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CURRENT CAPABILITIES OF TRANSIENT TWO-PHASE FLOW INSTRUMENTS

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ABSTRACT

The measurement of two phase flow phenomena in transient conditions representative of a Loss-of-Coolant Accident requires the use of sophisticated instruments and the further development of other instruments. Measurements made in large size pipes are often flow regime dependent. The flow regimes encountered depend upon the system geometry, transient effects, heat transfer, etc. The geometries in which these measurements must be made, the instruments which are currently used, new instruments being developed, the facilities used to calibrate these instruments, and the improvements which must be made to measurement capabilities are described.

INTRODUCTION

Transient two phase flow occur at start-up, termination and change of regimes in numerous engineering facilities. Some transiencs can be performed in a gradual, pre-planned way, while changes due to emergency situations may involve fast transients. In order to predict system response to such transients, instrumentation and analysis are being developed for application to fast changing two-phase flows. In extreme cases, non-equilibrium thermodynamic situations are encountered. Measurement of flow-parameters in these flows is imposing on instrumentation design, performance and data interpretation.

The LOFT facility provides a combination of the most difficult two phase flow requirements. Measurements must be made in a high pressure (15MPa), high temperature (300°C), in large pipes (14 inch schedule 160), under highly transient conditions (simulated pipe rupture), and in a radiation environment. The instruments must be able to withstand the high pressure, high temperature environment for long periods of time before the experiment begins. Therefore, this paper begins by reviewing the instruments which are currently installed in LOFT and the considerations which lead to their selection and development. This discussion provides a base to discuss future instrument development development possibilities. The discussion then turns to a presentation of measurements obtained with these instruments intended to exhibit the deficiencies which still exist in such measurements. Conclusions are then drawn concerning how some of these deficiencies can be corrected.

CURRENT INSTRUMENTATION CAPABILITIES - LOFT

The LOFT facility is a pressurized water reactor (PWR) with nuclear fuel used as a heat source (Reeder, 1978). This plant is rated at 55 Megawatt thermal. It is primarily used to investigate the Loss-of-Coolant Accident (Ybarrondo, 1972) which involves the measurement of highly transient two phase flow phenomena. The primary system in LOFT is illustrated in Figure 1. This facility is a scaled four loop PWR. The LOFT intact loop represents three unbroken loops in a PWR and the LOFT broken loop represents the remaining fourth loop with a hypothetical pipe break. The pipe break is simulated with two quick opening blowdown valves. The first test series (L1) has been completed and consisted of six non-nuclear tests. These were initiated from reactor initial operating conditions of 15 MPa and 282°C. A core simulator was installed to represent the pressure drop of a core. The nuclear test series has been initiated with one test being completed.

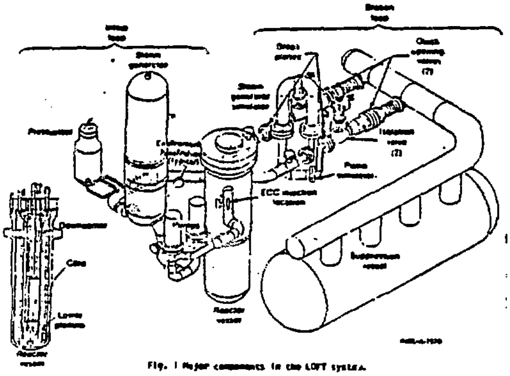

Fig. 1 Major components in the LOFT system.

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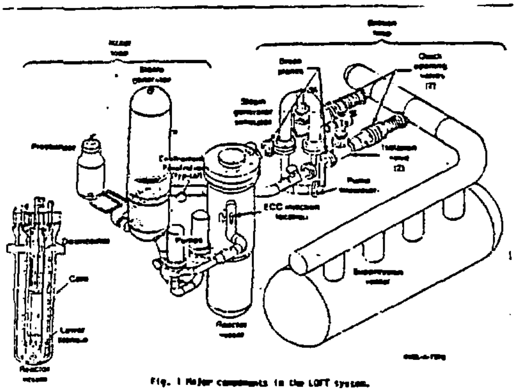


Fig. 1 Major components in the LOFT system.

The characterization of two phase flow requires the measurement of mass flow rate and at least one or more other properties such as quality, temperature, pressure, flow regime, etc. The desired measurements depend somewhat upon the theoretical models used to characterize two phase flow. It is believed, currently, that the best model to use is an unequal phase velocity, unequal phase temperature model. In this model, the measurement of the density, the velocity, or mass flow rate, and the temperature of each phase as well as the void fraction and flow pattern is necessary. In general, all of these quantities cannot be measured. Practically speaking no more than three properties are measured at a given location (in addition to pressure and temperature). Measurement of one property at a given location is usually not sufficient. The minimum information desired is the total mass flow rate which requires the use of at least two instruments. The current LOFT philosophy is to use three instruments at each measurement location in LOFT. For example, piping stations include a gamma densitometer to measure density, turbines to measure velocity, and drag disks to measure momentum flux.

These are five major measurement locations, in the LOFT piping as shown in Figure 1. Each of these locations currently include a drag disk turbine transducer (DTT) rake and a three beam gamma densitometer. The drag disk turbine rake, illustrated in Figure 2, consists of three DTT's.

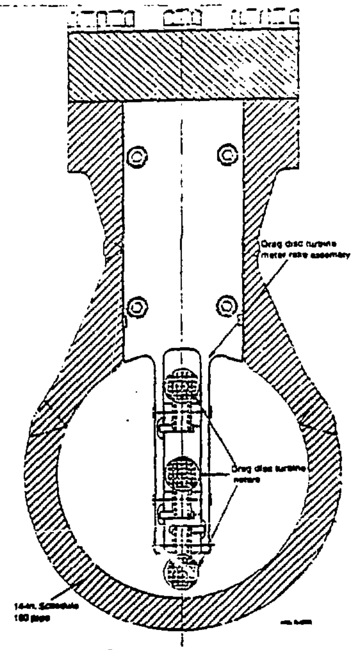


Fig. 2 Drag-disc turbine meter rake.

Each DTT, illustrated in Figure 3, without a schroud, consists of a drag disk, to measure momentum flux, and a turbine to measure fluid velocity.

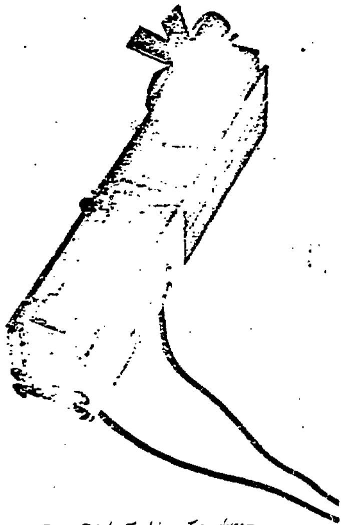


Fig 3. Drag Disk Turbine Transducer

A schematic of the beams traversing the pipe cross section is shown in Figure 4. The gamma densitometers mount on the piping instrumentation ports which include the DTT rake.

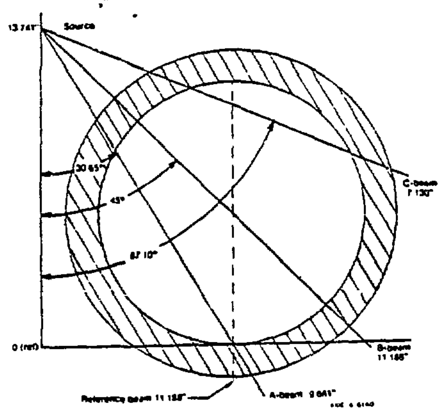


Fig. 4 Gamma densitometer schematic.

There are many instruments in the reactor vessel, as illustrated in Figure 5.

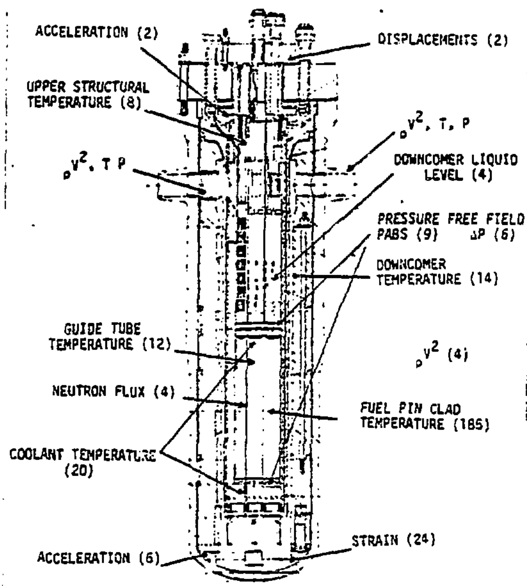


Figure 5. Reactor Vessel Instrumentation

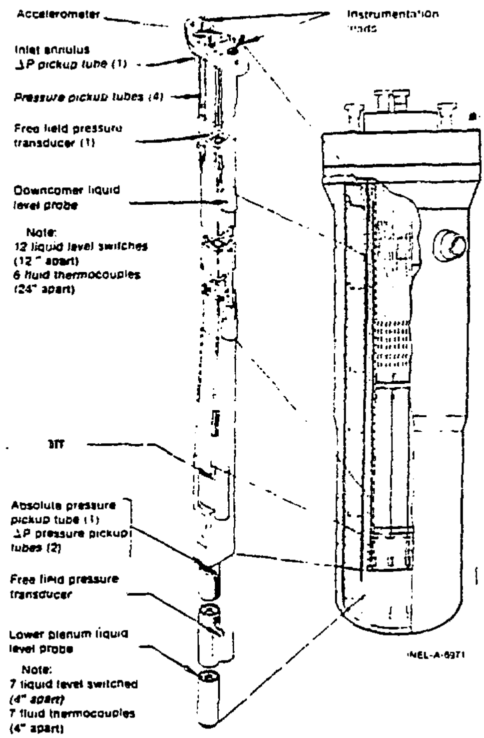


Fig. 6 Reactor vessel downcomer instrument stalk instrument locations.

The core contains 185 thermocouples on the fuel rods as well as thermocouples on in the coolant. DTT's are installed in the outlet of some of the fuel bundles. A newly designed core support plate will allow installation of DTT's and ultrasonic density detectors in the core inlet. The downcomer region, illustrated in Figure 6, contains two instrument stalks, which contain liquid level probes, as well as DTT's. In addition to the instruments mentioned, there are many pressure sensors, pressure difference sensors, and temperature measurements. Details of these instruments are included in Reeder (1978).

EFFECT OF GEOMETRY UPON INSTRUMENT SELECTION

Two phase flow measurements which are made in nuclear safety related experiments are expected to function in many different geometries. The use of certain instruments is restricted by geometry. For example an instrument installed in the LOFT core must be small so that the cooling capability of the fluid is not restricted. This section discusses the various geometries encountered in the LOFT experiment. It should be remembered that the entire two phase state of the mixture is desired and not just the flow rate.

There are several important effects which determine the selection of instruments in pipes. These include pipe size, upstream and downstream perturbances such as bends and penetrations, pipe orientation, flow regime expected, etc. It is generally assumed in the design of most measurements that the flow is in the direction of the pipe axis. Flow perpendicular to the pipe axis is usually not measured.

Pipe size can also effect the method in which the same instrument is applied. For example, Semiscale uses flow instruments which cover the entire pipe while LOFT uses instruments which only cover a small area. Semiscale (Ball, 1978) is a scale model of the LOFT facility and uses electric heater rods in the core instead of nuclear fuel rods. Semiscale is constructed with small pipes (three inch schedule 160 or smaller). The semiscale turbines are intended to be in contact with the entire cross section so that all the flow must go through it. The flow of a stratified two phase fluid through the turbine effects the turbine behavior in an uncertain manner. The liquid in contact with the blades causes a different effect than the vapor. The interpretation of the instrument output is further complicated if the phases are moving at unequal velocities. Annular flow which is characterized by a liquid film on the wall and stream flow through the center may not have turbine blades in the liquid at all and thus may be unaffected by it. Droplet flows should exhibit good behavior, however, the radial component of flow introduced by the turbine affects the droplets. Slug flow is a combination of the above regimes. Semiscale also uses drag disks. These devices cannot cover the pipe since they would block the flow. The area of these devices is determined by the range of the momentum fluxes expected. Semiscale is experimenting with screens and these appear to offer a better measurement of the flow since it is in contact with all portions of the flow.

LOFT uses free field devices. The principal measurement locations are in fourteen inch schedule 160 pipe. Turbines have not been developed which can operate under these flow conditions and fill the entire pipe cross section. The drag disc and turbine transducers (DTT) which are used by LOFT are approximately 40 mm in diameter compared to a pipe diameter of 276 mm. These devices see only a small percentage of the the flow area. In stratified flow, the DTT is probably in one phase or the other most of the time. Thus, the size of the pipe not only determines what instruments can be used, it also affects the interpretation of the measurements obtained.

Different flow regimes are encountered in vertical pipe than horizontal. The flow tends to be more homogeneous in fluid distribution but larger differences between the phase velocities are experienced. Different flow regimes are encountered in pipes at orientations other than horizontal or vertical.

In general, pipe locations allow the greatest variety of instruments to be inserted. This is due to the free area around the piping and the usual unobstructed area within the pipe.

Regions in LOFT and Semiscale other than piping locations are more complicated to make measurements in. For example, the downcomer region in LOFT is an annular region bounded on the outer diameter by a heavy section vessel wall and on the inner diameter by the core. A neutron shield surrounds the reactor vessel. Thus neither of these boundaries can be practically penetrated for insertion of intrusive measurements or surrounded with equipment for making non-intrusive measurements. LOFT has two downcomer stalks inserted through the vessel head. DTT's have been installed on these stalks. It appears to be virtually impossible to use a gamma densitometer in this region. The downcomer stalks also include liquid level indicators which attempt to determine the existence of steam or water at a given location. Work is progressing on using these probes to measure void fraction as a continuous function from all steam to all water. Since the flow in the downcomer is multi-dimensional, the fluid motion in this region is difficult to descern with the limited number of installed instruments.

The plenum regions offer difficulty in inserting either a DTT or a gamma densitometer. The fluid motion is multi-dimensional so that all one dimentional instruments are of limited usefulness in this region. The flow near the core inlet and outlet is basically one dimensional. DTT's have been inserted in the core outlet and will be inserted in the core inlet in future experiments. A densitometer based upon the damping of an imposed high frequency vibration of a metal bar has been developed and tested. This densitometer will be inserted in the core inlet.

The reactor core region consists of cylindrical rods of 1 cm in diameter and placed with a rectangular pitch of approximately 1.2 cm. The remaining open area is very small inhibiting the insertion of flow measuring instruments. For example, it does not seem possible to insert turbines, drag bodies or gamma densitometers in the core. However, thermocouples have been attached to some of the fuel rods. Testing of the thermocouples indicate that they measure the surface temperature very accurately. It may be possible to insert impedance probes or ultrasonic probes to measure void fraction.

This section has described the practical problems of insertion of instruments in selected geometries. The following section provides a classification method useful for selecting instruments for further development.

CLASSIFICATION OF INSTRUMENTATION

The classification of instrumentation is important for ease in comparing the advantages of different instruments. Instruments selected for further development should be based upon this classification. The following classification does not pretend to be the optimal one but it has emerged from the experience of numerous workers in the field and seems to serve practical purposes. The classification most desired for LOFT use are circled.

A. Region encompassed by the measurement of measured properties.

1. Global (averaged over volume or area, i.e. cross-section)
2. Semi-global (line-average, usually chordal average values)
③ Local ("point" values, in fact, pertaining to an elementary, finite difference volume).

Note: Any number of N line average measured values can be transformed into N local values of the basic property (or parameter). The mathematical procedure involved is often cumbersome, and the reconstruction accuracy depends principally upon the number, N where the larger N is, the higher the accuracy is.

B. Interference between the measuring and the measured system.

1. Instrusive (contact methods)
   1.1 Causing localized disturbance
   1.2 Causing radical change(s) of flow characteristics (e.g. quick opening valve method)
② Non-intrusive (contactless methods)

C. Mass exchange between the measured and the measuring system.

① Without injection or extraction
2. With injection of mass (fluid and/or solid)
3. With extraction
4. With injection and extraction

D. Time-behavior of flow

1. Steady-state methods
② Transient and steady-state methods.

E. Biological/health hazard effects.

① Without hazard
2. With radiological hazards (gammas, neutrons)
3. With light hazards (lasers)
4. With chemical hazards (tracers)
5. With other hazards (temperature, pressure, vibrations, electrical shocks, etc.)

F. Primary, directly measured property.

① Temperature (in direct-reading instruments)
② Force or pressure
③ Acceleration
④ Distance (length)
⑤ Time
⑥ Angular velocity (revolutions in given time)
⑦ Mass and mass flux
⑧ Momentum
⑨ Radiation flux: of photons (light, or x-rays or gammas) or of neutrons (transmitted or scattered)
⑩ Electrical and magnetic properties: resistance, current, voltage, capacitance, magnetic field, etc.

G. Geometry in which instrument can be used.

1. Pipe flow
   1.1 Full flow
   1.2 Free field
   1.3 Both of the above
2. Large volumes
3. Confined geometries
④ All of the above

H. Dimensionality of Instrument

1. One dimensional
② Multi-dimensional

I. Value as a reference instrument

① Primary standard
② Secondary standard
③ No standard

J. Environment in which instrument can be used.

1. High pressure
2. High temperature
3. Radiation background
④ All of the above

NEAR TERM INSTRUMENT IMPROVEMENT

The following instruments have been proven to be capable of further development and probable application to the environment required in LOFT or in facilities used to calibrate instruments to be used in LOFT. The instrument name, the basic property that it measures, and the near term improvement (by 1981) which can be expected are included in the following:

1. Compton scattering/absorption of gammas; local density and flow pattern; source energy optimization, in order to achieve maximum detector reading and resolution versus source strength.
2. Multiple beam gamma-attenuation (related to Tomography); local density and flow pattern determination; increase of the number of beams and decrease the uncertainty of results.
3. Pulsed neutron activation (PNA); total pipe-mass-flow rate and average pipe fluid density; decrease of the solid angle of fluid irradiation along the flow at the source; increase of the source strength and of the uniformity of activation over the pipe cross-section at the source; increase of the detector count rate and of its insensitivity to the flowpattern; (vapor configuration) at the detector location.
4. Ultrasonic devices; line-average density or vapor fraction; increase of the signal/versus vapor fraction sensitivity

and reduction or elimination of the influence of system temperature and fluid velocity on the instrumentation performance and reading; development of capability to record local fluid density (or vapor fraction) values.

5. Pitot tubes; local fluid momentum; reduction of damping effects due to fluid presence in connecting lines and elimination or modification of the line bleeding (purging), making the instrument more reliable in fast transients.

6. Drag bodies; local or total fluid momentum in the pipe; development of the dual-purpose ("one-post") turbine meters; capable to measure simultaneously velocity and momentum of a two phase single or two phase flow.

7. Turbine meters; fluid velocity; development of the dual-purpose ("one-post") turbine meters; capable to measure simultaneously velocity and momentum of a two phase single or two phase flow.

8. Transit time meters/methods; fluid velocity; transient-flow techniques have to undergo mathematical and electronic improvements.

9. Radioactive tracer injection; velocities of both fluid phases and thus the global slip factor; application in calibration facilities.

10. Storz lens (visual observation); flow pattern; application in appropriate locations.

PRACTICAL ASPECTS OF TWO PHASE FLOW DATA INTERPRETATION

Although many comparisons are available which show the ability to measure two phase flow (See, for example, Fincke, 1978) the intent of the section is to illustrate some of the practical difficulties encountered in making two phase flow measurements. Most of these difficulties stem from not being able to make all desired measurements at a given location, from not being able to make measurements over a large enough region, or from an incomplete understanding of what an individual instrument measures.

LOFT provides a unique opportunity to measure two phase mass flow rates in transient conditions with several different instruments. A comparison was made of several different methods of measuring the integrated mass flow rate from both sides of the simulated pipe break of the LOFT L1-2 experiment (Robinson, 1977). The comparisons involve at each location a three beam gamma densitometer, a single drag disk turbine transducer placed at the pipe center and a differential pressure measurement across the 14 x 5 inch contraction in the pipe just downstream of the instrument penetration. The DTT rakes, described earlier, were installed for later experiments and were not available in the L1-2 experiment. The DTT covers only a small fraction of the pipe area. The mass flow, by necessity, is calculated by assuming homogeneous flow (that is equal phase velocities) and flat velocity, momentum and density profiles.

The four possible methods used to calculate mass flow rates from instruments in the broken loop were:

(1) Differential Pressure across Contraction - Gamma Densitometer

$$\dot{m}_1 = K_1 \sqrt{(\Delta P)_c \times (\bar{\rho})_{GD}}$$

(2) Drag Disc - Gamma Densitometer

$$\dot{m}_2 = K_2 \sqrt{(\rho V^2)_{DD} \times (\bar{\rho})_{GD}}$$

(3) Turbine Meter - Gamma Densitometer

$$\dot{m}_3 = K_3 (\bar{\rho})_{GD} \times (V)_{TM}$$

(4) Drag Disc-Turbine Meter

$$\dot{m}_4 = K_4 \frac{(\rho V^2)_{DD}}{(V)_{TM}}$$

where

$(\bar{\rho})_{GD}$ = the average density calculated from the three beams of the gamma densitometer

$(\rho V^2)_{DD}$ = the momentum flux as measured by the drag disc at the center of the pipe

$(V)_{TM}$ = the velocity as measured by the turbine meter at the center of the pipe

$(\Delta P)_c$ = the differential pressure across the 14 to 5-inch (215.6 to 127 mm) contraction in the pipe

K_i = the calibration constant derived from single phase, all water flow tests on the installed instruments.

The total mass outflow at any time is the integrated mass flow from both ends of the break. These four results are plotted in Figure 7. In addition, the total mass in the system upstream of the instrument penetration is known and plotted as a reference in this figure. There is a considerable amount of difference between the different methods. Because a check on the total mass is available, the hypothesis was made that a calibration factor can be obtained for each of these methods which is equal to the ratio of the total known mass to the calculated mass.

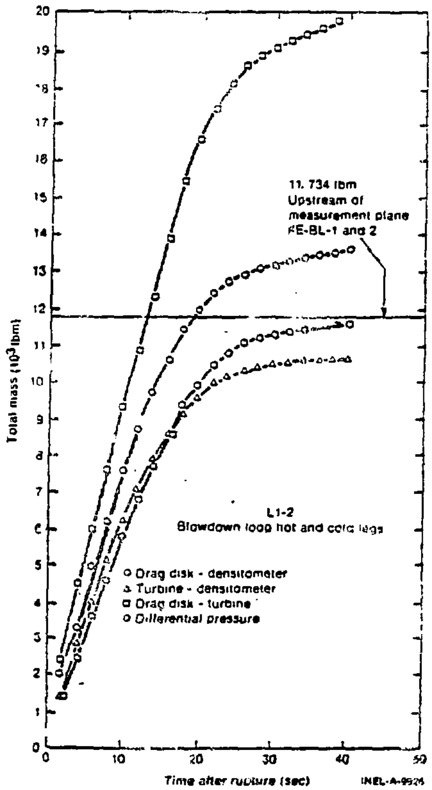


Figure 7. Comparison of Mass Flow Calculation Methods

While this normalization improves the agreement throughout the transient among the methods in the vessel side of the break, where essentially homogeneous flow exists, the pump side still shows that large errors exist in the local instantaneous flow rate even after normalization as shown in Figure 8 for L1-2 (Millar, 1976). This large remaining error leaves many practical problems. For example, it would be extremely difficult to characterize the resistance in the steam generator an pump simulator with the large uncertainty exhibited in these flow rate measurements.

The normalized results from the vessel side of the break are more encouraging since they not only agree between themselves but also with the semiscale counterpart experiments and the RELAP4 predictions.

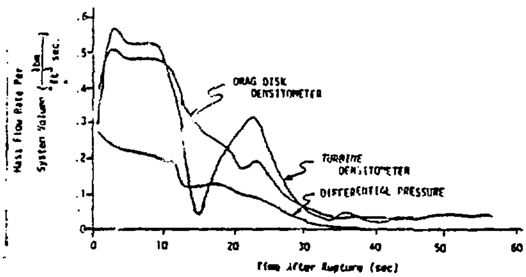


Figure 8. Comparison of Pump Side Mass Flow Rates After Normalization in L1-3

Figure 9 shows the comparison between the flow rates measured in the LOFT L1-3A experiment and the counterpart experiment (S-01-3) in the Semiscale facility. In addition, the RELAP4 prediction of this experiment is shown. The agreement between the two experiments is extremely good which gives some validity to the ability to scale between two different facilities of widely different size. The analytical predictions also agree very well until about 30 seconds, which corresponds to ECC injection. After this time, the predicted flow oscillates due to the known inability of the code to handle unequal temperature fluids.

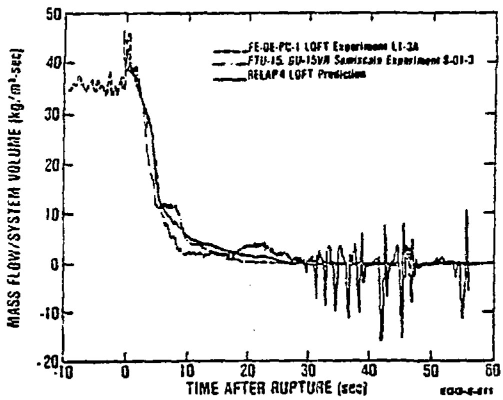
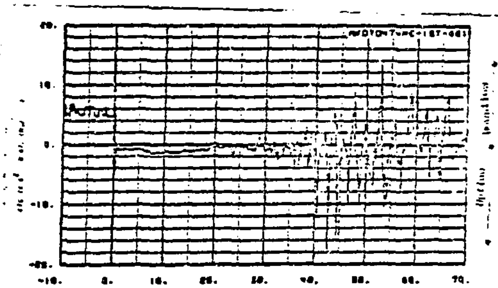
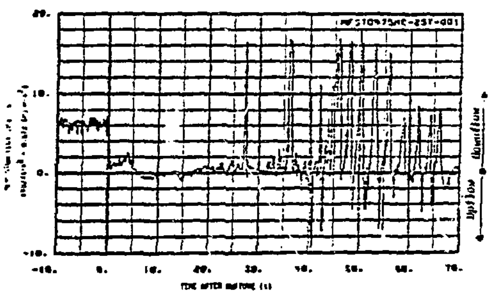


Figure 9. Mass Flow Comparisons of LOFT, Semiscale, and Predictions

Figure 10 shows the output of the drag disks at the bottom of the downcomer near the broken and intact loop cold legs for the L1-4 experiment (Batt, 1977). These curves illustrate a three dimensional flow pattern since most of the flow is downward near the intact loop and upward near the broken loop. This result is reasonable considering the location of the break. The liquid level devices confirm this three dimensional effect since the water level near the intact loop cold leg is higher than the level at the broken loop cold leg location. Due to the limited number of measurement locations in the downcomer, the entire three dimensional flow characteristics can only be hypothesized. For example, the amount of fluid which is traversing directly from the intact loop cold leg to the broken loop cold leg cannot be determined from the standard devices in the downcomer.



a. Momentum flux in reactor vessel downcomer near intact loop cold leg, 1.13 m above reactor vessel bottom ME-1ST-1 (filtered to 4 Hz).



b. Momentum flux in reactor vessel downcomer near broken loop cold leg, 1.13 m above reactor vessel bottom (ME-2ST-1) (filtered to 4 Hz).

Figure 10. Downcomer Momentum Flux in L1-4

Figure 11 illustrates typical output from the liquid level sensors in the LOFT downcomer for the L1-3A experiment (Millar, 1976). The output of these devices must be interpreted because it is not simply an on off signal. A discriminator level must be chosen to decide whether liquid or vapor is present. Residual water droplets are interpreted in some instances as solid water as can be seen from the output between 5 and 15 seconds. Since the measurement is made at several vertical levels, the interpretation can be made that steam is the continuous phase with water droplets causing sporatic contact. The water level in the system can be discerned reasonably well with this device if the "phantom signals" caused by these droplets are neglected.

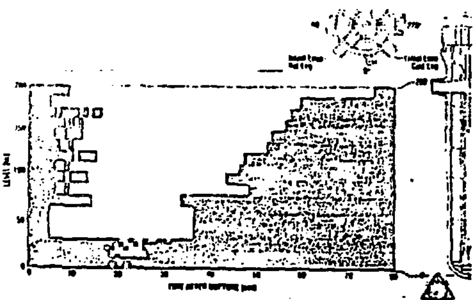


Figure 11. [illegible]

Figure 12 illustrates the mass flow rate uncertainty which can be encountered even if multiple DTT's are used. A comparison was made between two different methods of reducing the same data obtained with a gamma densitometer installed on a five-inch pipe in the Blowdown Facility located at the Idaho National Engineering Laboratory. Two steam-liquid interfaces are shown in Figure 11 which are both consistent with the gamma densitometer measurement. Hypothetical DTT locations are shown to illustrate that these could not be used to select which of two interfaces is correct. (A full-flow turbine meter was used to measure the velocity and a slip correlation was used to estimate the velocities of each phase.) Figure 12 illustrates that the error introduced by not knowing which of these two

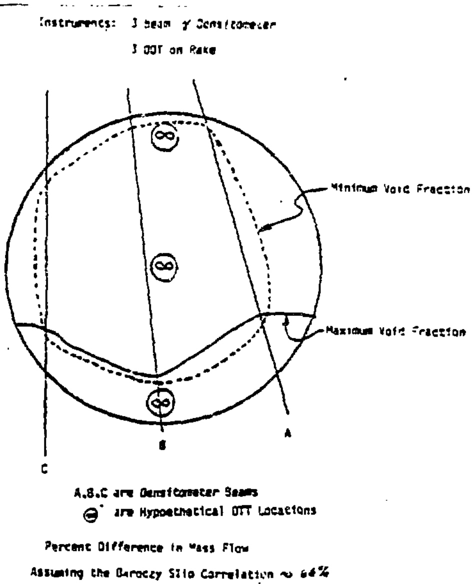


Figure 12. Difference Possible in Mass Flow Using the Same Data (From LOFT Blowdown Facility)

geometries exists is about 66 percent of the estimated flow rate. Of course, these two different interpretations are extreme and the actual situation is probably between these.

The measurement of fluid temperature can be performed satisfactorily if both phases are at saturation or if only one phase is present. If the fluid is a mixture of superheated steam and subcooled liquid, the thermocouple will usually measure the temperature of the liquid unless specially designed thermocouples are used to measure the steam temperature. If the thermocouple is in a steam environment where the walls are hotter than the steam, it can receive thermal radiation contributions. Figure 13 presents the behavior of three thermocouples in the intact loop in the L1-4 experiment. All three thermocouples follow the saturation temperature pressure history until 30 seconds. After 30 seconds, the cold liquid from the ECC mixes with the fluid in the cold leg and alternate slugs of hot and cold water are observed. Steam temperatures as well as hot wall effects are observed in the hot leg and steam generator outlet in this time period.

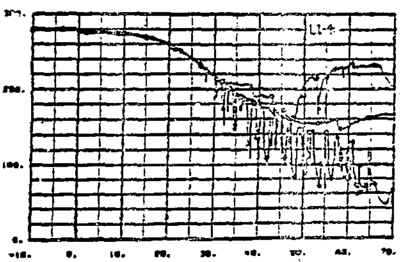


Figure 13. Temperature in Intact Loop Cold Leg, Hot Leg, and Steam Generator Outlet

The L1-4 density measurement in the intact loop cold leg is shown in Figure 14. The three beams are seen to diverge from 6 to 20 seconds indicating a stratified flow during this period. From 20 to 30 seconds, the density of steam is recorded. After 30 seconds, the alternate slugs of cold water and steam, observed on the thermocouple, are also seen in the densitometer. The densitometer measurements in the intact hot leg and steam generator outlet are shown in Figures 15 and 16 respectively. Density measurements corresponding to steam are observed after 30 seconds which account for the superheating observed in the thermocouple measurements.

The measurement of fuel surface temperatures is complicated by the requirement that the fuel rod may not be modified. If the fuel rods were modified, the gap conductance could be modified significantly which would affect the steady state stored energy and consequently the maximum temperature observed in a LOCA. The remaining alternative is to attach the thermocouple to the

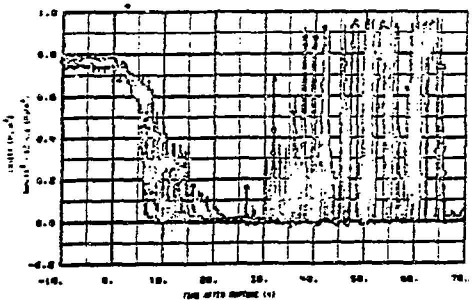


Figure 14. Density in Intact Loop Cold Leg, Chordal Density (three beams)

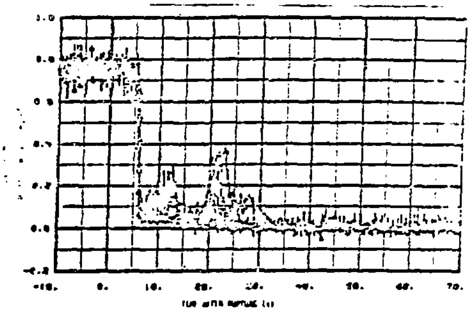


Figure 15. Density in Intact Loop Hot Leg, Chordal Density (3 beams)

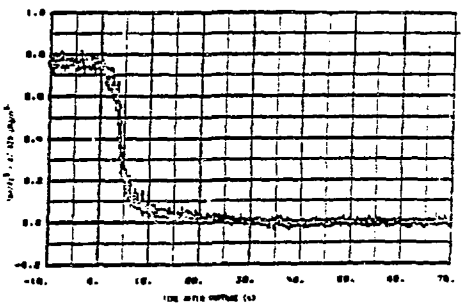


Figure 16. Density in Intact Loop at Steam Generator Outlet, Chordal Density (3 beams)

fuel clad surface. The method of attachment is very important since the danger of selective cooling by the liquid in the two phase mixture exists. The LOFT thermocouple has undergone a careful development program apparently yielding very successful results. Calibration tests were conducted in the Blowdown Facility to investigate the accuracy of these thermocouples. The tests simulated a LOFT blowdown. Figure 17 shows results of a representative experiment done on an electrically heated rod with both embedded and surface mounted thermocouples (Eaton, 1978). Figure 18 shows temperature difference. The agreement is seen to be very close with the difference being on the order of 10°C. The two spikes are due to time delays in the thermocouple during CHF and rewet.

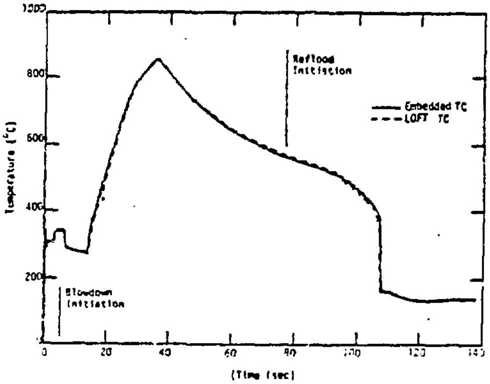


Figure 17. Temperature Comparison Between LOFT Type and Embedded Thermocouples

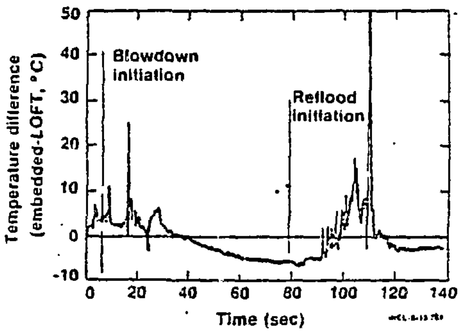


Figure 18. Temperature Difference History Between the Embedded and LOFT Type Thermocouples

This section has described representative results from two phase flow measurements and an indication of the state-of-the-art in interpreting these measurements.

CALIBRATION FACILITIES

The phenomenological calibration of two phase flow instruments can be seen to be very important from the previous discussion. Due to the high pressure, high temperature testing requirements, the facilities used for calibration can be quite extensive. LOFT has used several facilities for this purpose. A low pressure, low temperature small-pipe size air water facility has been used to test out principles. A small pipe, high temperature and pressure steam water facility in Karlsruhe Germany has been used to investigate the difference between steam water and air water calibrations. These data indicate that steam water calibrations are not easily relatable to air-water data. The Blowdown Facility has been used to investigate the effects of transient two phase behavior in small pipes. The FAST loop has been used to investigate the effect of pipe size in high pressure, high temperature single phase water. Currently, both steady state and transient facilities are being constructed which will allow high temperature, high pressure steam-water testing in full size LOFT pipes.

CONCLUSIONS

The measurement of two phase flow properties under adverse conditions which include high temperature, high pressure, fast transient conditions is an imposing task. A considerable improvement in this capability has occurred within the past few years. Improvements are still needed, however, in the capability of current instruments, the number of measurements made at a given location, the number of instruments which can be distributed through the experiment without completely changing the experiment, and the interpretation of the data. Current development efforts are improving the current situation and the completion of phenomenological calibration facilities now under construction will improve the understanding of what is being measured.

REFERENCES

(1) Ball, L. J., Hanen, D. J., Dietz, K. A., and Olson, D. J., "Semiscale Program Description," U.S. Nuclear Regulatory Commission, TREE-NUREG-1210, May 1978

(2) Batt, D. L., "Experimental Data Report for LOFT Non-nuclear Test L1-4," U.S. Nuclear Regulatory Commission, TREE-NUREG-1048, July 1977

(3) Fincke, J. R., "Development of the LOFT Prototype Drag Screen-Air-Water Testing," TREE-NUREG-1198, U.S. Nuclear Regulatory Commission, May 1978

(4) Millar, G. M., "Experimental Data Report for LOFT Non-Nuclear Test L1-3A," U.S. Nuclear Regulatory Commission, TREE-NUREG-1027, December 1976

(5) Millar, G. M., "Experimental Data Report for LOFT Non-Nuclear Test L1-3," U.S. Nuclear Regulatory Commission, TREE-NUREG-1065, April 1977

(6) Reeder, D. L., "LOFT System and Test Description," U.S. Nuclear Regulatory Commission NUREG/CR-0247, July 1978

(7) Robinson, H. C., "Experimental Data Report for LOFT Non-Nuclear Test L1-2," U.S. Nuclear Regulatory Commission, TREE-NUREG-1026, January 1977

(8) Ybarrondo, L. J.; Solbrig, C. W.; Isbin, H. S., The "Calculated" Loss-of-Coolant Accident: a Review, AIChE Monograph Series No. 7, 1972