CONF-790340--1

MASTER

DEVELOPMENT OF IN-VESSEL REFLOOD INSTRUMENTATION AT ORNL*

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Presented at the

MEETING OF THE JAPANESE NUCLEAR SOCIETY

OSAKA, JAPAN

March 26-28, 1979

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*Research sponsored by Water Reactor Safety Research, U.S. Nuclear Regulatory Commission under Interagency Agrrement DOE 40-551-75 and 40-552-75 with the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

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3.0 DEVELOPMENT OF IN-VESSEL REFLOOD INSTRUMENTATION AT ORNL

3.1 INTRODUCTION

A program under the sponsorship of the United States Nuclear Regulatory Commission was intiated at the Oak Ridge National Laboratory (ORNL) in late 1977. The program, Advanced Instrumentation for Reflood Studies (AIRS), is charged with developing instrumentation for measurement of in-vessel fluid phenomena in pressurized water reactor reflood facilities. The goal of the ORNL program is to develop techniques and systems for measuring fluid flow in-core, deentrainment in the upper plenum and liquid fallback from the upper plenum into the core. To obtain this goal, liquid film thickness and velocity, along with two-phase flow velocity and void fraction, must be measured. Liquid film thickness and film velocity measurement systems are being implemented utilizing concepts developed at Lehigh University.[1,2] A large portion of the development at ORNL is devoted to the impedance probes for measurement of two-phase flow velocities and void fractions. Film probe development at ORNL is limited to adapting the present techniques to the environment of a reflood facility. As the development progresses on all the measurement techniques, ORNL will fabricate and supply instrument systems to the reflood facilities included in the 2D/3D Program.

At this time some instrument systems, which could be regarded as the first generation, are being fabricated. The term first generation implies that these systems are probably not optimum at this time; therefore, a significant development effort is continuing to provide improvements.

3.2 OPERATING PRINCIPLES

The principles of operation of the impedance instrumentation being developed at ORNL are described in Figures 1 through 7. The primary technique being employed is based on the measurement of electrical impedance. The electrical conductivity and permittivity of steam are quite different; thus, as the two-phase flow regime at the point of measurement changes, so does the impedance between the probe electrodes, Figure 1. As noted the measured impedance is a function of geometry. With the proper electrode geometry, a sensor can be made sensitive to liquid film flow and thus provide a measure of film thickness. A different electrode geometry is possible which is sensitive to two-phase flow in a channel. Temperature also affects the measured impedance as water conductivity and permittivity are both functions of temperature.

The technique of analysis of random signals, illustrated in Figures 2 and 3, from two spatially separated impedance sensors is employed to measure two-phase flow velocity. Velocity of a liquid film is sensed by measuring the electrolysis current flowing between two long narrow electrodes located in the film and parallel to the direction of flow. This sensor is referred to as an electrolysis potential probe.[2]

In Figure 4 the relationship between impedance, void fraction and flow regime is illustrated. It is possible to have more than one flow regime at a single void fraction, due to other fluid parameters such as temperature, pressure and quality. Therefore the probe impedance alone in two-phase flow is not enough to determine void fraction. This fact is evidenced in Figure 5 for a flag type sensor, one of the sensor configurations being developed. As illustrated in Figure 6, one possible technique for determining void fraction is analysis of histograms of impedance probe signals. Necessary considerations for transient velocity and void fraction measurements are listed in Figure 7.

3.3 GEOMETRY AND FABRICATION METHODS

The range of the measurement parameters and the environmental conditions in a typical reflood test facility are given in Figure 8. The environmental conditions listed are the maximum expected in the core. The temperature in the upper plenum is lower with a maximum of approximately 350°C.

To meet the measurement criteria and environmental conditions, a variety of admittance or impedance sensor configurations are under development at ORNL[3], Figure 9. Sensors in a guide tube configuration are being developed for in-core subchannel measurement of void fraction and velocity. The string probe configuration can be applied in the upper plenum, the downcomer and other locations of larger cross sectional area. The flag, prong and band-to-ground probes, at present, appear to be best suited for in-core measurements and the band-to-band for the upper plenum. Figure 10 is a pictorial view of an in-core guide tube impedance measurement assembly of the flag type probe. A typical film thickness and film velocity probe module is shown in Figure 11. Film sensor assemblies will be used for film measurements on upper plenum structures and on core and other vessel walls.

A major development effort has been underway to produce insulators for the AIRS sensors. Figure 12 lists the numerous problem areas encountered in fabricating an insulator-seal suitable for in-vessel sensor assemblies. These insulators must tolerate very rigorous conditions: high temperatures, erosion due to steam and hot water and severe thermal shocks. Potential insulators were tested under reflood-like conditions, Figure 13, and it was found that commercially available ceramics are unsatisfactory for insulators for the reflood environment, Figure 14. A metallized ceramic or cermet (see Figure 15) developed at ORNL has proven to be very suitable for the reflood environment.

Once a suitable insulator was identified it was then necessary to develop techniques for joining complex geometries of dissimilar materials of the various sensors. Successful ceramic-to-metal seals have been made possible through the use of the so-called "graded seal." This method involves direct brazing of the cermet to a metal with a low coefficient of thermal expansion. This metal is then brazed to a metal with an intermediate coefficient which is in turn pulsed laser welded to the stainless steel of the basic structure. Successful brazes with high thermal shock and corrosion resistance are obtained using an experimental brazing alloy developed at ORNL.[4] The capabilities of the joining techniques are indicated in Figure 16 and some typical subassemblies which involve the materials and techniques developed to date are pictured in Figure 17. As indicated in Figure 18, a typical instrumented guide tube was tested for survivability under thermal cycles simulating reflood. The test showed that the probe-insulator assembly maintained mechanical integrity and the sensor remained operable throughout the test period.

3.4 SIGNAL CONDITIONING ELECTRONICS

Three major problems in designing the electronic circuitry to measure the probe impedance in a reflood facility are tabulated in Figure 19. Experimenters would like to detect the passage of small droplets past the probe as well as detect the presence of solid water. The capacitance changes due to small droplets are extremely small ($< 10^{-15}$ farads). The capacitance of the cables which connect the probes to the electronic circuitry may be as large as 10^{-8} farads. Thus, these small changes in probe capacitance may be approximately 0.00001% of the cable capacitance.

Even after solving the cable capacitance problem there is still the problem that the dynamic range of the impedance probe measurement can be more than 30,000 to 1. Another problem is the interference caused by the electrical power supply which energizes the bundle fuel pin simulators. The total power supplied to the bundle may be from hundreds of kilowatts to several megawatts. The power used to measure a probe impedance is typically less than a milliwatt. Great care must be taken to avoid corruption of the impedance measurement by the electromagnetic interference from the bundle power supply.

The present electronic design overcomes the aforementioned problems to the extent indicated in Figure 20, and it is expected that further improvements can be obtained. Figure 21 is a simplified schematic of the circuitry for measuring probe impedance.

3.5 TESTING AND RESULTS

As promising sensor configurations are identified they are tested in a two-phase, air-water test facility. Capabilities and instrumentation of the air-water test loop are shown in Figure 22. Some typical vertical upflow, air-water velocity results are shown in Figures 23 and 24 for in-core sensors. Typical void fraction results for these same air-water tests are given in Figures 25-27. A pictorial drawing and schematic circuit for an upper plenum string sensor are shown in Figure 28. Figures 29-31 show air-water test results of the string probe for steady-state velocity, transient velocity, and void fraction comparisons, respectively.

A photograph of the AIRS steam-water test stand is shown in Figure 32. This stand was designed for flow testing of reflood instrumentation in steady-state, high void fractions (> 0.50). Figure 33 is the bundle cross-section used in testing instrumented guide tubes. The locations of instrumented guide tubes are noted. Very encouraging results were obtained from the steam-water testing of flag and prong type instrumented guide tubes. The results suggest that at high void fractions the probes may give an accurate measure of the liquid velocity, Figure 34.

The measured velocity from the impedance sensor must be interpreted in relation to the separate phase velocities, steam and water. To this end, two experiments have been devised. One, the drywall droplet experiment, tests impedance probes in an ambient temperature droplet flow. The second experiment will calibrate probes in a "well-defined" annular flow. Figure 35 lists the purposes of the drywall droplet experiment and Figures 36 and 37 show the overall experimental setup and a typical droplet stream traversing a flag type probe, respectively. Preliminary test data are tabulated in Figure 38. The results of the tests, Figure 39, were that measured velocities agreed well with independent estimated droplet velocities for both flag and prong probes and that probe signals were well correlated even at very high void fractions. The goals and purposes of the annular flow experiments are indicated in Figure 40. Figure 41 is a schematic of the annular flow-impedance probe calibration system.

As illustrated in Figure 42, production film probe modules can be calibrated in steam-water flows. The calibration chamber can also be used to verify the performance in steam-water, determine calibration constants and to demonstrate the survivability of the film probes in a steam-water environment.

For the most part, the present measurement system capabilities, Figure 43, meet the expected in-vessel fluid flow criteria listed in Figure 8.

3.6 SUMMARY

In summary, Figure 44, techniques and equipment have been developed to measure void fraction and velocity in subchannels and the upper plenum and film thickness and film velocity on vessel internals. Many problems have been overcome. Among these are:

1. Development of materials and techniques for joining dissimilar materials to withstand the severe thermal environment of a reflood test.
2. Development of electronic techniques for measuring extremely small capacitance changes with a wide dynamic range, at the end of long, high-capacitance cables, in the presence of strong electromagnetic interference.
3. Development of signal analysis techniques to measure transit time and then calculate fluid velocity.

Probes, electronics and signal analysis techniques have been tested in air-water and steam-water facilities with generally good results. Also the measurement system has been proven to be sensitive to single droplets.

First generation instrument sensors have been fabricated and a signficant development effort is continuing for optimization and to provide improved understanding of the measurement.

Although not yet tested in an actual reflood test facility, it is believed that the techniques described will provide the first successful in-vessel, localized measurements of two-phase velocity, void fraction and film flow parameters.

REFERENCES

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2. John C. Chen, et al., "Investigation of Post-CHF Heat Transfer for Water-Cooled Reactor Application and Development of Two-Phase Flow Instrumentation, Progress Report January 1, 1978 to March 31, 1978," LU-NUREG-PR781.
3. B. G. Eads, et al., "Advanced Instrumentation for Reflood Studies Program Quarterly Progress Report October 1-December 31, 1977," ORNL-NUREG/TM-202.
4. C. W. Fox and G. M. Slaughter, "Brazing of Ceramics," Welding Journal, July 1964, pp. 591-597.

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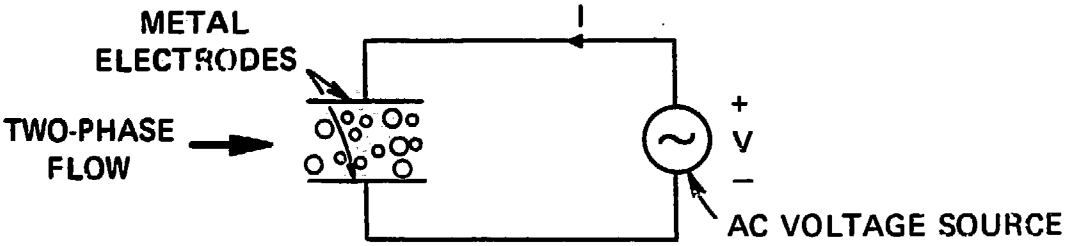
ORNL–DWG 79-9581

TWO-PHASE FLOW IS SENSED BY MEASURING IMPEDANCE



$$\text{IMPEDANCE, } Z = \frac{V}{I}$$

$$Z = R + \frac{1}{jwC}$$

R = f(CONDUCTIVITY, GEOMETRY)

C = f(PERMITTIVITY, GEOMETRY)

Fig. 1

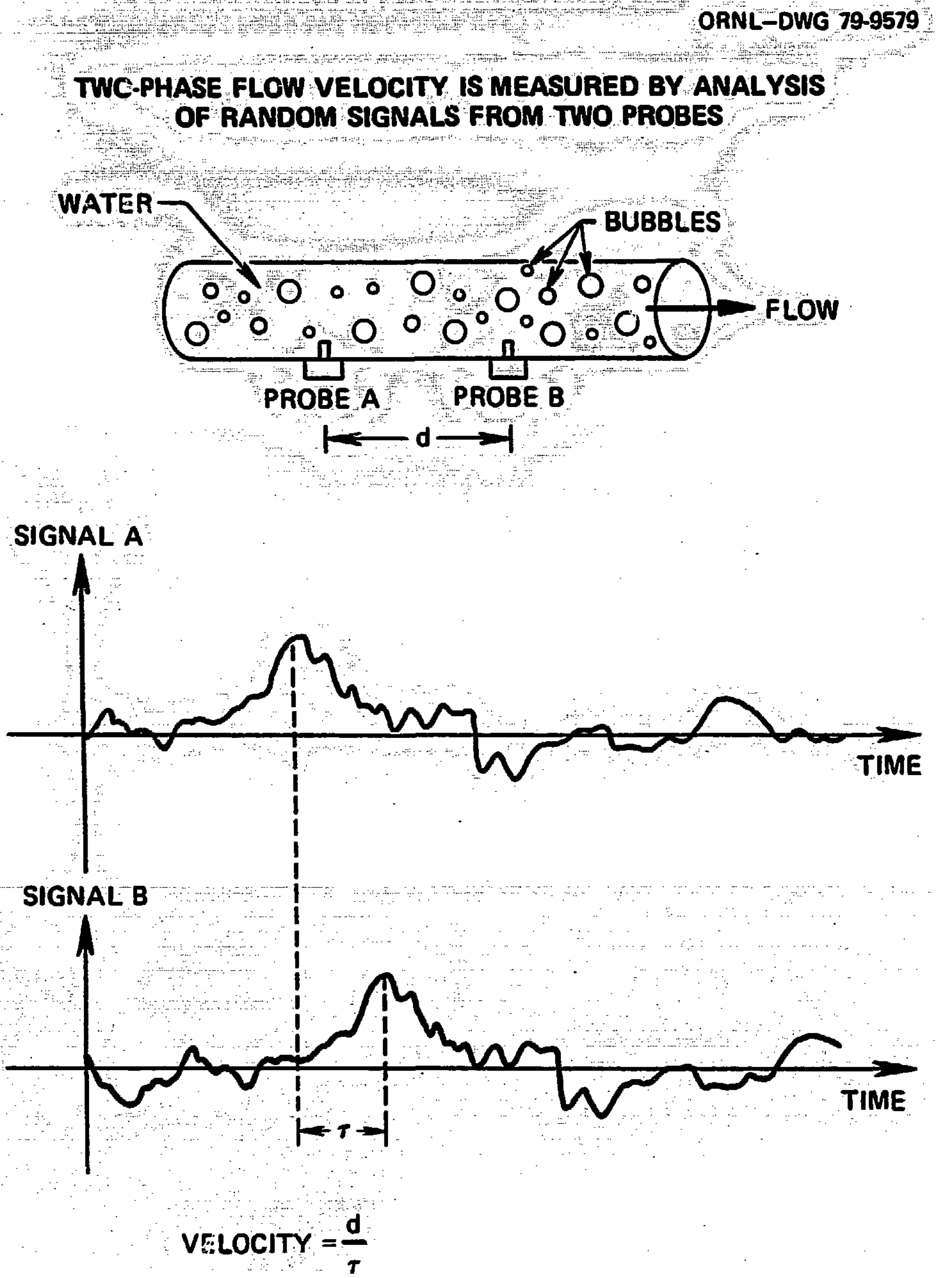
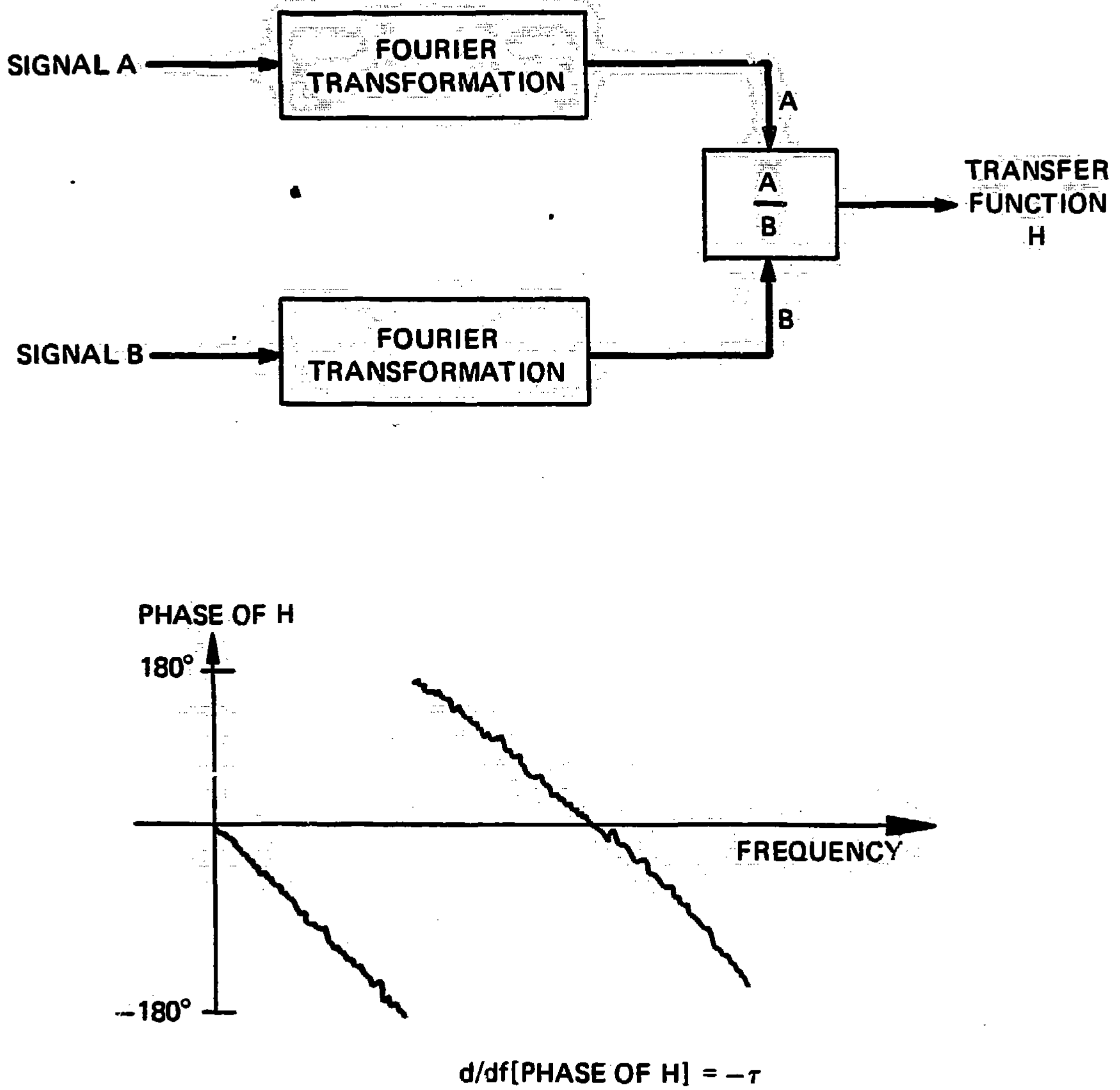

ORNL–DWG 79-9579
TWO-PHASE FLOW VELOCITY IS MEASURED BY ANALYSIS OF RANDOM SIGNALS FROM TWO PROBES
WATER
BUBBLES
FLOW
PROBE A
PROBE B
d
SIGNAL A
TIME
SIGNAL B
TIME
τ
VELOCITY = d/τ

Fig. 2



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TIME DELAY BETWEEN SIGNALS IS CALCULATED FROM THE TRANSFER FUNCTION FROM SIGNAL A TO SIGNAL B

Fig. 3

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THE RELATIONSHIP BETWEEN IMPEDANCE AND VOID FRACTION DEPENDS ON THE "FLOW REGIME"

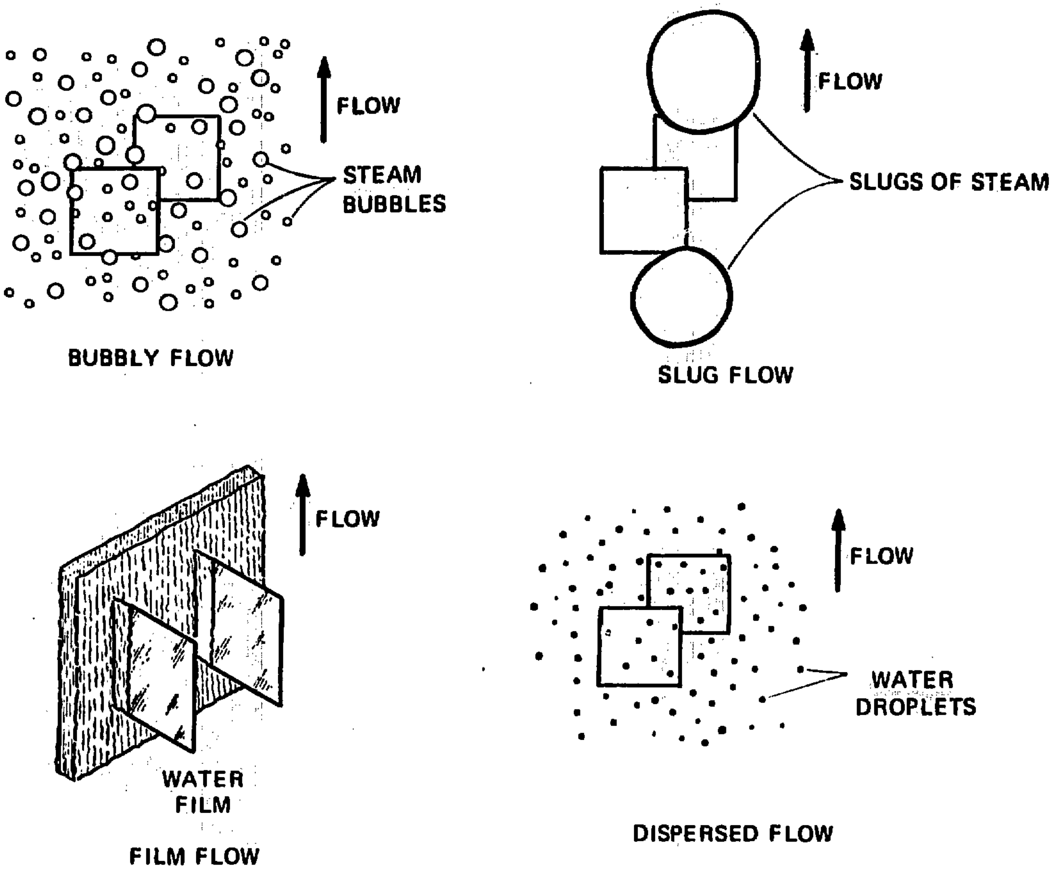
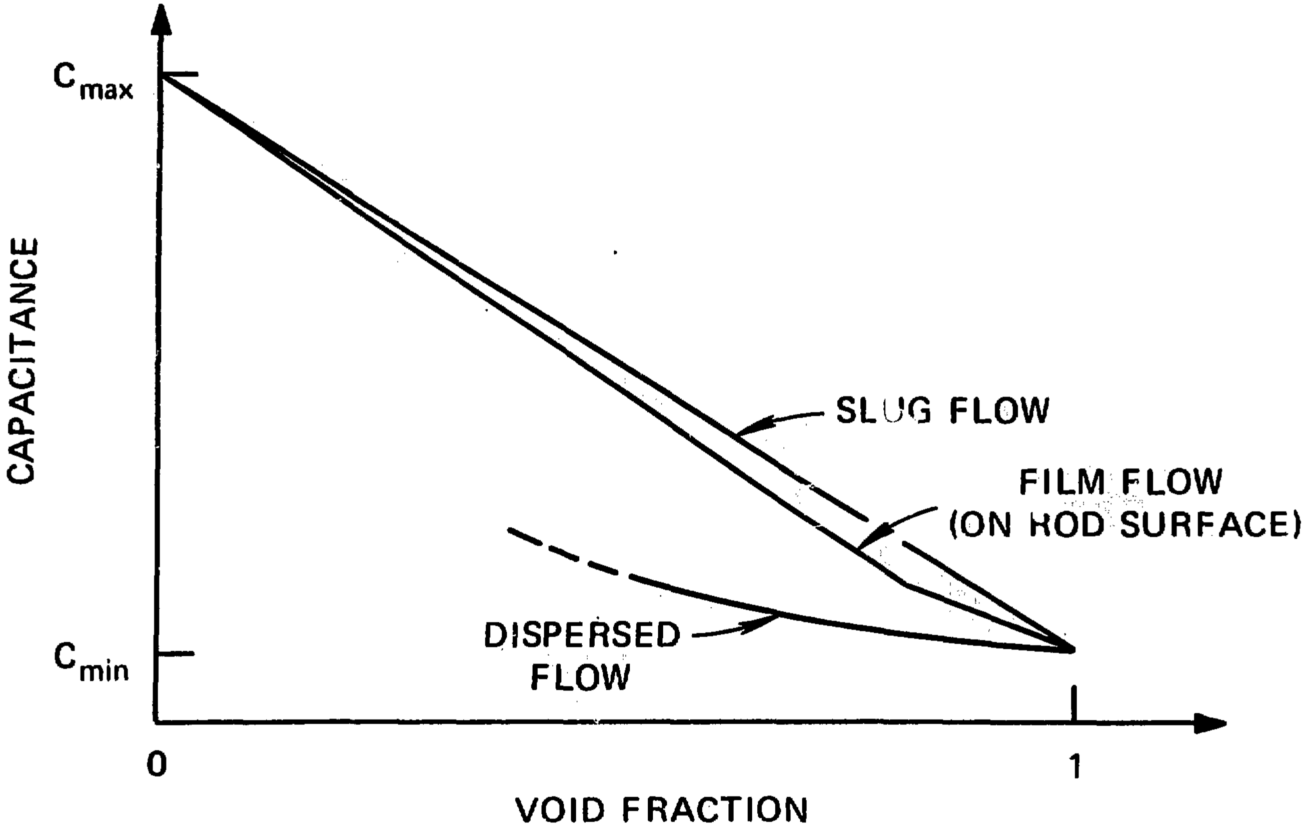


Fig. 4



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FOR THE AIRS "FLAG" PROBE THE CAPACITANCE VARIATION WITH VOID FRACTION IS SIGNIFICANTLY DIFFERENT FOR DIFFERENT FLOW REGIMES

Fig. 5

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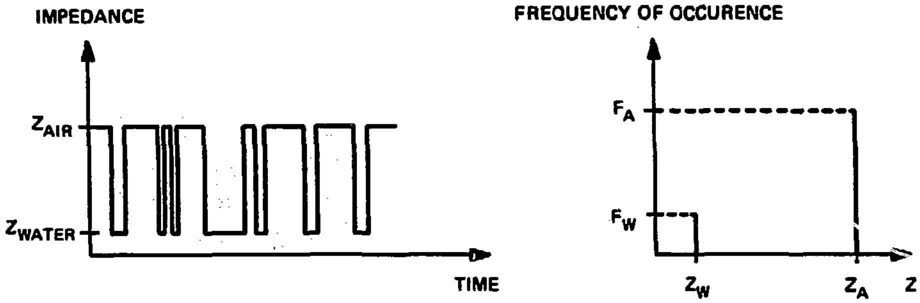
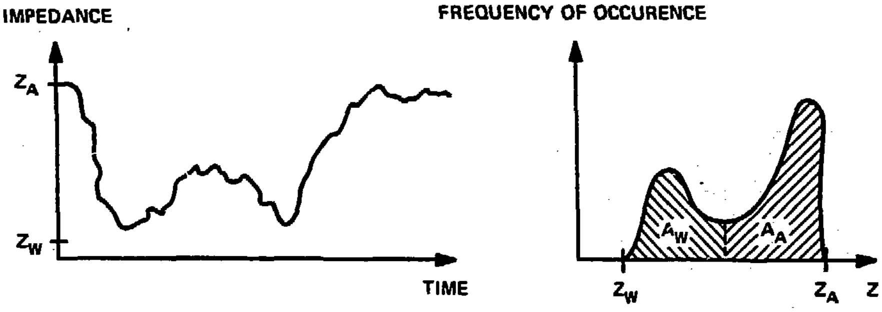
A HISTOGRAM OF SIGNAL VALUES GIVES AN INDICATION OF VOID FRACTION

FOR A VERY SMALL (POINT) PROBE:



VOID FRACTION = $F_A/F_A + F_W$

FOR A LARGER PROBE:



VOID FRACTION ≅ $A_A/A_W + A_A$

Fig. 6

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NECESSARY CONSIDERATIONS FOR TRANSIENT VELOCITY AND VOID FRACTION MEASUREMENTS

VELOCITY MEASUREMENT

- BETWEEN DATA POINTS THE VELOCITY IS ASSUMED TO BE AT STEADY STATE
- TIME BETWEEN VELOCITY DATA POINTS MUST BE:
  - SHORT ENOUGH THAT THE ASSUMPTION OF STEADY STATE APPLIES
  - LONG ENOUGH TO REDUCE STATISTICAL ERROR

VOID FRACTION MEASUREMENT

- IMPEDANCE ALONE IS NOT SUFFICIENT
- HISTOGRAMS OR PATTERN RECOGNITION TECHNIQUES SHOW PROMISE FOR DETERMINING FLOW REGIME EFFECT
- COMPENSATE FOR WATER PROPERTIES VARIATIONS WITH TEMPERATURE

Fig. 7

ORNL WS-1671

REFLOOD FACILITY IN-VESSEL MEASUREMENTS INVOLVE WIDE RANGEABILITY AND HOSTILE ENVIRONMENT

LIQUID FILM

- THICKNESS: 0 TO 4 mm
- VELOCITY: 0 TO 1.8 meters/sec

TWO-PHASE FLOW

- VOID FRACTION: 0 TO 1
- VELOCITY: 0 TO 15 meters/sec

ENVIRONMENT

- 950°C
- 300°C/sec THERMAL SHOCK
- HIGH ELECTRIC AND MAGNETIC FIELDS

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Fig. 8

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A VARIETY OF ADMITTANCE SENSOR CONFIGURATIONS ARE UNDER DEVELOPMENT FOR TRANSIT TIME AND VOID FRACTION MEASUREMENTS

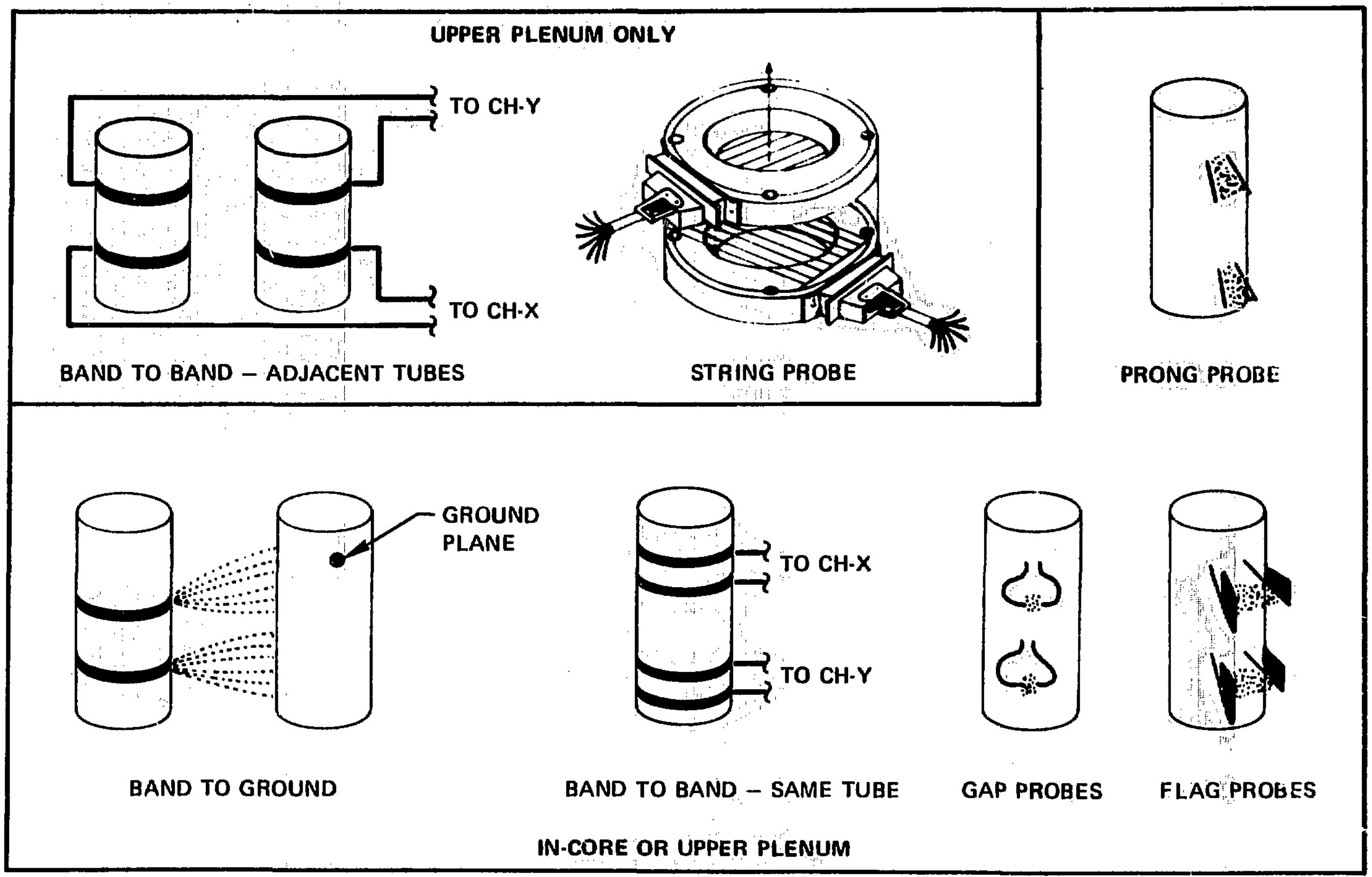

Fig. 9

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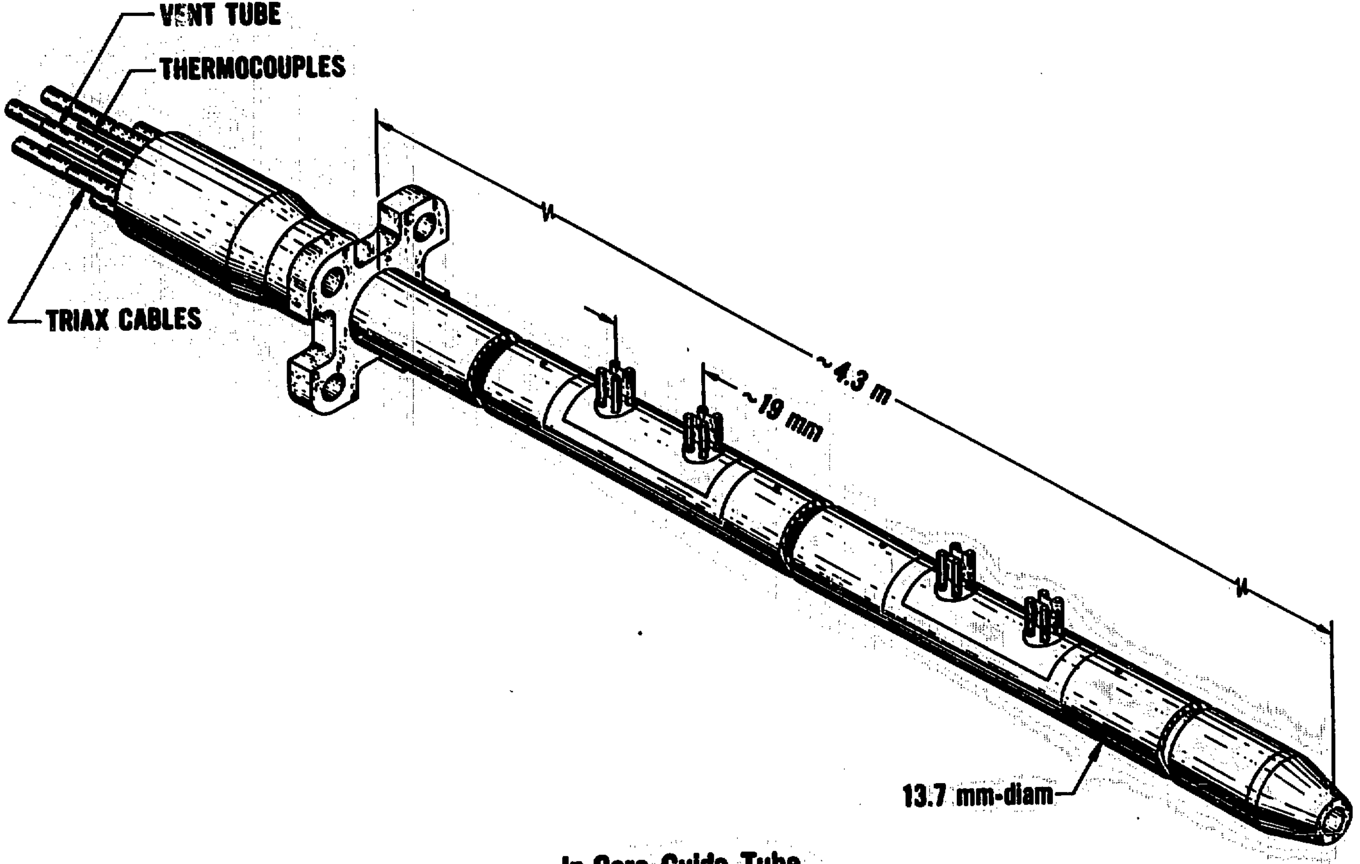
ORNL-DWG 79-19763



In-Core Guide Tube
Impedance Measurement Assembly
Flag Probe Type

Fig. 10

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PKL FILM PROBE MODULE

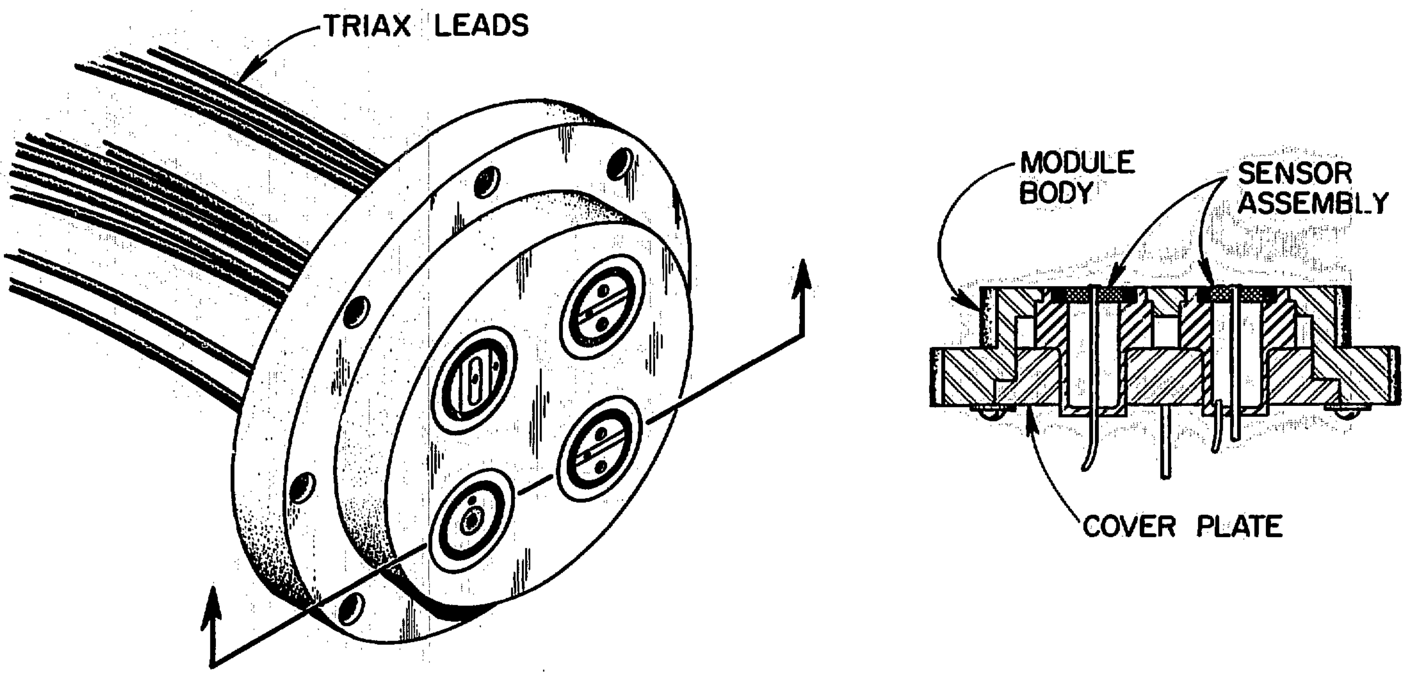
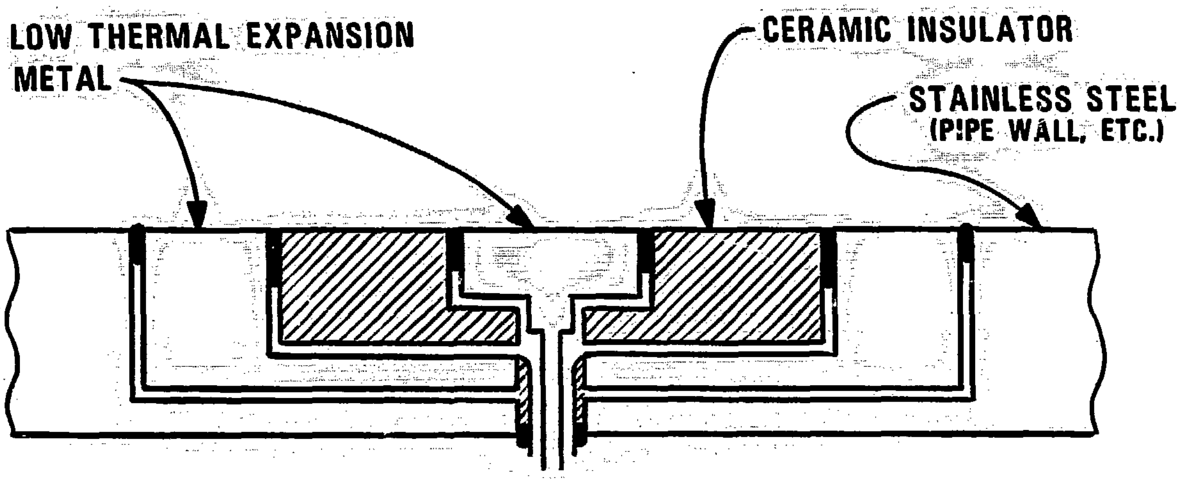


Fig. 11

PROBLEM AREAS IN FABRICATING CERAMIC-METAL SEALS



- **MATERIAL COMPATIBILITY WITH ENVIRONMENT**
  - CORROSION
  - LEACHING
- **ELECTRICAL PROPERTIES OF INSULATOR**
- **THERMAL SHOCK RESISTANCE**
  - LOW COEFF. THERMAL EXPANSION } POOR BRAZING
  - HIGH POROSITY } CHARACTERISTICS
- **THERMAL EXPANSION MISMATCH**
- **BRAZING & WELDING**
  - MACHINABLE TO CLOSE TOLERANCE (<.001")
  - SURFACE CONDITION-"WETTABILITY"
- **LEAKPROOF SEAL**

Fig. 12

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POTENTIAL INSULATOR MATERIALS WERE TESTED UNDER REFLOOD-LIKE CONDITIONS

1. THERMAL SHOCK TESTS — UP TO 55 QUENCHES

   520°C ⟶ HOT WATER (<100°C)

   (a) EXAMINED FOR CRACKS AT 30X

   (b) HELIUM LEAK TESTS

   NOTE: QUENCHING FROM 350° OR 800°C YIELDED SIMILAR RESULTS.

2. STEAM EROSION TESTS

   680°C, 100 h

3. HOT WATER TESTS

   180°C, 200 h

Fig. 13

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COMMERCIALLY AVAILABLE CERAMICS PROVED UNSATISFACTORY FOR INSULATORS IN CERAMIC-TO-METAL SEALS

- AVAILABLE <u>HIGH STRENGTH</u> CERAMICS ARE NOT SUITABLE FOR AIRS INSULATORS DUE TO POOR THERMAL SHOCK RESISTANCE
- AVAILABLE <u>LOW THERMAL EXPANSION</u> CERAMICS PROVED UNSATISFACTORY DUE TO CRACKING IN THERMAL SHOCK TESTS

Fig. 14

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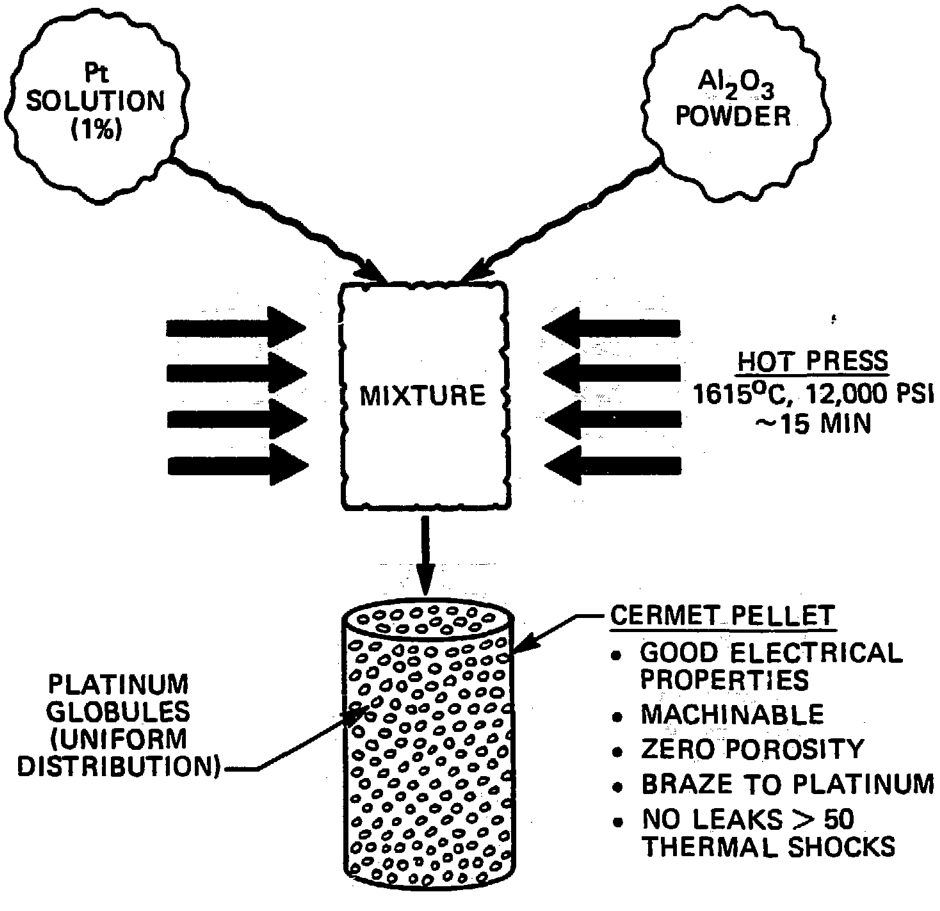
UNION CARBIDE ORNL

CERMET DEVELOPED BY ORNL AND DEMONSTRATED TO SURVIVE REFLOOD ENVIRONMENT (950°C, HIGH THERMAL SHOCK)



Pt SOLUTION (1%)

Al_2O_3 POWDER

MIXTURE

HOT PRESS
1615°C, 12,000 PSI
~15 MIN

PLATINUM GLOBULES (UNIFORM DISTRIBUTION)

CERMET PELLET

- GOOD ELECTRICAL PROPERTIES
- MACHINABLE
- ZERO POROSITY
- BRAZE TO PLATINUM
- NO LEAKS > 50 THERMAL SHOCKS

Fig. 15

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JOINING TECHNIQUES DEVELOPED AT ORNL HAVE BEEN USED TO FABRICATE COMPLEX REFLOOD INSTRUMENT ASSEMBLIES

- "GRADED SEAL" APPROACH ENABLES JOINING LOW COEFFICIENT OF EXPANSION CERMET TO HIGH COEFFICIENT STAINLESS STEEL

- EXPERIMENTAL ALLOY ALLOWS DIRECT BRAZING OF CERAMIC INSULATORS TO METALLIC COMPOUNDS

- PROCEDURES BASED ON OTHER JOINING PROCESSES INCLUDING INDUCTION AND FURNACE BRAZING AND PULSED LASER WELDING HAVE ALSO BEEN DEVELOPED

- CURRENT CAPABILITY:
    - MAXIMUM SERVICE TEMPERATURE 750°C
    - EXCELLENT CORROSION RESISTANCE
    - PROVEN THERMAL SHOCK RESISTANT

Fig. 16

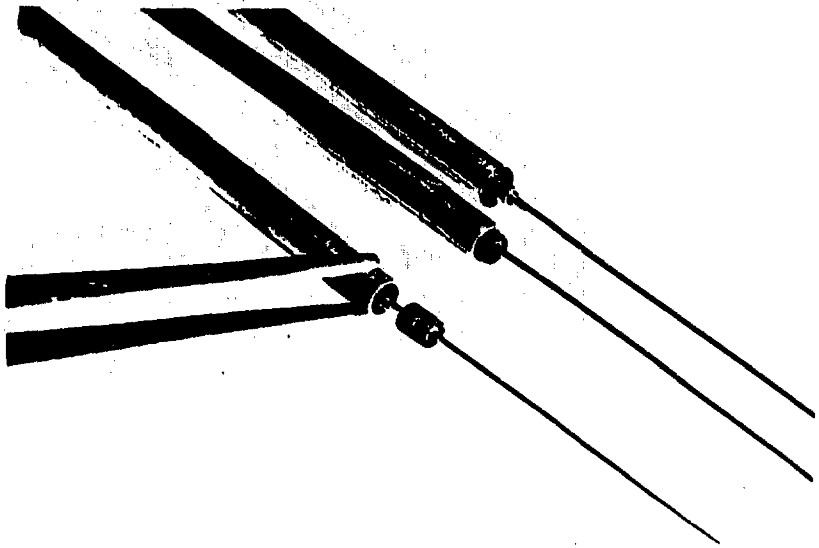

Fig. 17a. Ceramic-metal end seal for 3 mm (1/8-inch) OD triaxial cable

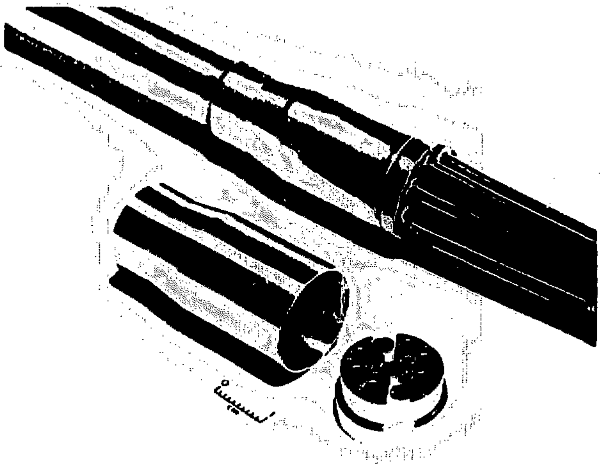

Fig. 17b. Upper-rod termination for an instrumented guide tube

Fig. 17c. Sensor "window" subassemblies for an instrumented guide tube using "graded seal" approach to transition from cermet to stainless steel

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A TYPICAL INSTRUMENTED GUIDE TUBE WAS TESTED AND HAS SURVIVED THERMAL CYCLES SIMULATING REFLOOD

- SUBJECTED TO 50 THERMAL CYCLES SIMILAR TO REFLOOD
- CERAMIC SEAL GAS LEAKAGE MEASURED BETWEEN CYCLES
- PROBE PRESSURE TESTED IN HELIUM AT 100 PSIG AND 750°C AT END OF TEST
- RESULTS:
  - MAINTAINED MECHANICAL INTEGRITY
  - REMAINED OPERABLE THROUGHOUT TEST

Fig. 18

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THREE MAJOR PROBLEMS IN DESIGNING ELECTRONIC CIRCUITRY TO MEASURE PROBE IMPEDANCES IN THE REFLOOD FACILITIES

EXTREMELY SMALL CAPACITANCE CHANGES AT THE END OF LONG, HIGH-CAPACITANCE CABLES

EXTREME DYNAMIC RANGES OF IMPEDANCE

- >30,000 TO 1 ON A SINGLE PROBE
- >1,000,000 TO 1 FOR ALL PROBES

ELECTROMAGNETIC INTERFERENCE FROM THE BUNDLE POWER SUPPLY

Fig. 19

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PRESENT ELECTRONIC DESIGN OVERCOMES PROBLEMS

PROBE CAPACITANCE CHANGES OF LESS THAN 10^{-15} FARADS HAVE BEEN DETECTED WITH CABLE CAPACITANCES OF $>10^{-9}$ FARADS

DYNAMIC RANGE OF CAPACITANCE MEASUREMENT SHOWN EXPERIMENTALLY TO BE BETTER THAN 15,000 TO 1

ELECTROMAGNETIC INTERFERENCE CAN BE GREATLY ATTENUATED BY FILTERING

Fig. 20

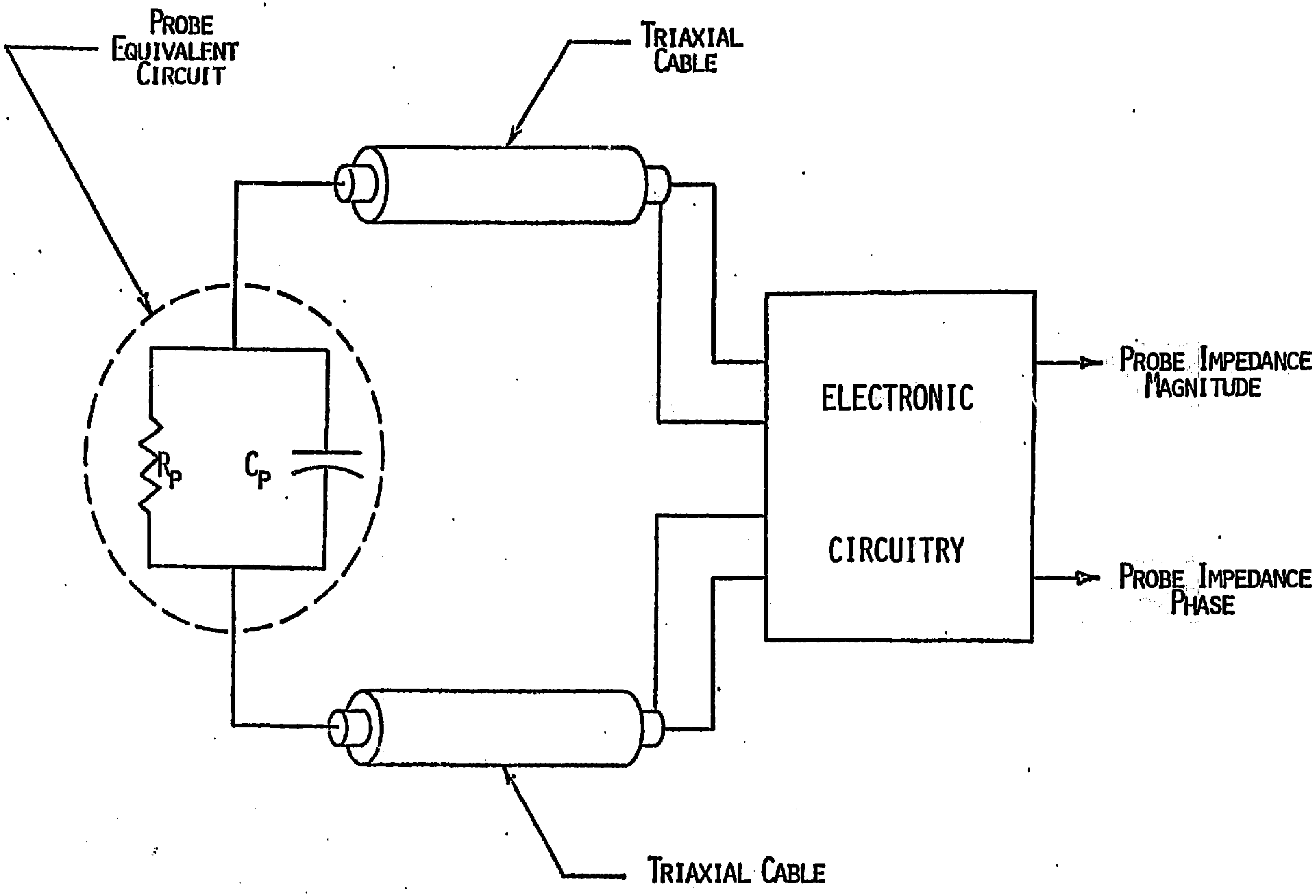

Fig. 21 ELECTRONIC CIRCUITRY FOR PROBE IMPEDANCE MEASUREMENT

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AIR-WATER LOOP CAPABLE OF ACHIEVING A WIDE RANGE OF QUALITIES AND VOID FRACTIONS USED IN THESE TESTS

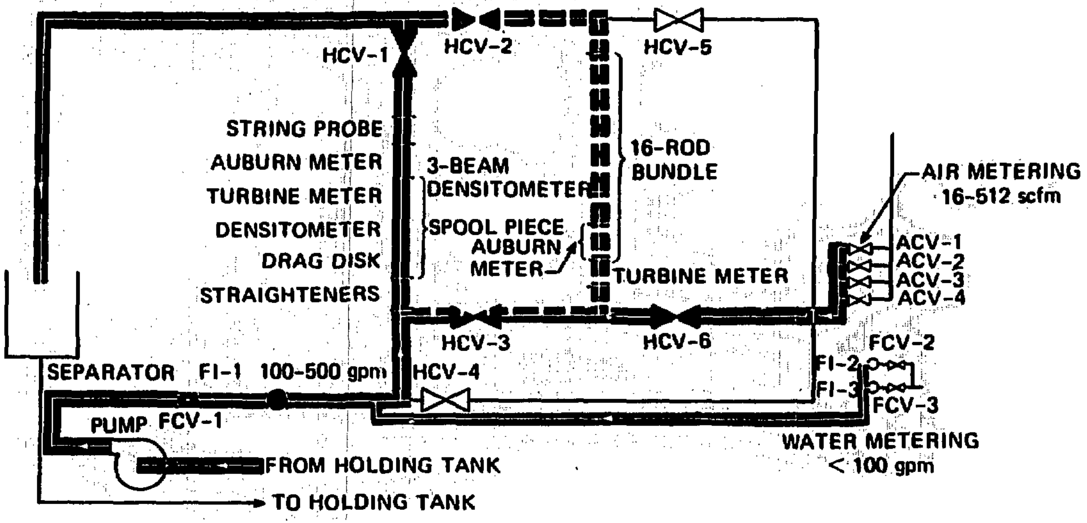

Fig. 22

ORNL–DWG 78–8291

COMPARISON OF NOISE ANALYSIS RESULTS WITH THE SEPARATED FLOW MODEL SHOWS THAT FLAG, PRONG, AND BAND-TO-GROUND ARE PROMISING FOR IN-BUNDLE LIQUID VELOCITY MEASUREMENT.
(STEADY-STATE, VERTICAL UP-FLOW, AIR-WATER TESTS)

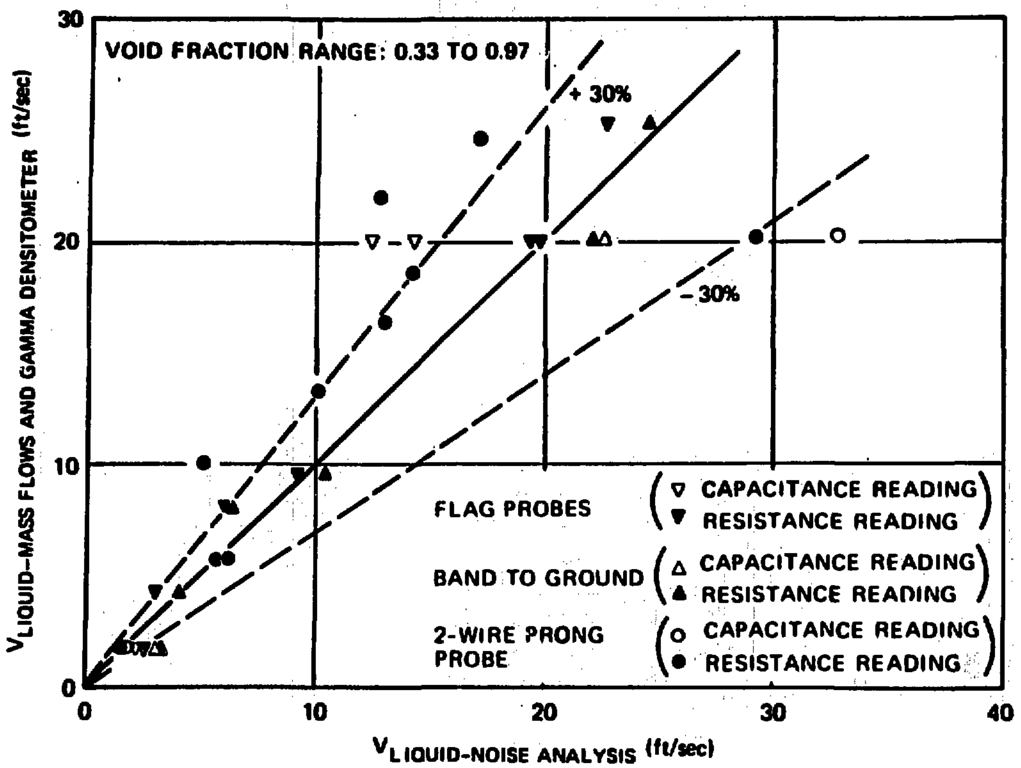

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Fig. 23

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2/7/79

VERTICAL UP-FLOW AIR-WATER TESTS OF IN-BUNDLE SENSORS YIELDED SEVERAL USEFUL VELOCITY MEASUREMENT RESULTS

- COMPARISON OF NOISE ANALYSIS RESULTS WITH SEPARATED FLOW MODEL SHOWS THAT FLAG, PRONG & BAND-TO-GROUND ARE ALL PROMISING FOR IN-BUNDLE LIQUID VELOCITY MEASUREMENT
- BAND-TO-GROUND EXHIBITED MOST REPRODUCIBLE RESULTS
- FLAG-TO-GROUND & PRONG-TO-GROUND PROBES GAVE RESULTS GENERALLY INCONSISTENT WITH FLAG-TO-FLAG AND PRONG-TO-PRONG PROBES

Fig. 24

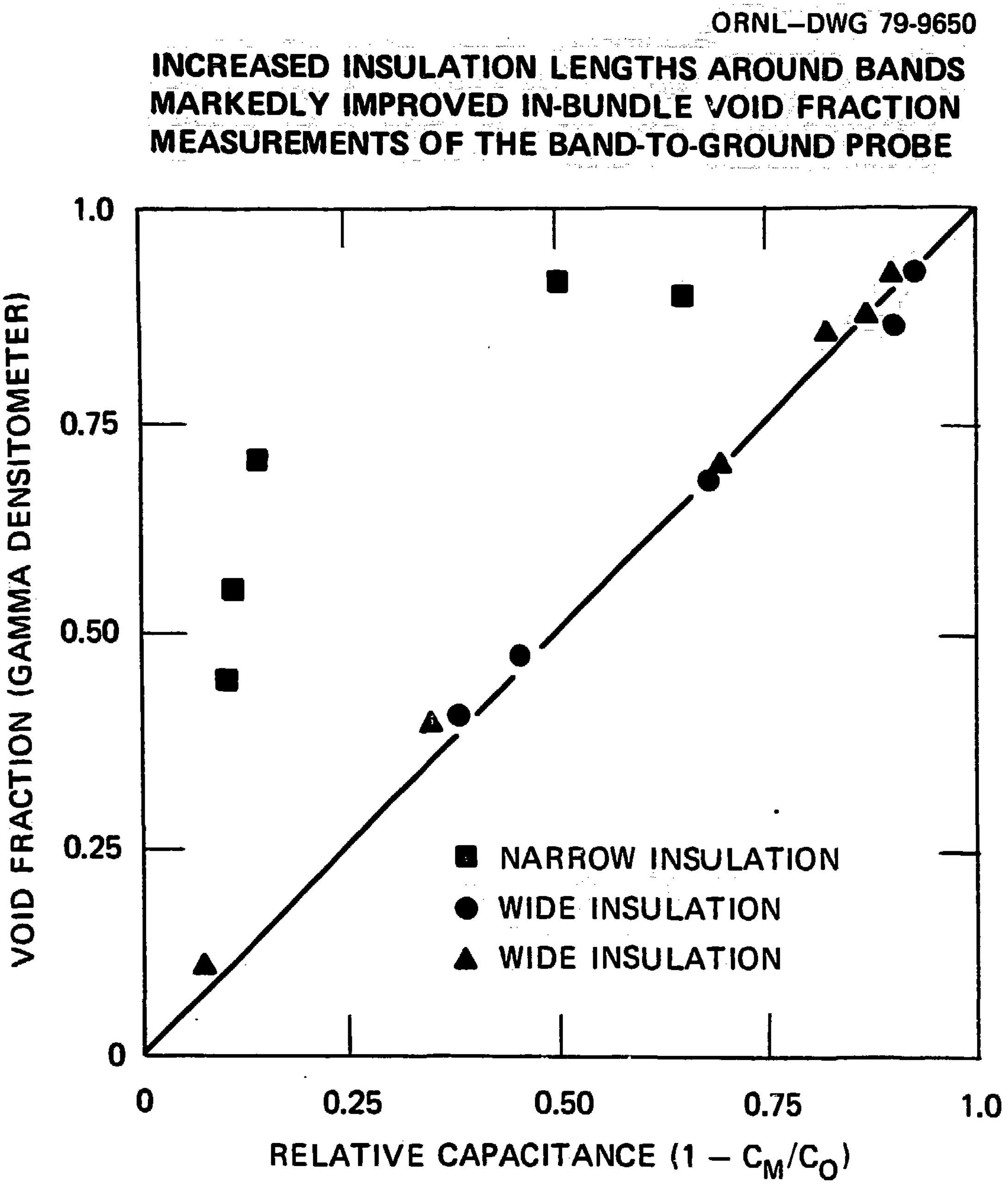
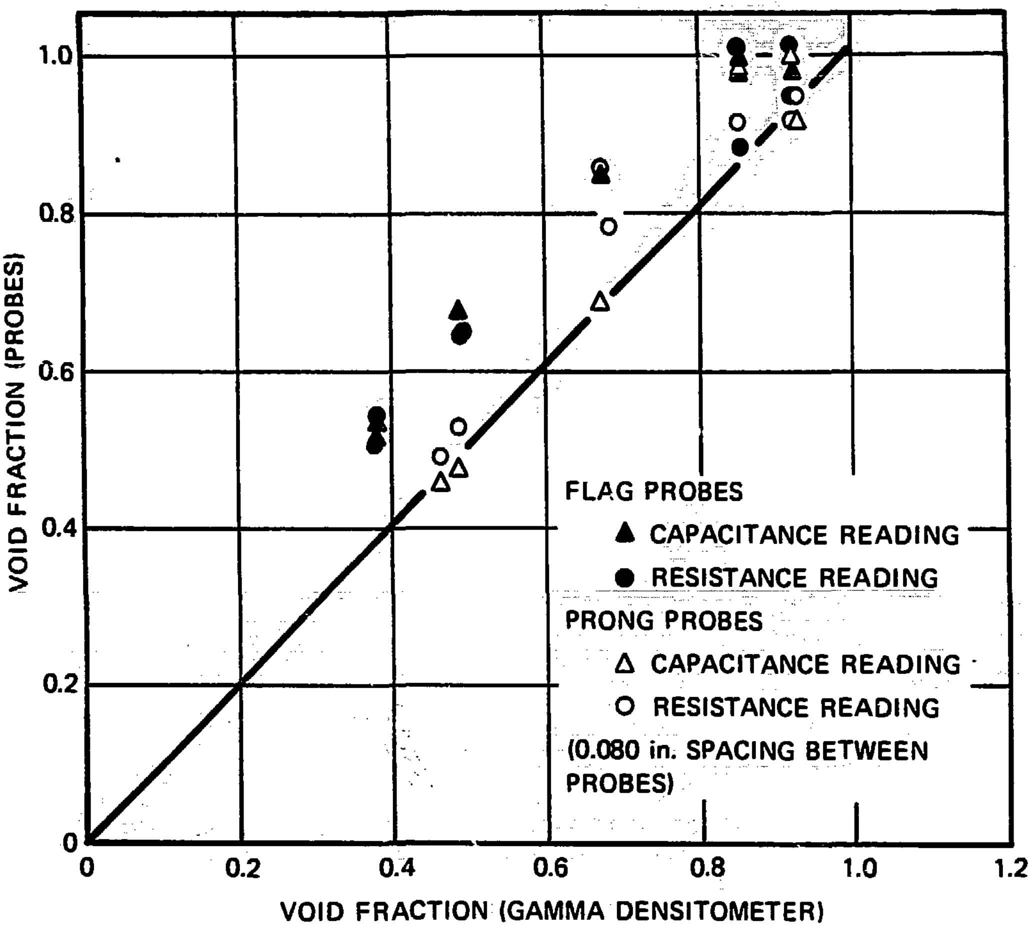

ORNL–DWG 79-9650
INCREASED INSULATION LENGTHS AROUND BANDS MARKEDLY IMPROVED IN-BUNDLE VOID FRACTION MEASUREMENTS OF THE BAND-TO-GROUND PROBE
VOID FRACTION (GAMMA DENSITOMETER)
1.0
0.75
0.50
0.25
0
0
0.25
0.50
0.75
1.0
RELATIVE CAPACITANCE (1 – C_M/C_O)
■ NARROW INSULATION
● WIDE INSULATION
▲ WIDE INSULATION

Fig. 25

ORNL-DWG 78-8294

FLAG AND PRONG PROBE READINGS YIELD IN-BUNDLE VOID FRACTIONS THAT AGREE FAIRLY WELL WITH GAMMA DENSITOMETER IN STEADY-STATE, VERTICAL UP-FLOW AIR-WATER TESTS



10/24/78

Fig. 26

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2/7/79

VERTICAL UP-FLOW AIR-WATER TESTS OF IN-BUNDLE SENSORS YIELDED SEVERAL USEFUL VOID FRACTION MEASUREMENT RESULTS

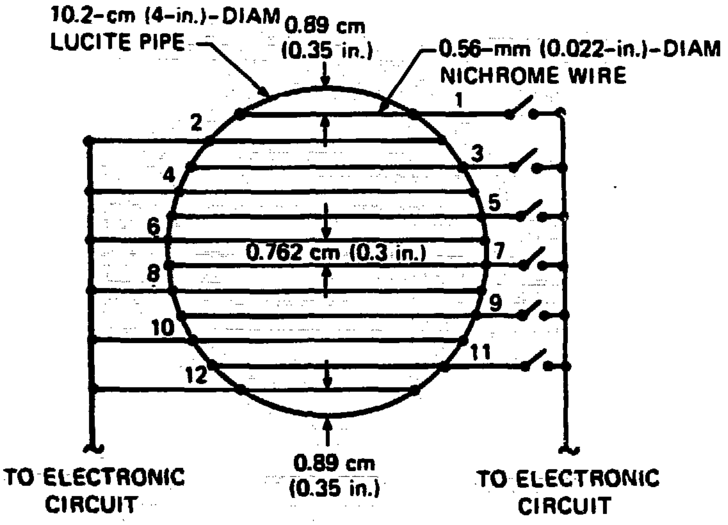
- FLAG, PRONG & BAND-TO-GROUND PROBES ALL YIELDED VOID FRACTIONS THAT AGREE FAIRLY WELL WITH GAMMA DENSITOMETER.
- FLAG PROBES EXHIBITED MOST REPRODUCIBLE RESULTS BUT HAVE LOW SENSITIVITY AT VERY HIGH VOID FRACTIONS.
- THE CAPACITIVE ADMITTANCE OF THE BAND-TO-GROUND PROBE YIELDED BEST OVERALL VOID FRACTION RESULTS.
- FLAG-TO-GROUND & PRONG-TO-GROUND GAVE RESULTS COMPARABLE TO FLAG-TO-FLAG AND PRONG-TO-PRONG.

Fig. 27

ORNL–DWG 78–8272

A VARIETY OF UPPER PLENUM AND IN–BUNDLE INSTRUMENTS TESTED TO DATE

UPPER PLENUM:



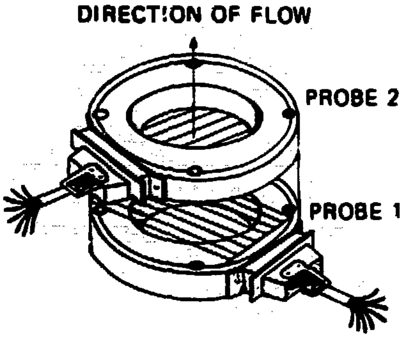
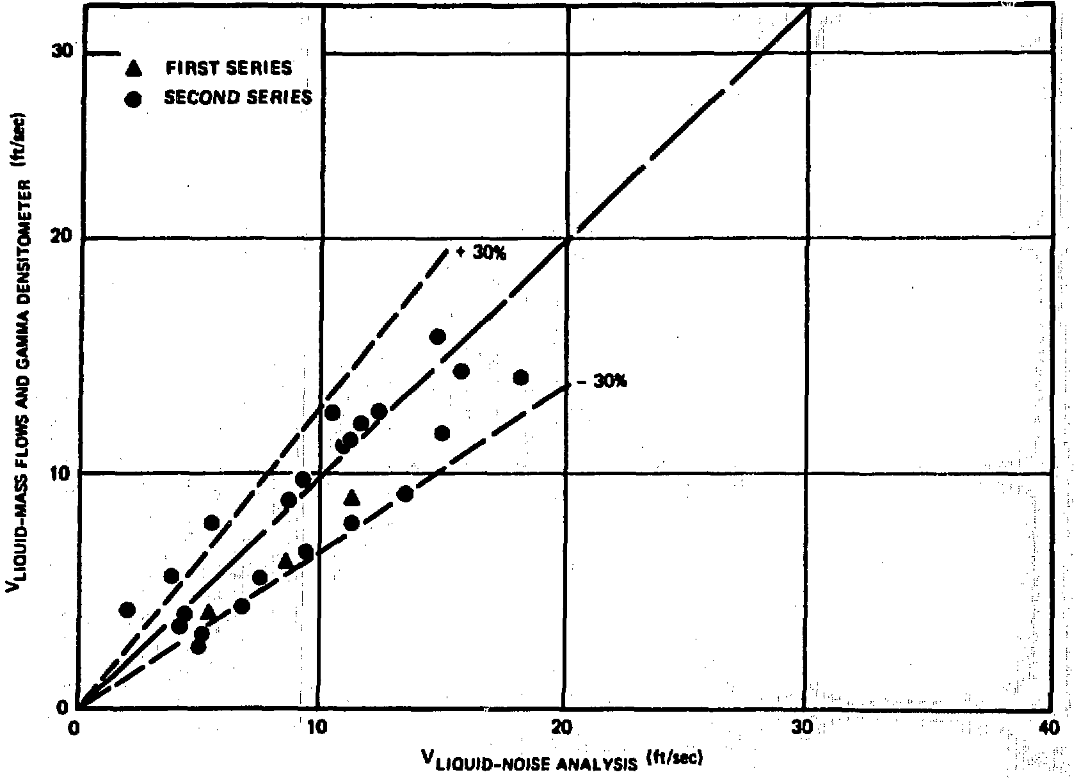


Fig. 28

ORNL-DWG 76-8280

NOISE ANALYSIS TECHNIQUES YIELD REASONABLE ACCURACY IN LIQUID VELOCITY DATA IN STEADY-STATE AIR-WATER (VERTICAL UP-FLOW) TESTS OF THE STRING PROBE WHEN COMPARED WITH THE SEPARATED FLOW MODEL



10/24/78

ornl

Fig. 29

ORNL–DWG 78-19762

COMPARISON OF STRING PROBE LIQUID VELOCITY FROM THE ALGORITHM WITH THE LIQUID VELOCITY DETERMINED FROM TWO-PHASE INSTRUMENTATION FOR A 30 SECOND TRANSIENT IN AIR-WATER VERTICAL UP-FLOW

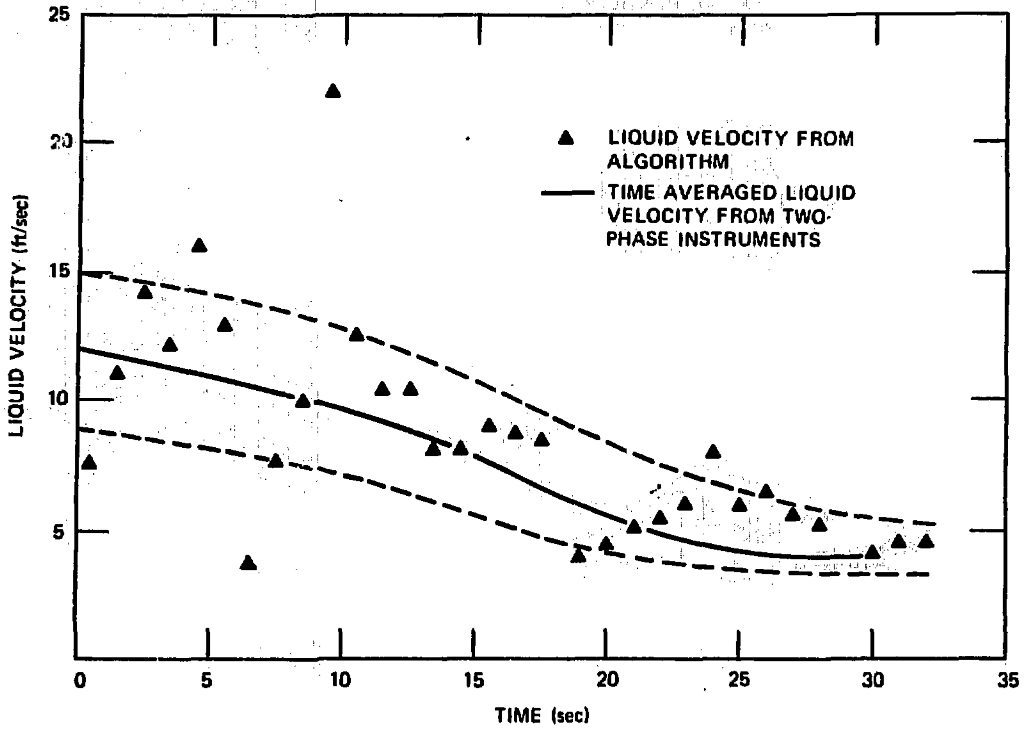


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Fig. 30

ORNL–DWG 78-8288AR

STRING PROBE IMPEDANCE MEASUREMENT AT LOW FREQUENCY (10 kHz) YIELDS VOID FRACTIONS THAT AGREE WELL WITH GAMMA DENSITOMETER VALUES IN STEADY-STATE AIR-WATER (VERTICAL UP-FLOW) TESTS

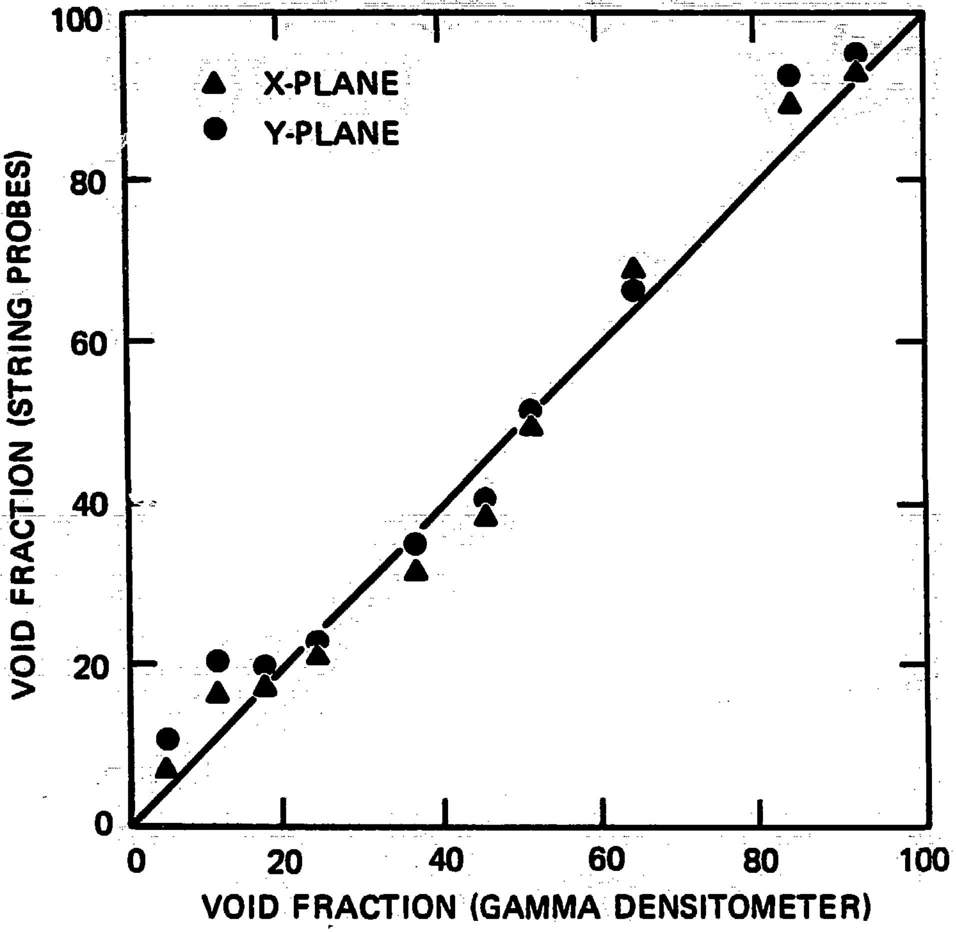

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Fig. 31

ORNL–PHOTO 7082–78

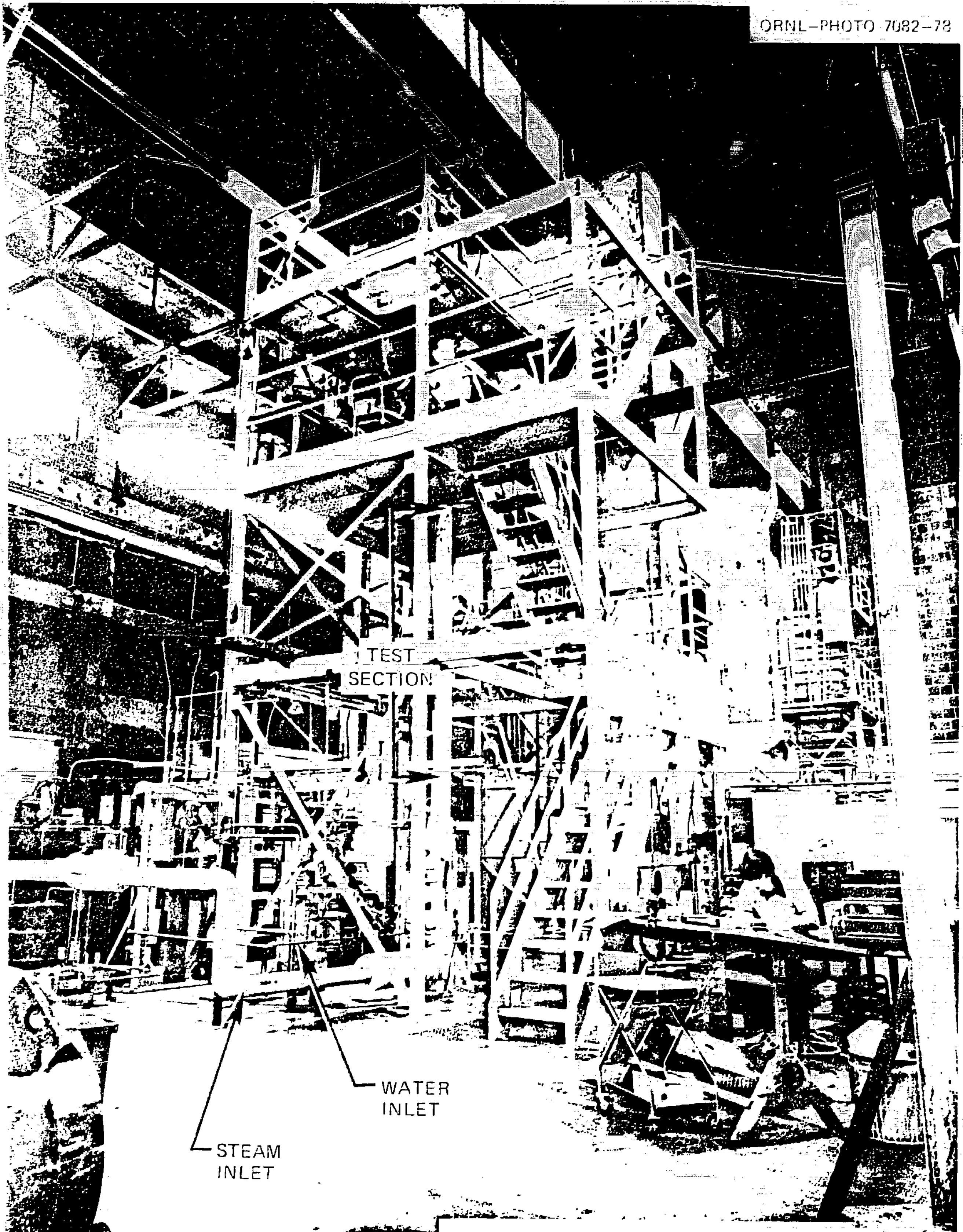
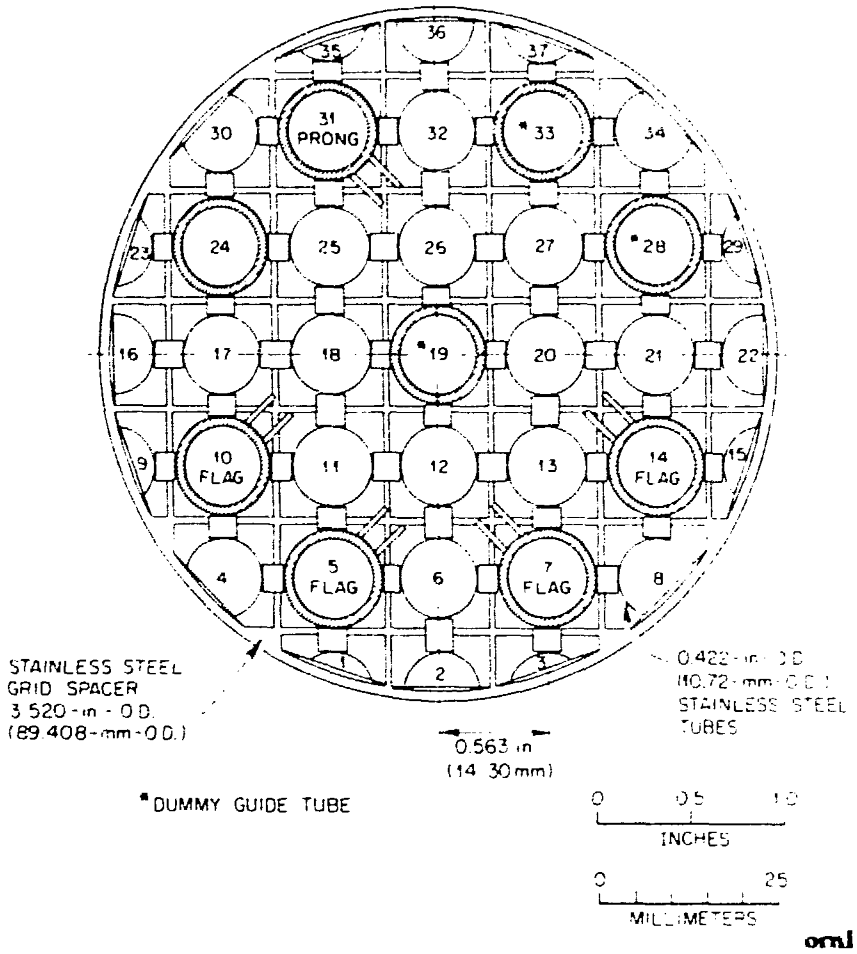


Fig. 31 AIRS Steam-Water Test Stand.

ORNL-DWG 78-19849

"PROOF-OF-OPERABILITY" STEAM-WATER TESTS OF FLAG AND PRONG, TYPE INSTRUMENTED GUIDE TUBES WERE CONDUCTED WITH IN-BUNDLE GEOMETRY



STAINLESS STEEL GRID SPACER 3.520-in.-O.D. (89.408-mm-O.D.)

0.422-in.-O.D. (10.72-mm-O.D.) STAINLESS STEEL TUBES

0.563 in (14.30mm)

*DUMMY GUIDE TUBE

10 24 78

ORNL–DWG 78-19847

ALTHOUGH INDEPENDENT CALIBRATION OF FLAG AND PRONG PROBES IS REQUIRED, PRELIMINARY ANALYSIS OF STEADY-STATE, STEAM-WATER "PROOF-OF-OPERABILITY" RESULTS AT HIGH VOID FRACTIONS ($0.7 < \alpha < 0.9+$) SUGGEST THAT PROBES MAY GIVE AN ACCURATE MEASURE OF LIQUID VELOCITY

			SEPARATED FLOW MODEL			
LOOP * CONDITION	AVERAGE NOISE ANALYSIS VELOCITY FROM FLAG AND PRONG PROBES[1] (ft/sec)	HOMOGENEOUS FLOW MODEL VELOCITY (ft/sec)	THOM (1964)		ZUBER AND FINDLAY (1965)	
			V_f (ft/sec)	V_g (ft/sec)	V_f (ft/sec)	V_g (ft/sec)
1	7.24	21.6	7.3	23.0	4.9	24.3
2	8.17	33.8	11.5	36.0	8.8	37.3
3	5.62	35.9	11.7	37.0	5.6	38.7
4	12.3	120	37.5	118	15.9	125
5	9.32	85.1	28.0	86.0	10.4	88.7

[1] AVERAGE OF 10 POINTS

*IN-BUNDLE PRESSURE – 105 ± 1.0 psia
IN-BUNDLE TEMPERATURE – 332 ± 2°F

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Fig. 34

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DRYWALL DROPLET EXPERIMENTS ARE BEING CONDUCTED TO IMPROVE UNDERSTANDING AND DETERMINE LIMITS OF OPERATION OF IMPEDANCE PROBES

- IMPEDANCE PROBES TESTED WITH WELL DEFINED AND CONTROLLABLE TWO-PHASE FLOW TEST CONDITIONS
- PURPOSES
  - ELIMINATE PROBE "BRIDGING" BY WALL FILM FLOW - A DRY WALL CONDITION
  - DETERMINE PRACTICAL SENSITIVITY LIMITS OF PROBE-ELECTRONICS COMBINATION
  - SERVE AS TOOL FOR ELECTRONICS DEVELOPMENT
  - COMPARE MEASURED RESULTS WITH PROBE RESPONSE MODELS

Fig. 35

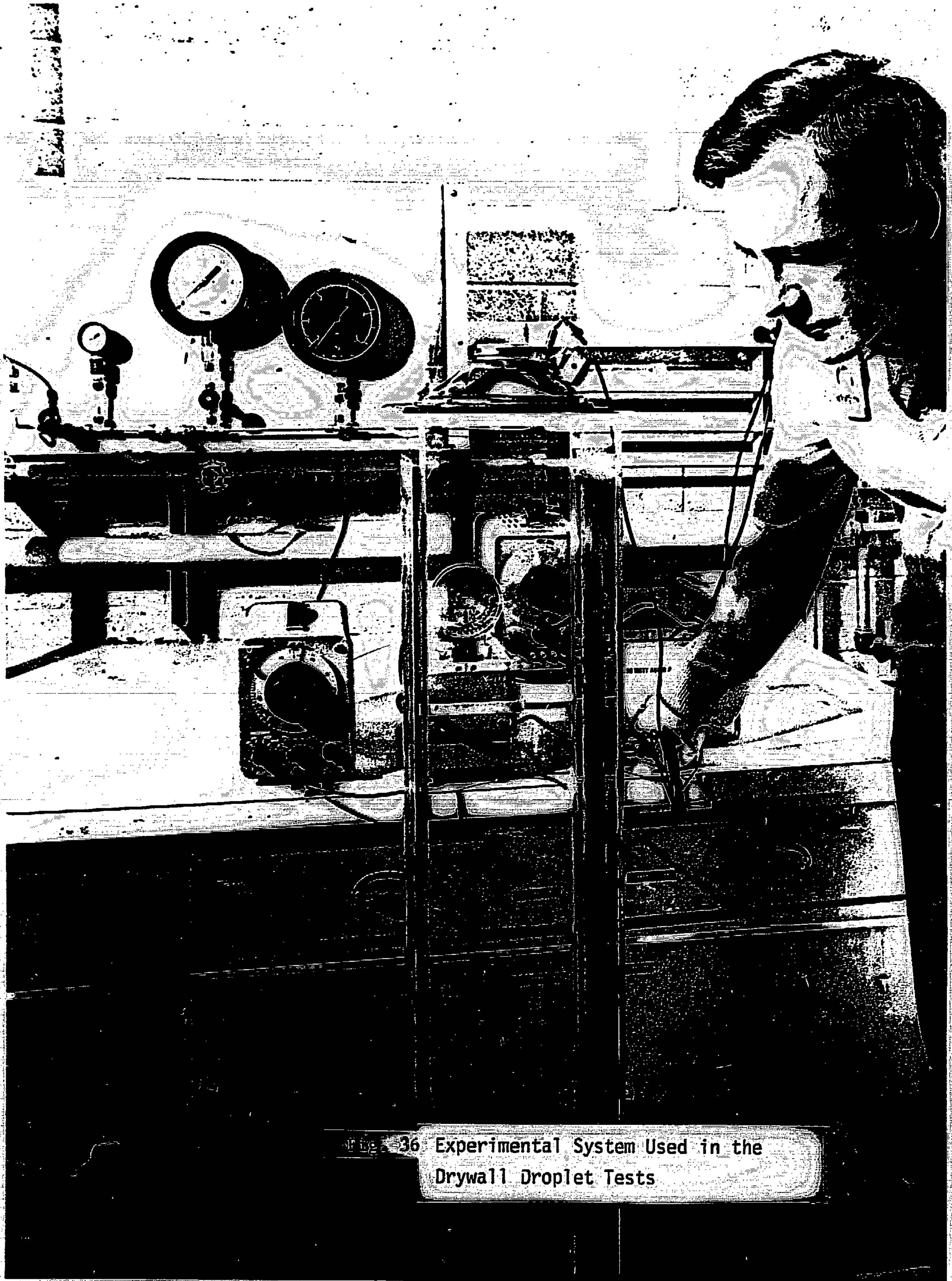

Fig. 36 Experimental System Used in the Drywall Droplet Tests

Fig. 37 Droplet Stream Traversing a Flag Type Impedance Probe

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PRELIMINARY DRYWALL DROPLET SCOPING EXPERIMENTS

RUN NO.	PROBE	DROPLET DIAMETER µM	[1]ESTIMATED VELOCITY FT/SEC	[2]NOISE ANALYSIS VELOCITY FT/SEC	[3]MINIMUM VOID FRACTION
1	FLAG	970	5-7	7.0	.983
2	↓	840	6-8	7.9	.989
3	↓	890	8½-10	9.8	.987
5	↓	690	6½-8	7.4	.994
6	↓	680	8-10	9.4	.994
8	PRONG	1170	5½-6½	6.2	.944
9	↓	1140	7-9	8.1	.947
10	↓	790	6½-8	7.8	.967

1. V = DROPLET SPACING × FREQUENCY
   - A. DROPLET SPACING MEASURED WITH A SCALE ADJACENT TO DROPLET STREAM.
   - B. FREQUENCY = OSCILLATOR FREQUENCY
2. AVERAGE COHERENCE IN ALL RUNS EXCEEDED 0.85 AND GENERALLY EXCEEDED 0.95.
3. CALCULATED ASSUMING A SINGLE DROP ENCLOSED IN THE VOLUME BETWEEN PROBE ELECTRODES (NOT TIME AVERAGED).

Fig. 38

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RESULTS OF PRELIMINARY DRYWALL DROPLET SCOPING TESTS

- MEASURED VELOCITIES AGREED WELL WITH INDEPENDENT ESTIMATED DROPLET VELOCITIES FOR BOTH FLAG AND PRONG PROBES
- PROBE SIGNALS WERE WELL CORRELATED FOR ALL CASES TESTED
- DEMONSTRATED CAPABILITY OF MEASURING VERY HIGH VOID FRACTION CASES, INDICATING GOOD SENSITIVITY OF THE PROBE-ELECTRONICS PACKAGE

Fig. 39

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ANNULAR FLOW EXPERIMENTS WILL BE CONDUCTED TO CALIBRATE IMPEDANCE PROBES

- IMPEDANCE PROBES WILL BE CALIBRATED IN A "WELL DEFINED" ANNULAR TWO-PHASE FLOW
- PURPOSES
  - DETERMINE CAPABILITIES OF MEASUREMENT SYSTEM IN ANNULAR AND ANNULAR-DISPERSED FLOW
  - DEVELOP INTERPRETATION TECHNIQUES FOR VOID FRACTION AND VELOCITY

Fig. 40

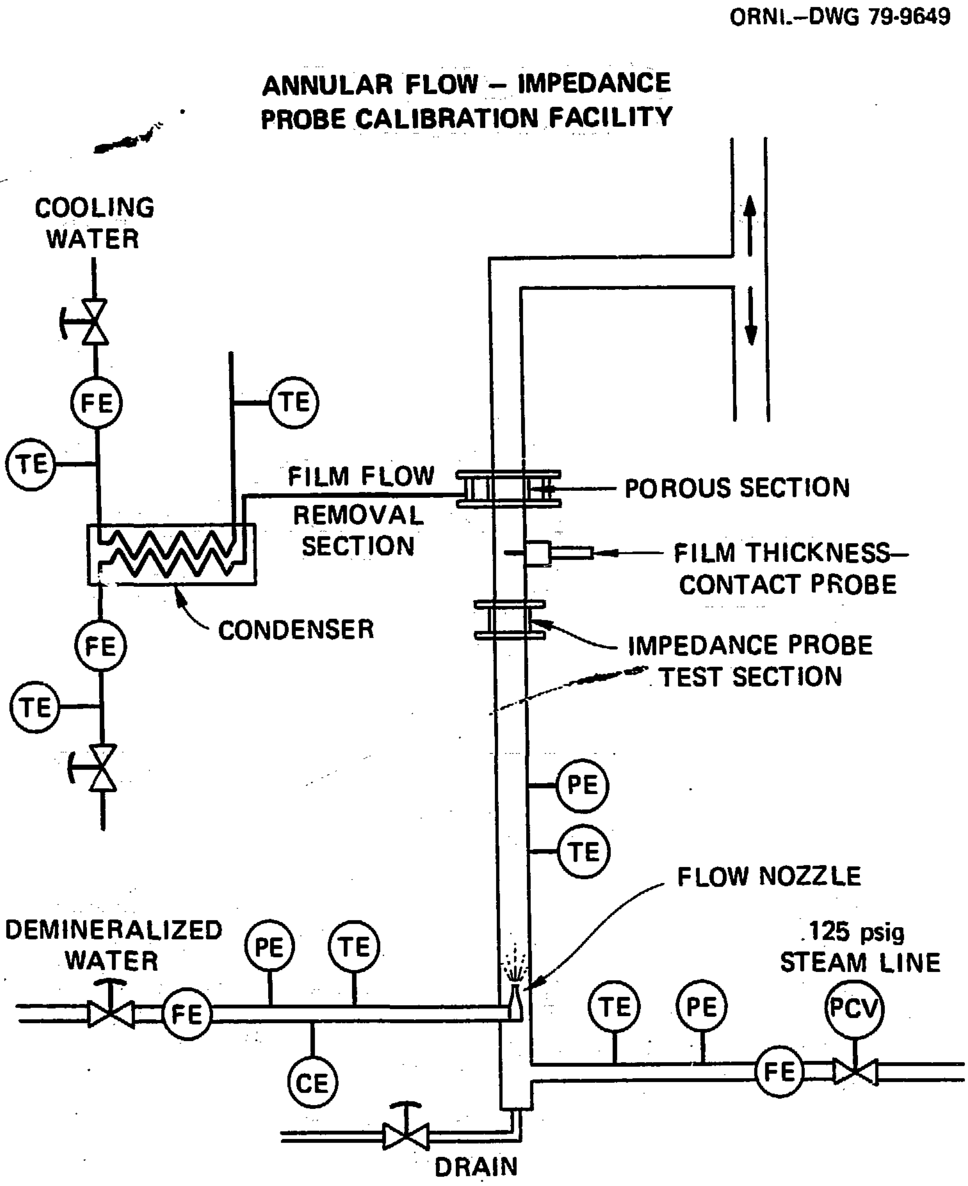
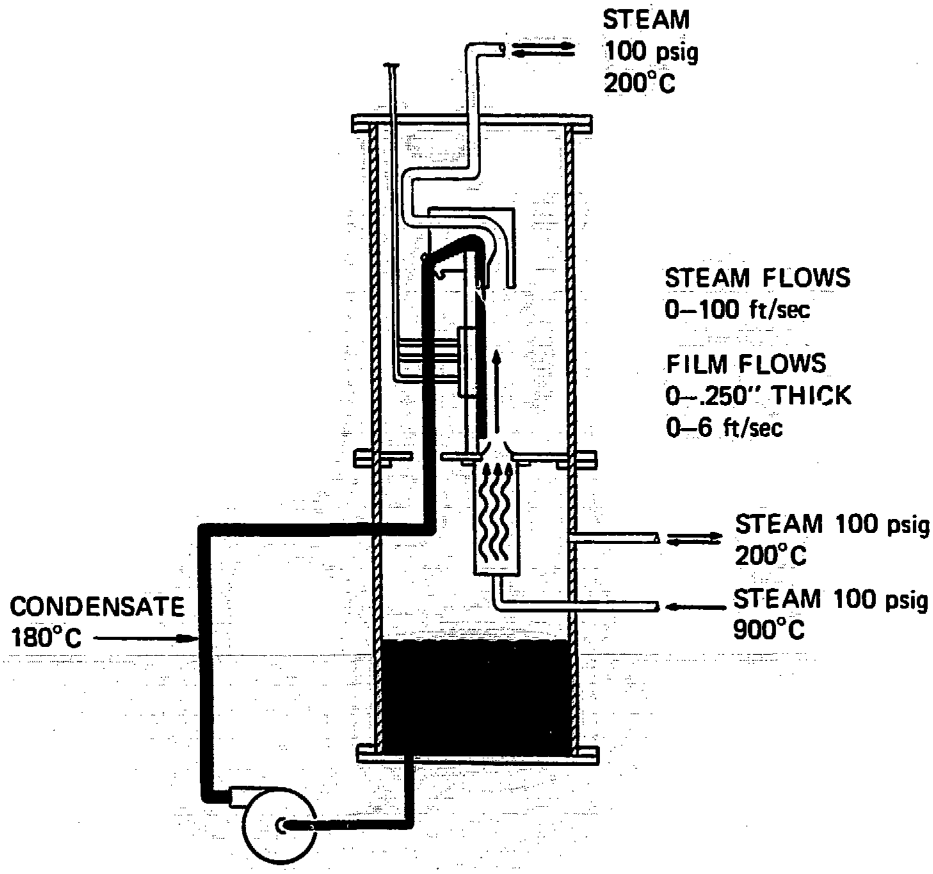

ORNL–DWG 79-9649
ANNULAR FLOW – IMPEDANCE PROBE CALIBRATION FACILITY
COOLING WATER
FE
TE
TE
FILM FLOW REMOVAL SECTION
CONDENSER
FE
TE
POROUS SECTION
FILM THICKNESS–CONTACT PROBE
IMPEDANCE PROBE TEST SECTION
PE
TE
FLOW NOZZLE
DEMINERALIZED WATER
FE
PE
TE
CE
.125 psig STEAM LINE
TE
PE
PCV
FE
DRAIN

Fig. 41

ORNL-DWG 79-9722



FILM PROBE CALIBRATION CHAMBER

Fig. 42

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PRESENT MEASUREMENT SYSTEM CAPABILITIES

VELOCITY AND VOID FRACTION IN-CORE, IN THE UPPER PLENUM, AND OTHER IN-VESSEL LOCATIONS

- VOID FRACTIONS FROM <20% to >98%
- VELOCITIES FROM 1 TO 15 M/SEC
- MEASUREMENT SYSTEM RESPONSE IS FASTER THAN EXPECTED FLUID CHANGES

FILM THICKNESS AND VELOCITY ON VESSEL INTERNALS

- VELOCITIES FROM 0.05 to 3 M/SEC
- FILM THICKNESS RANGE OF 0.13 - 4 MM

Fig. 43

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SUMMARY

- FLAG PROBES AND PRONG PROBES HAVE PROVED SATISFACTORY FOR USE AS IN-CORE IMPEDANCE PROBES. THE BAND PROBE IS ALSO SUITABLE BUT HAS MANUFACTURING PROBLEMS AND HAS NOT BEEN FABRICATED AT THIS TIME.
- PRELIMINARY TESTING AND PROTOTYPE DESIGNS FOR STRING PROBES (UPPER PLENUM) ARE COMPLETED.
- DEVELOPED HIGH-SENSITIVITY, WIDE-RANGABILITY IMPEDANCE MEASUREMENT ELECTRONICS.
- ORNL-DEVELOPED CERMET AND JOINING TECHNIQUES HAVE SURVIVED REFLOOD-LIKE ENVIRONMENTAL CONDITIONS.
- SENSOR PROTOTYPES FOR FILM PROBE ARE BEING FABRICATED.
- COMPLETED FABRICATION OF TEN INSTRUMENTED GUIDE TUBES FOR PKL-II REFLOOD FACILITY.
- STEAM-WATER TESTS OF PKL-II INSTRUMENTED GUIDE TUBES GAVE ENCOURAGING RESULTS.
- SCOPING TESTS OF DRYWALL DROPLET EXPERIMENT COMPLETED.

Fig. 44