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International Agreement Report

RELAP5/MOD2 Calculations of OECD LOFT Test LP-SB-2

Prepared by
P. C. Hall

Central Electricity Generating Board
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Barnwood, Gloucester GL4 7RS
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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

April 1990

Prepared as part of
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under the International Thermal-Hydraulic Code Assessment
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NOTICE

__Abstract__:

To help in assessing the capabilities of RELAP5/MOD2 for PWR Fault Analysis, the code is being used by CEGB to simulate several small LOCA and pressurised transient experiments in the LOFT experimental reactor. The present report describes an analysis of small LOCA test LP-SB-02, which simulated a 1% hot leg break LOCA in a PWR, with delayed tripping of the primary coolant pumps. This test was carried out under the OECD LOFT Programme.

An important deficiency identified in the code is inadequate modelling of the quality of the fluid discharged from the hot leg into the break pipework. This gives rise to large errors in the calculated system mass inventory. The effect of using an improved model for vapour pull-through into the break is described.

A second significant code deficiency identified is the failure to predict the occurrence of stratified flow in the hot leg at the correct time in the test. It is believed that this error contributed to gross errors in the loop flow conditions after about 1300s.

Additional separate effects data necessary to resolve the code deficiencies encountered are identified.

Executive Summary:

The RELAP5/MOD2 transient thermal-hydraulics computer code is being used by CEGB for calculation of small break loss of coolant accident (LOCA) sequences for Sizewell 'B'. To asist CEGB in assessing the capabilities and status of this code, it has been used to simulate SBLOCA test LP-SB-02 carried out in the LOFT experimental reactor under the OECD LOFT programme. This test simulated a 1.0% hot leg break in a PWR, with delayed tripping of the primary coolant circulating pumps. This report compares the results of the RELAP5/MOD2 analysis with experimental measurements, and with published analyses using earlier versions of RELAP5.

Overall agreement between calculated results and experimental data was reasonably good for the first 1200s of the transient, but was unsatisfactory at later times. The principle deficiencies identified in the code were as follows:

(a) In common with previous analyses of Test LP-SB-02 using RELAP5/MOD1, RELAP5/MOD2 failed to predict the onset of stratified flow in the hot leg at the correct conditions.

(b) The test data show that fluid quality in the offtake pipe leading to the break orifice was significantly higher than that in the hot leg. The RELAP5/MOD2 horizontal stratification entrainment (HSE) model, designed to model this effect, failed to predict the correct behaviour in this test. A modified code version incorporating improved correlations for the quality in the offtake pipe was found to produce markedly more accurate results.

(c) Large errors in calculation of the loop flow were encountered in the later part of the experiment. The most likely cause of these errors is thought to be the failure to calculate the correct flow regime in the hot leg, noted in (a) above.

To assist in developing code models which will give improved agreement with similar experiments, further separate effects experimental data are desirable on the following:

(a) Transition to stratified flow in geometries resembling a PWR hot-leg.

(b) Flow quality in a offtake pipe connected to a larger horizontal pipe in which there is a two-phase flow with a mass velocity of more than 1000 kg $m^{-2}s^{-1}$.

Experiments designed to provide this information are currently in preparation at AERE, Harwell.

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1. INTRODUCTION

The RELAP5/MOD2 code [1] is in use by CEGB for calculating Small-Break Loss-of-Coolant-Accident (SBLOCA) and pressurised transient sequences for the Sizewell 'B' PWR. RELAP5/MOD2 uses a six-equation two-fluid model to describe two-phase flow in the reactor primary and secondary systems. It supersedes the RELAP5/MOD1 code, which employed a five-equation model (one-phase constrained to be at thermal equilibrium) and used less sophisticated models for flow regime transitions and interphase interaction terms.

To assist in assessing the capabilities and status of RELAP5/MOD2, the code is being used by GDCD to simulate several small LOCA and pressurized transient experiments carried out in the LOFT experimental reactor under the OECD LOFT programme [2, 3, 4]. The present report describes an analysis of small LOCA test LP-SB-02, which was part of this test series. Test LP-SB-02 simulated a 1% hot leg LOCA in a PWR with a delay of approximately fifty minutes in tripping the primary coolant pumps. The test is described in Refs. [5], [6] and [7].

Comparisons are given with earlier calculations of the same experiment carried out with RELAP5/MOD1, and described in Refs. [6], [8] and [9]. The effect of modelling changes introduced into the MOD2 code version are highlighted.

2. DESCRIPTION OF TEST

The sequence of key events is given in Table 2. The transient is briefly described as follows. The test was initiated by opening the break (time zero) and isolation of the steam generator was initiated at SCRAM, 1.8s later. High Pressure Injection (HPI) flow and auxiliary feed to the steam generator were initiated at 42s and 64s respectively. At about 600s the pump head degraded sharply and there was evidence of flow stratification in the hot leg. However, the pumps maintained a flow circulation round the loop up to 1290s. Because of the complex effects of the stratified flow, the density of fluid entering the break line was systematically lower than the density of the fluid in the hot leg for most of this period. At about 1200s the entrance to the break line became completely uncovered, leading to an increase in the depressurization rate. HPI flow matched break flow at about 2300s and pressure fell steadily to the set point of 3.16MPa when the pumps were tripped (approximately 2900s). Pump trip caused minor changes in differential pressure and water distribution, but had no significant effect on break line density or break flow. The test was terminated at 6810s.

3. CODE VERSION AND INPUT MODEL

The basic code version used for this calculation was RELAP5/MOD2 cycle 36.04, with several error corrections (primarily Cray conversion errors) implemented by UKAEA, Winfrith. The semi-implicit numerical scheme was used throughout because code failure was found to result when use of the nearly-implicit scheme was attempted.

The input data was based on that used in Ref [2] for the analysis of LOFT cold leg break test LP-SB-01. Standard values of the single and two-phase break flow multipliers, CD1 and CD2 (0.93 and 0.81, respectively) were used (e.g Ref. [10]).

The noding diagram is shown in Figure 1. The model consisted of 120 volumes, 126 junctions and 125 heat structures. Junctions between the hot leg and break line, and between the hot land cold legs and the vessel were modelled as cross-flow junctions. This meant that relatively short hydrodynamic volumes were required in the hot leg and in the vessel upper plenum and downcomer.

A microfiche listing of the code input and output has been filed under Safety Technology Section in the Microfiche Archive at GDCD, Barnwood.

4. INITIAL AND BOUNDARY CONDITIONS

To establish the required steady state, a pseudo-transient calculation was run until the problem time reached 100s, when the code indicated that a satisfactory steady state had been achieved. Parameters controlled to achieve the desired steady state were steam and feed flow, and the pump speed. A dummy time-dependent volume was attached to the top of the pressurizer to maintain the desired steady primary pressure. After 100s these steady state controllers were all removed, the dummy volume deleted, and the calculation allowed to proceed for 20s before initiating the transient. Figures 2, 3 and 4 show the hot leg pressure, and pressurizer level, the flows into and out of the SG separator, and the steam generator pressure and level during the steady state run. The slow fall in primary pressure after 100s shown in Fig. 2 is the result of heat losses calculated from the pressurizer. These figures illustrate that a satisfactory steady state was achieved.

The RELAP5 calculated steady state initial conditions are compared with experimental values from Ref. [6] in Table 1. These can all be seen to be in agreement, except for the steam generator (SG) secondary side level, which had to be set artificially high in order to eliminate periodic emptying and filling of the separator volume. This modification was considered acceptable since in test LP-SB-02 the SG secondary plays only a minor role in the overall primary system energy removal.

Boundary conditions used in the test were obtained from the EG&G data package, Ref. [7].

The main primary circuit system (PCS) boundary condition was the High Pressure Injection (HPI) flow. This was modelled as a table of flow versus PCS pressure, rather than flow versus time. For the steam generator secondary side, auxiliary feed-water flow rate was modelled using a table of flow versus time, with flow being terminated 1800s after trip. Also modelled was the brief opening of the steam bypass valve to an area of $1.28.10^{-4}m^2$ when SG pressure first exceeded 6.5 MPa.

As in previous analyses of SBLOCA in LOFT (e.g, [3]), it was found necessary to model steam generator leakage in order to obtain reasonably accurate calculations of secondary pressure. The existence of leakage in test LP-SB-02 is confirmed by the observation of a falling liquid level after auxiliary feed was terminated. Acceptable results were obtained when the leakage was modelled by setting a minimum flow area for the Main Steam Control Valve of $2.0.10^{-3}m^2$.

5. BASE CASE CALCULATION

This section briefly describes comparison of the test results with predictions obtained using the standard version of RELAP5/MOD2, cycle 36.04. Key results are illustrated in figures 5 - 8; solid lines represent the experimental data and broken lines represent the RELAP5 calculations.

(a) Primary pressure.

Figure 5 shows that agreement between measured and calculated primary pressure is reasonably good until about 1200s. Also, beyond 1900s, the depressurization rate is accurately calculated. However, in the period 1200-1900s, there are significant errors in the calculated depressurization rate, leading to a systematic overprediction of pressure in the long term transient. Because of this pressure offset, the time of pump trip is overpredicted (approximately 4150s, rather than 2853s).

(b) Break flow rate.

Figure 6 shows the measured and calculated mass flow rate in the break nozzle. Before about 800s, the break flow rate is underestimated by about 15%. Subsequently it is overestimated by up to 50%, leading to large cumulative errors in system mass inventory. The overestimate in break flow is believed to arise from errors in the calculated conditions in the break line, as described in (c) below. In spite of the underestimation of system inventory, the calculation correctly predicted that no dryout occurred in the core.

In the early part of the calculation, prior to 250s unrealistically sharp steps in the break flow rate are evident. Similar behaviour was observed in previous RELAP5 calculations of subcooled and low quality discharge, e.g. Refs. [2, 3 and 9].

(c) Hot leg and break line density.

The hot leg density (Figure 7) is seen to be reasonably accurately calculated until about 1400s: thereafter large errors occur.

Figure 8 shows the measured and calculated fluid density in the break line. A large systematic overestimate is seen despite the fact that the hot leg density is well predicted until about 1400s. This discrepancy is believed to be responsible for the prolonged overestimate of discharge flow rate noted in (b) above.

The results summarised above indicate reasonably accurate calculation of the transient up to about 1200s, with increasing errors thereafter. The primary source of the errors is evidently the failure to calculate the correct relationship between the density in the hot leg and break line. Similar discrepancies in the break line density were found in RELAP5/MOD1 analysis of LOFT test LP-SB-02 reported in Refs. [6] and [9]. The authors of Ref. [6] attributed the error to the effect of flow stratification in the hot leg, which caused a preferential discharge of vapour into the break line T-junction.

Unlike RELAP5/MOD1, RELAP5/MOD2 contains a special purpose model (the horizontal stratification entrainment model) designed to correct the void fraction donored to an off-take pipe for the effects of flow stratification in an upstream horizontal volume. However, this model is invoked only when the horizontal stratified flow regime is calculated to occur in the upstream volume. For the forced circulation conditions calculated to exist in test LP-SB-02, RELAP5/MOD2 predicted the slug or annular mist flow regimes to persist in the hot leg until about 2250s. However, in the test, stratification in the hot leg began to occur at about 600s when the pump head degraded [6]. Therefore, the RELAP5/MOD2 horizontal stratification model was not applied during the appropriate phase of the test. In consequence results were similar to those of Ref. [6] obtained using RELAP5/MOD1.

To investigate this effect further the test was recalculated with a modified version of RELAP5/MOD2 containing an improved horizontal stratification entrainment model, which is applied at high mass velocities. Calculations with the modified code version are described in the next section.

6. CALCULATIONS USING MODIFIED CODE VERSION

As noted in the previous section, a revised horizontal stratification entrainment model has been developed and included in a modified version of RELAP5/MOD2. This section briefly describes the model and goes on to compare calculations performed using the modified code with the data from test LP-SB-02.

6.1 Description of the Modified Horizontal Stratification Entrainment Model

In the standard version of RELAP5/MOD2 the void fraction at a junction connected to a horizontal pipe containing stratified flow is calculated from an algebraic expression involving the void fraction in the donor volume, the phase velocities in the junction and thermodynamic and geometric properties. The equation is intended to model the effects of flow stratification and vapour/liquid pull-through on the flow in the side branch. The model is applied only when stratified flow is calculated in the donor volume: in other flow regimes the junction void fraction is taken as the donor volume void fraction.

In the modified code version [11] the junction void fraction is calculated from the expression:

$$(1-\alpha_{g,j})/\alpha_{g,j} = (1-X_j)\rho_g U_{g,j}/(X_j \rho_f U_{f,j}) \qquad (1)$$

where the subscript j refers to junction properties. The junction quality X_j is calculated from the empirical correlation given by Smoglie [12] based on air-water test data.

This method of calculating α_j is used at mass velocities in the main pipe below 2500kg $m^{-2}s^{-1}$. For mass velocities above 3000kg $m^{-2}s^{-1}$ the junction void fraction is taken simply as the donor void fraction.+ In between these limits linear interpolation is used.

+ The mass velocity 3000 kg $m^{-2}s^{-1}$ corresponds typically to the transition to the dispersed flow regime, in which effects of gravitational separation may be expected to be small.

The modified code version has been found to give much improved agreement with separate effects test data on two-phase flows in horizontal T-junctions in which there is stratified flow in the main pipe, [11]. However, it should be noted that no test data are available to confirm the modelling approach when there is high mass velocity (exceeding 1000kg m^{-2} s^{-1} in the main pipe). Further experiments are desirable to support the use of the model for these conditions.

6.2 Comparison of results of the modified code with experimental data

The results of the calculation with the modified code version are presented in figures 9 - 17. Experimental data are shown as solid lines and modified code calculations as chain-dotted lines. The timing of key events is given in Table 2. Results are described below:

(a) Primary pressure.

Figure 9 shows that the code modifications described above have little influence on primary pressure until about 1000s because the mass velocity does not fall below the 3000kg $m^{-2}s^{-1}$ limit until about 800s. Thereafter the modified horizontal stratification entrainment model has the effect of increasing the discharge enthalpy which increases the depressurization rate. The relatively rapid drop in pressure which occurred in the test between 1250s and 1750s is not, however, correctly predicted. Failure to predict this feature leads to a delay of about 700s in the calculation of the time of pump trip. This remaining error is discussed further below.

(b) Break flow rate and primary system mass inventory.

It can be seen from figure 10 that modified code produces a much improved calculation of break flow rate from 800s onwards.

Figure 11 shows primary coolant system mass inventory. As expected, the improvement in accuracy of the calculated break flow leads to more accurate calculation of the system mass inventory, particularly later in the transient.

(c) Hot leg and break line density.

The prediction of the density in the hot leg after 1500s is considerably improved in the calculation with the modified code (Figure 12). This is a consequence of more accurate calculation of the discharge flow rate. The fluctuations in calculated density arising at about 3600s are caused by the pump trip.

Figure 13 shows measured and calculated break line density. As expected the modified code version gives a major improvement beyond about 800s. Agreement with experimental data is reasonably good thereafter, except for the period 1250-2000s. Calculated errors in this period evidently arise primarily from errors in the calculated liquid inventory of the hot leg (see Figure 12).

(d) Secondary pressure.

Figure 14 shows a comparison of measured and calculated pressure in the SG secondary. Reasonable agreement is demonstrated, but this is to a large extent due to the tuning of the calculated leakage through the main steam control valve, described in Section 4.

(e) Loop behaviour.

Measured and calculated coolant velocities in the hot leg are shown in Figure 15. Measured data are from two turbine flow meters situated towards the top and bottom of the hot leg. The upper meter can be seen to uncover and show increased (steam) velocity at about 1100s (see ref [5]). The lower (liquid) velocity continues to fall, indicating complete flow stagnation at about 2000s.

The calculated results are significantly different, indicating continuing loop flow at velocities of 4-6ms^{-1} until pump trip.

A second important error is in the calculated flow regime in the hot leg. The 3-beam gamma-densitometers in the hot leg indicate a sharp increase in the vertical void gradient about 600s (Ref. [6]). The existence of fully stratified flow in the hot leg at 1100s is confirmed by the sudden increase in the velocity measured by the upper turbine flow meter, see figure 5. In the calculation using the modified code version stratification in the hot leg was not predicted until pump trip.

Surprisingly the observed occurrence of fully stratified flow in the hot leg at about 1100s took place at a mass velocity of approximately 1800 kg $m^{-2}s^{-1}$, almost an order of magnitude above the normally expected upper limit for the existence of stratified flow, e.g [1].

Additional evidence indicating errors in the calculated loop flow conditions is shown in Figure 16. This figure shows measured and calculated coolant densities in the loop seal, just below the SG discharge. Virtually no water leaves the SG beyond 1500s. In contrast, the calculated results show very similar densities in the loop seal (Figure 16,) cold leg (Figure 17) and the hot leg (Figure 12).

In summary, the experimental data indicate that forward flow of liquid around the loop fell sharply after about 1300s, when most of the water drained from the hot and cold legs. RELAP5/MOD2 predicted a continuation of forced circulation of liquid around the loop until the time of pump trip (3580s). Therefore, throughout the primary coolant system, detailed flow conditions calculated by the code were in error after about 1300s.

Sensitivity calculations were carried out in an attempt to identify the source of the error in the calculated loop flow-rate after about 1300s. These are described in Appendix 1. The sensitivity calculations included changes to the noding of the steam generators and hot legs and changes to the assumed pump characteristics. None of the revised calculations satisfactorily reproduced the experimental behaviour.

7. DISCUSSION AND COMPARISON WITH PREVIOUS ANALYSES

Test LP-SB-02 has been analysed previously with the code RELAP5/MOD1 [6, 8, 9]. In these calculations a significant overprediction of the break line density was also observed. This was attributed to failure to model the effect on the break flow of stratification in the hot leg, since RELAP5/MOD1 did not contain a Horizontal Stratification Entrainment (HSE) model describing this effect.

The released version of RELAP5/MOD2 gives similar results to those obtained previously with RELAP5/MOD1, indicating that the HSE model in RELAP5/MOD2 is ineffective in describing the flow separation observed in this test. Considerably improved agreement is however obtained with the code version containing the modified horizontal stratification entrainment model. Contrasting the two models, it is concluded that the main defects of the HSE model in the released version of the code are as follows:-

(1) failure to model effects of flow stratification at high mass velocities;

(2) inaccurate calculation of fluid quality in the side branch for stratified flow conditions.

The second major error observed in the RELAP5/MOD2 calculations was the failure to calculate rapid reduction in the forced circulation of liquid after about 1300s. Similar difficulties were encountered in the earlier RELAP5/MOD1 analyses, e.g [9]. Several sensitivity calculations were performed as part of the present analysis to try to trace the source of this error (see Appendix 1 for details). These included changes to noding of the steam generators and hot legs, and reductions in the assumed fully degraded pump heat characteristic. None of the additional calculations satisfactorily reproduced the measured liquid flow characteristics.

It is concluded that the error is probably connected with the failure of the code to correctly describe the flow regime in the hot legs. As discussed in the previous section, data from the turbine flow meters and gamma-densitometers indicates that the flow regime in the hot leg became fully stratified at t = 1100s, whereas stratified flow was not calculated to occur until much later (Table 2). It is likely that the error in identifying the flow regime leads to an overestimate of the interphase drag forces in the hot legs; this probably causes an erroneous prediction of continued forced circulation of liquid in the loop.

Further experiments on flow-regime transitions in representative geometries would assist in confirming this hypothesis.

8. GENERAL CODE PERFORMANCE AND CPU TIME

In the present calculations the code was found to be robust, stable and subject to negligible mass conservation errors. For the released code version, cpu:real time ratio was 2.76:1 on a Cray XMP computer. The calculation with the modified code version ran slightly more quickly. The cpu time per mesh cell was 6.58ms.

The cpu:real time ratio was about three times slower than that experienced in the Ref. [2] analysis of test LP-SB-01. This was because the higher fluid velocities in the loop, which arose as a result of delayed pump trip, led to the computational time steps being limited by the Material Courant Limit (MCL). The MCL restriction occurred in the shortest volumes, 104 and 184, which are used for the modelling of Tees with the cross-flow junction option and have a length to diameter ratio of unity in accordance with EG&G guidelines [12]. To investigate the need for restricting the length of these volumes, a sensitivity study was carried out in which the length of volumes 104 and 184 was increased by a factor of about 2.5. This change resulted in an increase in execution speed of x 1.8, yet the results were effectively identical. This observation indicates that the guideline for modelling Tees which requires the use of very short volumes may be unnecessarily restrictive when using the semi-implicit numerical integration scheme in RELAP5/MOD2.

9. CONCLUSIONS

1. This report has described the results of a RELAP5/MOD2 calculation of OECD LOFT Test LP-SB-02, which simulated a 1% equivalent area hot leg loss of coolant accident with delayed tripping of the primary coolant pumps.

2. Overall agreement between calculated results and experimental data was reasonably good for the first 1200s of the transient, but was unsatisfactory at later times. The principle deficiencies identified in the code were as follows:

   (a) In common with previous analyses of Test LP-SB-02 using RELAP5/MOD1, RELAP5/MOD2 failed to predict the onset of stratified flow in the hot leg at the correct conditions.

   (b) The test data show that fluid quality in the offtake pipe leading to the break orifice was significantly higher than that in the hot leg. The RELAP5/MOD2 horizontal stratification entrainment (HSE) model, designed to model this effect, failed to predict the correct behaviour in this test. A modified code version incorporating improved correlations for the quality in the offtake pipe was found to produce markedly more accurate results.

   (c) Large errors in calculation of the loop flow were encountered in the later part of the experiment. The most likely cause of these errors is thought to be the failure to calculate the correct flow regime in the hot leg, noted in (a) above.

3. To assist in developing code models which will give improved agreement with similar experiments, further separate effects experimental data are desirable on the following:

(a) Transition to stratified flow in geometries resembling a PWR hot-leg.

(b) Flow quality in an offtake pipe connected to a larger horizontal pipe in which there is a two-phase flow with a mass velocity of more than 1000 kg $m^{-2}s^{-1}$.

Experiments designed to provide this information are currently in preparation at AERE, Harwell.

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TABLE 1

Initial Conditions for LP-SB-02

	Experiment	RELAP5*
Cold Leg Temp. (K)	557.2±1.5	559.2
Mass Flow Rate (kg/s)	480.0±3.2	480.1
Core Temp Rise (K)	18.6±1.7	18.9
S.G. Secondary		
Liquid Level (m)	3.13±0.1	3.70
Pressure (MPa)	5.60±.05	5.61
Mass Flow (kg/s)	26.70±0.8	25.66
Pressuriser		
Pressure (MPa)	15.08±0.16	15.06
Liq. Level (m)	1.109±.003	1.135
Others		
Core Power (MW)	49.1±1.2	49.1
HPI Temp. (K)	306±7	306

* End of Null Transient.

TABLE 2

Sequence of Events for LP-SB-02 Calculation

Event	Time After Break Open (s)		
	Experiment	RELAP5/MOD2	Modified Code
Small-Break Valve Opened	0	0	0
Reactor Scrammed	1.8±.05	4.27	4.27
Main Feed-water Shut Off	1.8±.02	4.27	4.27
Main Steam Control Valve Started to close	2.8±0.2	5.28	5.28
Main Steam Control Valve Fully Closed	14.8±0.2	20	20s
Pressurizer Liquid Level Below Bottom	36.4±0.2	38	38
HPIS Flow Initiated	42.4±0.2	43.7	43.7
Subcooled Blowdown Ended (break line fluid reached saturation)	50.2±1.0	53	53
Auxiliary Feed-water Initiated	63.8±0.2	66.3	66.3
Onset of Stratification in Hot Leg	600	~2250	pump trip
Stagnation of Liquid Flow in Loop	1290	pump trip	pump trip
Primary System Pressure Became Less than Secondary System Pressure	1290±45	2650	2320
Auxiliary Feed-water Shut Off	1864.0±0.2	1866	1866
HPIS Flow Rate Exceeded Break Flow Rate	2284±200	>4000 +	~2500 +
Primary Coolant Pumps Tripped	2852.8±0.2	4152*	3580
Calculation Termination		4000	4000

* Approx. value, based on preliminary calculation.
\+ Time of minimum primary system inventory.

APPENDIX

Description of Sensitivity Studies

The objective of this Appendix is to summarise the results of a number of sensitivity calculations performed in an attempt to establish the cause of the failure of RELAP5 to predict the rapid reduction in water flow in the loop after about 1300.

The first possibility to be considered was that water was being erroneously entrained into the Steam Generator (SG) either as a result of overestimates in interfacial friction or because of failure to account for separation in the hot leg/SG inlet elbow.

In calculating the interfacial drag at a junction, RELAP5/MOD2 averages the values of drag derived in the adjacent volumes. It is therefore possible for the averaging process to suppress the effect of a volume in which low interphase drag is calculated, if high interphase drag is calculated in both upstream and downstream adjacent volumes. Because the SG inlet plenum has a large cross-sectional area relative to the two adjoining volumes, it was considered possible that interphase drag within the plenum was effectively overestimated. To eliminate this possibility, a sensitivity calculation was performed in which the SG inlet plenum in the RELAP5 input model was split into two vertically stacked volumes. As expected, the interfacial drag at the newly created internal junction was lower than in the other junctions, and a noticeable amount of water was calculated to accumulate in the SG inlet plenum. However, this accumulation had only a transitory effect on water flow into the SG tubes, and led to no long term improvement in the accuracy of the calculation of liquid flow rate.

A second more speculative attempt to eliminate water flow into the SG tubes was made by invoking the modified horizontal stratification off-take model developed for the hot leg/break line at the junction between the horizontal and inclined sections of the hot leg. This again caused slight accumulation of water in the hot leg, but produced no long term improvement in calculated loop flow.

Finally, the pump degraded head data was modified to reflect data uncertainties. Figure A1 shows the measured pump differential pressure compared with the value calculated using the modified version of the code (chain-dotted line). This indicates that the calculation overestimates the data somewhat. To assess the sensitivity of the system to errors in calculated pump differential pressure, a calculation was performed in which the fully degraded pump head was reduced by about 30%. The calculation began at 600s, continuing until 2500s. Results are also shown on Fig. A1 (broken line). Agreement with measurements is very good in the critical period around 1300 - 1500s when loop water flow actually ceased.

The effect on calculated loop flow rates is illustrated in Figure A2, which shows measured velocities at the top and bottom of the hot leg alongside liquid and vapour velocities arising from the two calculations mentioned above. The effect of reducing the fully degraded pump performance is to bring the calculated steam velocity into reasonable agreement with measured values (top of hot leg) for long periods. In spite of this, the water velocity does not fall to zero as measured, and the erroneous calculation of circulation of a near homogeneous two-phase mixture experienced in the previous calculations was maintained.

In this sensitivity analysis there were periods during which the hot leg steam velocity (Fig. A2) and hot leg mixture density (Fig. A3) were calculated correctly (750-1400s, 2000-2500s). Nevertheless, the code continued to calculate water flow along the hot leg and up the SG tubes. This implies that the failure to predict cessation of loop flow was probably due more to weaknesses in interphase drag calculation in the hot leg/SG inlet than to errors in the assumed pump characteristics.

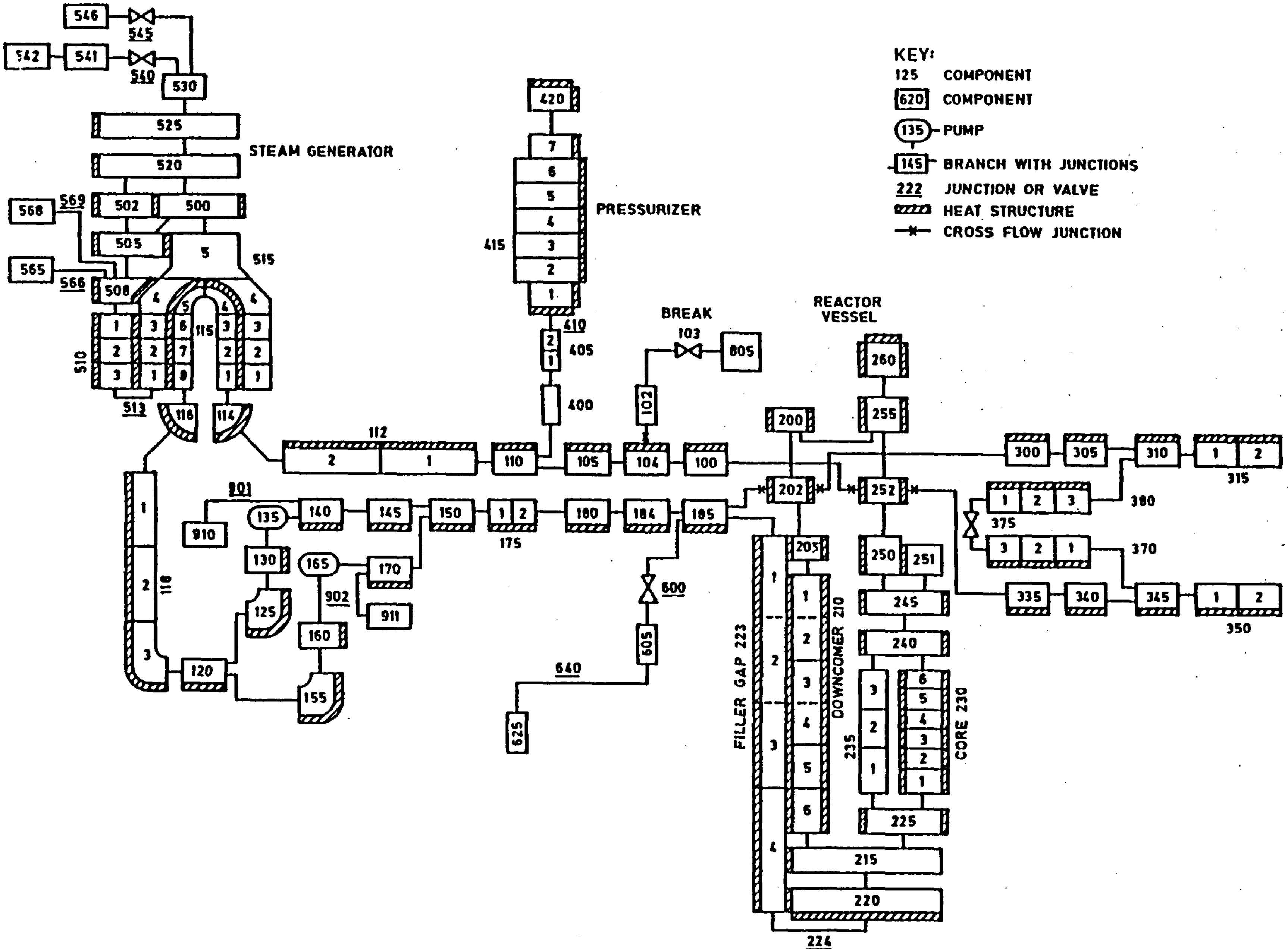


FIG. 1 RELAP 5 NODING DIAGRAM FOR LOFT LP-SB-2 CALCULATION

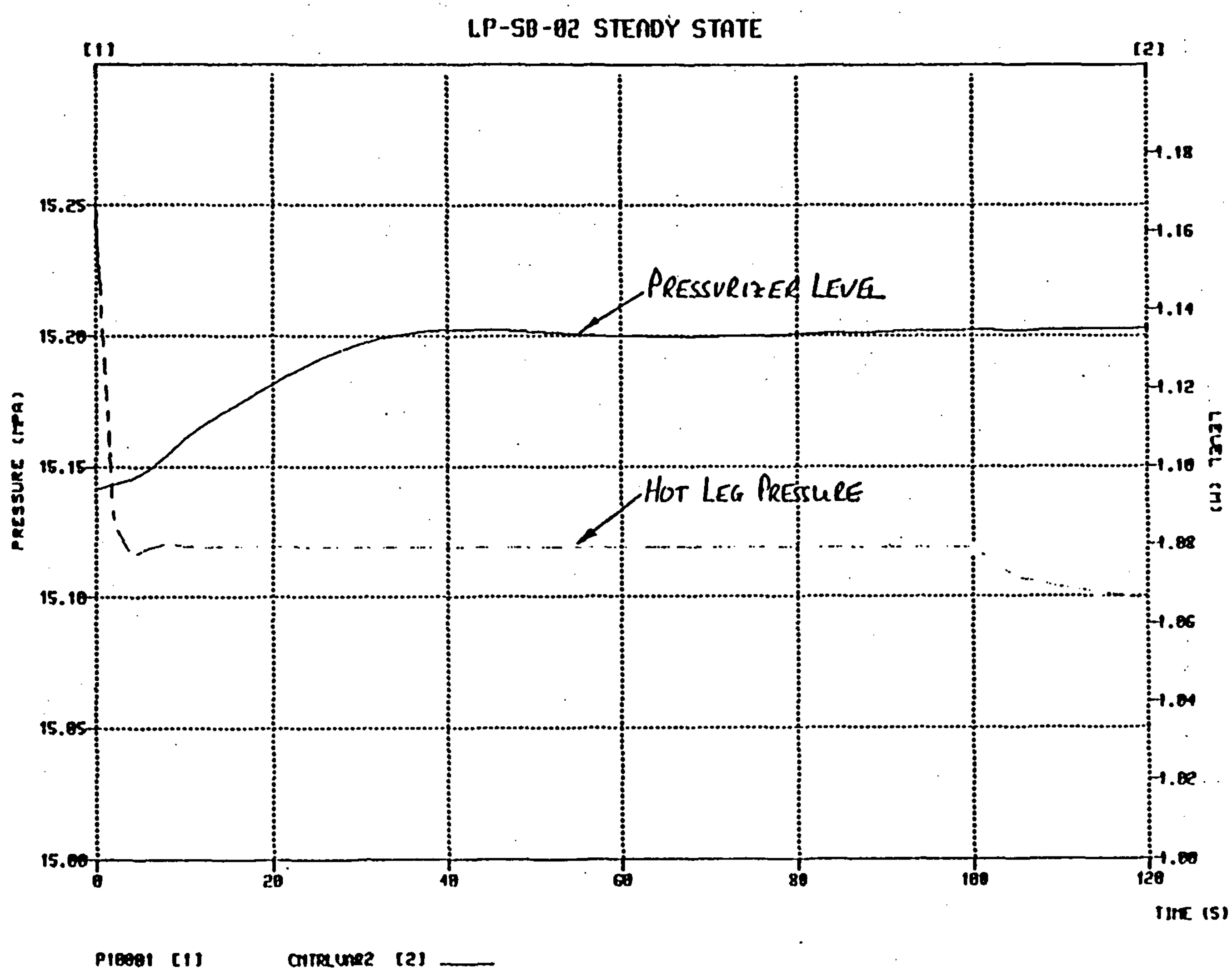


FIGURE 2 HOT LEG PRESSURE AND PRESSURIZER LEVEL

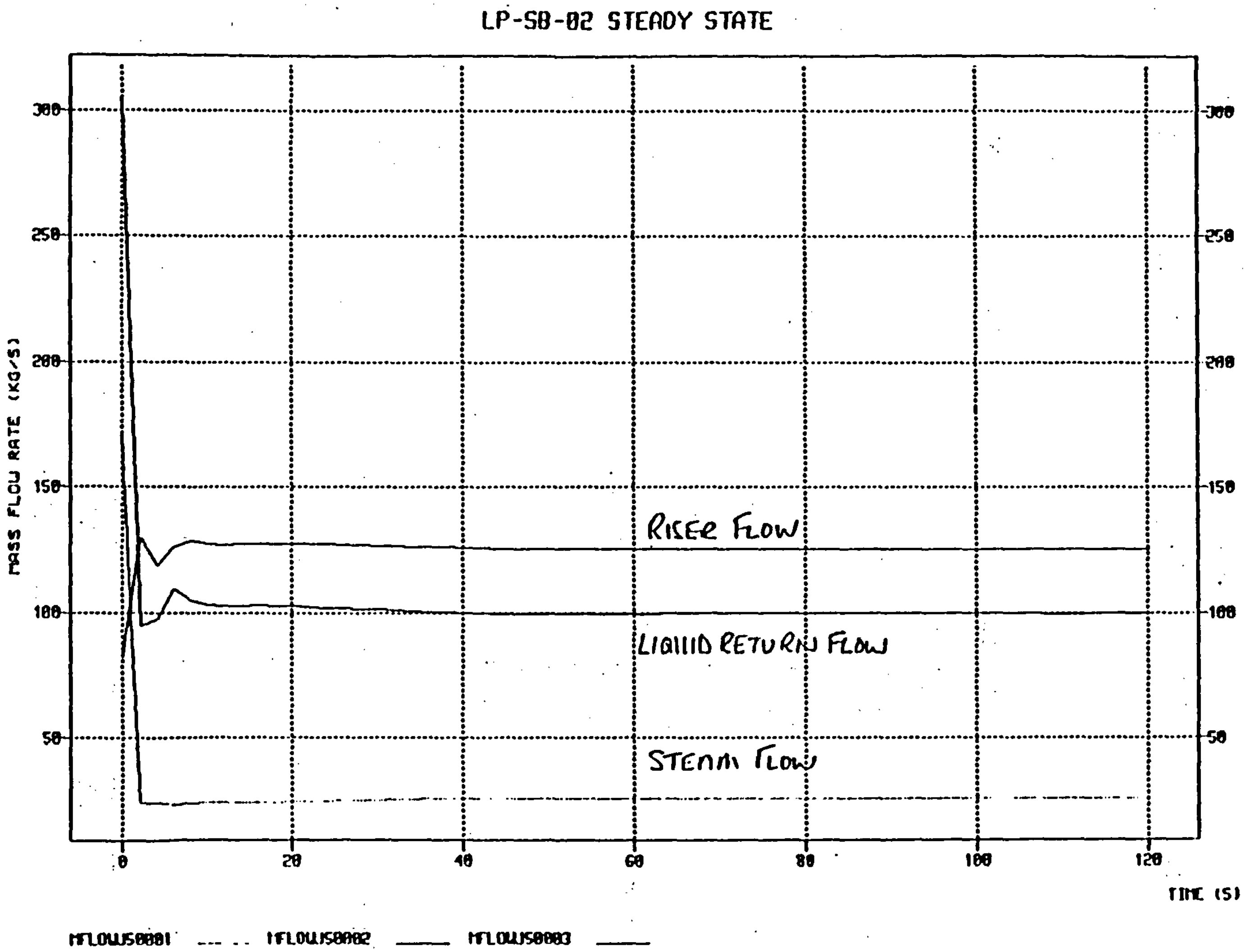


FIGURE 3 STEAM GENERATOR SEPARATOR MASS FLOW RATES

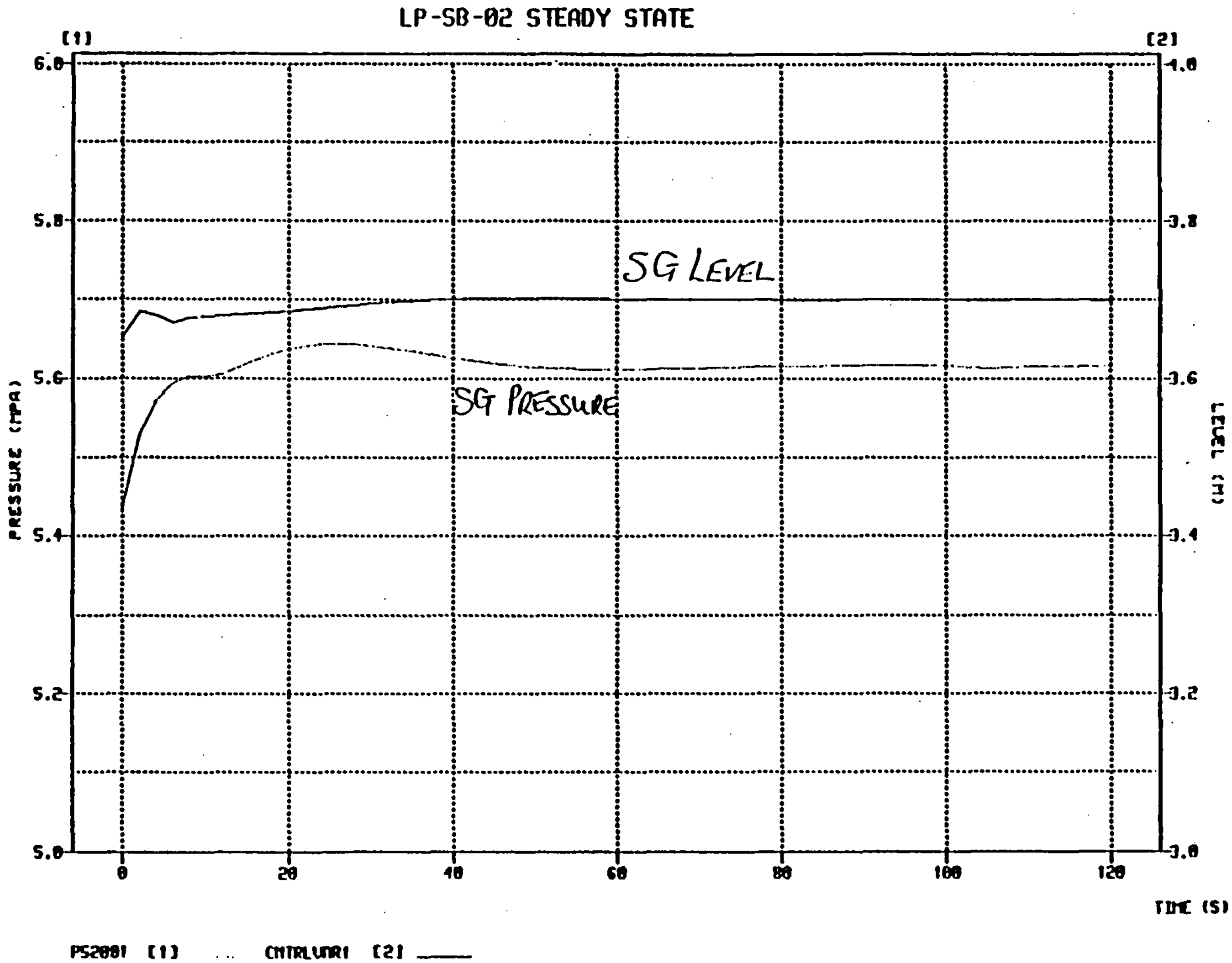


FIGURE 4 STEAM GENERATOR PRESSURE AND LEVEL

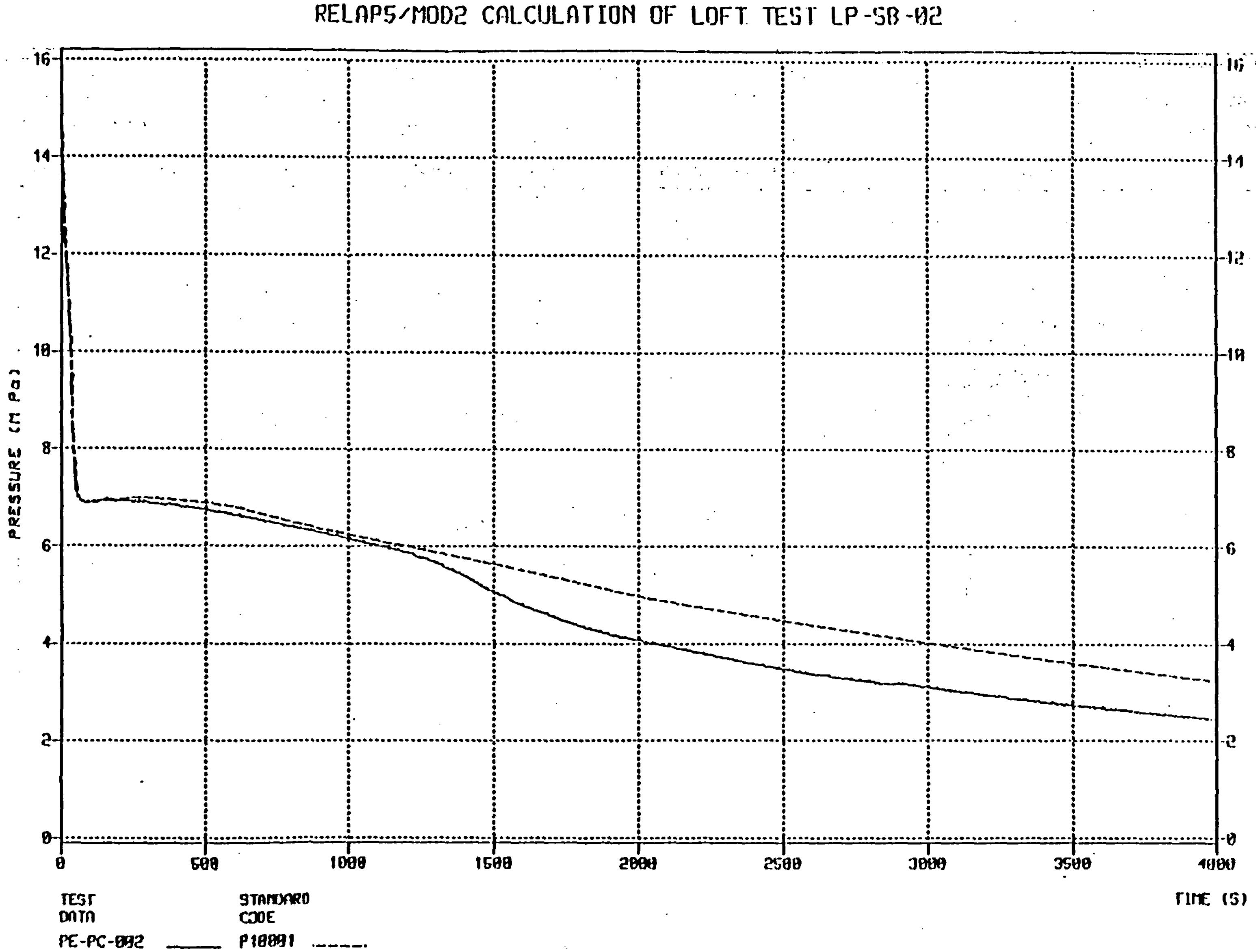


FIGURE 5 : MEASURED AND CALCULATED PRIMARY PRESSURES

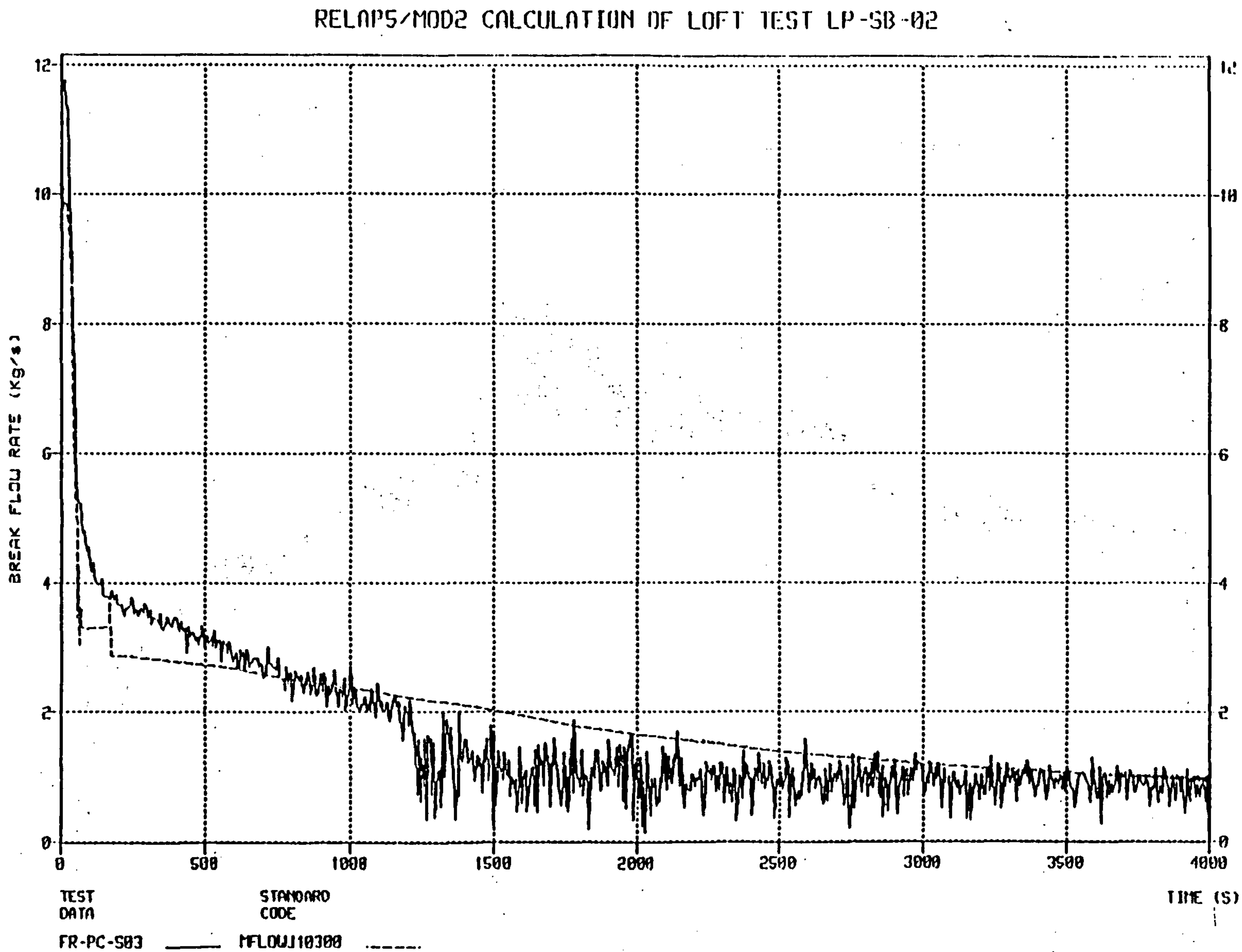


FIGURE 6 : MEASURED AND CALCULATED BREAK FLOW RATE

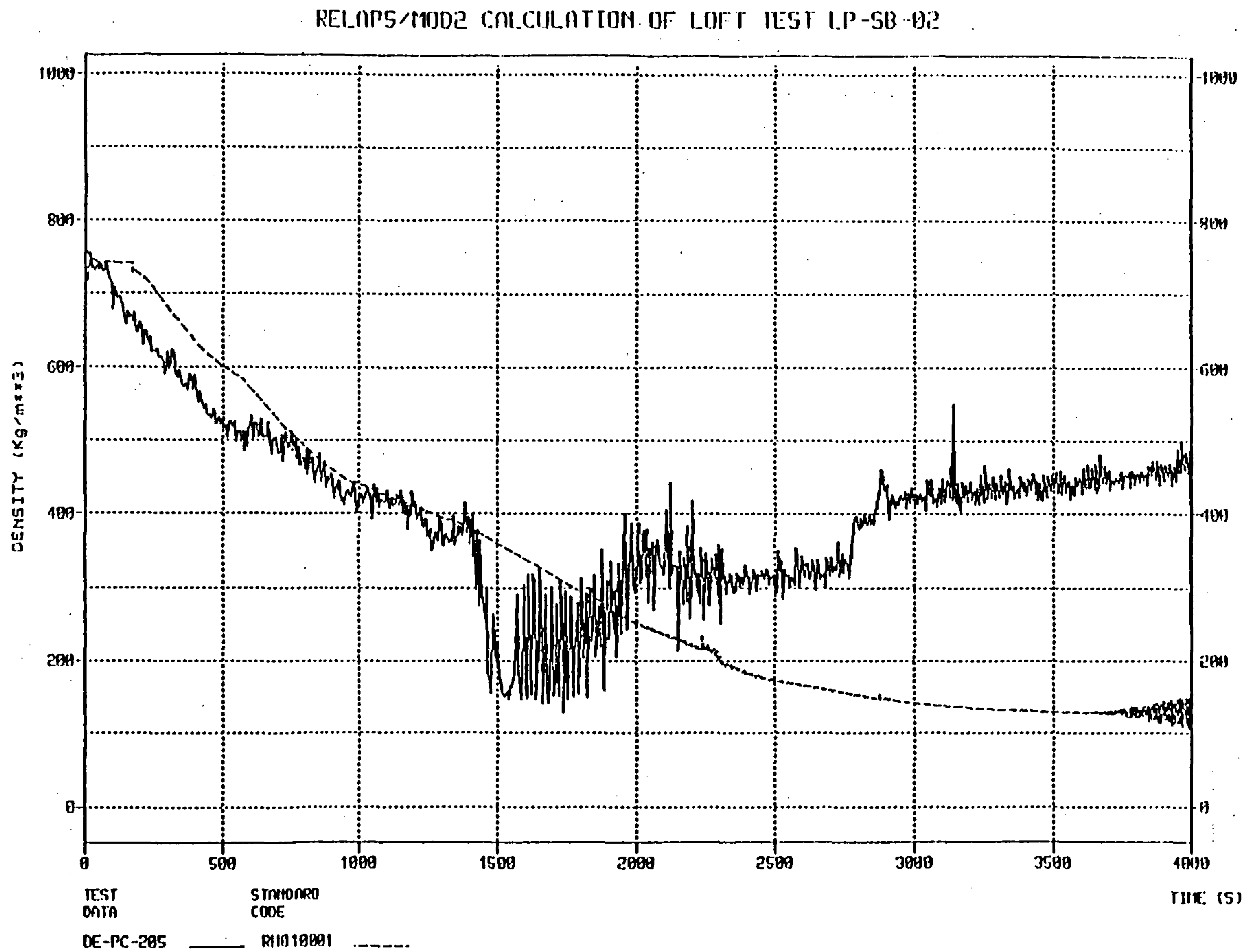
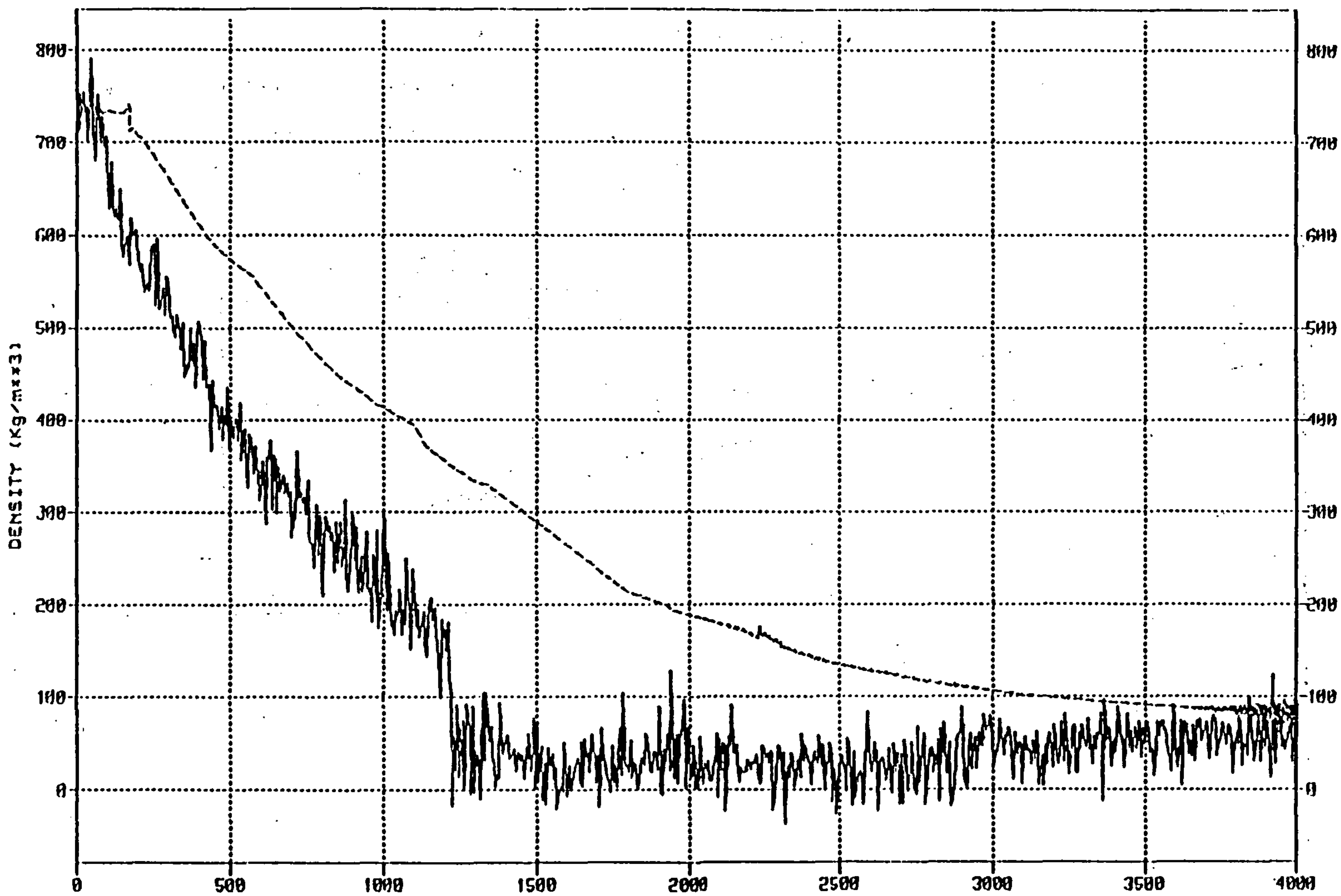


FIGURE 7 : MEASURED AND CALCULATED HOT LEG DENSITIES

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-SB-02



TEST DATA DE-PC-S048 ———— STANDARD CODE RH010201 - - - - -

FIGURE 8 : MEASURED AND CALCULATED BREAK LINE DENSITIES

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-SB-02

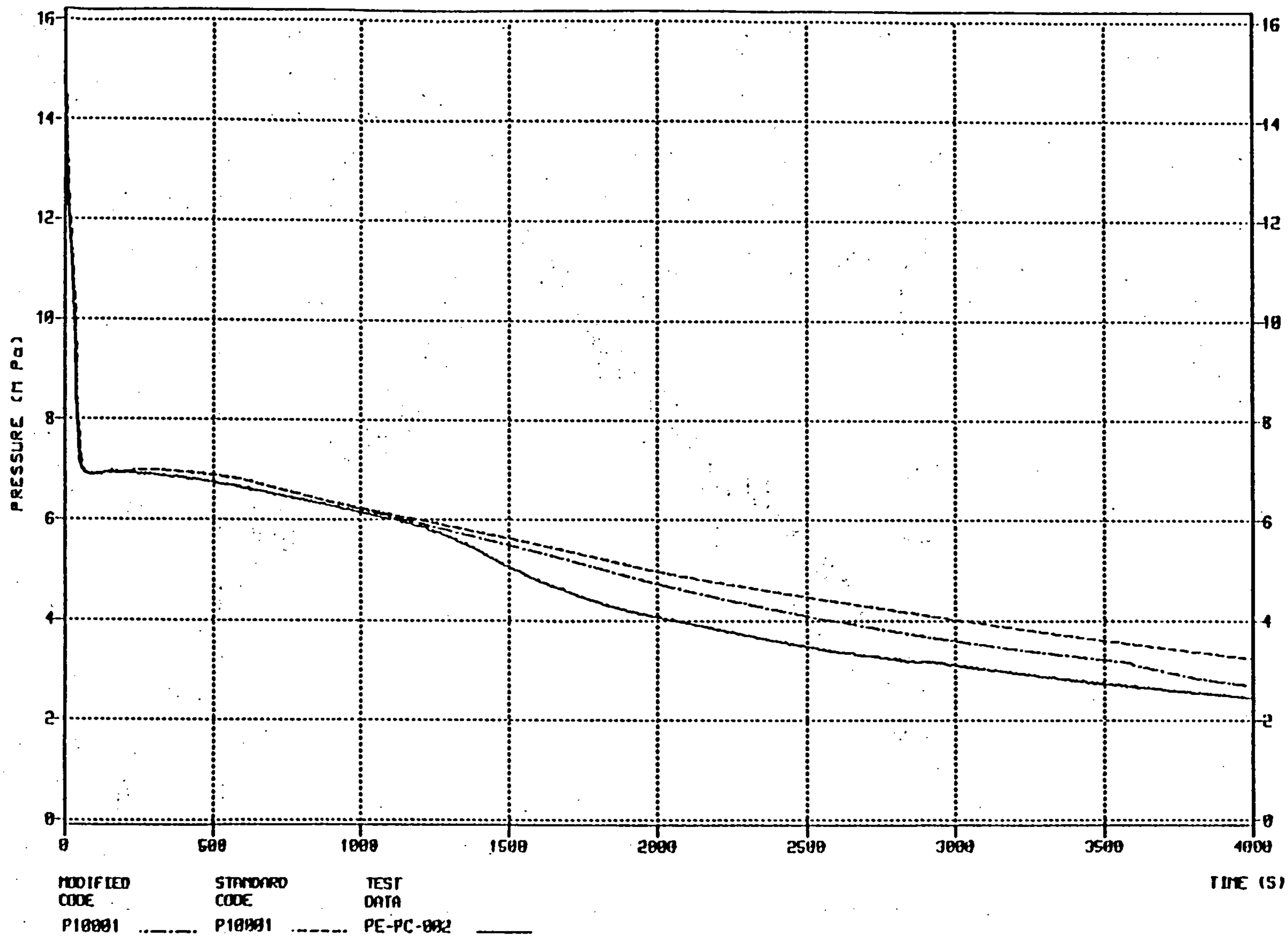


FIGURE 9 : MEASURED AND CALCULATED PRIMARY PRESSURES

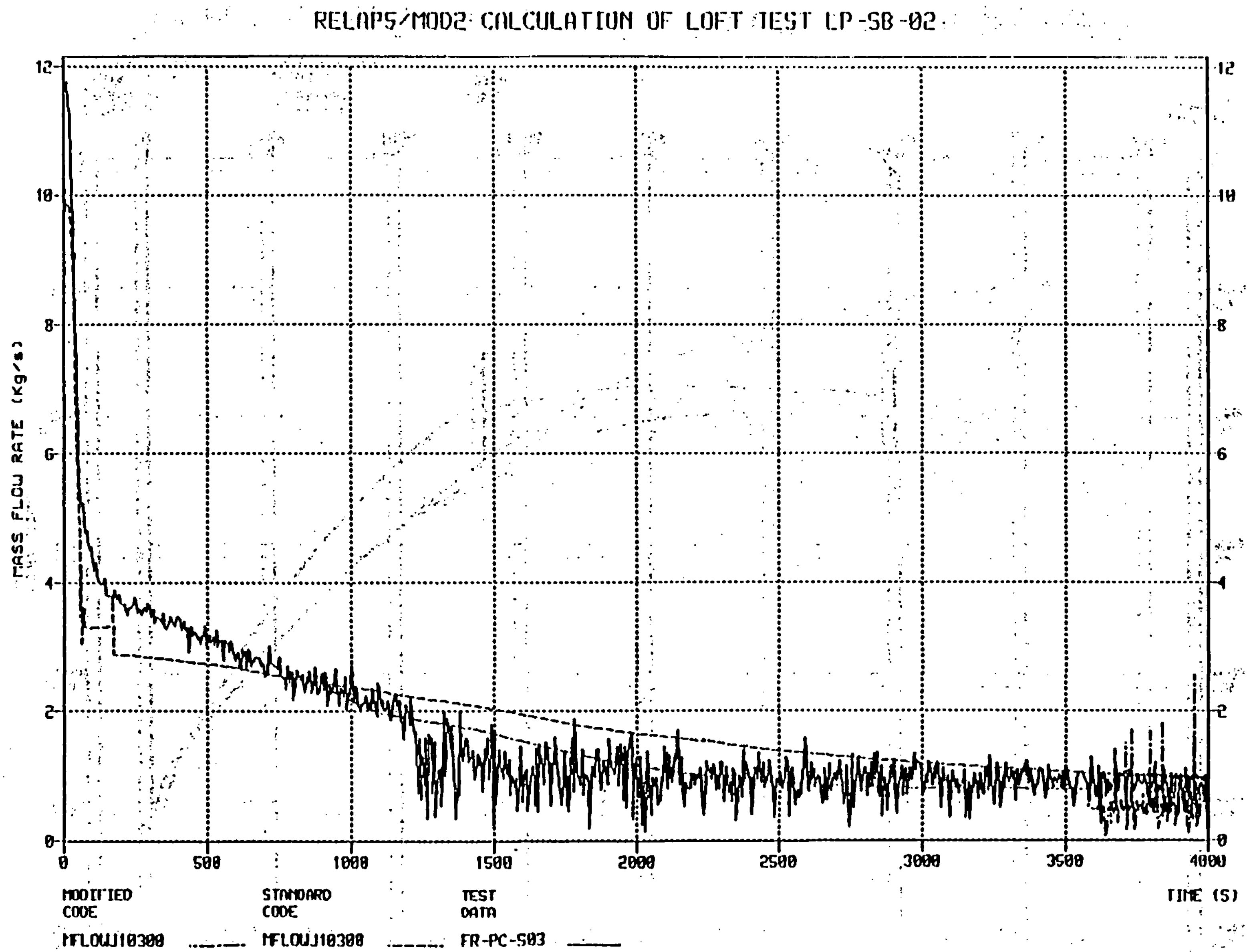


FIGURE 10 : MEASURED AND CALCULATED BREAK FLOW RATES

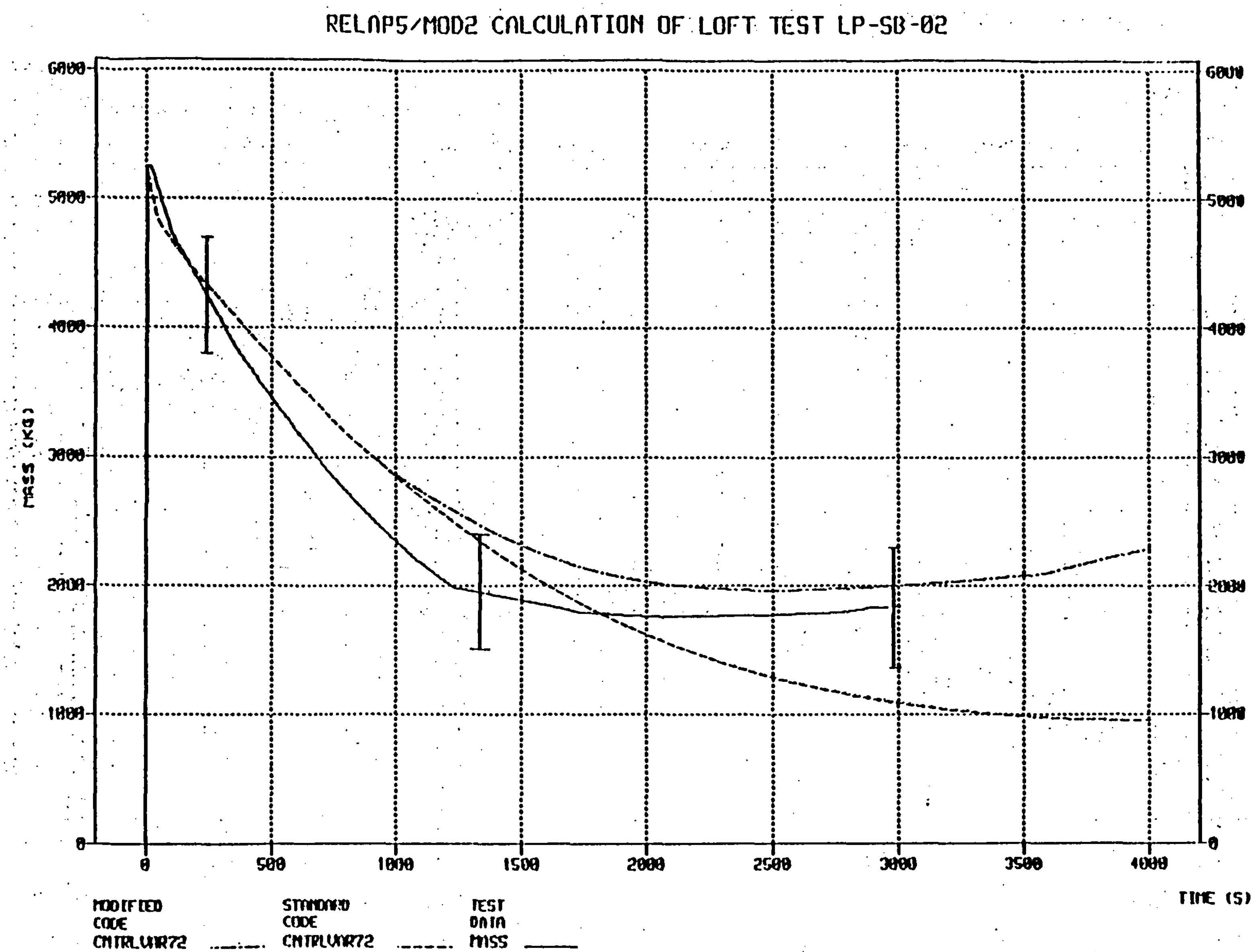


FIGURE 11 : MEASURED AND CALCULATED PRIMARY COOLANT SYSTEM MASS INVENTORY

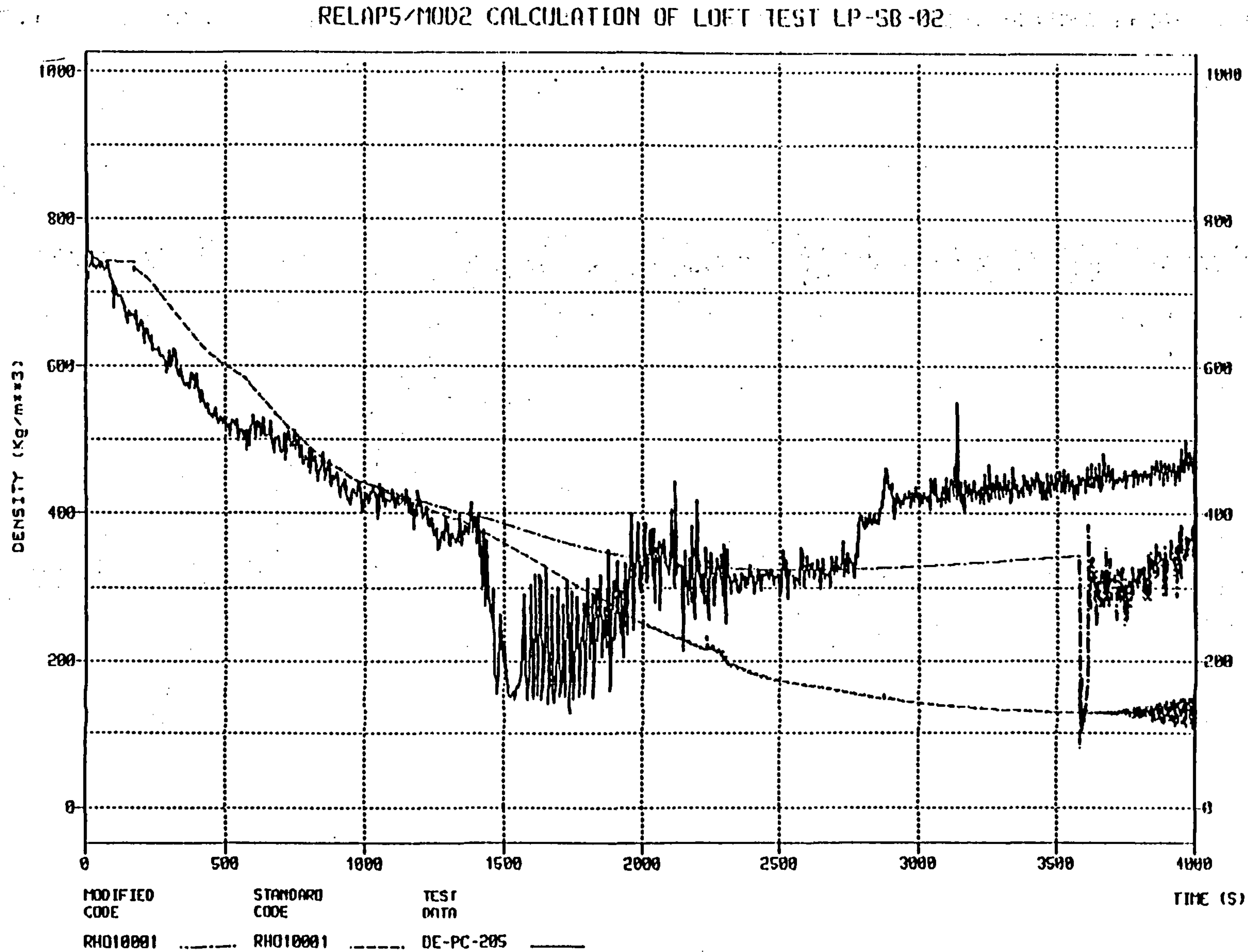


FIGURE 12 : MEASURED AND CALCULATED HOT LEG DENSITIES

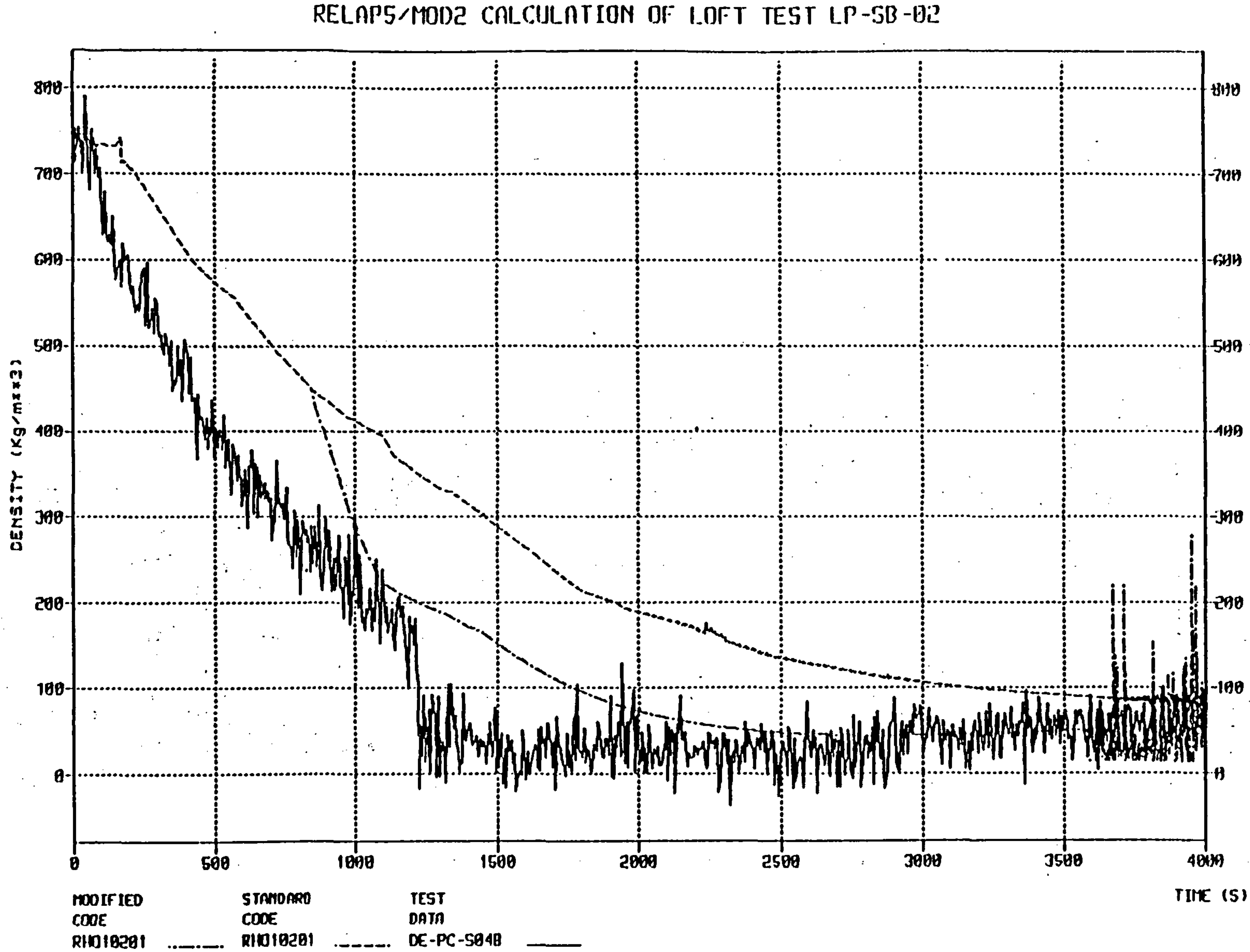


FIGURE 13 : MEASURED AND CALCULATED BREAK LINE DENSITIES

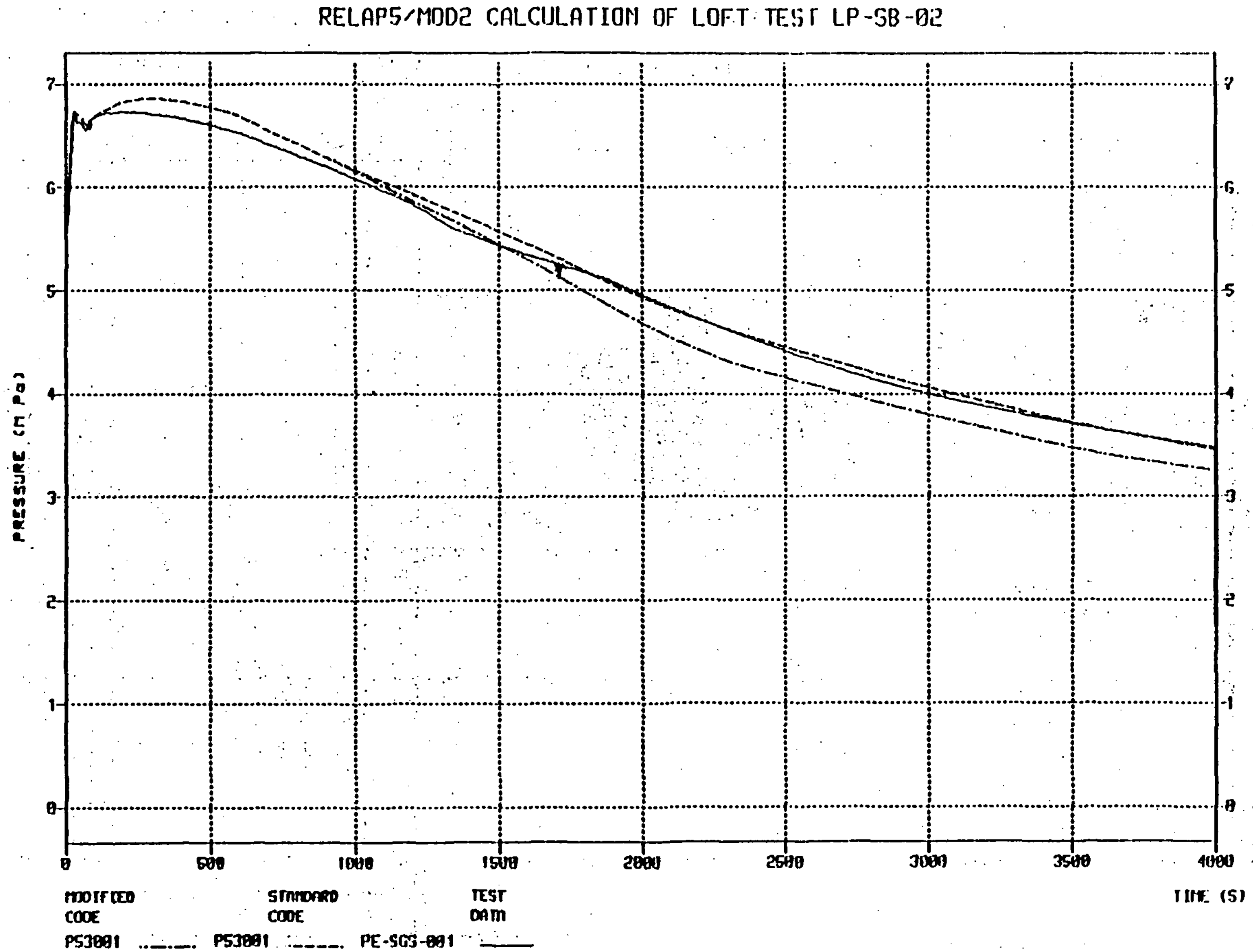


FIGURE 14 : MEASURED AND CALCULATED SECONDARY PRESSURES

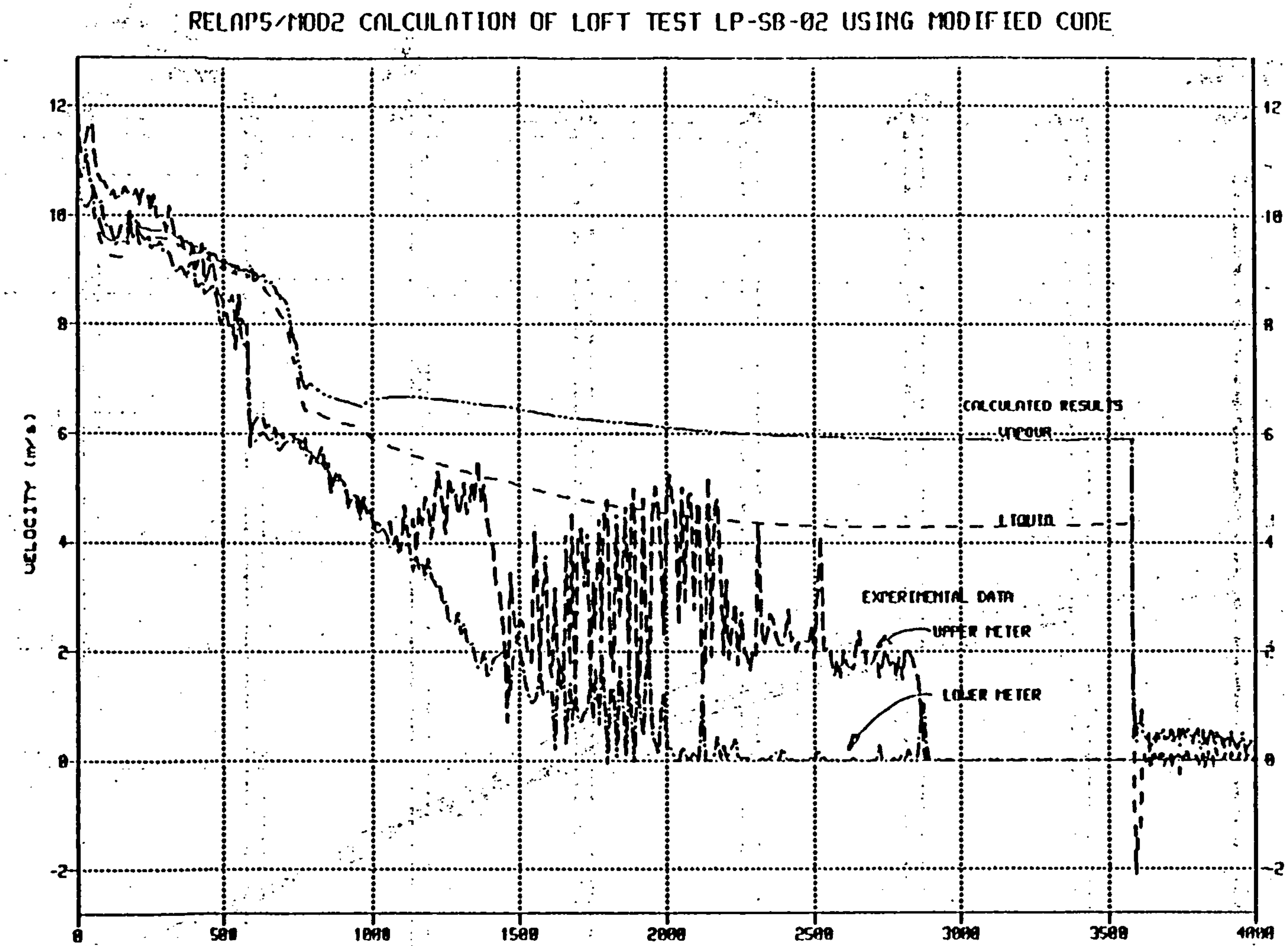


FIGURE 15 : MEASURED AND CALCULATED COOLANT VELOCITIES IN HOT LEG

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-SB-02

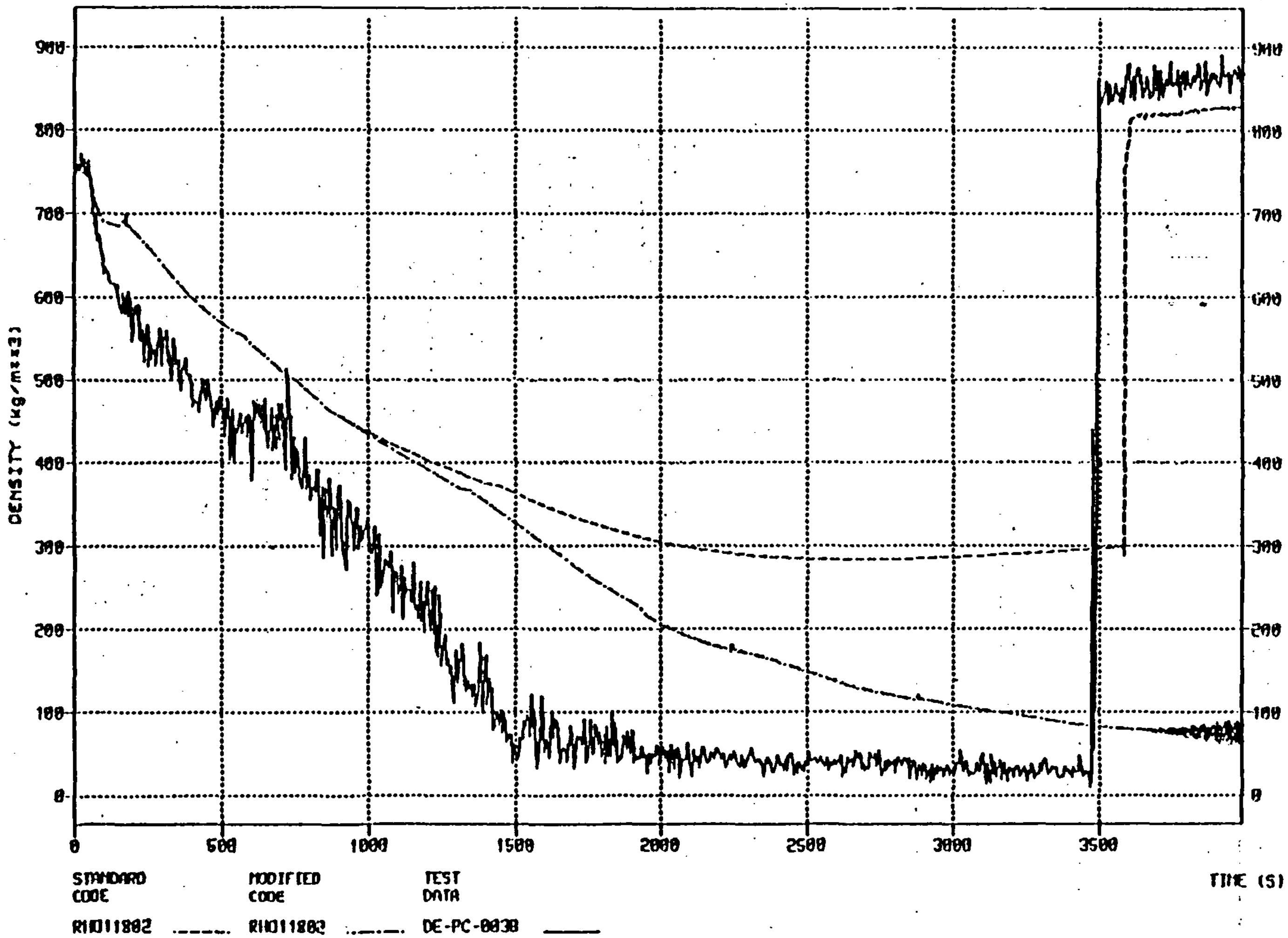


FIGURE 16 : MEASURED AND CALCULATED LOOP SEAL DENSITIES

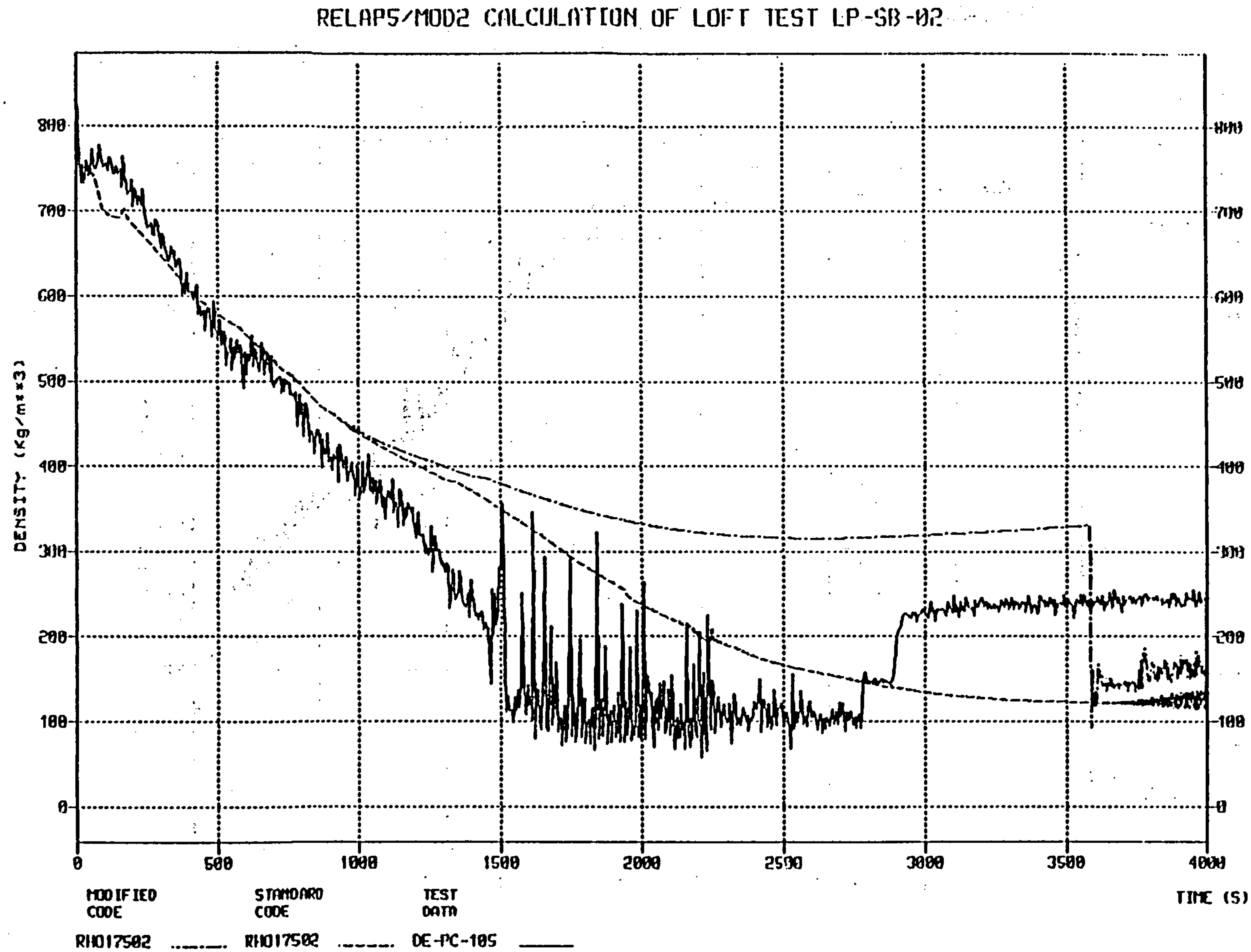


FIGURE 17 : MEASURED AND CALCULATED COLD LEG DENSITIES

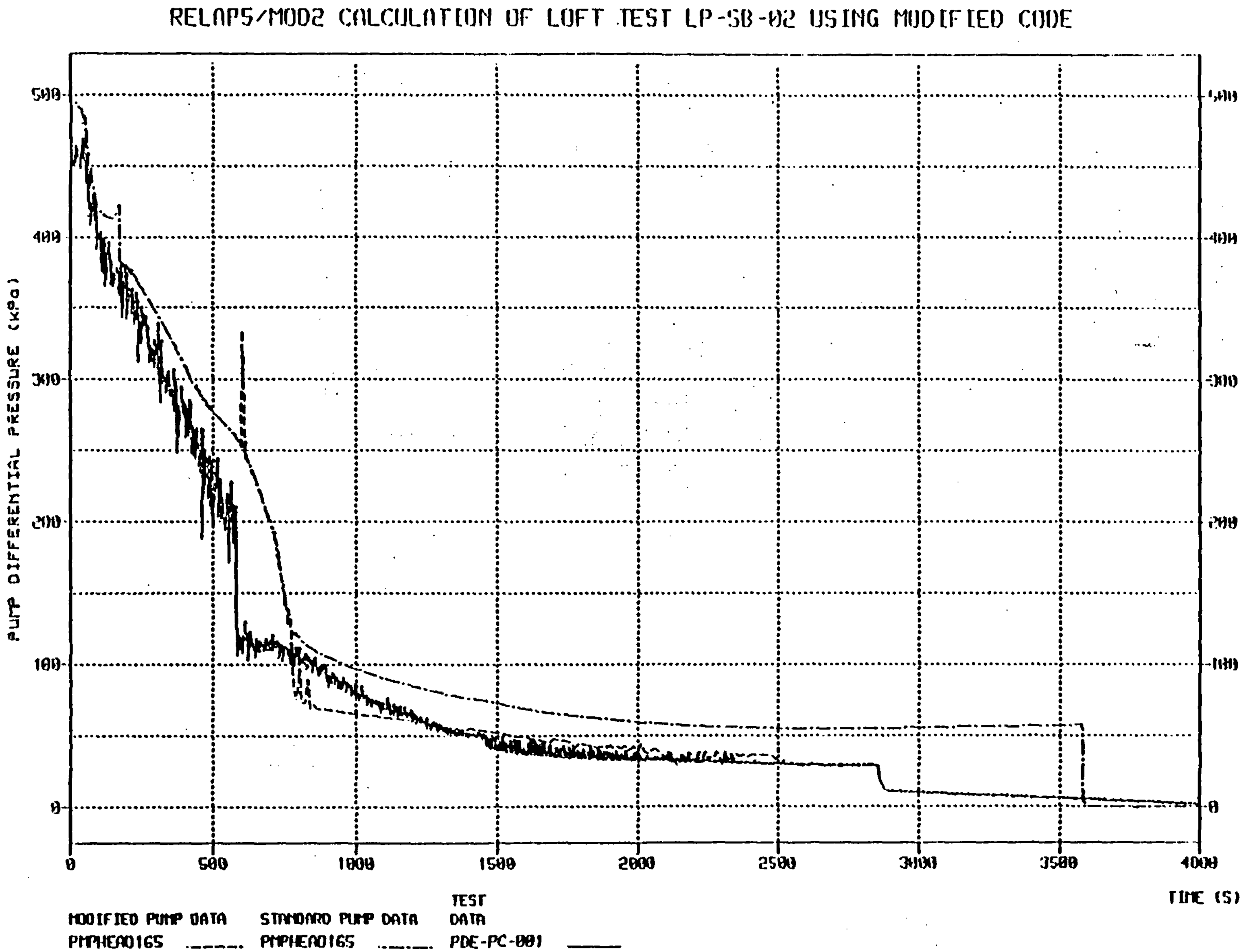


FIGURE A1 : MEASURED AND CALCULATED PUMP DIFFERENTIAL PRESSURES

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-SB-02 USING MODIFIED CODE

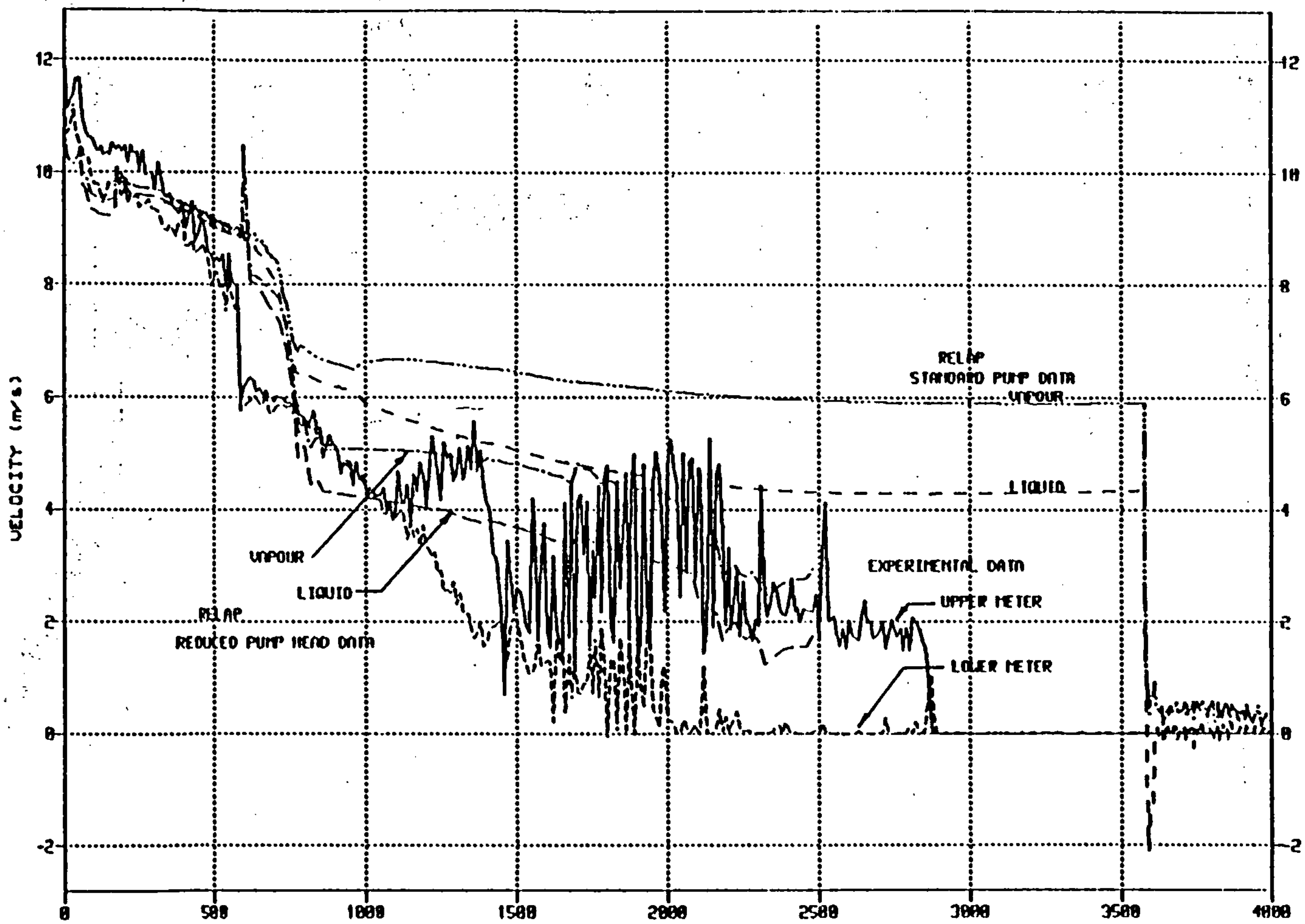


FIGURE A2 : MEASURED AND CALCULATED COOLANT VELOCITIES IN HOT LEG

RELAP5/MOD2 CALCULATION OF LOFT TEST LP-SB-02 USING MODIFIED CODE

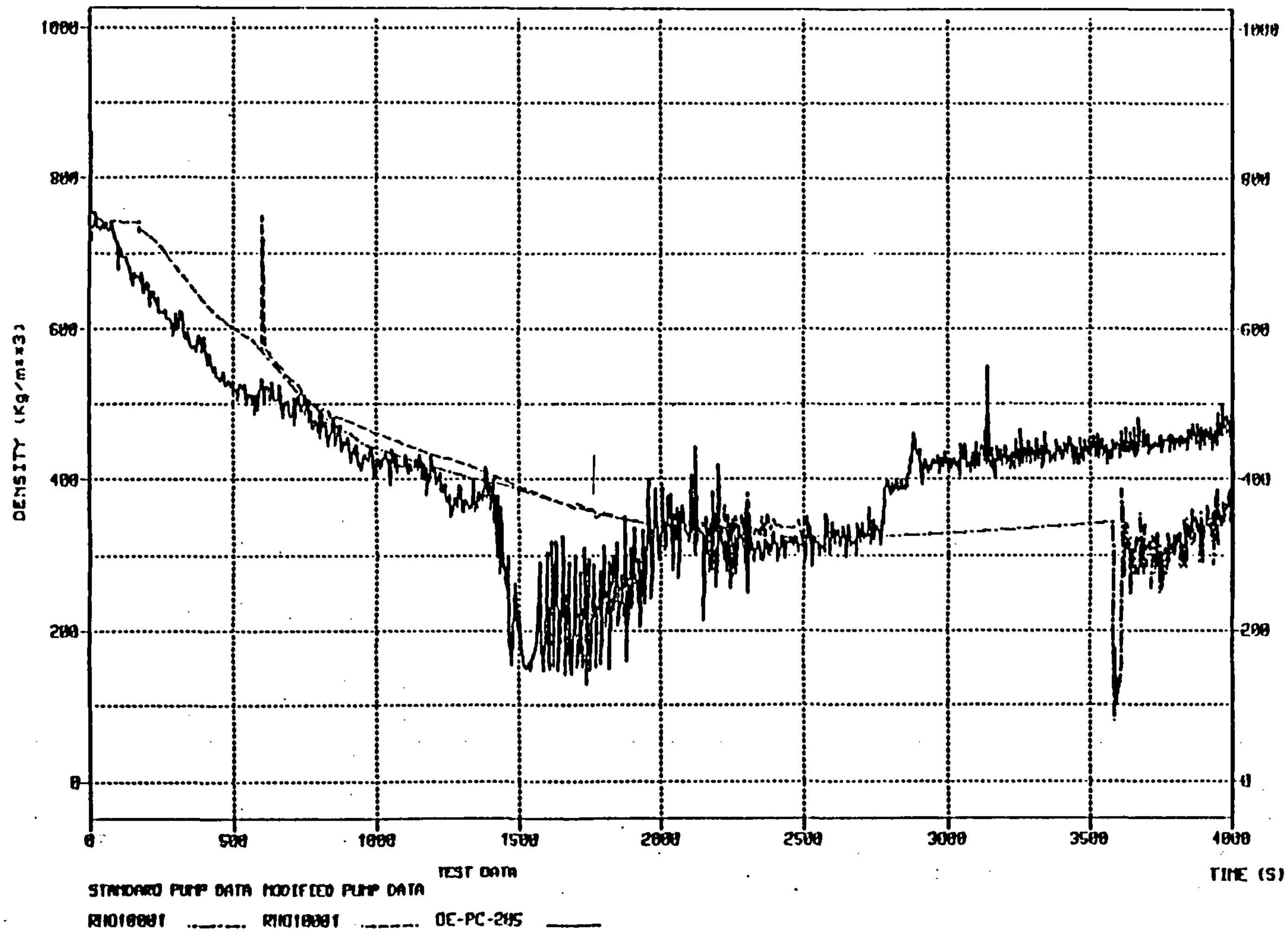


FIGURE A3 : MEASURED AND CALCULATED HOT LEG DENSITIES

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11. ABSTRACT (200 words or less)

To help in assessing the capabilities of RELAP5/MOD2 for PWR Fault Analysis, the code is being used by CEGB to simulate several small LOCA and pressurized transient experiments in the LOFT experimental reactor. The present report describes an analysis of small LOCA test LP-SB-02, which simulated a 1% hot leg break LOCA in a PWR, with delayed tripping of the primary coolant pumps. This test was carried out under the OECD LOFT Program.

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