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International Agreement Report

RELAP5/MOD2 Calculation of OECD LOFT Test LP-FW-01

Prepared by
M. G. Croxfod, C. Harwood, P. C. Hall

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Office of Nuclear Regulatory Research
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Prepared as part of
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CENTRAL ELECTRICITY GENERATING BOARD

GENERATION DEVELOPMENT AND CONSTRUCTION DIVISION

PLANT ENGINEERING DEPARTMENT

NUCLEAR PLANT BRANCH

Title: RELAP5/MOD2 Calculation of OECD LOFT Test LP-FW-01

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Head of Safety Technology Section

Summary: RELAP5/MOD2 is being used by GDCD for calculation of certain small break loss-of-coolant accidents and pressurised transients in the Sizewell 'B' PWR.

To test the ability of RELAP5/MOD2 to model the primary feed-and-bleed recovery procedure following a complete loss-of-feedwater event, post test calculations have been carried out of OECD LOFT test LP-FW-01. This report describes the comparison between the code calculations and the test data.

It is found that although the standard version of RELAP5/MOD2 gives a reasonable prediction of the experimental transient, the long term pressure history is better calculated with a modified code version containing a revised horizontal stratification entrainment model. The latter allows an improved calculation of entrainment of liquid from the hot leg into the surge line.

RELAP/MOD2 is found to give a more accurate simulation of the experimental transient than was achieved in previous UK studies using RETRAN-02/MOD2.

Date: June 1988

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CONTENTS

1. INTRODUCTION

RELAP5/MOD2 is being used by GDCD for calculation of certain small break loss-of-coolant accidents and pressurised transients in the Sizewell 'B' PWR.

To assist in assessing the capability of RELAP5/MOD2 for describing a loss-of-feedwater fault in a PWR, the code has been used to simulate test LP-FW-01 carried out in the LOFT experimental reactor under the OECD LOFT programme. LP-FW-01 simulated a fault sequence in which there was a complete loss-of-feedwater to the steam generator followed by recovery by primary system feed-and-bleed, where coolant is simultaneously injected by the High Head Safety Injection system and vented via the primary side Power Operated Relief Valve.

The present report describes the analysis in detail. Comparisons are given with previous simulations of the same test using RELAP5/MOD1[1] and RETRAN-02/MOD2[2].

2. DESCRIPTION OF CODE INPUT MODEL

The code version used for the present calculation was RELAP5/MOD2/CY36.04. Calculations were carried out with the standard code version and also a modified version which used an improved model to describe entrainment/pullthrough at the T-junction between the hot leg and pressuriser surge line.

The input model was based on that previously used by GDCD for the analysis of LOFT small break tests LP-SB-01[3], LP-SB-02 [4] and LP-SB-03[5]. The noding diagram is shown in figure 1. Changes to the basic input deck were as follows.

(a) hot and cold leg break connections were deleted;

(b) the steam generator auxiliary feed was removed, since there was no auxiliary feed in the test;

(c) the primary pump seal coolant injection system was deleted; in the test a total of 20.81kg of seal coolant was injected during the first 219s of the transient which is considered negligible;

(d) the control system and trip data where re-written to include the experimental setpoints used in LP-FW-01[1];

(e) the geometry for the pressuriser PORV, pressuriser spray and the HHSI was included, taken from the RELAP5/MOD1 data deck for LOFT LP-FW-01, developed by INEL[1];

(f) HHSI flow was specified as a table of flow versus cold leg pressure, based on the system performance measured in the test [1]. The value of PORV flow area was taken from the RETRAN-02 calculation reported in ref [2]. The RETRAN-02 value was deduced from experimental data for LOFT test L9-3 [2] which used the same valve type as in LOFT test LP-FW-01. The use of this valve area in the present calculation gave a good prediction of the rate of decrease of primary pressure during the phase of the transient where single phase steam was being discharged from the PORV;

(g) in the present calculation a value of 272kW was used for the total system heat loss to the containment. A value of 250±100kW was given in the experimental data report [1];

(h) Ref [1] reported that a main steam control valve leakage was present throughout the LOFT test series, but that the precise magnitude of the leakage for each test was unknown. In the present calculation a value for the MSCV leakage area, normalised to the MSCV junction area, of 18.25×10^{-4} was assumed. This value gave optimum rate of decline of secondary pressure during the transient;

(h) the reactor kinetics data was taken from the RELAP5/MOD2 deck for LP-FW-01 [1] developed by INEL. Modelling of the active core heat structures was altered to allow the use of the reactor kinetics model to calculate the core power. In preliminary calculations of the first 125s of the transient, RELAP5 was found to be over-predicting decay heat levels by approximately 4%, in comparison with experimental data reported in ref [6]. To compensate, the fission product yield factor in the reactor kinetics input data was reduced from 1.00 to 0.96;

(j) the SG flow resistances were adjusted in order to keep the water level high in the separator and prevent steam entrainment into the downcomer (carry under) from occurring. The SG re-circulation ratio increased from 4.09 to 4.83 as a result.

Before performing the transient calculation, a steady state calculation was first performed in which the pump speed, steam and feed flow were adjusted to obtain the desired initial values of separator mass flows, hot and cold leg temperatures, secondary pressure and steam generator and pressuriser levels. In the steady state calculation a dummy time dependent volume was connected to the pressuriser to maintain the desired primary pressure. Figures 2,3 and 4 show the results of the steady state run, demonstrating that a satisfactory steady state was achieved. The RELAP5 calculated steady state initial conditions are compared with experimental values from ref [1] in Table 1.

3. COMPARISON OF RELAP5/MOD2 RESULTS WITH EXPERIMENT

3.1 Test Description

The sequence of events in the test LP-FW-01 is given in Table 2. A brief description of the test is given below.

The experiment was initiated by terminating the main feedwater flow to the steam generator. Since the auxiliary feed had been disabled for the test, a degradation of the primary-to-secondary heat transfer occurred as the inventory boiled down, causing an increase in primary system temperature and pressure. The pressuriser spray was activated at 33s, but, after a brief reduction, the primary pressure continued to increase until reactor trip at 48.7s. At this time the MSCV started to close, causing the secondary pressure to increase. Subsequently, there was a gradual decrease in secondary side pressure as a result of MSCV leakage [1]. Following reactor trip the PORV was latched open by the operator, causing a primary pressure decrease as single phase steam discharge occurred through the PORV. The HHSI setpoint was reached at 221s, when the feed and bleed mode of operation started. Primary coolant pumps were tripped at 220s by the operator, and coastdown was completed at 235s. The experiment was terminated when the primary pressure reached 4.69MPa at 6820s into the transient.

3.2 Transient Calculation with Standard Code Version of RELAP5/MOD2

Calculation of the experimental transient with the standard version of RELAP5/MOD2/Cy36.04 is described below.

3.2.1 Short-term transient (0-500s)

Primary and secondary pressure histories for the period 0-500s are shown in Fig. 5. The rate of increase of primary and secondary pressure in the period up to reactor trip (t=47.7s) is well predicted by RELAP5, and the timing of pressuriser spray initiation is correctly predicted as t=33s. In the test, spray initiation caused a slight dip in primary system pressure which was not predicted by RELAP5. A sensitivity calculation was performed in which the initial temperature of water resident in the spray line was reduced by 30K, to investigate the possibility that a slug of cold water initially present in the spray line had caused the pressure dip; however, this change was found to have an insignificant effect on the calculation. The implication is that the flow and heat transfer modelling in RELAP5/MOD2 tends to somewhat underestimate the condensation capability of the pressurizer spray.

After reactor trip (t=48.7s: experiment; t=47.7s: calculation) the MSCV started to close, and the pressuriser PORV was latched open. RELAP5 gave a good prediction of the rate of decrease of primary pressure during the period in which there was single phase steam discharge through the PORV (50 to 220s). The depressurisation halted when saturation conditions (boiling) occurred in the hot leg; the calculated timing of this event (235s) was in fairly good agreement with the experimental value (245s).

Collapsed liquid levels in the pressuriser and steam generator downcomer are shown in fig.6. The initial SG level calculated by RELAP5 was a little higher than the experimental measurement, but the rate of decrease was somewhat faster, so that the calculated time at which the SG emptied was approximately correct. The faster boil-off in the RELAP5 simulation is thought to be due to an overprediction of void fraction in the SG riser, which resulted in an underprediction of initial secondary inventory.

The pressuriser level is, on the whole, well predicted by RELAP5. However, prior to reactor trip the level swell is somewhat underpredicted by RELAP5, implying too small an insurge during this period. This is consistent with slightly delayed prediction of degradation of primary to secondary heat transfer implied by the secondary pressure history (figure 5). The continued insurge for about 12s after reactor scram in the RELAP5 calculation probably results from very rapid reduction in primary to secondary heat transfer just prior to reactor trip. The calculated time at which the pressuriser begins to refill because of primary side boiling is a little early. This is to be expected, given this slight under-estimate of primary pressure until 240s. (Note that the apparent discrepancy in the final pressuriser and SG collapsed levels is due to the location of the differential pressure tappings in the experiment).

3.2.2 Long Term Transient (0-3000s)

Figure 7 shows the primary and secondary pressure predictions in the period 0-3000s. The primary and secondary pressures are accurately calculated during the steam discharge phase (50-330s). After 330s the liquid level in the pressuriser reaches the top of the pressuriser and two-phase mixture begins to be discharged through the PORV, giving a reduced energy discharge rate. This results in a repressurisation of the primary system, the repressurisation rate being somewhat overpredicted by RELAP5. Figure 8 shows that the PORV discharge density is overpredicted in the period 400-1500s. This results in an underprediction of the enthalpy discharge rate and in consequence an overprediction of the rate of increase in primary system pressure in the period 400-1500s.

3.3 Transient Calculation with Modified Version of RELAP5/MOD2

In an attempt to improve the calculation of the period of two-phase discharge through the PORV, a modified code version was used in which an improvement to the horizontal stratification entrainment model had been implemented [7]. This model contained improved correlations for entrainment/pullthrough effects at a T-junction in a large diameter horizontal pipe containing stratified flow. The model was applied at the connection between the pressuriser surge-line and the hot-leg, and had the effect of increasing the quality of the fluid entering the surge line from the hot leg. Results of the transient calculation with the modified code version are described below.

3.3.1 Short-Term Transient Results (t=0-500s)

Figures 9 and 10 show primary and secondary pressure histories and pressuriser and steam generator collapsed level histories for the short-term phase of the transient. The characteristic shape of the curves is very similar to that obtained with the standard code version. Note, however that the increase in steam flow quality into the pressurizer arising from use of the modified code causes a marked reduction in the rate of pressurizer fill calculated by RELAP5.

3.3.2 Long-Term Transient (0-6000s)

Figure 11 shows the calculated primary and secondary pressure obtained with the standard and modified codes for the long term phase of the transient. The primary pressure calculation for the period after commencement of two-phase flow in the PORV (t= 330s) is now seen to be more accurately calculated, with the exception of the prediction of intermittent periods of oscillatory behaviour which are not seen in the test. Figure 12 shows that pressure oscillations are calculated in the period 990 to 1600s when there is a tendency for the code to cycle between water and steam discharge. Inspection of the code output shows that oscillation is triggered when the void fraction at the top of the pressuriser and thus in the PORV decreases, causing the PORV mass flow and primary pressure to increase. The source of these oscillations is traced to errors in the calculated draining behaviour of the cold legs, described below.

The secondary pressure is well predicted, indicating that the steam line leakage is well modelled; sensitivity studies showed that the amount of leakage had a marked effect on secondary pressure, but an almost negligible effect on primary pressure prediction.

Figure 13 shows the calculated and measured fluid density in the PORV discharge line. Oscillations are seen in both calculation and experiment. The density is significantly lower in the period 500-1000s than obtained with the standard code calculation. Fig. 14 shows the measured and calculated hot leg density. In the experiment the hot leg remained mostly filled with water. RELAP5 predicted slightly higher void fraction in the hot leg. Given the overestimation of mass flow through the PORV, this implies that the modified HSEM may be underpredicting the quality of the fluid entering the surge line from the hot leg.

The oscillations in the calculated primary pressure, hot leg density and mass discharge rate in the period 990-1600s were traced to errors in the calculated draining behaviour of the intact loop cold leg and the downcomer. Instead of remaining liquid-filled as in the test, these computational cells drained sequentially during the period in question, causing surges of water to enter the core. A detailed investigation of this cold leg draining behaviour is described in the Appendix, where it is concluded that the most likely source of the errors is the simplified modelling of the complex steam by-pass flow paths that exist in LOFT between the upper plenum and the cold legs.

A plot of measured and calculated pressuriser PORV and HHSI integrated mass flow is shown in figure 15. HHSI mass flow is pressure dependent, and was therefore slightly underpredicted over most of the transient. The mass flow-rate through the PORV is systematically over-predicted after 1000s. This is again due to the erroneous calculaton of cold leg draining described in the Appendix.

3.4 Computing Times

The calculations were executed on a CRAY-XMP computer. For the standard code the CPU time was 2510s for a 3350 transient (0.75:1). The average time step was 0.07s. CPU time per volume per timestep was 6.14 x 10^{-4}S. The modified code used 6190 cpu seconds for a 6600s transient. The average time step was again 0.07s and the CPU time per volume per timestep was 6.23 x 10^{-4}S.

4. DISCUSSION AND COMPARISON WITH PREVIOUS ANALYSES

Use of the standard version of RELAP5/MOD2/Cy 36.04 gave a reasonable overall prediction of the experimental transient. However, the pressure increase during the initial period of two-phase discharge from the PORV was overestimated, leading to an overprediction of primary system pressure for the remainder of the transient. With the modified code version, in which there was improved modelling of entrainment in the hot-leg/surge line connection, a more accurate simulation of the early repressurisation period was achieved, leading to an improved primary pressure prediction. These calculations show the value of the improved entrainment/pullthrough correlation in modelling PORV mass and energy discharge.

LOFT test LP-FW-01 has previously been calculated using the codes RELAP5/MOD1[1] and RETRAN-02/MOD2[2]. The RELAP5/MOD1 calculation in ref [1] predicted the system behaviour reasonably accurately. However, several calculational anomalies were identified in ref [1]. These are discussed below, and comparisons made with the present calculation.

(a) in the ref [1] analysis the calculated rate of decrease of the steam generator liquid level was more rapid than measured in the test. This was attributed to errors in the predicted void distribution in the steam generator. A similar error was encountered in the present calculation, which is probably due to the same cause;

(b) during the feed and bleed portion of the transient the calculated PORV mass flow was well predicted by RELAP5/MOD1. However PORV effluent void fraction, and therefore enthalpy, was under-predicted, resulting in lower calculated energy loss-through the PORV. A similar trend was observed in the present calculations, in particular using the standard code version; with the code modification RELAP5/MOD2 achieved a more accurate long term primary pressure prediction than RELAP5/MOD1;

(c) Fig. 16 shows a plot of measured and calculated system mass histories, comparing the RELAP5/MOD1 calculation [1] with the present calculation. A calculation mass conservation error of 500kg accounted for a large proportion of the 800kg mass discrepancy of the ref [1] calculation. The present calculation had a very small mass conservation error of 50kg; the remaining error in mass inventory is a reflection of the over-prediction of mass flow through the PORV after 1000s. As noted in Section 3.3, the mass flow-rate error is thought due to the incorrect calculation of draining of the cold legs.

Comparisons between the present calculation and the results of the RETRAN-02/MOD2 calculation in ref. [2] are shown in Figs. 17-19.

Figure 17 compares the measured long term primary pressures with the RETRAN-02/MOD2 calculation and the present RELAP5/MOD2 calculation. RELAP5/MOD2 (modified) gives a somewhat better prediction than RETRAN. It is noted, however, that the standard version of RELAP5/MOD2 produced a primary pressure prediction similar to the RETRAN calculation. This indicates that the improvement is due to the modification to the treatment of liquid pullthrough at the hot-leg/surge-line connection.

Fig. 18 shows the measured and calculated secondary side pressure histories. RETRAN predicted an over-rapid drop in pressure in the first 100s, which caused a persistent off-set in the long-term transient. The improved result achieved with RELAP5 is thought to be due to a superior calculation of secondary inventory at the time of closure of the MSCV. In practice, the SG conditions have little influence on primary behaviour after about 100s.

Fig 19 shows a comparison of the pressuriser level transients calculated by RETRAN and RELAP5. Like RELAP5, RETRAN calculates too slow a rise in pressurizer level prior to trip. In addition, the calculated pressuriser insurge following hot leg saturation was too rapid. Ref [2] suggested that the inaccurate pressuriser level prediction was due to the premature prediction of dry-out on the secondary side, which inhibited heat transfer after 100s, and caused hot leg temperatures to rise between 100s and 270s. In the present calculation, a similar time for steam generator dry-out was predicted. It appears that the rate of pressurizer refill is strongly dependent on the flow quality in the surge line after the onset of 2-phase flow in the hot leg.

5. CONCLUSIONS

(a) To assess the ability of RELAP5/MOD2/Cycle 36.04 to model the feed-and-bleed recovery procedure following a loss-of-secondary feedwater event, post-test calculations have been carried out of OECD LOFT test LP-FW-01, which involved a complete loss-of-secondary-feed.

(b) The transient was generally well predicted by RELAP5/MOD2/Cy 36.04, though the rate of decrease of primary pressure was somewhat underpredicted during the long term depressurisation phase in which primary fluid was being vented from the pressuriser power operated relief valve (PORV).

(c) A modified version of RELAP5/MOD2 containing an improvement to the horizontal stratification entrainment model was found to give an improved prediction of the long term pressure history. The modified code gave an improved treatment of liquid entrainment at the hot-leg/surge-line connection, increasing the calculated enthalpy discharge rate in the PORV. There is, however, some evidence that the improved model still underpredicts the flow quality entering the surge line, under the conditions of this test.

(d) RELAP5/MOD2 over-predicted mass flow-rate through the PORV in the later part of the transient, and also predicted intermittent surges of liquid flow through the PORV which were not observed in the test. Detailed investigation revealed that these errors were probably due to the simplified modelling of the flow of steam in the complex bypass flow paths connecting the cold legs and the upper plenum in LOFT, rather than due to an error in the physical models in the code.

(e) The calculation with the standard version of RELAP5/MOD2 Cy.36.04 was similar to a previous analysis of the same transient using RELAP5/MOD1. However with the modification to the horizontal stratification entrainment model, RELAP5/MOD2 was able to produce a superior transient prediction. Mass conservation errors in the RELAP5/MOD2 calculations were considerably smaller than in the RELAP5/MOD1 calculation.

(f) Comparison with a previous analysis of the same test using RETRAN-02/MOD2 has shown that RELAP5 gives a superior prediction of secondary pressure and pressuriser level in this transient. The improvement is believed due in part to more accurate modelling of the primary-to-secondary heat transfer in the steam generator boil-off phase, in the RELAP5 calculation.

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TABLE 1 - INITIAL CONDITIONS OF LP-FW-1

Parameter	Measured	Calculated (at end of steady state)
Primary Coolant System;		
Core T/K	27.0 ± 1.3	27.58
Hot leg pressure/MPa	14.80 ± 0.06	14.79
Cold leg temperature/K	554.3 ± 1.0	553.2
Mass flow rate/kgs^{-1}	346.13 ± 2.59	346.1
Power Level/MW	49.2 ± 0.5	49.7
Steam Generator, Secondary Side;		
Pressure/MPa	5.30 ± 0.06	5.16
Feed flow rate/kgs^{-1}	26.36 ± 0.79	25.83
Water temperature/K	537.7 ± 2.6	539.06
Liquid level/m	2.78 ± 0.04	2.94
Pressuriser;		
Liquid volume/m^3	0.56 ± 0.01	0.43
Steam volume/m^3	0.44 ± 0.01	0.57
Water temperature/K	615.5 ± 6.4	614
Pressure/MPa	14.83 ± 0.09	14.76
Liquid level/m	0.96 ± 0.01	0.88

TABLE 2 - SEQUENCE OF EVENTS FOR LP-FW-1

Event	Experiment	RELAP5/MOD2
Main feed tripped	0.0	0.0
Pressuriser spray initiated	33.2 ± 0.3	33
Reactor tripped on high pressure	48.8 ± 0.01	47.7
MSCV starts to shut	48.8 ± 0.2	47.7
PORV latched open	50.8 ± 0.2	47.7
Steam generator liquid level reached bottom of indicating range	85 ± 15	90
MSCV fully shut	61.0 ± 0.2	59.9
Primary coolant pump coastdown	219 ± 0.1	206.9
HPIS initiated	221.6 ± 0.2	207.2
Primary coolant pump coastdown completed	235.5 ± 2.0	
First void formation in primary	245 ± 10	235
Pressuriser liquid level reached top of indicating range	333.2 ± 0.4	400
PORV transition from steam flow to two phase flow	339.0 ± 2.0	360
HPIS flow exceeds PORV discharge flow	2370 ± 100	4300
Experiment terminated	6820 ± 110	-

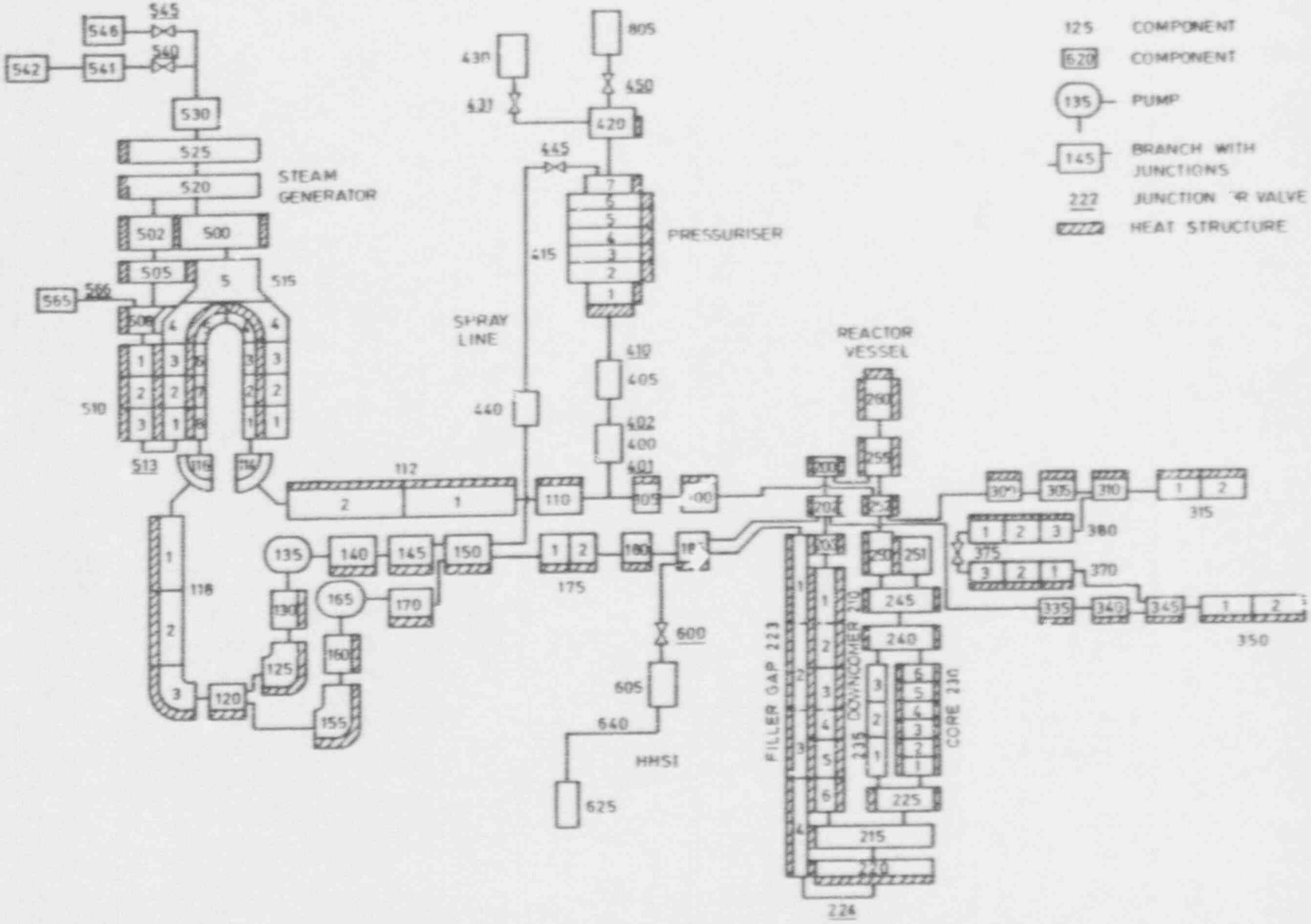


FIGURE 1 - RELAP 5/MOD 2 NODING DIAGRAM FOR CALCULATION OF LOFT TEST LP-FW-01

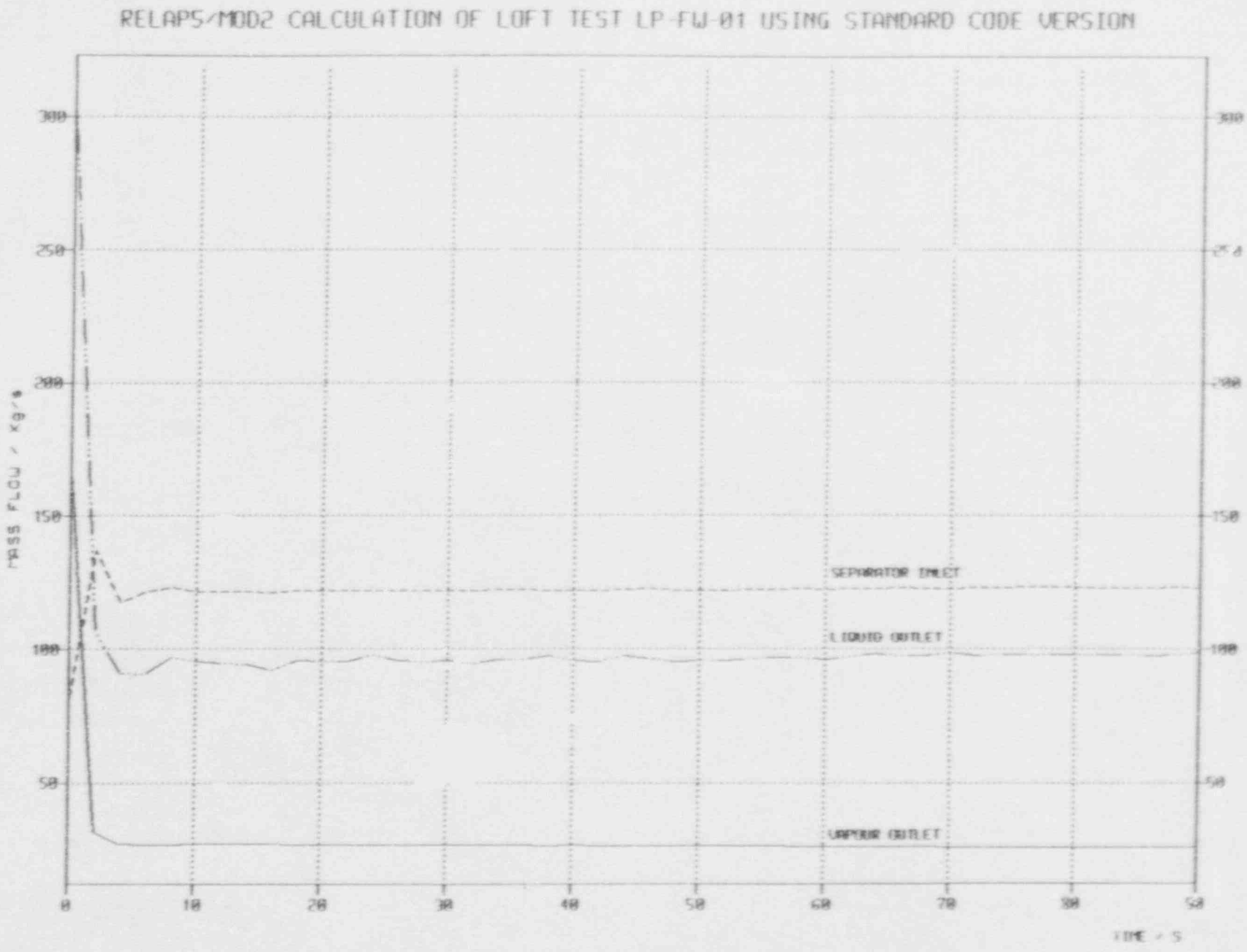


FIGURE 2 :STEAM GENERATOR SEPARATOR MASS FLOWS DURING STEADY STATE

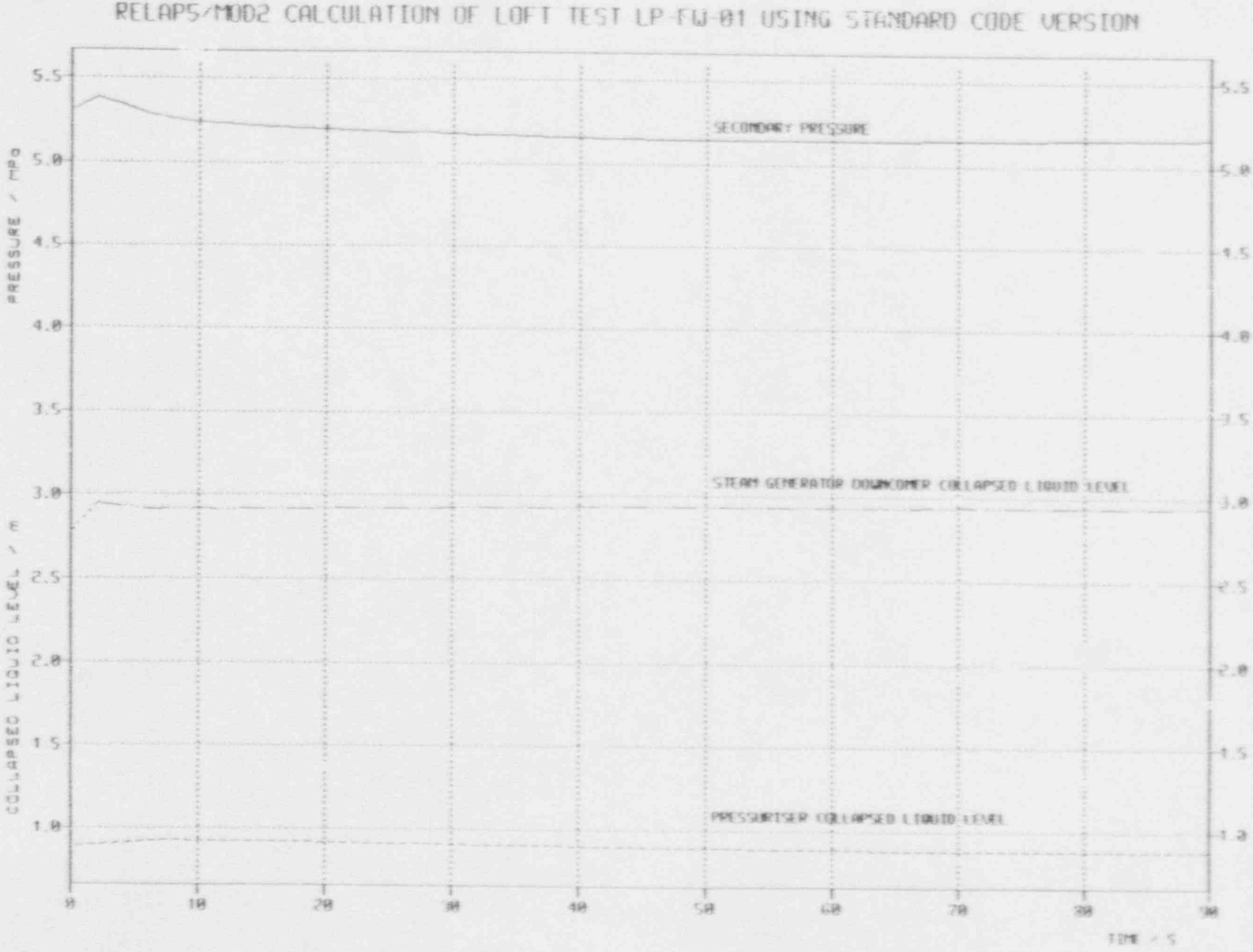


FIGURE 3 : SECONDARY PRESSURE, SG AND PRESSURISER LEVELS DURING STEADY STATE

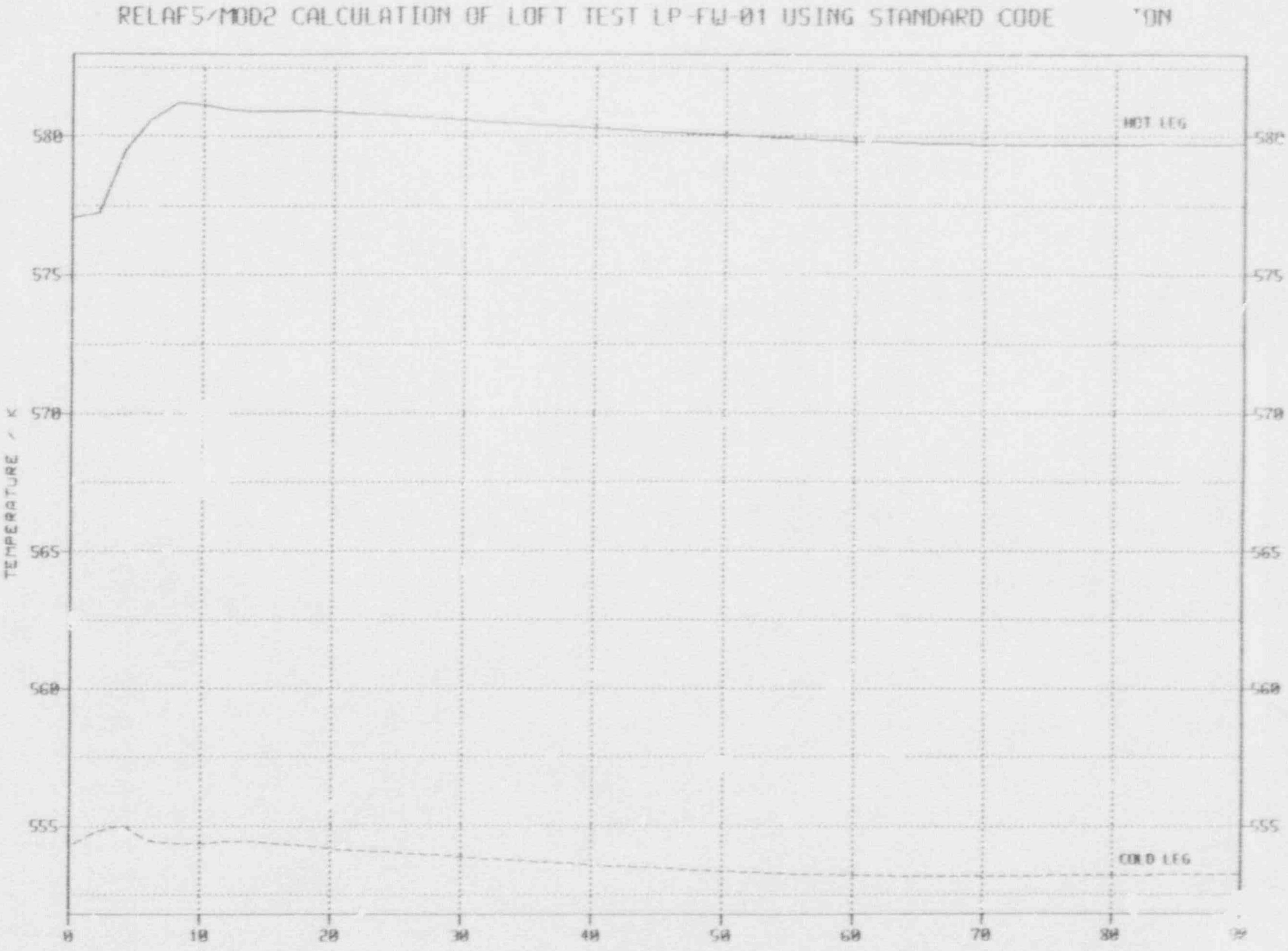
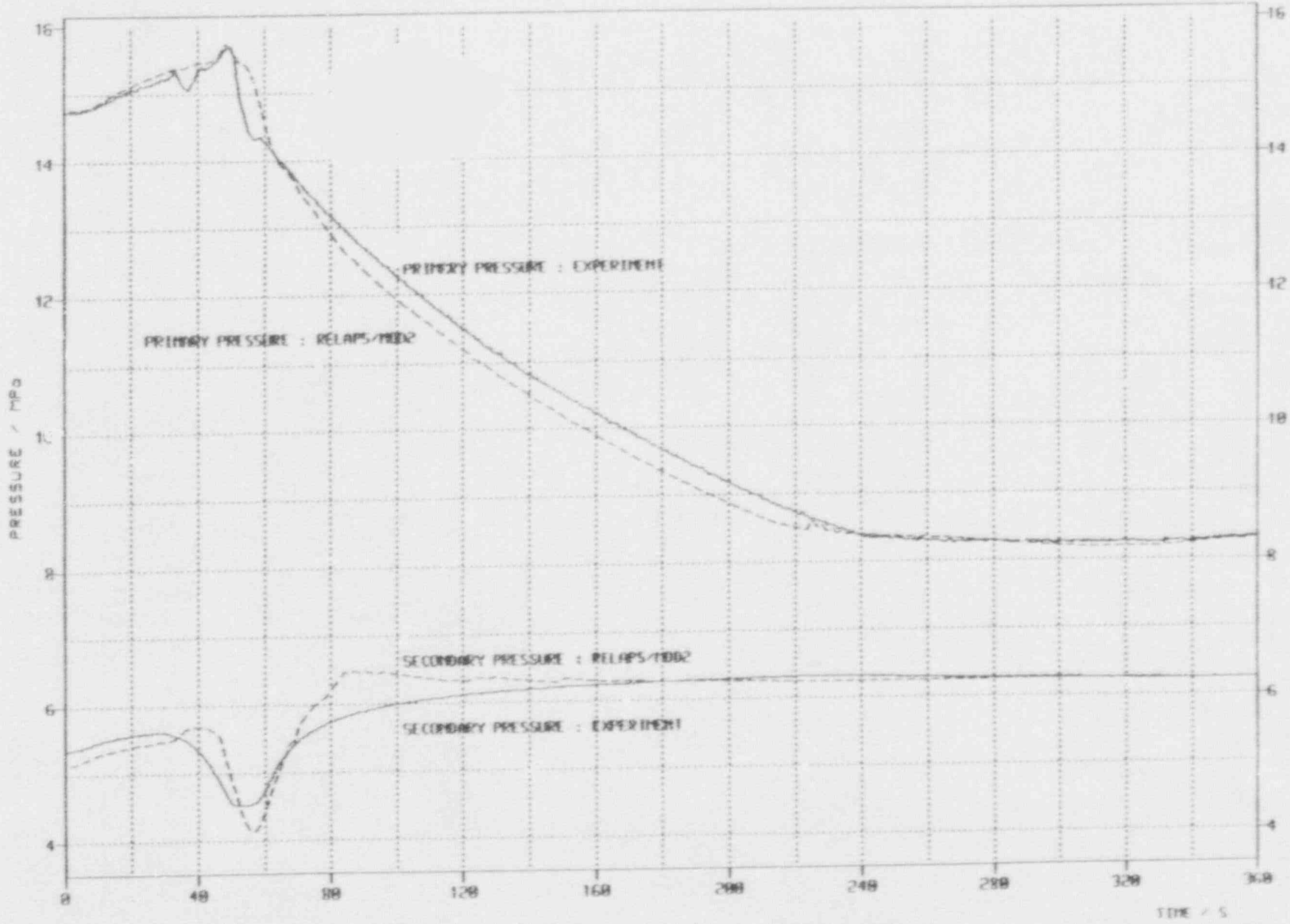


FIGURE 4 : HOT AND COLD LEG TEMPERATURES DURING STEADY STATE



RELAP5/MOD2 CALCULATION OF LOFT TEST LP-FW-01 USING STANDARD CODE VERSION

FIGURE 5 : MEASURED AND CALCULATED PRIMARY AND SECONDARY PRESSURES

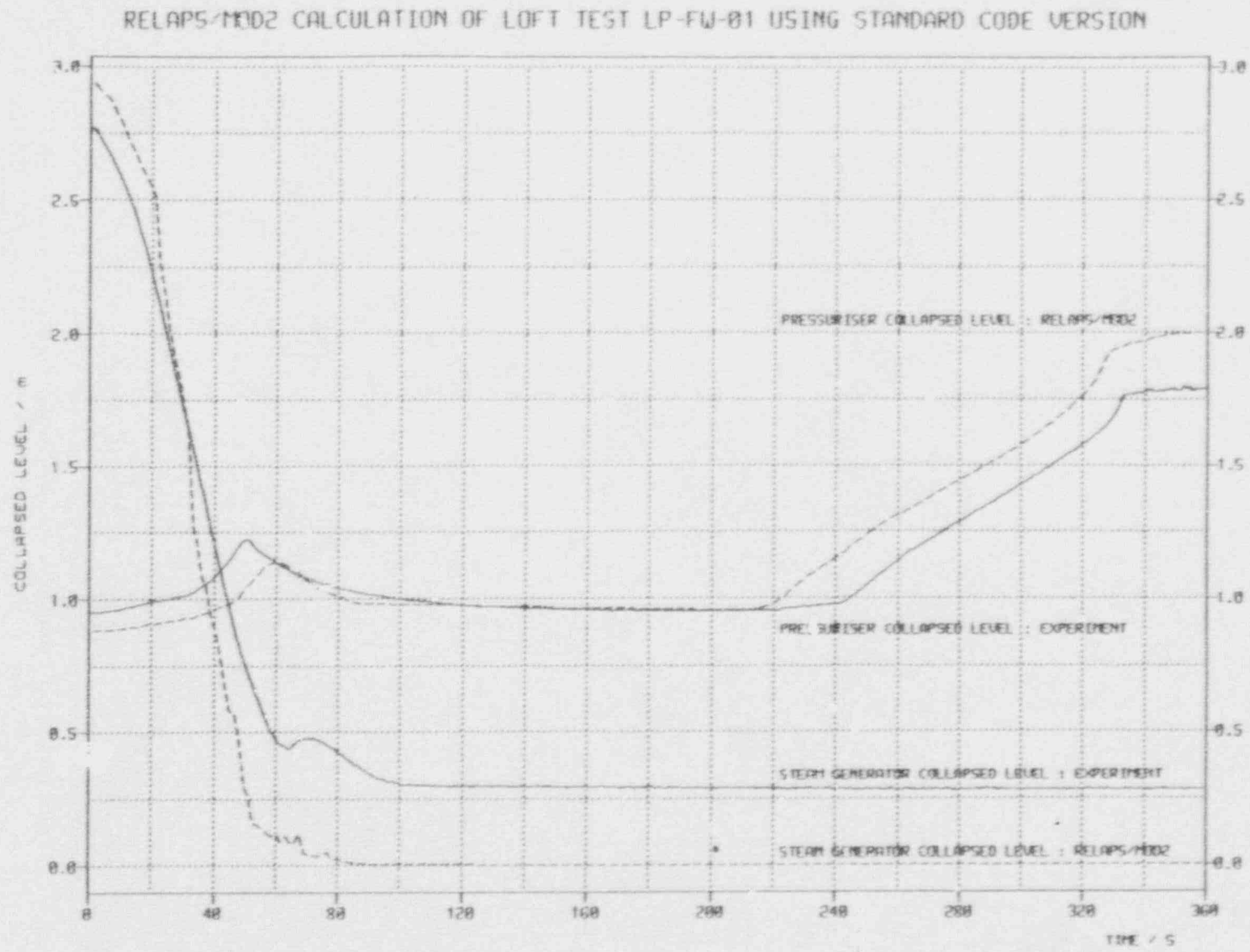
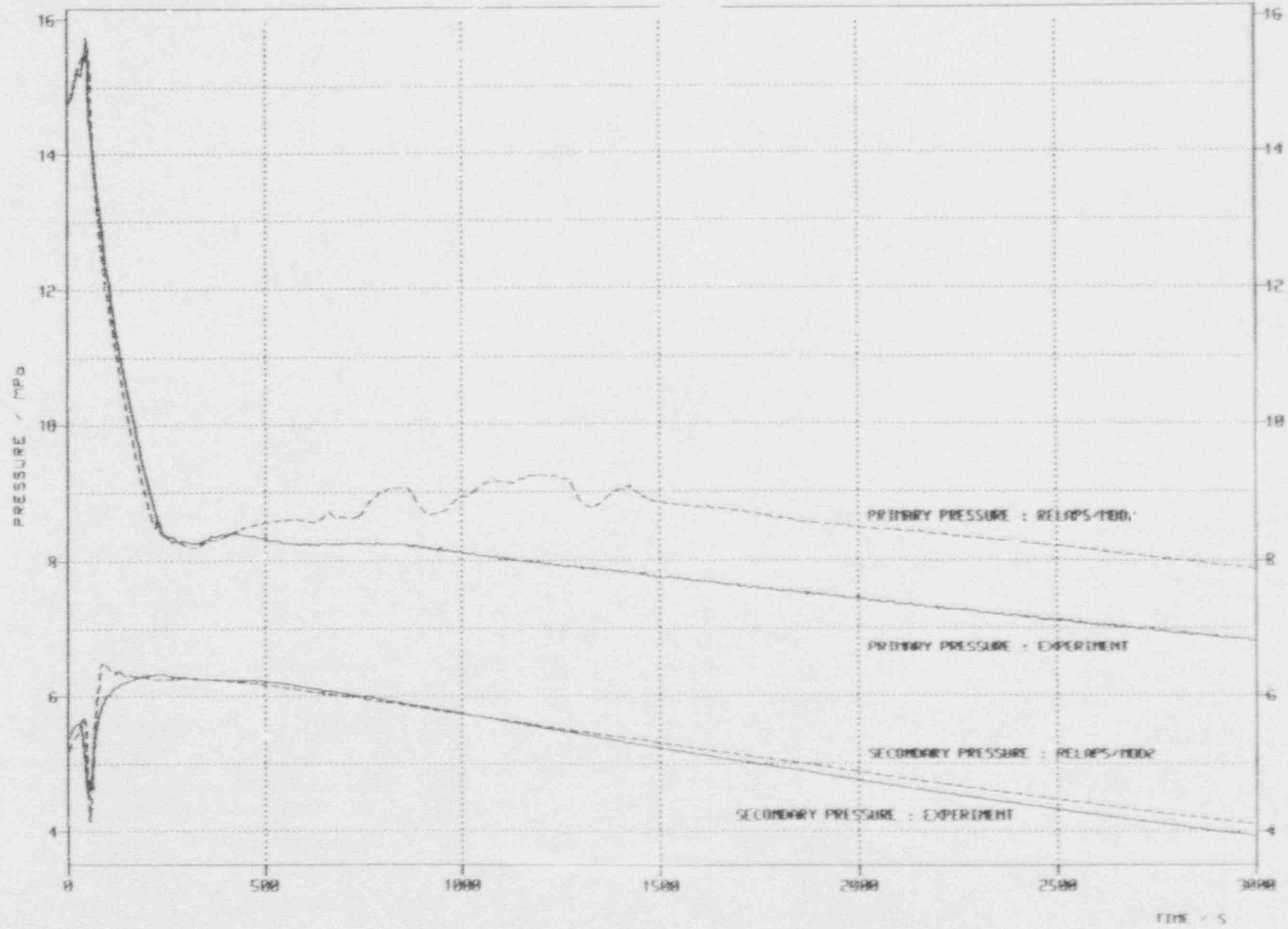


FIGURE 6 : MEASURED AND CALCULATED SG AND PRESSURISER COLLAPSED LEVELS



RELAP5/MOD2 CALCULATION OF LOFT TEST LP-FW-01 USING STANDARD CODE VERSION

FIGURE 7 : MEASURED AND CALCULATED PRIMARY AND SECONDARY PRESSURES

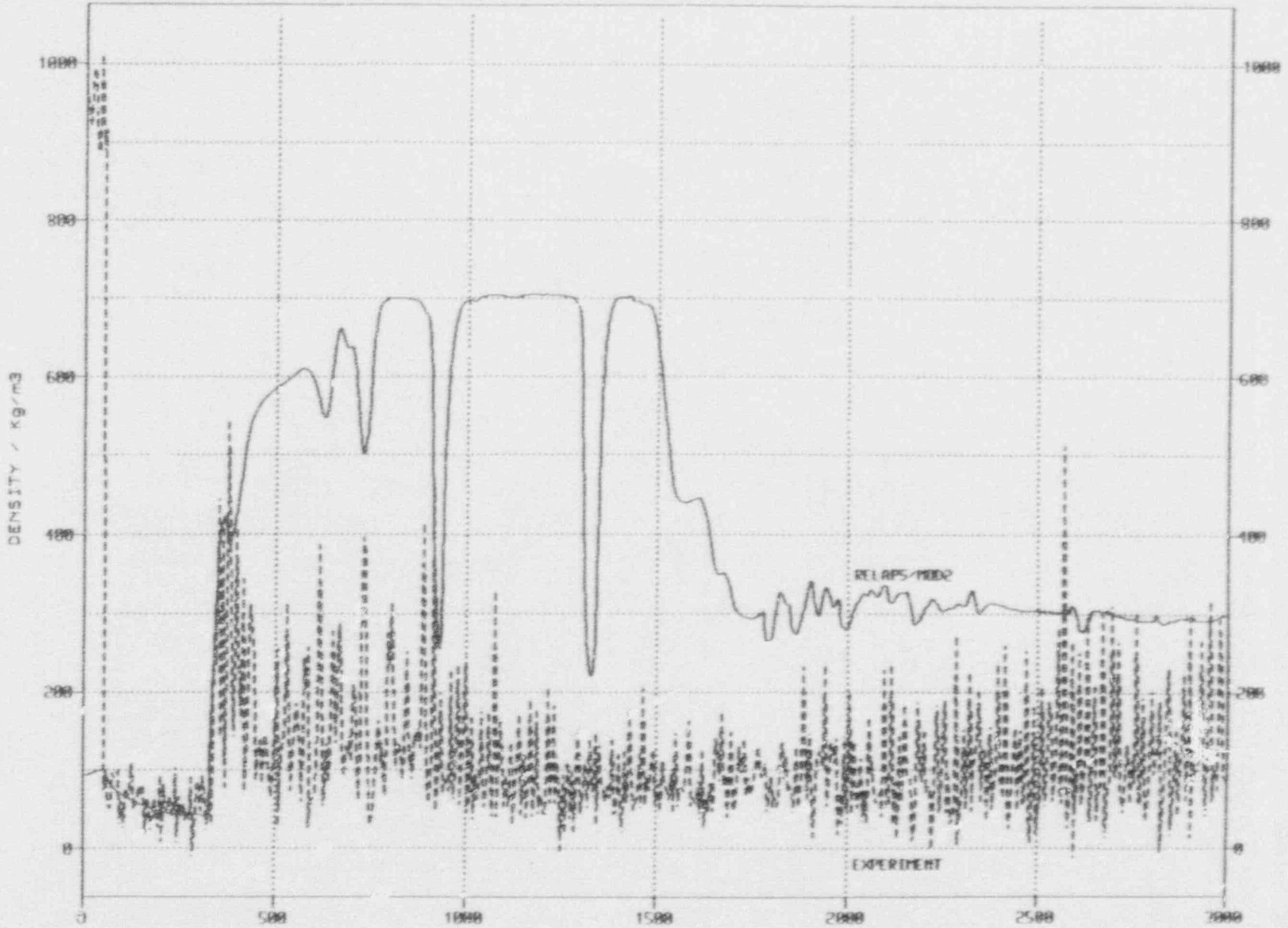


FIGURE 8 : MEASURED AND CALCULATED PRESSURISER PORV FLOW DENSITY

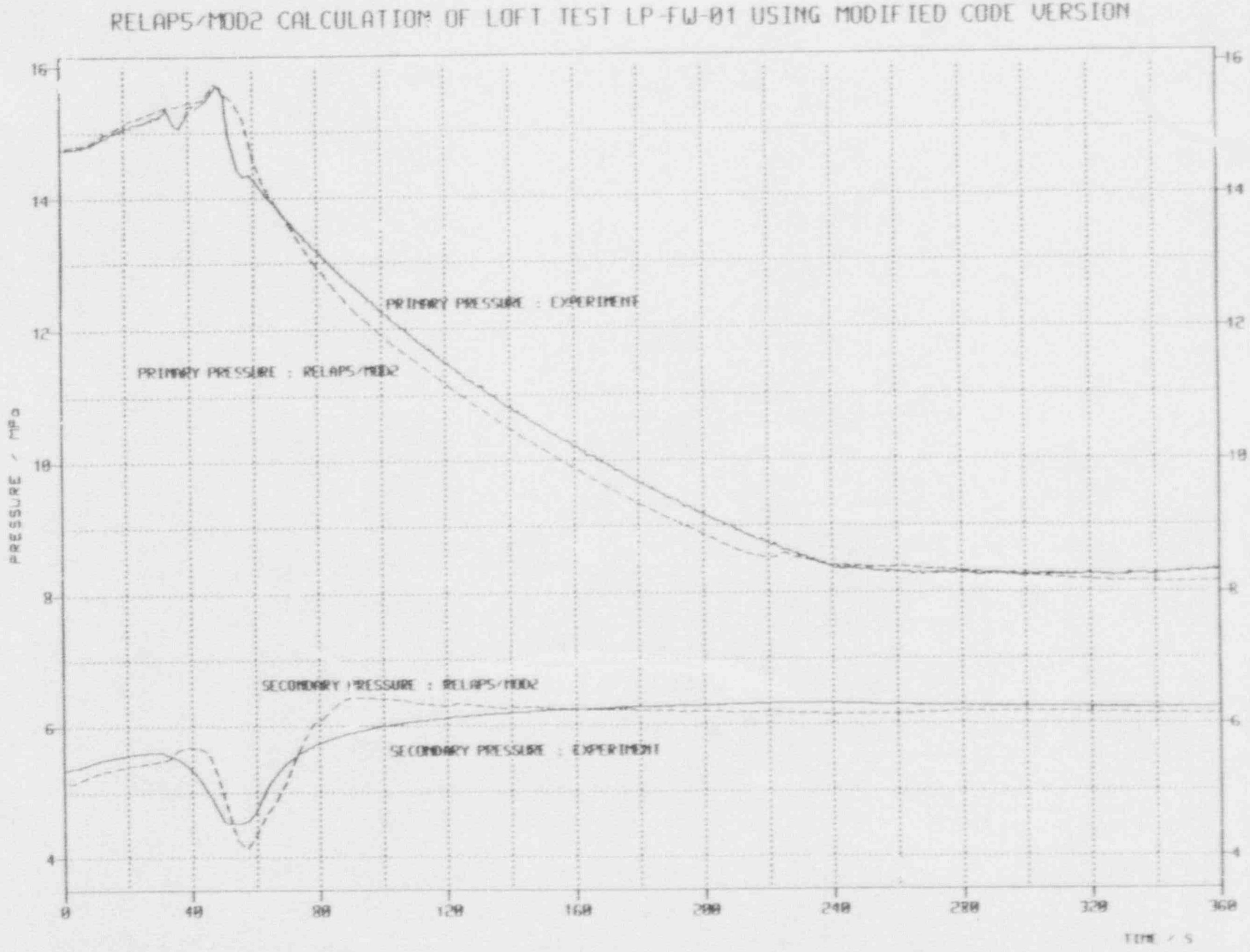


FIGURE 9 : MEASURED AND CALCULATED PRIMARY AND SECONDARY PRESSURES

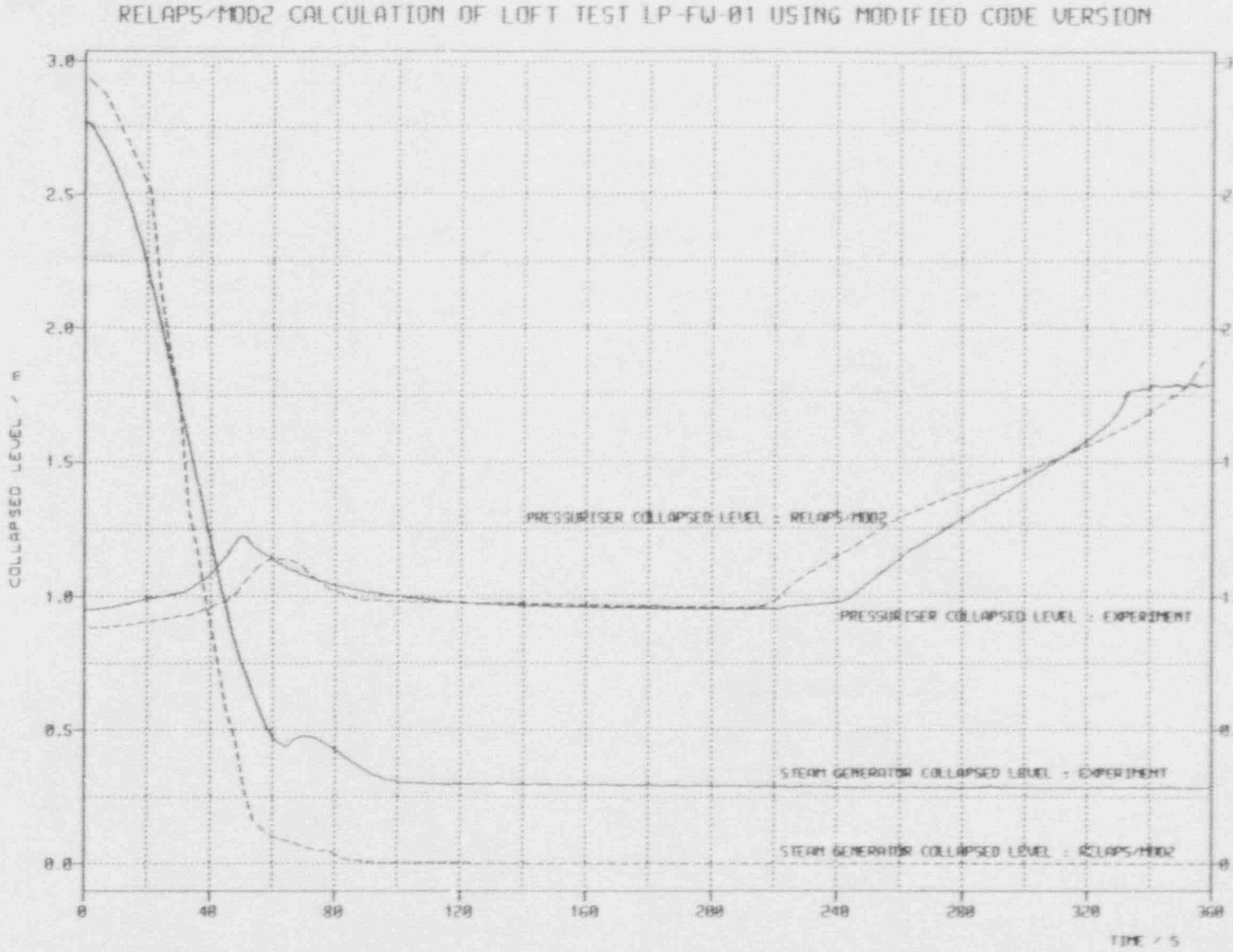


FIGURE 10 : MEASURED AND CALCULATED SG AND PRESSURISER COLLAPSED LEVELS

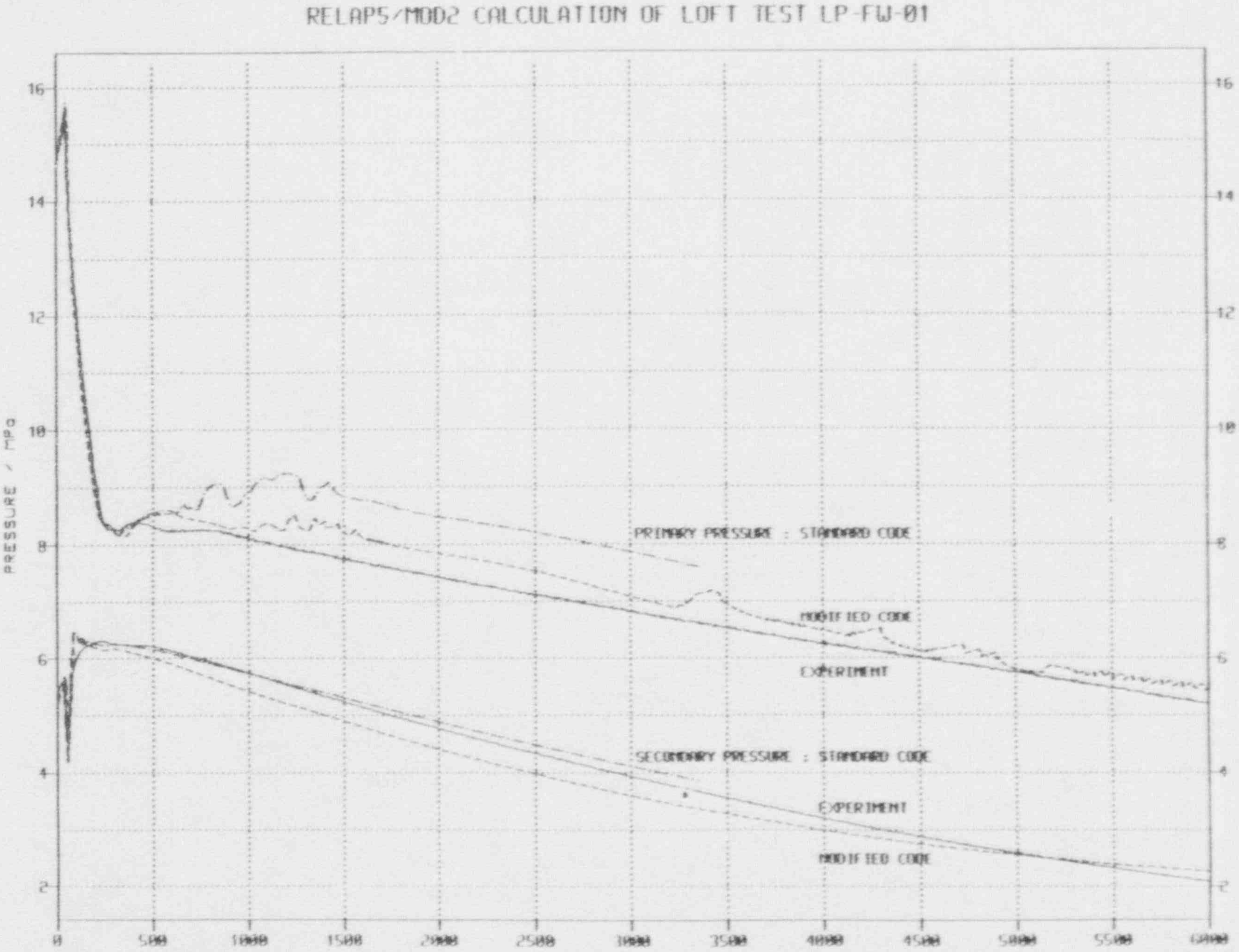

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-FW-01

FIGURE 11 : MEASURED AND CALCULATED PRIMARY AND SECONDARY PRESSURES

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-FW-01 USING MODIFIED CODE VERSION

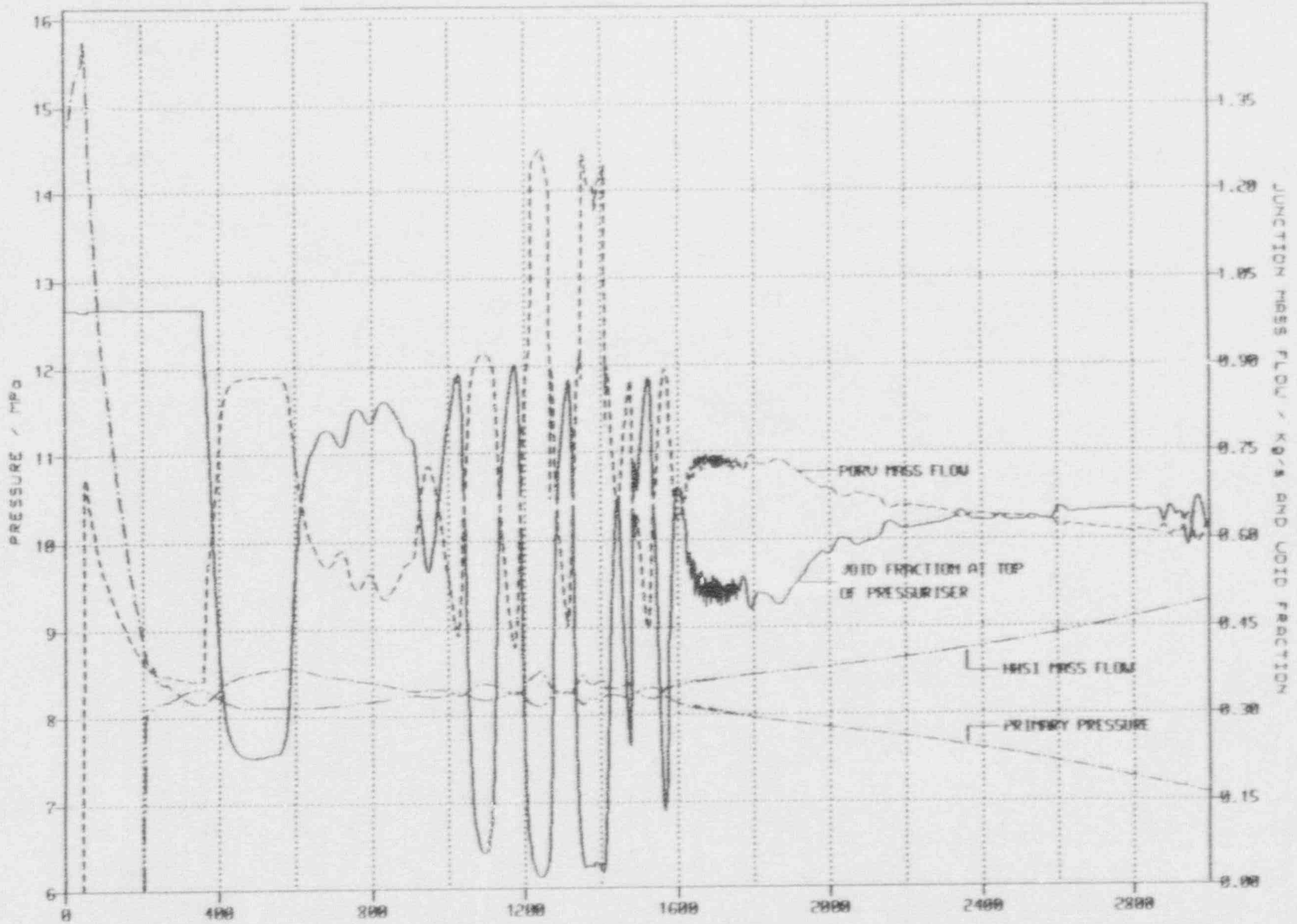


FIG 12 : HHSI AND PORV MASS FLOW, PRIMARY PRESSURE AND PRESSURISER VOID FRCN

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-FW-01 USING MODIFIED CODE VERSION

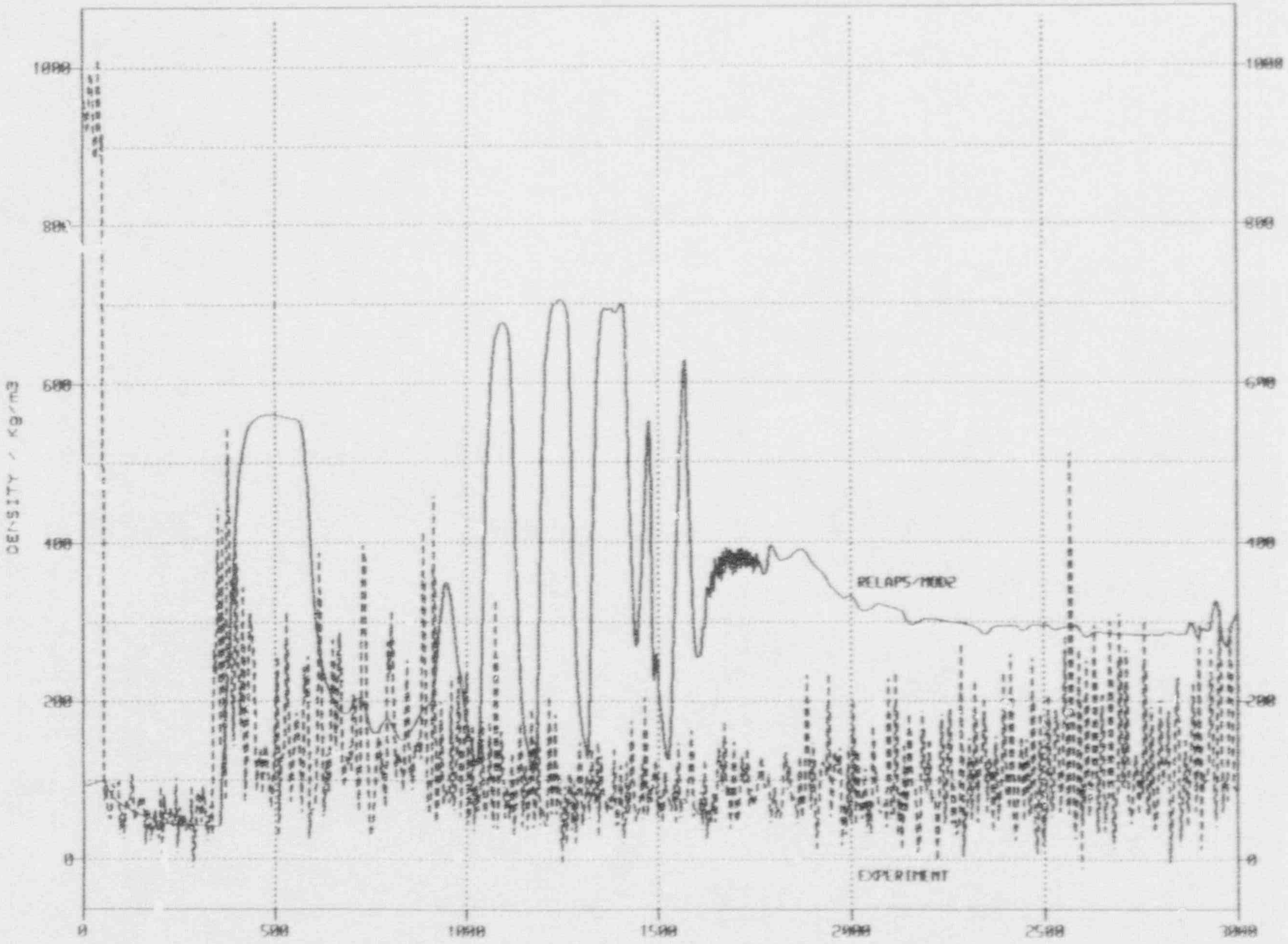


FIGURE 13 : MEASURED AND CALCULATED PRESSURISER PORV FLOW DENSITY

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-FW-01 USING MODIFIED CODE VERSION

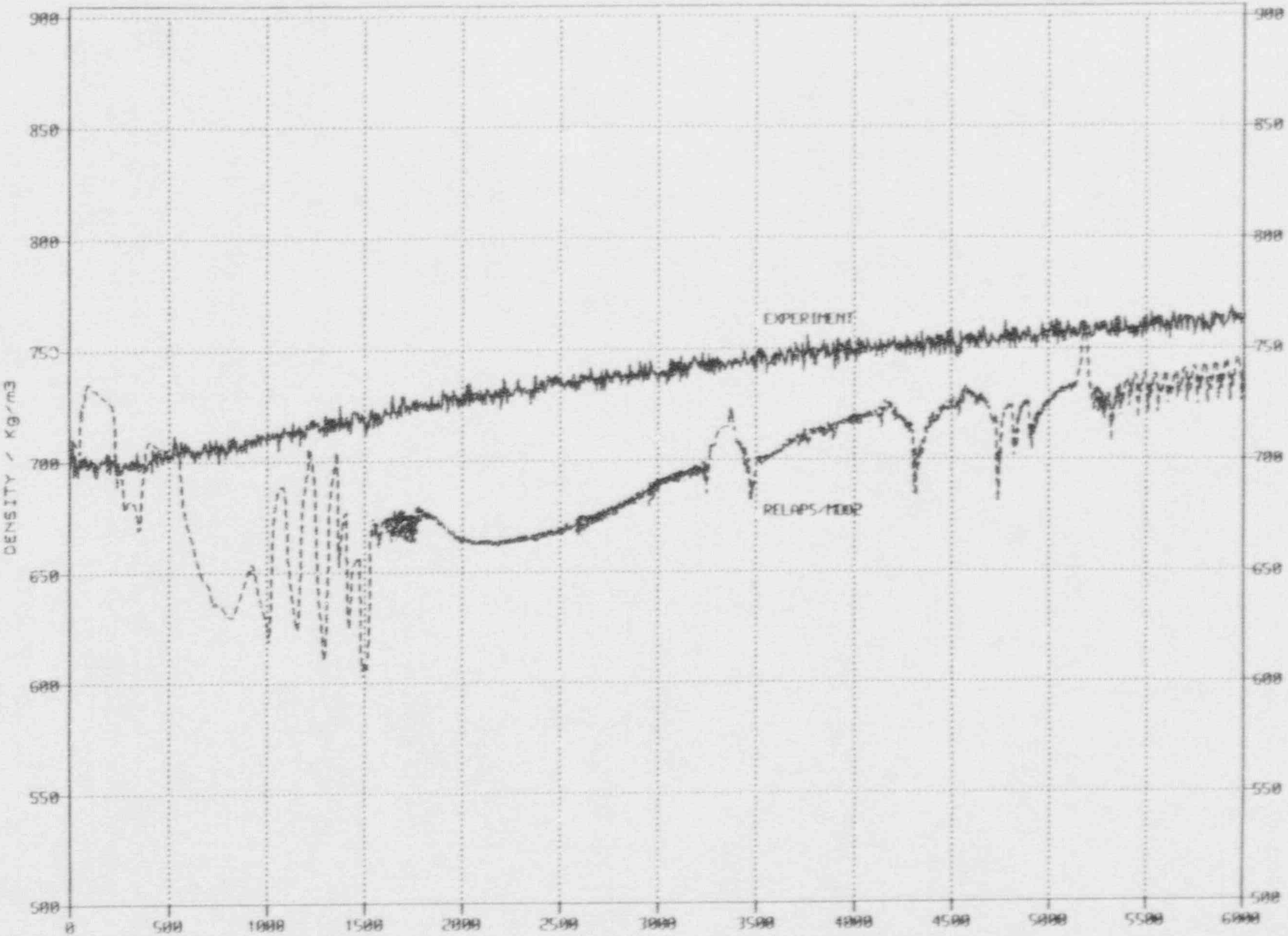


FIGURE 14 : MEASURED AND CALCULATED HOT LEG DENSITY

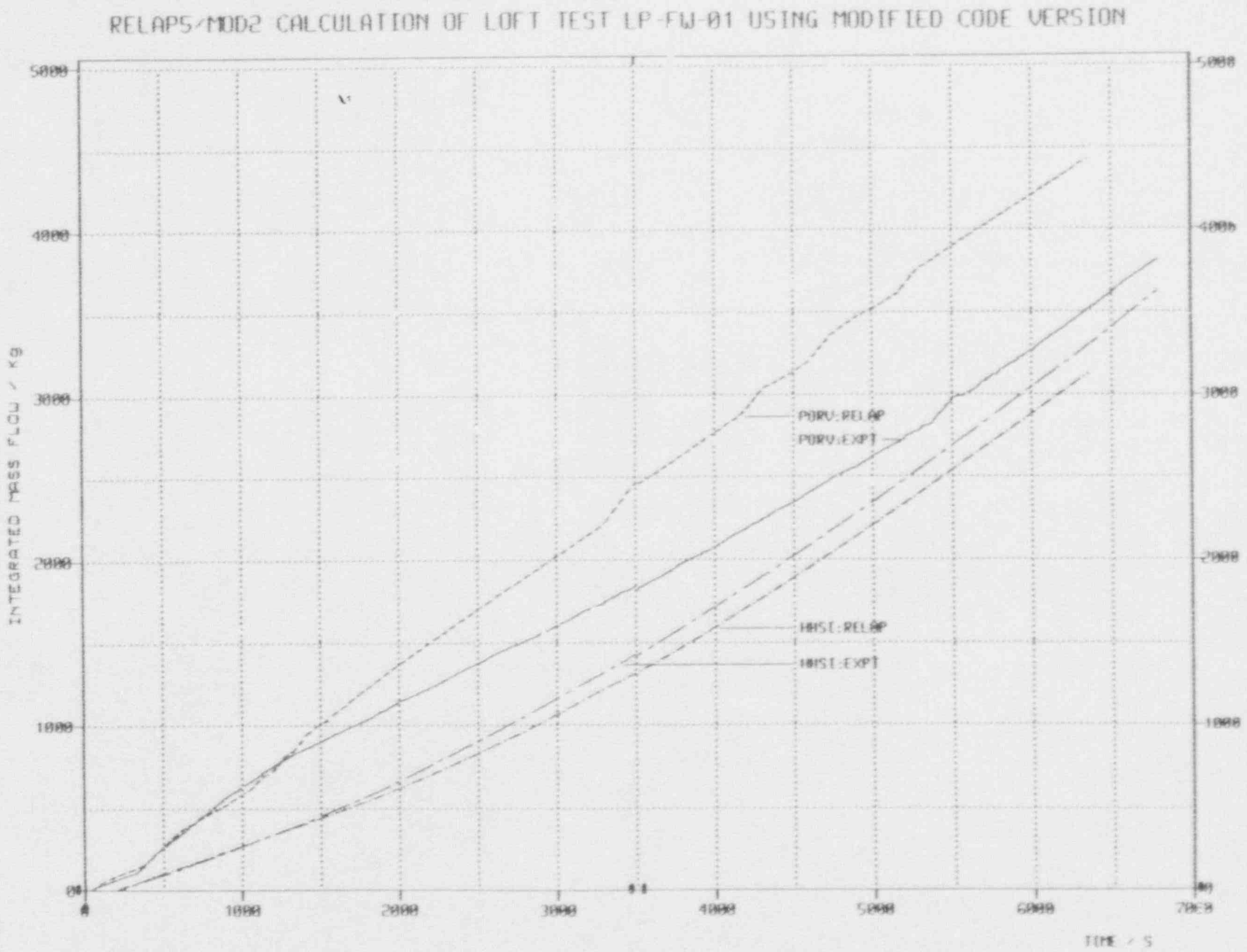


FIGURE 15 : PRESSURISER PORV AND HHSI INTEGRATED MASS FLOWS

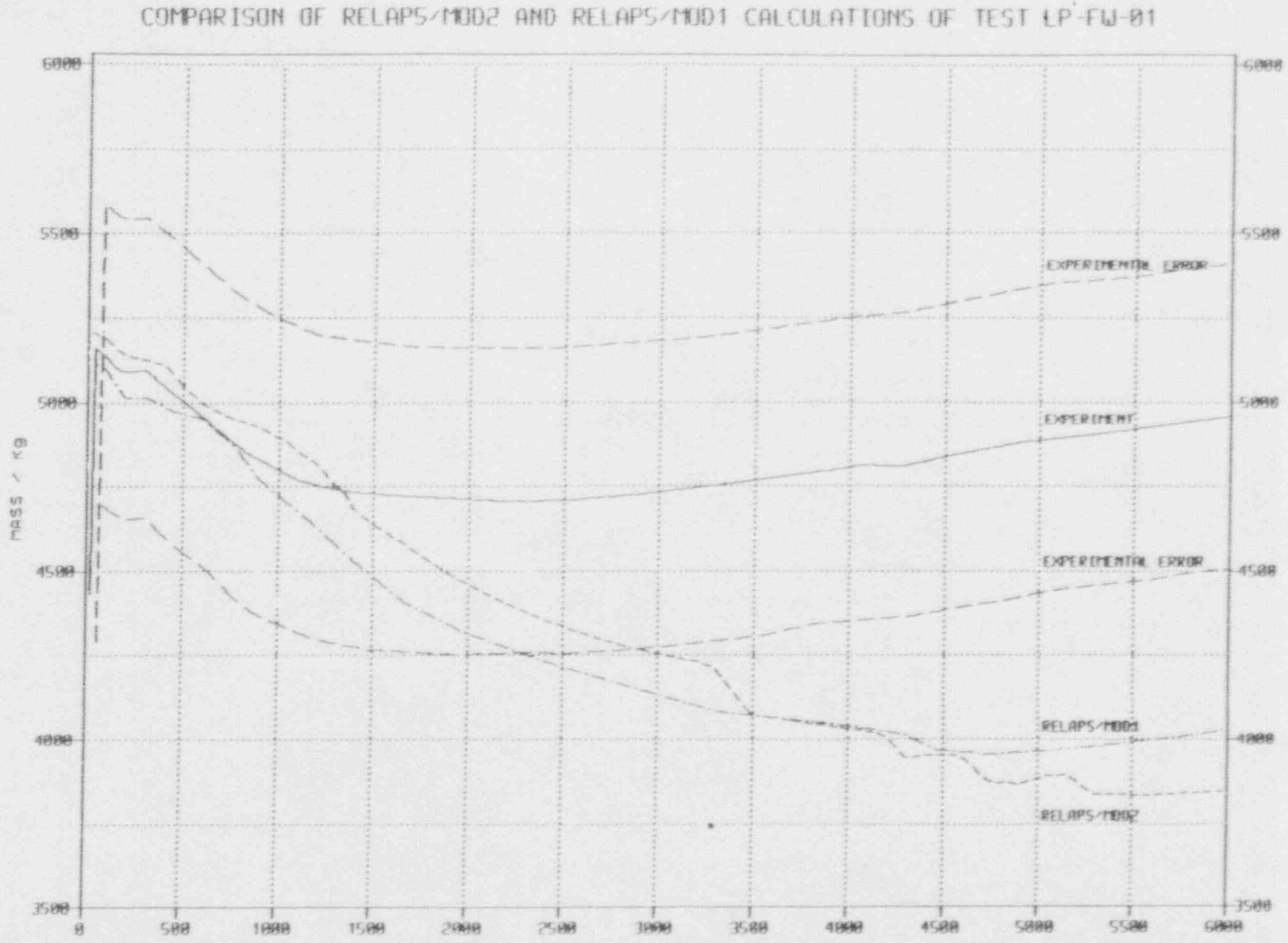


FIGURE 16 : MEASURED AND CALCULATED SYSTEM INVENTORY HISTORIES

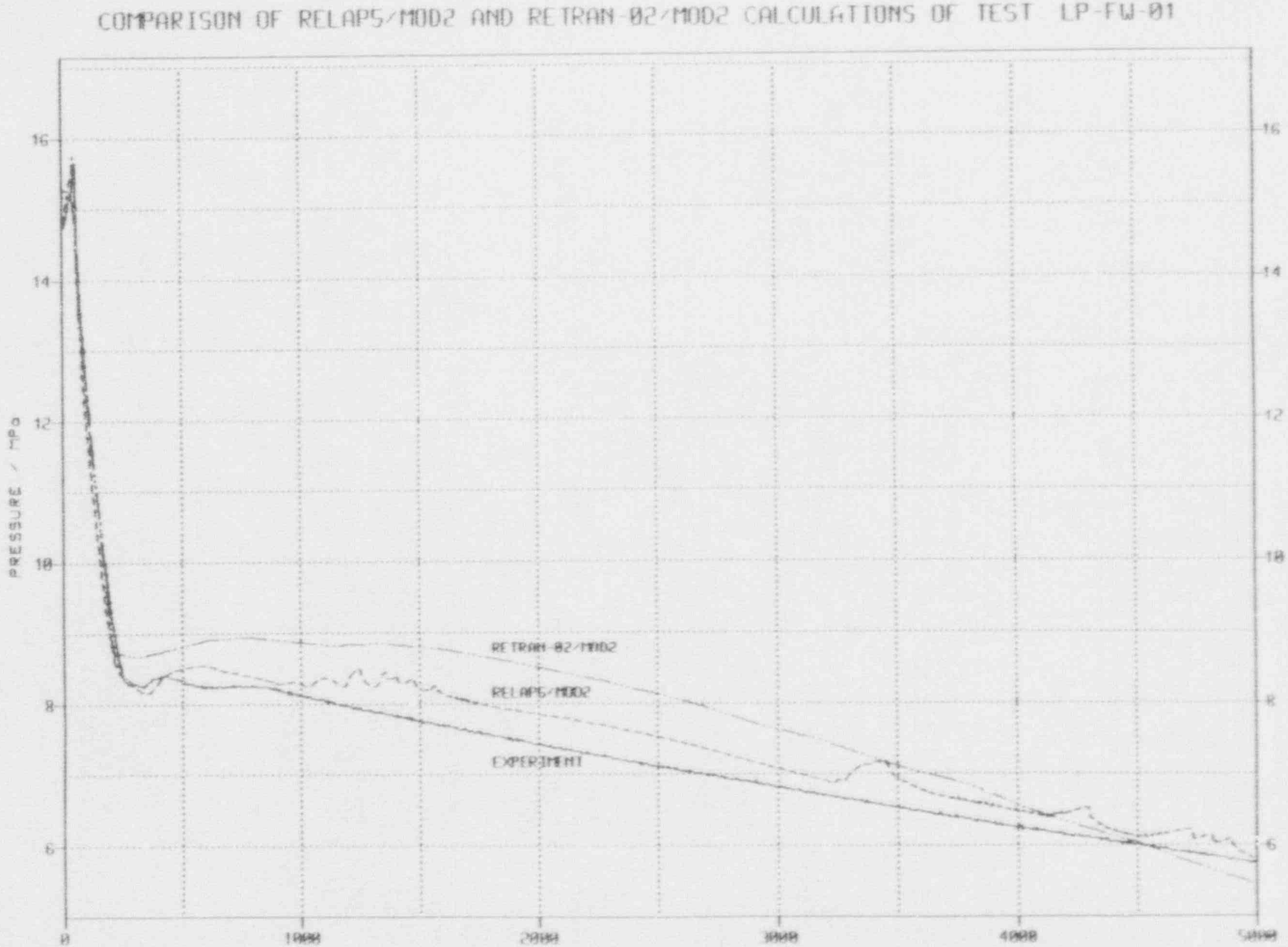


FIGURE 17 : MEASURED AND CALCULATED PRIMARY PRESSURES

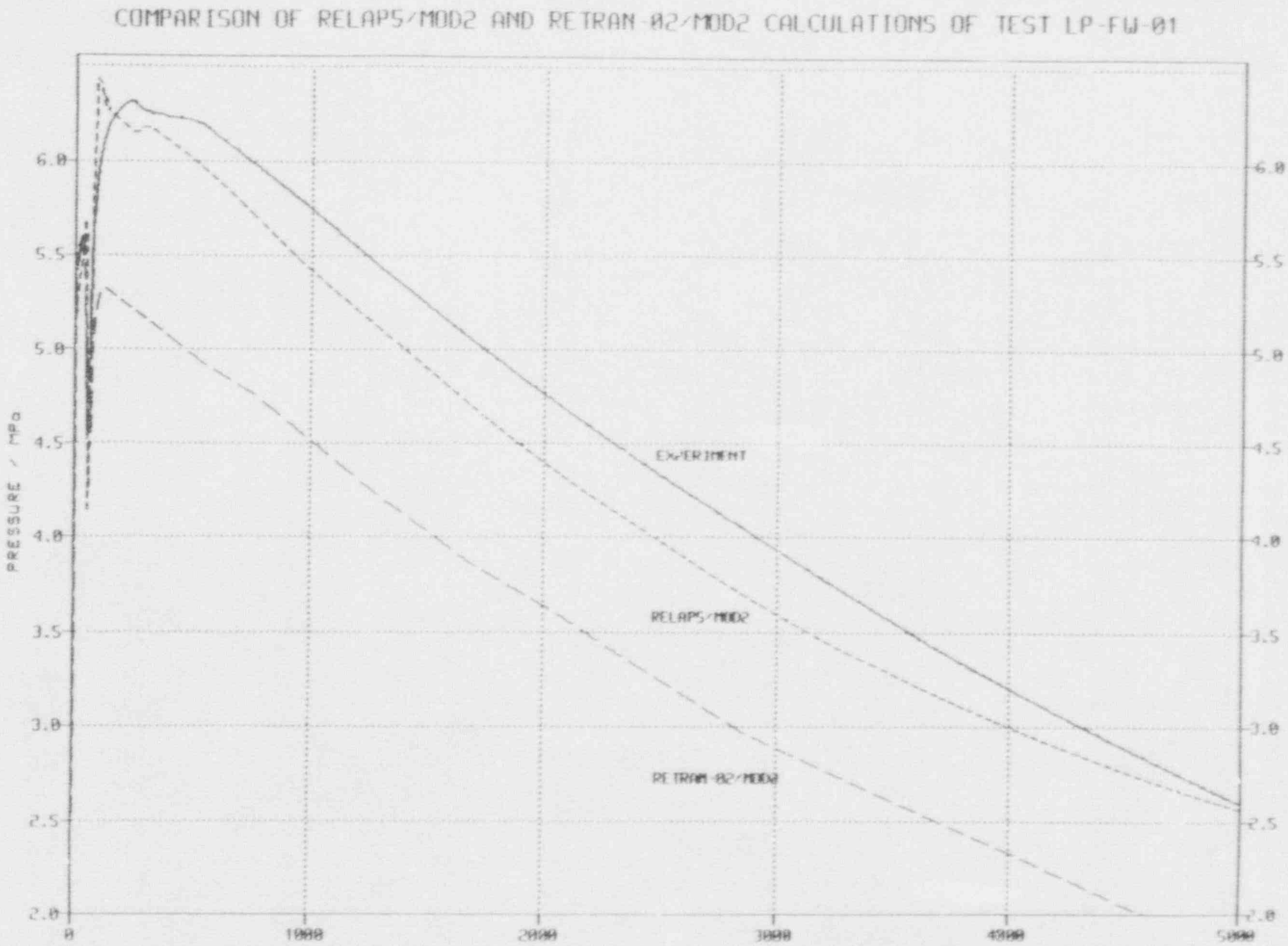

COMPARISON OF RELAP5/MOD2 AND RETRAN-02/MOD2 CALCULATIONS OF TEST LP-FW-01

FIGURE 18 : MEASURED AND CALCULATED SECONDARY PRESSURES

APPENDIX

Sensitivity Study of Cold Leg Draining Behaviour

A1. Introduction

As noted in the main text, the experimental data show the intact and broken cold legs to remain water-filled throughout the test, whereas in the calculation, both of these cold leg volumes drain. To investigate the causes of this behaviour several sensitivity calculations were performed. These calculations were carried out with RELAP5/MOD2 Cycle 36.05. Results are described below.

A2. Sensitivity Calculation

Figure A1 compares measured intact loop cold leg density with results of a reference calculation. It is seen that draining of the cold leg is predicted during the period 750-1500s, whereas in the experiment, draining did not occur.

In order for cold leg draining to occur a path must exist for steam to enter the cold legs from the upper plenum. As the loop seals remain water-filled throughout, only the bypass flow paths are available for the flow of steam to the cold legs.

In the LOFT facility three 'by-pass' flow paths exist between the upper plenum and the cold legs:

(i) leakage between the upper plenum and downcomer (LOFT has no engineered upper head by-pass flow path). This flow path is modelled in the standard RELAP5 LOFT deck used in this analysis by a junction between volumes 255 and 200 (Figure 1);

(ii) leakage between the upper plenum and downcomer through the clearances around the hot leg nozzles (not modelled in the present RELAP5 deck);

(iii) leakage through the Reflood Assist By-Pass Valve, (RABV) modelled as junction 375 (Figure 1).

Since the relative importance of by-pass flow paths (i) and (ii) is not known, a sensitivity calculation has been performed in which the upper head by-pass path (255 to 200) was replaced by a nozzle by-pass flow path (100 to 185) with estimated values for junction area and loss coefficient. Minor improvements were also made to the modelling of the RABV pipework, including invocation of the improved horizontal stratification entrainment model at the junction with the hot leg.

A3. Results of Sensitivity Calculation

Figure A1 compares the reference calculation with the sensitivity calculation. It is seen that the changes have a large effect on cold leg density, delaying draining until 2250s. In consequence, the calculated hot leg density was significantly lower than in the reference case (Figure A2). Agreement with measured PORV density (Figure A3) and discharge mass flow rate (Figure A4) was greatly improved. Somewhat surprisingly, the increased enthalpy discharge rate in the sensitivity calculation did not lead to a noticeable improvement in the prediction of primary system pressure (Figure A5). The source of this apparent anomaly was traced to compensating changes in the calculated heat transfer rate from the heat structures within the reactor vessel downcomer (filler blocks), arising from changes in the flow pattern in the downcomer. The cause of these changes was not resolved due to lack of time.

Draining of the cold legs ultimately occurred in the sensitivity calculation because, with increased hot leg void fraction, steam began to pass through the RABV. This indicates that the hot leg void fraction was probably overestimated in the sensitivity calculation. In spite of this the density at the PORV was overpredicted. This implies that the HSEM of Ardron and Bryce [7] may have tended to underpredict the flow quality entering the surge line in this test.

A4. Conclusions

Errors in the calculation of PORV discharge flow rate and quality in the reference calculation appear to be due to incorrect prediction of cold leg draining behaviour. It is considered that the errors in the prediction are due primarily to uncertainties in modelling the complex by-pass flow paths that exist in LOFT, rather than to errors in the physical models in the code.

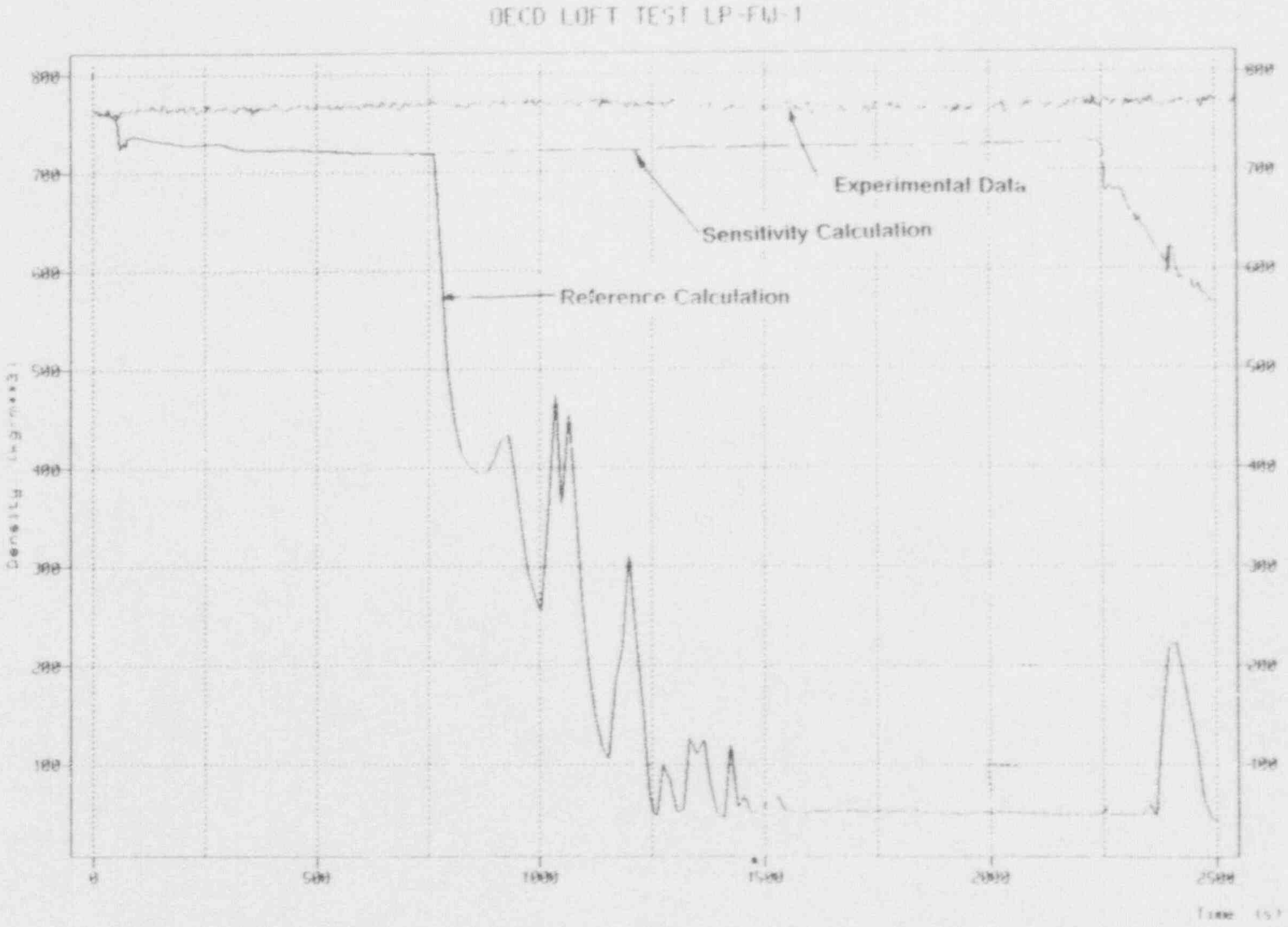


Figure A1 Cold Leg Density

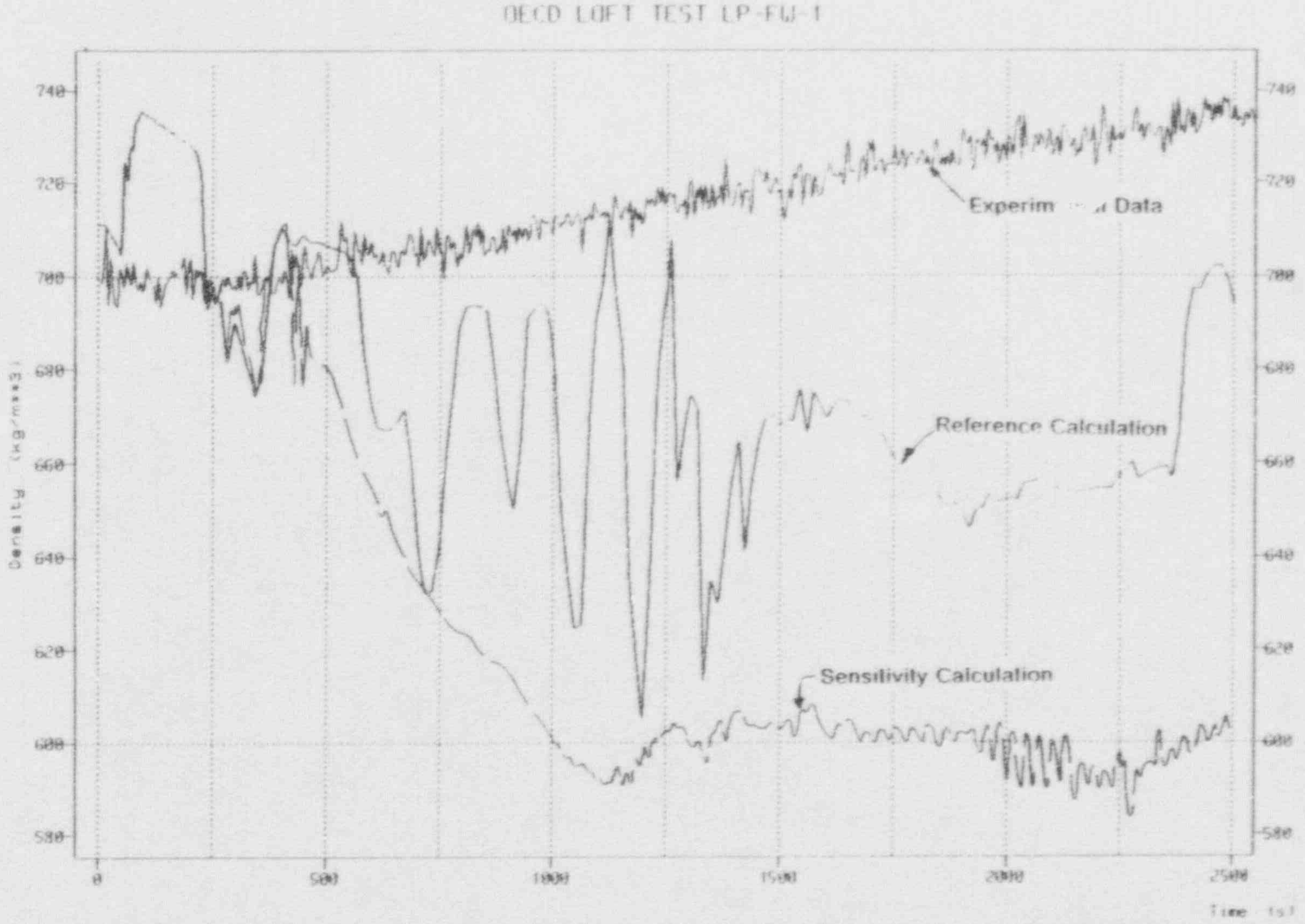


Figure A2 Hot Leg Density

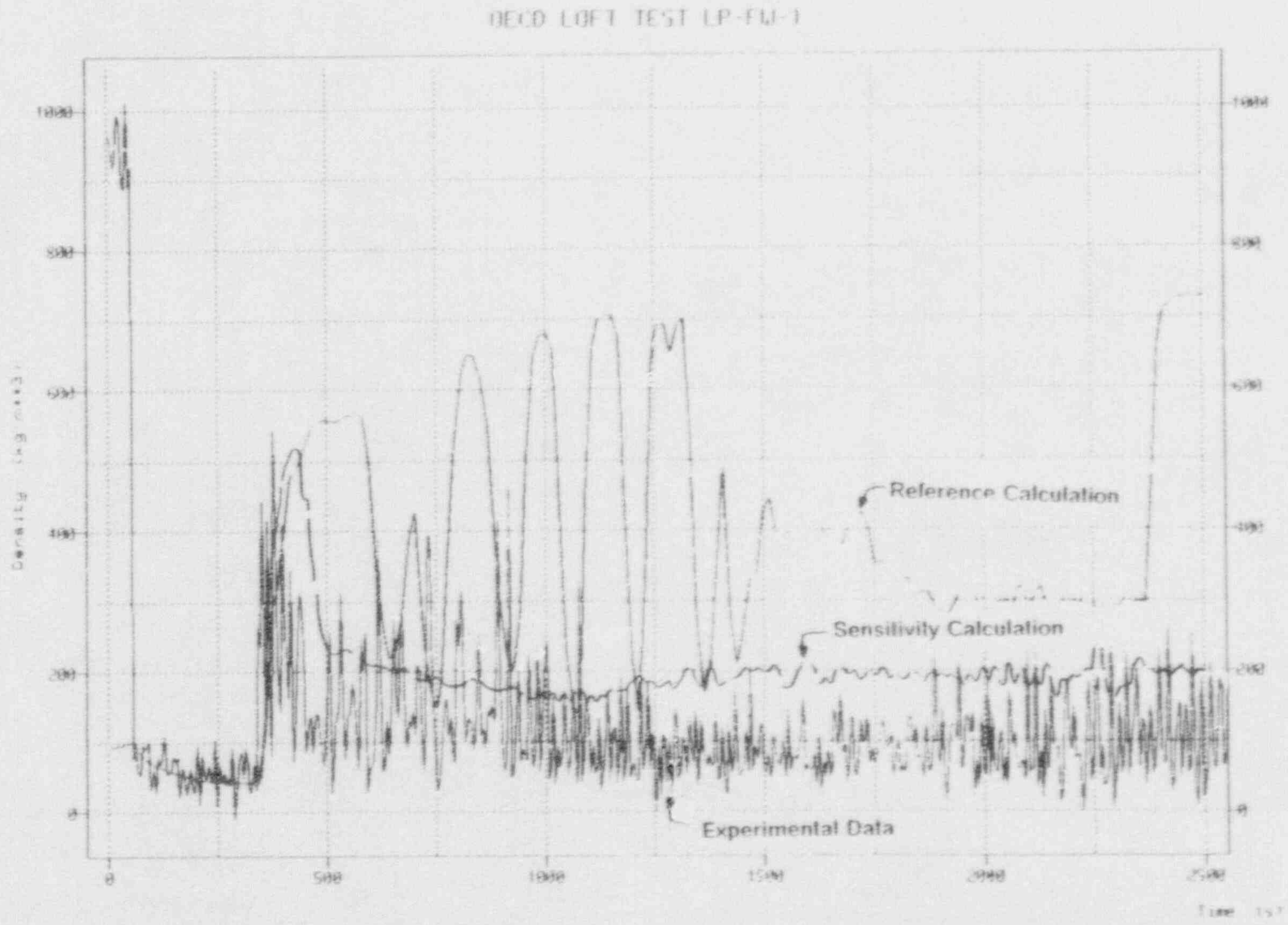


Figure A3 PORV Density

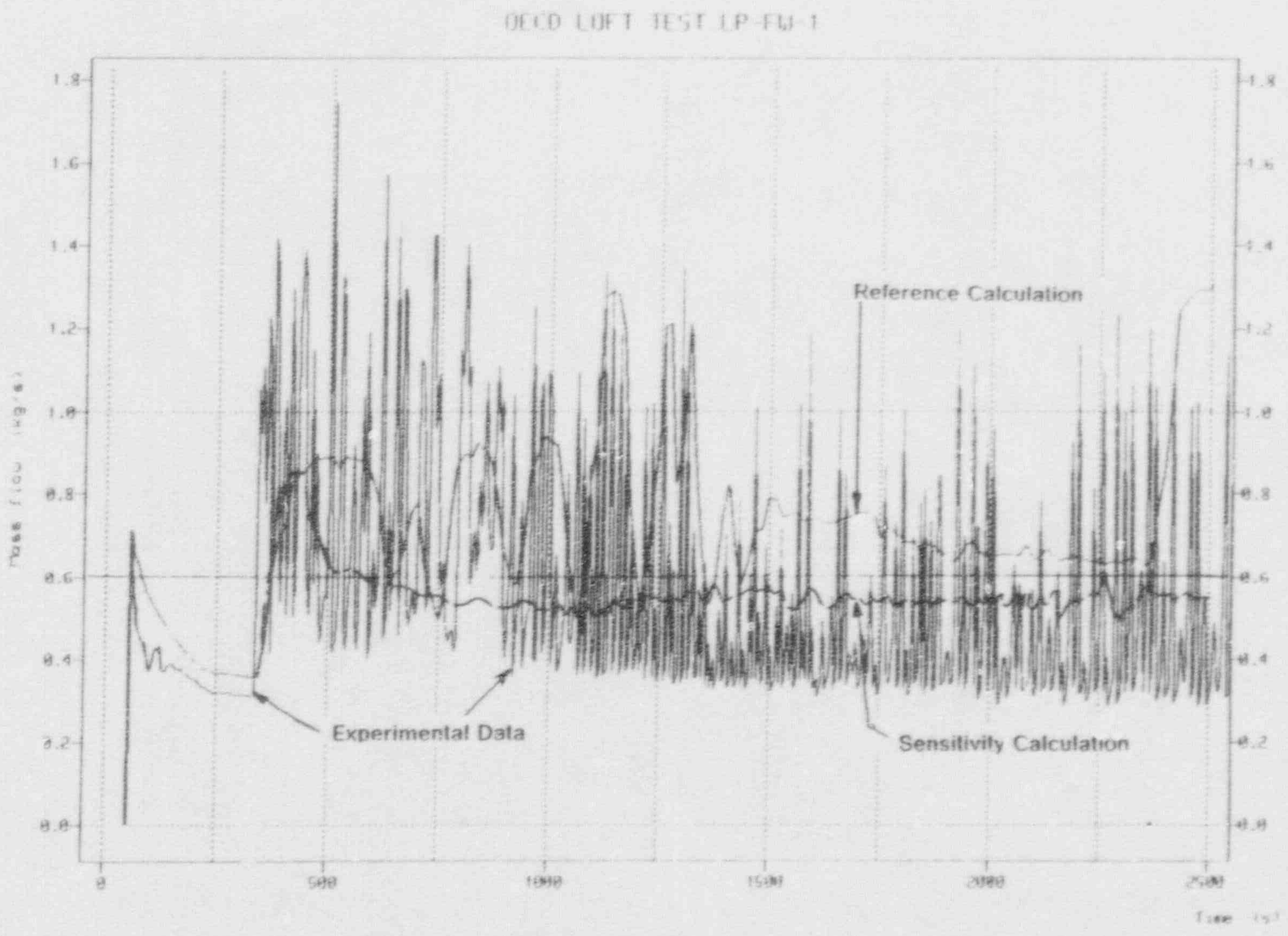


Figure A4 PORV Flow Rate

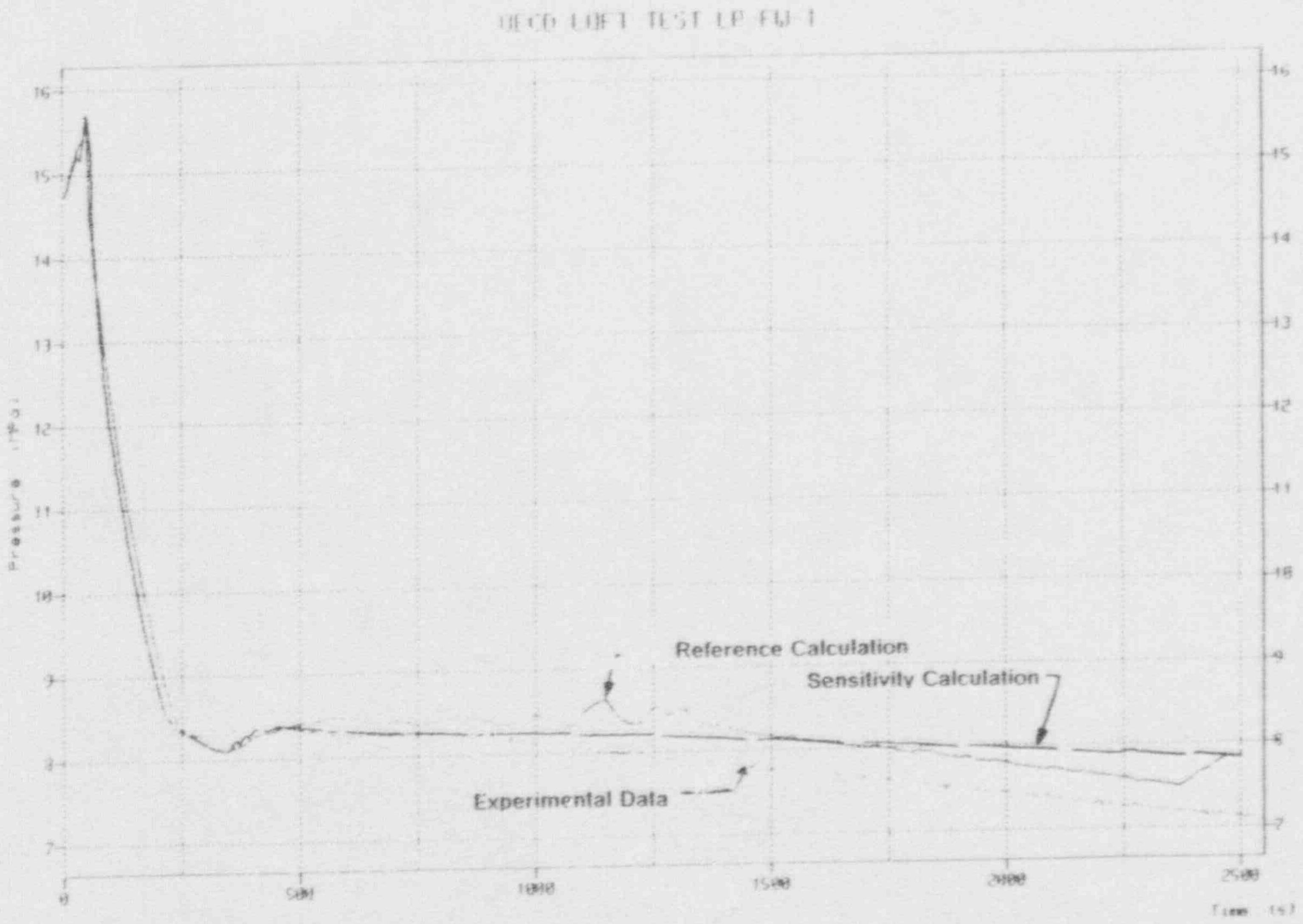


Figure A5 Primary Pressure

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RELAP5/MOD2 is being used by GDCD for calculation of certain small break loss-of-coolant accidents and pressurized transients in the Sizewell 'B' PWR. To test the ability of RELAP5/MOD2 to model the primary feed-and bleed recovery procedure following a complete loss-of-feedwater event, post test calculations have been carried out of OECD LOFT test LP-FW-01. This report describes the comparison between the code calculations and the test data. It is found that although the standard version of RELAP5/MOD2 gives a reasonable prediction of the experimental transient, the long term pressure history is better calculated with a modified code version containing a revised horizontal stratification entrainment model. The latter allows an improved calculation of entrainment of liquid from the hot leg into the surge line. RELAP5/MOD2 is found to give a more accurate simulation of the experimental transient than was achieved in previous UK studies using RETRAN-02/MOD2.

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