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TWO-PHASE FLOW MEASUREMENTS WITH ADVANCED INSTRUMENTED SPOOL PIECES

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K. G. Turnage

ABSTRACT

A series of two-phase, air-water and steam-water tests performed with instrumented piping spool pieces is described. The behavior of the three-beam densitometer, turbine meter, and drag flowmeter is discussed in terms of two-phase models. Results from application of some two-phase mass flow models to the recorded spool piece data are shown.

Results of the study are used to make recommendations regarding spool piece design, instrument selection, and data reduction methods to obtain more accurate measurements of two-phase flow parameters.

1. INTRODUCTION

The measurement of two-phase mass flow rate is of primary importance in reactor safety studies involving loss-of-coolant experiments. Because of the severe environments present during blowdown and reflood, relatively few instrument types have been widely used to make two-phase flow measurements in piping geometries; these include turbine flowmeters, gamma densitometers, and drag flowmeters. (Pressure and temperature measurements are also required for the reduction of data from the other instruments.)

In the Thermal-Hydraulic Test Facility (THTF) at Oak Ridge National Laboratory (ORNL)[1] and in the Semiscale Facility at Idaho National Engineering Laboratory (INEL),[2] three full-flow instruments have been located in a relatively short piping segment called a spool piece. The design of spool pieces is important because the turbine meter and drag flowmeter are intrusive and may seriously alter the flow regime.[3] On the other hand, the location of all three instruments in close proximity is desirable because of the often unsteady and inhomogeneous nature of two-phase flow.

As part of the Advanced Two-Phase Flow Instrumentation Program at ORNL, advanced instrumented piping spool pieces were tested in air-water and steam-water two-phase flow. The 8.9-cm-ID (3.5-in.) stainless steel spool pieces tested incorporated a three-beam gamma densitometer, a turbine flowmeter, and a drag flowmeter with full-flow target.

The purpose of the tests was to evaluate, for a wide range of liquid and gas flow rates, the performance of the spool pieces in terms of available analytical techniques. Of particular interest was the use of larger drag target designs, which sample the flow to within 3.2 mm of the pipe wall. The effects of such targets on the flow pattern detected by the three-beam densitometer were studied using a transparent spool piece that was geometrically like the steel spool piece.

Comparisons of velocities predicted by the Aya, Rouhani, and volumetric models of turbine behavior to reduced turbine readings were made, and information gained from studies of each spool piece instrument was used to evaluate the results of two-phase mass flow models that require the instrument readings.

This report documents the most important results and conclusions obtained to date from the spool piece experiments and analyses.

2. AIR-WATER STUDIES

2.1 Experiment Description

The instrumented spool piece used in the air-water studies (Fig. 1) incorporates several design improvements: (1) the upstream drag flowmeter (normal flow direction), the densitometer, and the turbine are located within 46 cm (18 in.) of each other; (2) the location of a drag flowmeter on either end allows one drag meter to always be upstream of the turbine in case of bidirectional flow; (3) the "full-flow" turbine rotor and drag targets sample the fluid flow in the pipe to within 3.2 mm (0.125 in.) of the pipe wall; and (4) fast response, high sensitivity turbine monitor electronics were used with the turbine meter.

Detailed descriptions of the spool piece instrumentation, signal conditioning equipment, and data acquisition methods used are reported elsewhere.[4,5]

The ORNL two-phase air-water test facility (AWTF) shown in Fig. 2 was used to supply air at flow rates up to 242 liters/s (512 scfm) and water at flow rates up to 32 liters/s (500 gpm). In the 8.9-cm-ID (3.5-in.) spool piece tested, those rates correspond to superficial velocities of 39 m/s (128 fps) for air and 5.2 m/s (17 fps) for water. The air and water flow was at ambient temperature and near atmospheric pressure. In the air-water loop, the air flow rate is determined using a pressure gage upstream of critical flow orifices, and water is metered into the loop by means of rotameters [flow rates less than 6.3 liters/s (100 gpm)] or by a magnetic flowmeter.

The spool piece was tested[5-7] in the AWTF in the three locations shown in Fig. 2. By adjusting of valves, two-phase flow was made to pass horizontally, vertically upward, or vertically downward through the test section. Experiments were conducted by setting the desired air flow rate and then taking data at successively higher water input rates until either the system pressure became high enough to unchoke the critical flow orifice or one of the spool piece instruments was overranged. The air flow rate was then doubled, and the procedure of taking data with various water flow rates was repeated.

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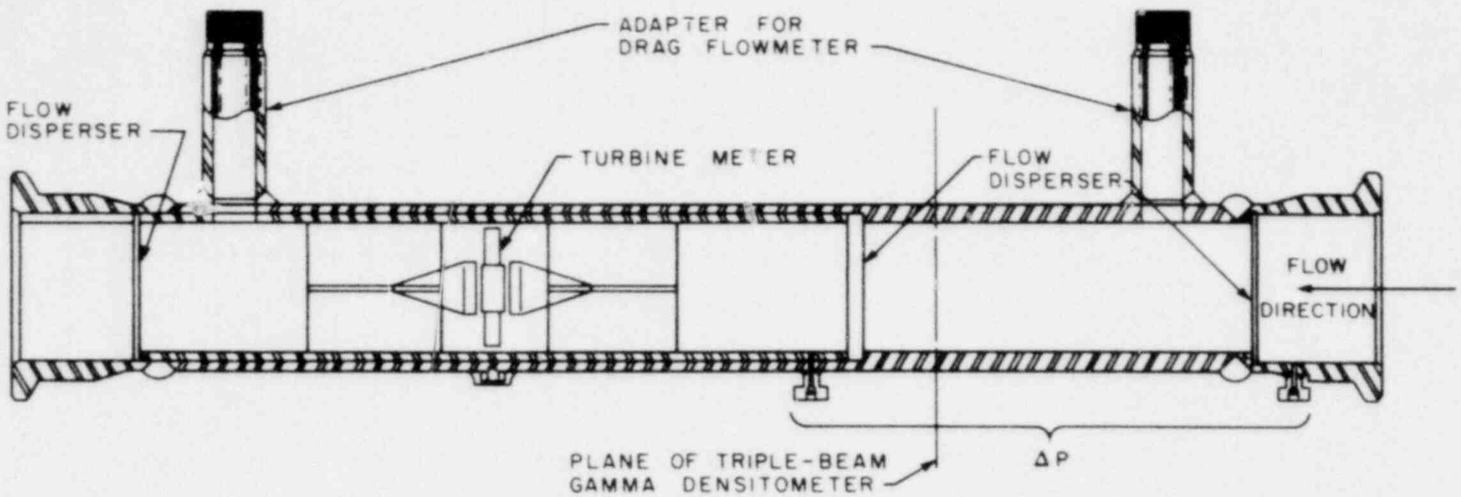

Fig. 1. Instrumented piping spool piece used in air-water testing.

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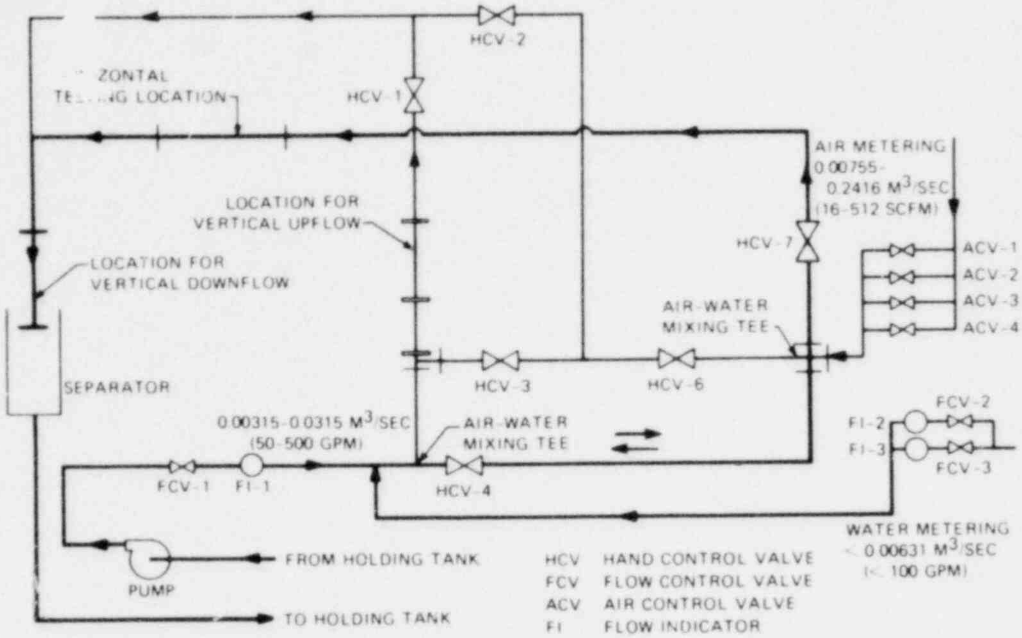

Fig. 2. ORNL Air-Water Test Facility.

The flow rates used resulted in many two-phase flow regimes (Figs. 3, 4, and 5). The flow regimes observed through the transparent loop piping at various flow rates generally agreed with those indicated by Mandhane and Aziz[8] (Fig. 3) and by Oshinowa and Charles[9] (Figs. 4 and 5).

The spool piece instrumentation was calibrated in single-phase flow immediately prior to each two-phase test. Simple equations[5] were then used to reduce the turbine and drag flowmeter data recorded from the two-phase tests, yielding a velocity V_t from the turbine and a momentum flux I_d indicated by the drag flowmeter. A mean pipe density ρ_a was deduced from the three-beam densitometer data using models which postulated three regions, each with uniform density. An annular model (Fig. 6) was used with the vertical upflow and vertical downflow data, and a "stratified" model (Fig. 7) was used to reduce data from the horizontal tests. Lucite inserts representing various flow regimes (Fig. 8) were used to verify the accuracy of the density measurements.

The FORTRAN computer program used to process the raw data tapes calculated V_t, I_d, ρ_a, and the pressure for short intervals of real time

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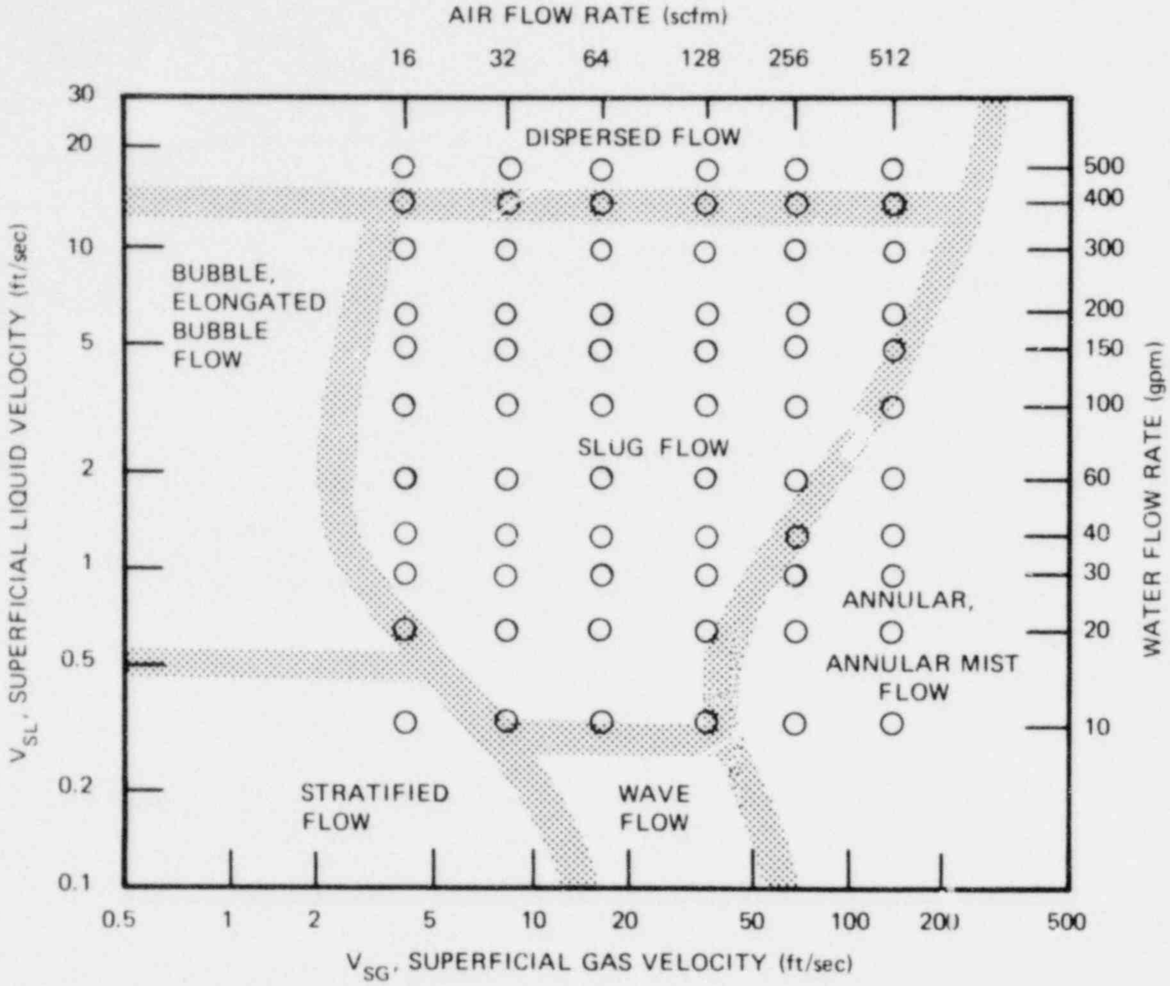

Fig. 3. Flow pattern map proposed by Mandhane et al. for horizontal flow with locations of data points used in air-water studies.

(≈0.1 s). These "instantaneous" quantities were used to evaluate modeling expressions for each short-time interval during a scan at a particular flow rate. The short-time interval modeling expressions were then averaged over time to yield the data presented here. This method is appropriate for evaluating models and instrumentation intended for transient or slug flow application.

2.2 Individual Instrument Response

The important results obtained with the triple-beam densitometer, turbine flowmeter, and drag flowmeter in the air-water, two-phase flow

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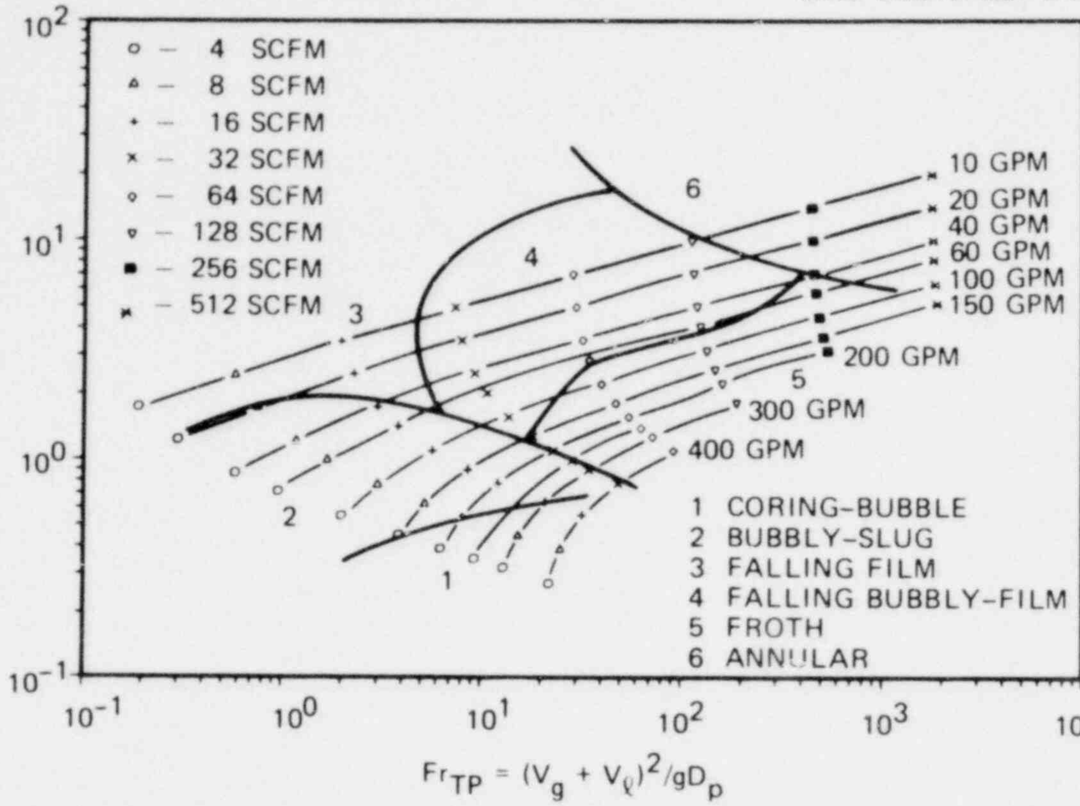

Fig. 4. Flow pattern map proposed by Oshinowa and Charles for vertical downflow with locations of data points used in air-water studies.

tests are presented here. Where the spool piece orientation, for example, horizontal vs downflow, had a significant effect on instrument behavior, the differences are indicated.

A Plexiglas spool piece with dimensions essentially identical to the steel test section was used for visual studies of how the drag bodies and the turbine perturbed the flow. The studies revealed that when full-flow drag targets were used in the spool piece, they caused considerable disturbance of the upstream flow regime to occur at the plane of the densitometer. The composite densities calculated from densitometer data were most seriously affected at the lowest void fractions when use of large targets apparently caused underestimates of the density by both the annular and the stratified models. In vertical downflow (Fig. 9), when a full-flow drag target was mounted on the upstream drag flowmeter, a pronounced discontinuity in calculated density occurred at the transition from bubbly slug to coring bubble flow. The discontinuity did not

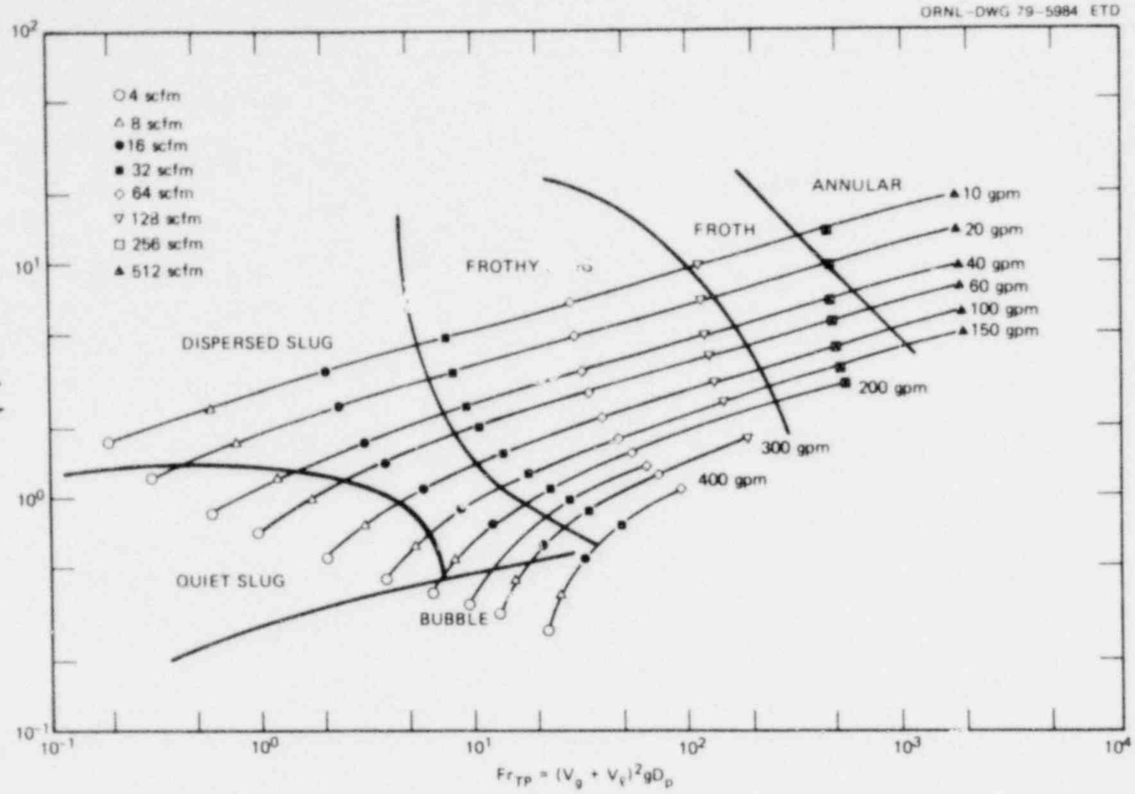

Fig. 5. Flow pattern map proposed by Oshinowa and Charles for vertical upflow with locations of data points used in air-water studies.

occur without the drag target. Thus, if full-flow drag targets are to be used, they should be positioned downstream of the densitometer. An analysis of data from the upflow experiments showed that there was no apparent effect on the composite density calculated using the densitometer, when a full-flow drag target was located upstream of the densitometer.

The accuracy of the single-phase input flow metering systems of the AWTF has been verified using standardized methods. For all data reported here, the error in the metered mass flow rates was less than 10% of reading. Some flow rates indicated in the flow regime maps (Figs. 3, 4, and 5) caused mean output readings of the turbine to be intermittent or identically zero, or they produced drag flowmeter readings of less than 0.5% of full scale. Such data are omitted from the following graphs presented for model and spool piece evaluation. It is, of course, crucial that all measurement systems designed for two-phase flow application be carefully sized for the flow rates expected.

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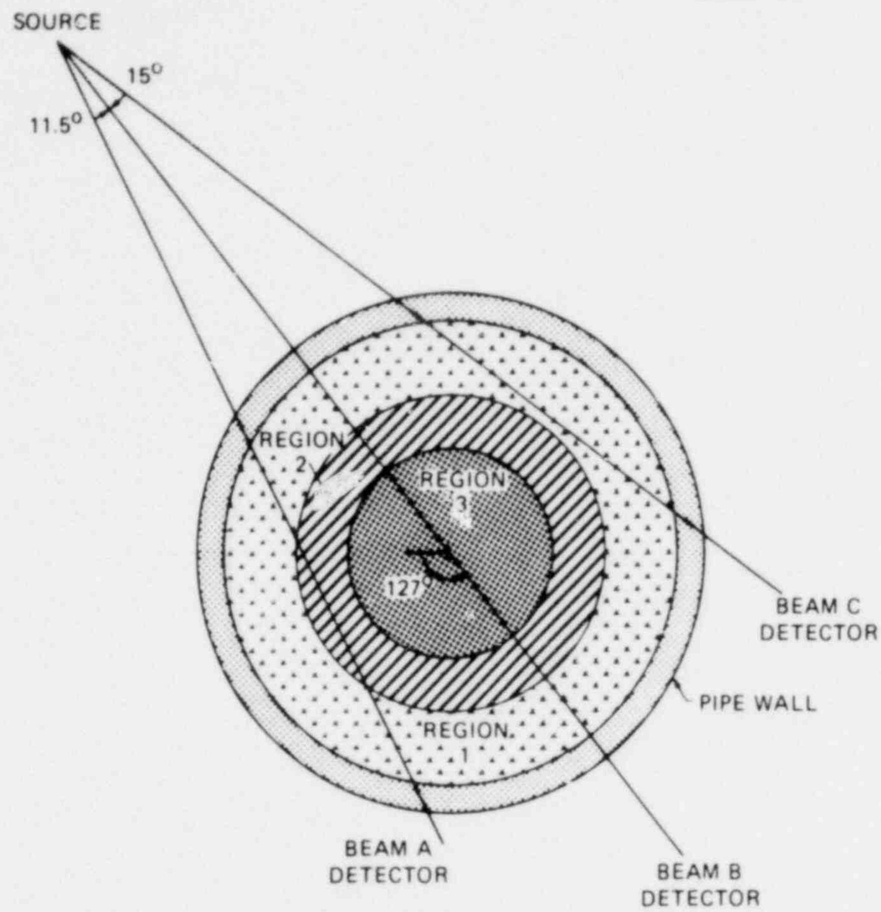

Fig. 6. Diagram showing uniform density regions used in annular model for reduction of three-beam densitometer data.

Mean phase velocities (based on metered inputs and densitometer data) were substituted into expressions for the turbine velocity postulated by Aya,[10] Rouhani,[11] and the volumetric[12] model. Comparisons between the turbine speed predicted by the models and mean turbine speeds recorded in the horizontal flow (Fig. 10) revealed that the Aya and the Rouhani models perform well, with the Rouhani model doing slightly better. In vertical downflow, the slip ratios may be significantly less than unity because of gravitational and buoyancy effects. When $S < 1$, the turbine meter velocity may be less than both the mean liquid and the mean vapor velocities. The Aya and Rouhani turbine models (Fig. 11) simulate actual turbine behavior poorly at those flow rates, but they perform satisfactorily at high air flow rates when $S \gtrsim 1$. The volumetric turbine model was the most

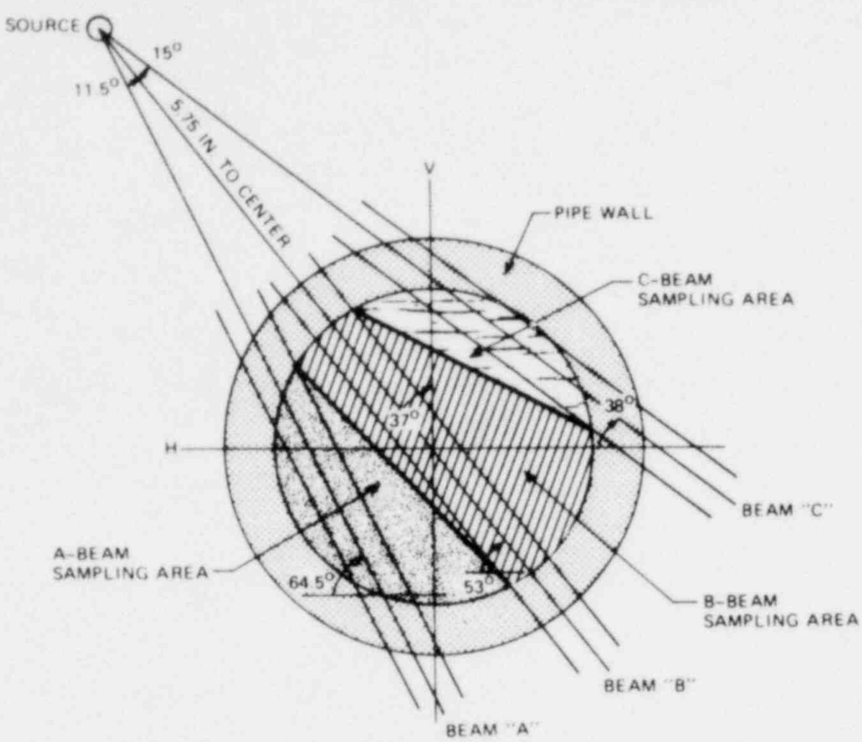

Fig. 7. Diagram showing uniform density regions used in stratified model for reduction of three-beam densitometer data.

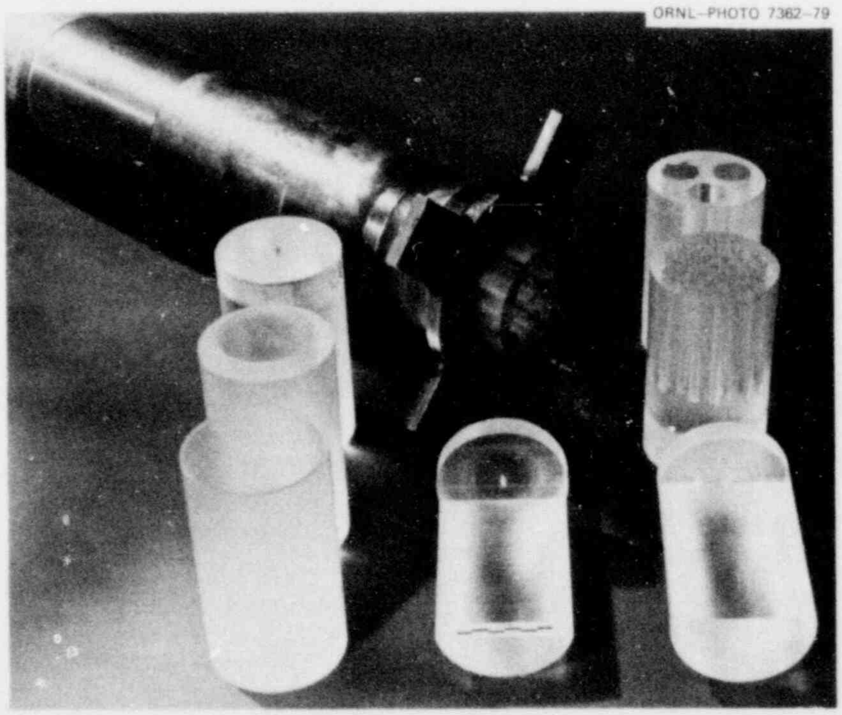

Fig. 8. Plexiglas inserts representing two-phase flow regimes, used to evaluate accuracy of densitometer measurements.

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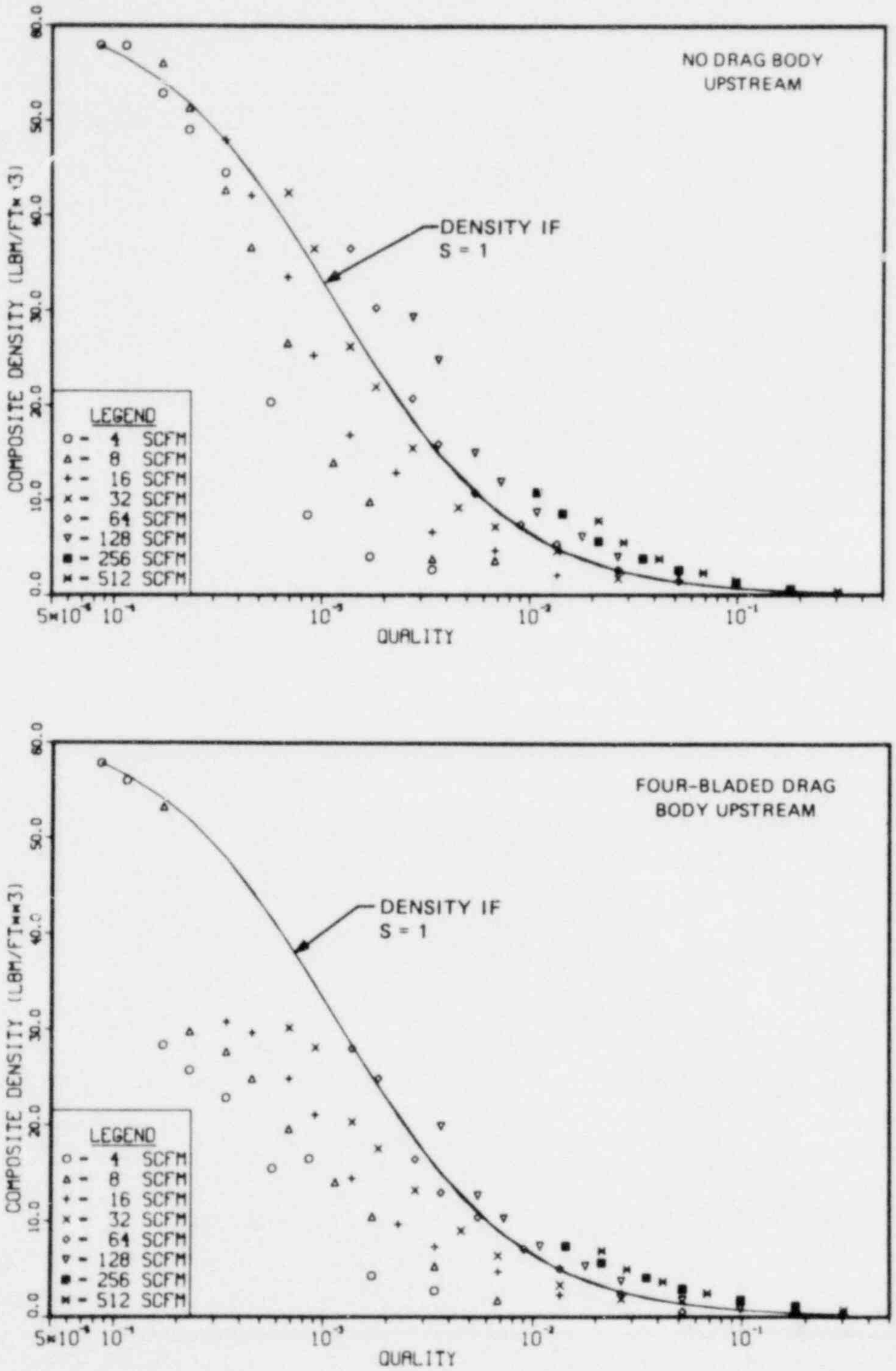

Fig. 9. Comparison showing effects of location of full-flow drag target upstream of densitometer in air-water vertical downflow.

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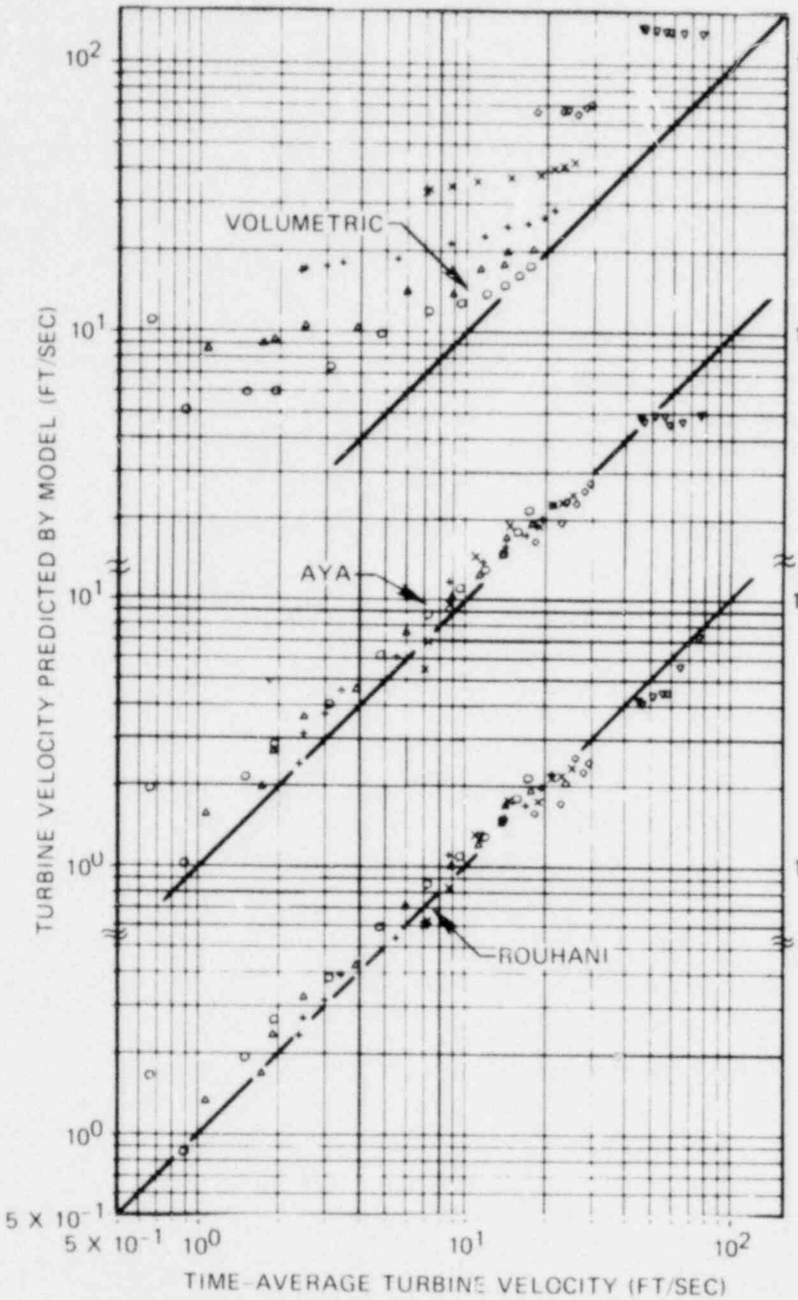

Fig. 10. Turbine velocity predicted by three turbine models vs actual mean turbine velocity recorded in horizontal flow. Solid lines denote perfect agreement for each model.

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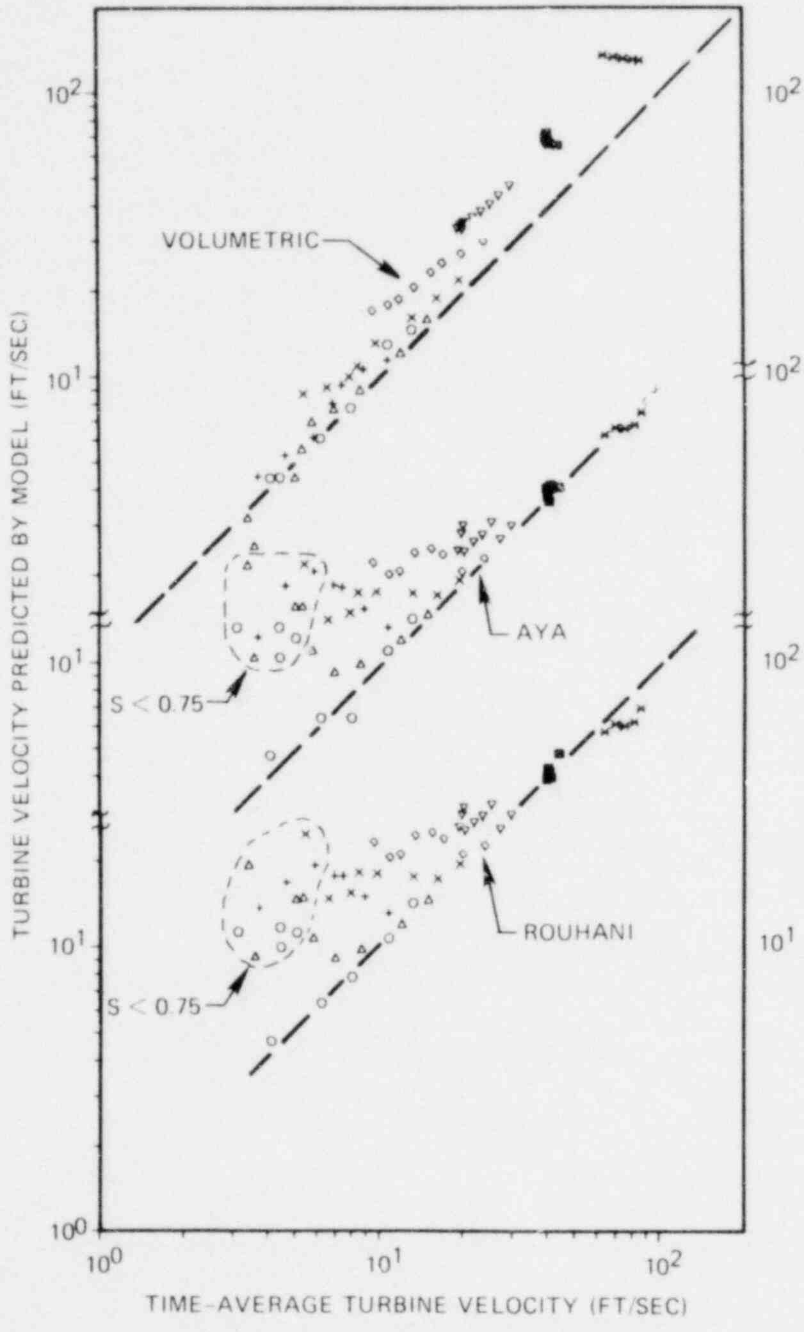

Fig. 11. Turbine velocity predicted by three turbine models vs actual mean turbine velocity recorded in vertical downflow. Solid lines denote perfect agreement for each model.

successful of the three models when $S < 1$. When data recorded in vertical upflow was used (Fig. 12), the volumetric turbine model's predictions were found to greatly exceed the turbine velocity at all flow rates. The Aya and the Rouhani turbine models predicted the turbine speed reasonably well over most of the range of flow rates used, except that their predictions were less than the turbine speeds at high air flow rates with low water flow rates (high void fraction) and slip ratios greater than 5.0.

The momentum flux I_d indicated by the drag flowmeter was calculated using single-phase calibration factors and drag transducer output. This was compared to a two-velocity momentum flux based on either turbine meter or density data and metered inputs to the loop. In horizontal flow (Fig. 13) and in vertical downflow at flow rates where the calculated standards were deemed reliable, the two-phase drag coefficients appeared to be less than the single-phase C_D's by ≈20%. This suggests that the accumulation of a vapor pocket just downstream of the drag target, observed in high-speed motion pictures made through the transparent spool piece, causes a significant reduction in drag. (Hoerner[13] has presented data showing the reduction in drag which occurs due to accumulation of a vapor pocket behind a bluff body.) For the vertical upflow tests, the two-phase drag coefficient of the four-bladed drag target was found to approximate the single-phase value.

2.3 Two-Phase Mass Flow Rate Models

In this section, data are shown relating the mass flow rates obtained using combinations of the spool piece instrument readings to the metered-in mass flow rates. These results are believed to be typical of those expected when similar instruments are used with analogous two-phase flow rates and when the output readings are within the normal operating ranges of the instruments. Significant strengths and weaknesses of the simple mass flow models tested may be inferred from the grouping of the mass flow ratios relative to the line of perfect agreement (unity).

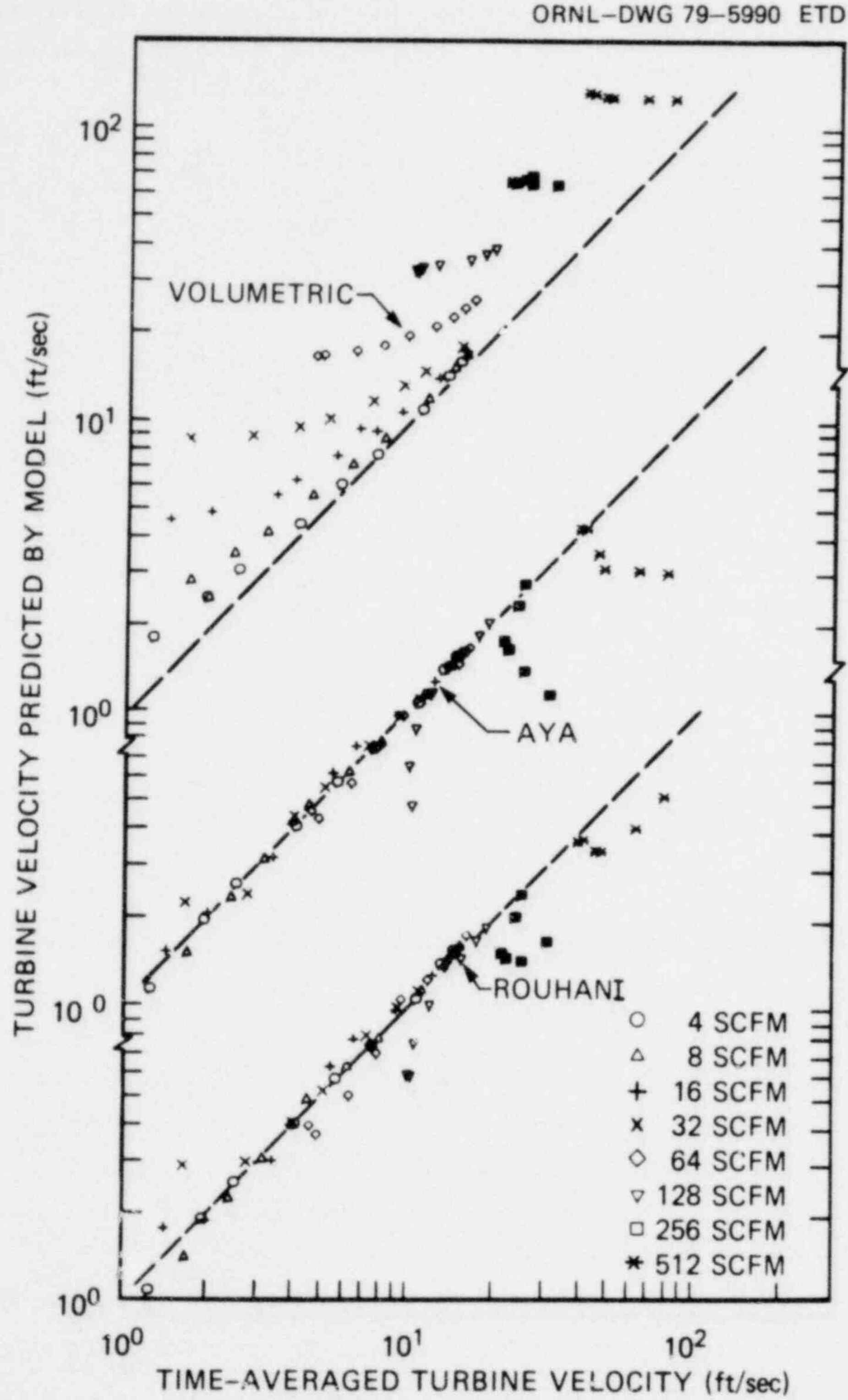

Fig. 12. Turbine velocity predicted by three turbine models vs actual mean turbine velocity recorded in vertical upflow. Solid lines denote perfect agreement for each model.

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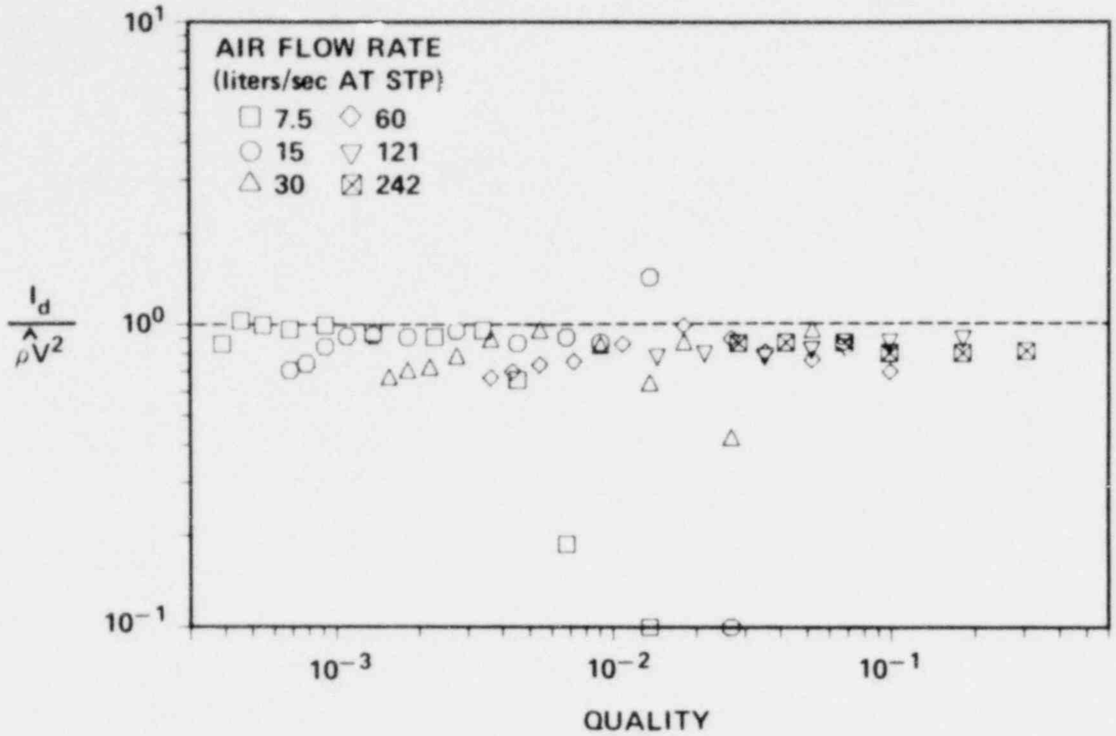

Fig. 13. Ratio of momentum flux indicated by drag flowmeter to momentum flux calculated using metered flow rates and turbine velocity (horizontal flow, perforated plate target).

Comparisons of data calculated using the mass flow models $G_1 = \rho_a V_t$, $G_2 = \sqrt{\rho_a I_d}$, and $G_3 = I_d/V_t$ to the actual two-phase mass flux have indicated the following:

1. G_1 (Fig. 14) is reliable when the turbine velocity approximates the liquid velocity (Fig. 15), particularly when the void fraction is less than 50%. G_1 increasingly overpredicts the true mass flux at higher void fraction. Also, G_1 is recommended in cases where the drag flowmeter signal is less than 0.5% of full scale.

2. G_2 (Fig. 16) is also reliable at low void fractions and relatively low slip ratios. But, like G_1, G_2 tends to overpredict the correct mass flux at the highest slip ratios. Uncertainties in the two-phase flow drag coefficient are minimized with G_2 because the square root is taken. G_2 is also recommended for cases such as low-velocity vertical downflow when the slip ratio is less than unity.

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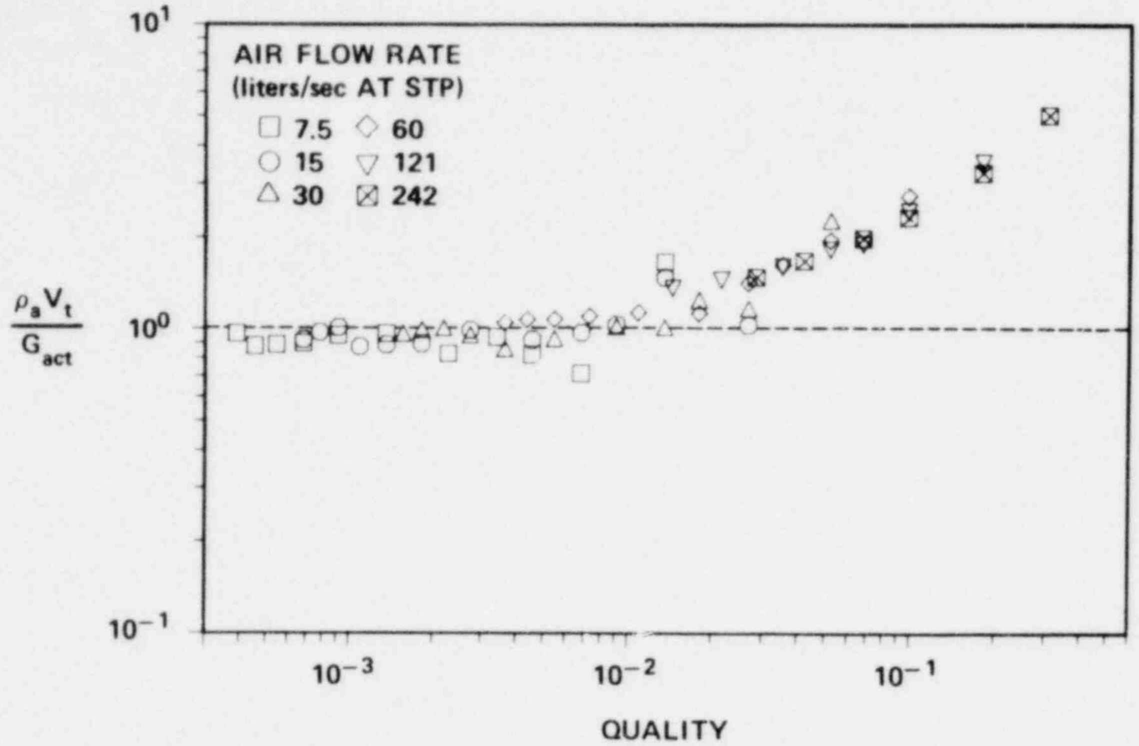

Fig. 14. Ratio of mass flux determined using densitometer and turbine to actual mass flux in horizontal two-phase flow.

3. G_3 (Fig. 17) was found to yield fairly consistent mass flux calculations with respect to the actual values, even at the highest slip ratios. (G_3 conforms to a two-velocity assumption, if the Rouhani-Estrada turbine model is used.) In horizontal flow and in downflow, G_3 usually underestimated the correct mass flux by some 10 to 30%, perhaps because of variations in the two-phase flow drag coefficients from the single-phase values. These variations cause more scatter in the results from G_3 than for G_1 and G_2. Therefore, the use of G_3 in low-quality flow is discouraged, particularly if void fraction measurements are available.

4. The use of flow dispersing screens in the locations indicated in Fig. 1 was found to produce no improvement in the mass flow rate calculations or drag flowmeter response, except when small, centrally located drag targets were used.

A flow chart for the selection of mass flow models when the available data are from a spool piece similar to the one tested here has been prepared (Fig. 18).

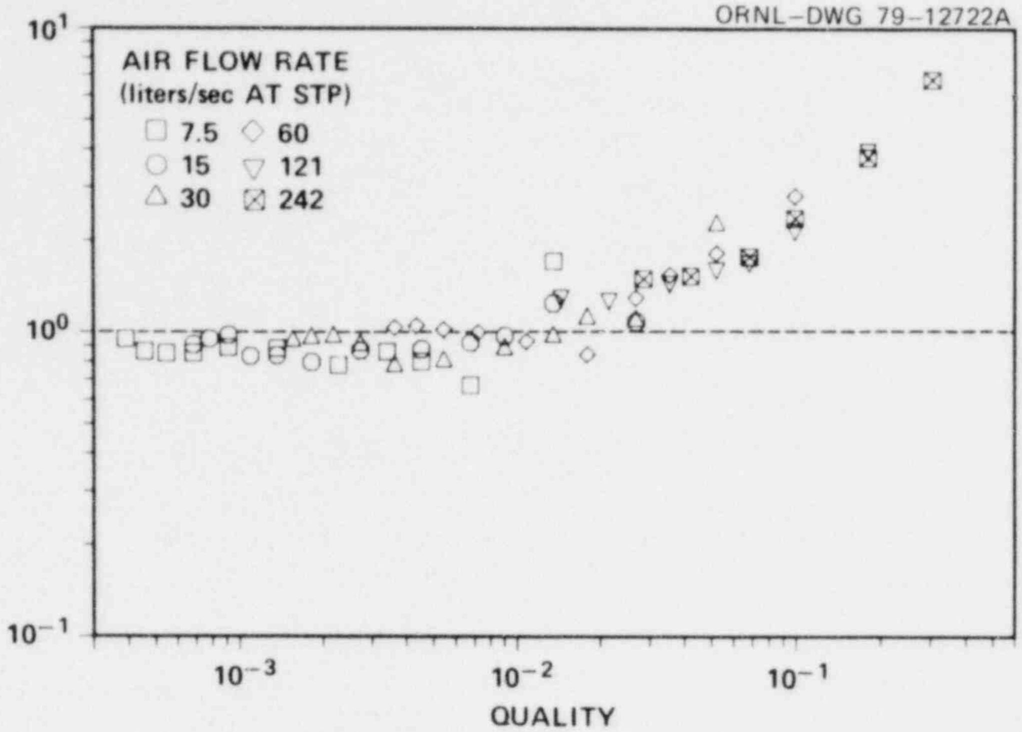

Fig. 15. Ratio of turbine speed to mean liquid phase velocity in horizontal two-phase flow.

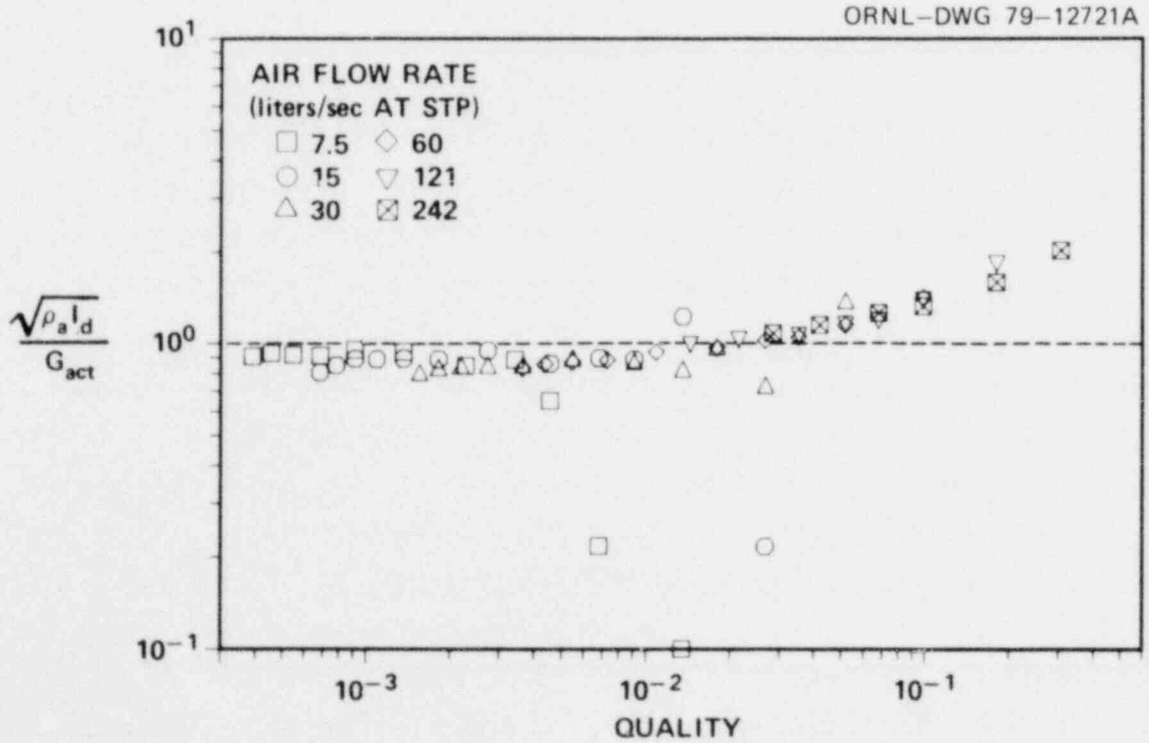

Fig. 16. Ratio of mass flux determined using densitometer and drag flowmeter to actual mass flux in horizontal two-phase flow.

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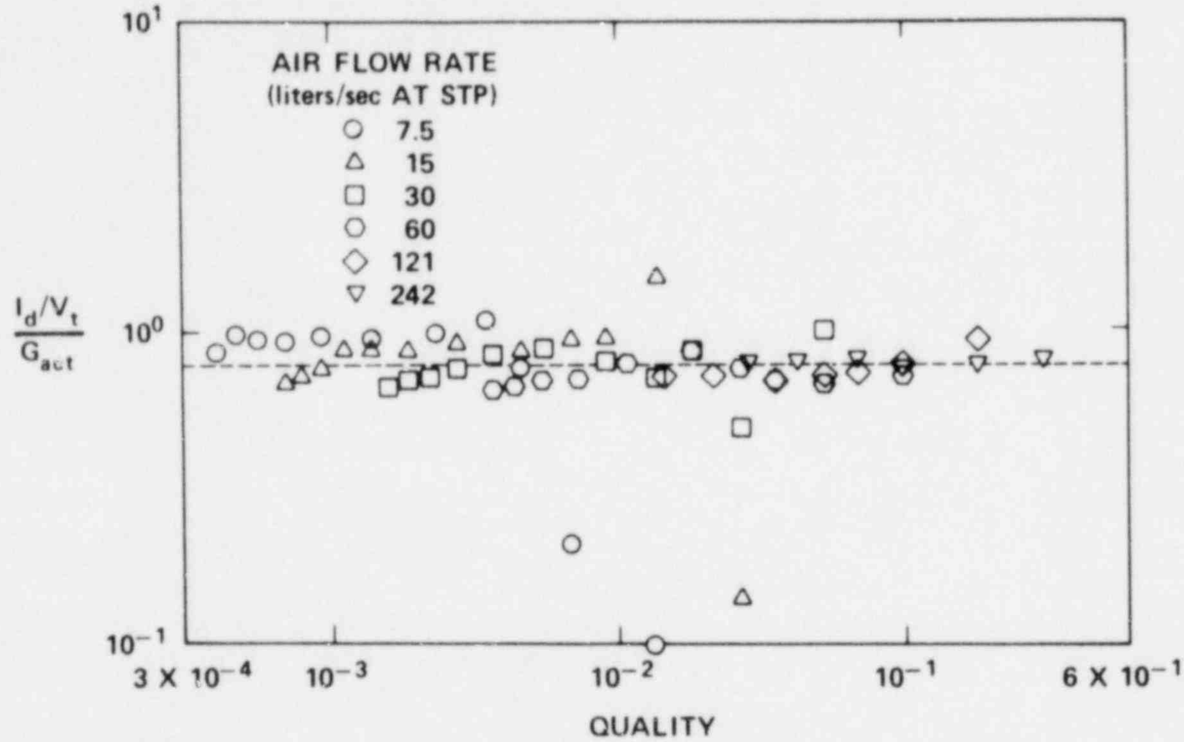

Fig. 17. Ratio of mass flux determined using turbine and drag flowmeter to actual mass flux in horizontal two-phase flow.

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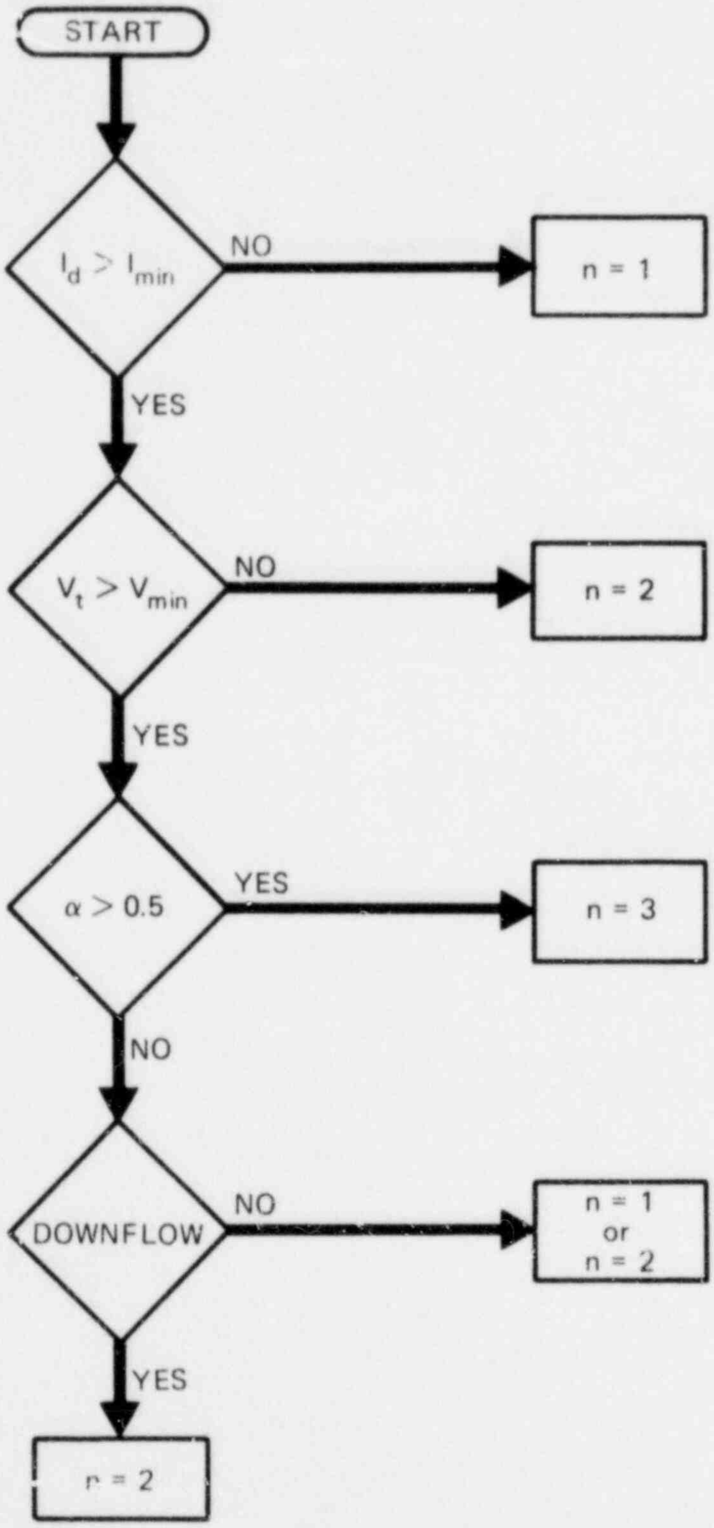

Fig. 18. Flow chart for selection of two-phase mass flow model. Subscript n denotes model number G_n as defined in text.

3. STEAM-WATER SPOOL PIECE TESTS

The Advanced Instruments for Reflood Studies (AIRS) Test Stand spool piece tests were conducted to examine how observations made in the air-water experiment regarding instrument response and mass flow rate determination translate to a steam-water flow system. In particular, the primary objective was to determine whether the mass flow rate in two-phase steam-water flow could be obtained with sufficient accuracy using only a drag flowmeter and a turbine flowmeter. If possible, then useful instrumented spool pieces could be constructed without using relatively expensive gamma attenuation densitometers.

This section describes the AIRS Test Stand and the methods of data acquisition and analysis used for the spool piece tests. Results from analysis of the data are discussed.

3.1 Experimental Equipment and Methods

The (AIRS) Steam-Water Test Stand (Fig. 19) is used for testing instrument systems in flow conditions similar to those in a postulated nuclear reactor reflood. Superheated steam at 830 kPa (120 psia) and 440 K (340°F) and water at ambient temperature and pressure are mixed and passed vertically upward through piping where flow instruments are located. Input flow rates of each phase to the system are measured using rotameters for water input and a Gilflo steam flowmeter for steam input. Visual observations of the mixed flow stream may be made both upstream and downstream of the test sections. An instrumented piping spool piece is located near the top of the facility; measurements made with the spool piece instrumentation are compared to analogous measurements obtained with impedance probes or other devices installed in the lower sections.

The instrumented spool piece used for the steam-water testing (Fig. 20) consisted of a 91-cm-long (3.0-ft), 8.9-cm-ID (3.5-in.) stainless steel pipe with fittings for a drag flowmeter and a turbine meter. A triple-beam gamma attenuation densitometer was installed on the spool piece at the location shown in Fig. 20.

The two-phase flow tests described here are summarized in Table 1. The tests were performed at a spool piece pressure of ≈725 kPa (≈105

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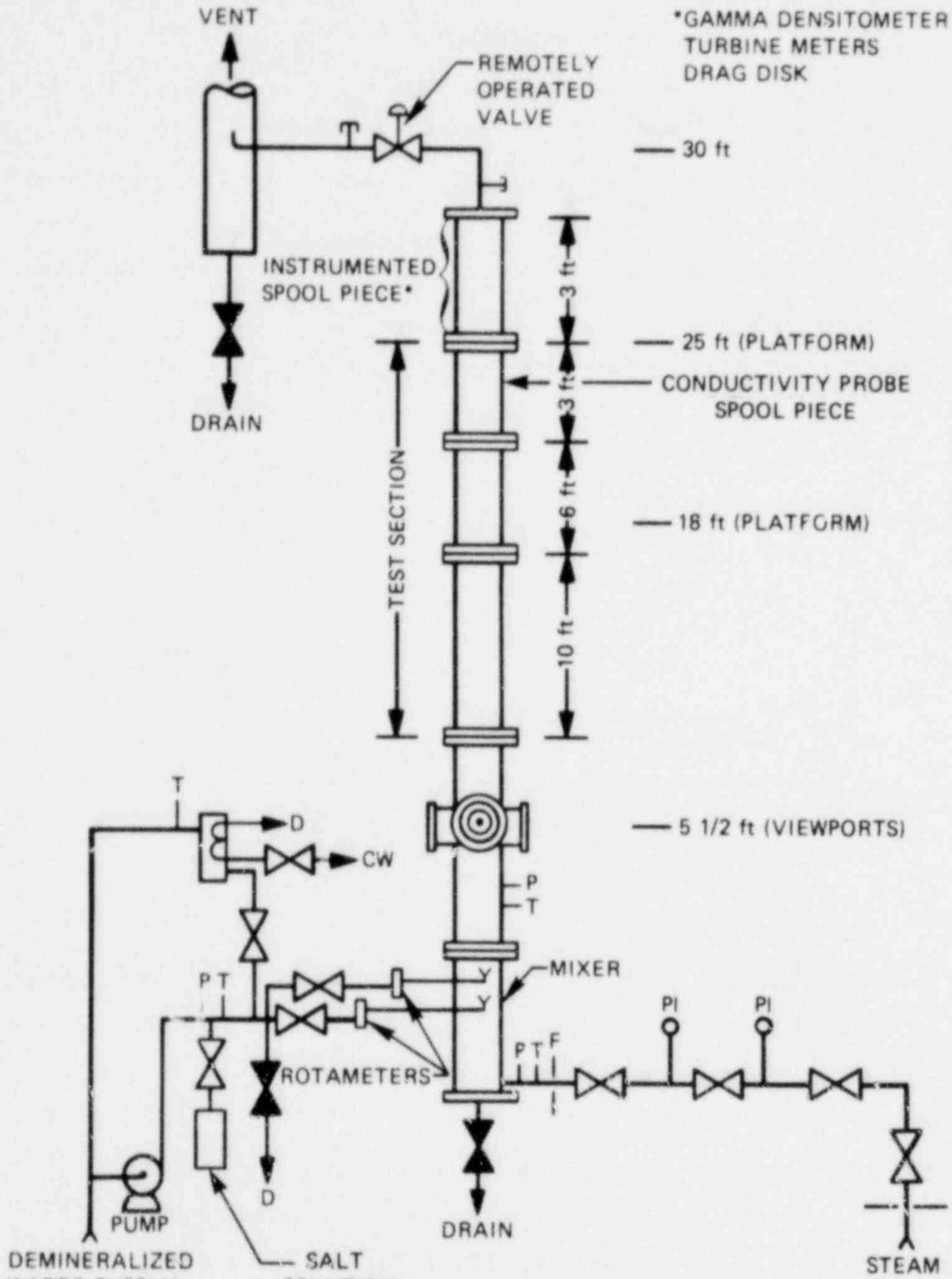

Fig. 19. AIRS steam-water test stand.

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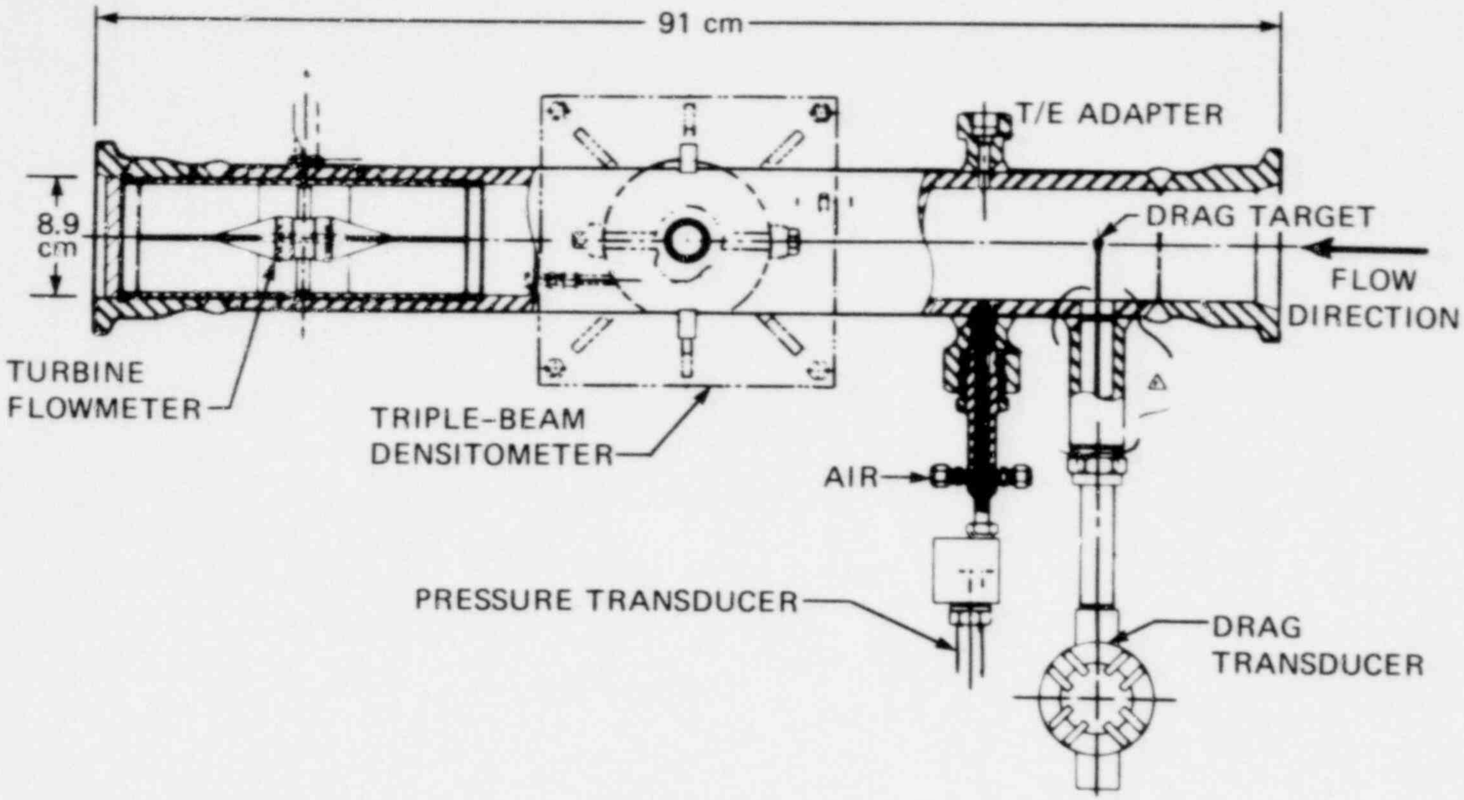

Fig. 20. Instrumented spool piece used in steady-state steam-water tests.

Table 1. Two-phase flow conditions for AIRS Test Stand steam-water tests

Superficial liquid velocity [m/s (ft/s)]	Superficial vapor velocity [m/s (ft/s)]	Quality (%)	Void fraction[a] (%)
0.25 (0.81)	0.23 (0.74)	0.4	59
0.25 (0.83)	2.1 (7.07)	3.4	73
0.25 (0.82)	5.0 (16)	7.7	81
0.25 (0.82)	10.0 (33)	15.0	93
0.25 (0.81)	19.0 (63)	24.0	95
0.17 (0.57)	0.39 (1.3)	0.9	63
0.17 (0.57)	2.3 (7.6)	5.3	76
0.17 (0.57)	5.5 (18)	12.0	84
0.17 (0.57)	13.0 (42)	24.0	95
0.12 (0.38)	15.0 (50)	36.0	96
0.11 (0.36)	6.5 (21)	19.0	90
0.12 (0.38)	2.4 (8)	8.1	75
0.12 (0.38)	0.88 (2.9)	3.1	60
0.073 (0.24)	1.7 (5.6)	9.0	70
0.073 (0.24	3.7 (12.0)	18.0	83
0.073 (0.24)	6.2 (20)	26.0	89
0.073 (0.24)	16.0 (52)	48.0	96

[a]Based on gamma densitometer data.

psia). An energy balance was applied to the input flow rates and enthalpy to obtain the mixture quality at the spool piece. For the flow rates used, the calculated test section quality was between 0.004 and 0.48, while the void fraction in the spool piece, derived by using the densitometer data, ranged from 0.59 to 0.96. The flow rates were chosen to allow examination of unsteady, slug flow regimes (low-steam flow rates) as well as annular mist flow regimes (high-steam flow rates).

3.2 Steam-Water Test Results

Analysis of the densitometer data showed that the pipe-average slip ratios for the steam-water flow points were high, ranging from ≈3 to ≈10. The turbine velocity was found to greatly exceed the mean liquid phase velocity; its velocity was fairly close to the mean steam velocity over most of the flow range. Consequently, the Aya and the Rouhani turbine models seriously underestimated the turbine velocities for these tests. The volumetric model, however, predicted the turbine velocity reasonably well, except at the lowest steam flow rates used. (The twelve-bladed turbine used in the steam-water tests was also found to greatly overestimate the liquid velocity in the air-water system, in contrast to the five-bladed turbine used previously.)

Comparisons of the data calculated using the mass flow models $G_1 = \rho_a V_t$, $G_2 = \sqrt{\rho_a I_d}$, and $G_3 = I_d/V_t$, to the actual two-phase mass flux in vertical upflow, have suggested the following:

1. At the flow rates and void fractions used in the steam-flow tests, G_1 grossly overestimates the mass flux (Fig. 21), largely due to turbine speeds well in excess of the mean liquid velocity.

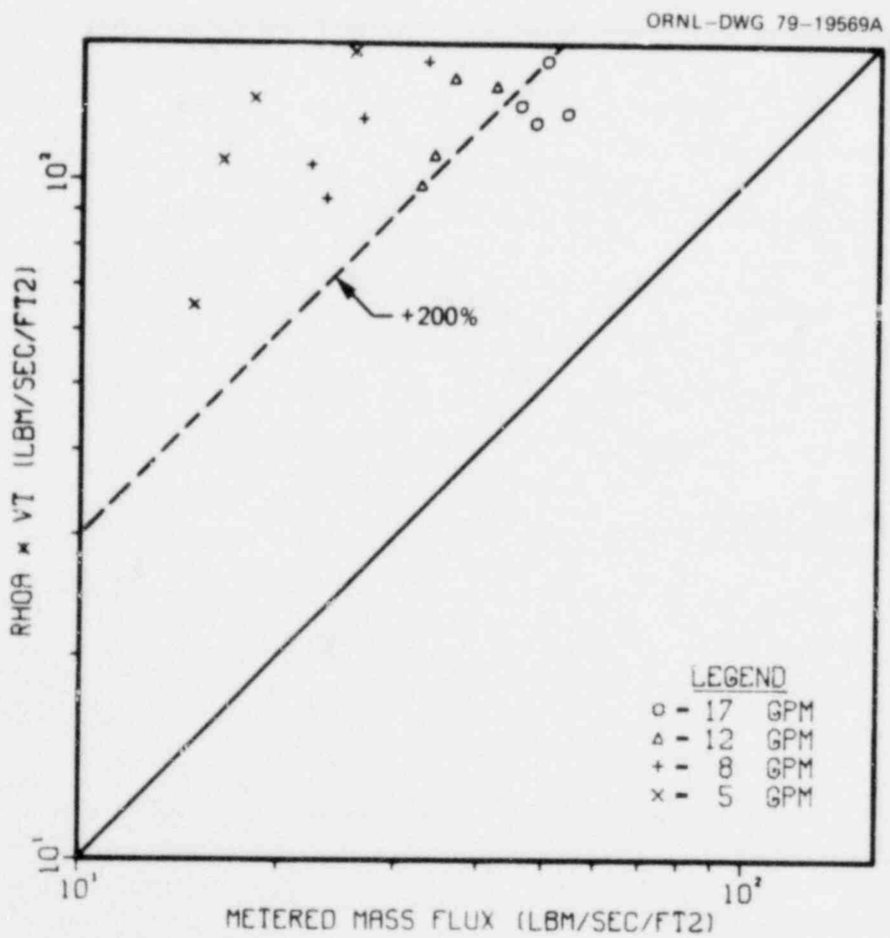

Fig. 21. Mass flux determined using densitometer and turbine meter vs metered mass flux, steam-water vertical upflow.

2. G_2 overestimates the mass flux at the high slip ratios characteristic of the steam-water tests (Fig. 22), although not as badly as G_1.
3. When the drag flowmeter output was high enough to be significant, G_3 was found to yield consistent results but fell somewhat below the true mass flux because of the turbine overspeed problem mentioned above (Fig. 23).

In summary, the steam-water spool piece tests, limited to vertical upflow at void fractions above 50%, tend to confirm indications regarding instrument performance observed in the air-water loop. That is, of the models tested, $G_3 = I_d/V_t$ is the most accurate mass flux model for use at high void fractions.

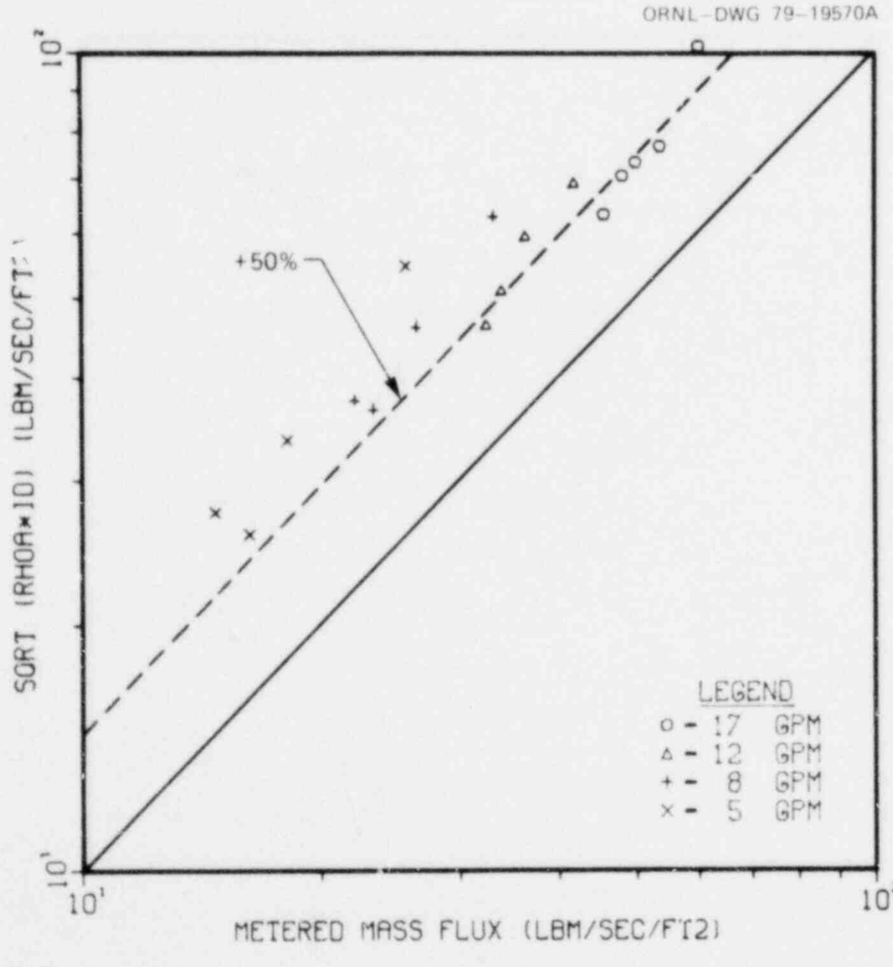

Fig. 22. Mass flux determined using densitometer and drag flowmeter vs metered mass flux, steam-water vertical upflow.

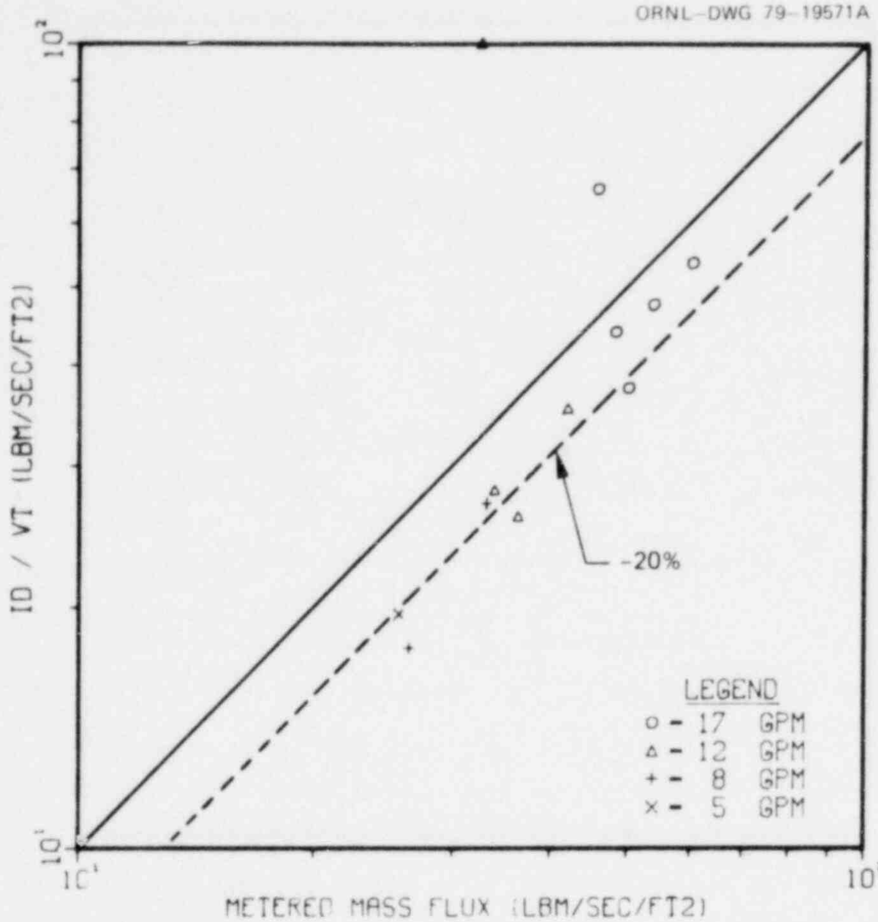

Fig. 23. Mass flux determined using turbine and drag flowmeter vs metered mass flux, steam-water vertical upflow.

Recommendations made with respect to further steam-water testing of instrumented spool pieces of the type described here are:

1. use of drag transducers ranged to more accurately measure fluid momemtum fluxes below ≈300 kg/m·s^2 (≈200 lb$_m$/ft·s^2);
2. use of a five-bladed turbine so that the Rouhani model is more appropriate, or, alternately, development of a two-phase mass flow rate model that incorporates the volumetric turbine model assumption for use with data from the twelve-bladed turbine;
3. extension of the testing to include higher water flow rates and lower void fractions, so that the transitions in instrument behavior to single-phase liquid flow could be studied.

4. SUMMARY

Experiments performed in air-water and steam-water two-phase flow with improved instrumented spool pieces have yielded significant results regarding spool piece design and two-phase flow modeling.

The advanced spool piece I (Fig. 1) was found to be well designed with one important exception: the location of the gamma densitometer downstream of an intrusive, full-flow drag target. The two-phase mass flow rates and pipe average densities calculated from the densitometer data were significantly affected by whether or not a full-flow drag target was installed upstream. If they are to be used, nonintrusive densitometers should be located upstream of all intrusive instruments. The use of flow-dispersing screens in the locations indicated in Fig. 1 was found to produce no improvement in the drag flowmeter response or the mass flow rate calculations, except when small, centrally located drag targets were used. The individual instrument systems used in the air-water tests were properly ranged and had adequate time response for that application. However, a considerable amount of data from the high-void-fraction, steam-water experiments was disregarded for model evaluation because of very low drag flowmeter readings. That fact emphasizes the importance of properly sizing the drag flowmeter for the expected momentum fluxes, even when full-flow targets are used.

Two-fluid models were used to aid in interpreting the drag flowmeter and turbine data. Mean drag flowmeter readings were compared with estimates of the two-phase momentum flux calculated from the metered air and water flow rates and from the turbine and densitometer data. These studies indicate that the two-phase drag coefficients in air-water are significantly less than the single-phase coefficients. When the slip ratios were betweeen 1 and 5, the Aya and the Rouhani turbine models were found to adequately predict the response of the five-bladed turbine in all flow orientations.

Results based on calculations of the mass flow rates from the air-water and steam-water spool piece testing may be summarized as follows (Fig. 18): the models $G_1 = \rho_a V_t$ and $G_2 = \sqrt{\rho_a I_d}$ are generally recommended for use with void fractions below 50% and when slip ratios are $\gtrsim 1$. (That result was not confirmed in steam-water, due to facility limitations.) When void fractions and slip ratios are relatively high, the model $G_3 = I_d/V_t$ is the most accurate of the three models examined. Significant errors are likely if either turbine or drag flowmeter data are used when the flow rates are below the instruments' normal operating ranges.

REFERENCES

1. *Project Description ORNL-PWR Blowdown Heat Transfer Separate-Effects Program — Thermal-Hydraulic Test Facility*, NUREG/CR-0104 (ORNL/NUREG/TM-218) (1978).

2. E. M. Feldman and D. J. Olson, *Semiscale MOD-1 Program and System Description for the Blowdown Heat Transfer Tests (Test Series 2)*, Idaho National Engineering Laboratory Report No. ANCR-1230 (August 1975).

3. J. D. Sheppard, P. H. Hayes, and M. C. Wynn, "An Experimental Study of Flow Monitoring Instruments in Air-Water Two-Phase Downflow," presented at OECD/NEA Symposium on Transient Two-Phase Flow, Toronto, Canada, August 1976.

4. K. G. Turnage et al., *Advanced Two-Phase Flow Instrumentation Program Quarterly Progress Report for April–June 1978*, ORNL/NUREG/TM-279 (January 1979).

5. K. G. Turnage et al., *Advanced Two-Phase Flow Instrumentation Program Quarterly Progress Report for July–September 1978*, ORNL/NUREG/TM-309 (May 1979).

6. K. G. Turnage et al., *Advanced Two-Phase Flow Instrumentation Program Quarterly Progress Report for October–December 1978*, ORNL/NUREG/TM-313 (May 1979).

7. K. G. Turnage et al., *Advanced Two-Phase Flow Instrumentation Program Quarterly Progress Report for January–March 1979*, ORNL/NUREG/TM-331 (in press).

8. J. D. Mandhane et al., "A Flow Pattern Map for Gas-Liquid Flow in Horizontal Pipes," *Int. J. Multiphase Flow* 1, 537–53 (1974).

9. T. Oshinowo and M. E. Charles, "Vertical Two-Phase Flow, Part I. Flow Pattern Correlations," *Can. J. Chem. Eng.* 53, 25 (1974).

10. Izuo Aya, *A Model to Calculcte Mass Flow Rate and Other Quantities of Two-Phase Flow in a Pipe with a Densitometer, a Drag Disk, and a Turbine Meter*, ORNL/TM-4759 (November 1975).

11. S. Z. Rouhani, "Application of the Turbine Type Flowmeters in the Measurements of Steam Quality and Void," *Symposium of In-Core Instrumentation, Oslo, Norway, June 1974*.

12. S. Silverman, *Principles of Operation and Data Reduction Techniques for the LOFT Drag Disk Turbine Transducer*, TREE-NUREG-1109, p. 33 (1977).

13. S. F. Hoerner, *Fluid Dynamic Drag*, 2nd ed., Hoerner Fluid Dynamics, Brick Town, N.J., 1965.

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