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International Agreement Report

Analysis of Semiscale Test S-LH-2 Using RELAP5/MOD2

Prepared by
P. Brodie, P. C. Hall

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Barnett Way
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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

April 1992

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NATIONAL POWER - NUCLEAR
TECHNOLOGY DIVISION

STATION PERFORMANCE BRANCH

Title: Analysis of Semiscale Test S-LH-2 using RELAP5/MOD2

Author: P. Brodie and P.C. Hall, Analytical Investigation Section

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To assist in validating RELAP5/MOD2 for the above application, the code is being used to model a number of small LOCA and pressurised fault simulation experiments carried out in integral test facilities. The present report describes a RELAP5/MOD2 analysis of the small LOCA test S-LH-2 which was performed on the Semiscale Mod-2C Facility. S-LH-2 simulated a SBLOCA caused by a break in the cold leg pipework of an area equal to 5% of the cold leg flow area. S-LH-2 was identical to the earlier test S-LH-1 except for an increase in the flow area between the upper plenum and the cold leg which resulted in the core bypass flow increasing from 0.9% to 3.0%.

RELAP5/MOD2 gave reasonably accurate predictions of system thermal hydraulic behaviour but failed to calculate the core dryout which occurred due to coolant boil-off prior to accumulator injection. The error is believed due to combinations of errors in calculating the liquid inventory in the core and steam generators, and incorrect modelling of the void fraction gradient within the core.

Task No. G212

Date: August 1989.

Approved: ....
K.H. Ardron,
Head of Analytical Investigation Section

CONTENTS

1. INTRODUCTION

The RELAP5/MOD2 code [1] is being used by National Power Nuclear Technology Division for calculating Small Break Loss of Coolant Accidents (SBLOCA) and pressurised transient sequences for the Sizewell 'B' PWR. These calculations are being carried out at the request of the Sizewell 'B' Project Management Team and Health and Safety Department.

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2. CODE VERSION AND INPUT MODEL

The code version used for these calculations was the same as used for the ref. [2] analysis (RELAP5/MOD2/cycle 36.05 EO3).

The RELAP5/MOD2 model was also the same as that used in ref [2] except for the loss coefficient for the core bypass junction which was reduced from 2.57 to 0.125. This was found to give the correct bypass flow ratio (3%) in the initial steady state.

3. INITIAL AND BOUNDARY CONDITIONS

The initial and boundary conditions for the present calculations were taken from reference [3]. To establish the required steady state conditions a steady state calculation was first run for 300s of problem time. The control systems used to achieve steady state were identical to those used in the S-LH-1 calculations, though the steady state conditions differed slightly from those detailed in reference [2]. After 300s the dummy volumes and control systems were deleted. The calculation was then allowed to proceed for 50s as a 'null transient' before the transient was initiated, to ensure that an acceptable initial steady state had been achieved.

Figures 1 - 3 show the hot leg pressure and pressuriser level, the flows into and out of the intact loop steam generator (SG) separator, and the intact loop SG pressure and level during the steady state run. These figures indicate that a satisfactory steady state was reached. The steady state conditions are compared with experimental data, obtained from reference [3], in Table 1.

As with test S-LH-1 the intact loop SG secondary side level had to be set artificially low to allow RELAP5 to calculate stable operation of the SG. All other steady state conditions were satisfactorily calculated, however.

4. DESCRIPTION OF TEST S-LH-2

The experimental transient was similar to that occurring in test S-LH-1, which is described in detail in reference [2].

Calculations are in fairly good agreement with data and the core level depression at about 200s, which occurs because of manometric effects is predicted. In test S-LH-2 the increased core bypass flow resulted in a manometric level depression which was much less severe than seen in test S-LH-1. Consequently the severe core level depression which ocurred at about 200s in S-LH-1 did not take place in S-LH-2 and RELAP5 correctly identified this effect. As in the simulation of test S-LH-1, accumulator injection was calculated too early in S-LH-2 analysis. Therefore the minimum core inventory in the boil-off phase (350s onwards) was again noticeably overestimated.

Calculated axial variations in core void fractions are shown in figure 12. As in the S-LH-1 calculations the core dry-out that occurs in the test at around 500s is not predicted. Again, as in the S-LH-1 case, failure to predict the dry-out appears to be due to a combination of the over-prediction of the liquid inventory in the core, and the calculation of an unrealistic core void fraction distribution.

Figure 13 compares the measured and calculated heater rod temperatures in the core, close to the 250cm elevation. It is seen that as discussed above RELAP5 fails to calculate the rod heat-up associated with core uncovery in the period 525 - 610s.

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The main difference between the S-LH-1 and S-LH-2 transients is the pump suction clearing behaviour. The experimental trends in both tests are captured surprisingly well by RELAP5/MOD2. As a result of differences in the loop seal behaviour, the core level depression due to manometric effects is much more severe in S-LH-1 than in S-LH-2. The minimum core inventory in the manometric depression phase is in both cases calculated accurately by RELAP5.

In both S-LH-1 and S-LH-2 the loop seal clearance was followed by a slow coolant boil-off phase in which core uncovery and dry-out occurred. In both cases RELAP5 failed to calculate the fuel dry out in this phase. This discrepancy is believed due to a combination of over-prediction of the core liquid inventory, and errors in modelling the void fraction distribution in the core. It was noted in ref. [2] that calculation of the core level trajectory in such cases is likely to be unreliable in RELAP5 simulations, in which the core is represented by a small number of nodes. It was recommended therein that the level trajectory calculation would be best performed with a separate code using a fine axial mesh, taking boundary conditions from the RELAP5 calculation. Development of such a model is now under way [4]

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As with the S-LH-1 analysis calculations were performed on the Cray-2 computer at the Atomic Energy Research Establishment (AERE), Harwell. 1516 seconds of CPU time were used to calculate 600 seconds of transient, giving a CPU : Real time ratio of 2.53 : 1.

1. INTRODUCTION

The RELAP5/MOD2 code [1] is being used by National Power Nuclear Technology Division for calculating Small Break Loss of Coolant Accidents (SBLOCA) and pressurised transient sequences for the Sizewell 'B' PWR. These calculations are being carried out at the request of the Sizewell 'B' Project Management Team and Health and Safety Department.

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The experimental transient was similar to that occurring in test S-LH-1, which is described in detail in reference [2].

Briefly, upon initiation of the transient, a block valve off the cold leg was opened to simulate a break, core power was reduced to represent decay heating, the feed water and main steam control valves (MSCV) closed and the primary circulating pumps were tripped. The sequence of events is given in Table 2. As can be seen there is much similarity with test S-LH-1.

The main difference between the S-LH-1 and S-LH-2 tests was that the manometric imbalance in the pump suction legs did not produce a liquid level depression below the top of the heated core, prior to loop seal clearance, and therefore no early core dry-out occurred. Early dry-out did occur in S-LH-1. This difference was a consequence of the larger by-pass flow in S-LH-2 which acted to prevent a differential pressure developing between the top of the core and the cold legs.

The slow reduction in core liquid level due to coolant boil-off observed in S-LH-1 after pump suction clearance was, however, also observed in S-LH-2. Again this resulted in a core dry-out which commenced at about 525s and was terminated at about 620s, approximately 50s after initiation of accumulator injection.

5. DESCRIPTION OF RELAP5/MOD2 CALCULATION

The calculated timing of key events is compared with the experimental data in Table 2.

The measured and calculated primary system pressures are shown in Figure 4. As with the calculated S-LH-1 in ref [2] the calculation is accurate up to 50s, after which there is a small systematic over-prediction of pressure until loop seal clearance. After loop seal clearance the calculated depressurisation is too rapid, indicating a possible overestimation of the break discharge enthalpy. Accumulator injection pressure set point is reached at 500s in the calculation, approximately 75s earlier than the experiment.

The secondary side pressures are compared in Figure 5. Secondary side pressures are over predicted at all times after the closure of the MSCVs, as found in the S-LH-1 calculation. These errors are thought to have only a minor effect on the calculations.

The measured and calculated break flow rates are compared in Figure 6. Periods of underestimation (45 - 140s) and overestimation (230 - 280s) are evident. Overall, however, as in the ref [2] analysis, the mean flow rate through the break is reasonably accurately calculated.

Figures 7, 8, 9 and 10 compare the measured and calculated collapsed liquid level in the intact loop and broken loop SG U-tubes and pump suction legs. Trends in calculations and the test data are similar to those described in ref [2].

The larger bypass flow in test S-LH-2 compared with S-LH-1 resulted in later clearance of the intact loop pump suction leg, and failure of the broken loop pump suction leg to clear at all. RELAP5 correctly predicted both of these effects. The late prediction of clearance of the intact loop (250s c.f 204s) was due to errors in the calculated discharge flow rate noted above.

In figure 11 calculated collapsed liquid levels in the downcomer and core are compared with experimental data. (Note that the experimental data, which are derived from pressure differential values, are invalid until the termination of forced loop flow at about 50s).

Calculations are in fairly good agreement with data and the core level depression at about 200s, which occurs because of manometric effects is predicted. In test S-LH-2 the increased core bypass flow resulted in a manometric level depression which was much less severe than seen in test S-LH-1. Consequently the severe core level depression which ocurred at about 200s in S-LH-1 did not take place in S-LH-2 and RELAP5 correctly identified this effect. As in the simulation of test S-LH-1, accumulator injection was calculated too early in the S-LH-2 analysis. Therefore the minimum core inventory in the boil off phase (350s onwards) was again noticeably overestimated.

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8. CONCLUSIONS

1. RELAP5/MOD2 cycle 36.05 Version E03 has been used to analyse test S-LH-2 (5% cold leg break loss of coolant accident simulation) carried out in the Semiscale PWR test facility.

2. RELAP5/MOD2 gave reasonably accurate predictions of system thermal hydraulic behaviour but failed to calculate the core dry out which occurred due to coolant boil off prior to accumulator injection. This failure is believed to be due to a combination of errors in calculating the liquid inventory in the core and steam generators, and incorrect modelling of the void fraction gradient within the core.

3. The need for a code to calculate core mixture level trajectory, taking boundary conditions from RELAP5/MOD2, has been confirmed.

9. REFERENCES

1.	NUREG/CR-4312	RELAP5/MOD2 Code Manual Volumes 1 and 2 V.H. Ransom et al.	December 1985
2.	GD/PE-N/725 Report	Analysis of Semiscale Test S-LH-1 Using RELAP5/MOD2 P.C. Hall and D.R. Bull	February 1989
3.	NUREG/CR-4438	Results of Semiscale Mod-2C Small Break (5%) LOCA Experiments S-LH-1, S-LH-2. G.G. Loomis, J.E. Streit	November 1985
4.	CISD/CC/N1042	A Quality Plan for RELPIN G. Ahmed	March 1989

TABLE 1

INITIAL CONDITIONS FOR S-LH-2

	UNITS	EXPERIMENT	RELAP5
[illegible] pressure	MPa	15.42	15.42
[illegible]	kW	2007.09	2007.09
Core temperature rise	K	37.17	38.4
Pressuriser liquid level (collapsed above bottom)	cm	393	393
Cold leg fluid temperatures	K		
Intact loop		561.9	560.8
Broken loop		564.4	563.1
Primary flow rate	kgs^{-1}		
Intact loop		7.37	7.37
Broken loop		1.99	1.99
Initial bypass flow (% of total core flow)		3.0	3.0
Leak rate	kgs^{-1}	[illegible]	0.0
SG secondary pressure	MPa		
Intact loop		5.70	5.74
Broken loop		5.95	6.10
SG secondary side mass	kg		
Intact loop		191	150*
Broken loop		48.2	48.21

* Approaching limit of stable operation of steam generator by RELAP5

TABLE 2

TIMING OF EVENTS FOR S-LH-2

EVENT	TIME AFTER BREAK OPENS (s) EXPERIMENT	RELAP5
Small break valve opened	0.0	0.0
Pressuriser pressure reaches trip level (12.6MPa)	15.91	17.6
Pump coast down initiated		
Intact loop	20.65	22.0
Broken loop	20.65	22.0
HPIS initiated		
Intact loop	41.6	42.4
Broken loop	41.6	42.4
Pressuriser empty	34.8	53.0
Minimum core collapsed liquid level	204.35	250
Pump suction clearing		
Intact loop	205.4	255
Broken loop	Did not clear	Did not clear
Core dry out	600	Did not dry out
Accumulator flow initiated		
Intact loop	575.0	500
Broken loop	Not initiated	500

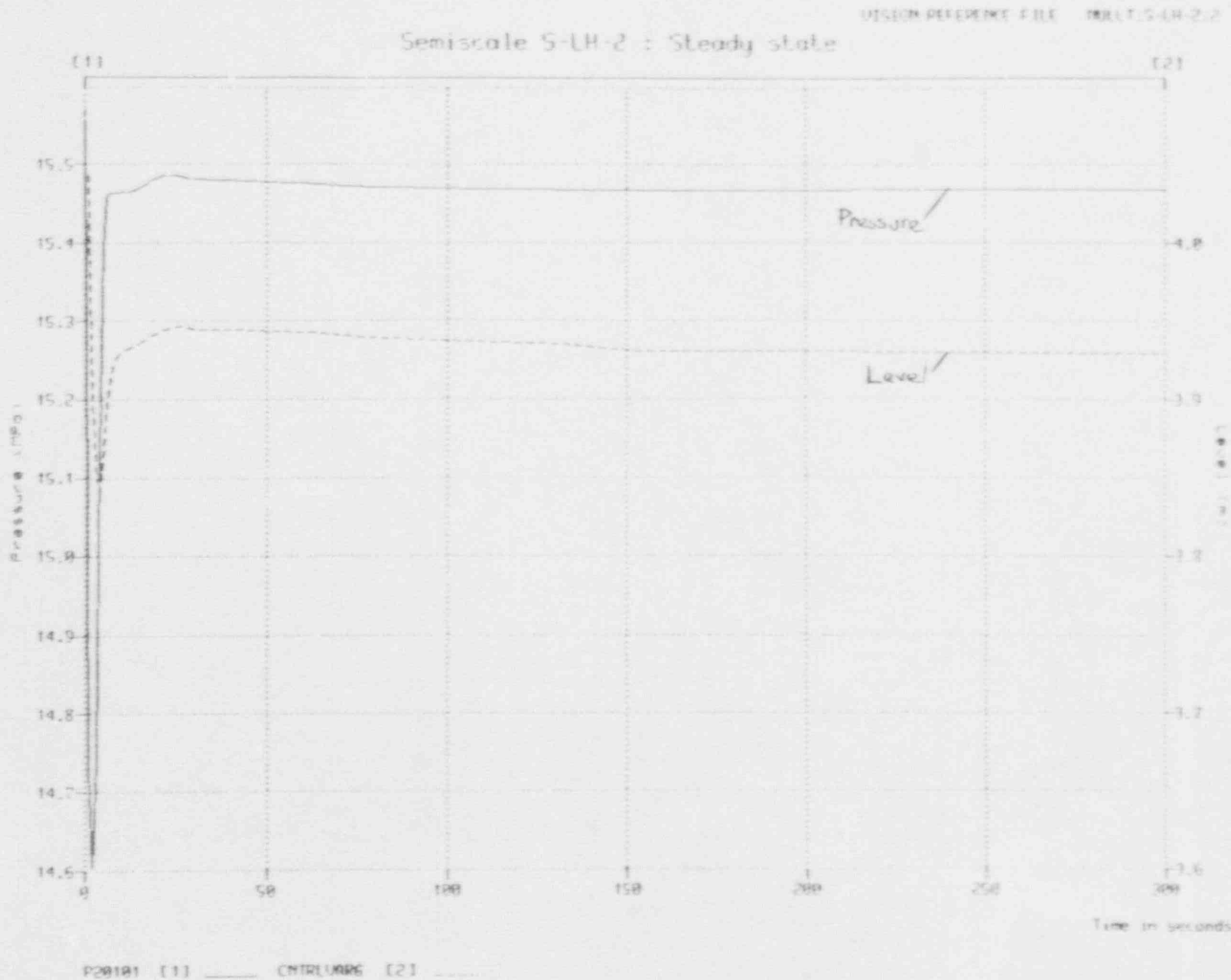

Figure 1:Hot leg pressure and pressuriser level

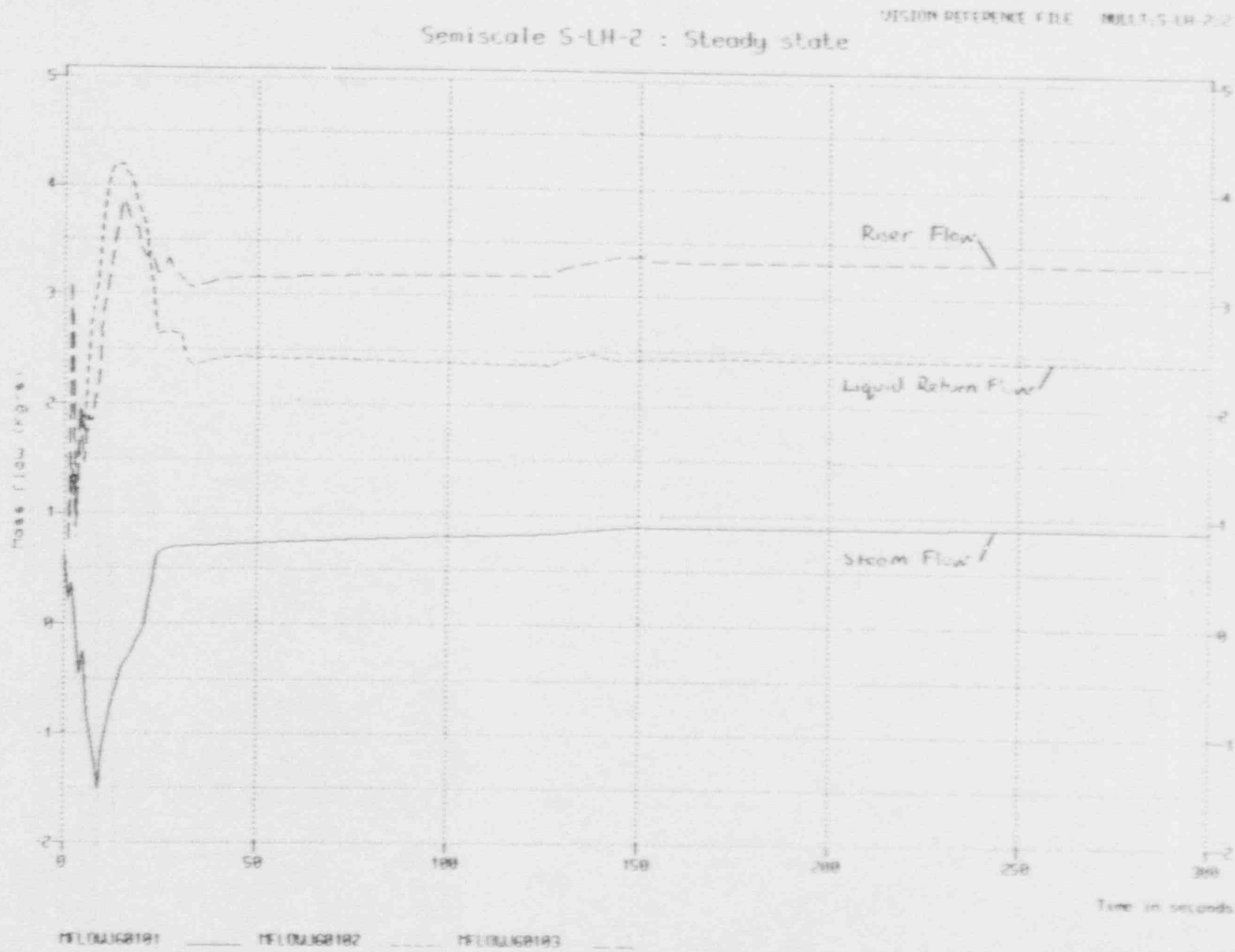

Figure 2:II Steam generator mass flow rates

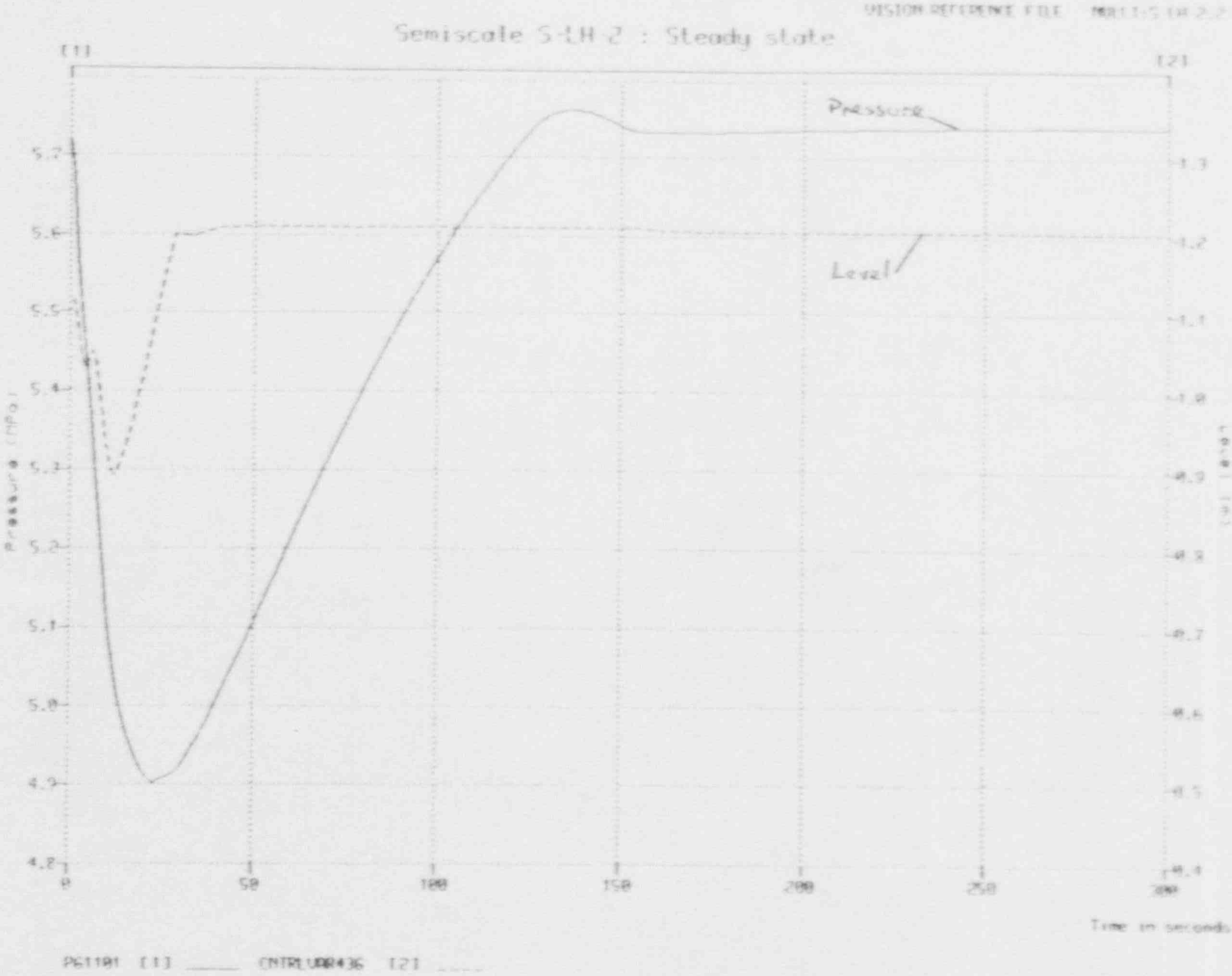

Figure 3:IL Steam generator pressure and collapsed liquid level

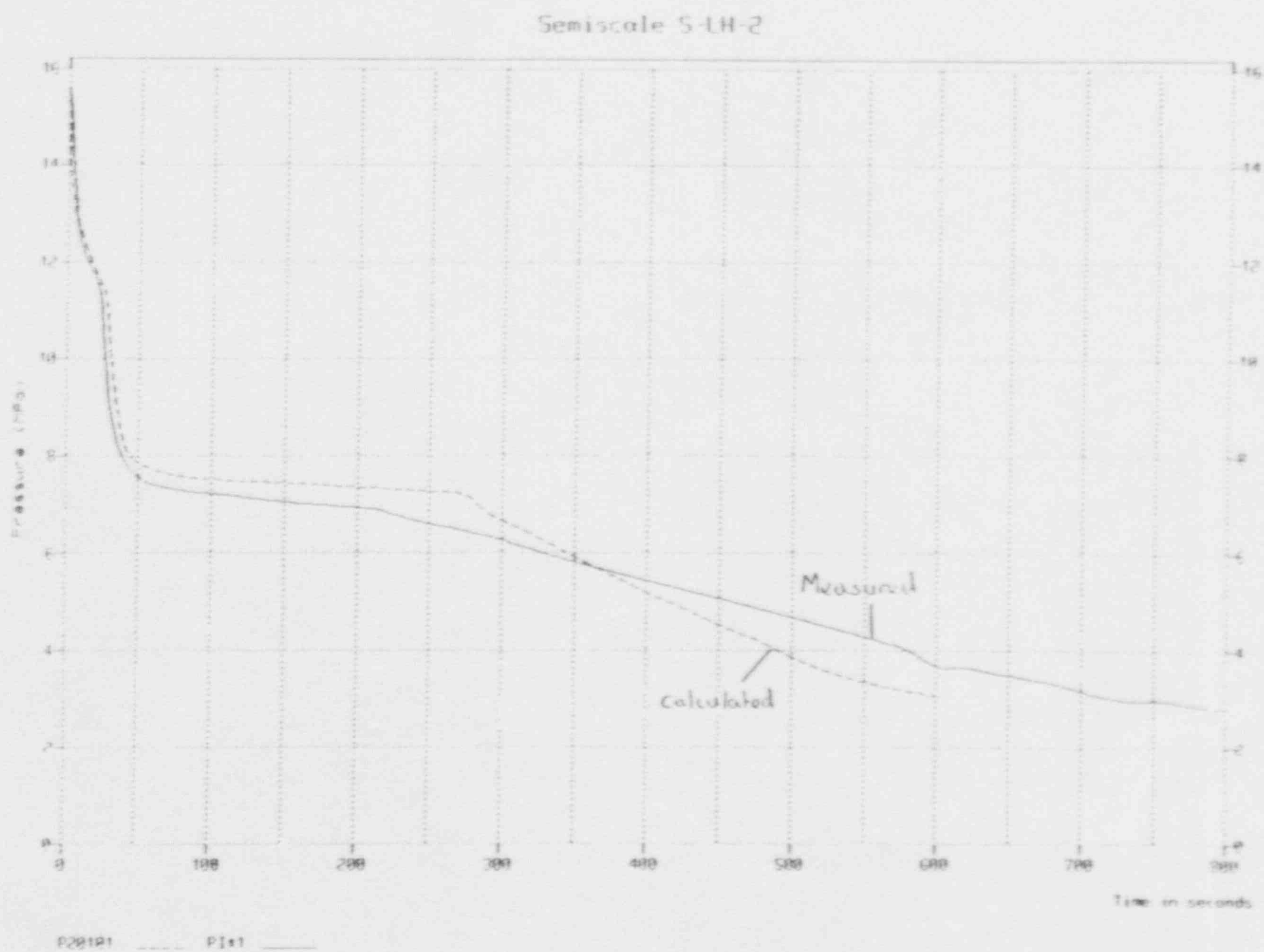

Figure 4:Measured and calculated primary pressure

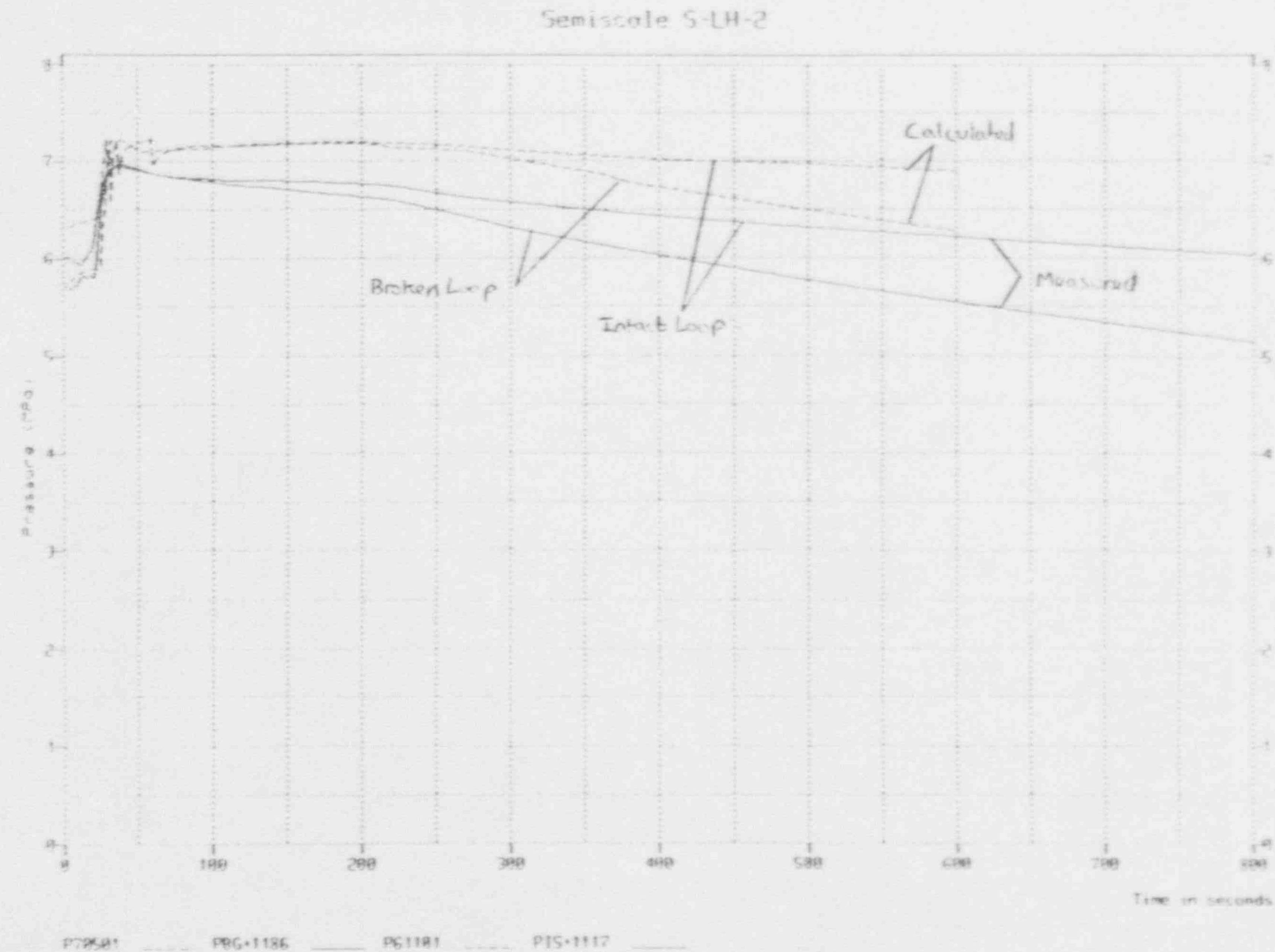

Figure 5:Measured and calculated secondary pressures

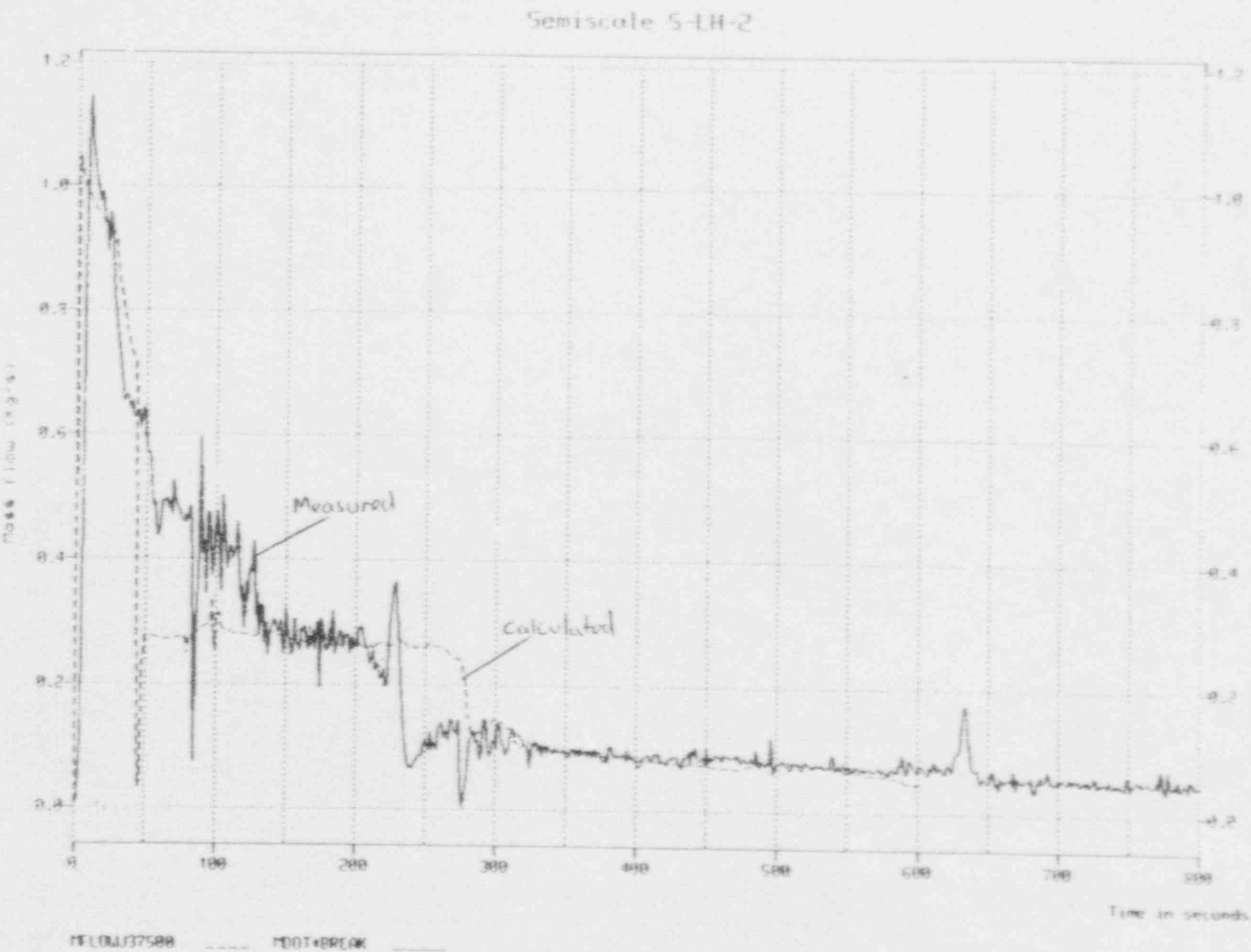

Figure 6: Measured and calculated break flow

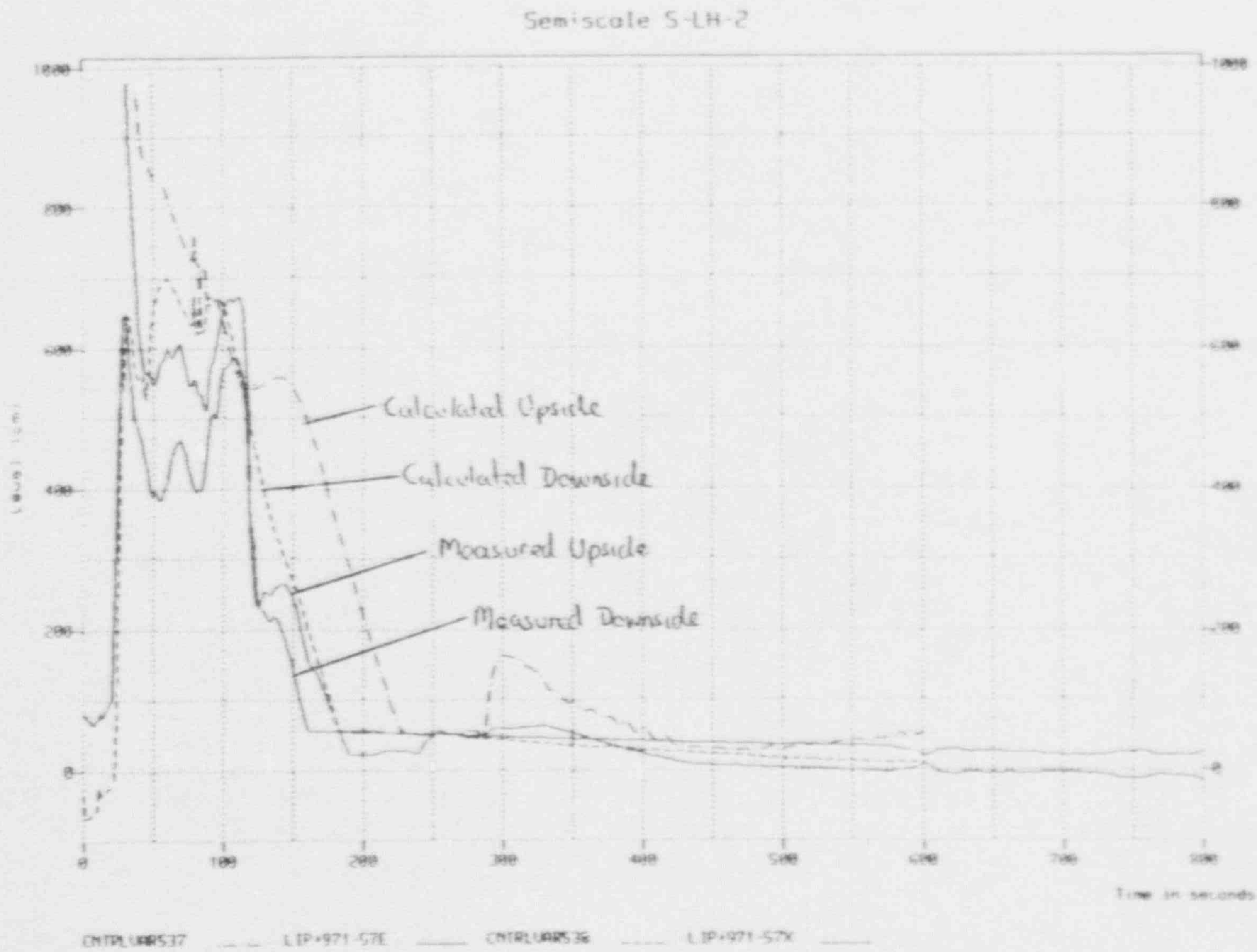

Figure 7:Collapsed liquid level in IL U-tubes

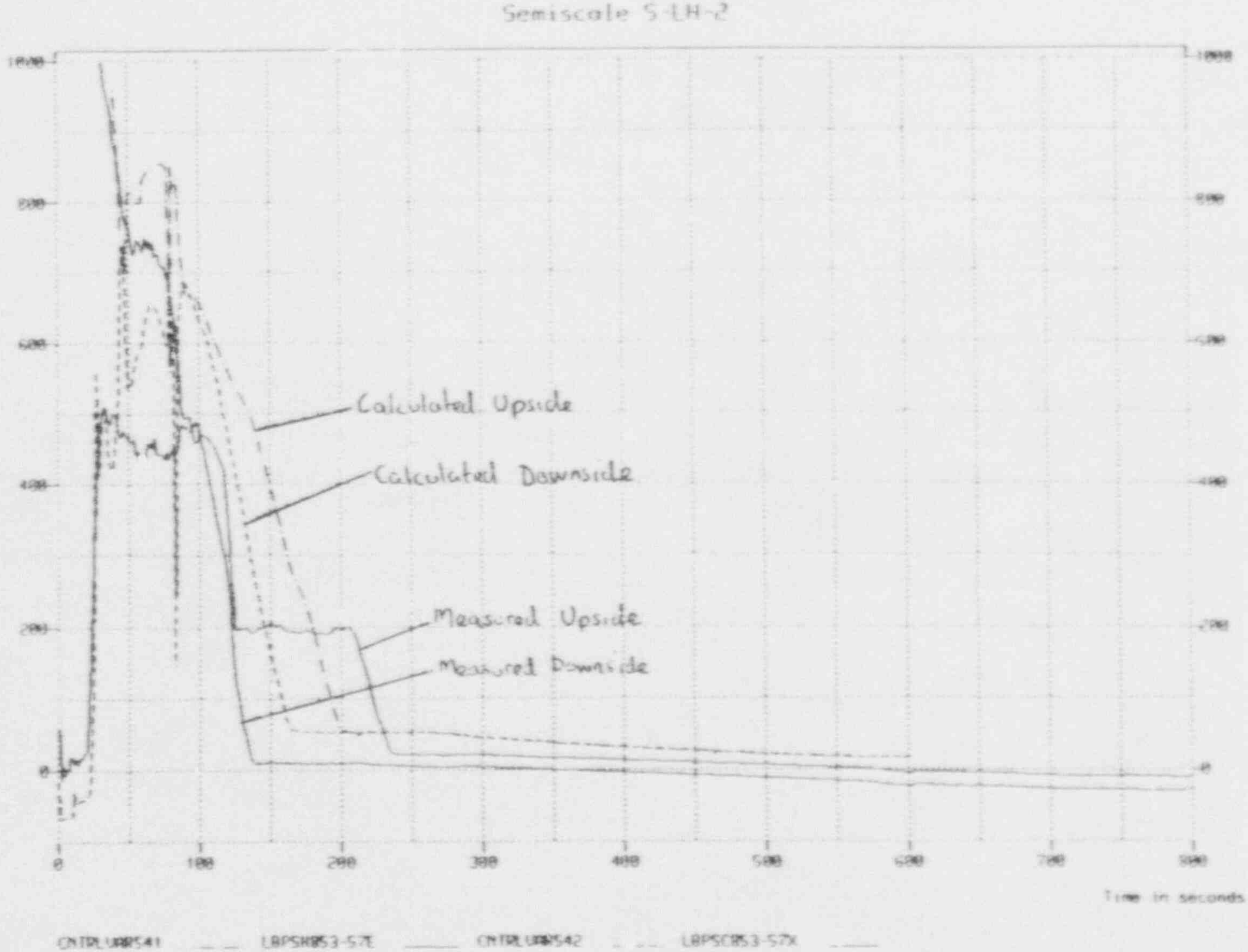

Figure 8:Collapsed liquid level in BL U-tubes

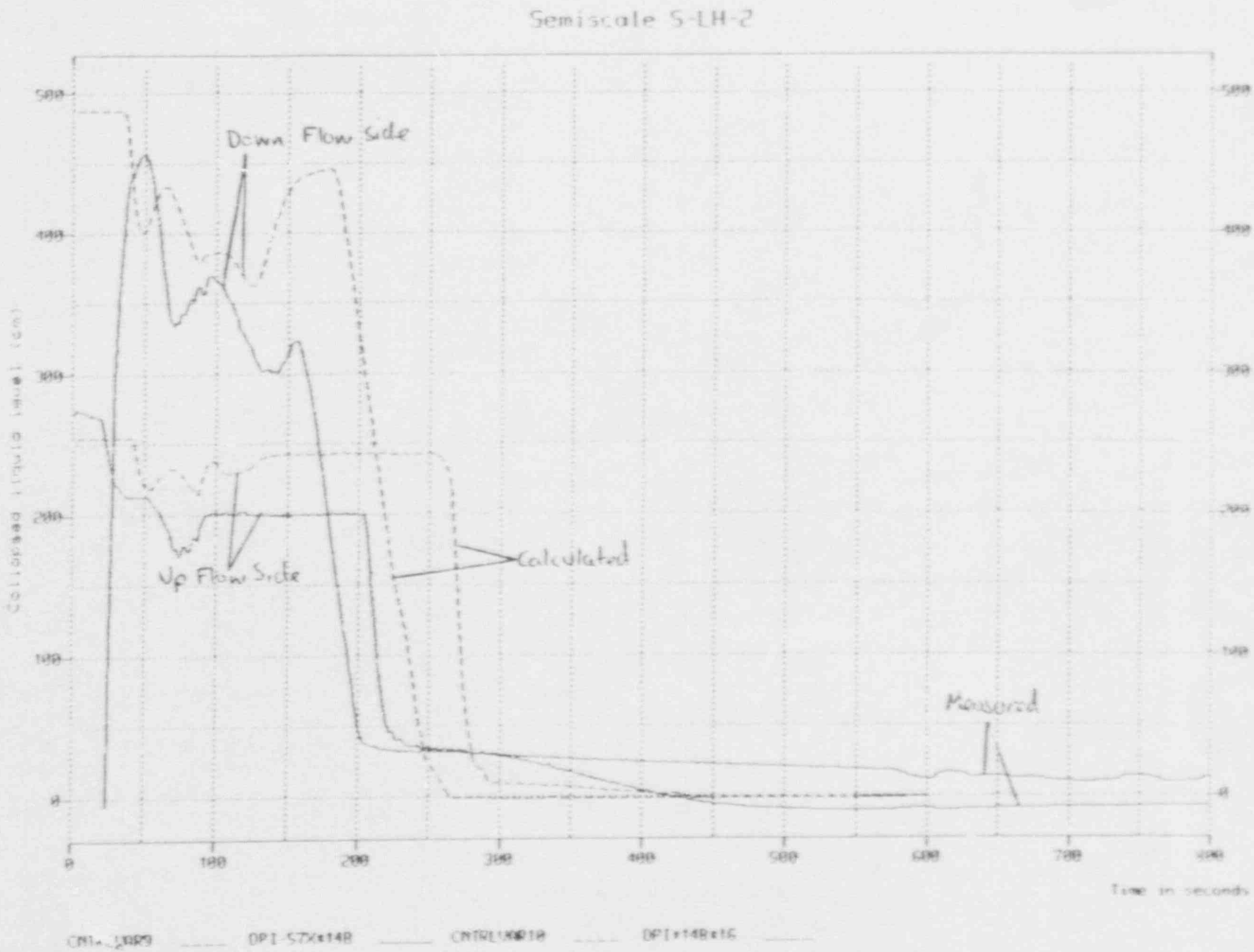

Figure 9: Measured and calculated IL pump suction collapsed liquid level

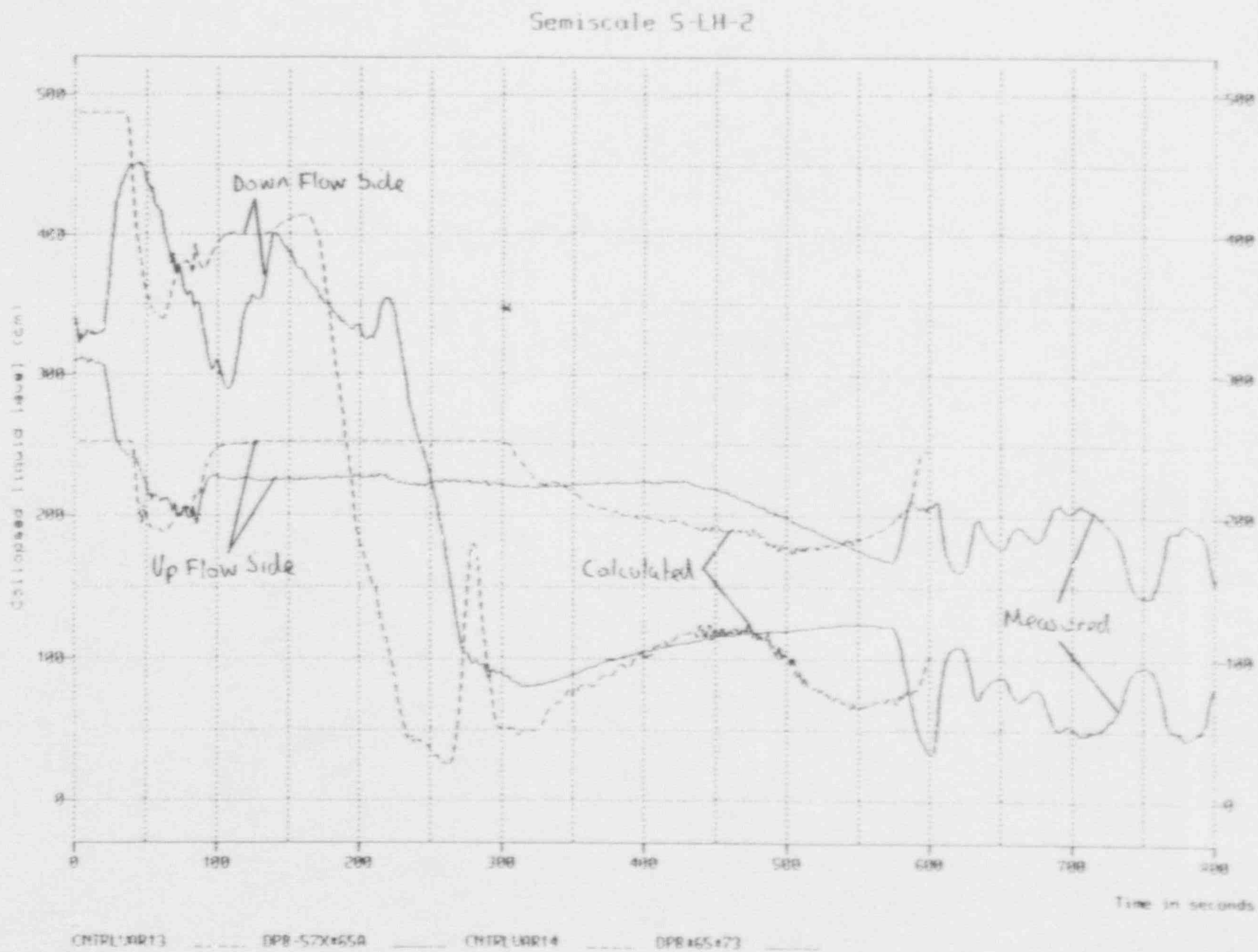

Figure 10: Measured and calculated BL pump suction callapsed liquid level

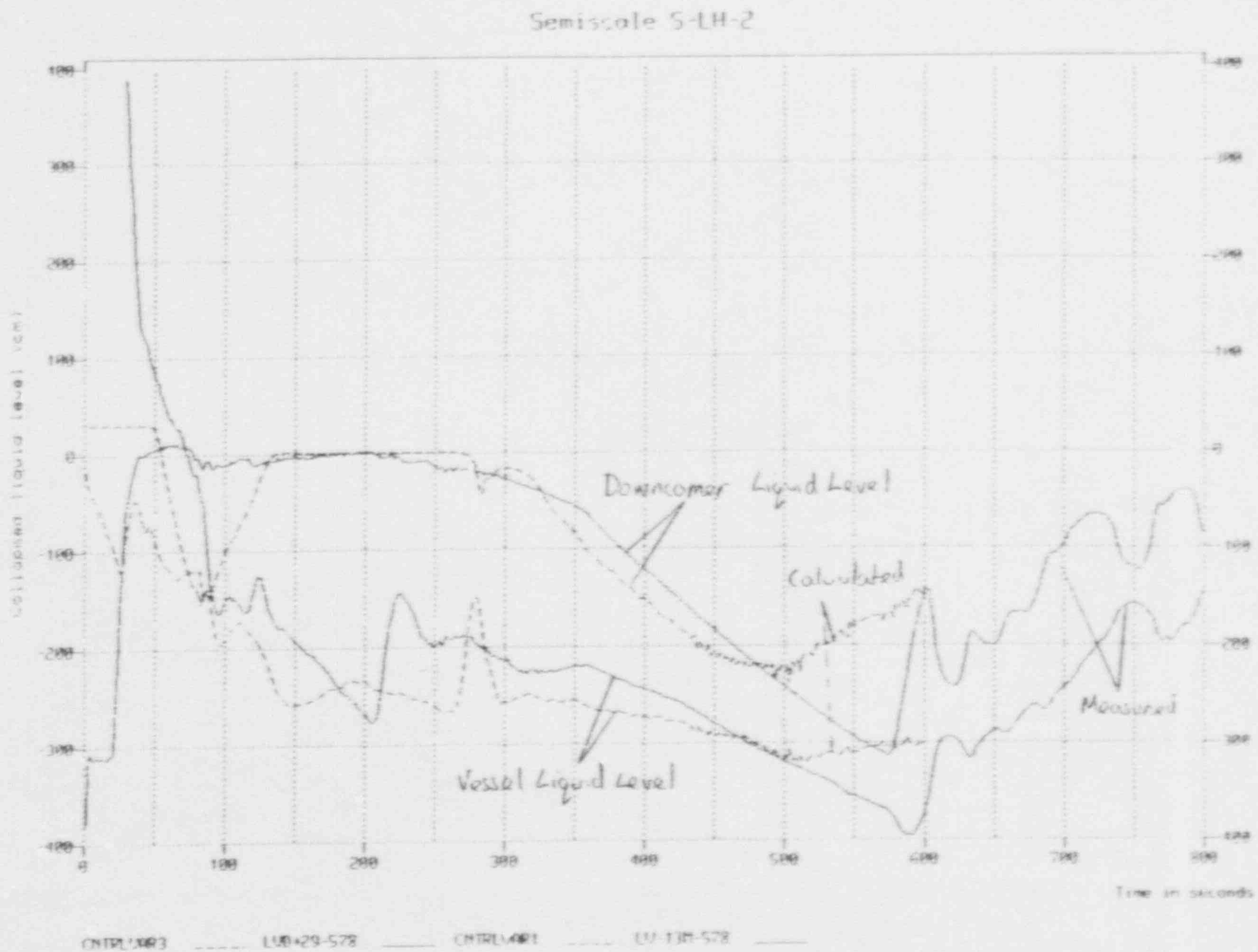

Figure 11:Vessel and downcomer collapsed liquid levels

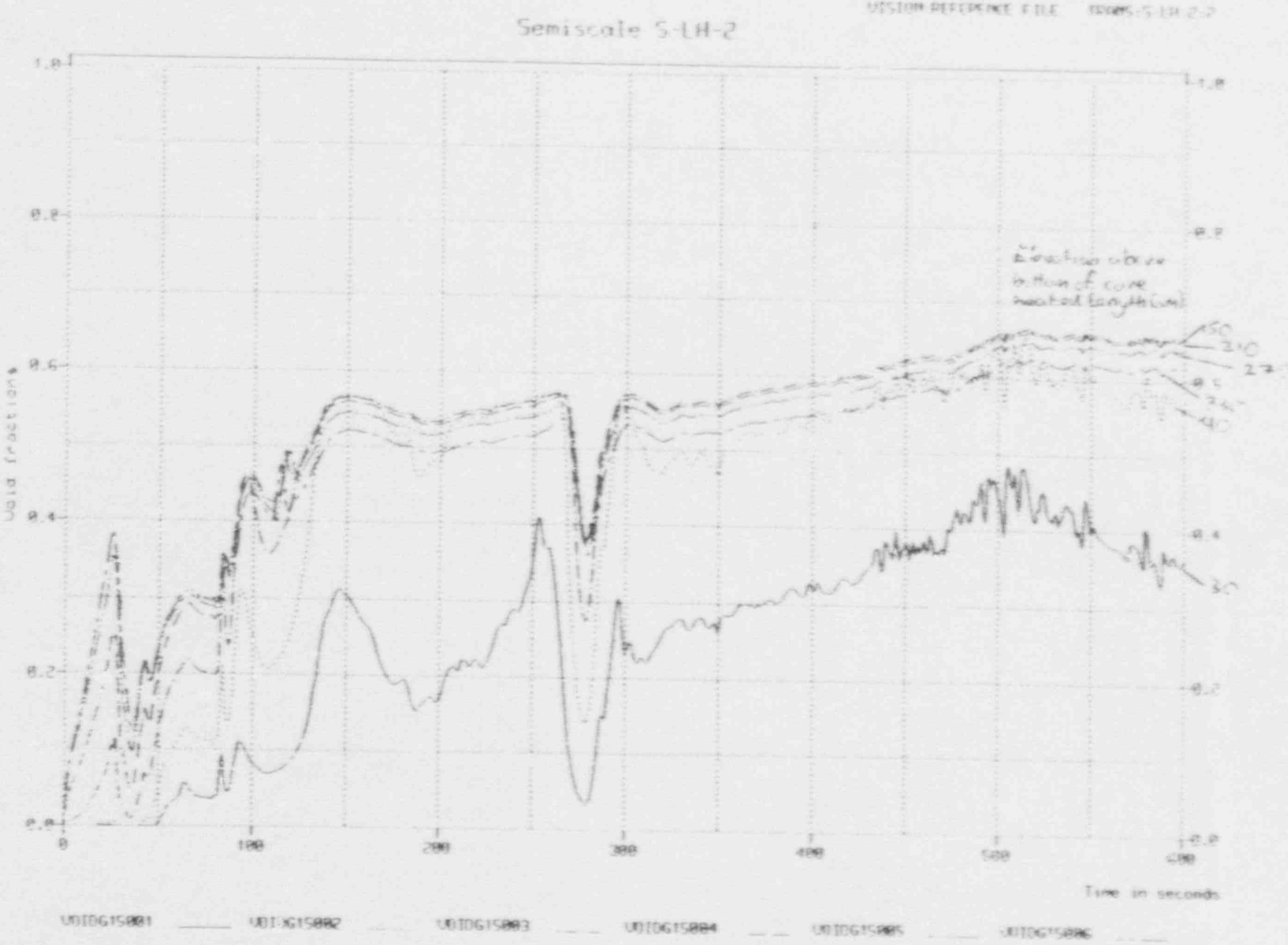

Figure 12:Calculated core void fractions

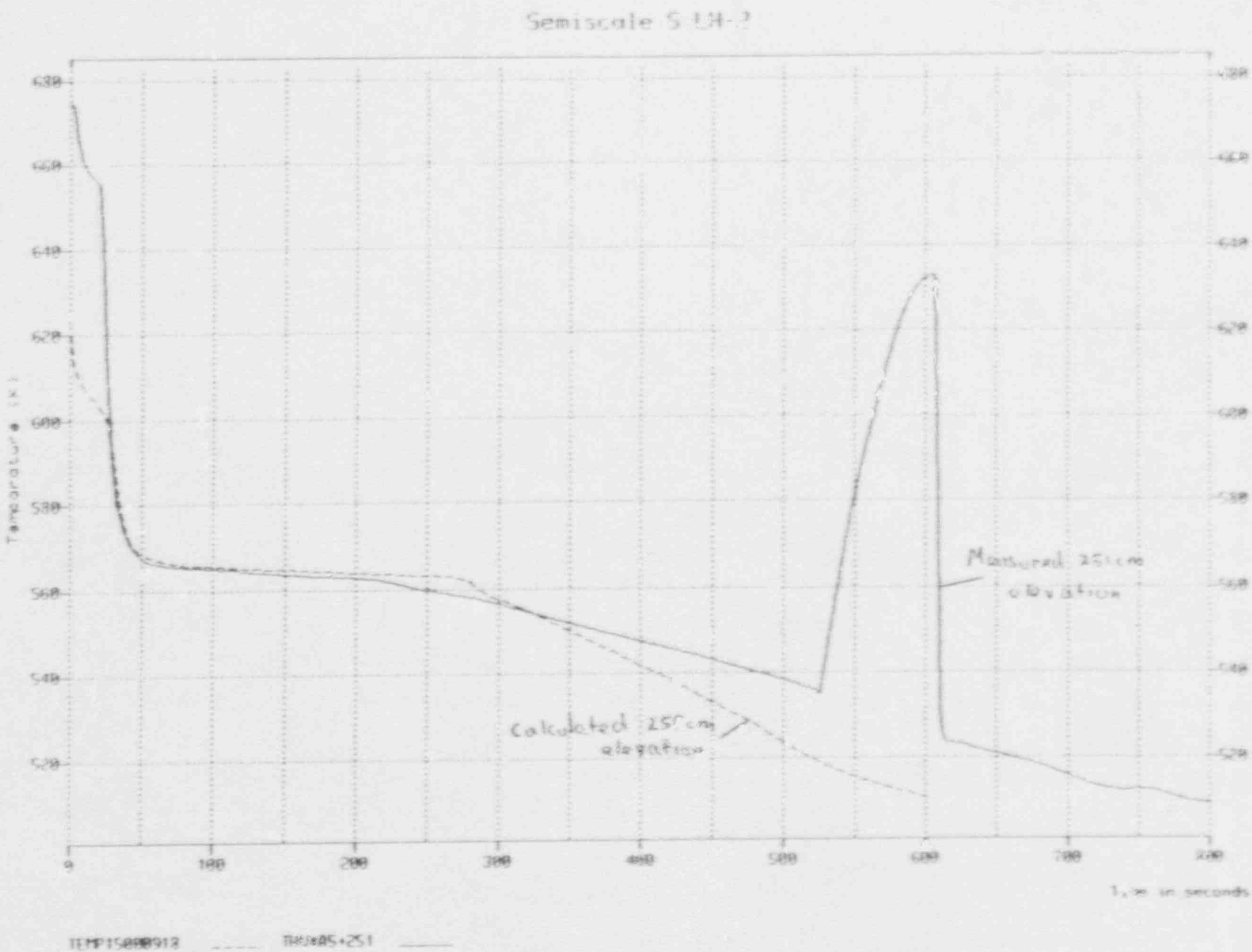

Figure 13: Measured and calculated heater rod temperatures

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Washington, DC 20555

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

The RELAP5/MOD2 code is being used by National Power Nuclear Technology Division for calculating Small Break Loss of Coolant Accidents (SBLOCA) and pressurized transient sequences for the Sizewell 'B' PWR. To assist in validating RELAP5/MOD 2 for the above application, the code is being used to model a number of small LOCA and pressurized fault simulation experiments carried out in integral test facilities. The present report describes a RELAP5/MOD2 analysis of the small LOCA test S-LH-2 which was performed on the Semiscale Mod-2C Facility. S-LH-2 simulated a SBLOCA caused by a break in the cold leg pipework of an area equal to 5% of the cold leg flow area. RELAP5/MOD2 gave reasonably accurate predictions of system thermal hydraulic behavior but failed to calculate the core dryout which occurred due to coolant boil-off prior to accumulator injection. The error is believed due to combinations of errors in calculating the liquid inventory in the core and steam generators, and incorrect modelling of the void fraction gradient within the core.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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