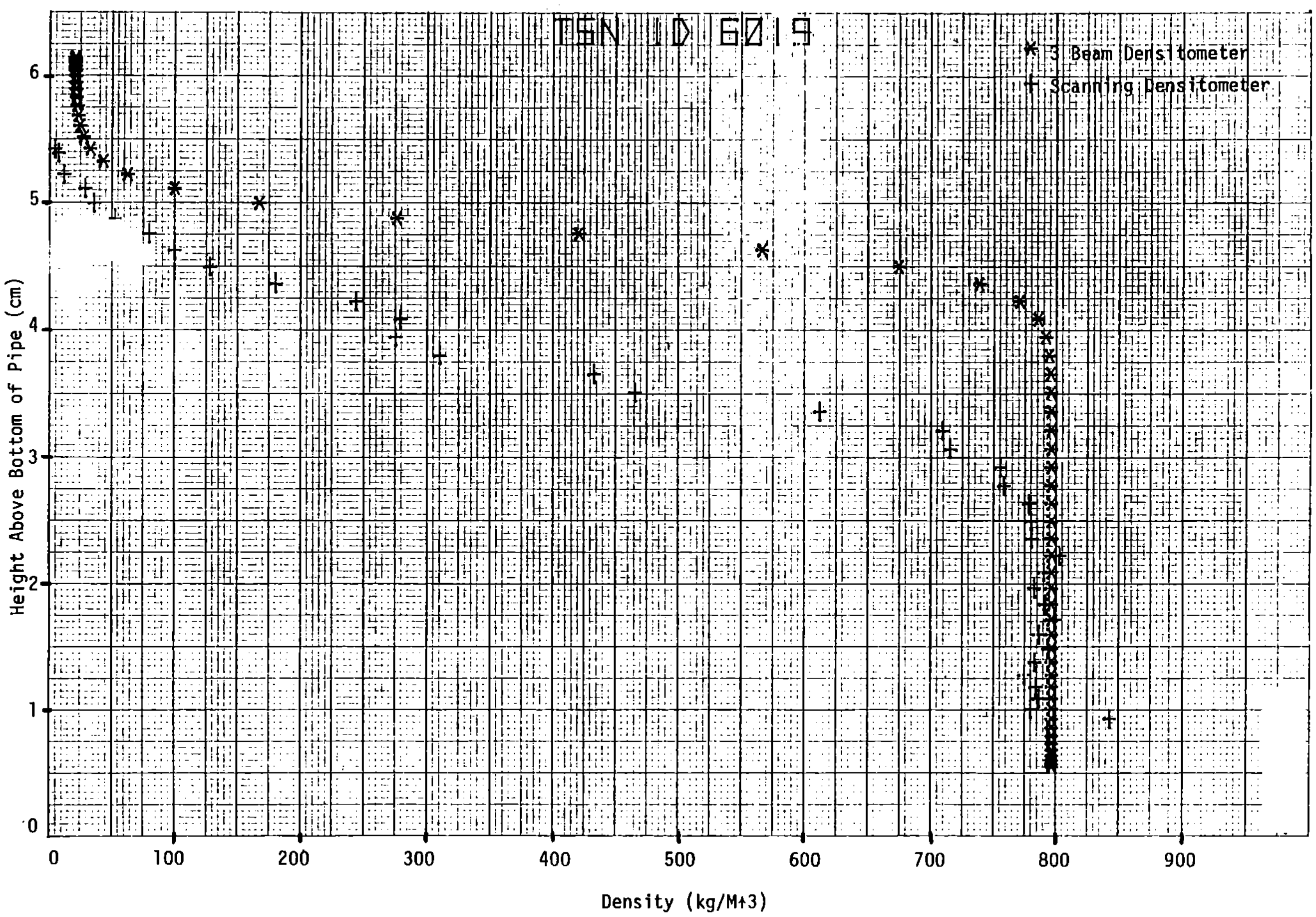


FIGURE II.3: COMPARISON OF DENSITY PROFILES (TSN 6016 AND 6017)



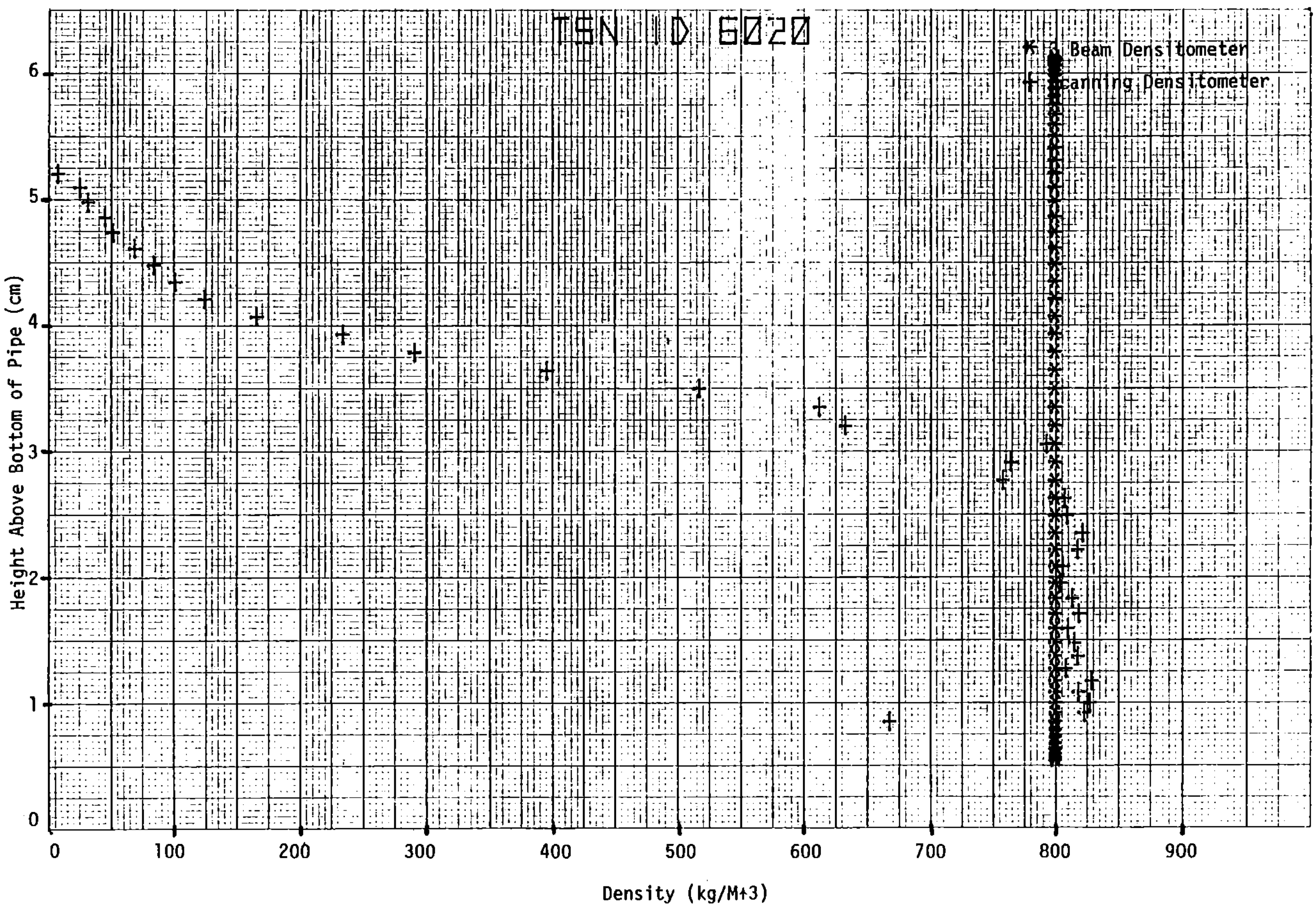
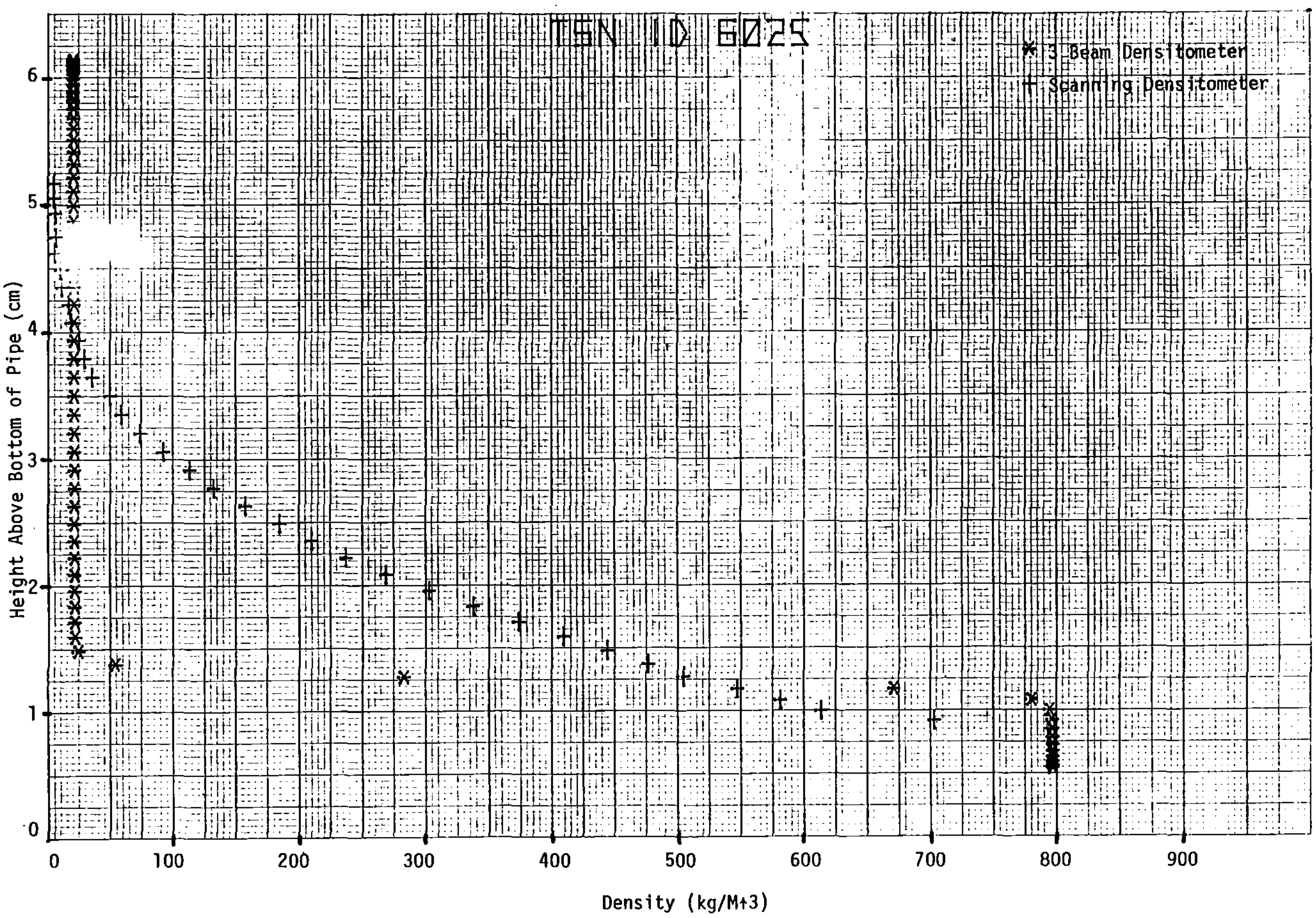


FIGURE II.4: COMPARISON OF DENSITY PROFILES (TSN 6019 AND 6020)



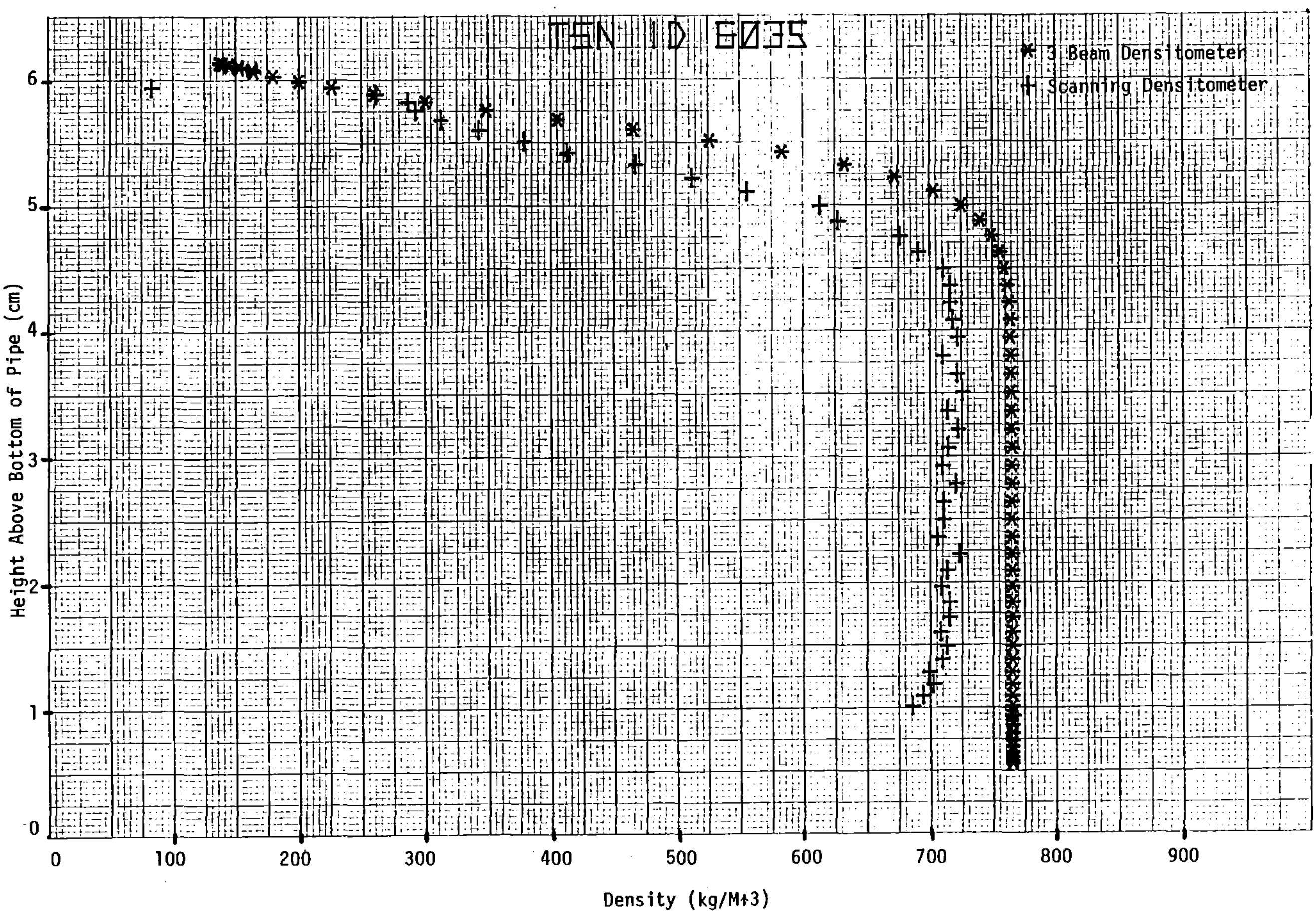
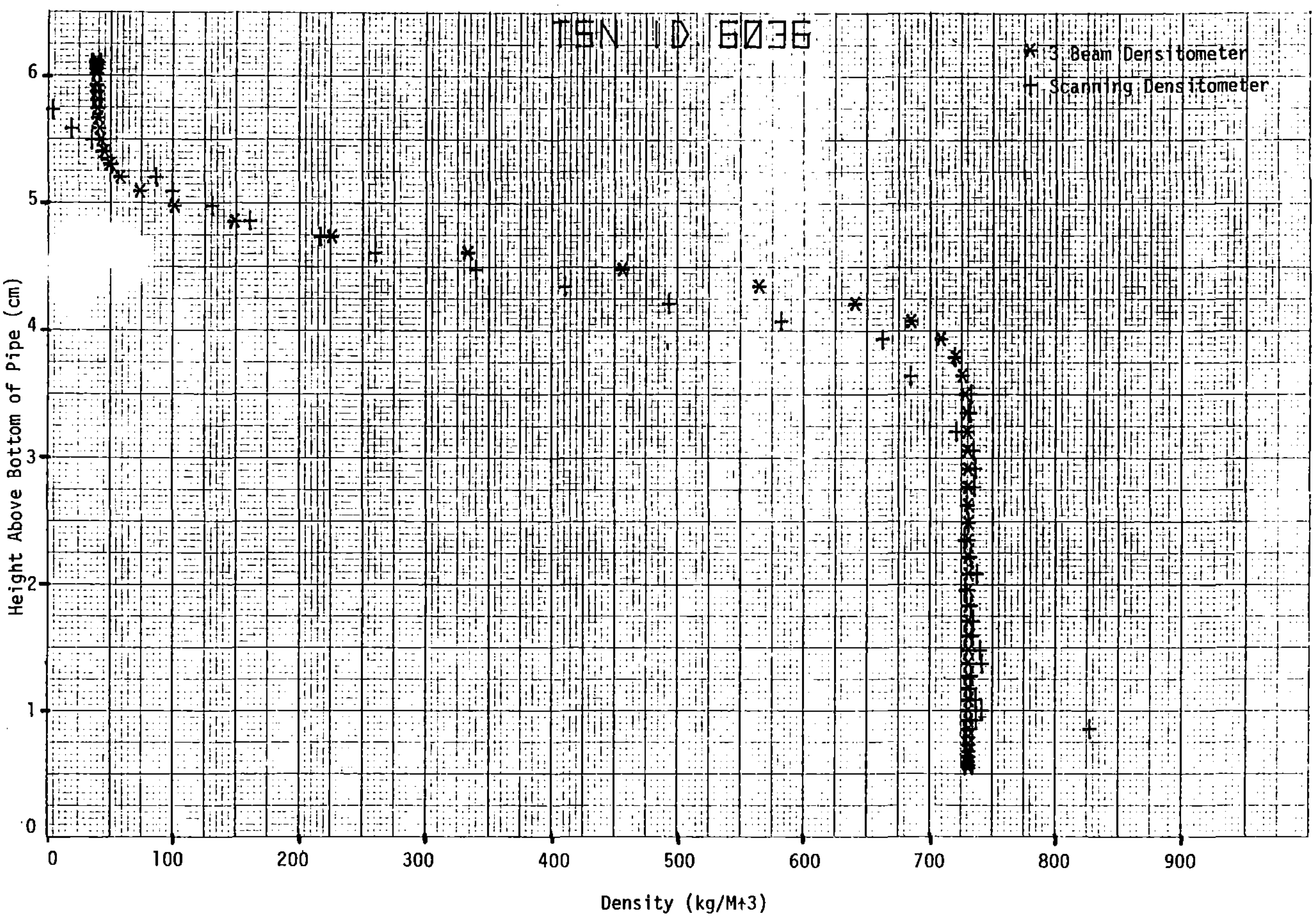


FIGURE II.5: COMPARISON OF DENSITY PROFILES (TSN 6025 AND 6035)



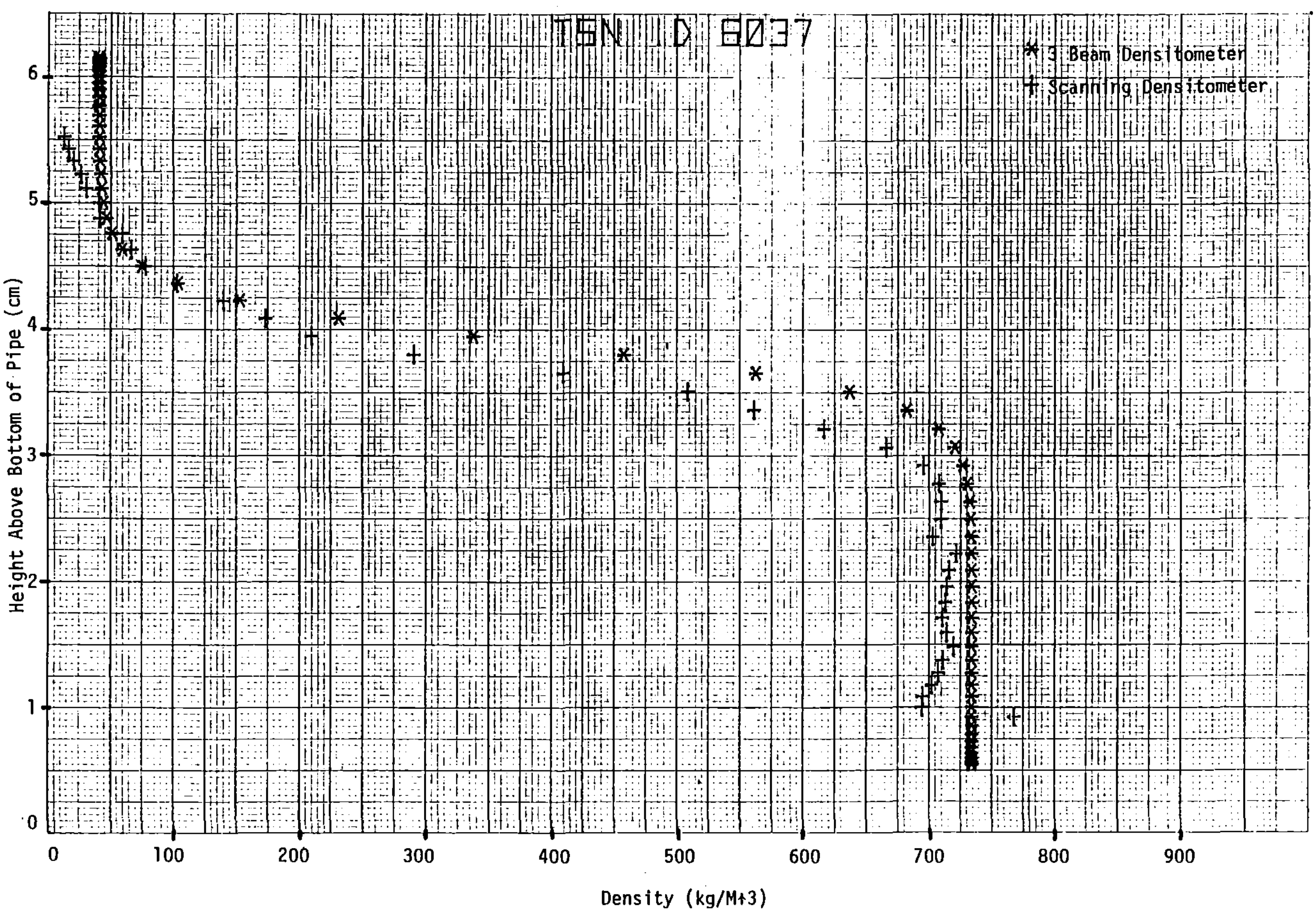
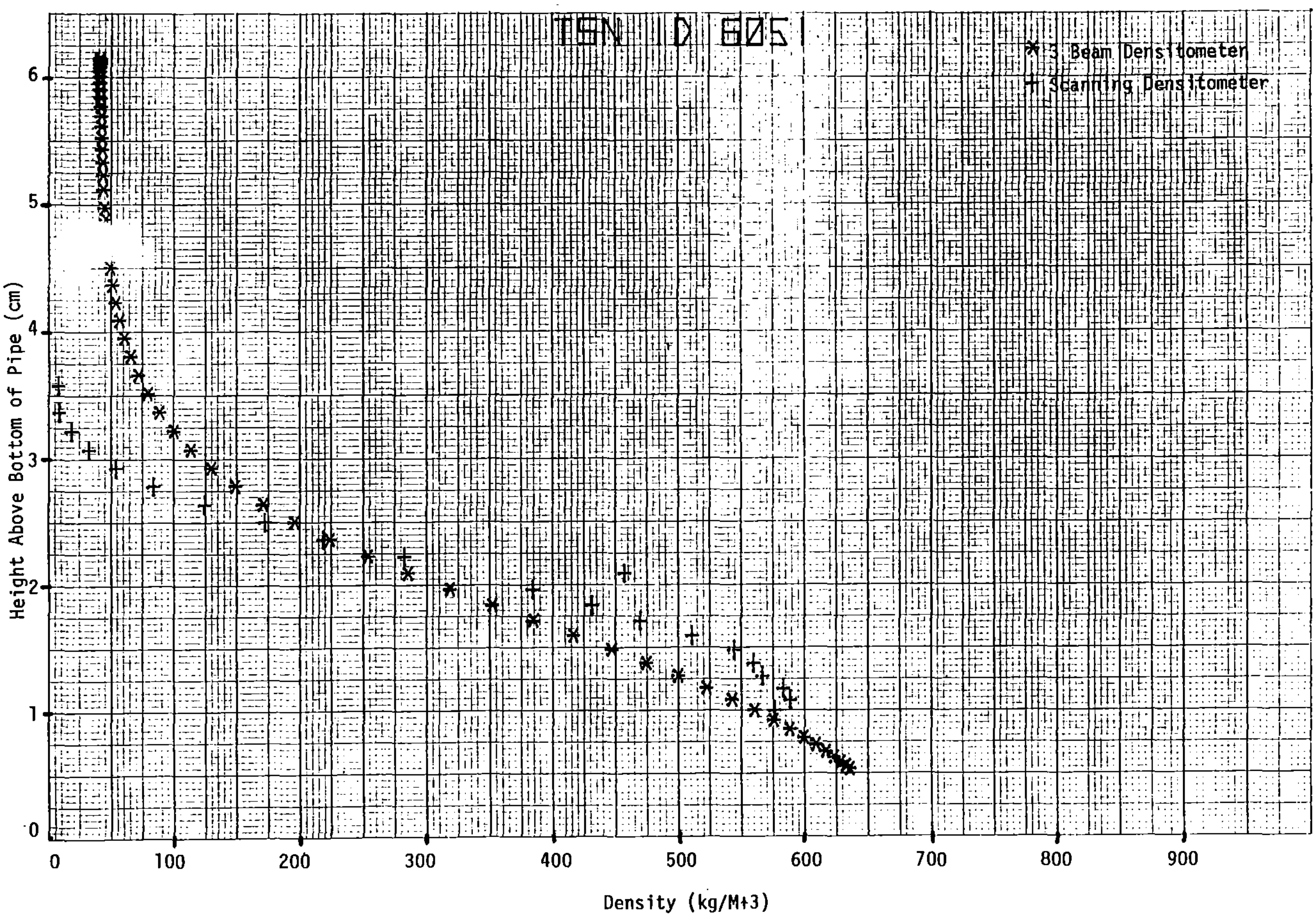


FIGURE II.6: COMPARISON OF DENSITY PROFILES (TSN 6035 AND 6037)



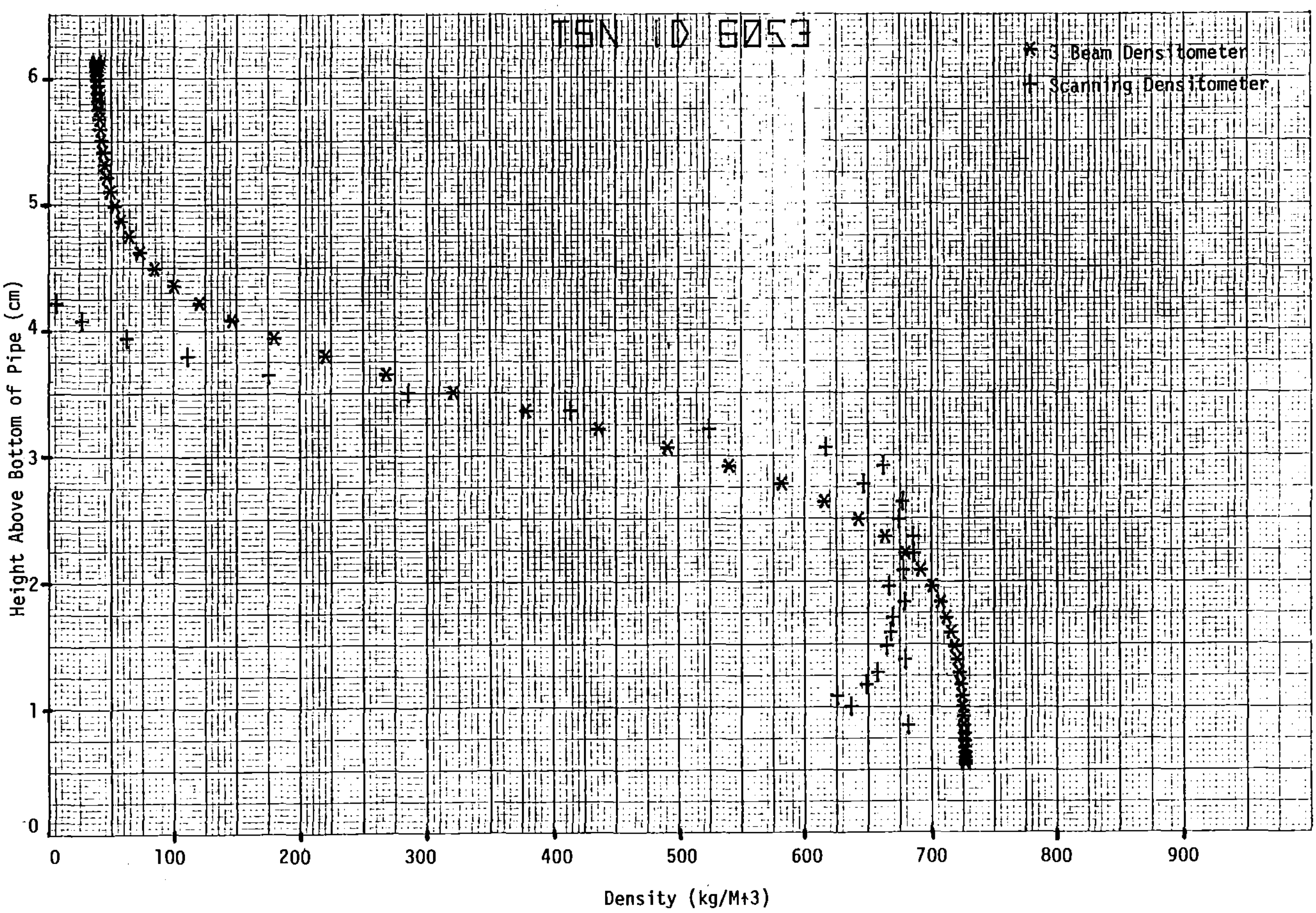
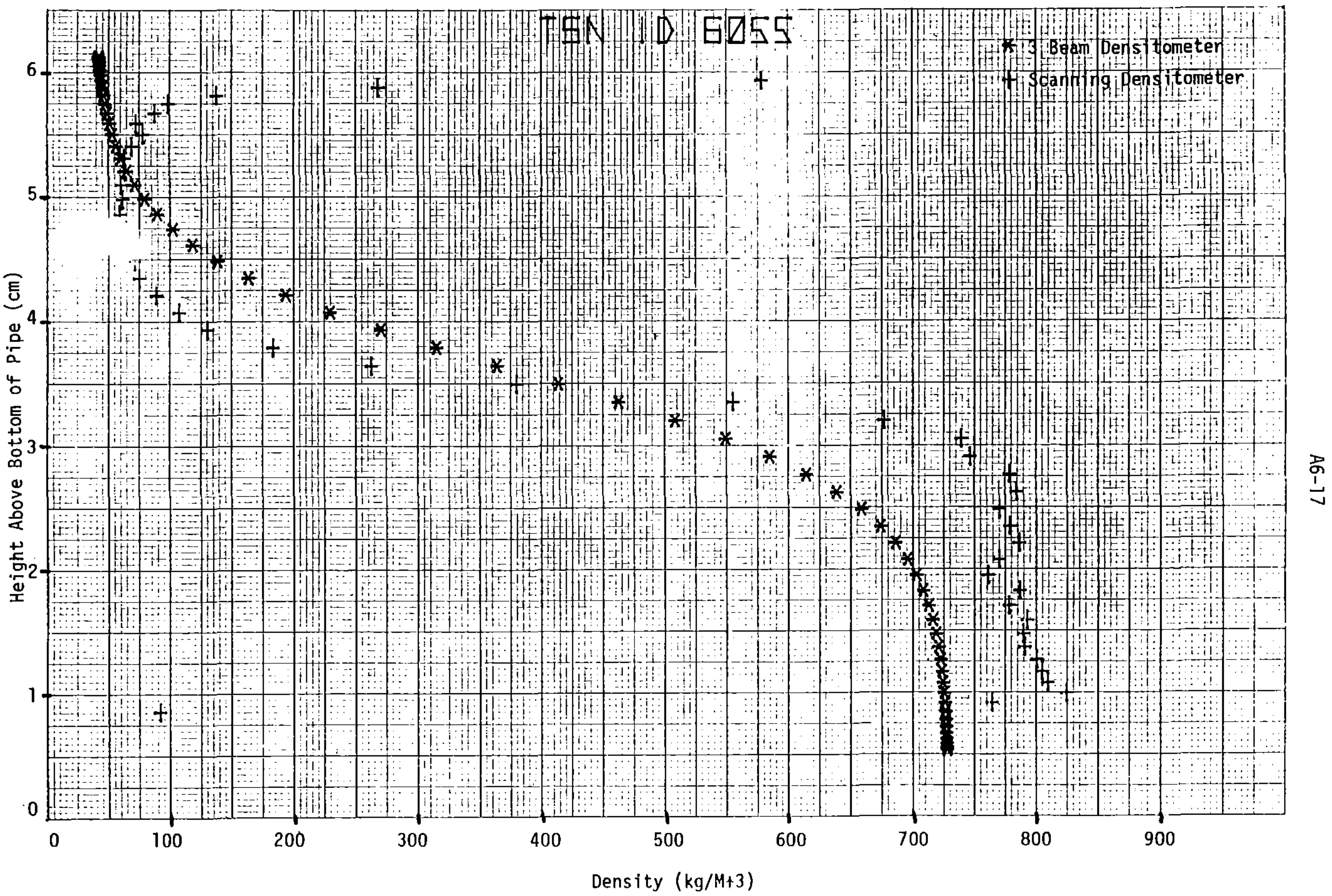


FIGURE II.7: COMPARISON OF DENSITY PROFILES (TSN 6051 AND 6052)



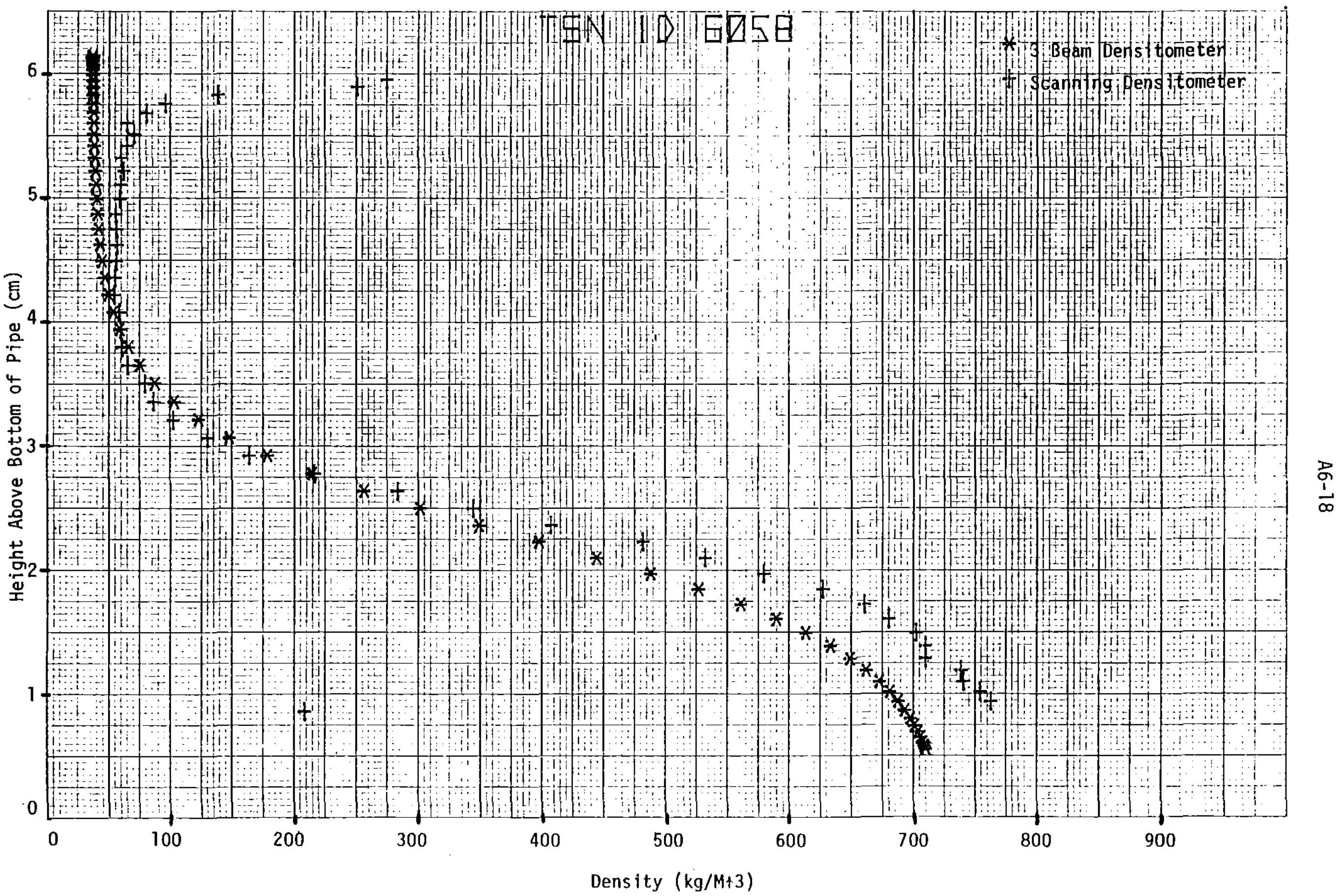


FIGURE II.8: COMPARISON OF DENSITY PROFILES (TSN 6055 AND 6058)

Appendix III

The Radioactive Tracer Velocity Measurement Technique

1. The Equipment for Radiotracer Velocity Measurement

With the radiotracer technique, gaseous and liquid tracers are injected periodically into the flow. Figure III. 1 presents a schematic diagram of the radiotracer equipment. After a mixing distance the "radiotracer cloud" reaches the same velocity as the corresponding phase of the two-phase mixture and is detected by detectors, arranged downstream in two or more measurement planes. The velocity of the individual phases is determined from the given measurement distances and the elapsed time.

The technique presented in the following is also described in /9/. The radiotracer of the gaseous phase Ar-41 (E = 1.29 MeV, $T_{1/2}$= 1.83 hours) was used in the steam phase of the flow and for the liquid phase Mn-56 dissolved in water (E = 0.85 MeV, 1.81 MeV, and 2.11 MeV, $T_{1/2}$= 2.58 hours) was used in water phase of the flow. Both tracers were activated in the research reactor FR2 of the Kernforschungszentrum Karlsruhe.

Four tracer injection valves are arranged along the test section with a distance between each valve of 100 mm. The valves are electromagnetic with a nominal diameter of 1.2 mm. The valves are of a fast opening and closing type to permit as high injection frequencies as possible. The valve nozzles are partially inserted into the test section. A copper packing prevents vapor or water from escaping at the Connection. As the test section is at an elevated temperature during operation, the valves are water-cooled. The nozzles of the injection valves are of two different lengths. The short nozzles end at the inside wall of the tube, while the long nozzles reach within 10 mm of the center of the test section. The injection valves are arranged (in the direction of the fluid flow) as follows: first long nozzle for the Mn solution, second, long nozzle for Ar, third, short nozzle for Mn solution and finally, short nozzle for Ar.

The first measuring plane was installed at a distance of 500 mm downstream from the last injection valve. It consisted of two 2" x 2" detectors, opposing each other and installed vertically to the tube in the same direction as the injection valves. The detectors were in a water cooled casing. They were shielded by 50 mm of lead around the NaI(Tl) crystal. Between the test section and the detector a slit-type lead collimator (length: 50 mm) was installed; its 20 mm broad slit was in a vertical direction relative to the horizontal axis of the test section. The other five measuring planes with similar NaI(Tl) detector equipment were arranged each spaced 600 mm apart. For shielding against the background radiation from the injection valves, a wall of lead (thickness: 100 mm) was erected between the last injection valve and the first measurement plane.

2. The Control of Tracer Injection

2.1 Valve Control Unit

The prepared tracer reaches the electromagnetic injection valves at an injection pressure higher than the system pressure of the test facility. The injection valves are operated above their normal operational range in order to obtain the performance necessary for the injection technique. The control of the injection valves is carried out directly, without transformers and time-delaying elements, by a valve control unit in the measuring room, developed and built by the Laboratorium für Isotopentechnik (LIT). This valve control unit opens and closes the injection valves at precisely determined times. The injection valves are open for about 10 to 20 ms for the gaseous tracer Argon-41 and about 20 to 60 ms for the liquid tracer Mn-56, depending on the activity needed per injection and the specific activity of the electric charge displacement of a mechanically loaded piezocrystal. These pressure measurements are recorded with the data during the experiment.

The tracer labeling of the steam phase and of the water phase is performed alternately. The valve control unit produces a precisely adjustable delay time between the four different injection valves. This is advantageous for data evaluation when the tracers tend to bunch together within the measurement distances as is the case when slip occurs. The frequency of the injection periods (a period includes all four injections) varies between 0.1 cps to 3 cps depending upon the expected linear velocities for the two-phases in the test section. The valve control unit permits injections with different frequencies, which are automatically controlled in exactly determinable times. Thus it is possible to accurately label a flow with varying velocities for the two-phases.

2.2 Specific Activities, Count Rates Obtained

The mean value of the activity per injection amounts to 1 - 15 mCi. The detection of the tracer cloud is performed by NaI(Ti) scintillation detectors. The "sensitive field" of the detectors is focused by slit-type collimators (width: 20 mm). For the 3-in. test section, the typical tracer cloud viewed by the detector has an activity of 50-500μCi.

3. Detection

The starting distance, i.e., the distance between the last injection valve and the first detector plane amounted to about 0.5 m. It is expected that within this distance the injected tracer is mixed with the corresponding phase and also is accelerated up to phase velocity. The distance required for this purpose depends, among other things, on the phase velocities, the flow pattern and the thermodynamic circumstances and was determined experimentally. After this starting distance, four measuring planes followed at a distance of 1/2 to 1 m. Each measuring plane consisted of two detectors arranged opposite to each other and installed vertically. After these four measuring planes, two single detector stations were placed above the test section, arranged at a distance of 2-1/2 and 1-1/2 m, respectively. The individual phase velocities were determined by measuring the elapsed time of the corresponding tracer cloud between two measuring planes. The positioning of two detectors in one measurement plane offers redundancy. Also, indications for the distribution of the tracer in the test section can be determined. By arranging more than two measurement planes velocity transients can be measured, thereby providing conclusions on the thermodynamic state.

4. Data Acquisition

In the measuring room, all devices for injection control, tracer measurement and data collection are installed, so that personel are not needed at the facility. Here the preamplified signal coming from the detectors is amplified once more by the factor 100. The adjustment of high voltage to the operating point of the photomultiplier and the determination of the supplementary amplification are performed by using the gamma-ray spectrum from a radioactive calibration source, which had been attached to each detector for a short time before starting the experiment (generally Co^{60} with an activity of 10μCi). The calibration spectra are collected by a multichannel analyzer. During the measurement the functioning of the detectors and the tracer behaviour are continuously monitored by the spectra of the tracers, registered in the multichannel analyzer.

At the outlet of each amplifier three single channel analyzers are installed. Here the analog signals coming from the amplifier are transformed into digital pulses. The first single channel analyzer is used as an lower level discriminator. That is, a digital output pulse is created if the analog pulses are higher than the noise threshold. The other two single channel analyzers are used to identify the individual tracers. That is, these two single channel analyzers are set to provide a digital output signal within the gamma-ray energy regions of the two radiotracers (Ar-41; E = 1.29 MeV, Mn-56; E =0.85, 1.81 and 2.11 MeV). The single channel analyzers are adjusted with a multichannel analyzer by placing the "energy windows" over the photopeaks of the tracer spectra; Ar-41; 2.29 MeV; Mn-56; 1.81 MeV. This identification of the tracer by energy discrimination is a supplement to the tracer determination by injection control. With count rate meters, the pulse rate from the single channel analyzers is linearly transformed into an analog voltage. The resolution time of the count rate meters has been modified to 1 ms.

4.1 Recording Technique

The control pulses of the valve control unit, the signals of the pressure gauges at the injection valves and the analog voltage from the count rate meters are adapted to the tape recorder by attenuators and recorded on magnetic tape. Two recorders with a total of 28 channels are available, furthermore there is a PCM unit (pulse code modulation) which records 8 signals in one channel. During the experiment, signals are transmitted through adequate low-pass filters to a high speed UV-recorder, so that prompt evaluation of the data can be made during the experiment.

5. Data Evaluation Technique

The linear phase velocities are determined by evaluation of the integrally measured count rates according to a cross-correlation technique, whereby the tracer are identified both by injection control and energy discrimination. The radio-tracer signals were recorded in an analog mode and evaluated on an IBM 370/3033 computer using a program developed by KfK. Two data blocks (gates), each containing one peak, were read in synchronously. In the evaluation of these data blocks, the relations shown below were used. The cross correlation function of two signals x(t), y(t):

$$\phi_{xy}(\tau) = \int_{-\infty}^{\infty} x(t) \cdot y(t+\tau) dt$$

represents the time delay between these two signals.

We suppose that the signals were zero outside an interval T: x(t), y(t) = o for /t/> T/2.

From
$$\phi_{xy}(\tau) = \int_{+T/2}^{-T/2} x(t) \cdot y(t+\tau) dt$$

simple numerical integration furnishes:

$$\phi_{xy}(\tau_i) = 1/nT^* \sum_{i+1}^{n} x(iT^*)y(iT^*+kT^*)$$

$$T = nT^*, \ k = \tau/T^*$$

On the basis of the time shift of the peak centroids an approximate value of τ_0 is determined, from which τ_{min} and τ_{max} are found. For convolution (calculation of the cross-correlation functions) τ is now varied within these limits τ_{min}, τ_{max}. As a result one obtains the curve of the cross-correlation function in the interval $t_{min}<t<t_{max}$. The peak of the cross-correlation function supplies the mean transit time of the respective tracer between the points of measurement. Tables III. 1 and III. 2 show the measured velocities between the different detector locations. It is clearly seen that the values for both phase velocities differ at the different locations. This is due to the development of the two-phase flow along the flow path.

5 INCH 40 BAR
RADIOTRACER VELOCITIES

Run ID	V_g D1 - D3	V_ℓ D1 - D3	V_g D3 - D5	V_ℓ D3 - D5	V_g D5 - D7	V_ℓ D5 - D7
5054	10.40	3.50	11.00	3.56	11.00	2.98
5056	5.00	1.30	4.70	1.29	4.45	1.33
5057	5.00	1.36	5.00	1.36	5.45	1.27
5058	10.67	2.83	10.00	2.49	10.00	2.32
5059	11.00	3.16	10.00	2.86	10.00	2.52
5060	1.21	1.21	1.23	1.06	1.35	1.00
5061	1.08	0.59	1.20	0.30	1.15	0.31
5062	1.35	2.08	1.39	1.94	1.36	1.83

5 INCH 70 BAR
RADIOTRACER VELOCITIES

5066	5.43	2.95	5.27	2.59	5.27	2.27
5067	5.21	3.36	5.11	2.96	5.25	2.51
5068	1.00	1.30	1.02	1.16	1.03	0.96
5069	1.17	1.91	1.18	1.80	1.20	1.57
5070	1.21	0.76	1.30	0.62	1.22	0.50
5071	5.55	2.86	5.64	2.40	5.65	1.87

TABLE III.1: RADIOTRACER VELOCITIES 5 INCH TEST SECTION

3 INCH 40 BAR
RADIOTRACER VELOCITIES

Run ID	V_g D1 - D3	V_ℓ D1 - D3	V_g D3 - D5	V_ℓ D3 - D5	V_g D5 - D7	V_ℓ D5 - D7
6013	12.41	11.61	12.61	9.77	12.93	9.12
6014	5.56	4.59	6.09	3.70	6.26	2.99
6015	1.56	2.19	1.10	1.87	2.12	1.50
6016	1.47	1.45	1.61	1.08	1.83	0.89
6017	6.67	2.81	7.14	2.34	6.51	2.20
6018	10.56	6.20	10.56	5.45	10.72	4.04
6019	1.96	2.83	2.11	2.27	2.37	2.03
6020	1.94	2.75	2.21	2.33	2.71	2.03
6021	7.62	7.18	8.15	5.44	8.61	4.00
6022	3.79	4.11	4.13	3.35	4.76	2.77
6023	6.13	5.69	6.78	4.08	6.86	3.63
6024	9.02	8.16	8.98	6.40	8.94	5.01
6025	11.02	10.01	11.04	9.06	10.96	6.50
6026	8.05	7.13	7.89	5.66	7.85	4.82
6027	4.66	4.46	4.92	3.63	5.20	3.09

3 INCH 70 BAR
RADIOTRACER VELOCITIES

Run ID	V_g D1 - D3	V_ℓ D1 - D3	V_g D3 - D5	V_ℓ D3 - D5	V_g D5 - D7	V_ℓ D5 - D7
6052	8.88	8.43	9.14	7.12	9.53	5.23
6053	2.81	3.22	2.91	2.83	3.29	2.54
6054	1.61	1.43	1.66	1.12	1.83	0.94
6055	1.97	2.51	2.10	2.15	2.21	1.80
6056	5.99	4.05	6.21	3.08	6.46	2.66
6057	4.52	3.98	4.81	3.37	5.05	3.02
6058	6.06	5.40	6.34	4.25	6.62	3.64
6059	7.67	7.09	7.92	5.63	8.06	4.47
6060	5.03	4.58	5.25	3.85	5.59	3.62
6061	2.91	3.22	3.07	2.79	3.47	2.58
6062	7.28	6.79	7.42	5.62	7.59	5.03
6063	11.82	10.41	12.48	10.41	12.18	10.02

TABLE III.2: RADIOTRACER VELOCITIES 3 INCH TEST SECTION

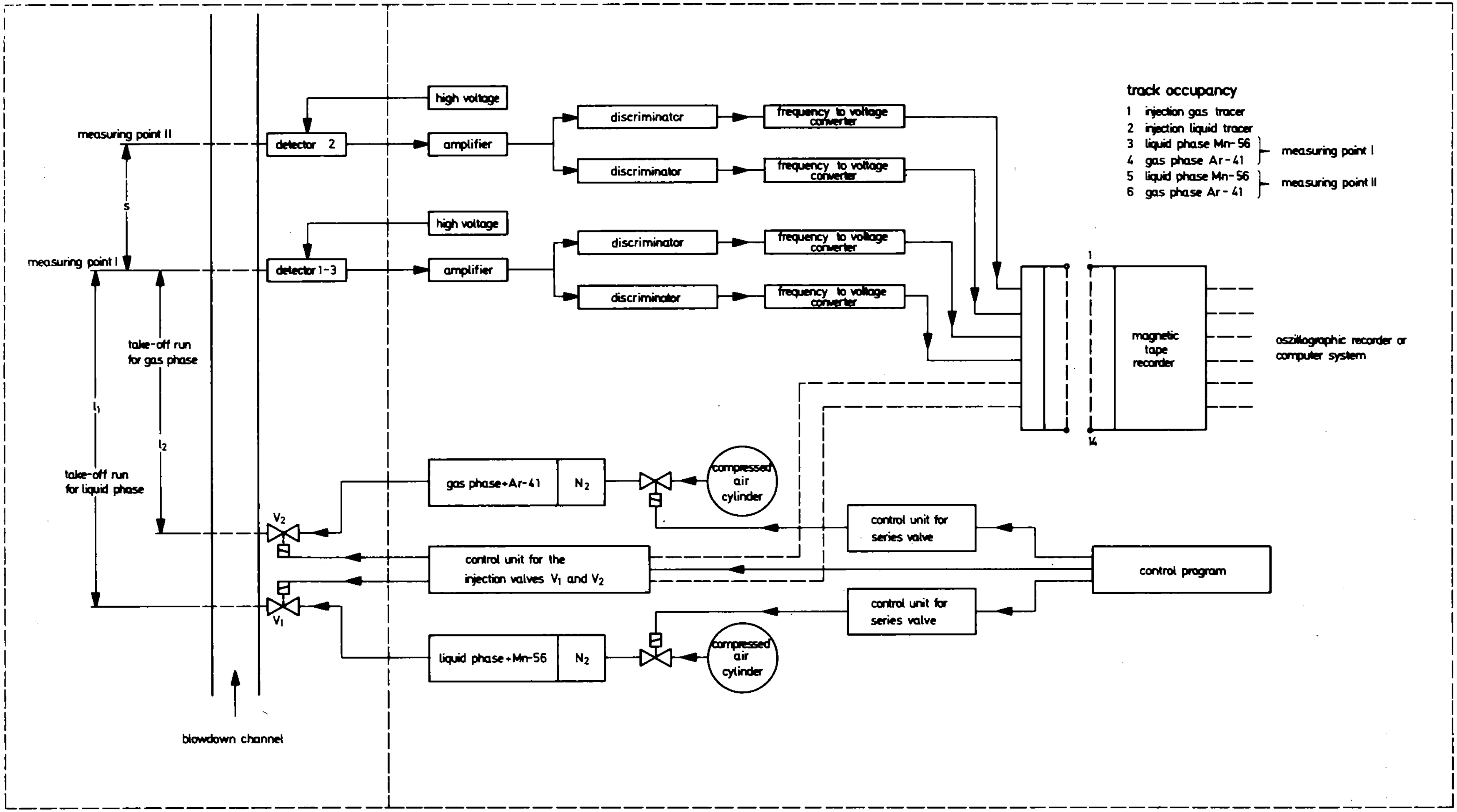


FIGURE III.1: SCHEMATIC DIAGRAM OF RADIOTRACER EQUIPMENT