CAAP-TR-78-028
September 1978

CODE VERIFICATION AND APPLICATIONS PROGRAM

PRESSURIZER COMPONENT STUDIES WITH RELAP4/MOD6

by
T. D. Knight

NRC Research and Technical Assistance Report

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

CAAP-TR-78-028
September 1978

PRESSURIZER COMPONENT STUDIES
WITH RELAP4/MOD6

by
T. D. Knight

ABSTRACT

This report presents the results of the independent assessment studies of the RELAP4/MOD6 computer code for the pressurizer component during the blowdown phase of the loss-of-coolant accident. RELAP4 pressurizer component models were driven with measured boundary conditions from Semiscale and LOFT blowdown experiments, and the results were compared to test data. The sensitivity of the calculated results to model nodalization, code options, and uncertainty in the boundary conditions was determined.

SUMMARY

This report describes the assessment of the RELAP4/MOD6 computer code for predicting pressurizer component behavior during simulated loss-of-coolant accidents. The assessment process involved comparing calculations of pressurizer component models with data from Semiscale Test S-04-4 and LOFT Test L1-4. A separate calculation to study thermal stratification was compared with Semiscale Test S-06-5. The two Semiscale tests were heated blowdown tests simulating large cold leg breaks. The LOFT test was an isothermal blowdown simulating a large cold break.

The RELAP4 component models were driven with time dependent measured boundary conditions. The base run models were developed consistent with modeling guidelines established during code checkout.

The base run models for both Semiscale Test S-04-4 and LOFT Test L1-4 over predicted mass flow leaving the pressurizer. This overprediction resulted in the early emptying of the pressurizer, relative to the data.

A number of additional runs were made in order to investigate the observed deficiencies in the base run models. These studies indicated that the compressible momentum equation and improved modeling of critical flow provided modest improvements in the comparisons. However, the problem of the overprediction of flow rates was not resolved. The solution appears to involve high Reynolds number, high void fraction flow through bends and elbows, with resulting higher losses.

The base run models were more finely noded than typical pressurizer models in system calculations. In addition, heat transfer in the pressurizer was also modeled. A sensitivity study indicated that heat transfer had only a minor effect on the data comparisons and therefore can be ignored.

The system type, simplified nodalization of the pressurizer produced better comparisons than the base run calculations and most of the sensitivity studies with the detailed nodalization. This result is due to the modeling guidelines for system calculations forcing a compensating modeling error for the pressurizer component. This compensating error is revealed in increased friction factors and thus lower flows.

Finally, it is recommended that future assessment studies of pressurizer component behavior be delayed until the sensitivity of important system parameters on the pressurizer performance is determined. This sensitivity information is necessary for specifying adequate performance criteria for the pressurizer component.

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

This study represents part of the initial effort to apply assessment techniques to the RELAP4/MOD6 [1] computer code (INEL Computer Center Configuration Control Numbers C0010005 for this version of the code and H002011B for the associated steam tables [2]). Code Assessment is a new field of study and is presently being developed into a structured process. The initial objectives of this effort were as follows:

(1) to explore and develop optimum techniques, rules and guidelines for performing the assessment of codes [3]; and

(2) to apply these techniques, rules and guidelines to the RELAP/MOD6, Update 3 code to understand the components of a successful code assessment and to gain further knowledge about the quality of the code.

At the time this study began, RELAP4/MOD6 had not been released to the Argonne Code Center; therefore, these comparisons must be considered as code checkout. However, the analyses were treated in the structured manner of the assessment process, one of the first steps of which is to develop a matrix (Table I) identifying the complete scope of effort. As shown in the table, that scope includes analyses of component, system and integral blowdown and reflood phenomena. This report presents the results of pressurizer component studies performed for the PWR (pressurized water reactor) blowdown portion of the code assessment of RELAP4/MOD6 as shown in subtask 2 of Table I.

Specific ground rules were formulated prior to all analyses. These ground rules covered modeling techniques, code option selection, and code user input values and were based on the best published (and unpublished) information available. Sources used were the NRC guidelines for assessment of codes [3], the limited guidelines for model

TABLE I

MATRIX FOR CODE ASSESSMENT

OF RELAP4/MOD6

	EXPERIMENTS SELECTED	FEATURES EVALUATED								
		BLOWDOWN HEAT TRANS. & HYDRAULICS	REFLOOD HEAT TRANS. AND HYDRAULICS	FUEL BEHAVIOR	SCALING EFFECTS	DIFFERENT SYSTEMS	TEST PREDIC-TION	COMPONENT EFFECTS	SYSTEMS EFFECTS	INTEGRAL EFFECTS
1. SEMISCALE, THTF CORE BLOWDOWN	SEMISCALE S-06-5, THTF 105	X				X		X		
2. SEMISCALE, LOFT PRESSURIZER BLOWDOWN	SEMISCALE S-04-4, S-06-5, LOFT L1-4				X	X		X		
3. SEMISCALE, LOFT STEAM GENERATOR BLOWDOWN	SEMISCALE S-01-4A, S-06-5, LOFT L1-4				X	X		X		
4. STANDARD PROB. 7 LOFT L1-4	LOFT L1-4						X		X	
5. SEMISCALE, LOFT ISOTHERMAL COMP.	SEMISCALE S-01-4A, LOFT L1-4				X	X			X	
6. SEMISCALE, FLECHT CORE REFLOOD	SEMISCALE S-03-0, FLECHT LFR 4019, 11003		X			X		X		
7. SEMISCALE, FLECHT-SET, PKL COMP.	SEMISCALE S-03-5 FLECHT-SET 27148 PKL K5A		X		X	X			X	
8. PKL PREDICTION	PKL K5A		X				X		X	
9. SEMISCALE INTEGRAL EXPERIMENTS (6)	SEMISCALE S-04-5, S-04-6, S-06-1, S-06-2, S-06-5, S-06-6	X	X						X	X
10. MARVIKEN CRITICAL FLOW TESTS	T30				X			X		
11. SEMISCALE MOD-3 BLOWDOWN	SEMISCALE S-07-1	X				X	X		X	
12. SEMISCALE MOD-3 REFLOOD	SEMISCALE S-07-4		X			X	X		X	
13. SEMISCALE MOD-3 INTEGRAL	SEMISCALE S-07-4	X	X			X	X		X	X
14. PBF LOCA SERIES	LOC-11, LOC-3	X		X				X		
15. ADDITIONAL THTF TEST (Extension to Subtask	THTF 177	X					X	X		
16. LOFT L1-5 PREDICTION	LOFT L1-5						X		X	
17. ADDITIONAL SEMI-SCALE, FLECHT CORE REFLOOD (Extension to Subtask 6)	SEMISCALE S-03-4 FLECHT LFR 2414, 13404, 13609		X			X		X		
18. ADDITIONAL SYSTEM REFLOOD TESTS (Extension to Subtask 7)	SEMISCALE S-03-6, FLECHT-SET 22128 PKL K7A		X		X	X			X	

and option selection given in the RELAP4/MOD5[4] and RELAP4/MOD6[1] manuals, and consultations with code developers and with Semiscale, LOFT, code checkout and assessment personnel. The use of a fixed set of ground rules was necessary to avoid any appearance of code tuning during the base runs, and to provide consistency between the several models.

In addition to the RELAP4 fluid equations, the effects of the following significant options were investigated: heat transfer, phase separation in volumes, critical flow, rough wall friction, and the two-phase friction multiplier. The effects of nodalization and boundary condition uncertainty were also considered.

Data from two Semiscale MOD-1 tests and one LOFT test were used in this study. Section II describes the experimental facilities and test selection. Section III describes the base case RELAP4 input models; the results of the comparisons of the base case models to data are described in Section IV. Section V gives the results of certain additional comparisons that were conducted to investigate problem areas detected in the base case comparisons. Section VI contains the conclusions and recommendations that resulted from the study.

II. EXPERIMENTAL FACILITIES

The Semiscale Program[5] and the LOFT Program[6] are conducted by EG&G Idaho, Inc. for the United States Govenment. The programs are sponsored by the Nuclear Regulatory Commission through the Department of Energy and are part of the overall program designed to investigate the response of the pressurized water reactor system to a hypothesized LOCA (loss-of-coolant-accident). Both programs are intended to provide integral system test data for thermal-hydraulic code assessment.

1. SEMISCALE

The objectives of the Semiscale program are to quantify the physical processes controlling system behavior during a LOCA and to provide an experimental data base for assessing reactor safety analysis methods. The Semiscale Mod-1 program has the further objective of providing support to other experimental programs in the form of instrumentation assessment, optimization of test series, selection of test parameters, and the evaluation of test results.

1.1 Facility Description

A description of the overall Semiscale program and test series with a detailed system description can be found in Reference 5. The major components of the system are shown in Figure 1. As shown in Figure 1, the pressurizer is attached to the intact loop hot leg piping upstream of the steam generator.

Figure 2 shows a schematic of the Semiscale pressurizer. The pressurizer consists of a vertically oriented cylindrical tank with 32 vertical electrical heater rods that extend from near the bottom of the pressurizer through the top. At steady state initial conditions

for a blowdown test, a liquid level (liquid-vapor interface) exists within the pressurizer. Connected to the bottom of the pressurizer are piping sections containing a fluid thermocouple, a gamma densitometer, and a turbine flow meter. The surge line connecting the pressurizer to the intact loop piping (not shown in Figure 2) is 3/8 inch nominal stainless steel tubing (inside diameter of 0.739 cm). The surge line is 3.05 m long and makes four 90° bends, one 45° bend, and one 15° bend.

In the Semiscale Mod-1 system there is no provision for circulating water through the pressurizer prior to the test, and the possibility exists for the liquid in the pressurizer to stratify thermally.

1.2 Test Selection

Criteria for selection of the Semiscale experiments included PWR typicality (based on the BE/EM study[7]), similarity to the LOFT experiment, ability for exercising the code, and correct performance of instrumentation. Tests from Series 4 (ECC Baseline) and Series 6 (LOFT counterpart) were considered. Test S-04-4 was selected for the base case comparisons because the thermal stratification in the pressurizer and surge line was not as severe as in other tests. Test S-06-5 was selected for a sensitivity study with simple nodalization (a pressurizer model similar to that used in system calculations) to determine the effect of thermal stratification. The data for Tests S-04-4 and S-06-5 are reported in References 8 and 9, respectively. The tests simulated the system response to a 200% double ended cold leg break from a system pressure of 15.6 MPa and an intact hot leg temperature of 590 K.

1.3 Measurements and Accuracy

Semiscale instrumentation and associated uncertainties pertinent to the pressurizer data comparisons are given in Table II. The uncertainties are based on the information contained in References 10 and 11; the uncertainties do not include the effects of nonhomogeneous, transient, two-phase flow and thus must be considered unrefined estimates.

2. LOFT

One of the primary objectives of the LOFT Program is to provide data required to evaluate the adequacy of and to improve the analytical methods currently used to predict the LOCA response of LPWRs.

2.1 Facility Description

A description of the overall LOFT program and test series with a detailed system description can be found in Reference 6. The major components of the system are shown in Figure 3. As with the Semiscale system, the pressurizer is connected to the intact loop hot leg piping upstream of the steam generator.

Figure 4 shows the LOFT pressurizer assembly. The pressurizer consists of a vertically oriented cylindrical tank similar to that in Semiscale. However, there are 12 electrical heaters oriented horizontally as compared to the 32 vertical heaters in Semiscale. In the steady state operating condition there is a spray bypass flow from downstream of the primary pumps that is injected at the top of the pressurizer. This spray bypass flow results in a slow circulation of fluid through the pressurizer and minimizes any thermal stratification.

TABLE II

SEMISCALE INSTRUMENTATION

Measurement	Instrument Designation*	Estimated Uncertainty**
Boundary condition pressure in the intact loop hot leg, based on nearest reliable measurement	PV-UP+10 for S-04-4 PV-LP-166 for S-06-5	0.1 MPa
Pressurizer pressure in the steam dome	PU-PRIZE	0.1 MPa
Pressurizer fluid temperature, in the surge line near the pressurizer exit	TFU-PRIZE	3 K
Pressurizer fluid density, in the surge line near the pressurizer exit	GU-PRIZE	16 kg/m^3
Volumetric flow rate in the surge line below GU-PRIZE	FTU-PRIZE	0.0001 m^3/s
Mass flow rate in the surge line	FTU-PRIZE & GU-PRIZE	0.08 kg/s
Differential pressure between pressurizer top and intact loop hot leg piping	DPU-PR-4	0.1 MPa

* Instrument designations are consistent with the nomenclature of the Semiscale data reports.

** Estimated two standard deviation value.

The surge line in LOFT is fabricated from 2 inch Schedule 160 stainless steel pipe and elbow fittings. The surge line inside diameter is 4.30 cm, and the length is 6.43 m. There are nine 90° elbows in the line.

There are three sets of differential pressure taps around the pressurizer for measuring liquid level in the pressurizer. There are also two thermocouples, one to measure liquid temperature and the other vapor temperature in the pressurizers. There is a differential pressure measurement along the length of the surge line.

2.2 Test Selection

LOFT Test L1-4 was selected because it was the only LOFT cold leg break test for which data were available at the initiation of this study and had not been used in code checkout. Test L1-4 was an isothermal blowdown from a system pressure of 15.65 MPa and temperature of 553 K; a 200% double ended cold leg break was simulated. The test data are contained in Reference 12.

2.3 Measurements and Accuracy

LOFT instrumentation and associated uncertainties pertinent to the data comparisons for this study are given in Table III. The uncertainties in the LOFT data are currently under evaluation by the LOFT program. The uncertainties listed in Table III are estimates based on information contained in Reference 12.

TABLE III

LOFT INSTRUMENTATION

Measurement	Instrument Designation*	Estimated Uncertainty**
Boundary condition pressure in intact hot leg	PE-PC-2	0.2 MPa
Pressure in pressurizer	PE-PC-4	0.2 MPa
Liquid level in pressurizer	LT-P139-6 LT-P139-7 LT-P139-8	0.04 m 0.04 m 0.04 m

* Instrument designations are consistent with the nomenclature of the LOFT data reports.

** Estimated two standard deviation value.

III. BASE RUN MODELS

The base run models for both the Semiscale pressurizer and the LOFT pressurizer were developed with the same modeling philosophy. The volumes were dictated by geometric details, with separate volumes representing geometrically distinct regions. It was recognized that the base run models would be more finely noded than would be practical in system calculations, and coarser nodalizations will be addressed in Section V. Code options were identical for both base run calculations. The input decks, including control cards, necessary for all calculations reported for this study are contained on file with the INEL Computer Center under Historical Configuration Control No. H003621B.

1. NODALIZATION

The Semiscale pressurizer nodalization is shown in Figure 5 and consists of five volumes. Volume 1 represents the pressurizer. Volume 2 at the exit from the pressurizer is the piping section that contains both the gamma densitometer and the fluid temperature thermocouple. Volume 3 is the piping section with the turbine flowmeter. The surge line is represented by Volume 4, and the section of intact loop hot leg piping is represented by the time dependent Volume 5.

There are two stacks of heat slabs in Volume 1. One stack of six heat slabs represents the vertical heater rods; the second stack of six slabs represents the pressurizer vessel wall mass. The volume flow area was adjusted to take account of the heater rods.

The surge line is represented as a single volume even though there are six bends in it. Because the bends are spaced along the entire length of the surge line and in order to obtain benefit from the frictional two-phase multiplier during two phase flow, the bends

were converted to an equivalent l/d [13], which incorporated a correction factor [14] that relates the two-phase flow effect in a bend to that in straight pipe. (In the base case calculation significant voiding of the surge line had occurred by one second.) The surge line equivalent diamete was adjusted to maintain the length.

The LOFT pressurizer nodalization is shown in Figure 6. The LOFT model consists of the following four volumes: Volume 1 is the pressurizer; Volume 2 is surge line nozzle; Volume 3 is the surge line; and Volume 4, which is time dependent, represents a section of intact hot leg piping. There is a single stack of six heat slabs in Volume 1; the horizontal heaters were lumped with the wall mass at appropriate elevations in the heat slabs. The nine 90 bends in the surge line have been converted to equivalent l/d's as with the Semiscale surge line.

2. CODE OPTIONS

For the base run calculations complete separation (via a bubble rise velocity of 3.05 x 10^5 m/s) was specified in the pressurizer volume (volume 1 in both models); the remaining volumes were homogeneous. The incompressible form of the momentum equation was specified at each junction, and vertical slip was not used. Choking was allowed at each junction with 1.0 x HEM (homogeneous equilibrium critical flow model). Heat transfer was calculated with the blowdown heat transfer surface HTS2. Rough wall friction was used.

As explained in Section III.1, the equivalent diameter was changed (decreased) in order to incorporate into the friction term the pressure losses associated with the bends and elbows in the surge lines. The reduction in the equivalent diameter increased the ratio of the roughness to equivalent diameter, and because rough wall friction is a fucntion of that ratio, the magnitude of the rough wall

friction was increased artificially. The rough wall friction factor multiplier (on card 082020) was used to offset the increased friction due to the altered equivalent diameter. Also, for Semiscale the rough wall friction factor multiplier was used to account for the reduced roughness in the surge line, which is drawn tubing.

The intact hot leg piping volume in each model utilized the time dependent conditions option in order to specify the proper boundary conditions on the models.

3. BOUNDARY CONDITIONS

The pressurizer models were initialized at zero flow. During the transient, the flow at the junction between the surge line and the hot leg piping (junction 4 for Semiscale and 3 for LOFT) is always into the hot leg. Therefore, the pressure in the hot leg volumes is the only controlling boundary condition on the pressurizer response. Figure 7 shows the pressure as a function of time for the Semiscale hot leg; this pressure curve was input to the Semiscale model. Figure 8 shows the hot leg pressure boundary condition input to the LOFT model.

IV. BASE RUN RESULTS

This section describes the comparisons of the calculations with the base run models described in Section III to the appropriate test data. The comparisons for the base run calculations are more extensive than for the remaining calculations described in Section V. The purpose of the comparisons in this section is to describe completely the response of the calculations relative to the data. Both calculations in this section began at time zero and ended on normal end of problem trips.

1. SEMISCALE TEST S-04-4

Figure 9 through 14 show comparisons between the base run calculation for the Semiscale pressurizer and appropriate data. Figure 9 shows the pressure history comparison for Volume 1, the pressurizer volume. While the depressurization rates agree closely early, the calculated pressure indicates emptying to occur at approximately 8 s compared 11 s in the data.

Figure 10 compares the calculated fluid temperature in Volume 2 to the data. The fluid in this volume is initially subcooled almost 50 K but warms to saturation at one second; the calculation shows saturation at 2 s. This small difference is probably due to a point measurement in a poorly mixed fluid as opposed to the volume averaged calculated value. The difference in emptying times is reflected by the temperature comparison. Both calculation and data show superheated vapor occurring late in the transient as a result of heat transfer in the pressurizer.

Figure 11 compares the calculated and measured density at the exit from the pressurizer; the behavior during the first 2 s reflects the temperature behavior. The data clearly indicates that the code

underpredicted the time of emptying (8 s versus 10 s). The measured density, because of the discrete nature of the measurement and its location, gives a good indication of the emptying time for this test. Except for the difference in emptying time, the comparison is very good. The slight difference between calculation and data between 11 and 16 s reflects the difference in the pressure comparison (see Figure 9).

Figure 12 gives the comparison between calculated volumetric flow and the data. From 2 s until the calculation shows emptying, the code overpredicts the data and is consistent with the early emptying time. The data trace after 11 s is not representative of the behavior in other tests, in which trends are similar to the calculation. Figure 13 shows the mass flow comparison, which reflects the differences in the volumetric flow comparisons. Relative to other Semiscale Mod-1 tests, the calculation underpredicts the data after emptying instead of overpredicting as shown in Figure 13.

2. LOFT TEST L1-4

Figure 14 compares the data to the calculated differential pressure from the pressurizer to the hot leg piping. Again the comparison is good until emptying is calculated to occur. All comparisons demonstrate an early depletion and flows that are too high prior to emptying.

Figures 15 and 16 depict the performance of the base run analysis for LOFT test L1-4. Figure 15 is the pressurizer pressure comparison; this comparison is similar to the pressure comparison for Test S-04-4. The calculated emptying time is 11 s compared to 13 s indicated by the data.

Figure 16 shows the comparison of calculated and measured liquid levels in the pressurizer and confirms the behavior exhibited in the

pressure comparison previously. (Note that there are three measurements of this parameter; additional comparisons of liquid level will be to the middle data trace that indicates emptying between 13 and 14 s.

The LOFT L1-4 base run comparison supports the conclusions from the Semiscale S-04-4 comparisons: the calculated flows are too high prior to emptying and the pressurizer is calculated to empty early.

V. ADDITIONAL STUDIES

Additional studies were conducted to investigate three different areas. The first area involves the capability of the thermal hydraulic model, RELAP4/MOD6, to simulate the pressurizer performance. The second area addresses the effect of nodalization and boundary condition uncertainty on the comparison and relates the calculations to pressurizer nodalization appropriate for system models. The third area concerns the effect of thermal stratification on the calculation capability. All calculations in this section were ended on normal end of problem trips.

1. CODE OPTION SENSITIVITY

Because of the large frictional pressure drop from the pressurizer to the hot leg, the validity of the two-phase friction factor model was checked. Sahota[11] states that the range of the two-phase friction factor is from 0.35 to 1.65 times the correlation in RELAP4/MOD6 for 99% of the applicable data. A calculation was made with the two-phase friction factor multiplier set to 1.5 in order to increase the frictional effects. Figures 17 through 20 show the effect of the change on the Semiscale S-04-4 and LOFT L1-4 comparisons.

For Semiscale, the pressure comparison, Figure 17, is good throughout the transient. The mass flow, as shown in Figure 18, is still overpredicted before the pressurizer emptied, although the comparison is much improved from the base case comparison. The LOFT pressurizer pressure comparison, Figure 19, is also very good. The liquid level comparison, Figure 20, is much improved over the base case comparison. In both Semiscale and LOFT the time at which the pressurizer empties is now calculated well.

Although the data comparisons are much improved, the magnitude of the change required in the two-phase friction factor is large relative to the data uncertainty, and other sources of modeling deficiencies should be investigated.

Because of the large pressure drop from the pressurizer to the hot leg piping and the flashing that takes place in the surge line, the effect of critical flow at the exit from the surge line was investigated. In the base run analyses, choking did not occur. In order to improve the calculation of fluid conditions that are input into the critical flow calculation, the surge line was divided to provide a small volume at the exit. Also, the coefficient on the HEM critical flow model was changed from 1.0 to 0.8. Critical flow was then calculated to occur at the exit from the surge line; and the comparisons improved over the base case, but not to the extent shown in Figures 17 through 20 previously. To reproduce the comparisons in Figures 17 through 20, a two-phase friction factor multiplier of 1.3 was required instead of the 1.5 previously. Clearly, proper calculation of critical flow, including the appropriate stagnation conditions, is important to calculated pressurizer performance.

The sensitivity of the calculated behavior to heat transfer in the pressurizer volume was checked by rerunning the calculations with a two-phase friction factor multiplier of 1.5 and no heat slabs. The comparisons were quite similar to those shown in Figures 17 through 20. For Semiscale Test S-04-4, the calculated pressure prior to emptying decayed marginally faster (a change of about 1 MPa at 10 s) and the flow rate was 1 kg/s lower from 4 to 10 s. Hence, the calculated emptying time increased about one second. For LOFT, there was no change in the comparisons due to the removal of the heat slabs. Relative to the deficiencies noted in the base run comparison in Section IV, the heat slabs are not important to the calculated performance of the pressurizers. However, without slabs the fluid temperature late in the transient will not exhibit superheat as seen in the data (see Figure 10).

The final code option that was varied was the form of the momentum equation. The base run model had specified the incompressible form of the momentum equation. Calculations with the compressible form of the momentum equation at all junctions and a two-phase friction factor multiplier of 1.5 were run. The comparisons are slightly improved over those shown in Figures 17 through 20. For both Semiscale and LOFT the calculated pressures were about 0.3 MPa higher than the previous calculations shown in Figures 17 and 19. Marked improvement was seen in the calculated mass flow rate for Semiscale (Figure 21) between 2 and 10 s. For LOFT, the calculated liquid level (Figure 22) shows the same emptying time of 14 s as exhibited by the data trace (recall that this trace lies between the other two as shown in Figure 16). The compressible form of the momentum equation should be used at junctions between volumes with correctly specified volume flow areas in order to calculate the momentum flux effects due to area changes.

2. NODALIZATION AND BOUNDARY CONDITION UNCERTAINTY EFFECTS

The base case pressurizer nodalizations described in Section III.1 are too finely noded to be practical in whole system models. A more typical pressurizer nodalization for system models is shown in Figure 23. Such models were set up for Semiscale Test S-04-4 and LOFT L1-4. No heat slabs were used.

The compressible form of the momentum equation was specified at junction 1, and the incompressible form at junction 2 (because the correct volume flow area appropriate for junction 2 flow is not normally specified in the hot leg piping volume. The homogeneous equilibrium choking model with a coefficient of 1.0 was specified at both junctions. Because the models were intended to reflect system modeling considerations, the two-phase friction factor multiplier and the rough wall friction factor multiplier were defaulted to 1.0.

The models were run, and the comparisons of the calculations to data are shown in Figures 24 through 27. The pressurizer pressure comparison for S-04-4, Figure 24, is excellent except for a small (approximately 2 s) apparent discrepancy in the emptying time. The mass flow comparison in Figure 25 supports the observations of a generally good comparison except for the difference in emptying time (recall from Section IV.1 that the data after 12 s is inaccurate).

The pressurizer pressure comparison for L1-4 is shown in Figure 26; the comparison is excellent with the calculation and data nearly overlaying throughout the transient. The liquid level comparison for L1-4 indicates that prior to emptying the code underpredicts the liquid level, but the difference in emptying time is only one second.

In general, the comparisons of the system type pressurizer model are superior to the base case comparisons discussed in Section IV. In Section V.1, it is demonstrated that additional effective resistance (through two-phase friction factor, choking, and momentum flux contributions) is needed to improve the comparisons.

For the system type models, the compressible form of the momentum equation, with momentum flux terms, was invoked. The other difference is that the rough wall friction factor multiplier was defaulted to 1.0 instead of being used to maintain the surface roughness to diameter ratio for the surge line. As explained in Section III.2, the result of defaulting the rough wall friction factor multiplier is to impress a friction multiplier on the calculation that, for both cases, approximated the two-phase friction factor multiplier used in Section V.1. Hence, the assumptions for the system model tend to balance deficiencies in the hydraulic calculations of pressurizer behavior.

An additional calculation was made with each model with the time dependent volume (Volume 3) pressure reduced by the uncertainties shown in Tables II and III. The results were virtually identical to the results shown in Figures 24 through 27. The uncertainty in the pertinent boundary condition has no effect on the calculated behavior. The uncertainty in the initial liquid inventory will have a significant, almost linear, effect on the calculated emptying time. Because the effect is obvious, the uncertainty in initial inventory was not considered in the calculations.

Finally, the assumption of complete separation in the pressurizer volume was checked by specifying the Wilson bubble rise model instead of complete separation. There were no significant differences (less than 1 s) observed in the calculated time of emptying. The mixture level swelled slightly over the complete separation case; in LOFT L1-4, the maximum swell amounted to about 0.2 m between 3 and 5 s.

3. THERMAL STRATIFICATION EFFECTS

In the Semiscale Test S-04-4, the fluid temperature measurement at the exit from the pressurizer indicates that initially the liquid at that location was subcooled about 49 K. The effect of this subcooling, which conceivably might extend into the pressurizer, was checked with the system type pressurizer model shown in Figure 23.

For this additional comparison, Semiscale Test S-06-5 was selected. The data for this test indicates that the subcooling is approximately 91 K, nearly twice the subcooling for S-04-4. In the calculation, the pressurizer was saturated at the measured pressure, and the surge line temperature was set at the measured value.

Figure 28 shows the pressurizer pressure comparison. The calculated pressure is low at 10 s, but both data and calculation indicate

emptying at 10 s. Figure 29 is the mass flow comparison and supports the observations made for Figure 28. The comparisons are similar to those for the S-04-4 system type model (Figures 24 and 25). Based on these calculations, thermal stratification in the pressurizer and surge line is not a significant phenomena that requires special modeling consideration.

VI. CONCLUSIONS AND RECOMMENDATIONS

1. *The predictive capabilities of the RELAP4/MOD6 hydraulic models are deficient with regard to pressurizer behavior. It is recommended that the frictional pressure drops associated with high Reynolds number, high void fraction flow through bends and elbows be investigated.*

As shown in Section IV the base case models for both Semiscale and LOFT overpredict the mass flow leaving the pressurizer and result in an early emptying time. In order to produce reasonable hydraulic comparisons, the two-phase friction factor must be forced to the extreme of its range (Section V.1); because of the large change required, the differences in the comparisons are probably not the result of reasonable uncertainty in the two-phase friction factor model. Critical flow, if properly modeled, offers a potential improvement in the comparisons. The compressible form of the momentum equation with the momentum flux terms should also be used at all junctions (assuming that the volume flow areas are properly defined).

After all modeling improvements had been made, a residual two-phase friction factor multiplier remained, and representing approximately a two standard deviation change, it was unacceptably large. Other phenomena for which there is no corresponding model in RELAP4 must be taking place. The flows in the surge lines were large with significant void fraction. Because of the bends/elbows in the surge line, it is recommended that the effects of high Reynolds number, high void fraction flows through such geometries be investigated as a possible source of the discrepancies.

2. *The system type models of the pressurizer resulted in better comparisons to data than the more detailed base run models because of a compensating effect of the system model assumptions.*

As discussed in Section V.2, the comparisons with the system type pressurizer models were better than the base run models and most of the change cases considered. The surge lines were modeled in all cases with the same philosophy (Section III.1 and 2): calculate an equivalent length to diameter ratio for the bends and elbows and adjust the equivalent diameter of the surge line to maintain the new length to diameter ratio. In the detailed component models, the rough wall friction factor multiplier was used to maintain the roughness ratio consistent with actual roughness and equivalent diameter; in the simplified system type models, the multiplier was set to 1.0 as for system models. This 1.0 multiplier, as explained in Section V.2, results in significant additional friction, which does not occur in the detailed models.

In Section V.1 the heat tran[illegible] removed from the base run models and found to have only m[illegible] effect. The heat slabs should not be used in problems for which [illegible]er problem dimensions or computer time is a concern.

3. *It is recommended that the sensitivity of important system parameters such as peak clad temperature and core flow to pressurizer performance be determined.*

This sensitivity study is necessary in order to determine the predictive requirements for pressurizer behavior, and it should be completed prior to additional assessment studies involving the pressurizer component.

VII. REFERENCES

1. RELAP4/MOD6 A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems User's Manual, CDAP TR 003 (January 1978).

2. K. V. Moore, ASTEM - A collection of FORTRAN Subroutines to Evaluate the 1967 ASME Equation of State for Water/Steam and Derivatives of These Equations, ANCR - 1026 (October 1971).

3. S. Fabic, Ltr to Distribution, Independent Verification of Codes, United States Nuclear Regulatory Commission, (November 18, 1977).

4. RELAP4/MOD5 A Computer Program for Transient Thermal - Hydraulic Analysis of Nuclear Reactors and Related Systems User's Manual, ANCR-NUREG-1335 (September 1976).

5. E. M. Feldman and D. J. Olson, Semiscale Mod-1 Program and System Description for the Blowdown Heat Transfer Tests (Test Series 2), ANCR-1230 (August 1975).

6. H. C. Robinson, LOFT System and Test Description (Loss-of-Coolant Experiments Using a Core Simulator), TREE-NUREG-1019 (November 1976).

7. G. W. Johnsen et al, A Comparison of "Best Estimate" and "Evaluation Model" LOCA Calculations: The BE/EM Study, PG-R-76-009 (December 1976).

8. H. S. Crapo et al, Experiment Data Report for Semiscale Mod-1 Test S-04-4 (Baseline ECC Test), TREE-NUREG-1003 (October 1976).

9. Vicente Esparza and Kenneth E. Sackett, Experiment Data Report for Semiscale Mod-1 Test S-06-5 (LOFT Couterpart Test), TREE-NUREG-1125 (June 1977).

10. E. M. Feldman and S. A. Naff, Error Analysis for 1-1/2 Loop Semi-scale System Isothermal Test Data, ANCR-1188 (May 1975).

11. M. S. Sahota, Recommended Parameters and Uncertainties for an Uncertainty Analysis of RELAP4-MOD6 as Applied to Semiscale MOD1, PG-R-77-08 (March 1977).

12. Doyle L. Batt, Experiment Data Report for LOFT Nonuclear Test L1-4, TREE-NUREG-1084 (July 1977).

13. Flow of Fluids through Valves, Fittings, and Pipe, Technical Paper No. 410, Crane Co. (1976).

14. D. E. Fitzsimmons, Two-Phase Pressure Drop in Piping Components, HW-80970 REV1, AEC-GE Richland (1964).

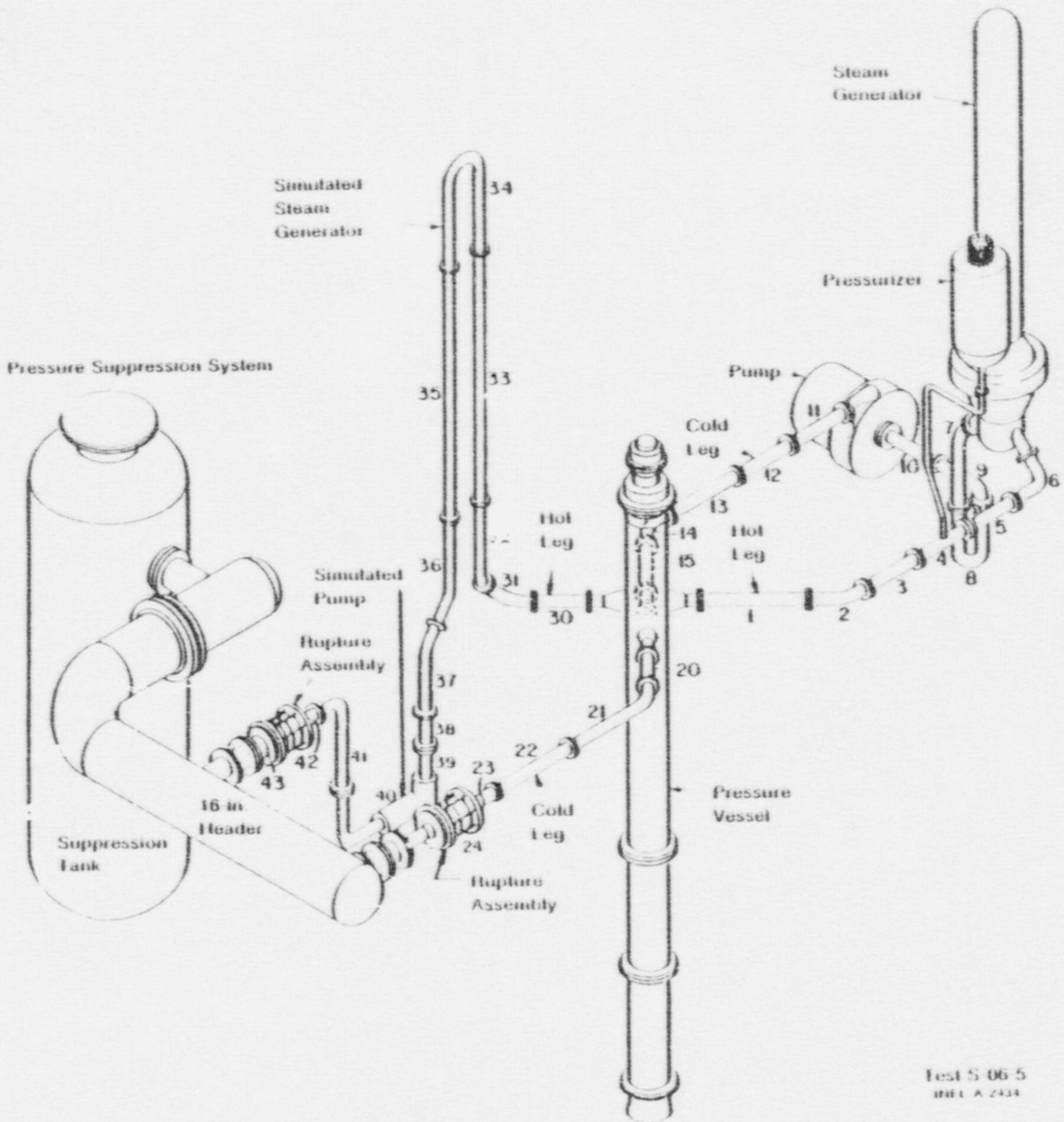

Fig. 1 Semiscale Mod-1 system for cold leg break configuration.

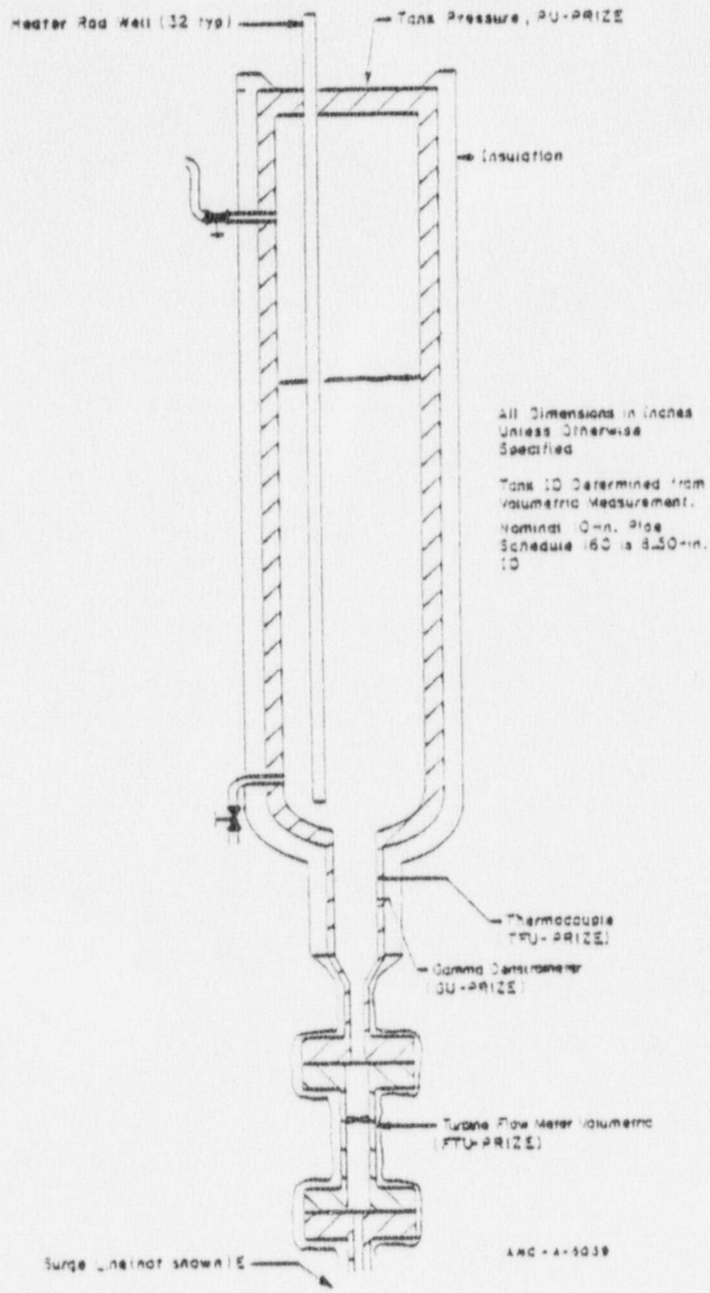

Fig. 2 Semiscale Mod-1 pressurizer.

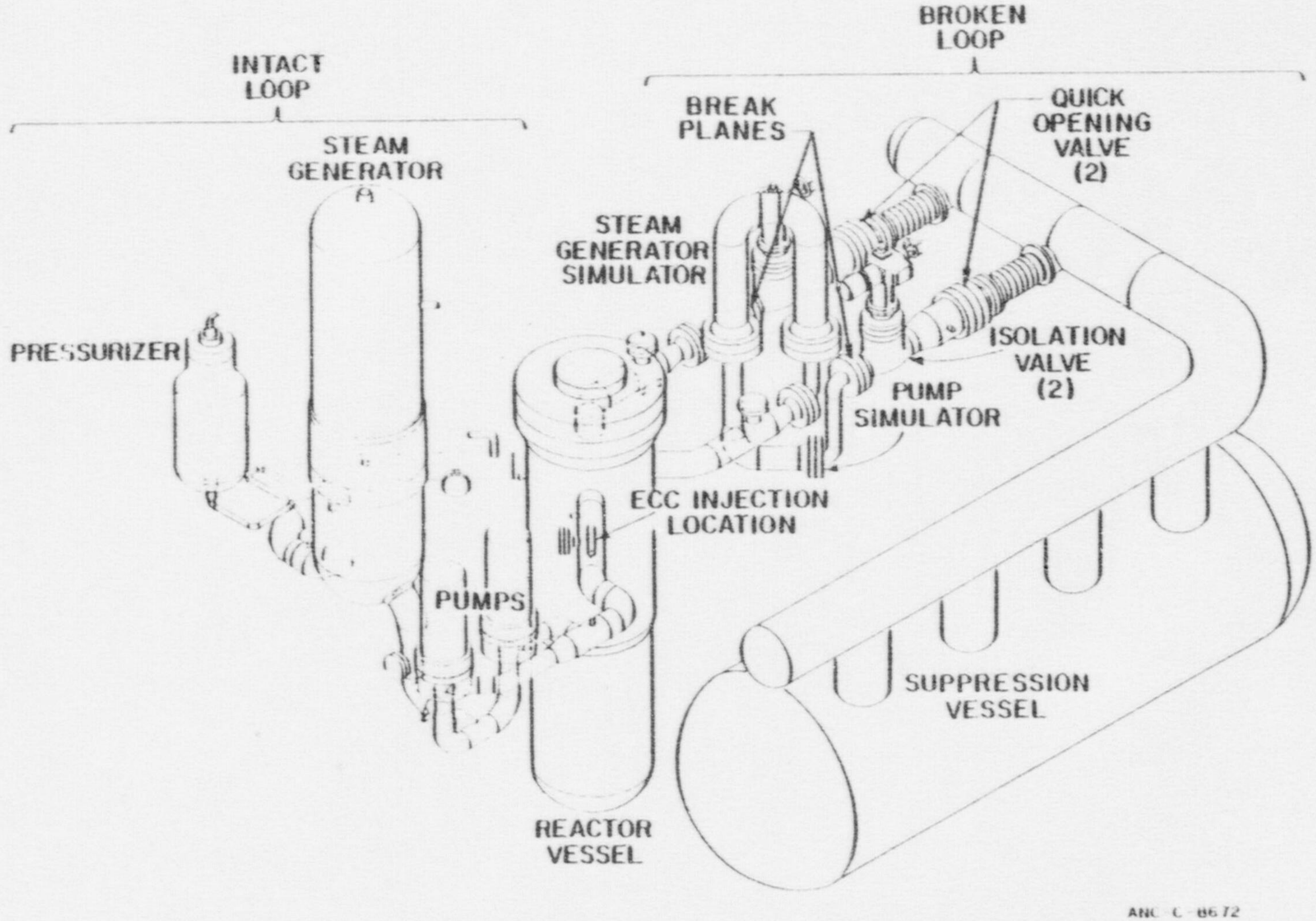

Fig. 3 LOFT system for cold leg break configuration.

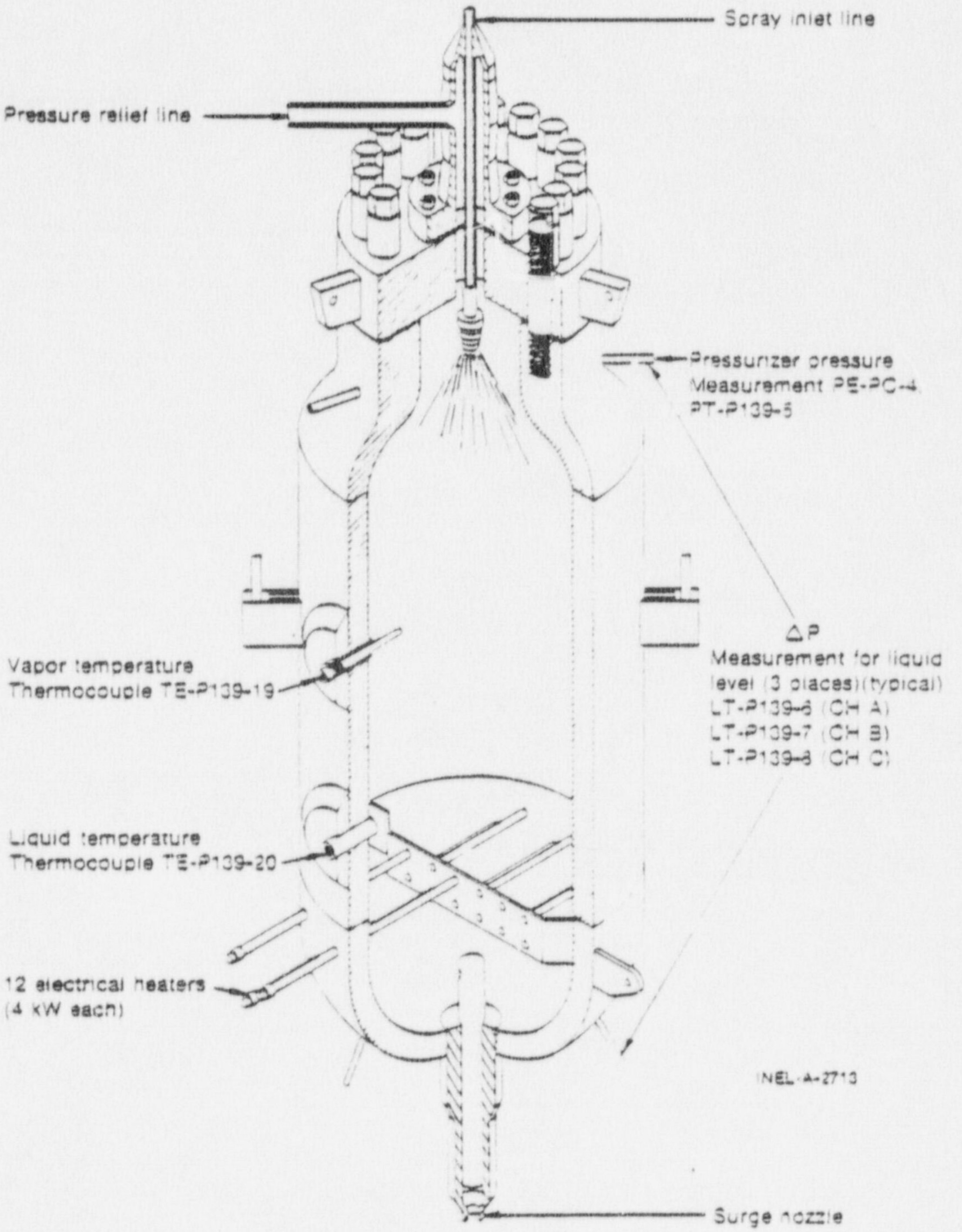

Fig. 4 LOFT pressurizer.

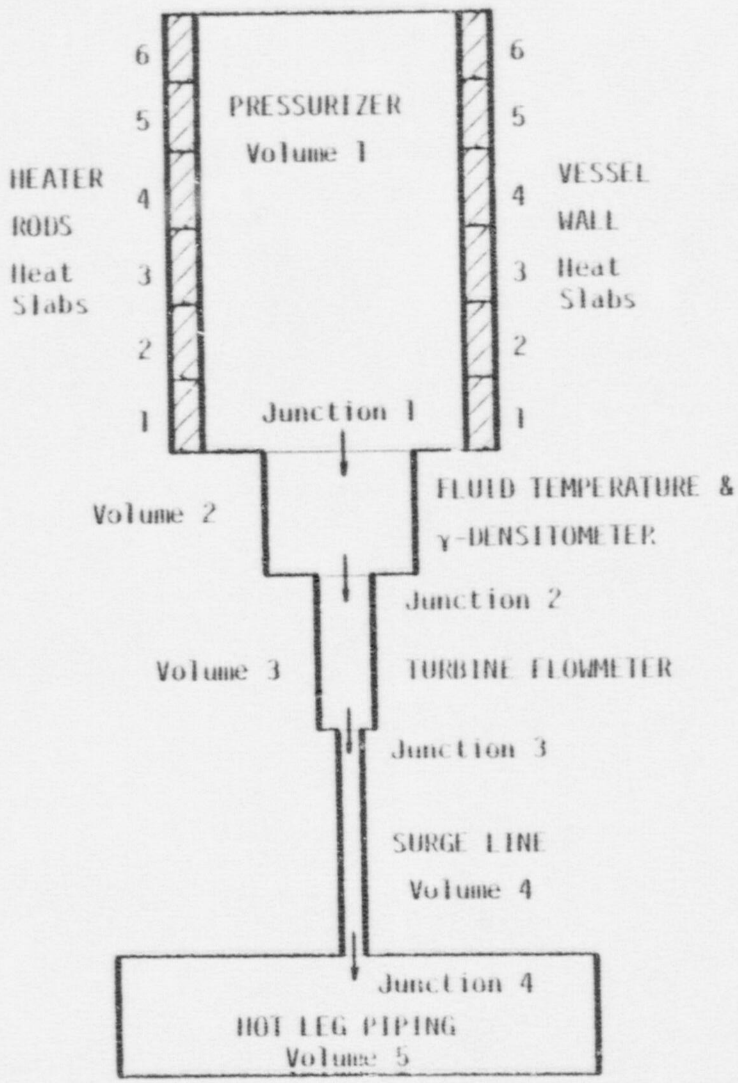

Fig. 5 Semiscale pressurizer base run nodalization.

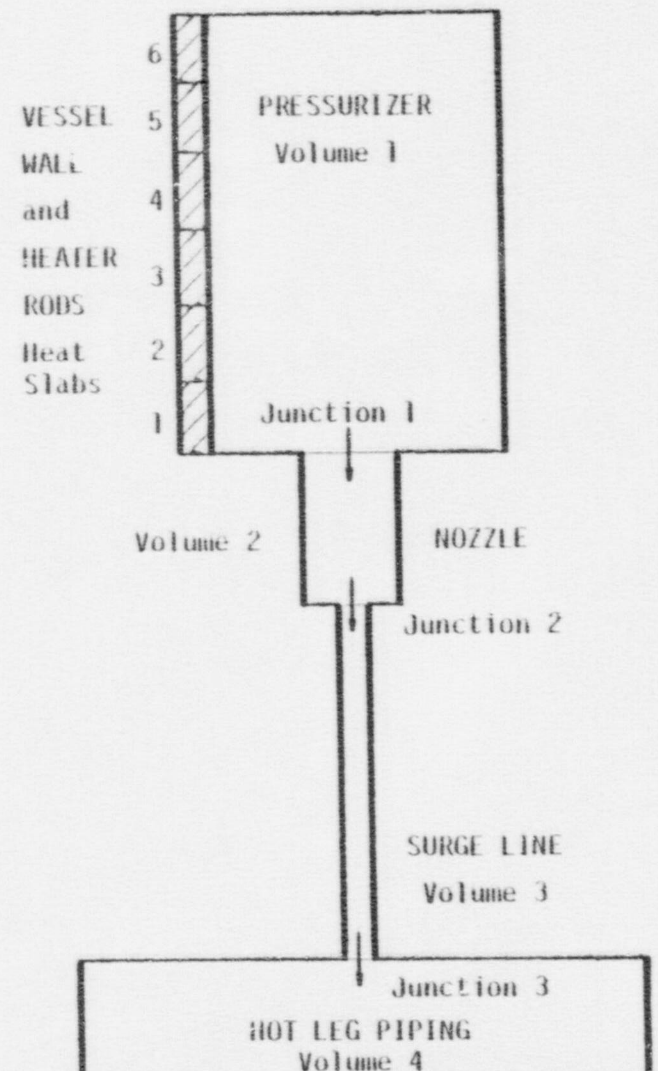

Fig. 6 LOFT pressurizer base run nodalization.

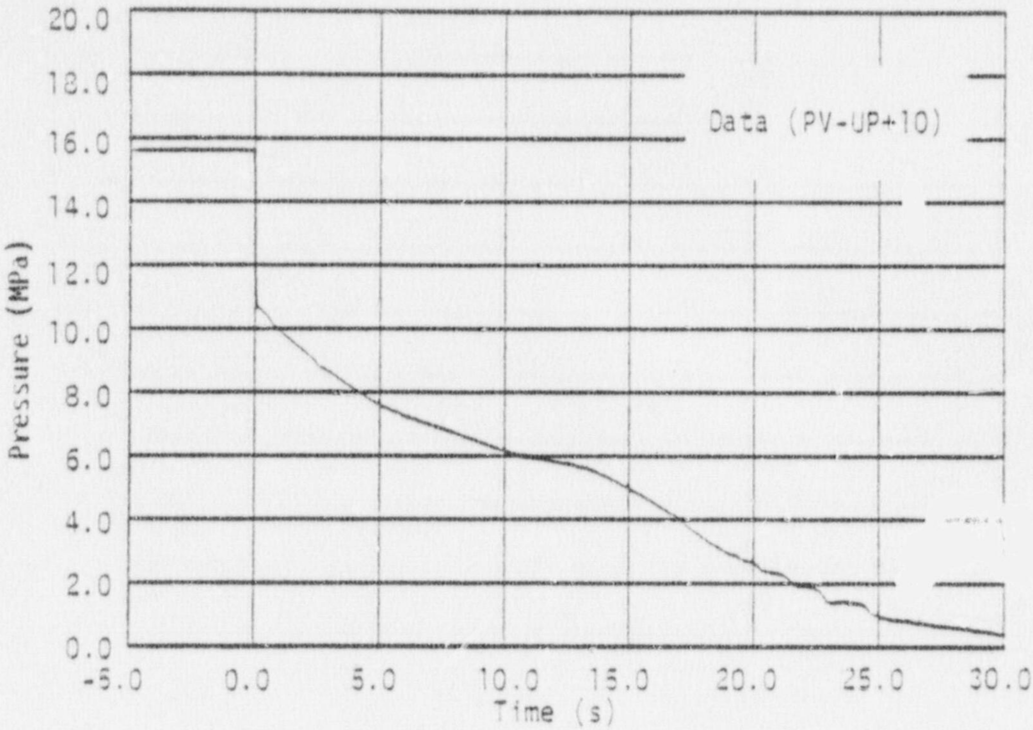

Fig. 7 Boundary condition pressure for Semiscale Test S-04-4.

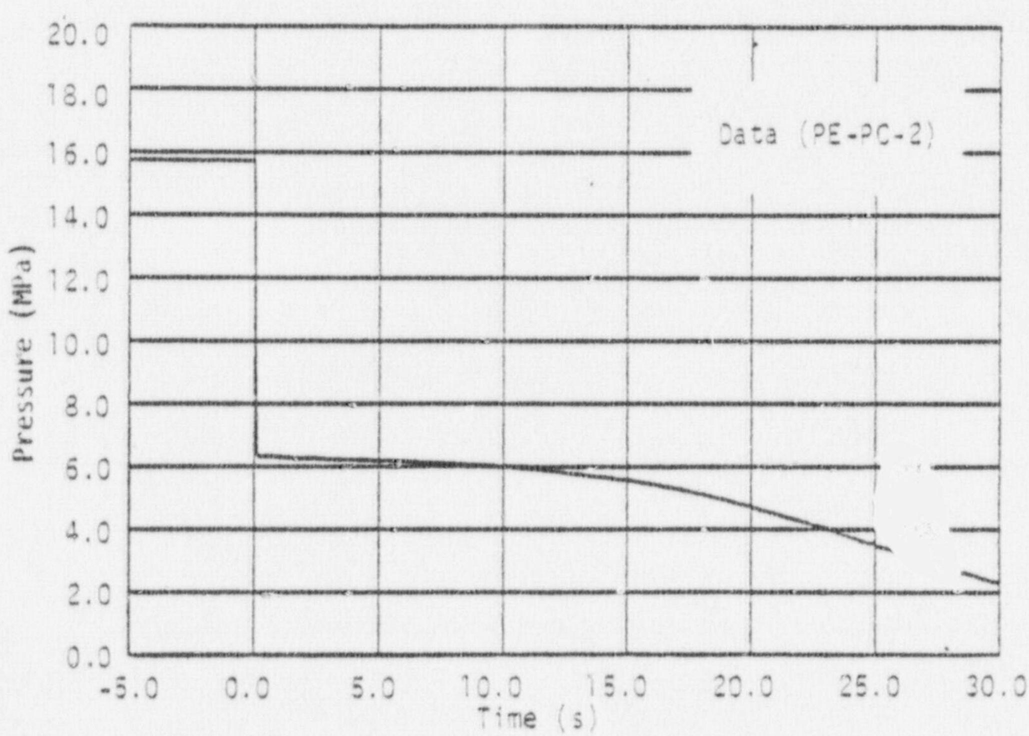

Fig. 8 Boundary condition pressure for LOFT Test L1-4.

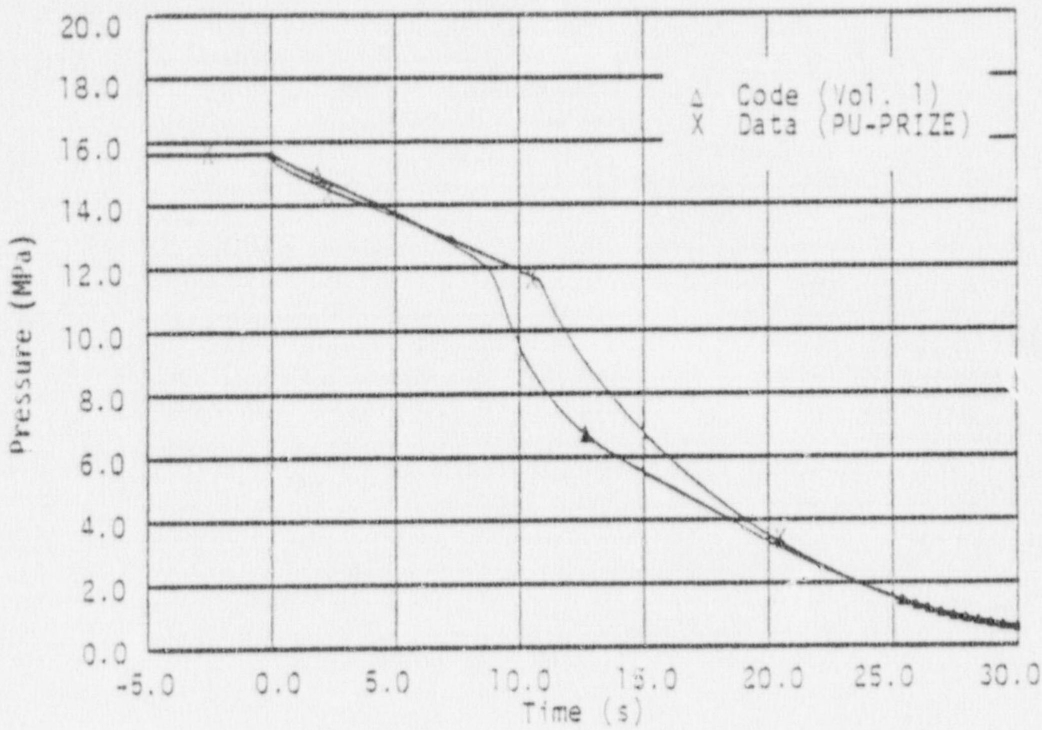

Fig. 9 S-04-4 pressurizer pressure base run comparison.

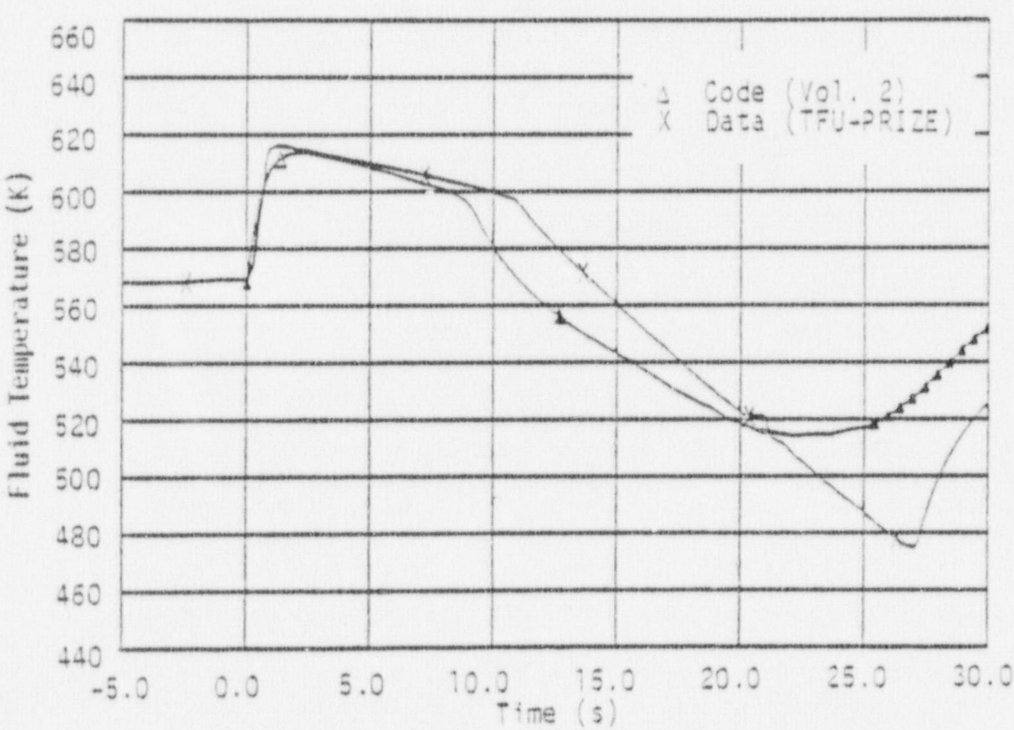

Fig. 10 S-04-4 fluid temperature base run comparison.

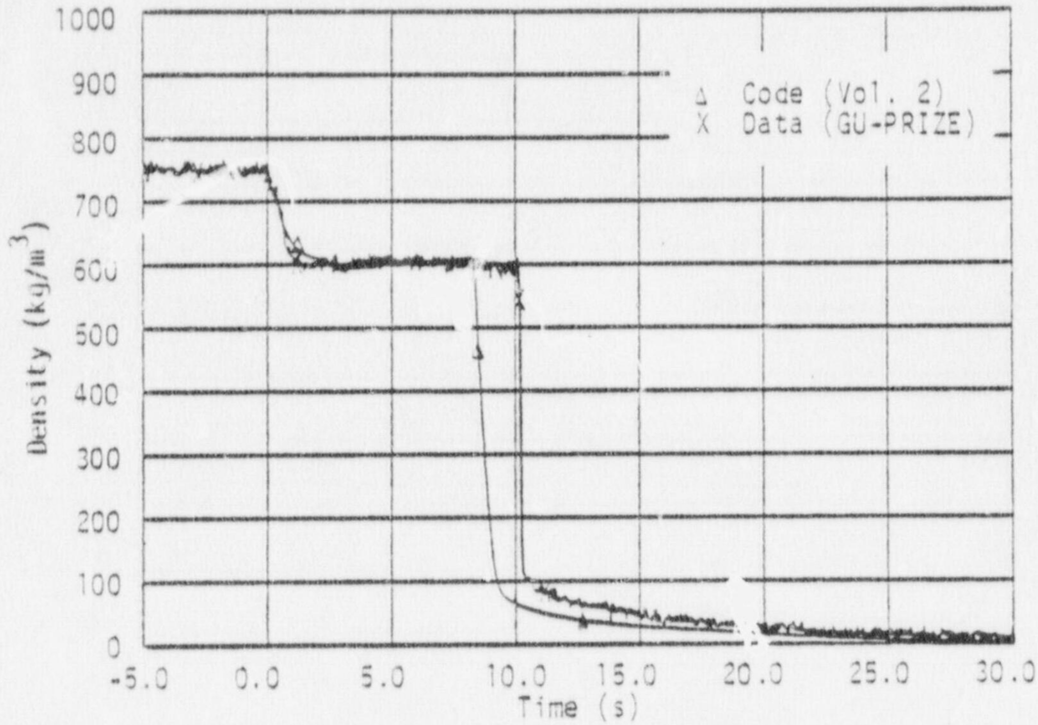

Fig. 11 S-04-4 density base run comparison.

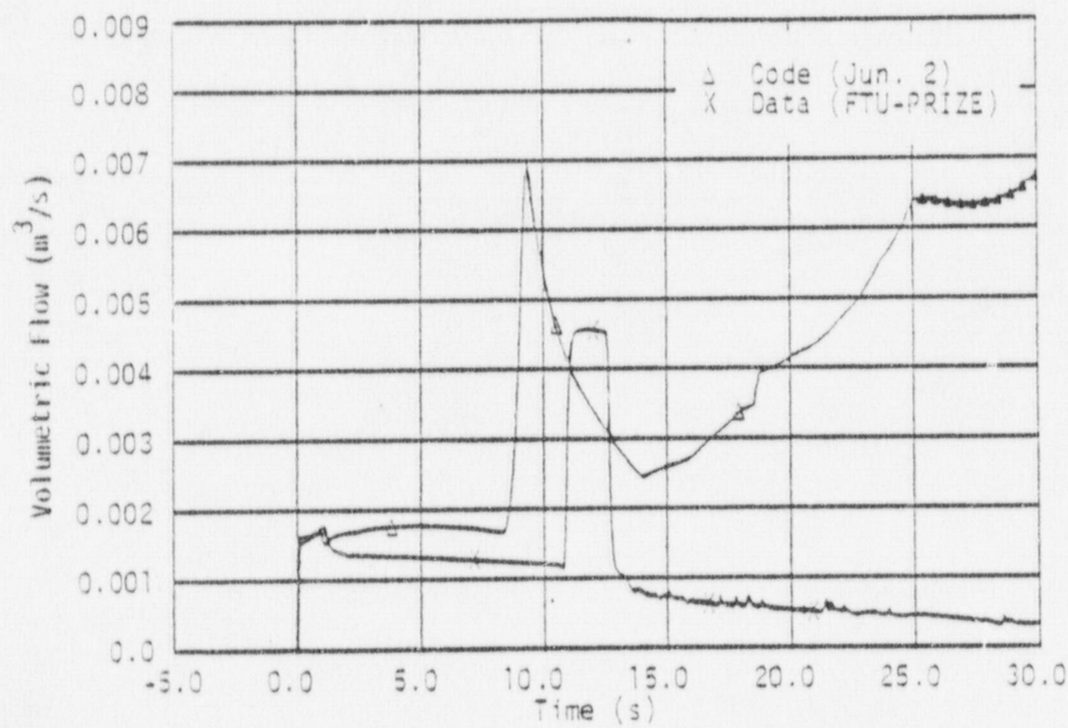

Fig. 12 S-04-4 volumetric flow base run comparison.

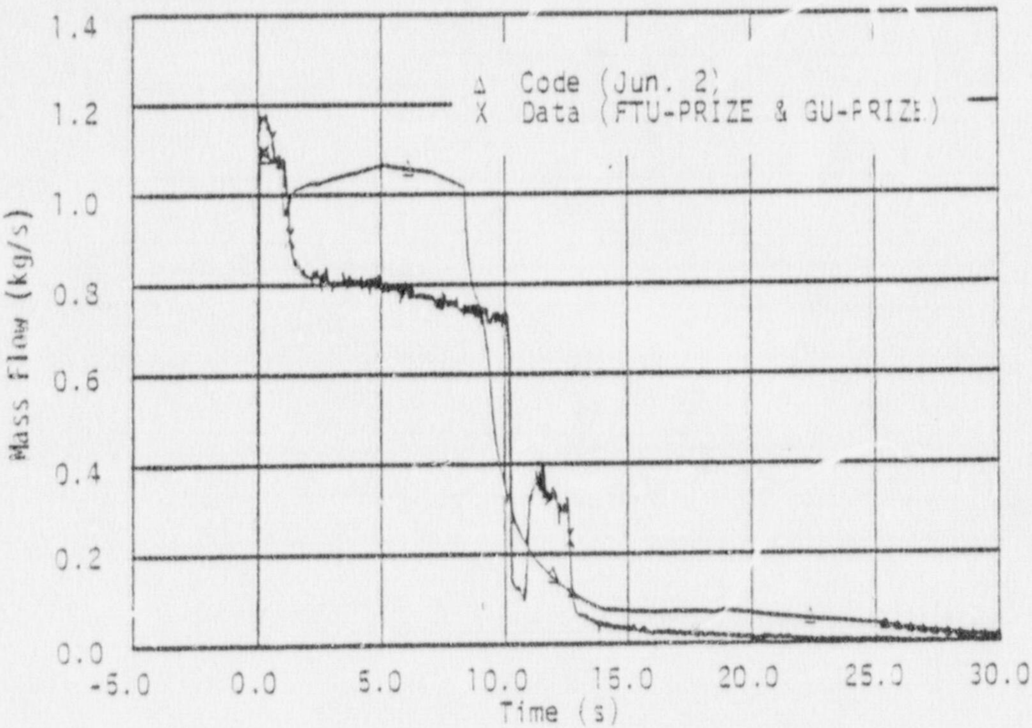

Fig. 13 S-04-4 mass flow base run comparison.

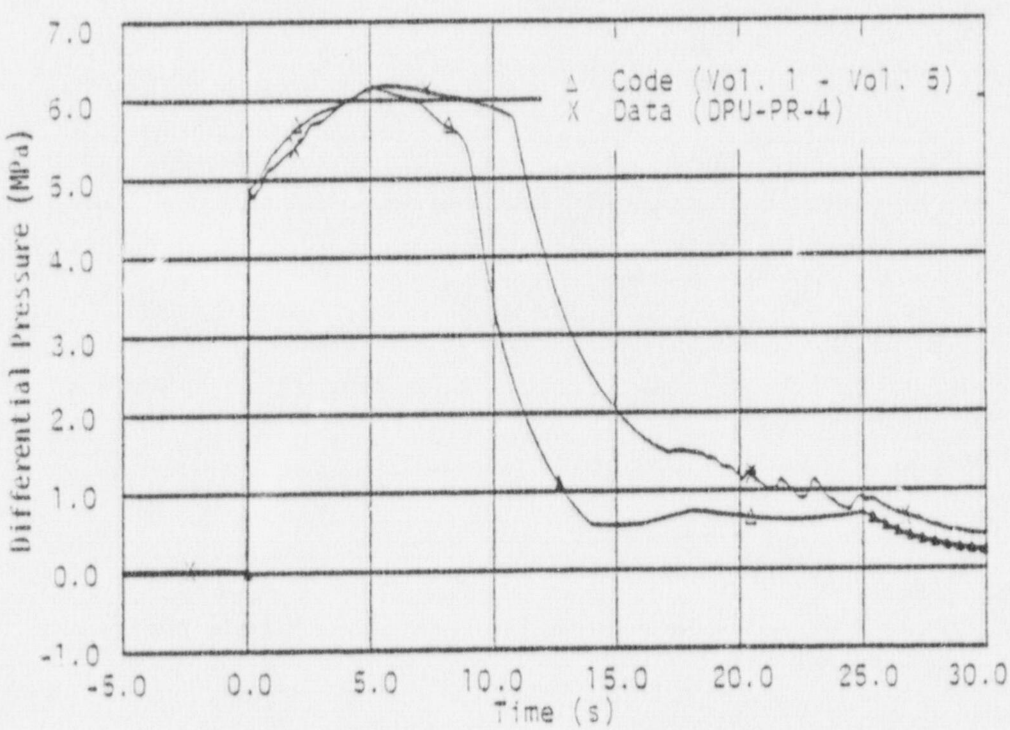

Fig. 14 S-04-4 pressurizer to intact hot leg differential pressure base run comparison.

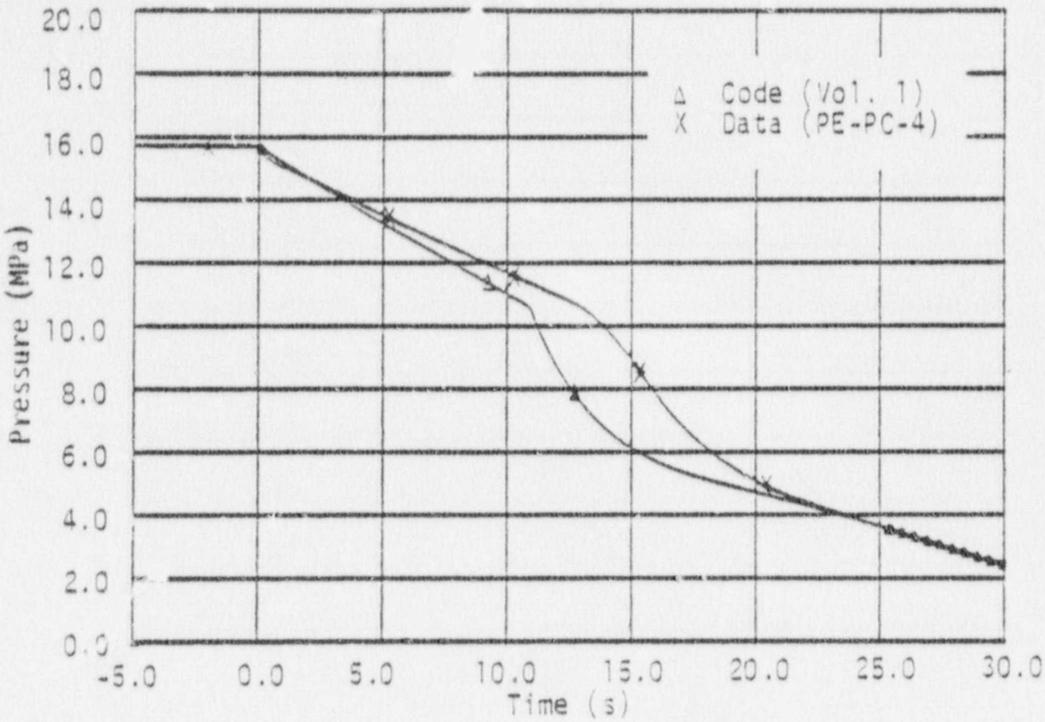

Fig. 15 L1-4 pressurizer pressure base run comparison.

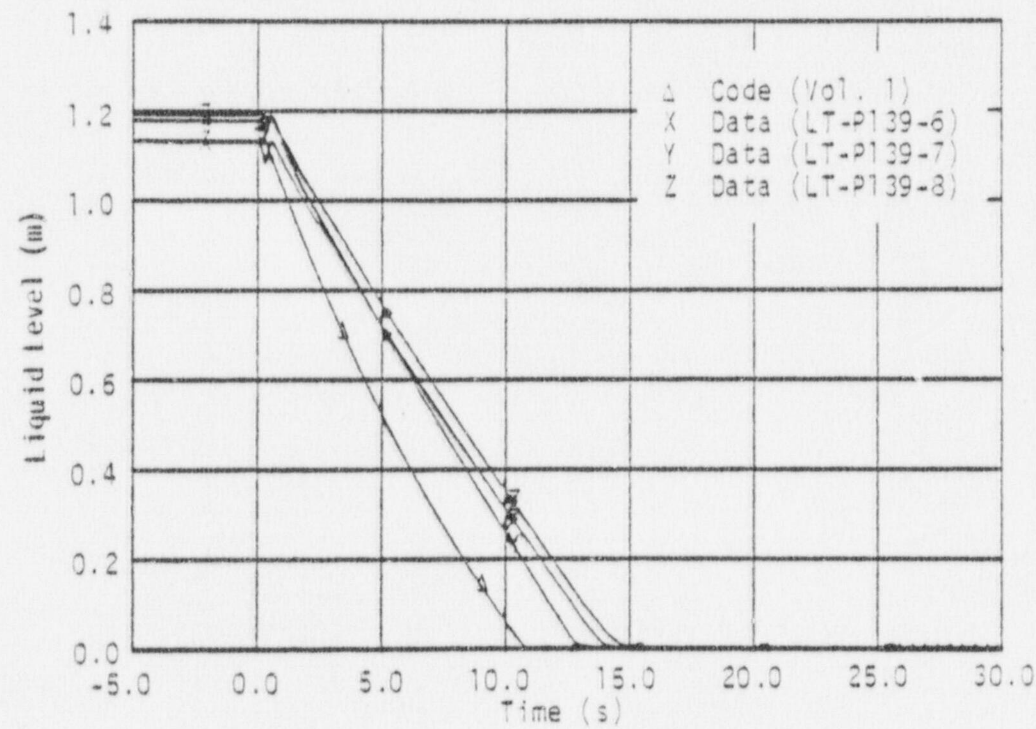

Fig. 16 L1-4 pressurizer liquid level base run comparison.

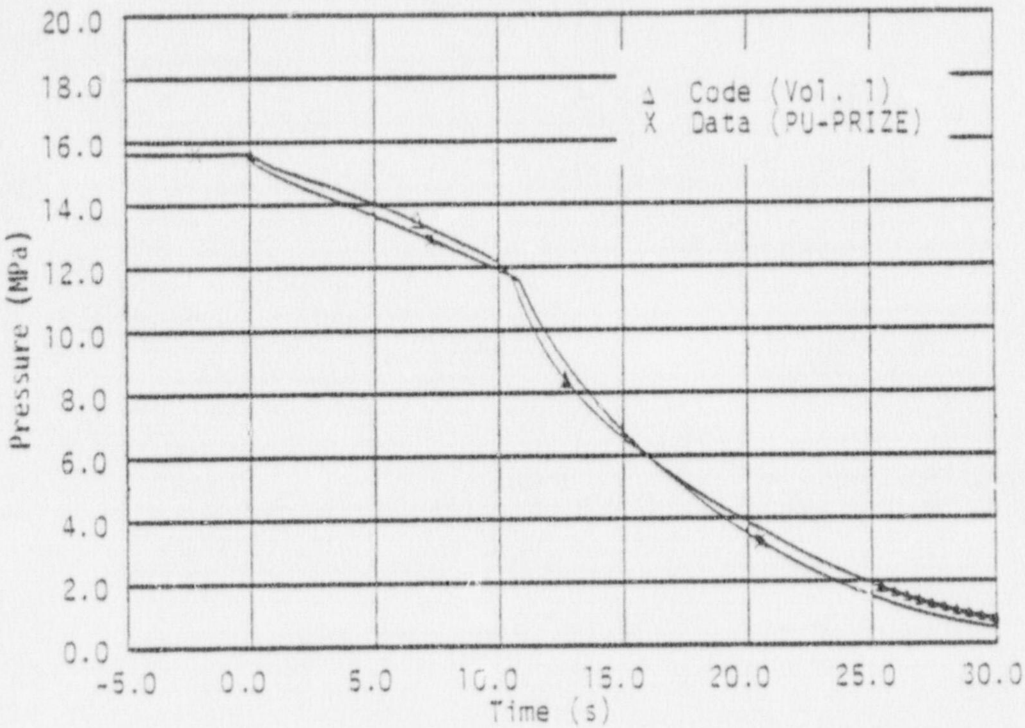

Fig. 17 S-04-4 pressurizer pressure comparison with adjusted tow-phase friction factor.

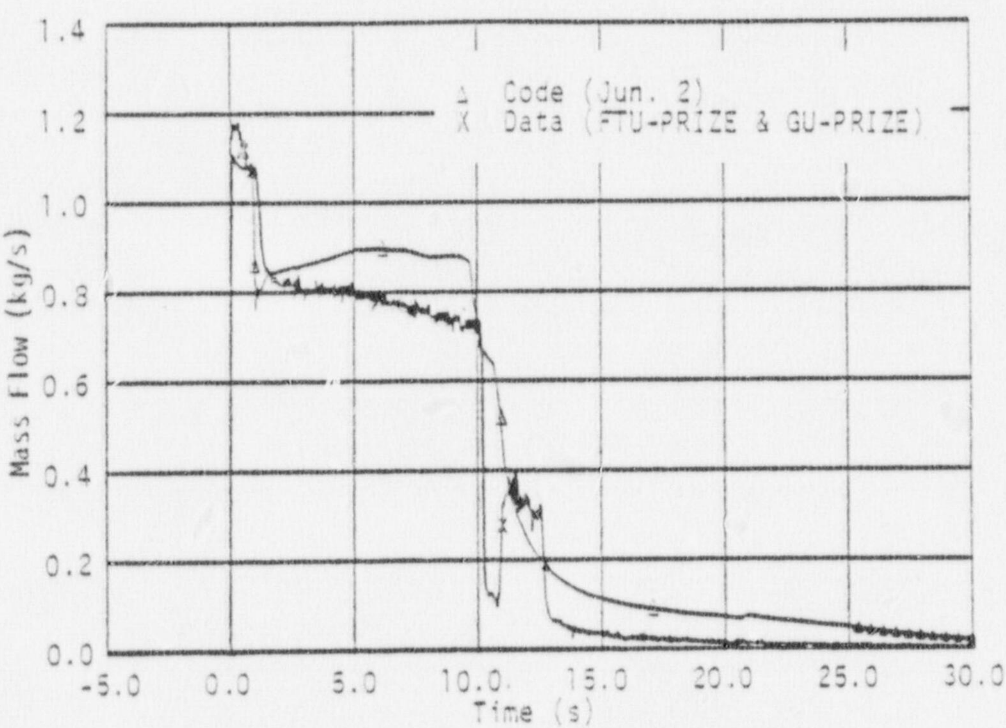

Fig. 18 S-04-4 mass flow comparison with adjusted two-phase friction factor.

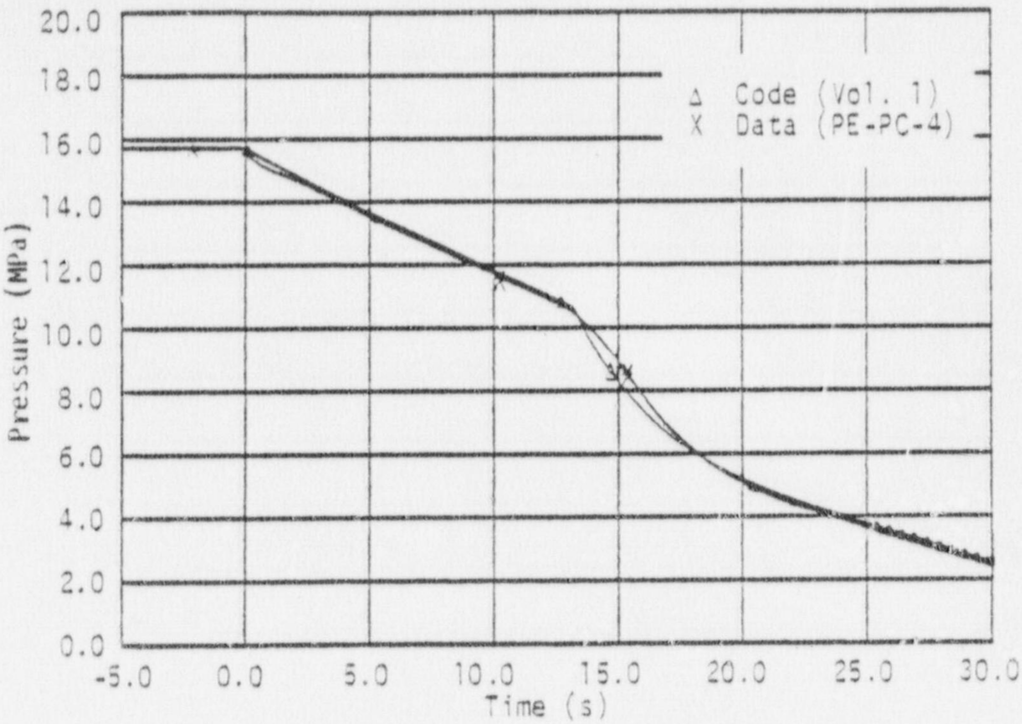

Fig. 19 L1-4 pressurizer pressure comparison with adjusted two-phase friction factor.

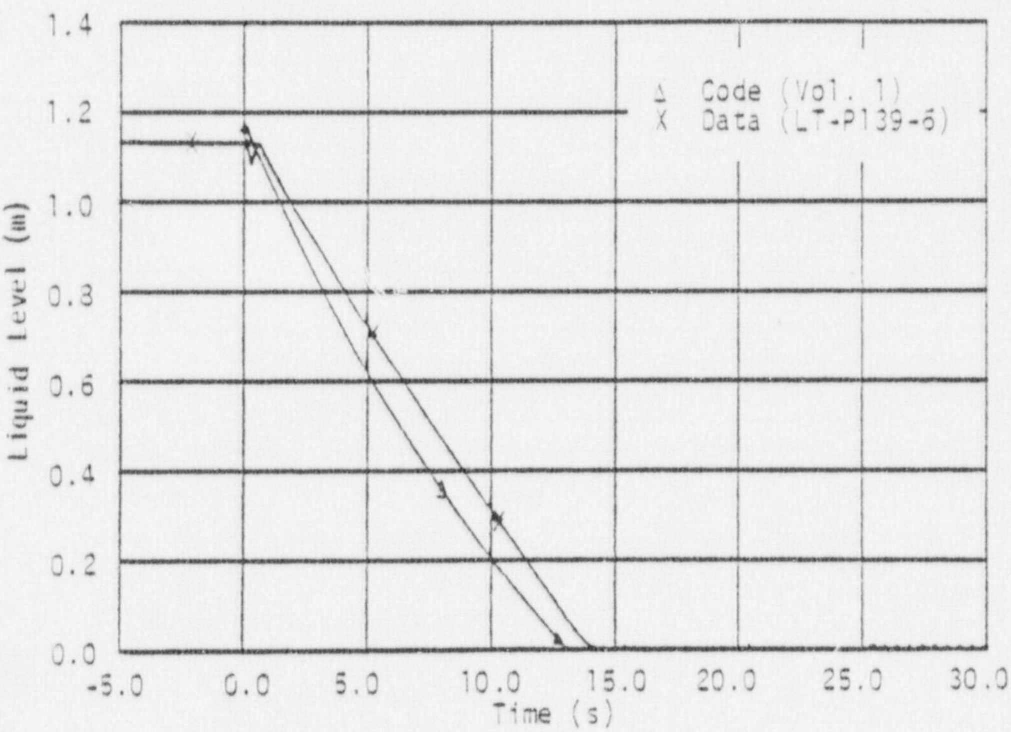

Fig. 20 L1-4 liquid level comparison with adjusted two-phase friction factor.

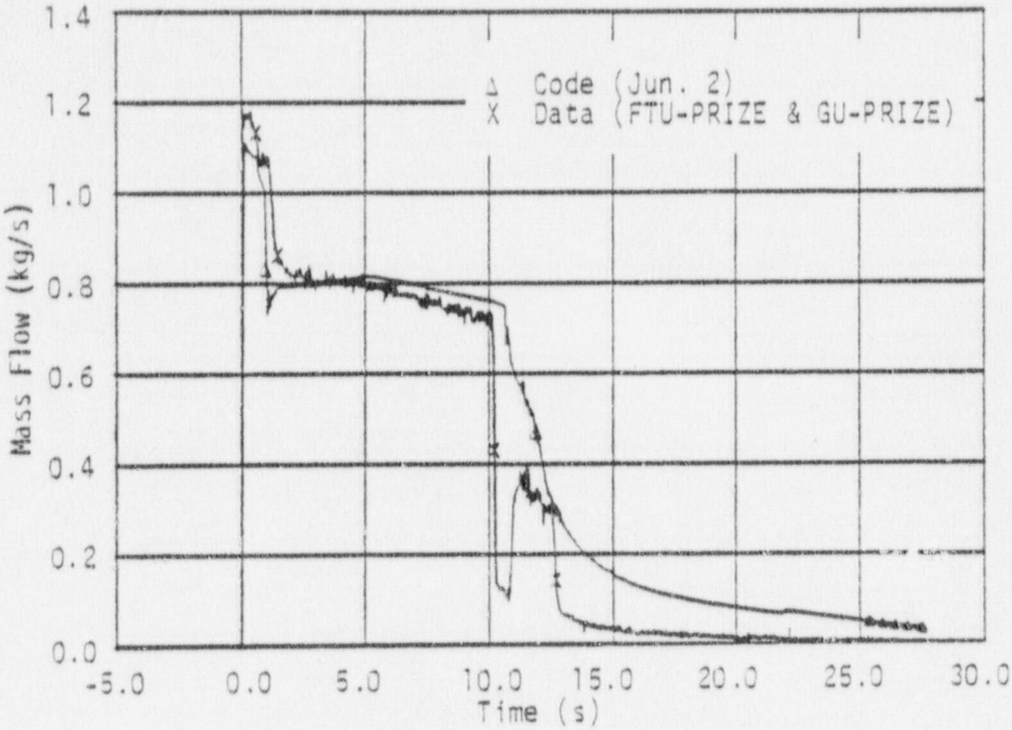

Fig. 21 Mass flow rate at exit from Semiscale pressurizer with compressible momentum equation.

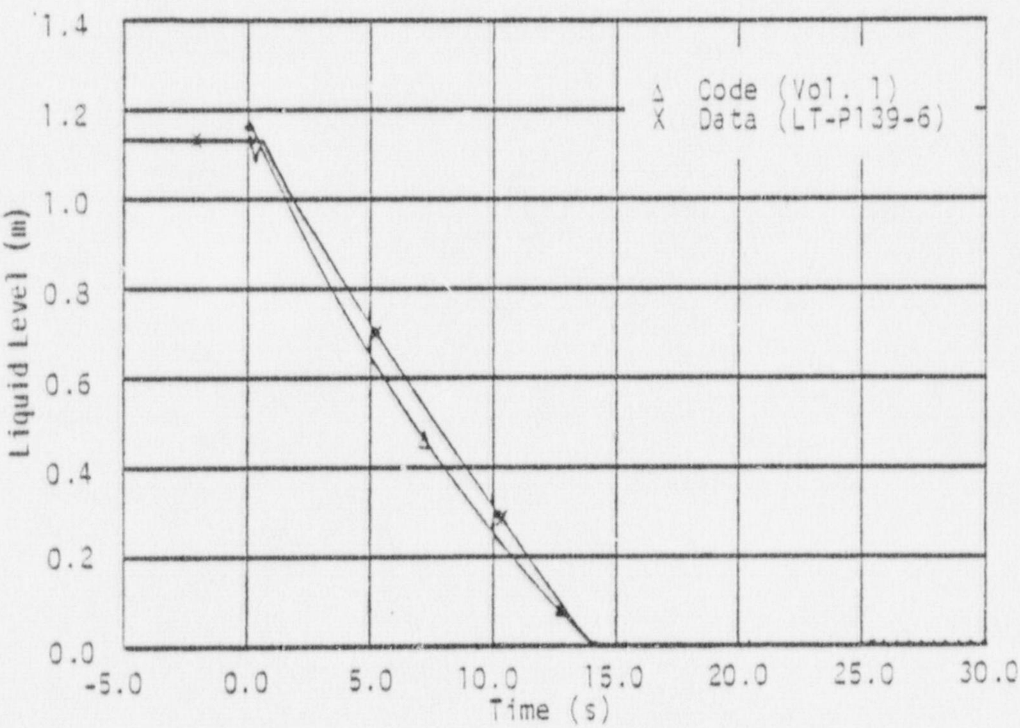

Fig. 22 LOFT pressurizer liquid level with compressible momentum equation.

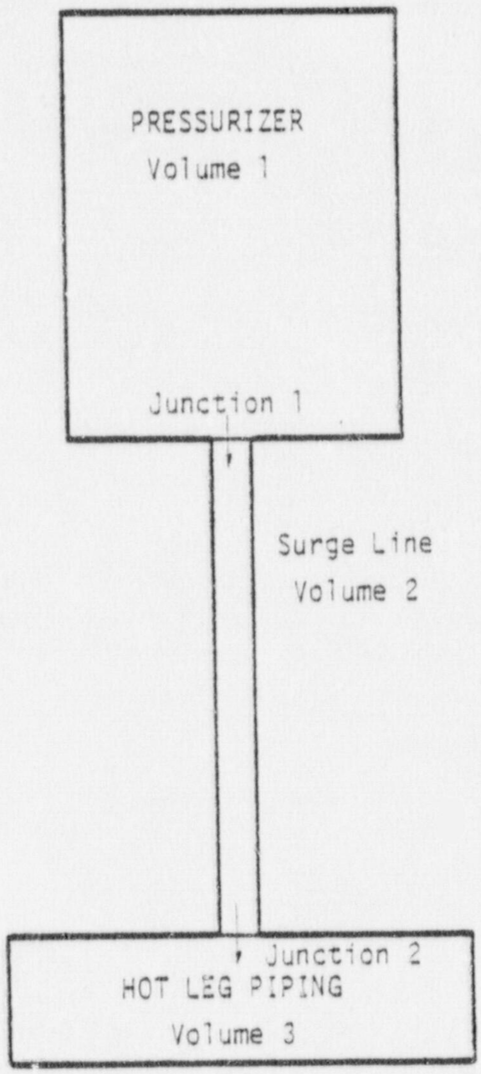

Fig. 23 System type model for the pressurizer.

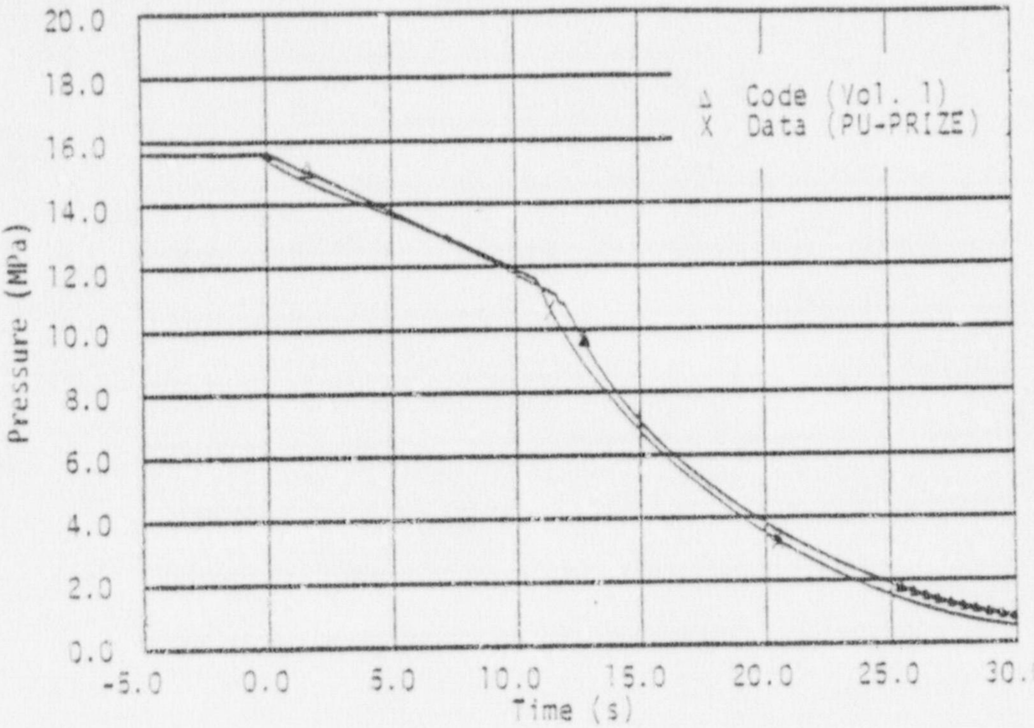

Fig. 24 Semiscale Test S-04-4 system type model pressurizer pressure comparison.

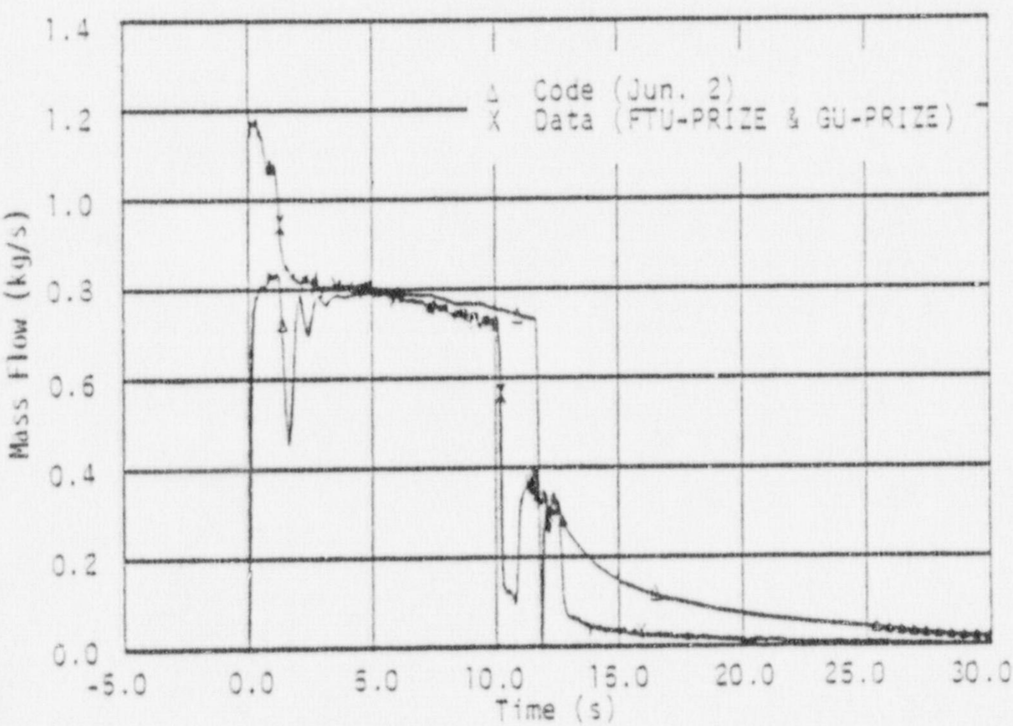

Fig. 25 Semiscale Test S-04-4 system type model mass flow comparison.

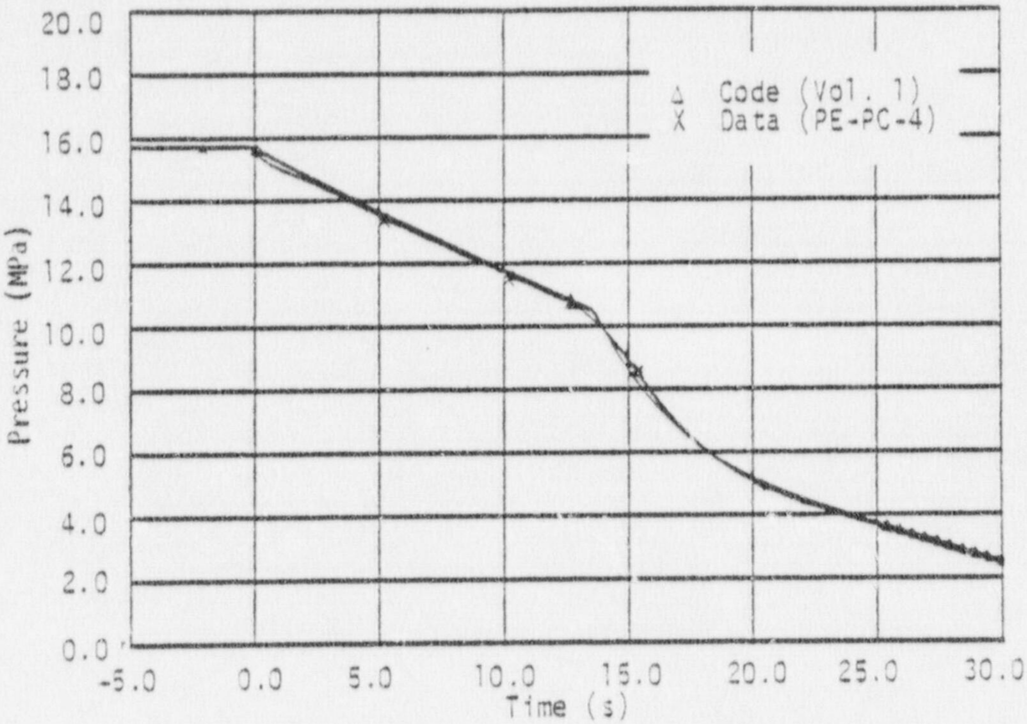

Fig. 26 LOFT L1-4 system type model pressurizer pressure comparison.

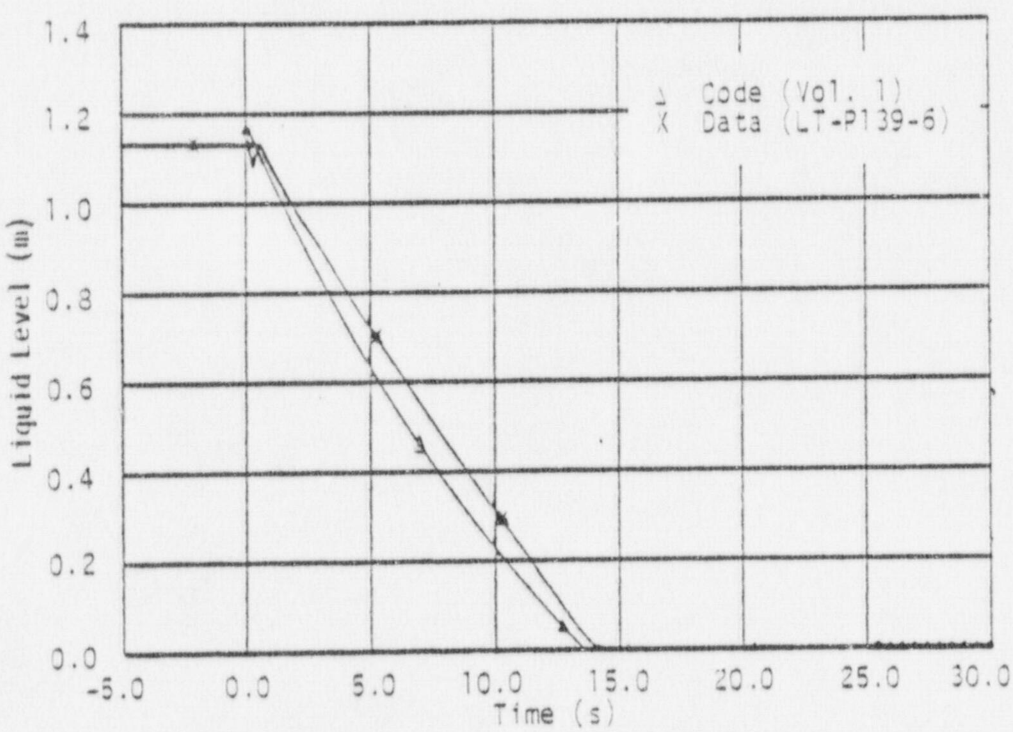

Fig. 27 LOFT L1-4 system type model pressurizer liquid level comparison.

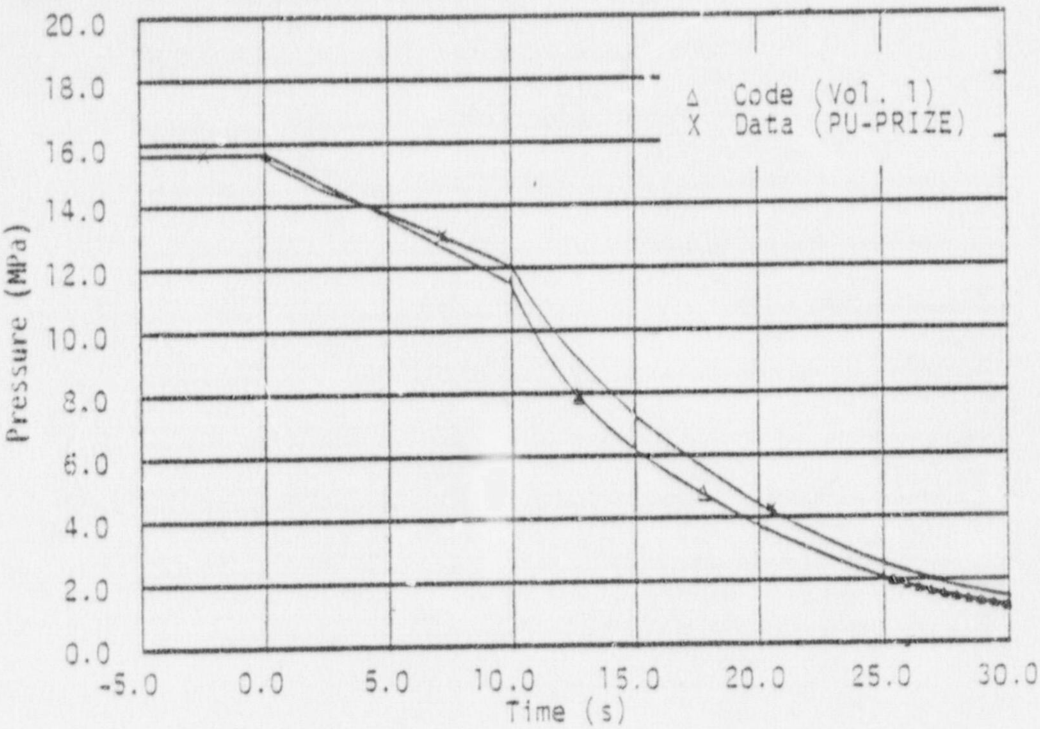

Fig. 28 Semiscale Test S-06-5 pressurizer pressure comparison.

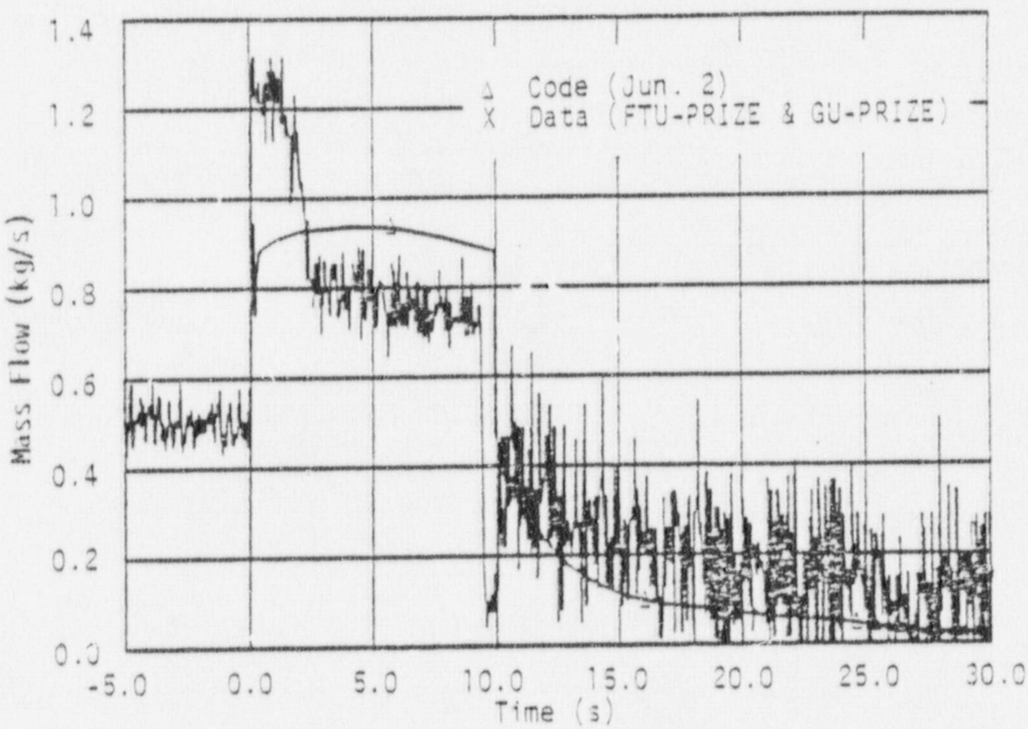

Fig. 29 Semiscale Test S-06-5 mass flow comparison.