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# ABSTRACT

Preliminary comparisons of calculated parameters to experimental data for the LOFT Loss-of-Coolant Experiment (LOCE) L3-1, designated a special test by the Nuclear Regulatory Commission, are documented. LOCE L3-1 was a 2.5% single ended cold leg break blowdown experiment. The LOFT system for LOCE L3-1 was operated at 49 MW with a nuclear core of 1300 unpressurized fuel rods. The initial pressure and temperature in the intact loop hot leg were 2166 psia and 574°F, respectively. Results of calculations for experiment L3-1 submitted by Babcock and Wilcox, Combustion Engineering, Exxon Nuclear Company, Westinghouse Electric Corporation, Idaho National Engineering Laboratory and Los Alamos Scientific Laboratory are presented and evaluated.

## ACKNOWLEDGEMENTS

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# SUMMARY

This report provides preliminary documentation of the comparative analysis of the LOFT LOCE L3-1 test results with participant calculations. LOFT Test L3-1 was identified as a special test by the Nuclear Regulatory Commission (NRC). The identification of the LOCE L3-1 test as a special test required the submitting of pretest calculations by U.S. reactor vendors and other selected participants to the NRC. The total participation in calculations of this special test were: Babcock and Wilcox (B & W), Combustion Engineering (CE), Exxon Nuclear Company (ENC), Westinghouse Electric Corporation (WEC), Idaho National Engineering Laboratory (INEL), and Los Alamos Scientific Laboratory (LASL).

LOCE L3-1, the experimental data base for this comparison, was a 2.5% single ended cold leg break with an initial pressure of 2166 ± 6 psia and an intact loop hot leg temperature of 574 ± 2°F. ECC injection was limited to the intact loop cold leg. The maximum linear heat generation rate was 15.8 ± 0.3 kW/ft.

The LOFT system for LOCE L3-1 was operated at an initial power of 48.9 ± 1 MW. The core consisted of 1300 unpressurized nuclear fuel rods arranged in five square and four triangular fuel modules. The test was performed as part of the LOFT Small Break Experiment Series L3.

A quantitative and qualitative evaluation of the calculations by the participants was performed based on key parameters that best describe the small break transient behavior of LOCE L3-1. However, due to instrument failures during the experiment, the number of qualified measurements available for comparison was somewhat limited. The parameters selected for the evaluation were upper plenum pressure, intact loop accumulator pressure, steam generator secondary pressure, break mass flow rate, and intact loop cold leg density.

The results of the preliminary comparisons of LOCE L3-1 calculations with experimental results show the pressure of the secondary side of the steam generator was not calculated accurately, this effected the calculation of system pressure. Most of the participants did not accurately calculate the time the fluid at the break became single phase steam, this effected their break mass flow rate calculations.

# 1. INTRODUCTION

The purpose of the report is to provide preliminary documentation for the comparative analysis of the LOFT LOCE L3-1 test results with participant calculations. LOFT Test L3-1 was identified as a special test by the Nuclear Regulatory Commission (NRC). The identification of the LOCE L3-1 test as a special test required the submitting of pretest calculations by U.S. reactor vendors and other selected participants to the NRC. The total participation in calculations of this special test were Babcock and Wilcox (B & W), Combustion Engineering (CE), Exxon Nuclear Company (ENC), Westinghouse Electric Corporation (WEC), Idaho National Engineering Laboratory (INEL) and Los Alamos Scientific Laboratory (LASL).

LOCE L3-1, the experimental data base for this comparison, was a test designed to provide data for a pressurized water reactor (PWR) small break transient. The test was a simulated 2.5% single ended break in the cold leg with ECC injection limited to the intact loop. The break was large enough to cause system depressurization. The core consisted of 1300 nuclear fuel rods arranged in five square and four triangular fuel assemblies. A facility description, list of initial test conditions, and sequence of events for Test L3-1 are presented in Section 2.

The pretest calculations for the L3-1 comparison[1] were calculated using the specified initial conditions of the L3-1 Test. Each participant was requested to submit information identifying the computer codes used, system nodalization employed, a sequence of specified events and any special analytical or systematic modeling features utilized. This information is summarized in Section 3 for each participant.

Also contained in Section 3 is a discussion of the analytical approach used for comparing calculations to data. The list of specific test parameters requested from the participants and the results of the comparisons of participant calculations to selected key parameters are contained in Section 4. The conclusions from these comparisons are stated in Section 5.

Two leakage paths occurred during Test L3-1 that were not identified to the participants. For the evaluations presented in this report the potential effects of leakage through the cold leg warmup lines and Reflood Assist Bypass Values (RABVs) that occurred during LOFT Test L3-1 were not addressed. The magnitude of this leakage is currently unknown, however, LOFT personnel have analytical determined that the effect of these leakages was small.

# 2. LOFT LOCE L3-1

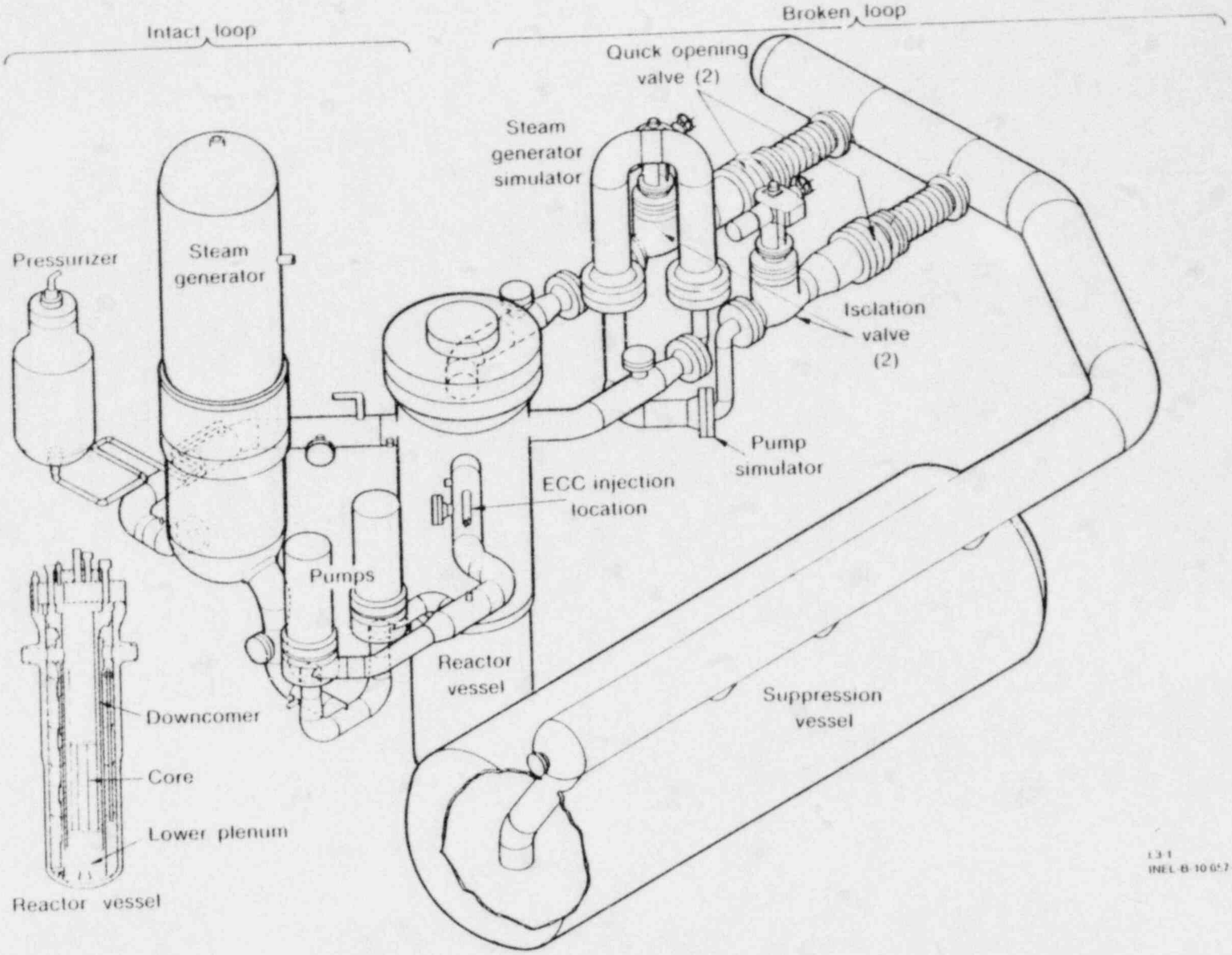
LOCE L3-1 was the second experiment in the LOFT Small Break Experiment Series L3. LOCE L3-1 was designed to provide large scale integrated data on thermal hydraulic and fuel behavior during a PWR small break transient. The general requirements for the LOFT L3 experiment series were specified in Reference 2. The objectives of L3-1, as specified in Reference 3, are listed below:

1. Determine the principal variables of temperature, pressure, density, mass flow, and mass inventory as functions of time associated with the core, primary coolant system coolant, and ECC sufficient for comparisons with and assessment of code calculations
2. Determine ECC system performance and core reflood characteristics
3. Determine the existence of thresholds and/or events not expected from review of the pretest analyses
4. Determine sequence of events during the transient and the effectiveness of typical process instruments in indicating the true conditions
5. Define operational methods and system design variations whereby specific small break transient phenomena can be made less severe.

The LOFT system used for L3-1 consisted of the reactor vessel, including a core with 1300 unpressurized nuclear fuel rods: an intact loop with steam generator, two pumps in parallel and a pressurizer; a broken loop with a simulated steam generator and pump, and two quick opening blowdown valves (QOBV); a blowdown suppression system consisting of a suppression tank and header; and an Emergency Core Coolant System (ECCS) consisting of an accumulator, high-pressure injection system (HPIS), and low-pressure injection system (LPIS). LOFT system configuration information is provided in Reference 4. Figure 1 shows the system configuration for Test L3-1. Figure 2 is provided as a quick reference for locating the LOCE L3-1 measurement locations. The instrument nomenclature shown in Figure 2 is described in detail in Reference 3.

The system was subjected to a simulated single ended cold leg break. The reactor was scrammed 2 s before blowdown. When the control rods were fully inserted, the experiment was initiated by opening the broken loop cold leg QOBV. The primary coolant pumps were tripped off at blowdown.

Test L3-1 pretest conditions at the initiation of blowdown are given in Tables 1 and 2. The pretest conditions supplied to the participants are given in Reference 1. The sequence of events relative to the initiation of blowdown is presented in Table 3. Reference 3 contains the published test data, instrumentation location and data uncertainties, and a more comprehensive system and test description.



L3-1
INEL-B-10 657-3

Figure 1. LOFT L3-1 system for small break configuration.

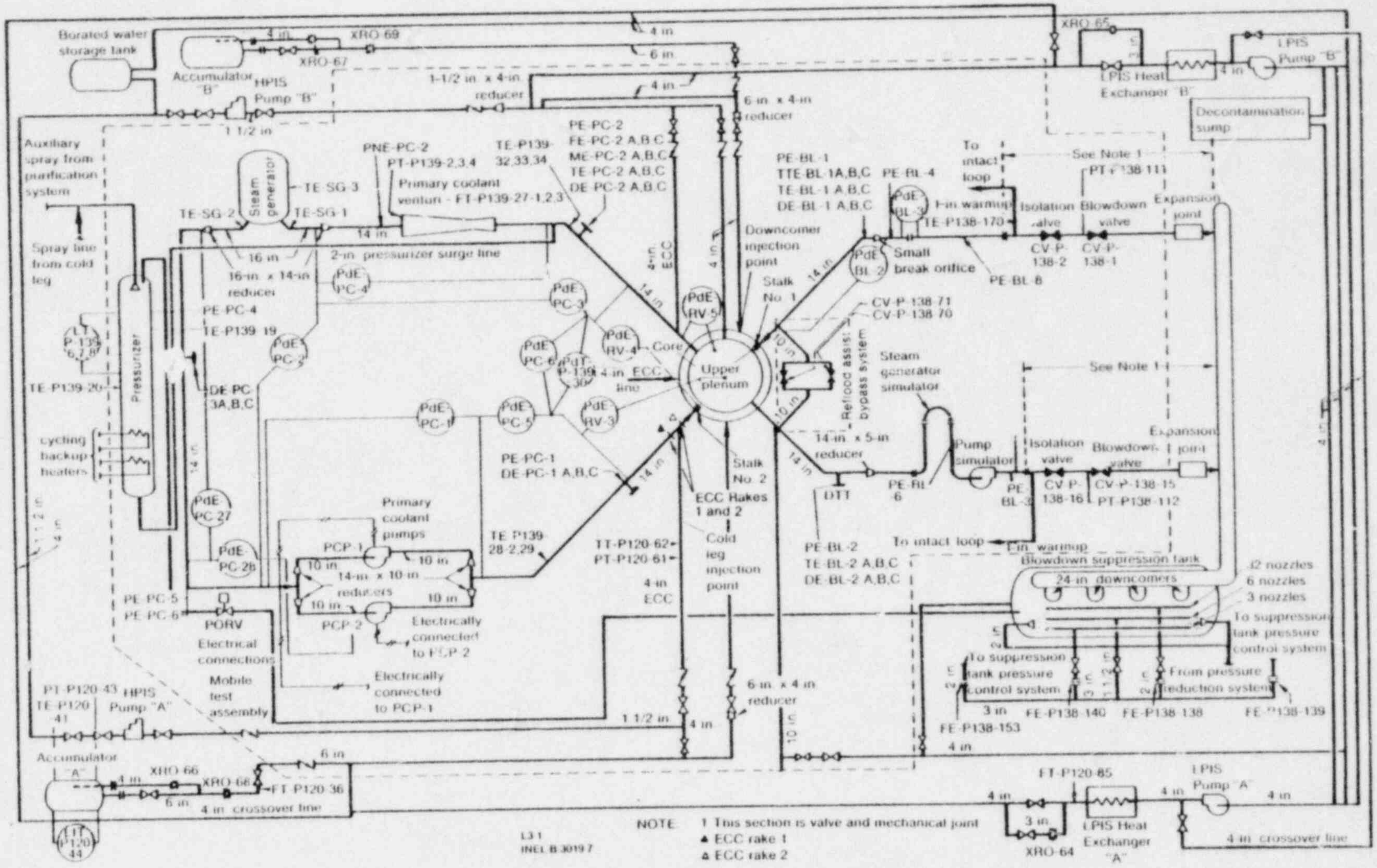


Figure 2. LOFT L3-1 system and instrumentation for small break configuration.

TABLE 1. CONDITIONS AT BLOWDOWN INITIATION

| Parameter | Specified Value | Measured Value |
|---|---|---|
| **Primary Coolant System** | | |
| Mass flow rate (lbm/sec) | 1056. ± 19. | 1067. ± 14. |
| Hot leg pressure (psia) | 2181. ± 49. | 2166. ± 6. |
| Cold leg temperature (°F) | 542.4 ± 4.0 | 537.5 ± 5 |
| Hot leg temperature (°F) | -- | 573.5 ± 2 |
| Boron concentration (ppm) | As required to maintain temperature | 733 ± 15 |
| **Reactor Vessel** | | |
| Power level (MW) | 50.0 ± 2 | 48.9 ± 1 |
| Maximum linear heat generation rate (kW/ft) | -- | 15.8 ± 0.3 |
| Control rod position (above full-in position) (ft) | 4.501 ± 0.043 | 4.498 ± 0.03 |
| **Pressurizer** | | |
| Steam volume (ft$^3$) | -- | 12.1 ± 0.3 |
| Liquid volume (ft$^3$) | -- | 21.9 ± 0.3 |
| Water temperature (°F) | -- | 650.9 ± 5 |
| Pressure (psia) | 2181. ± 49. | 2160. ± 6. |
| Level (ft) | 3.71 ± 0.59 | 3.61 ± 0.03 |
| **Broken Loop** | | |
| Cold leg temperature (°F) | 542.4 ± 25.0 | 543.5 ± 9.0 |
| Hot leg temperature (°F) | 542.4 ± 25.0 | 551.9 ± 9.0 |
| **Steam Generator Secondary Side** | | |
| Water level (ft)[a] | 0.82 ± 0.2 | 0.66 ± 0.1 |
| Water temperature (°F) | -- | 505.1 ± 7. |
| Pressure (psia) | -- | 800. ± 16. |
| Mass flow rate (lbm/sec) | -- | 55.1 ± 0.9 |
| **ECC Accumulator A** | | |
| Liquid level (ft)[b,c] | 6.07 ± 0.16 | 5.61 ± 0.03 |
| Standpipe position (ft)[b,c] | 2.59 ± 0.1 | 1.57 ± 0.03 |
| Gas volume (ft$^3$) | -- | 49.1 ± 1. |
| Pressure (psia) | 624. ± 25. | 646. ± 9. |
| Temperature (°F) | 90.05 ± 10. | 88.79 ± 5. |
| Boron concentration (ppm) | 3000 | 3314 ± 15 |

TABLE 1. (Continued)

| Parameter | Specified Value | Measured Value |
|---|---|---|
| HPIS | | |
| Initial flow rate ($ft^3/s$) | 0.011 ± 0.0046 | 0.012 ± 0.0007 |
| LPIS | | |
| Initiation pressure (psia) | 150. ± 28. | 160. ± 4. |
| Suppression Tank | | |
| Liquid level (ft) | 4.17 ± 0.2 | 4.13 ± 0.1 |
| Liquid volume ($ft^3$) | -- | 1030. ± 20. |
| Gas volume ($ft^3$) | -- | 1970. ± 20. |
| Liquid temperature (F) | -- | 176.6 ± 4.9 |
| Pressure (psia) | -- | 27.8 ± 1. |

---

a. The water level is defined as 0.0 at 9.68 ft above the top of the tube sheet.

b. Out of specification, but did not affect experiment success.

c. The total accumulator liquid volume injected, including the pipe volume, was 69.6 ± 1 $ft^3$.

TABLE 2. PRIMARY COOLANT TEMPERATURE DISTRIBUTION PRIOR TO RUPTURE

| Location | Detector | Temperature °F |
|---|---|---|
| Intact loop hot leg (near vessel) | TE-PC-002B | 575.2 ± 5.4 |
| Intact loop steam generator inlet | TE-SG-001 | 576.1 ± 7.0 |
| Intact loop steam generator outlet | TE-SG-002 | 548.2 ± 7.0 |
| Intact loop cold leg (near vessel) | TE-PC-004 | 545.5 ± 5.4 |
| Reactor vessel downcomer: | | |
| Instrument Stalk 1 | TE-1ST-001 | 547.4 ± 9.2 |
| Instrument Stalk 2 | TE-2ST-001 | 549.4 ± 9.2 |
| Reactor vessel lower plenum | TE-1LP-001 | 546.9 ± 9.2 |
| Reactor vessel upper plenum | TE-1UP-001 | 591.7 ± 9.2 |
| | TE-4UP-001 | 586.7 ± 9.2 |
| | TE-5UP-001 | 597.8 ± 9.2 |
| Broken loop hot leg (near vessel) | TE-BL-002B | 551.9 ± 9.0 |
| Broken loop cold leg (near vessel) | TE-BL-001B | 543.5 ± 9.0 |
| Intact loop pressurizer:[a] | | |
| Saturation | PE-PC-004 | 646.1 ± 2.3 |

---

[a] Saturation temperature was determined from pressurizer pressure.

## TABLE 3. SEQUENCE OF EVENTS FOR SMALL BREAK EXPERIMENT L3-1

| Event | Time After LOCE Initiation (s) |
|---|---|
| Reactor scrammed | -2.15 |
| Control rods on bottom | -0.97 |
| LOCE initiated | 0.0 |
| Primary coolant pumps tripped | 0.04 ± 0.01 |
| HPIS injection initiated | 4.6 ± 0.5 |
| Pressurizer emptied | 17.0 ± 1 |
| PCP coastdown completed | 19.0 ± 1 |
| Upper plenum reached saturation pressure | 24.4 ± 0.5 |
| SCS auxiliary feed pump started | 75.0 ± 1 |
| Accumulator injection initiated | 633.6 ± 0.5 |
| Accumulator liquid level below standpipe | 1570.0 ± 1 |
| Indication that ACC-A line empty of fluid | 1741.0 ± 1 |
| SCS auxiliary feed pump tripped | 1875.0 ± 1 |
| Initiate SCS steam bleed | 3622.5 ± 1 |
| LPIS injection initiated | 4240.0 ± 1 |
| Experiment completed[a] | 4368.0 ± 1 |

---

[a] The experiment was terminated when the LPIS pumps were tripped after running for ∿2 minutes.

# 3. PRETEST ANALYTICAL METHODOLOGY

In the following section analytical models used by the participants and the root mean square method of quantifying comparisons of computer code calculations are discussed.

## 3.1 Analytical Models

The analytical methods and models obtained from the participant submittal reports are described in this section. This information is a summary of the methodology used by the participants for the calculation of Experiment L3-1. Detailed descriptions are presented in the participants' submittal reports which are contained in References 5 through 11.

### 3.1.1 Babcock and Wilcox[5]

The TAFY3 and CRAFT2 computer codes were used by B&W to calculate Test L3-1. The TAFY3, version 20, computer code was used to compute the average initial fuel pellet temperature of the LOFT L3-1 nuclear core. The results of the TAFY3 analysis were used for input into the CRAFT2 thermal hydraulic computer code.

The CRAFT2, version 9.3, computer code was used to calculate the thermal hydraulic behavior of LOFT during Test L3-1. The model consisted of 18 nodes and 36 flow paths. Dual flow paths were used throughout the model to allow for countercurrent flow. The Bernoulli - Moody Discharge Model was used with a discharge coefficient ($C_D$) of 0.[illegible] for the subcooled and two-phase blowdown portion of the transient. A discharge coefficient of 0.9 was used after the break flow had stabilized to pure steam (approximately 375 s after rupture).

The calculation was terminated at 1500 s, the maximum duration of the calculation requested in Reference 1.

### 3.1.2 Combustion Engineering[6,11]

The analysis by Combustion Engineering was performed with the CEFLASH-4AS and STRIKIN-II computer codes. The version of CEFLASH-4AS (CE-FLASH-4AS, Version 79338) used in performing this analysis contained options which were specifically created to perform non-licensing analysis such as calculations of LOFT and Semiscale small break tests. The details of the system nodalization for LOCE L3-1 are classified as proprietary by CE. Most of the plots received from CE ended prior to the initiation of accumulator injection.

The hydraulic analysis for the blowdown was performed with the CEFLASH-4AS computer code. The core flow and pressure calculated by CEFLASH-4AS were input into the STRIKIN-II computer code to calculate the fuel rod temperature until the first core flow reversal. Since no core uncovery was calculated to occur, the fuel rod temperature following the first flow reversal was calculated by CEFLASH-4AS.

### 3.1.3 Exxon Nuclear Company[5]

Exxon submitted two calculations for LOCE L3-1. One calculation was performed with the RELAP4-EM small break code, which is a current licensing code version. A second calculation was performed with the RELAX-EM code which is an advanced version of the small break RELAP4 code. The primary change for the RELAX code was the incorporation of a slip flow model.

The RELAX-EM code nodalization of the LOFT system for LOCE L3-1 consisted of 21 volumes, 26 junctions and 47 heat slabs. The Henry-Fauske critical flow model was used for the subcooled portion of the calculation and the Moody critical flow model was used for the saturated portion. A critical flow multiplier of 1.0 was used for the entire calculation.

The RELAP4-EM code nodalization consisted of 20 volumes, 25 junctions and 50 heat slabs. The same critical flow models were employed in this calculation as in the Exxon RELAX code calculation.

### 3.1.4 Westinghouse Electric Corporation[8]

The WFLASH computer code was used to calculate the thermal-hydraulic behavior during LOCE L3-1. A model consisting of 16 nodes and 16 flowpaths was employed. The break flow model used was the modified Zoloudek for subcooled blowdown and Moody during two phase break flow. A discharge coefficient of 1.0 was used throughout the transient.

The version of the WFLASH code used had some modifications and options not normally employed in the small LOCA ECCS evaluation model used by WEC. A pressurizer surge line calculation modification and the utilization of "water packing" logic were used. A pump modification allowing for programmed and free coastdown and a best estimate decay heat curve were also utilized. In addition, the capability to model the LOFT steam generator control valve was added to the code.

A core fuel temperature calculation was not performed since core uncovery was not calculated to occur.

### 3.1.5 Idaho National Engineering Laboratory[9]

The INEL best estimate prediction for the L3-1 comparison was performed using the RELAP4/MOD6 Update 4 computer code stored under INEL Configuration Control Numbers C0010006 (RELAP4/MOD6) and H002011B (steam tables). The code was updated to model the steam generator secondary control valve operation in the LOFT L3-1 system. The code update directives are listed in Table 1 of Reference 9. The LOFT system nodalization used for the calculation consisted of 37 volumes, 44 junctions, and 16 heat slabs.

The Henry-Fauske critical flow model was used in both the subcooled and saturated regions with discharge coefficients of 1.0 and 0.8, respectively.

### 3.1.6 Los Alamos Scientific Laboratory[10]

The submittal by LASL was performed with the TRAC-P1A computer code. The L3-1 system model consisted of 24 components and 124 cells. The vessel was modeled with 9 axial levels, 2 radial rings and 2 azimuthal segments for a total of 36 cells.

## 3.2 Root Mean Square Method

Comparisons of code calculations to data have generally been qualitative. A method for quantifying the comparisons would aid in their interpretation. There are, however, problems inherent with comparing a code calculation with data. There are not a multiple of measurements from which to calculate a sample mean; the data and calculation are in time series and there are few statistical methods for comparing two time series. At the present time a strictly quantitative analysis rather than a statistical analysis appears more feasible.

A quantitative assessment of the participants' performance for the pretest calculation of Test L3-1 can be determined by a modified root mean square (RMS) equation. The magnitude of the RMS deviations computed from this equation would be dependent on the units a parameter was measured in, the range of the data for each test parameter and the distance (in units) between the calculation and the data.

The sensitivity of the RMS deviation to units used could be removed by dividing the deviations by a reference number equivalent to the range of a test parameter. The resulting ratios represent a measure of closeness to the data.

The equation used to calculate the RMS deviations was

$$PD = \left[ \frac{\sum_{i=0}^{n} (d_i)^2}{n} \right]^{1/2}$$

where

PD = participant root mean square deviation from data

n = number of points evaluated

$d_i$ = The difference between the calculated value and the data band (upper or lower bound)

The above equation varied from a root mean square equation in that differencing was done on the data band rather than the measured data. The difference between the calculated value and the data band, $d_i$, was zero if the calculated value was between the upper and lower bound of the data band. If the calculated result was above the data band then the difference from the calculated result to the upper bound of the data band was used. If the calculated result was below the data band, then the difference from the calculated result to the lower bound was used. The number of points evaluated was n. The value of n was evaluated by the following expression

$$n = \frac{t_2 - t_1}{\Delta t} + 1$$

where

$t_2$ = stop time of regime

$t_1$ = start time of regime

$\Delta t$ = time increment

The data for each parameter evaluated were segmented into three time intervals or regimes. The regimes were selected on the basis of easily definable events, for example, accumulator injection initiation. The time intervals chosen were:

| Regime No. | Time Interval (sec) | Time Increment (sec) | Test Sequence for Regimes |
|---|---|---|---|
| 1 | 0-75. | 2.5 | Beginning of transient until the steam generator auxiliary feed pump started |
| 2 | 75-633.6 | 20. | Start of steam generator auxiliary feed pump until accumulator injection initiated |
| 3 | 633.6-1500. | 30. | Initiation of accumulator injection until end of requested calculation |

The time increments were chosen to produce about 30 points in each regime. An RMS calculation was not performed for a regime in which a participants calculation did not cover the entire time interval.

Three ranges for each measured parameter were determined by computing the absolute difference of the maximum of the upper bound of the data band from the minimum of the lower bound of the data band in each time interval. The RMS deviations were then divided by the appropriate range. The division converted the RMS deviations to dimensionless quantities; thus, the effects of the measurement units were cancelled and values were computed for percent of range of the data bands.

The magnitude of the resulting percent of range numbers was due solely to the deviation of code calculated parameters to data bands. These numbers should be used as a measure of closeness to the data band with a zero indicating the calculation remained inside the data band for a particular regime.

The results of the quantitative analysis are meant to provide a method to assist in evaluating calculations. A limitation of the analysis which must be considered is that the analysis does not always indicate how well the trend of the data was calculated. As will be seen later in the report, a calculated parameter can be almost entirely within a data band for a time regime, yet not be exhibiting the same trend as the data.

## 4. PRETEST DATA COMPARISONS

The following section discusses the comparison of pretest calculations for Test L3-1 with data. The calculations are overlayed with data bands denoting instrument error of the test measurements. A discussion of the procedure by which the data bands were established is described in Reference 12. A complete list of the parameters requested from each participant by the NRC for the calculation of the LOFT L3-1 experiment is presented in Table 4. From this list of parameters, five comparisons were performed. The number of comparisons were limited because of unqualified measurements and requested parameters not being supplied by the participants. A comparison of the time of selected events calculated by the participants and the measured chronology of events is shown in Table 5. The results of the analytical portion of the comparisons are listed in Tables 6 and 7 at the end of the pretest comparisons section.

### 4.1 Steam Generator Secondary Pressure

The steam generator secondary pressure quickly rose after scram due to the closing of the steam flow control valve. The steam control valve was to control pressure between 920 and 1020 psig. This valve did not open during the initial 1500 s of the transient.The auxiliary feed pump was started at 75 s cooling the mixture in the steam generator and causing a decrease in the secondary side pressure.

The steam generator secondary pressure comparisons are shown in Figures 3 and 4. B&W's calculation of secondary pressure exhibited the same trend as the data: however, the pressure was underpredicted for the first 250 s and then overpredicted from 400 s.

The calculation of secondary pressure by CE rose to the steam control valve set point (1020 psig) twice in the initial 90 s of the transient. The auxiliary feed pump was started at 60 s, however, the pressure did not immediately decrease as in the test, instead, the pressure rose and remained fairly constant until approximately 290 s when the calculated primary pressure (upper plenum pressure) dropped below the secondary pressure.

## TABLE 4. RECOMMENDED PARAMETERS FOR LOFT EXPERIMENT L3-1 CALCULATIONS

| Pressure (psia) | Instrument |
|---|---|
| Pressurizer (vapor space)[1] | PE - PC - 4 |
| Broken loop hot leg[1] | PE - BL - 2 |
| Broken loop cold leg, near break[1] | PE - BL - 1 |
| Upper plenum (upper end box)[1] | PE - 1UP - 1 |
| Accumulator, intact loop[1] | PT - P120 - 43 |
| Steam generator secondary[1] | PT - P4 - 10A |

| Density (lbm/ft$^3$) | Instrument |
|---|---|
| Intact loop cold leg[1] | DE - PC - 1 |
| Intact loop hot leg | DE - PC - 2 |
| Broken loop cold leg | DE - BL - 1 |
| Broken loop hot leg | DE - BL - 2 |
| Pump Suction | DE - PC - 3 |

| Differential Pressure (psid) | Instrument |
|---|---|
| Across core | Not measured |
| Across intact loop pump[1] | PdE - PC - 1 |
| Pump suction leg | Not measured |
| Intact hot leg to top of vessel | Not measured |

| Fluid Temperatures (°F) | Instrument |
|---|---|
| Upstream of break, cold leg[1] | TE - BL - 1 |
| Upper plenum[1] | TE - 1UP - 1 |
| Pressurizer (liquid) | TE - P139 - 20 |
| Lower Plenum[1] | TE - 1LP - 1 |

| Flow Rates (lbm/sec ) | Instrument |
|---|---|
| Core inlet | Not measured |
| Core outlet | Not measured |
| Break flow[2] | TTE - BL - 1 |
| Cold leg, intact loop | FE - PC - 1 |
| Hot leg, intact loop | PNE - PC - 2 |
| Accumulator, intact loop | FT - P120 - 36 - 1 |
| LPIS[1] | FT - P120 - 85 |
| HPIS[1] | FT - P128 - 104 |
| Pressurizer surge line | Pde - PC - 8 |

TABLE 4. (Continued)

| Metal Temperatures (°F) | Instrument |
|---|---|
| Average rod @ 15, 21, 30 and 39 inches | Not measured |
| Hot rod @ 15, 21, 30 and 39 inches | Not measured |
| PCT (calculated) | Not measured |

| Mass Inventories (lbm) | Instrument |
|---|---|
| Primary system liquid mass inventory | Not measured |
| Vessel mass inventory | Not measured |
| Integrated mass leaving system through break junction | Not measured |
| Energy released to containment | |

| Qualities, Heat Transfer Coefficients Btu/hr* ft$^2$* °F) | Instrument |
|---|---|
| At core elevations corresponding to rod temperatures | Not measured |

| Collapsed Mixture Level (ft) | Instrument |
|---|---|
| Vessel | LE - 3F10 |
| Downcomer | LE - 1ST or 2ST |
| Pressurizer | LE - P139 - 6, 7, 8 |

| Pump Performance (rpm) | Instrument |
|---|---|
| Pump speed[1] | RPE - PC - 1<br>RPE - PC - 2 |

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[1] Measurement was designated as "Qualified" in Reference 3.

[2] See Section 4.5.

## TABLE 5. MEASURED AND CALCULATED CHRONOLOGY OF EVENTS FOR LOCE L3-1[a]

| EVENT | DATA | B&W | CE | Exxon RELAP | Exxon RELAX | Westinghouse | INEL | LASL |
|---|---|---|---|---|---|---|---|---|
| HPIS injection initiated | 4.6 ± 0.5 | 5.0 | 1.0 | 2. | 1.30 | 1.73 | 2.8 | 0.93 |
| Pressurizer emptied | 17.0 ± 1 | ∼24.0 | 22. | 20. | 23.95 | ∼19.5 | 23.5 | 30. |
| Upper plenum reached saturation pressure | 24.4 ± 0.5 | 32.0 | NS[d] | 28. | 38.95 | e | ∼25[13] | NS[d] |
| SCS[b] auxiliary feed pump started | 75.0 ± 1[f] | 60.0 | 60. | 60. | 60. | 60. | 60.[13] | 60. |
| Accumulator injection initiated | 633.6 ± 0.5 | 850.0 | 783. | NC[c] | NC[c] | 1033.7 | 905. | 1030. |

---

a. LOCE L3-1 was initiated when the four control rods were fully inserted, which corresponds to time 0. in the experiment.

b. SCS is an abbreviation for secondary coolant system

c. Phenomena was not calculated.

d. Information not supplied.

e. It cannot be determined from the information supplied if the time saturation pressure was reached applied to the upper plenum or the steam generator outlet plenum.

f. Reference 1 specified 60. s after blowdown one auxiliary feed pump would be started.

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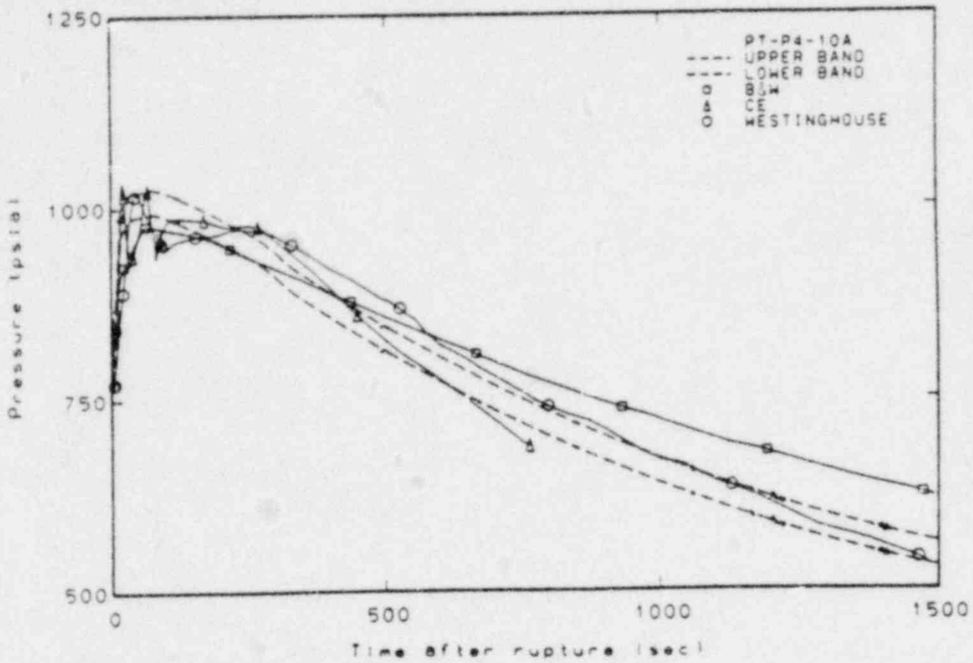


Figure 3. Comparison of B&W, CE and Westinghouse calculations of steam generator secondary side pressure to data.

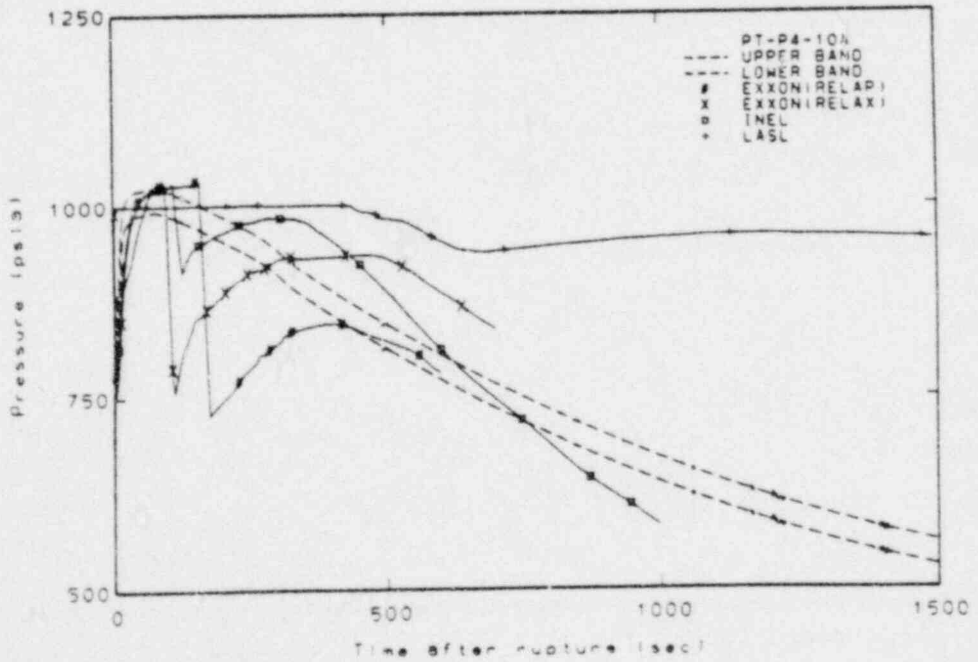


Figure 4. Comparison of Exxon RELAP, Exxon RELAX, INEL and LASL calculations of steam generator secondary side pressure to data.

The calculation of the secondary pressure by Westinghouse initially increased at a slower rate than the measured secondary pressure: the pressure dropped when the upper steam control valve set point of 1020 psig was reached at about 45 s. The pressure continued to drop until about 90 s when the lower control valve set point was reached and the valve closed. The pressure remained nearly constant until about 270 s. At 270 s the secondary pressure was above the primary pressure and as a result of secondary to primary heat transfer the secondary pressure decreased.

The Exxon RELAP, Exxon RELAX and INEL calculations underpredicted the initial rate of pressure increase in the steam generator secondary system. The secondary pressure in the three calculations dropped sharply when the steam control valve set point was reached. The secondary pressure of the Exxon RELAP and Exxon RELAX calculations decreased significantly below the lower control valve set pressure. For each of these three calculations the pressure then increased until the secondary pressure was above the primary pressure. Later in the calculations when the primary pressure was below the secondary pressure, the secondary pressure decreased.

The LASL calculation overpredicted the rate of pressure increase for the first 20 s. The secondary pressure remained between 930 and 1000 psia for the remainder of the calculation and did not follow the trend of the data.

## 4.2 System Pressure

The system pressure was characterized by a rapid depressurization to the system fluid saturation pressure. The depressurization rate then decreased until approximately 300 s when the system liquid level decreased below the break orifice allowing steam to escape and the system to depressurize more rapidly. From 1000-1500 s the depressurization rate was decreased as a result of the liquid level in the broken loop increasing above the break orifice.

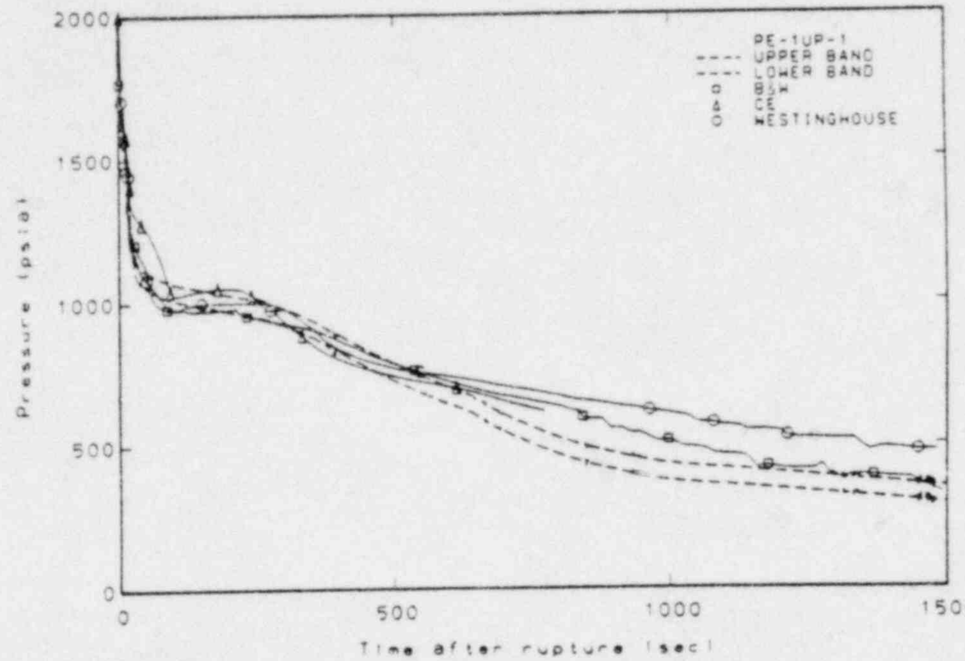


Figure 5. Comparison of B&W, CE and Westinghouse calculations of upper plenum pressure to data.

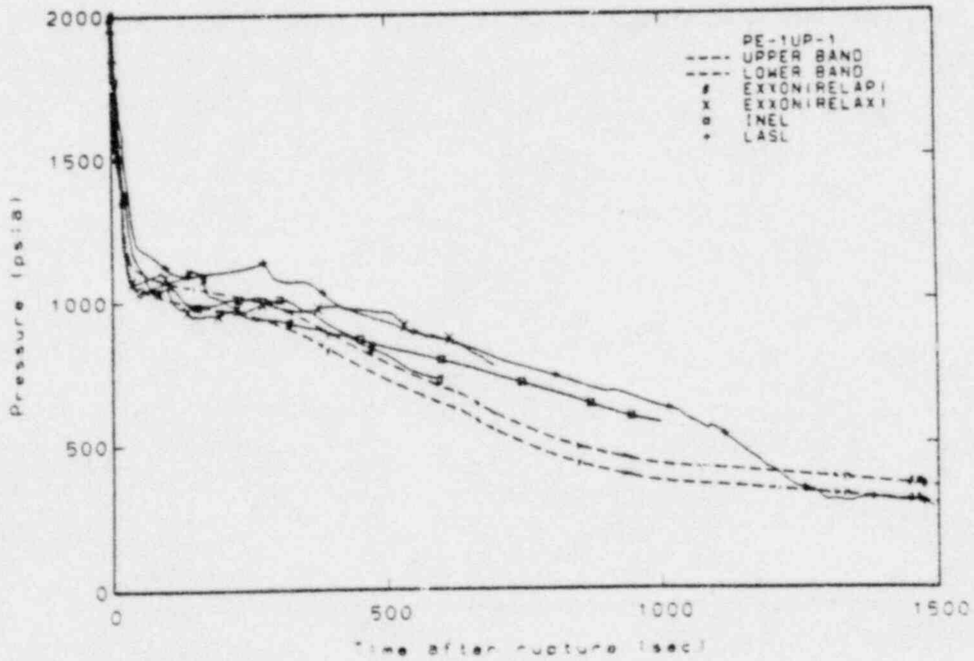
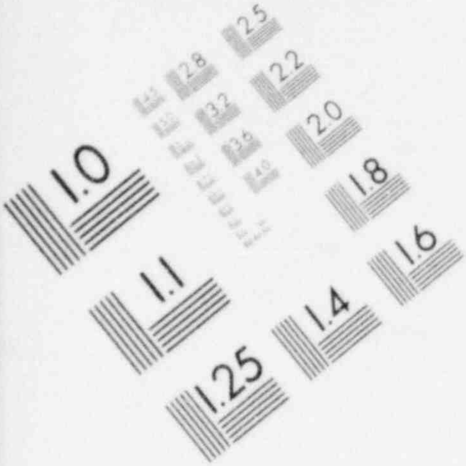
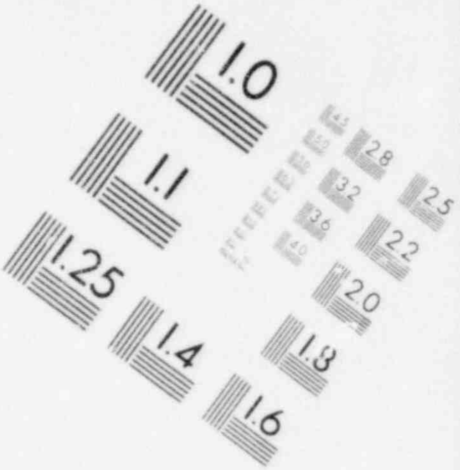
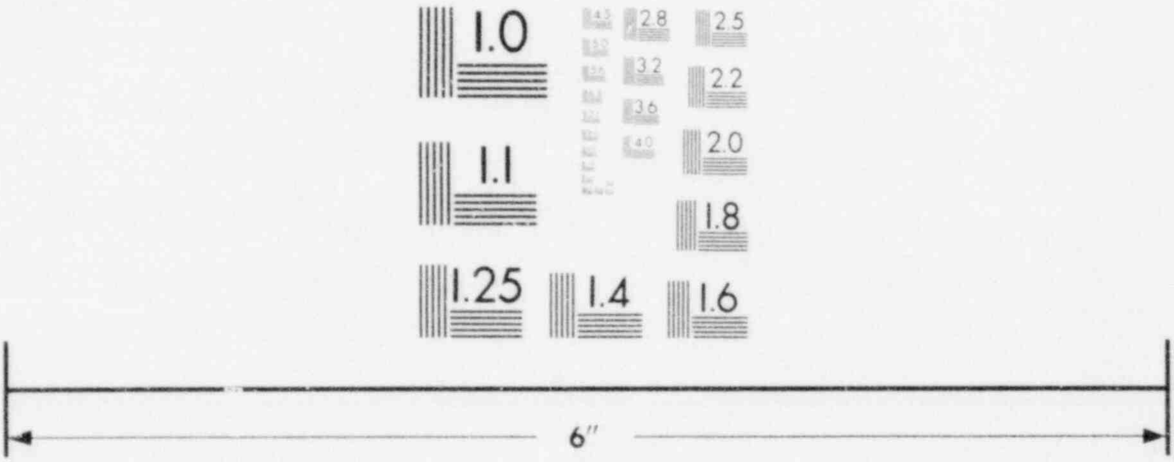


Figure 6. Comparison of Exxon RELAP, Exxon RELAX, INEL and LASL calculations of upper plenum pressure to data.





# IMAGE EVALUATION TEST TARGET (MT-3)



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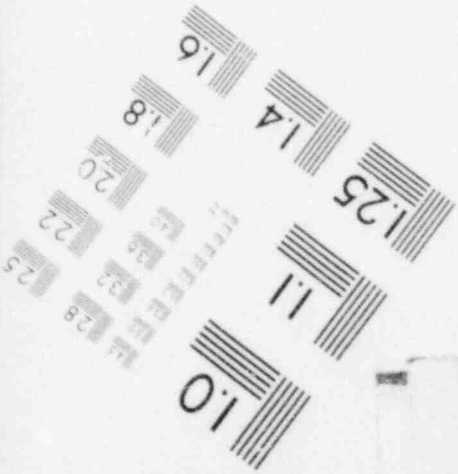
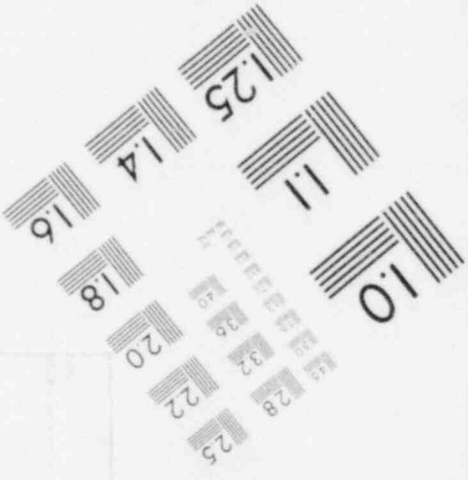
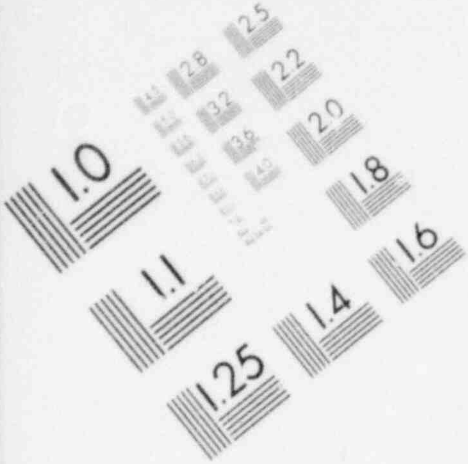
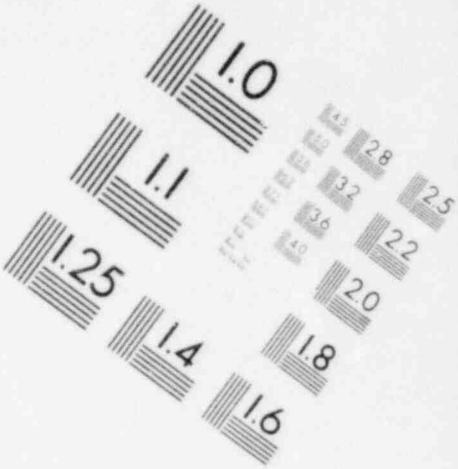
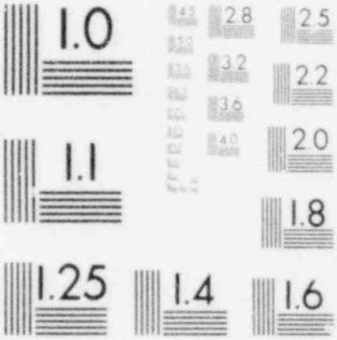


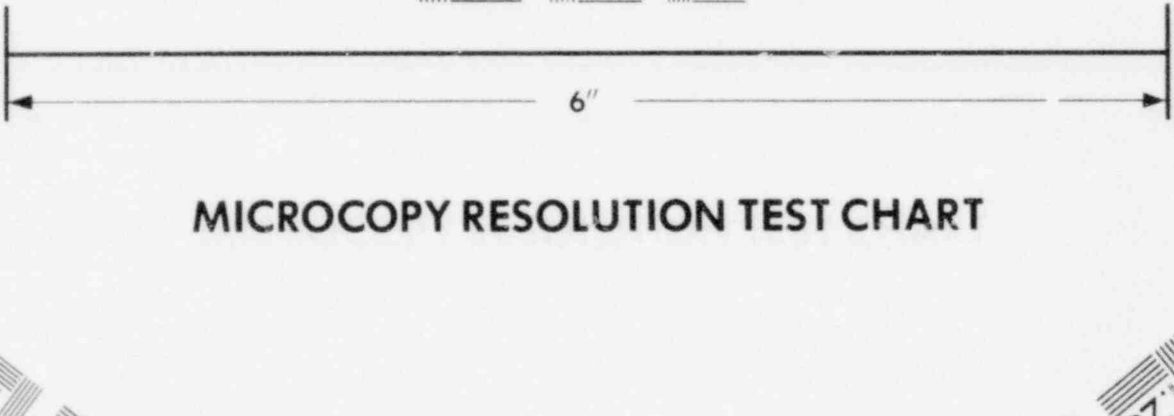






# IMAGE EVALUATION TEST TARGET (MT-3)





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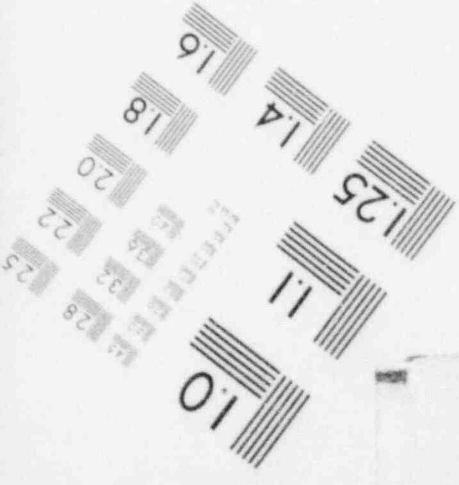

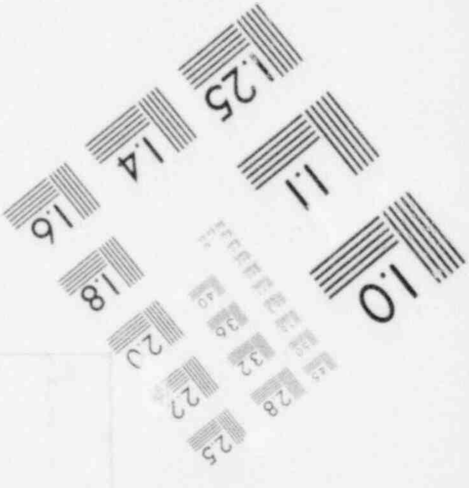

The system pressure comparisons, calculated for the upper plenum, are shown in Figures 5 and 6. Figure 5 shows the comparison for the B&W, CE and Westinghouse calculations. The calculation by CE underpredicted the depressurization rate from 25 to 75 s. Whereas B&W and Westinghouse results were within the range of the data. Between 75 and 300 s the measured system pressure was decreasing; however, CE B&W and Westinghouse calculated a rise in system pressure for that time period. Beyond 550 s the calculation by Westinghouse overpredicted system pressure by as much as 180 psia.

The comparisons for the Exxon RELAP, Exxon RELAX, INEL and LASL calculations are shown in Figure 6. For each of the code calculations, the intial system pressure decrease followed the general trend of the data for about 30 s. Each of the calculations then exhibited an increase in system pressure. This increase in system pressure was probably a result of the increase in the void generation in the core being larger than the change in volumetric flow out the break.

The LASL calculation overpredicted the system pressure for most of the transient. This was apparently a result of the difference between the measured and calculated response of the secondary side of the steam generator. There was a decrease in the calculated pressure after 1030 s due to initiation of accumulator injection.

### 4.3 Intact Loop Accumulator Pressure

The accumulator injection during LOCE L3-1 was initiated at 634 s after rupture. The specified initial accumulator pressure in Reference 1 was 600 psig. The measured initial pressure was 633 psig. This difference caused the measured pressure to initially be above the calculated results. The 33 psi difference in initial pressure did not effect the calculations prior to 634 s into the transient.

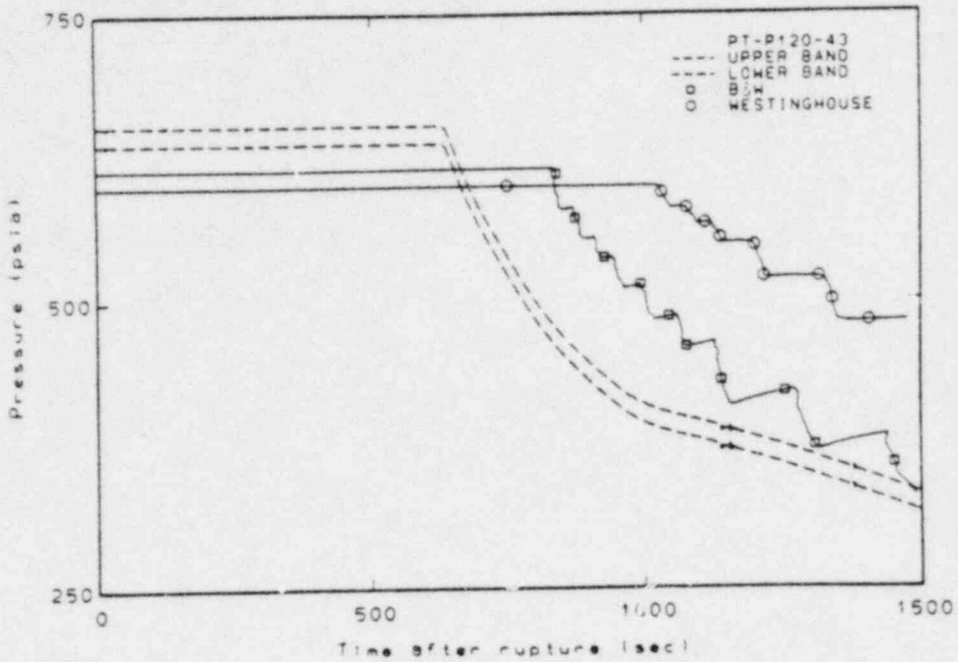

Figure 7. Comparison of B&W and Westinghouse calculations of intact loop accumulator pressure to data.

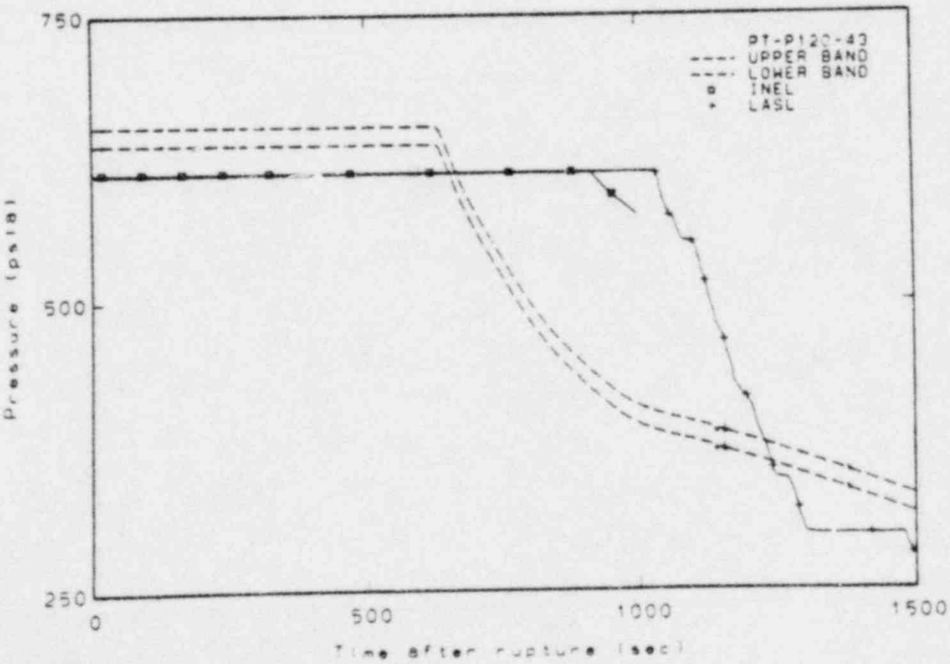

Figure 8. Comparison of INEL and LASL calculations of intact loop accumulator pressure to data.

Figures 7 and 8 show the comparisons of calculated accumulator pressure to data. Exxon RELAP and Exxon RELAX did not calculate accumulator initiation for the duration of their calculations. CE calculated accumulator injection at 783 s; however, a plot showing the accumulator pressure was not submitted. B&W and Westinghouse predicted initiation at 850 and 1034 s, respectively. INEL predicted accumulator injection at 905 s and LASL predicted initiation at 1030 s.

The calculation of accumulator pressure response by B&W showed a trend similar to the data indicating that the accumulator emptied at a rate similar to the experiment. The calculation by Westinghouse indicated a slower depressurization and therefore slower emptying of the accumulator than was measured. LASL's calculation exhibited a more rapid drop in accumulator pressure which was not indicative of the trend of the data.

### 4.4 Intact Loop Cold Leg Density

The test results indicate that voiding of the intact loop cold leg occurred at about 100 s after rupture.

The comparison of the intact loop cold leg density with participants calculations are shown in Figures 9 and 10. Except for the INEL calculation which is shown in Figure 10, each of the participants calculated the voiding in the intact loop cold leg later than was measured in the test. CE did not submit a density plot; however, their quality plot indicated voiding at 230 s.

The density increased at about 640 s as a result of accumulator initiation; however, the participants for the most part underpredicted the density since they did not accurately calculate the time of accumulator injection.

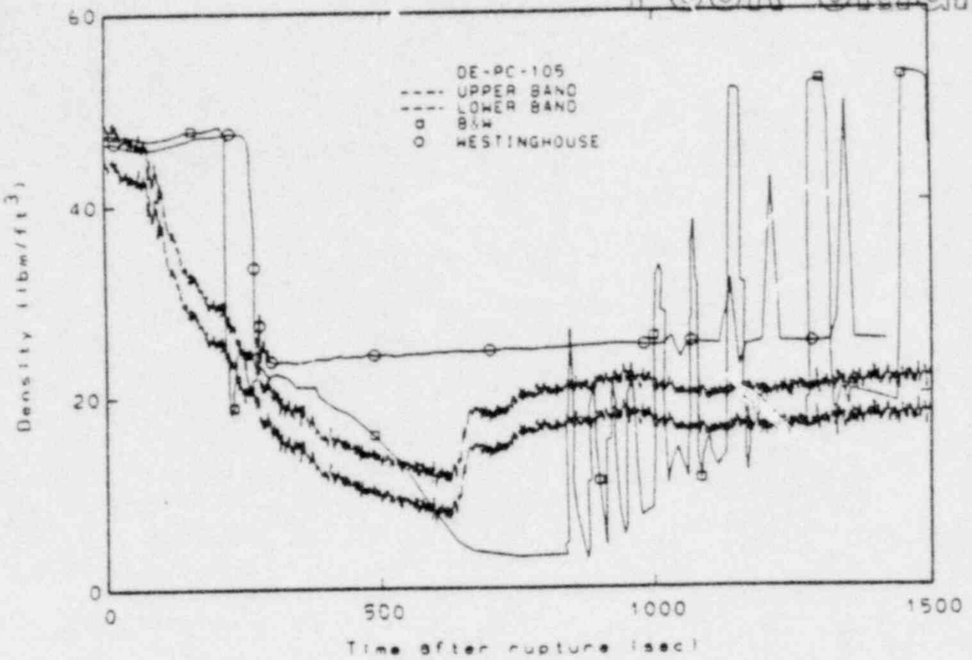

Figure 9. Comparison of B&W and Westinghouse calculations of intact loop cold leg density to data.

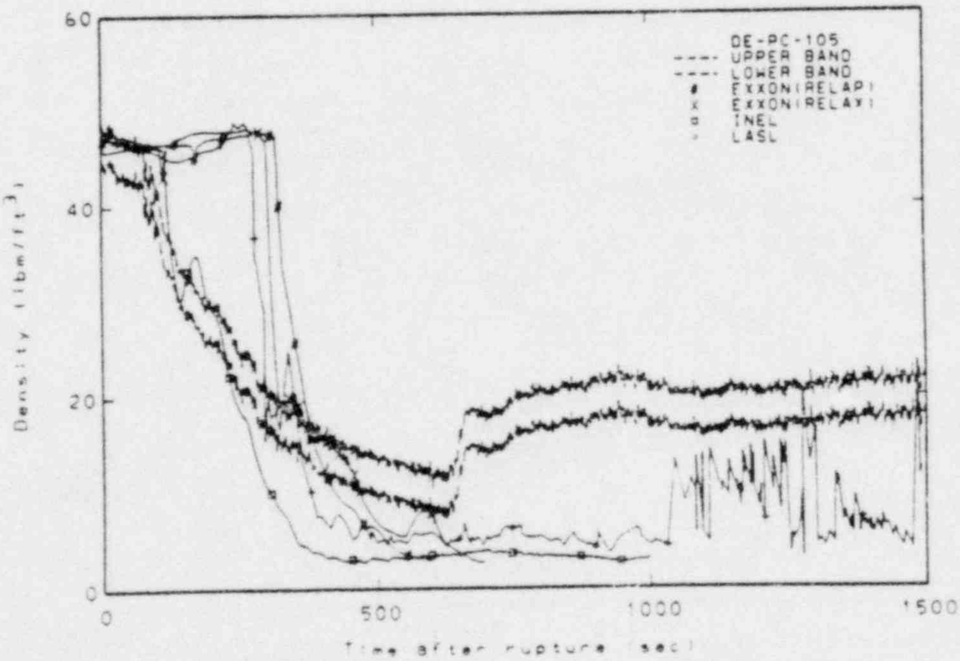

Figure 10. Comparison of Exxon RELAP, Exxon RELAX, INEL and LASL calculations of intact loop cold leg density to data.

## 4.5 Break Flow

The break mass flow presented in this report was qualified on July 3, 1980 by the LOFT Data Integrity Review Committee, after LOFT obtained additional information from the L3-1 test data, and therefore is not shown in Reference 3.

After an initial sharp increase at the initiation of the test, the break mass flow decreased rapidly until about 37 s. At about 37 s an increase in break flow was indicated. The cause of this increase in flow is uncertain at this time. At 94 s the break mass flow rate decreased rapidly as a result of a decrease in the density of the fluid at the break. At approximately 300 s the liquid level decreased below the level of the break orifice and the mass flow rate decreased.

The calculations of break mass flow by each of the participants exhibited the trend of the data for the initial 40 s. The calculated break flows submitted by B&W, CE and Westinghouse dropped sharply as a result of a decrease in the calculated fluid densities near the break. The decrease in density at the break was calculated late by the participants, therefore, the effect on the break flow was calculated later than occurred in the test.

The calculated break mass flows submitted by Exxon overpredicted the measured break mass flow from 200 s until the calculation was terminated. The Exxon RELAP calculation of break mass flow rose between 80 and 160 s and then dropped as a result of a decrease in the fluid density in the broken loop cold leg. The Exxon RELAX calculation of break mass flow remained fairly constant between 40 and 85 s due to the high density of the fluid in the broken loop cold leg. The flow decreased and rose between 200 and 280 s as a result of a decrease and increase in the calculated broken loop cold leg density.

The INEL calculation of break mass flow followed the trend of the data. This was probably due to the fairly close calculation of the time the fluid at the break became steam. The calculation submitted by LASL overpredicted the break mass flow rate after 230 s.

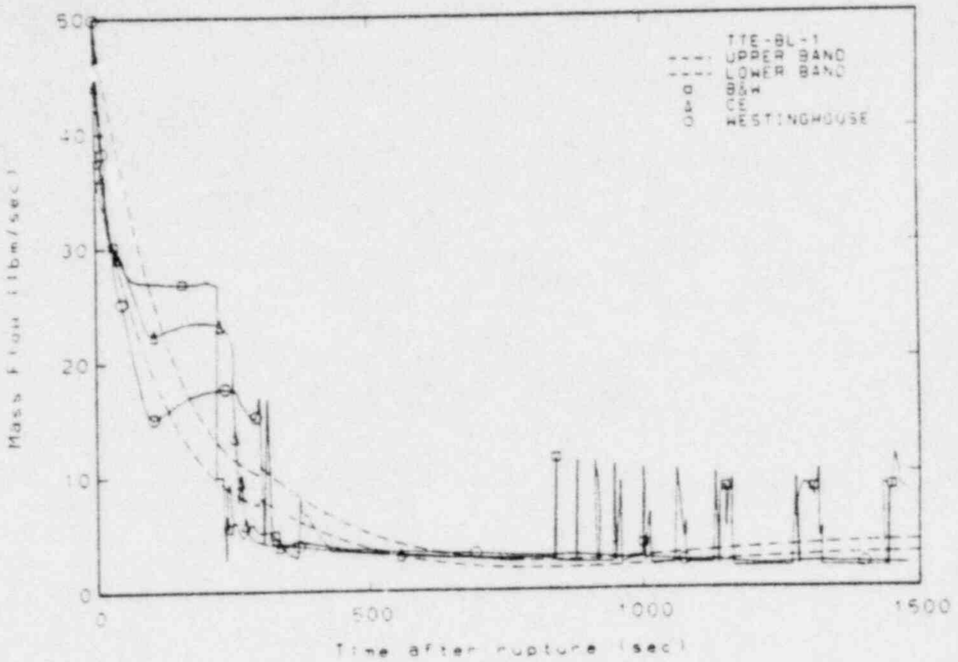

Figure 11. Comparison of B&W, CE and Westinghouse calculations of break mass flow to data.

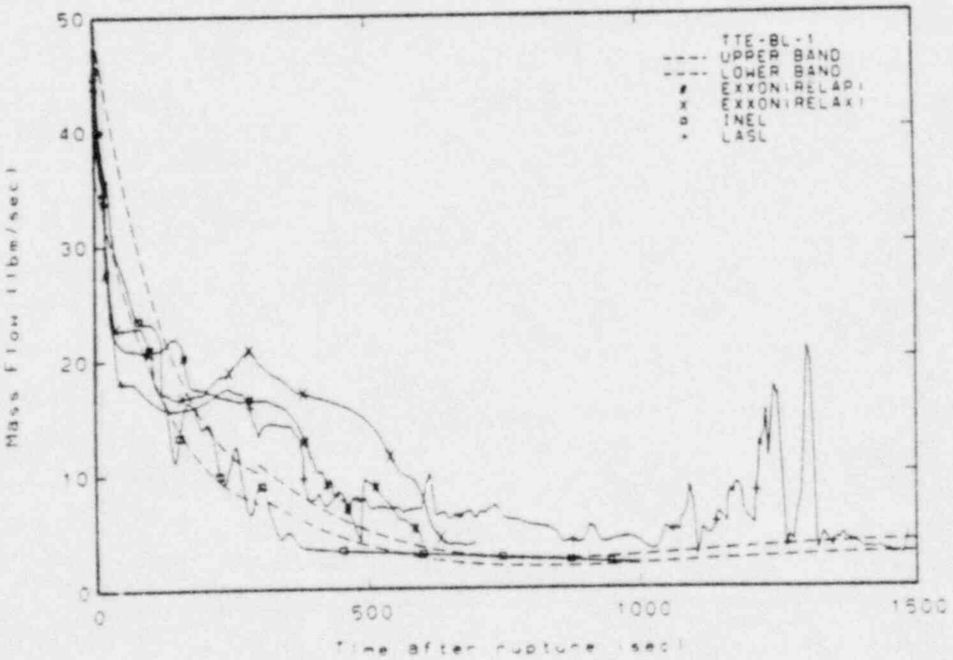

Figure 12. Comparison of Exxon RELAP, Exxon RELAX, INEL and LASL calculations of break mass flow to data.

## 4.6 Quantitative Results

The results of the quantitative analysis of the calculations as described in Section 3.2 are shown in Tables 6 and 7. A plus (+) or a minus (-) are listed by some of the results in Table 6. These symbols denote when the calculation was generally above or below the data bands. The criteria was 2/3 of the data points for a particular time regime and parameter had to lie above the data band for a plus (+) and below the data band for a minus (-).

Table 7 contains the RMS numbers, obtained from Table 6, divided by a reference number. The reference number was the approximate range of the data band for each measured parameter in a time regime. The reference numbers are listed in Table 7.

The percent of range numbers in Table 7 are a measure of the closeness of the calculated values to data. They, however, are not an indication of how well the trends in the data were calculated.

It can be observed from Table 7 that the participants did not calculate secondary pressure accurately with most of the percentages being above 10%. The system pressure was calculated accurately in the first regime, however, there was an increase in most of the percentages in the second and third regimes. B&W, CE and Westinghouse were each 3% of range in the second regime of system pressure. This was due to the calculations being generally contained within the data band, although the trend of the data was not exhibited for the first half of the regime.

The percentages for the break flow indicate that B&W, CE and INEL calculated the first regime fairly accurately; for the last two regimes, the participants calculations ranged from 5% to 112% of range.

TABLE 6. L3-1 RMS MATRIX

|  |  | Participants[2,3,4,5] |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| Instrument | Regime[1] | B&W | CE | Exxon RELAP | Exxon RELAX | INEL | LASL | Westinghouse |
| PE-1UP-1 (psia)<br>Upper plenum pressure | 1 | 62.64 | 130.75 (+) | 59.49 | 32.19 | 54.37 | 155.25 (+) | 41.42 |
|  | 2 | 14.08 | 15.81 | * | 99.84 (+) | 43.53 (+) | 116.32 (+) | 14.24 |
|  | 3 | 61.46 (+) | 61.82 (+) | * | * | * | 150.80 (+) | 138.51 (+) |
| PT-P120-43 (psia)<br>Intact loop accumulator pressure | 1 | NA | NS | NS | NS | NA | NA | NA |
|  | 2 | NA | NS | NS | NS | NA | NA | NA |
|  | 3 | 49.71 (+) | NS | NS | NS | * | 111.26 | 141.56 (+) |
| PT-P4-10A (psia)<br>Steam Generator secondary pressure | 1 | 31.55 (-) | 26.12 | 22.28 | 39.99 | 43.98 (-) | 46.57 | 40.39 |
|  | 2 | 11.33 | 9.13 | * | 78.84 | 39.65 (+) | 97.25 (+) | 25.78 (+) |
|  | 3 | 49.71 (+) | * | * | * | * | 298.97 (+) | 6.27 |
| Broken loop cold leg mass flow (lb/sec) | 1 | 0.60 | 1.13 | 4.01 | 2.79 | 1.69 | 5.98 | 3.79 |
|  | 2 | 4.68 (-) | 4.02 (-) | * | 6.84 (+) | 2.23(-) | 4.31 (+) | 4.30 |
|  | 3 | 1.79 | * | * | * | * | 2.69 (+) | 0.62 |
| DE-PC-105 (lb/ft$^3$)<br>Intact loop cold leg density | 1 | 0.54 | NS | 0.24 | 0.16 | 0.51 | 0.05 | 0.0 |
|  | 2 | 7.64 (+) | NS | * | 11.70 | 5.94 (-) | 10.32 | 11.94 (+) |
|  | 3 | 12.28 | NS | * | * | * | 9.03 (-) | 6.90 (+) |

1. Regimes are defined as: 1 0-75 seconds
75-633 seconds
633-1500 seconds

2. Asterisk shown for regimes not fully predicted by participants.
3. NS - Not submitted by participant.
4. + Prediction was generally higher than measured data.
- Prediction was generally lower than measured data.
5. NA - Not applicable - Accumulator injection does not initiate until regime 3.

TABLE 7. L3-1 PERCENT OF RANGE MATRIX

| Instrument | Regime[1] | Reference Number (range) | B&W (%) | CE (%) | Exxon RELAP (%) | Exxon RELAX (%) | INEL (%) | LASL (%) | Westinghouse (%) |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Participants[2,3,4] |  |  |  |  |
| PE-1UP-1 (psia)<br>Upper plenum pressure | 1 | 1180 | 5 | 11 | 5 | 3 | 5 | 13 | 4 |
|  | 2 | 460 | 3 | 3 | * | 22 | 9 | 25 | 3 |
|  | 3 | 390 | 16 | 16 | * | * | * | 39 | 36 |
| PT-P120-43 (psia)<br>Intact loop accumulator pressure | 1 | NA | NA | NS | NS | NS | NA | NA | NA |
|  | 2 | NA | NA | NS | NS | NS | NA | NA | NA |
|  | 3 | 330 | 15 | NS | NS | NS | * | 34 | 43 |
| PT-P4-10A (psia)<br>Steam Generator secondary pressure | 1 | 240 | 13 | 11 | 9 | 17 | 18 | 19 | 17 |
|  | 2 | 270 | 4 | 3 | * | 29 | 15 | 36 | 10 |
|  | 3 | 260 | 19 | * | * | * | * | 15 | 2 |
| Broken loop cold leg mass flow (lb/sec) | 1 | 26.0 | 2 | 4 | 15 | 11 | 7 | 23 | 15 |
|  | 2 | 40.6 | 12 | 10 | * | 17 | 5 | 11 | 11 |
|  | 3 | 2.4 | 75 | * | * | * | * | 112 | 26 |
| DE-PC-105 (lb/ft$^3$)<br>Intact loop cold leg density | 1 | 6.3 | 9 | NS | 4 | 3 | 8 | 1 | 0 |
|  | 2 | 38.4 | 20 | NS | * | 30 | 15 | 27 | 31 |
|  | 3 | 13.0 | 94 | NS | * | * | * | 77 | 53 |

1. Regimes are defined as: 1 0-75 seconds
75-633 seconds
633-1500 seconds

2. Asterisk shown for regimes not fully predicted by participants.
3. NS - Not submitted by participant.
4. NA - Not applicable - Accumulator injection does not initiate until regime 3.

## 4.7 Additional Parameters

To aid in the evaluation of the calculations by each participant, additional calculated results are compared in Figures 13 to 22. Experimental data were not qualified to compare with these calculated results.

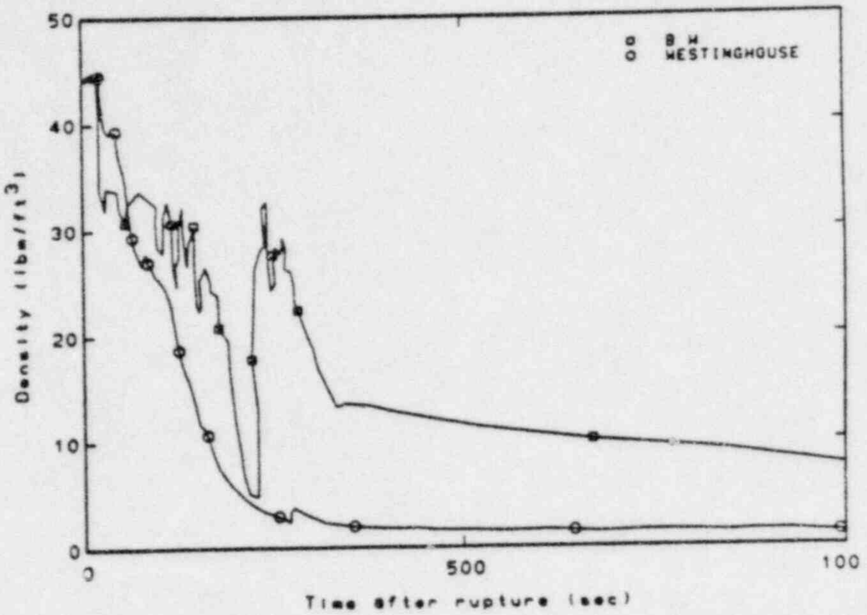

Figure 13. Calculations of intact loop hot leg density by B&W and Westinghouse.

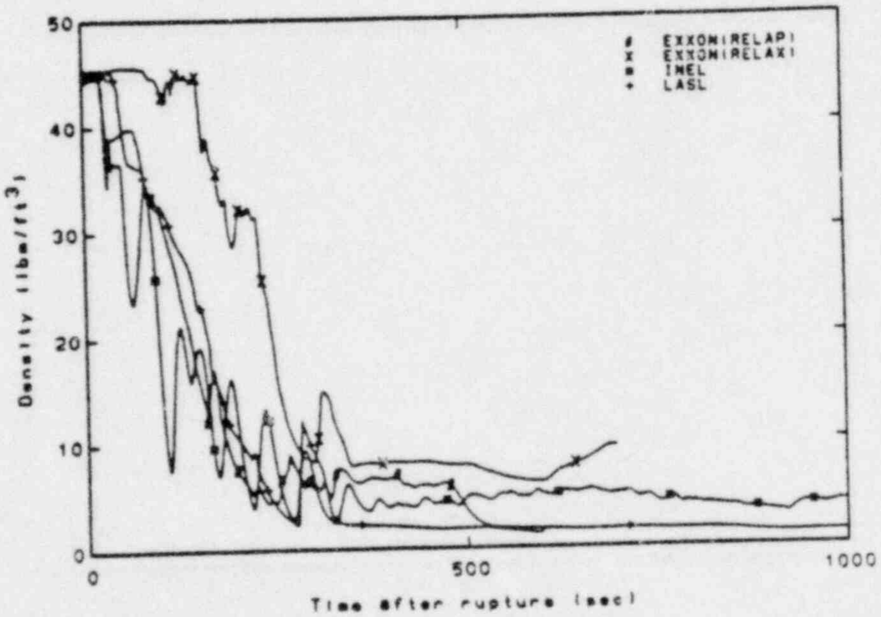

Figure 14. Calculations of intact loop hot leg density by Exxon RELAP, Exxon RELAX, INEL, and LASL.

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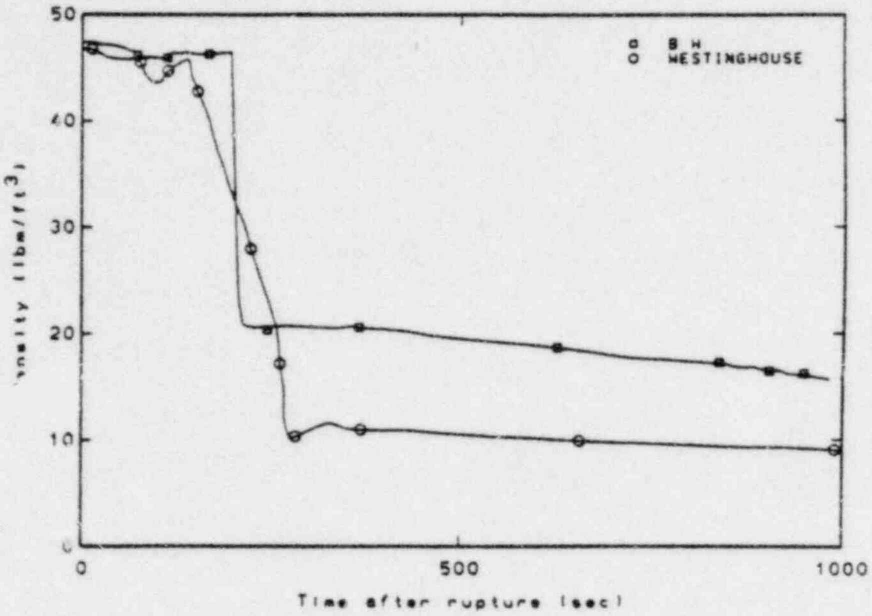


Figure 15. Calculations of pump suction density by B&W and Westinghouse.

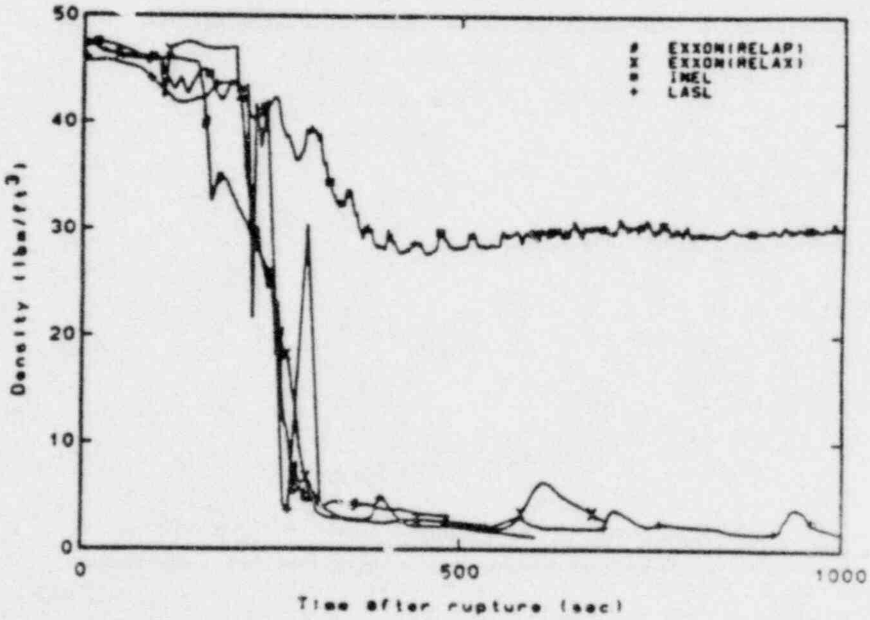


Figure 16. Calculations of pump suction density by Exxon RELAP, Exxon RELAX, INEL, and LASL.

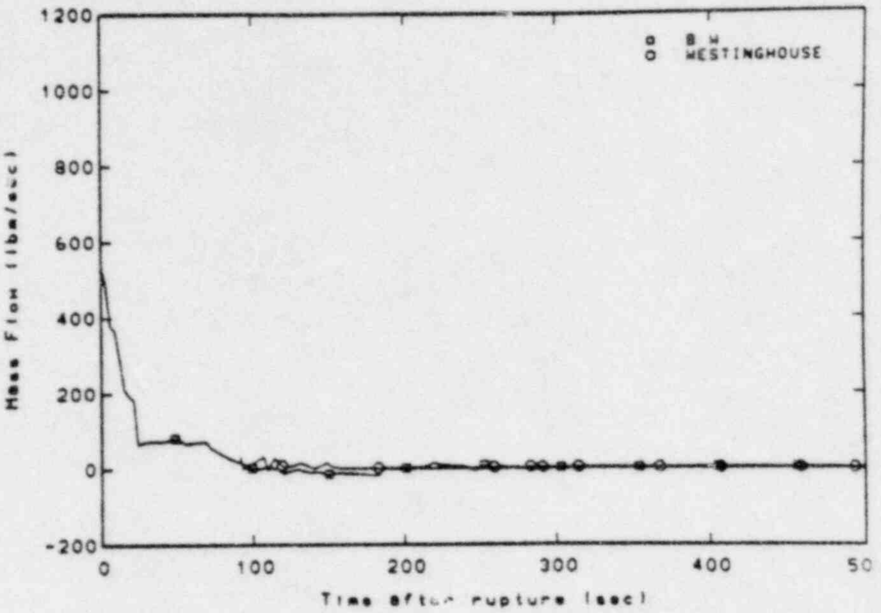


Figure 17. Calculations of intact loop hot leg mass flow by B&W and Westinghouse.

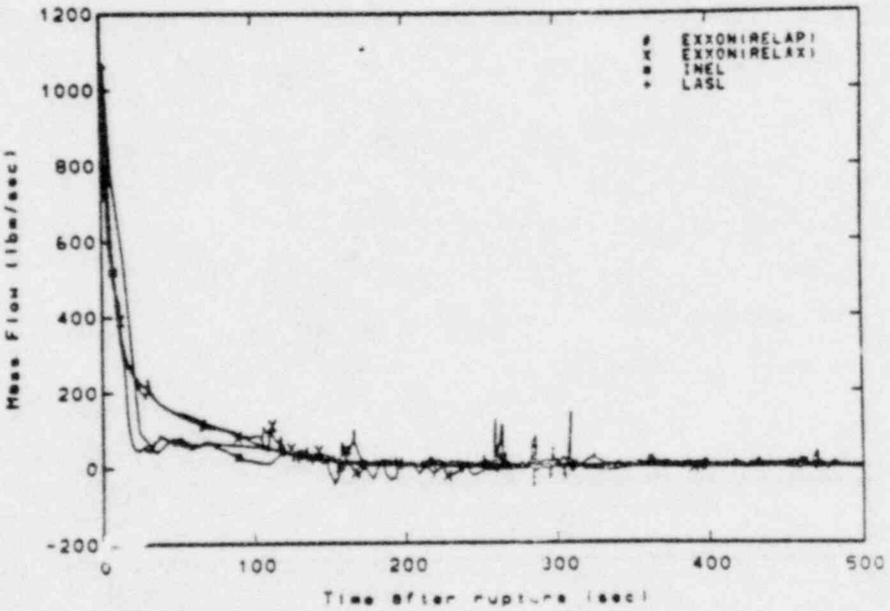
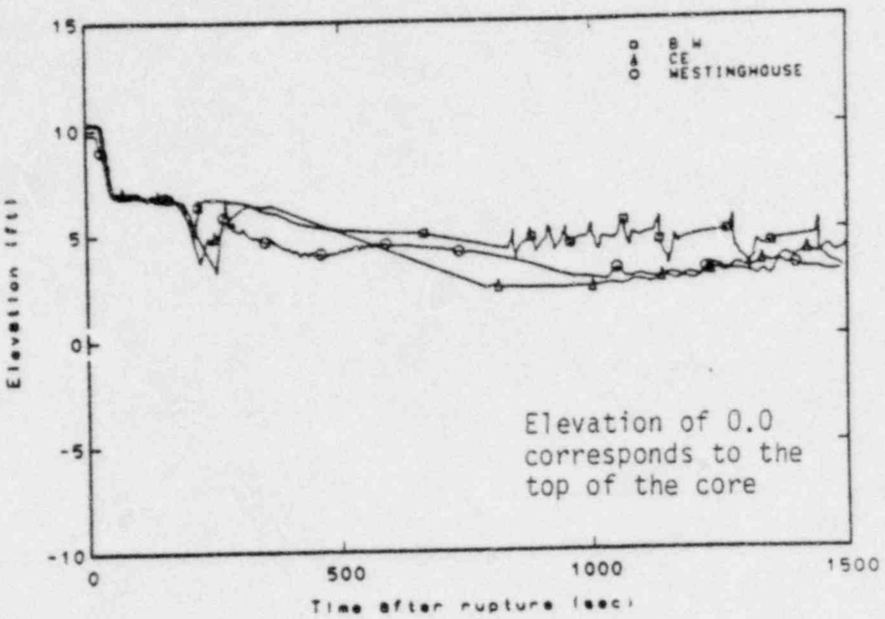
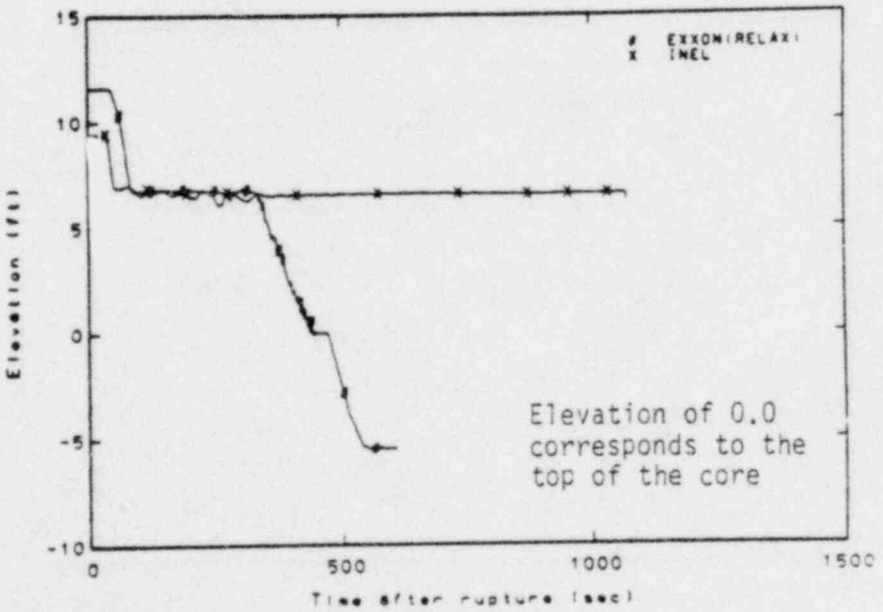


Figure 18. Calculations of intact loop hot leg mass flow by Exxon RELAP, Exxon RELAX, INEL, and LASL.



Elevation of 0.0
corresponds to the
top of the core

Figure 19. Calculations of collapsed liquid level in the vessel by B&W, CE and Westinghouse.



Elevation of 0.0
corresponds to the
top of the core

Figure 20. Calculations of collapsed liquid level in the vessel by Exxon RELAX and INEL.

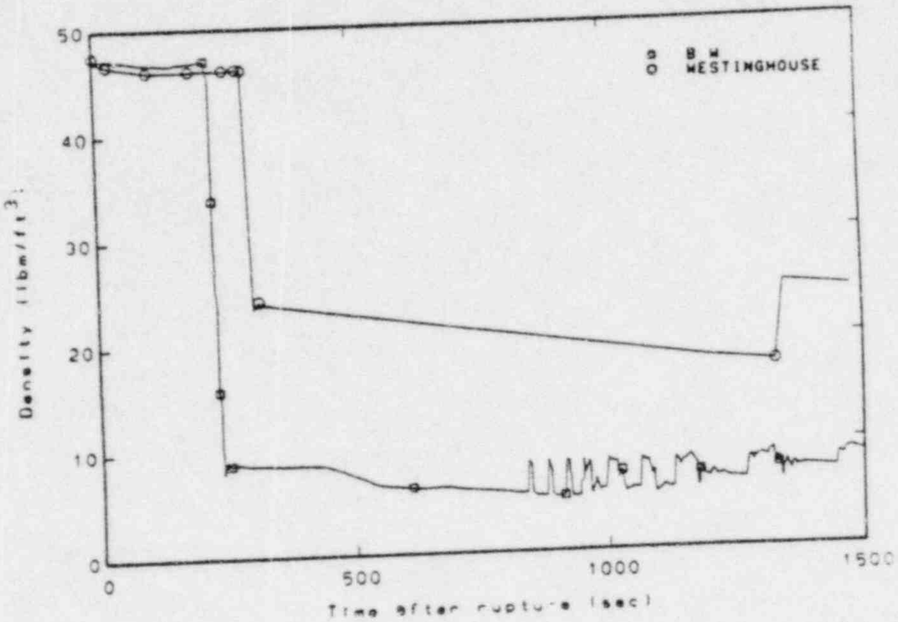


Figure 21. Calculations of broken loop cold leg density by B&W and Westinghouse.

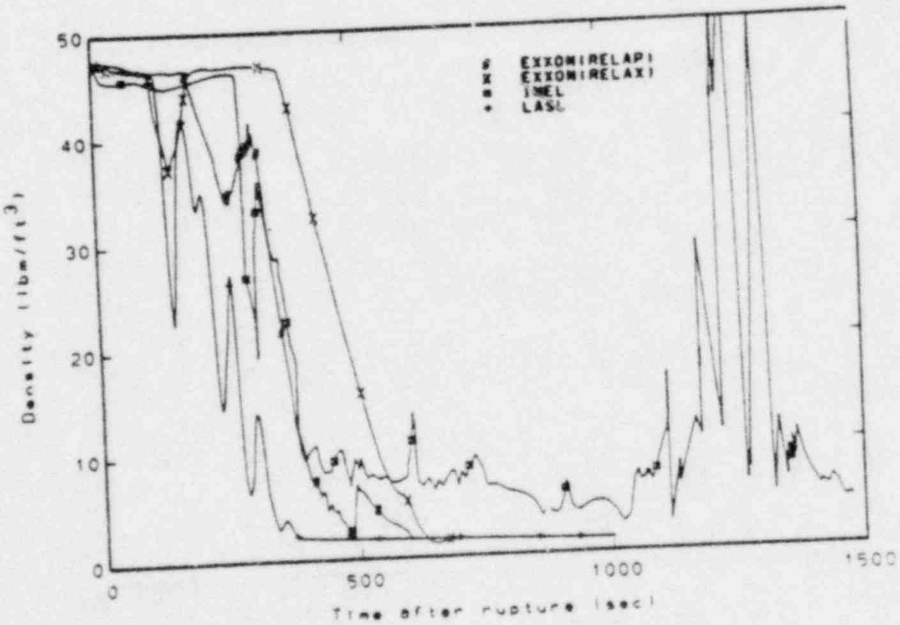


Figure 22. Calculations of broken loop cold leg density by Exxon RELAP, Exxon RELAX, INEL and LASL.

# 5. CONCLUSIONS

The comparisons of participants pretest calculation with LOFT Experiment L3-1 has lead to the following conclusions:

Except for B&W, the participants did not accurately calculate the behavior of the secondary side of the steam generator.

> In the experiment the secondary pressure did not reach the steam valve set point and the auxiliary feed upon being started immediately began to cool the secondary side of the steam generator.

The trend of the experimental system pressure was not calculated during the 75 to 634 s portion of the transient.

> The system pressure was monotonically decreasing during this time period; however, the participants calculated a rise in system pressure between 75 and 300 s.

The trend of the break mass flow between 100 and 600 s was generally not seen in the calculation.

> The difference between the measured and calculated mass flow appears to be a result of not accurately calculating the fluid density near the break.

## 6. REFERENCES

1. N. C. Kaufman, "Information for L3-1 Standard Problem", letter, EG&G Idaho, Inc., September 28, 1979.

2. H. J. Welland, LOFT Experiment Operating Specification, "Small Break Test Series L3", NE L3 Series, Rev. 0, July 1979.

3. P. D. Bayless, et al., Experimental Data Report for LOFT Nuclear Small Break Experiment L3-1, NUREG/CR-1145, EGG-2007, January 1980.

4. D. L. Reeder, LOFT System and Test Description (5.5 - ft. Nuclear Core 1 LOCEs), NUREG/CR-0247, TREE-1208, July 1978.

5. J. H. Taylor, "LOFT L3-1 Pre-test Prediction", letter, EG&G Idaho, Inc., December 13, 1979.

6. G. Liebler, "LOFT L3-1 Test", letter, EG&G Idaho, Inc., November 19, 1979.

7. J. N. Morgan, letter, EG&G Idaho, Inc., November 20, 1979.

8. C. Reed, "LOFT L3-1 Test Predictions", letter, EG&G Idaho, Inc., December 15, 1979.

9. J. A. Dearien, "Transmittal of Corrected RELAP4/MOD6 Calculation of United States Standard Problem 11," letter, EG&G Idaho, Inc., December 5, 1979.

10. T. D. Knight, letter, EG&G Idaho, Inc., January 21, 1980.

11. G. Liebler, "LOFT L3-1 Test Analysis," letter, EG&G Idaho, Inc., February 28, 1980.

12. G. L. Biladeau et al., "LOFT Experimental Measurements Uncertainty Analysis," letter, EG&G Idaho, Inc., September 5, 1975.

13. J. L. LaChance, RELAP4/MOD6 Calculation of LOFT LOCE L3-1, EGG-CAAP-5081, January 1980.