NUREG/IA-0201

International Agreement Report

Description and RELAP5 Assessment of the PMK-2 CAMP-CLB Experiment

2% Cold Leg Break Without HPIS With Secondary Bleed

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ABSTRACT

There is a general interest to validate best estimate (**BE**) reactor safety system codes for **VVER**-type reactors. The OECD-VVER code validation matrix is used for the selection of tests in support of accident management (AM) and to eliminate "white spots" in the matrix. Based on this matrix - test types not yet covered - a proposal was made at the 12th (Spring '98) CAMP meeting in Ankara:

- perform VVER-440/213 related experiment on the Hungarian **PMK-2** test facility
- validate **RELAP5/mod 3.2** code.

The CAMP-CLB test is an AM-type experiment with small leak in the primary coolant system needing secondary side heat removal. The break size is 2 %, heat removed by break is insufficient to depressurise primary circuit below secondary pressure. Steam dump valve to atmosphere regulates secondary pressure until - as an AM action - secondary bleed is started following core fuel rod simulator overheating which is a consequence of unavailability of the high pressure injection systems.

Report presents a short description of the PMK-2 facility, the initial and boundary conditions of the test followed by an evaluation of the results by measured parameters. After reviewing modelling aspects and results of post-test calculations by RELAP5/mod3.2.2Gamma a sensitivity study is described. The "bifurcation type" behaviour encountered in parametric studies could be the result of the code calculating by different constitutional models depending on the time step or secondary heat losses. This behaviour needs further investigation and it is reported as a new RELAP5 User Problem.

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1. INTRODUCTION

There is a general interest to validate best estimate (**BE**) reactor safety system codes for **VVERs**. As it was reported in Refs. [1] and [2] the OECD-VVER code validation matrix is used for the selection of tests in support of accident management (AM) and to eliminate "white spots" in the matrix. Based on this matrix - test types not yet covered - a proposal was made at the 12th (Spring '98) CAMP meeting in Ankara:

- perform VVER-440/213 related experiment on the Hungarian **PMK-2** test facility
- validate **RELAP5/mod 3.x code**

as an in-kind contribution of Hungary.

The proposed time table was:

- Test definition and pre-test analysis: October 1998
- Experiment execution: October 1999
- Post-test analysis with RELAP5/mod3.2.2: October 2000

The CAMP-CLB test is an AM-type experiment with the main features (as specified at the Fall '98 CAMP meeting [10]) as follows:

- small leak in the primary coolant system needing secondary side heat removal;
- break size: 2 % (nozzle diameter = 1.3 mm), heat removed by break should be insufficient to depressurise primary circuit below secondary pressure;
- unavailability of high pressure injection systems (HPIS);
- two of four hydroaccumulators (HA) are available, both injecting to the downcomer;
- secondary coolant system (steam lines and feed water) is isolated,
- steam dump valve to atmosphere (labelled BRU-A) regulates secondary pressure
- HA starts to inject at 6 MPa and stops, when primary pressure stagnates
- HA injection cannot compensate coolant loss: hot and cold leg loop seals clear and core uncovers
- as an AM action secondary bleed is started following rod overheating
- steam dump valve is used for bleed
- HA injection induced by secondary depressurisation assures reflood of the core

In Section 2 a short description of the PMK-2 facility is provided to help the understanding of the test results.

In Section 3 a definition of the test is given to outline the most important features of the test. In the other part of this Section the objectives of the test are shortly described.

Section 4 specifies the initial and boundary conditions of the test followed by an analysis of the results in Section 5.

Section 6 presents modelling aspects and results of post-test calculations by RELAP5/mod3.2.2. The sensitivity studies being described in Section 7.

The main conclusions are presented in Section 8.

2. THE PMK-2 TEST FACILITY

The Paks Nuclear Power Plant is equipped with four VVER-440/213-type reactors. Such plants are slightly different from PWRs of usual design and have a number of special features, viz.: 6-loop primary circuit, horizontal steam generators (SG), loop seal in hot and cold legs, set-point pressure of hydroaccumulators (HA) higher than secondary pressure, the coolant from HAs is directly injected to the upper plenum and downcomer, etc. As a consequence of the differences the transient behaviour of such a reactor system should be different from the usual PWR system behaviour.

The **PMK-2** facility at the KFKI-AEKI, Budapest, is a full pressure, scaled down model of the primary and partly the secondary circuit of the Paks NPP [3]. The PMK-2 was primarily designed for the investigation of operational and off-normal transient processes and of small-break loss of coolant accidents (SBLOCA) of VVER-440/213 plants. The volume and power scaling ratios are 1:2070. Due to the importance of gravitational forces in both single- and two-phase flow the elevation ratio is 1:1 except for the lower plenum and pressuriser (PRZ). The six loops of the plant are modelled by a single active loop. The coolant is water under the same operating conditions as in the nuclear power plant, i.e. transients can be started from nominal operating conditions.

The first design of the **PMK-NVH** facility only modelled the primary circuit of the plant. This version was used until 1990. The **PMK-2** facility is an upgraded version (first of all by addition of a controlled secondary heat removal system) extending the capability of the test loop to modelling transient processes initiated by secondary circuit disturbances or including accident sequences in support of AM procedures.

During the 15 operational years - from May 1986 onwards with the first of four IAEA-SPE tests [4] - 48 different experiments, including cold and hot leg break LOCA, leakage from primary to secondary (PRISE), loss of flow, loss of feedwater, disturbances of natural circulation, etc. tests, were performed on this integral type test facility [5], [6], [7].

2.1 System components description

The main characteristics of the PMK-2 facility is given in **Table 2.1.** The flow diagram of the facility is presented in **Fig. 2.1,** while the component layout and elevations are shown in **Fig. 2.10. Table 2.2.** gives the identification of valves with reference to Fig.2.1, including their the location, type and function. **Figs. 2.2 to 2.9** show the main components of PMK-2.

The reactor vessel model consists of the reactor model and the external annular downcomer (Fig. 2.8). The core is modelled by 19 electrically heated rods with uniform power distribution. The nominal initial value is given in each test. After the reactor scram the non-dimensional decay heat - time curve is modelled, while from 1000 s a constant value is used. In the core the heated length, spacer type and elevations, as well as the channel flow area are the same as in the Paks NPP (Fig. 2.3).

Cold and hot legs are volume scaled and care was taken to reproduce the correct elevations of the loop seals in both the cold and the hot legs. Cold and hot leg cross section areas if modelled according to volume scaling principles would have produced much too high pressure drops. Since, for practical reasons, length could not be maintained 1:1, relatively large cross sections were chosen for the PMK-2 loop. On the one hand this results in smaller cold and hot leg frictional pressure drops than in the NPP, on the other hand, however, it improves the relatively high surface to volume ratio of the PMK-2 pipework. As to the former effect, the small frictional pressure drop of the PMK-2 cold and hot legs have a negligible effect on small-break processes. Since, the pressure drop is increased using orifices around the loop. The upper head and the hot leg with pressuriser surge line are presented in Figs. 2.6 and 2.7.

For the pressuriser the volume scaling, the water to steam volume ratio and the elevation of the water level is kept. For practical reasons the diameter and length ratios cannot be realised. The pressuriser is connected to the lower part of the hot leg as in the reference system. Electrical heaters are installed in the model and the provision of the spray cooling is similar to that of Paks NPP (Fig. 2.9).

The main circulating pump of the PMK-2 serves to produce the nominal operating conditions corresponding to that of the NPP as well as to simulate the flow coast-down following pump trip early in the transient. In order to avoid operation of the pump in two-phase condition, it is accommodated in a by-pass line. Flow coast-down is modelled by closing a control valve in an appropriate manner and if flow rate is reduced to that of natural circulation, the valve in the by-passed cold leg part is opened while the pump line is simultaneously closed.

The horizontal design of the VVER-440 steam generator is modelled by horizontal heat transfer tubes between hot and cold collectors in the primary side (Figs. 2.4 and 2.5). This horizontal design affects the primary circuit behaviour during a small break LOCA in quite a different way to the usual vertical steam generators. In the modelling the tube diameter, length and number were determined by the requirement of keeping the 1:2070 ratio of the product of the overall heat transfer coefficient and the equivalent heat transfer area. The elevations of tube rows and the axial surface distribution of tubes are the same as in the reference system. On the secondary side the water level and the steam to water volume ratios are kept.

From the emergency core cooling systems (ECCS) the four hydroaccumulators of the Paks NPP are modelled by two vessels with prescribed initial and minimum (empty in the plant) coolant levels. They are connected to the downcomer and upper plenum similar to those of the reference system. The high and low pressure injection systems (HPIS and LPIS) are modelled by use of piston pumps. The flow rates measured during the start-up period of the Paks NPP are used to control this pumps.

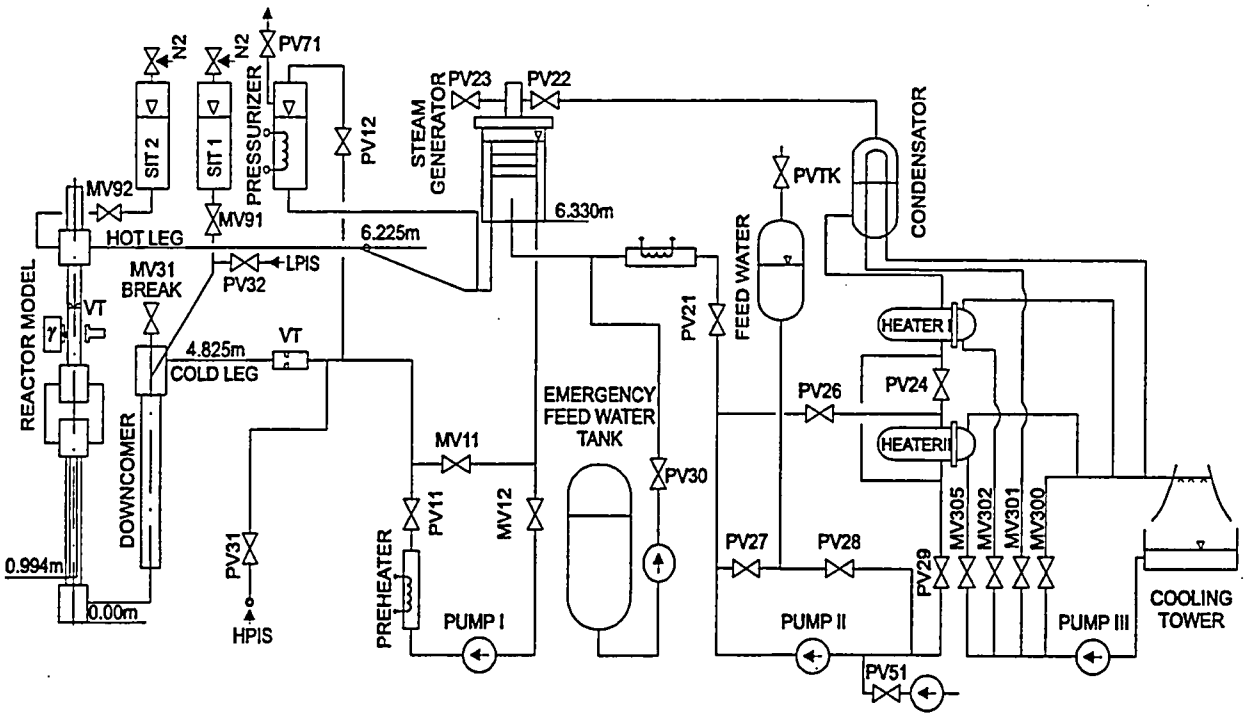

Fig. 2.1 Flow diagram of PMK-2 test facility

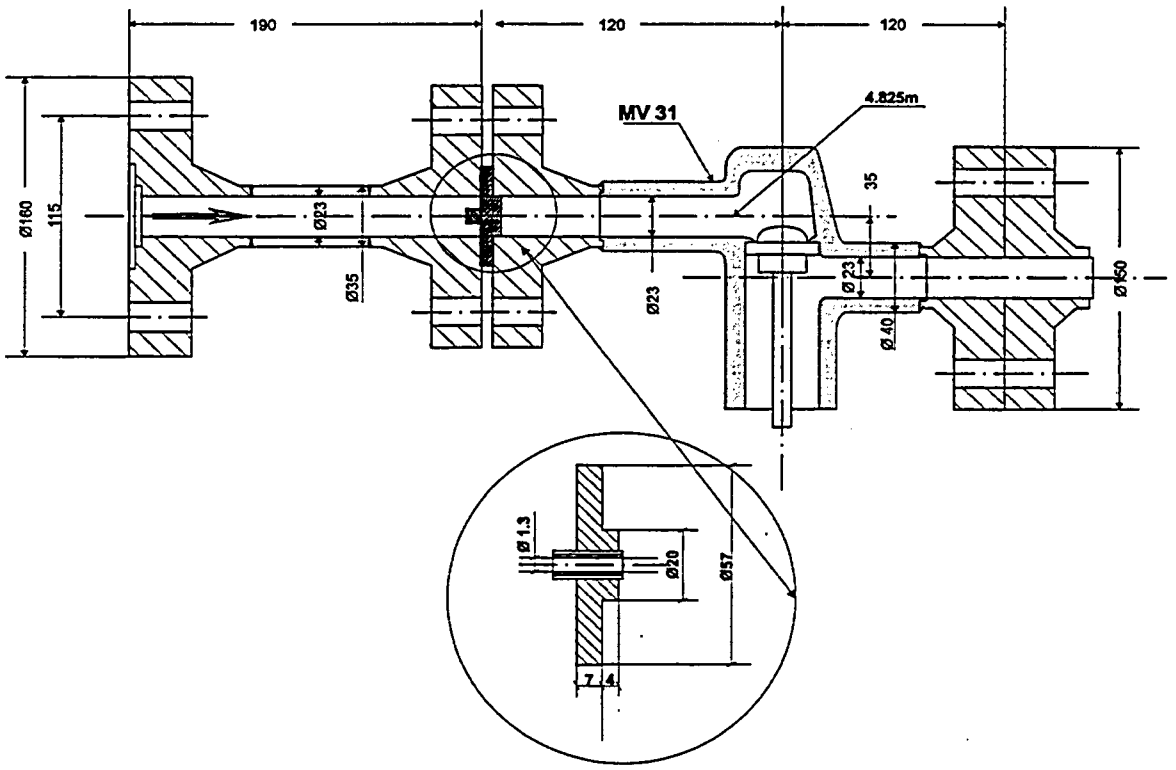

Fig. 2.2 Break flow unit (length of orifice is 15 mm)

Table 2.1

PMK-2 Test Facility Characteristics

Reference NPP:

Paks Nuclear Power Plant with VVER-440/213 reactors
1375 MWt - hexagonal fuel arrangement
6 loops - horizontal steam generators

General Scaling factor:

Power, volumes: 1/2070, loop: 1/345 (1 loop representation)
Elevations: 1/1

Primary coolant system:

- Pressure: 12.4 MPa (nominal), 16 MPa (max.)
- Nominal core inlet temperature: 540K
- Nominal core power: 664 kW
- Nominal flow rate: 4.5 kg/s

Special features:

- 19 heater rods, uniform axial and radial power distribution
- 2.5 m heated length
- External downcomer
- Horizontal SG heat transfer tubes
- Pump is accommodated in by-pass line
  - -- flow rate 0 to nominal value
  - -- NPP pump coastdown simulation
- Loop piping: 46 mm ID

Secondary coolant system:

- Pressure: 4.6 MPa
- Feed water temperature: 493 K
- Nominal steam mass flow: 0.36 kg/s

Special features:

- Vertical part of horizontal steam generator
- Controlled heat removal system

Safety injection systems:

- HPIS
- LPIS
- SITs
- Emergency feed water

Control system:

- Automatic control of sequences by computer
- Control desk

Table 2.2

Valve description

Item No.	Identif. No. Fig.2.1	Position	Type *	Function	Size Nom.I.D. (mm)	Comments
1	PV11	Pump delivery line	1	Flow control, pump coast down (see Section 4)	50	
2	MV11	Cold leg loop seal	2	Pump cost down (see Section 4)	50	
3	MV12	Pump suction line	2	Isolation of by-pass for pump after pump trip (see Section 4)	100	
4	PV12	Pressuriser spray line	1	Control of spray cooling in pressuriser	15	Closed after transient initiation
5	PV21	Feedwater line	1	Control of feedwater	15	closing time 3s
6	PV22	Steam line	1	Control of steam	25	closing time 3s
7	PV23	Steam generator	1	Secondary side steam relief valve (BRU-A)	25	diameter of orifice 4 mm opening/closing time 3 s
8	PV31	HPIS line	1	Modelling of the HPIS system	15	
9	PV32	LPIS line	1	Modelling of the LPIS system	15	
10	MV31	Break location	2	Break valve	25	diameter of orifice 1.3 mm
11	MV91	SIT line	2	Actuation of SIT	15	
11	MV92	SIT line	2	Actuation of SIT	15	
12	PV71	Pressuriser	1	Pressuriser safety valve	25	diameter of orifice 1 mm

* 1 - Honeywell control valve
  2 - Motor valve from Paks NPP

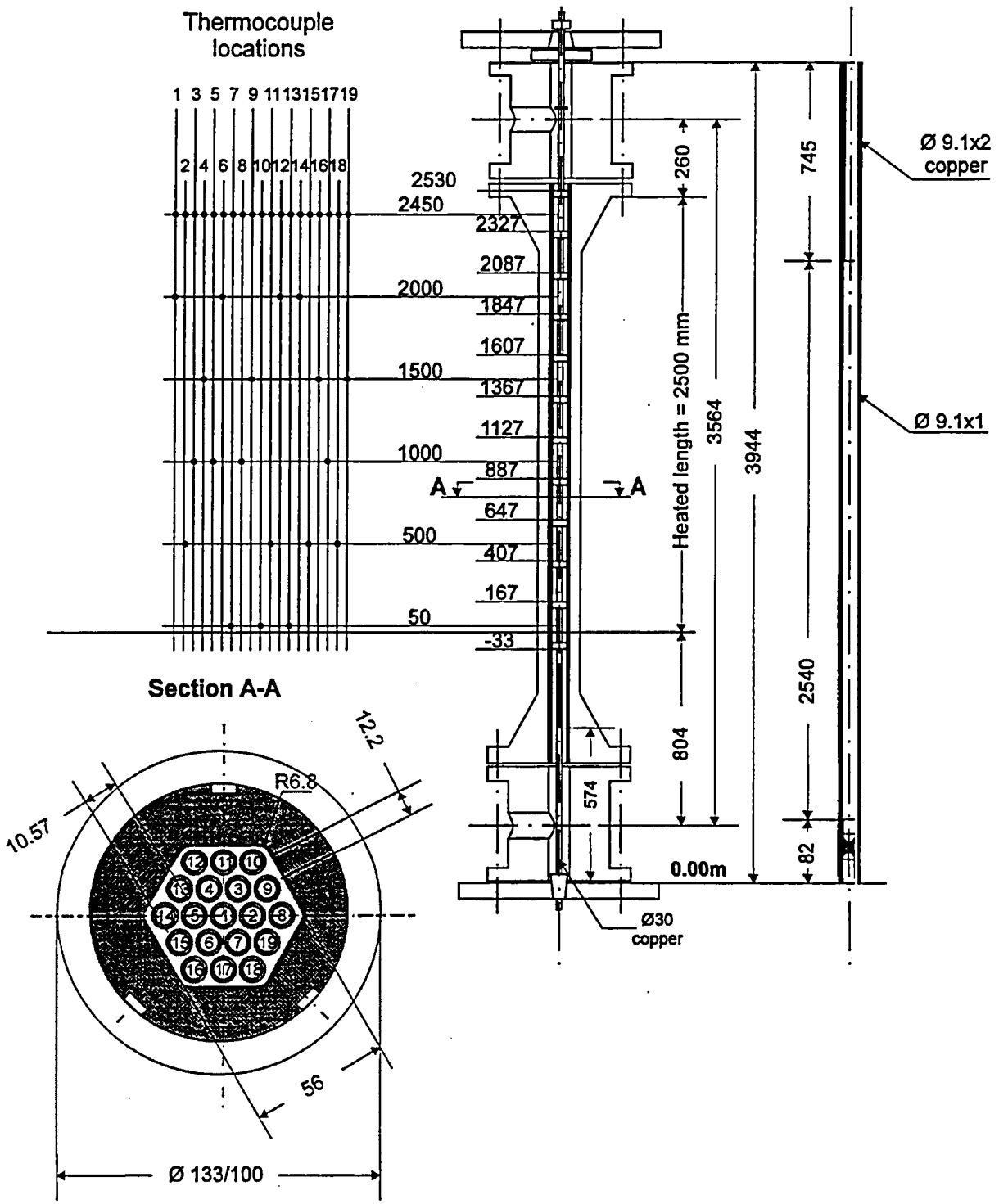

Fig. 2.3 19-rod bundle

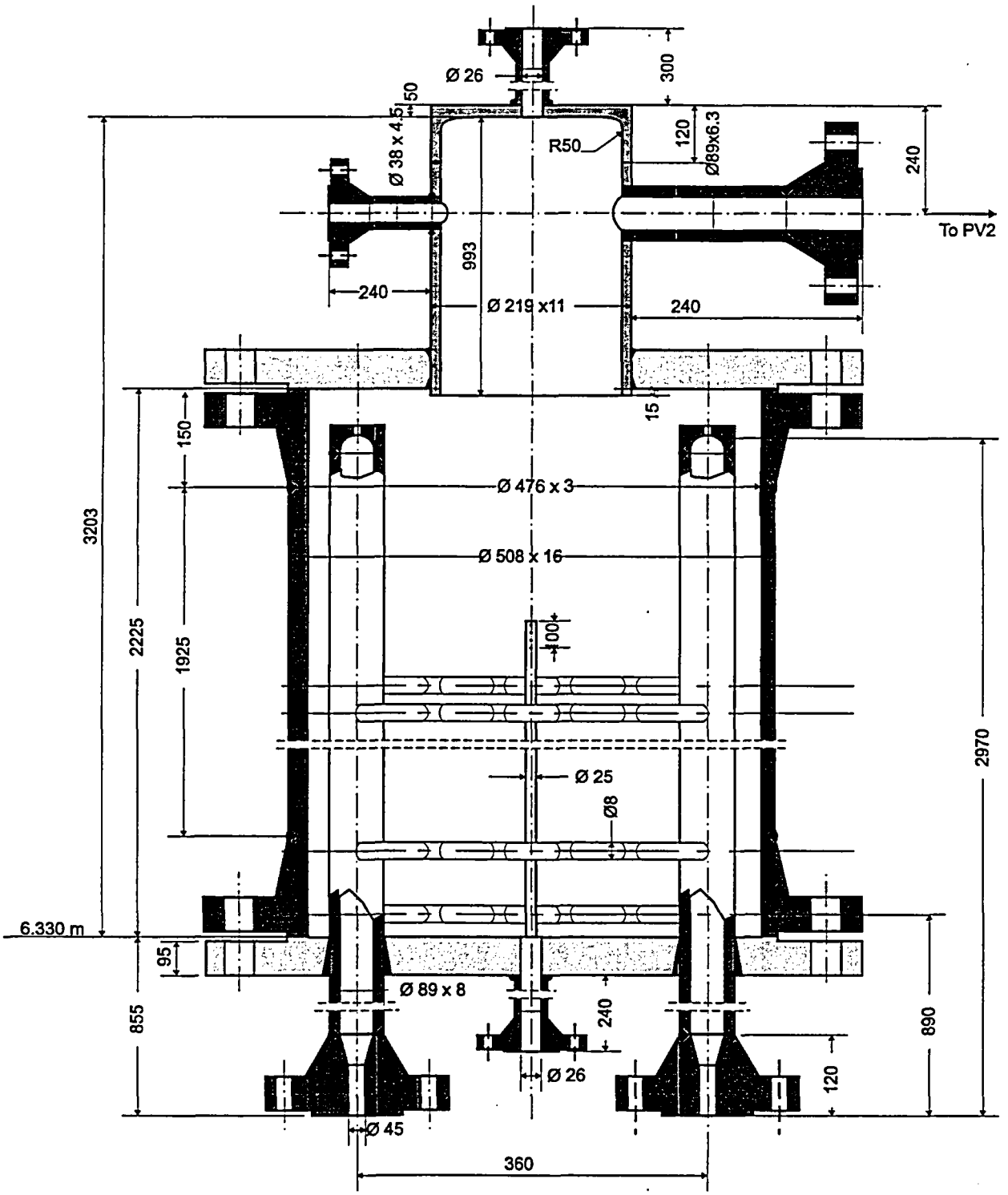

Fig. 2.4 Horizontal steam generator

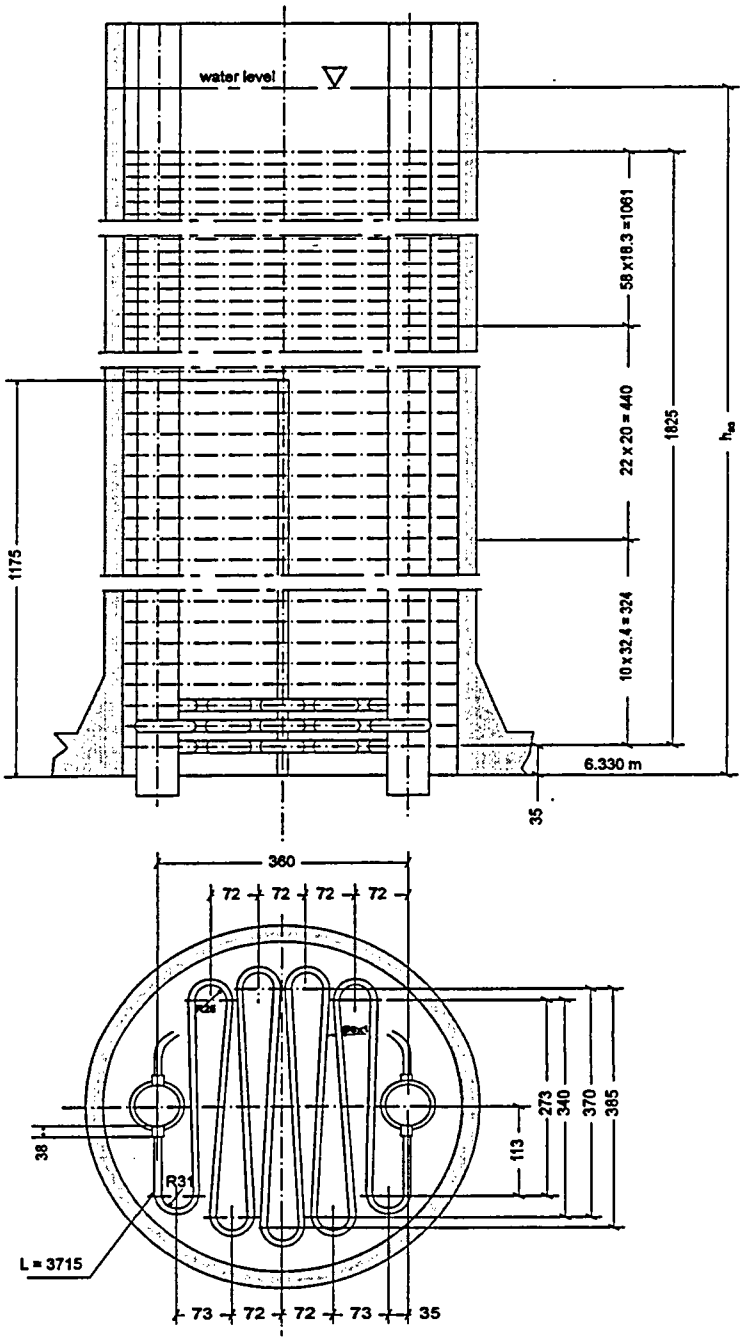

Fig. 2.5 Steam generator pipeworks

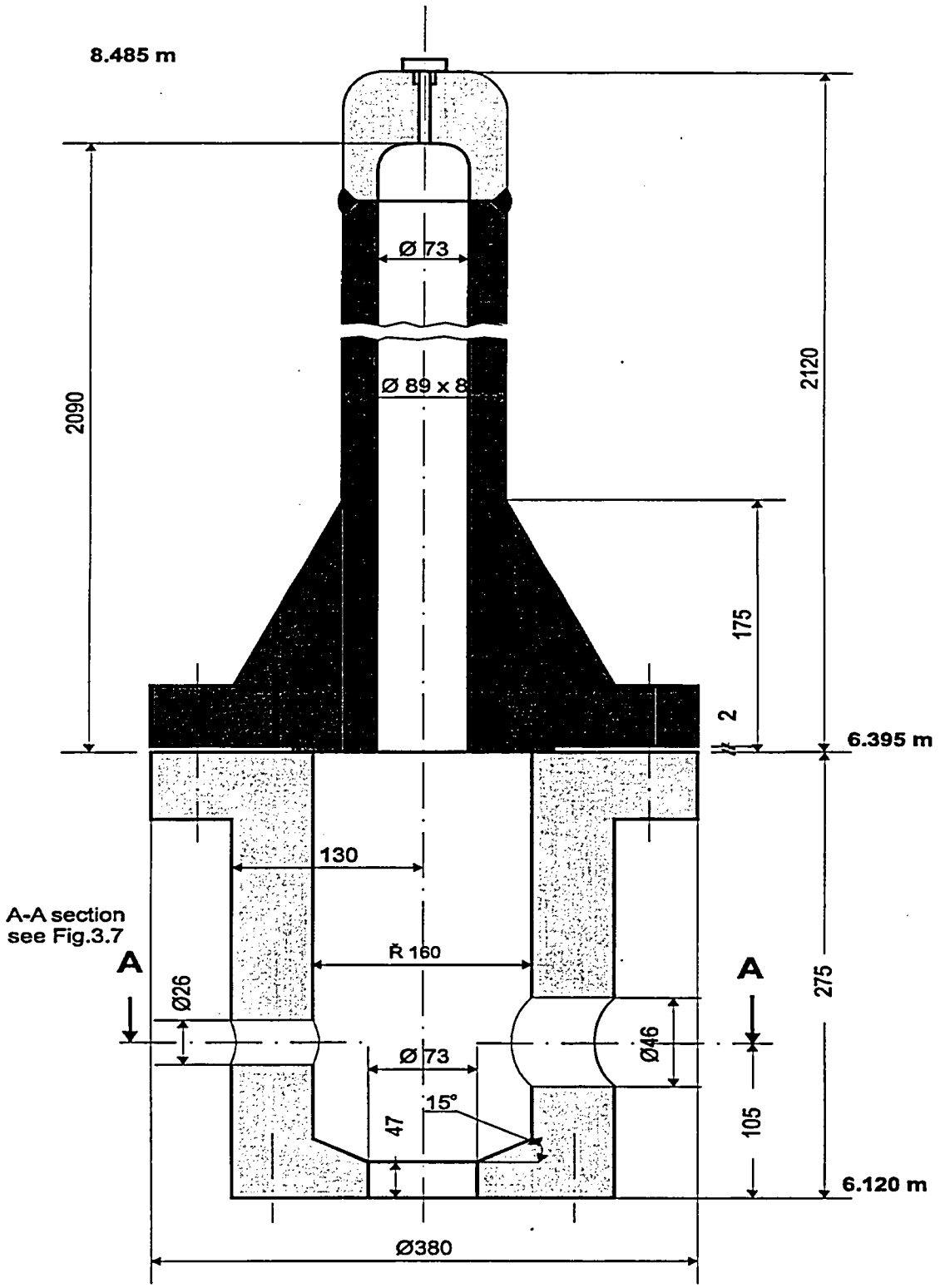

Fig. 2.6 Upper head

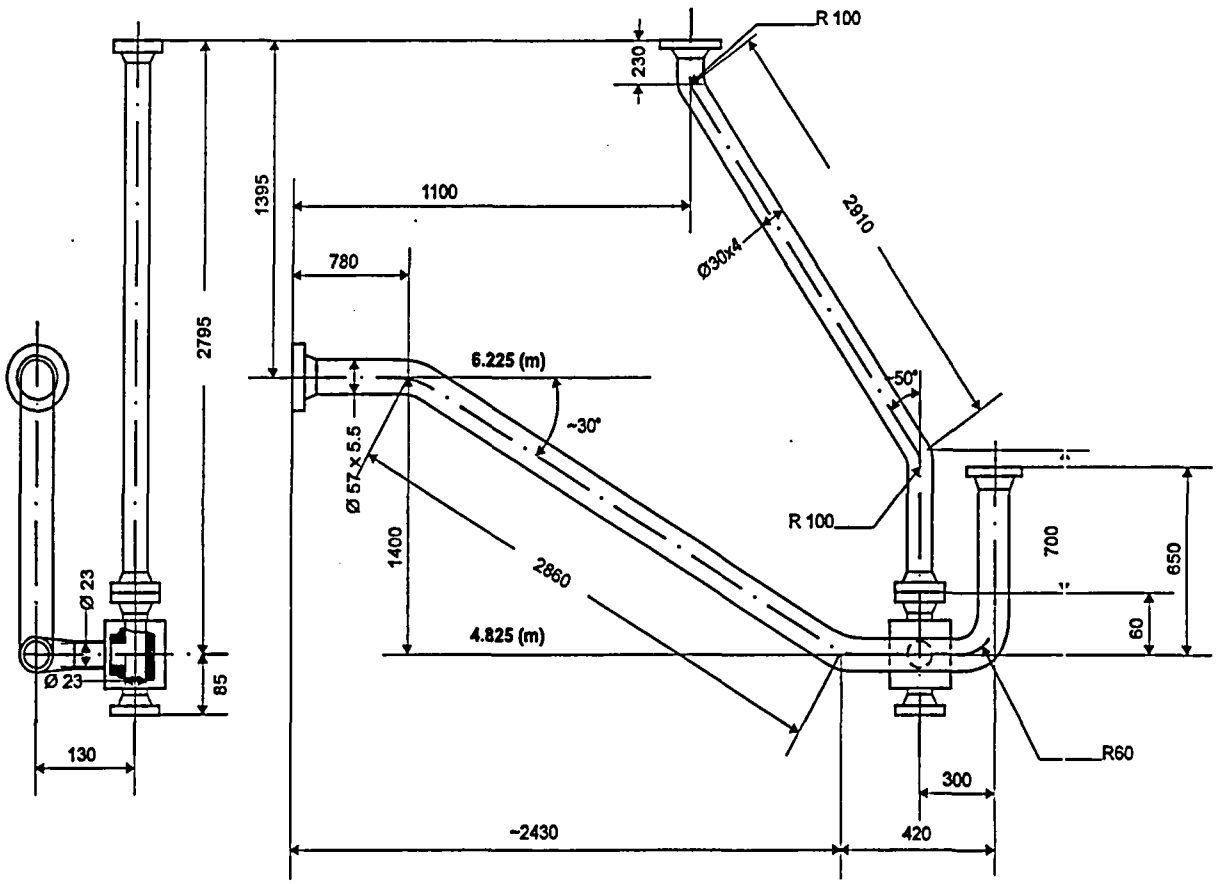

Fig.2.7 Hot leg with pressuriser surge line

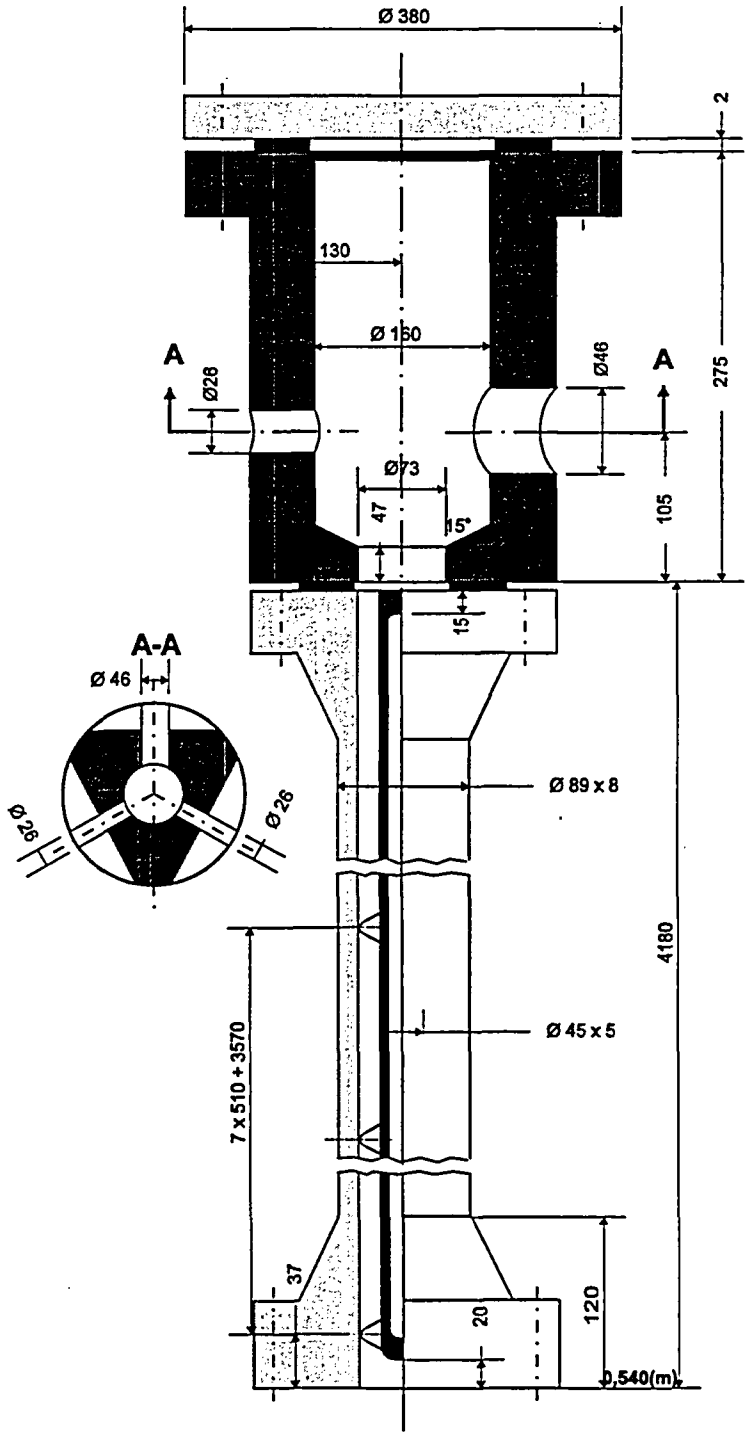

Fig. 2.8 External downcomer

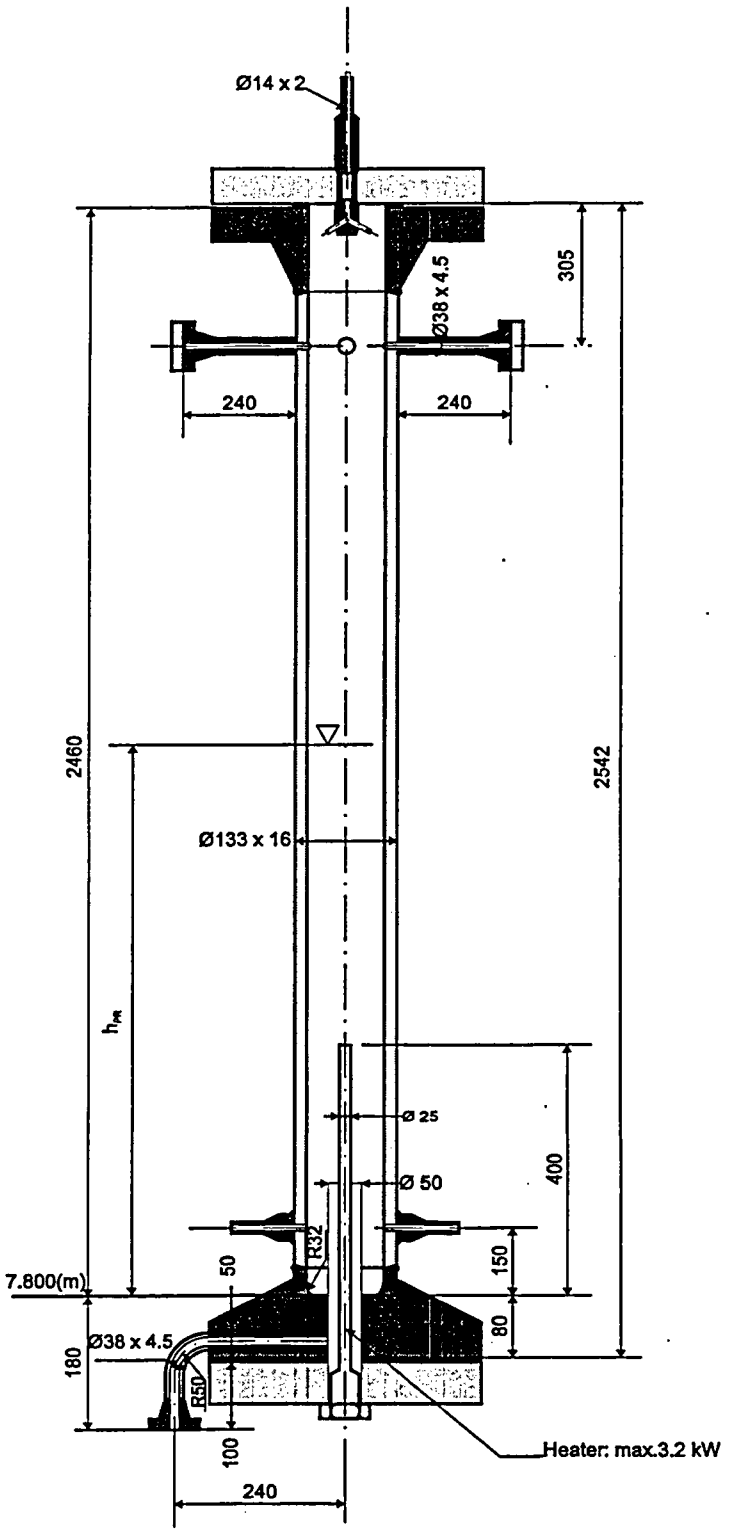

Fig. 2.9. Pressuriser

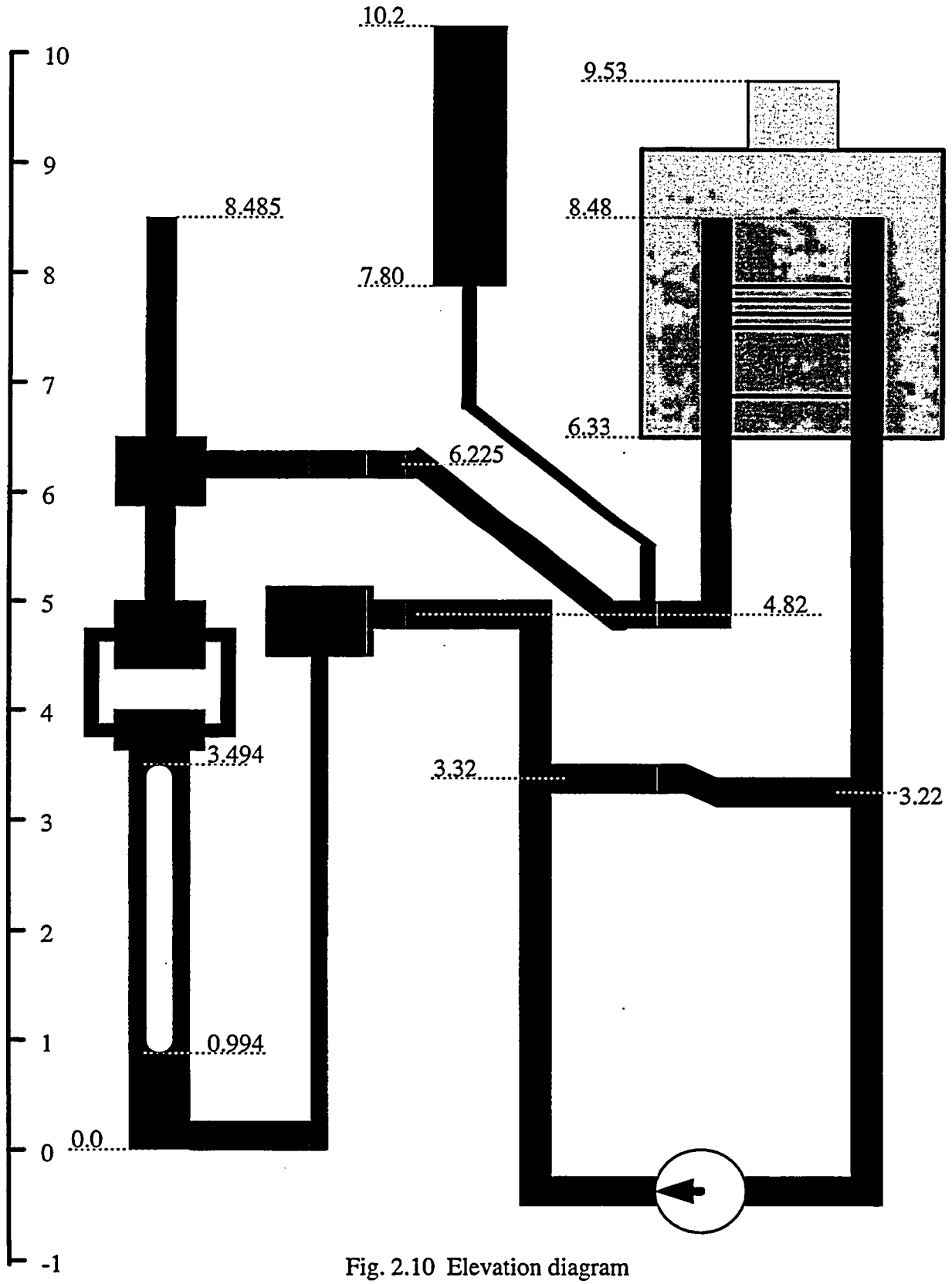

Fig. 2.10 Elevation diagram

2.2 Basic instrumentation and specific data to the test

The basic instrumentation of the PMK-2 facility is given in the Handbook [3]. Since specific data are needed, some additional, specific instruments are to be installed.

The test specific break flow unit with a break orifice of 1.3 mm diameter is presented in Fig. 2.2.

The reference level for elevation is the bottom plate of the lower plenum. To facilitate the interpretation of the liquid levels a simple elevation diagram is provided in Fig. 2.10, giving the heights from the 0.00 m reference level.

Coolant levels are measured by DP-type transducers, therefore the levels are collapsed levels. Collapsed levels in the data base are derived from the signals of the DP-type transducers, together with the necessary corrections, which are related to the density differences

An important part of the instrumentation is the local void (LV) measurement system consisting of needle shaped conductivity probes developed at Forschungszentrum Rossendorf e. V, Germany. The location of the needle probes in the PMK facility is shown in Fig. 2.13. There are three probes in the reactor model. One of them is located near to the core outlet (LV25). The other probe is at the reactor outlet (LV21). The third (LV22) is placed into the top of upper plenum. There are four probes in the inclined section of the hot leg loop seal (LV30, LV32, LV35, LV34). The probes LV33 and 41 are placed at the bottom of the loop seal and at the inlet of the steam generator, respectively. LV51 and 52 are mounted into the cold leg loop seal. The LV71 is located at the bottom of pressuriser. The error of the measured value reaches maximum values at medium void fraction. At 0% and 100% voids the probes give always the right signal for water or steam.

The location and main characteristics of the instrumentation with data of measurement parameters is given in **Figs. 2.11 to 2.13.** and in **Table 2.3** where the last three columns have the following meanings:

C additional constant in engineering units (for absolute and differential pressure measurements this value is the hydraulic head, for temperatures this is a calibration constant)
Δ absolute maximum error of the measurement in % or in engineering units
σ standard deviation of the measurement in % or in engineering units

Identification of the measured parameters are as follows:

Pressure	:	PR
Differential pressure	:	DP
Temperature	:	TE
Level	:	LE
Flow	:	FL
Integrated flow rate	:	MA
Density	:	DE
Local void	:	LV
Power	:	PW

Table 2.3 Data of the measurement transducers

Identi-fication	Location and type	Elevation (m)	Unit	Min.	Max.	C	Δ ±	ó ±
TE10	Heater rod surface (10), THC	1.044	K	273.15	1273.15	0.0	1.96	1.30
TE11	Heater rod surface(2), THC	1.494	K	273.15	1273.15	0.20	1.96	1.30
TE12	Heater rod surface(8), THC	1.994	K	273.15	1273.15	0.0	1.96	1.30
TE13	Heater rod surface(9), THC	2.494	K	273.15	1273.15	-0.20	1.96	1.30
TE14	Heater rod surface(6), THC	2.994	K	273.15	1273.15	0.20	1.96	1.30
TE15	Heater rod surface(11), THC	3.444	K	273.15	1273.15	-0.20	1.96	1.30
TE16	Heater rod surface(1), THC	3.444	K	273.15	1273.15	-3.0	1.96	1.30
TE17	Heater rod surface(16), THC	3.444	K	273.15	1273.15	-5.0	1.96	1.30
TE18	Heater rod surface(2), THC	3.444	K	273.15	1273.15	-4.0	1.96	1.30
TE19	Heater rod surface(3), THC	3.444	K	273.15	1273.15	-4.20	1.96	1.30
TE22	Upper plenum temperature, PTR	4.664	K	273.15	673.15	2.20	1.67	1.16
TE23	Wall in upper plenum, THC	6.225	K	273.15	1273.15	0.00	1.96	1.30
TE24	Upper plenum temperature, PTR	8.315	K	273.15	673.15	0.00	1.67	1.16
TE41	SG primary coolant inlet, PTR	5.925	K	273.15	673.15	6.1	1.67	1.16
TE42	SG primary coolant outlet, PTR	5.925	K	273.15	673.15	9.4	1.67	1.16
TE43	Heat transfer tube inlet 1, THC	8.163	K	273.15	1273.15	0.00	1.96	1.30
TE44	Heat transfer tube outlet 1, THC	8.163	K	273.15	1273.15	0.00	1.96	1.30
TE45	Heat transfer tube inlet 2, THC	7.591	K	273.15	1273.15	0.00	1.96	1.30
TE46	Heat transfer tube outlet 2, THC	7.591	K	273.15	1273.15	0.00	1.96	1.30
TE47	Heat transfer tube inlet 3, THC	6.385	K	273.15	1273.15	0.00	1.96	1.30
TE48	Heat transfer tube outlet 3, THC	6.385	K	273.15	1273.15	0.00	1.96	1.30
TE61	Coolant downcomer inlet, PTR	4.520	K	273.15	673.15	1.0	1.67	1.16
TE62	Wall in downcomer, THC	4.995	K	273.15	1273.15	0.00	1.96	1.30
TE63	Coolant at core inlet, PTR	0.190	K	273.15	673.15	3.0	1.67	1.16

Table 2.3 cont.

Identi-fication	Location and type	Elevation (m)	Unit	Min.	Max.	C	Δ ±	ó ±
TE70	Surge line temperature, THC	5.325	K	273.15	1273.15	+6.62	1.96	1.30
TE80	Sec. water hot coll. 1, THC	8.163	K	273.15	1273.15	0.00	1.96	1.30
TE81	Feedwater temperature, PTR	5.475	K	273.15	673.15	0.0	1.67	1.16
TE82	Sec. water hot coll. 2, THC	7.591	K	273.15	1273.15	0.00	1.96	1.30
TE84	Sec. water hot coll. 3, THC	6.385	K	273.15	1273.15	+1.52	1.96	1.30
TE83	Sec. water middle 1, THC	8.163	K	273.15	1273.15	+4.61	1.96	1.30
TE85	Sec. water middle 2, THC	7.591	K	273.15	1273.15	-4.61	1.96	1.30
TE87	Sec. water middle 3, THC	6.385	K	273.15	1273.15	0.00	1.96	1.30
TE86	Sec. water cold coll. 1, THC	8.163	K	273.15	1273.15	-3.79	1.96	1.30
TE88	Sec. water cold coll. 2, THC	7.591	K	273.15	1273.15	-2.81	1.96	1.30
TE89	Sec. water cold coll. 3, THC	6.385	K	273.15	1273.15	+6.62	1.96	1.30
TE01	Break flow temp., THC	4.825	K	273.15	1273.15	0.00	1.96	1.30
TE02	BRU-A flow temp., THC	9.213	K	273.15	1273.15	0.00	1.96	1.30
PR01	Break back pressure	4.825	MPa	0.0	1.0	0.01	0.065	0.048
PR02	Back pressure behind BRU-A valve	9.213	MPa	0.0	1.0	0.01	0.065	0.048
PR21	Upper plenum pressure	3.764	MPa	0.0	16.0	0.01	0.005	0.004
PR71	Pressuriser pressure	9.955	MPa	0.0	16.0	0.01	0.051	0.045
PR81	SG secondary	10.010	MPa	0.0	10.0	0.01	0.032	0.028
PR91	SIT-1	10.350	MPa	0.0	10.0	0.01	0.032	0.028
PR92	SIT-2	10.350	MPa	0.0	10.0	0.01	0.032	0.028
LE11	Reactor model	0.190/8.315	kPa	-60.0	100.0	79.71	0.563	0.458
LE21	Upper plenum part 1, DP	6.750/8.315	kPa	0.0	38.0	15.21	0.134	0.109
LE22	Upper plenum part 2, DP	4.683/6.750	kPa	0.0	10.0	20.61	0.035	0.029

Table 2.3 cont.

Identi-fication	Location and type	Elevation (m)	Unit	Min.	Max.	C	Δ ±	ó ±
LE23	Upper plenum part 3, DP	3.764/4.683	kPa	0.0	16.0	8.83	0.051	0.045
LE31	Hot leg loop seal, DP (reactor side)	4.802/6.225	kPa	0.0	16.0	13.96	0.051	0.045
LE44	Cold leg part 2, DP	5.920/4.802	kPa	0.0	16.0	11.18	0.051	0.045
LE45	SG primary, hot leg, DP	4.802/8.997	kPa	0.0	100.0	41.03	0.352	0.286
LE46	SG primary, cold leg, DP	2.785/8.997	kPa	0.0	186.0	60.65	0.655	0.532
LE51	Cold leg part 1, DP	2.785/5.920	kPa	0.0	38.0	31.10	0.134	0.109
LE52	Cold leg pressure drop, reactor side	3.605/4.825	kPa	0.0	25.0	12.07	0.090	0.072
LE60	Downcomer head, DP	4.505/5.355	kPa	0.0	7.50	8.29	0.016	0.013
LE61	Downcomer, DP	0.190/4.825	kPa	0.0	60.0	45.47	0.211	0.172
LE71	Pressuriser, DP	8.010/9.990	kPa	0.0	40.0	25.06	0.141	0.114
LE72	Pressuriser surge line, DP	4.802/8.010	kPa	0.0	38.0	30.88	0.134	0.109
LE81	SG secondary, DP	6.565/10.010	kPa	0.0	40.0	33.92	0.141	0.114
LE91	SIT-1 level, DP	8.13/10.35	kPa	0.0	40	21.78	0.141	0.114
LE92	SIT-2 level, DP	8.13/10.35	kPa	0.0	40	21.78	0.141	0.114
FL52	Core outlet, normal, venturi	5.504	kPa	0.0	60.0	0.0	0.211	0.172
FL51	Core outlet, low flow, venturi	5.504	kPa	0.0	2.5	0.0	0.008	0.005
FL53	Cold leg, normal, venturi	4.825	kPa	0.0	60.0	0.0	0.211	0.172
FL54	Cold leg, low flow, venturi	4.825	kPa	0.0	2.5	0.0	0.008	0.005
FL81	Feedwater flow, venturi	4.990	kPa	0.0	100.0	0.0	0.352	0.286
FL01	Break flow, venturi	4.825	MPa	0.0	1.0	0.0	0.381	0.282
FL02	Secondary bleed flow, venturi	9.213	kPa	0.0	100.0	0.0	0.381	0.282
MA01	Total mass break outflow, DP	-	kPa	0.0	16.0	0.0	0.053	0.053
MA02	Total mass BRU-A outflow, DP	-	kPa	0.0	16.0	0.0	0,053	0.045
PW01	Electrical power	-	kW	0.0	1000.0	0.0	-	-

Table 2.3 cont.

Identi-fication	Location and type	Elev. (m)	Unit	Min.	Max.	C	Δ ±	ó ±
LV21	Local void in upper plenum, VP	6.225						
LV22	Local void in upper plenum VP	7.635						
LV25	Local void in upper plenum VP	4.440						
LV30	Local void in hot leg, VP	6.225						
LV32	Local void in hot leg loop seal, VP	5.400						
LV33	Local void in hot leg loop seal, VP	4.802						
LV34	Local void in hot leg loop seal, VP	4.945						
LV35	Local void in hot leg loop seal, VP	5.178						
LV41	Local void in SG hot collector, VP	5.995						
LV42	Local void in SG cold collector, VP	5.995						
LV51	Local void in cold leg, VP	3.525						
LV52	Local void in cold leg, VP	3.525						
LV71	Local void PRZ bottom, VP	7.800						

Abbreviations:

PTR = platinum resistance
THC = thermocouple
VP = void probe

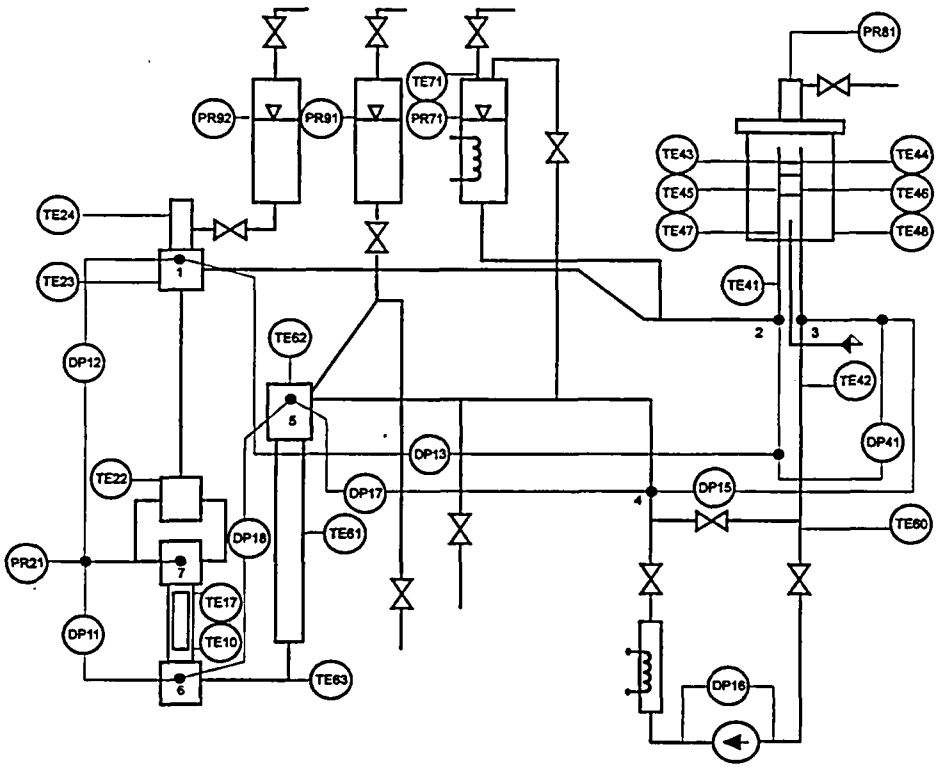

Fig. 2.11 Measurement locations (1)

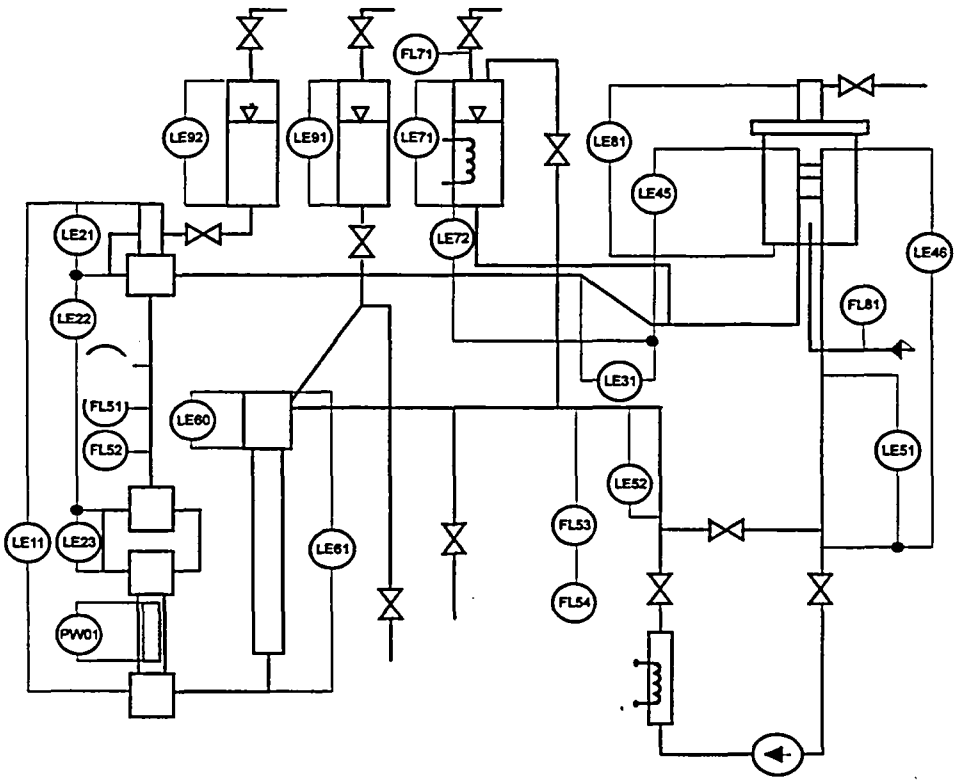

Fig. 2.12 Measurement locations (2)

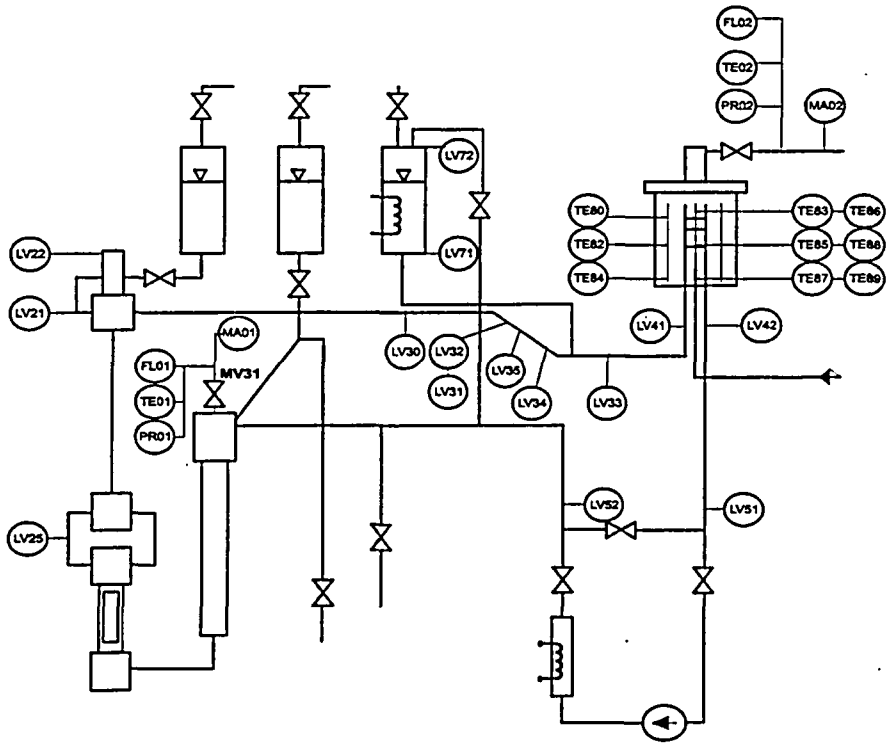

Fig. 2.13 Measurement locations (3)

3. TEST DEFINITION AND OBJECTIVES

The CAMP-CLB test primarily addresses the question whether the secondary bleed is effective to recover the core without the availability of the HPI systems if the break is too small to depressurise primary system below secondary pressure.

The specific features of the experiment are as follows:

- The test begins from a steady-state condition with nominal parameters.
- The break location is in the cold leg (at downcomer head), with a size of 2%. In the PMK-2 the nozzle diameter is 1.3 mm.
- 2 HAs are available in the test modelled by one safety injection tank (SIT) injecting to the downcomer, the water temperature is 293 K.
- No HPIS applied to the test.
- Scram is initiated low primary pressure of 11.3 MPa (the decay heat is stabilised at 32.5 kW).
- Secondary side is isolated 10 s after scram.
- The pump coast-down begins by high containment pressure signal - 0.11 MPa - supposed at t=80 s.
- The secondary bleed is modelled by the BRU-A valve (PV23). In the PMK-2 the nozzle diameter is 4.0 mm.
- No secondary feed is modelled.

The main objective of the test is to study the following phenomena:

- effect of hot leg loop seal behaviour on primary flow, steam generator heat transfer, hydroaccumulator injection
- substantial core heat-up due to loop seal effects

- effectiveness of secondary side bleed to recover the core and reinitiate hydroaccumulator injection.

4. TEST DESCRIPTION

The CAMP-CLB experiment - as specified in Section 3 - is presented in detail below [11].

4.1 Initial conditions

The initial steady state conditions of the test are summarised in **Table 4.1** (for last column see Section 6). The parameters are nearly the same as the nominal operating parameters of the plant considering the scaling ratio.

Table 4.1

	Unit	Nominal	Test	Calculation
Primary pressure	MPa	12.3	12.28	12.325
Core inlet temperature	K	541	539.6	538.17
Primary loop flow rate	kg/s	4.5	4.4	4.4
Core power	kW	664	663	661.1
Pressuriser level	m	9	8.868	8.865
Hydroaccumulator level	m	9.65	9.663	9.665
Hydroaccumulator pressure	MPa	5.9	6	6
Secondary pressure	MPa	4.6	4.5	4.49
Secondary flow rate	kg/s	0.36	0.47	0.55
Feedwater temperature	kg/s	496	471.2	471.2
Steam generator level	m	8.4	8.43	8.159

4.2 Boundary conditions

The boundary conditions are listed in **Table 4.2.**

Table 4.2

	Unit	Nominal	Test	Calculation
Break opening at	s	0	0	0
Scram by low primary pressure	MPa	11.3	11.18	11.15
Secondary side isolated (scram +)	s	10	9	10
Pump coast-down initiated at	s	80	80	80
Duration of pump coast-down	s	148	138	150
SIT injection starts	MPa	5.9	6	6
Steam dump opens	MPa	5.3	5.35	5.35
Steam dump closes	MPa	4.9	4.915	4.92
Secondary bleed initiated T_{clad}	K	730	731	1505. s*
SIT empty	m	8.25	8.27	8.27
Test terminated	s	3600	3596	3600

*synchronised boundary condition

4.3 Sequence of major events

The measured sequence of major events of the test are presented in **Table 4.3.**

Table 4.3

	Test	Calculation
• Break opening	0. s	0. s
• Scram generated	28. s	21. s
• Secondary side isolated	37. s	32. s
• Pressuriser emptied	43. s	34. s
• Pump coast-down initiated	80. s	80. s
• SIT injection starts	159. s	118. s
• End of pump coast-down	218. s	230. s
• Vessel level at hot leg elevation	240. s	216. s
• Hot leg loop seal clearing	352. s	344. s
• Steam dump first opens	469. s	495. s
• Steam dump first closes	504. s	515. s
• Steam dump opens again	897. s	847./1226. s
• Steam dump closes	946. s	887./1264. s
• Rod temperatures begin to rise	1115. s	1036. s
• Cold leg loop seal opening	1150. s	1038. s
• First peak rod temperature	1179. s	1046. s
	711. K	596. K
• Second peak rod temperature	1260. s	-
	712. K	-
• Temperatures escalate again	1410. s	1460. s
• Secondary bleed initiated	1504. s	1505. s
• Maximum rod temperature	1514. s	1526. s
	742. K	726. K
• SIT empty	2548. s	2481. s
• Test terminated	3596. s	3600. s

4.4 Results of the test

The time history of the measured parameters characterising the transient process and the phenomena under consideration are plotted on **Figs. 4.1 - 4.30** (on the figures TS01 and TS02 are the saturation temperatures derived from the primary and secondary pressures). The first 20 minutes are presented in zoomed graphs: **Figs. 4.1z - 4.30z.** Results of local void probe measurements in comparison to the measured levels are shown in **Figs. 4.31** to **4.37.** (The position of 50 % void corresponds to the elevation of the probe). The figures are shown in Appendix 1.

4.5 Reproducibility of the test

In general an experiment must be repeated several times to get the expected transient and accurate database for code validation. This offers the opportunity to answer the question to what extent a test at the PMK-2 facility is reproducible. Since in the case of the CAMP-CLB test only

the third experiment (marked with **exp.2**) was declared as a successful one (and described in this paper) it is worth presenting some comparison plots with the results of the second one (**exp.1**) which had been rejected because of failure of recording the void probe data.

The main deviations in initial conditions were:	exp.1	exp.2
primary pressure	12.50 MPa	12.28 MPa,
secondary pressure	4.44 MPa	4.50 MPa,
core inlet temperature	538.6 K	539.6 K.

As a consequence of this differences the scram was in exp.1 at 50 s against 28 s. Nevertheless the main characteristics of the two tests are very similar - because of the close initial state of the facility and the same boundary conditions - as shown in Appendix 1 by **Figs. 4.38 - 4.40**. The main parameter of exp.1, the peak cladding temperature is 697 K at 1509 s against 742 K at 1514 s for the exp.2.

5. EVALUATION OF TEST RESULTS

The transient is initiated by opening the break. The system pressures in Fig. 4.1z show a characteristics typical to that of small break LOCA accidents: in early phase of the transient the primary pressure and pressuriser level decreases rapidly. The primary pressure (PR21) begins to stagnate as soon as upper head and SG hot collector reach saturation (Fig. 4.14z - TE24) and start voiding.

Scram is generated by low primary pressure of 11.18 MPa and from 28 s the core power reduces to decay heat level (see Fig. 4.30z). The pressuriser level decreases from its initial value (Fig. 4.7z - LE71), after the scram this becomes more rapid and the PRZ is empty at 41 s.

After secondary side isolation (scram + 9 s) the secondary pressure (PR81) quickly increases (Fig. 4.1z), but up to 469 s does not reach the steam dump set-point due the decrease of hot leg temperatures (Fig. 4.14z - TE22 and Fig. 4.15z - TE41).

MCP coast down begins at 80, at the end of pump run out natural circulation is established as can be seen in Fig. 4.24z. After 850 s there is no natural circulation, below 0.2 kg/s value of flow rate the curve of narrow range measurement (FL54) is valid.

Two HAs (modelled by one vessel) are available and the injection is actuated at a primary pressure of 6.0 MPa at the transient time of 159 s, but injection is immediately stopped by the increasing primary pressure (Fig. 4.2z - PR91 and Fig. 4.8 - LE91). The pressure and level increase are not limited because the check valve of the SIT is not modelled in PMK-2.

At 88 s the vessel level starts to decrease (Fig. 4.3z - LE11 and Fig. 4.4z - LE21) and at 240 s drops to the hot leg elevation and begins to stagnate. The hot leg loop seal clearing process is started at about 280 s (Fig. 4.5z - LE31 and Fig. 33). As a consequence, primary pressure increases and vessel level is depressed again, while loop flow rate (Fig. 4.24z) is decreasing.

At 352 s the hot leg loop seal (HLLS) starts to vent steam, as evidenced by the decreasing SG hot collector level (Fig. 4.5z - LE45) and void measurement (Fig. 34). This involves:

- recovering loop flow rate (Fig. 4.24z);
- enhanced SG heat transfer (see secondary pressure increase in Fig. 4.1z);
- decreasing primary and increasing secondary pressures leading to steam dump opening at 469 s, closing at 504 s (Fig. 4.28z);
- recovery of the vessel level (Fig. 4.3z);
- renewed SIT injection (Fig. 4.8z);
- the SG side of the cold leg loop seal (CLLS) starts to empty (Fig. 4.6z - LE46).

However, due to the fact that the break cannot remove the energy produced by the core, the primary pressure stabilises and SIT injection stops at about 600 s. This leads to further decrease of the primary mass inventory:
- vessel and SG collector levels are decreasing (Figs. 4.3z and 4.5z);
- loop flow decreases (Fig. 4.24z)
- heat transfer to secondary side deteriorates, secondary pressure increases only slowly.

At 897 s the steam dump opens again (Fig. 4.28z), resulting in temporarily improved primary to secondary heat transfer, increased loop flow and vessel level (Fig. 4.3z). However, stagnation conditions soon prevail, the SG side of the CLLS continues to empty (Fig. 4.6z - LE46) and opens at 1150 s.

When the core collapsed level drops to about 3 m fuel rod imitator temperatures begin to rise (1115 s) not only at core outlet (Fig. 4.12z), but at an elevation 0.45 m below as well (Fig. 4.11z). The first peak is limited to 711 K at 1179 s (Fig. 4.13z) due to partial opening of the CLLS: steam vented via the CLLS to the break results in core level recovery (Fig. 4.3z) and partial rewetting of heater rods (Fig. 4.11z).

Oscillatory behaviour can be observed for about 200 s in loop flow (Fig. 4.24 - FL54), cold leg (Fig. 4.36 - LE52) and vessel levels (Fig. 4.3) that limits the second maximum of heater rod temperatures (712 K at 1260 s). Finally, as loop parameters tend to stabilise and mass inventory further decreases, core temperatures again escalate from 1410 s (Figs. 4.12z and 4.13z).

At a heater rod temperature of 730 K secondary bleed is started (Fig. 4.28). Condensation on the SG primary side quickly reduces primary pressure (Fig. 4.1), enhances loop flow temporarily (Fig. 4.24 - FL54) and allows core level to recover: as a consequence, heater rods are rewetted after a maximum temperature of 742 K at 1514 s (Fig. 4.13z - TE19). SIT injection is activated, leading to increasing vessel inventory.

As a consequence of the secondary bleed without feed the level in SG is decreasing (Fig. 4.9) and some of the temperature sensors (thermocouples) in the SG secondary side show superheated steam after 2000 s, as can be seen in Fig. 4.20 (TE80, TE82), Fig. 4.21 (TE83, TE85) and Fig. 4.22 (TE86).

At 2548 s the SIT runs empty (injection is stopped by level criterion, see Fig. 4.8) that again leads to decreasing mass inventory. Repeated core temperature increase after some 2000 s later should be limited by the low pressure injection. The set-point of low pressure ECCS was not reached during the one hour of the transient.

6. POST TEST ANALYSIS

6.1 Modelling aspects of RELAP5 analyses

The RELAP5/MOD3 code was the tool for most of the pre-test and post-test analyses of PMK-2 tests with good experiences. The short summary of the RELAP5 input model and nodalisation is given below.

A general RELAP5 model for the PMK-2 facility has been developed and validated already for the analyses of different IAEA Standard Problem Tests [4] and in the different EU-PHARE projects (pre- and post-test calculations) [9]. RELAP5 model has been continuously upgraded during the last decade on the basis of experiences of different PMK tests and taking into consideration requirements of the new RELAP5 versions. The standard PMK-2 nodalisation is given in **Fig. 6**. The nodalisation scheme consists of 119 volumes including 14 time dependent volumes, 128 junctions including 5 time dependent junctions and 92 heat structures with 395 mesh points. Some details are given in **Table 6.1.**

As the main character of the input model the core is represented by nine control volumes in one channel, seven from them covering the active lengths of the heated core. The steam generator heat transfer tube bundle is simulated by three horizontal channels, with three control volumes in each, while in the secondary side there are three vertical channels.

Table 6.1

PMK-2 nodalisation

GROUPS OF COMPONENTS	COMPONENT NUMBERS	NUMBER OF NODES
Hot leg	100-112	7
Primary side of steam generator	120-156	19
Cold leg from steam generator collector to pump simulator bypass	160-164	3
Pump simulator bypass valves MV11, MV12, PV11	190-192	-
Pump simulator bypass tubes	166-176	6
Cold leg from pump simulator tubes to downcomer	178-186	5
Reactor vessel	200-250	26
LPIS system	620-623	2
HPIS system	624-625	1
Accumulators SIT-1 and SIT-2	660-682	4
Pressuriser, surge line, spray line, safety valve	400-450	14
Break simulator	618-619	1
Feedwater simulation	580-592	4
Secondary side of steam generator	500-560	15
Safety, relief and steam dump valves	598-628	4

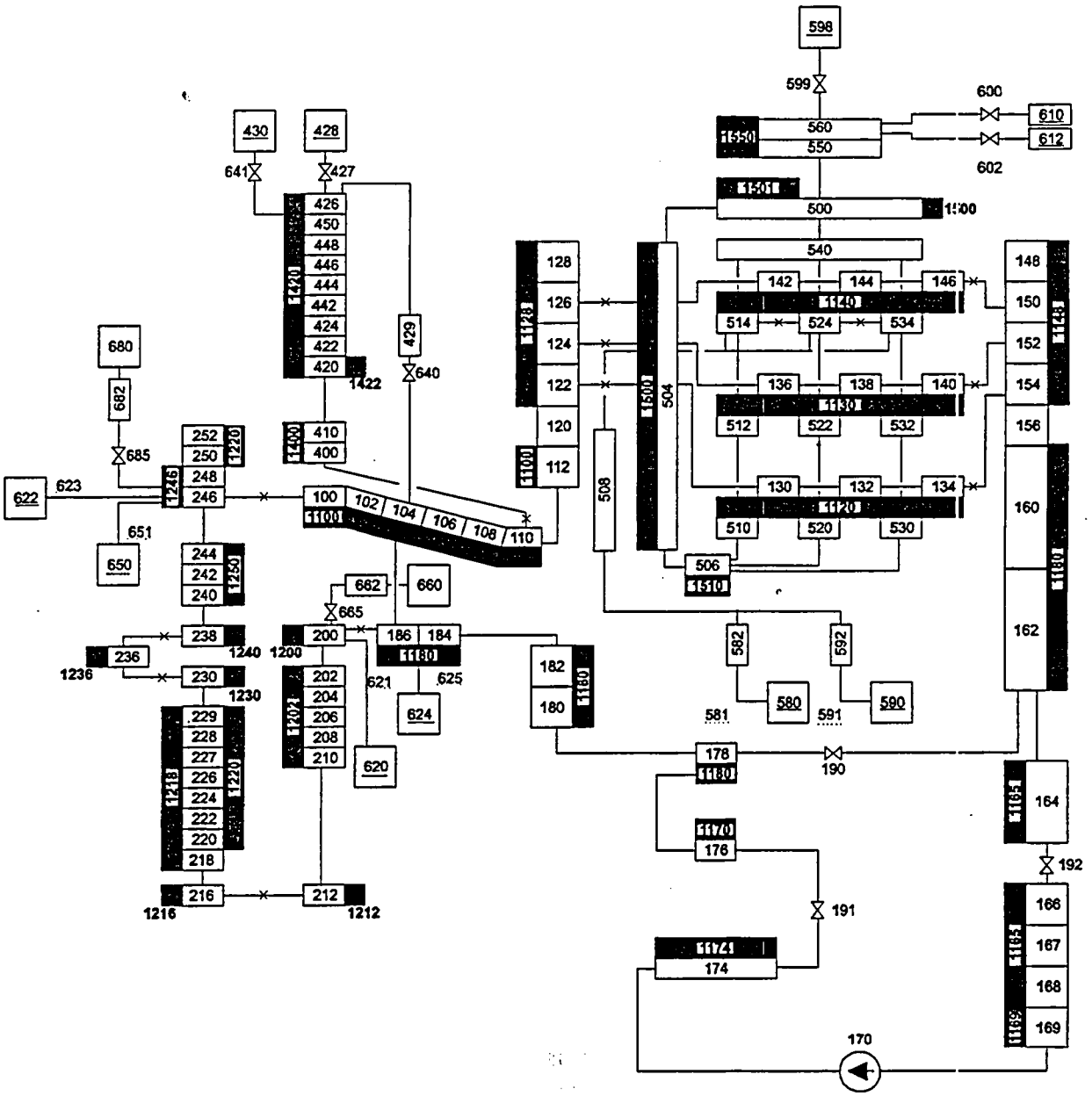

Fig. 6
PMK-2 nodalisation scheme for RELAP5/mod3.2

6.2 Initial and boundary conditions

The nominal and the measured initial conditions together with the data from the post test calculation (after 100 s steady-state run) are presented in **Table 4.1.** The scenario of the actions representing the boundary conditions are shown in **Table 4.2** (Tables are in Section 4).

6.3 Run parameters and critical flow options

In the post-test calculation a time step limit of 0.01 s was chosen. For the heat losses from primary to the environment 4 W/m^2K, from SG 8 W/m^2K as heat transfer coefficients were used. At the break and the steam dump valve the Henry-Fauske critical flow model was applied, the

discharge coefficient was set to 0.85, while the thermal nonequilibrium constant to 0.14.

The post-test was calculated using the developmental code version RELAP5/mod3.2.2Gamma [8] on a PC Pentium II 350 computer under Windows-NT with performances: CPU time/transient time = 18887s/3700s = 5, advancements = 548185 and emass/system mass = 0.045 kg/1002.7 kg.

6.4 Sequence of major events

The results of the post-test calculation in term of the sequence of major events are presented in **Table 4.3**. The time history of the characteristic parameters are displayed on comparison figures in Appendix 2 by **Figs. 6.1 - 6.20**.

Although the agreement between the measured and calculated curves is fairly good some remarks must be added to the figures:

- Figs. 6.2 and 6.9: the steam dump valve opens three times in the calculation instead of two as in the test (in the calculation the pressure controlled operation of the BRU-A and the operator initiated bleed are modelled by two valves: 600 and 602 - see Fig. 6).
- Figs. 6.3, 6.4 and 6.9: the critical flows seem to be low, but higher discharge coefficient leads to loss of the core heat-up (see Chapter 7);
- Figs. 6.7 and 6.8: the pressure and level increase in the calculation is limited because the check valve in RELAP accumulator model is included;
- Figs. 6.11, 6.13 and 6.14: the hot leg loop seal behaviour is good (compare LE11 and RV calculated levels on Fig. 6.11), but there is no stagnation after HLLS clearing, so the cold leg loop seal opens earlier by about 120 s, an oscillation appears after this as it was in the test because of incomplete loop seal clearing;
- Fig. 6.11: the minimum collapsed level in RV is predicted deeper than the measured level by about 0.5 m
- Figs 6.15 and 6.16: the effect of SIT injection on the cold part temperatures is higher in the test, after the termination of the injection (2500 s) the decrease of TE63 continues unexplainable;
- Fig. 6.20: the first core heat-up in the calculation is very short because total rewetting occurs before oscillatory behaviour can be observed.

7. SENSITIVITY CALCULATIONS

During the post-test analysis it was found, that the core heat-up is very sensitive to small changes in some parameters leading to suppression of the temperature excursions. Two types of sensitivity study were performed to see the effect of two input parameters: the requested (maximum) time step and the heat loss (i.e. heat transfer coefficient to the environment) of the steam generator.

7.1 Study on the Maximum Time Step

In first series four calculations were made with time step limitations as follows:

dt = 0.1 s, 0.05 s, 0.01s and 0.001s.

The results are presented by curves of some sensitive output parameters: the timing of steam dump valve operation and the heater rod temperature escalation as well as by secondary pressure and reactor vessel level (**Figs. 7.1 - 7.4**). In Figs. 7.1 and 7.2 can be seen that with dt = 0.001 and 0.01 s in time period of 400 - 800 s the first BRU-A opening and the secondary pressure is very close to the measured one, but later, at 1200 s a third actuation occurs due to the quicker pressure increase. Using higher time step limit the first opening shifted near to 700 s and the third action is disappeared. The rod temperature peak at 1500 s is the highest with dt = 0.05 s and lowest with 0.001 s time step. Finally the first small temperature increase disappears totally with dt = 0.1 s time step.

To investigate the changes between dt = 0.05 and 0.01 s new runs with requested time step = 0.02 and 0.025 s were performed. In both cases the results are very close together but unexpected: **Figs. 7.5 - 7.7** present surprising changes in timing of valve operations (those aren't between dt = 0.05 and 0.01 s but between 0.1 and 0.05 s), in RV collapsed level (it increases at 1085 s above 3.0 m and sharply oscillates between 1100 and 1500 s of transient time), finally in rod temperature (its increase disappeared totally as a consequence of oscillation).

7.2 Study on the SG Heat Losses

The heat transfer coefficient to the environment at SG was varied between 6 and 15 W/m^2K. The results are shown in **Figs. 7.8 - 7.14.** As shown in Figs. 7.8 - 7.9 if the value is 12 or greater the BRU-A valve opens only two times. There is no effect on the SG cold collector level history (Fig. 7.9), still at the other side of the CLLS (Fig. 7.11), as well as at the RV level (Fig. 7.12) the oscillation like in Fig. 7.6 turns up. Simultaneously the temperature excursion disappears (Fig. 7.14).

7.3 Study on discharge coefficient

The discharge coefficient of HF critical flow model was varied between 1.0 and 0.85. The results for values of 0.85 (the presented calculation) and 0.90 are shown in **Figs. 7.15 - 7.22.** (Using discharge coefficients of 0.95 and 1.0 resulted in the same behaviour as for 0.90). The history of displayed parameters shows similar changes - a strong oscillation (see Figs. 7.18 and 7.20) and the absence of the temperature excursion (see Fig. 7.22) - as in the cases of time step and heat loss variations.

The "bifurcation type" behaviour encountered in parametric studies could be the result of the code calculating by different constitutional models depending on the maximum time step or secondary heat losses. Because there is no explanation of the strong oscillation during the partial clearing of the cold leg loop seal till now this was reported as a new RELAP5 User Problem.

8. CONCLUSIONS

The 2 % SBLOCA test was performed according to the test definition. The test results show a number of important phenomena:

- effect of hot leg loop seal behaviour on primary flow, steam generator heat transfer, hydroaccumulator injection
- inefficiency of hydroaccumulators on the downcomer side if the break is too small to depressurise below secondary pressure
- substantial core heat-up due to loop seal effects
- effectiveness of secondary bleed to recover the core and reinitiate hydroaccumulator injection.

The test may be quite demanding for code validation in the following aspects:

- partial clearing of the loop seals
- vapour condensation in the horizontal, parallel tubes of the SG
- effect of condensation in the SG on primary mass inventory distribution (i.e. vessel and loop levels)
- prediction of the oscillatory behaviour during partial clearing of the CLLS, including repeated core heat-up.

Results of post-test analysis with RELAP5/mod3.2.2Gamma show quite good agreement regarding the main system parameters and partly the important phenomena as presented in the previous chapters.

The "bifurcation type" behaviour encountered in parametric studies could be the result of the code calculating by different constitutional models depending on the maximum time step or secondary heat losses. This behaviour needs further investigation. It was discussed with the code developers and it was taken as a new RELAP5 User Problem.

9. REFERENCES

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[9] L. Perneczky et al.: RELAP5/MOD3.2.2 Pre-Test Analysis for Test 3. 7.4% Cold Leg Break Without HPIS and With Secondary and Primary Bleed. PH SRR3/95 Meeting, Budapest, September 30 - October 1, 1999.

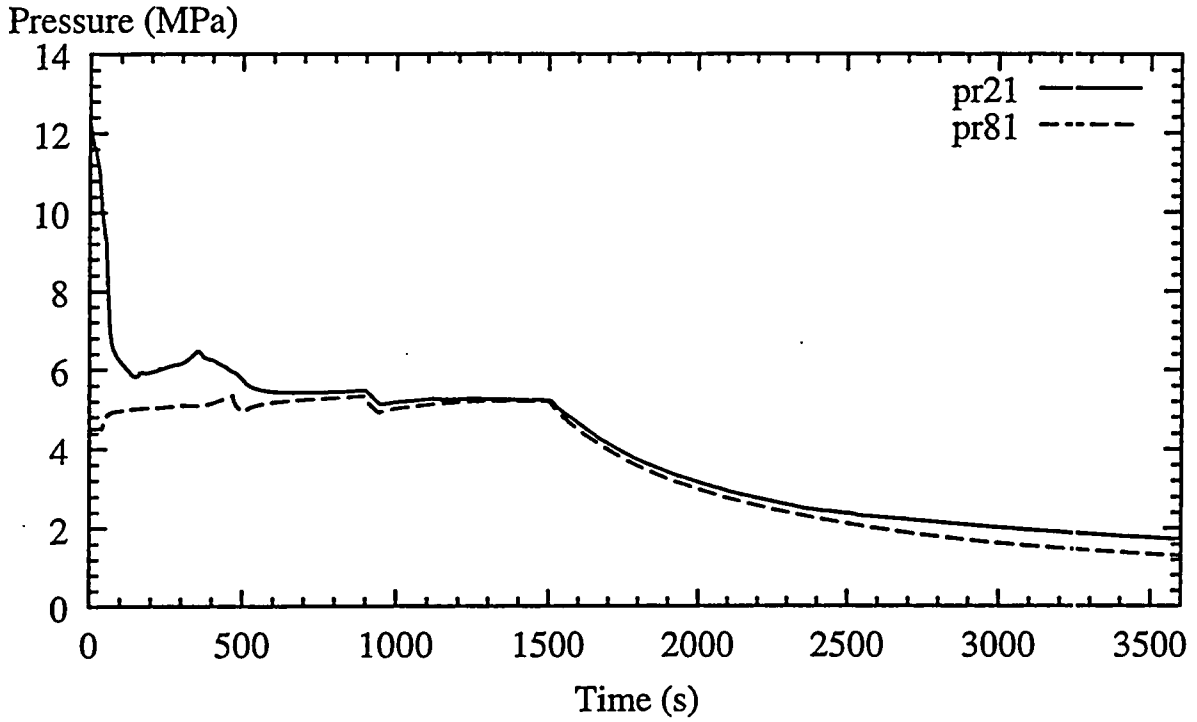
[10] L. Perneczky and I. Tóth: Pre-test Calculations of PMK-2 Tests Using RELAP5/MOD3.2.2Beta, Fall 1998 CAMP Meeting, Bethesda, October 21-23, 1998.

[11] I. Tóth et al.: Test Results of the PMK 2% SBLOCA Experiment, Spring 2000 CAMP Meeting, Terrasini, April 17-19, 2000.

APPENDIX 1

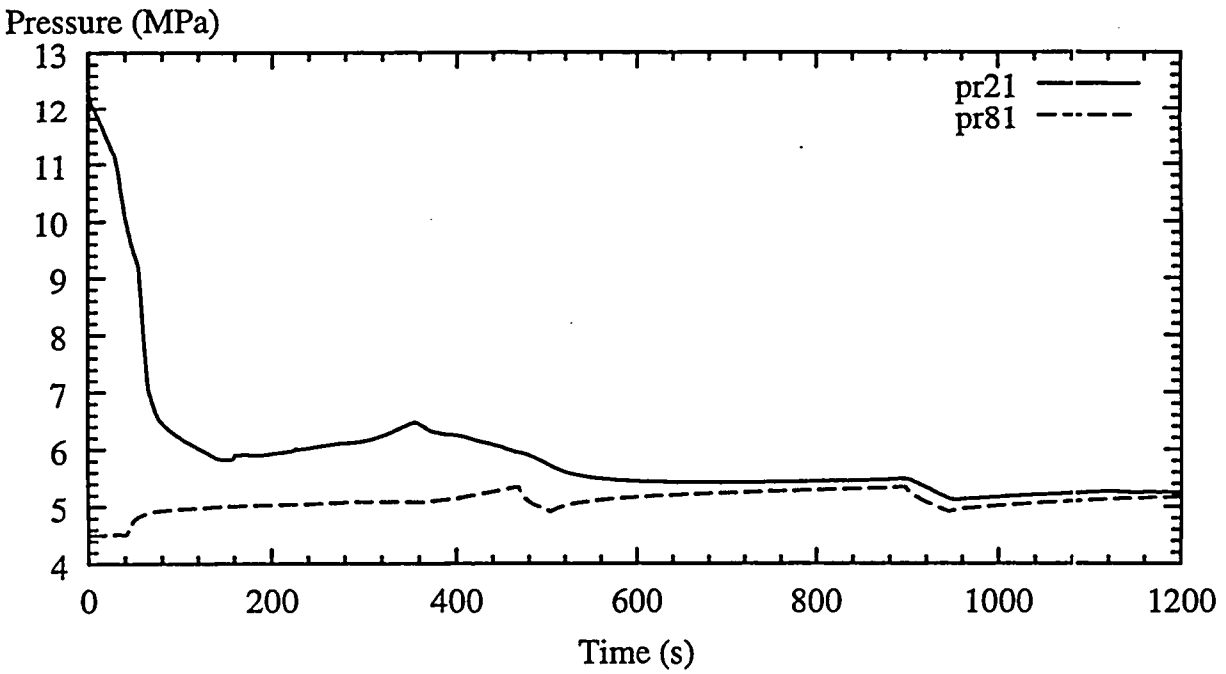
PMK-2 CAMP EXPERIMENT

Fig. 4.1 Primary (UP) and Secondary Pressures



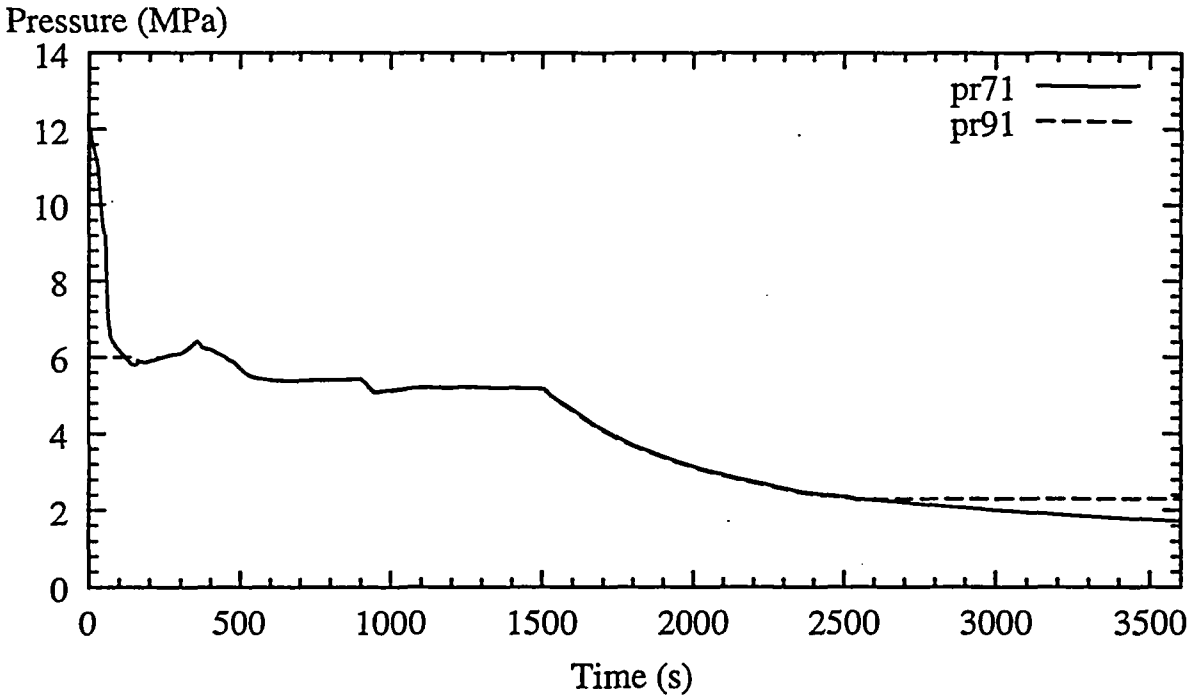
PMK-2 CAMP EXPERIMENT

Fig. 4.1z Primary (UP) and Secondary Pressures



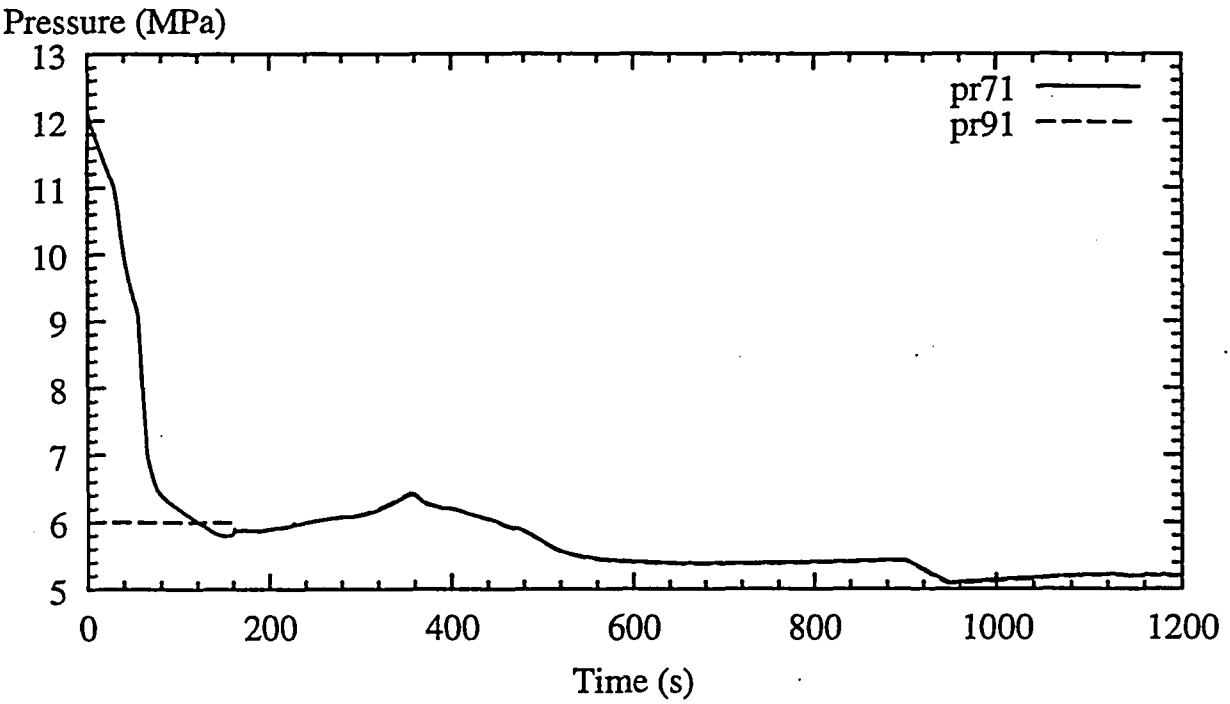
PMK-2 CAMP EXPERIMENT

Fig. 4.2 Pressurizer and Hydroaccumulator Pressures



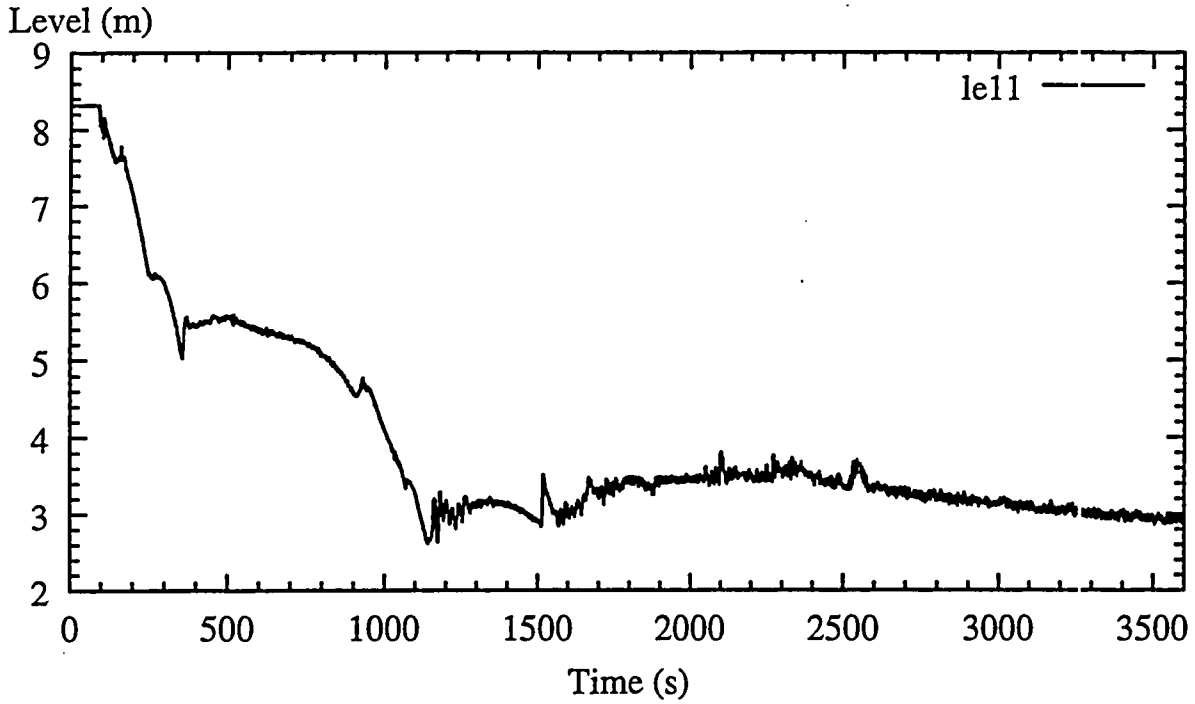
PMK-2 CAMP EXPERIMENT

Fig. 4.2z Pressurizer and Hydroaccumulator Pressures



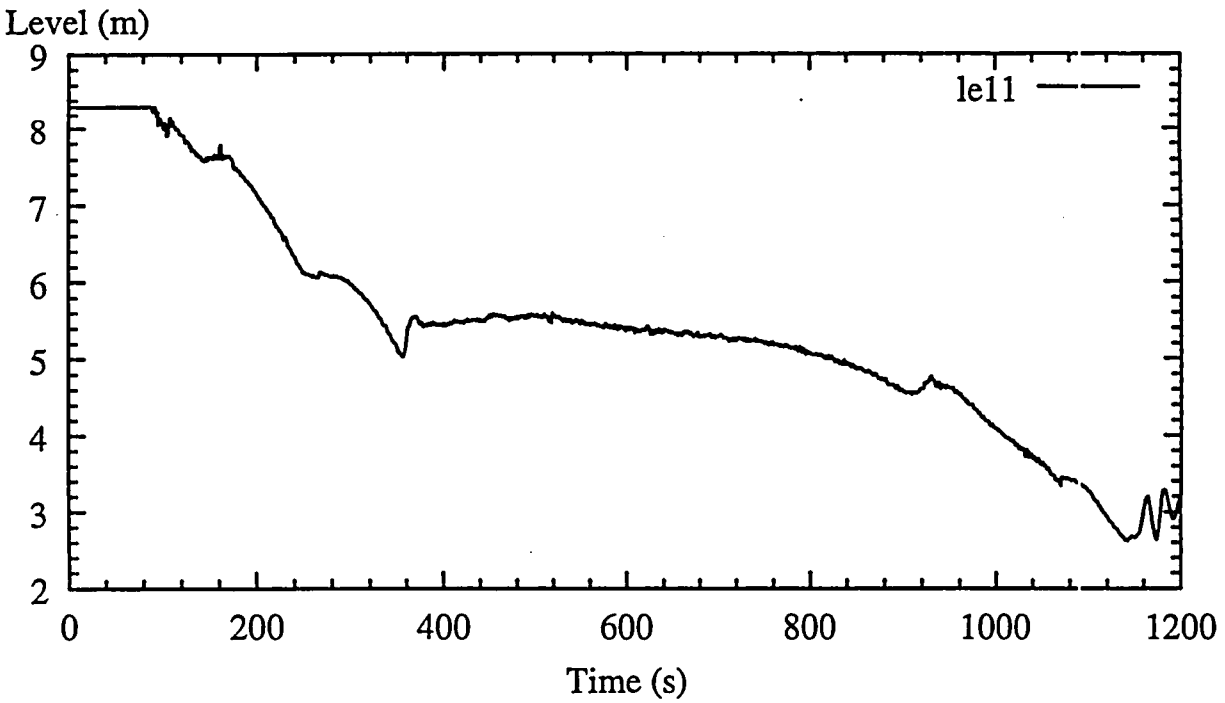
PMK-2 CAMP EXPERIMENT

Fig. 4.3 Collapsed level in the Vessel



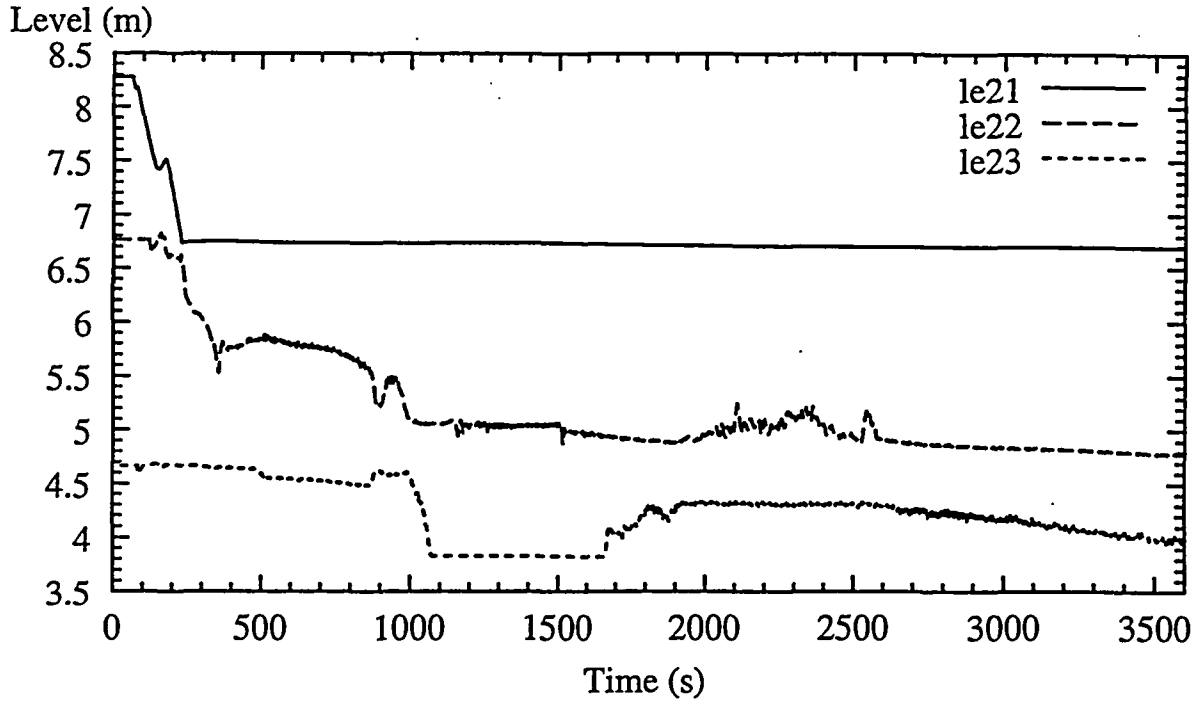
PMK-2 CAMP EXPERIMENT

Fig. 4.3z Collapsed level in the Vessel



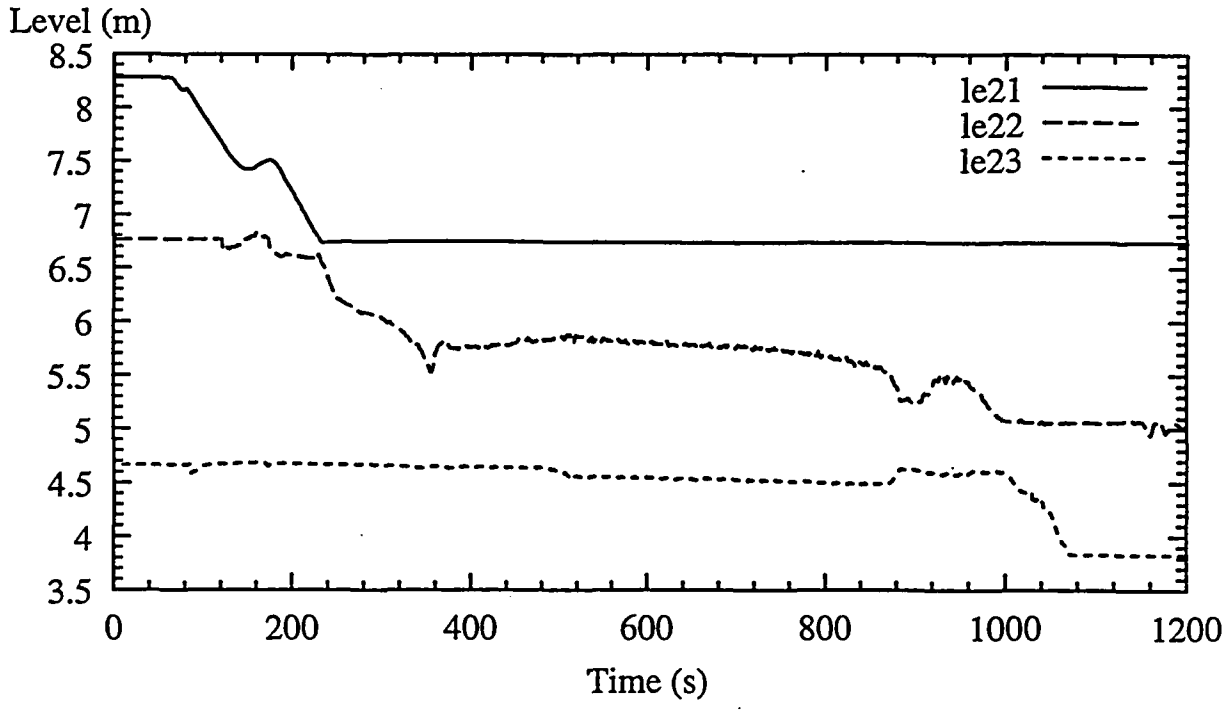
PMK-2 CAMP EXPERIMENT

Fig. 4.4 Levels in the Vessel



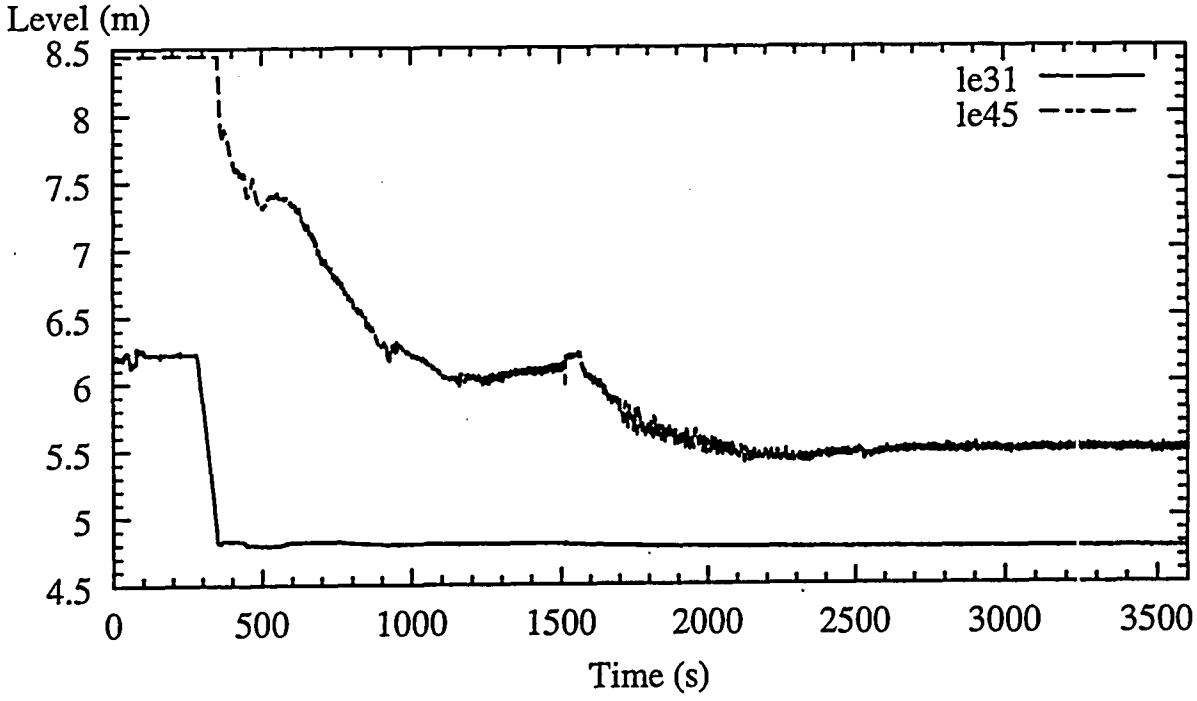
PMK-2 CAMP EXPERIMENT

Fig. 4.4z Levels in the Vessel



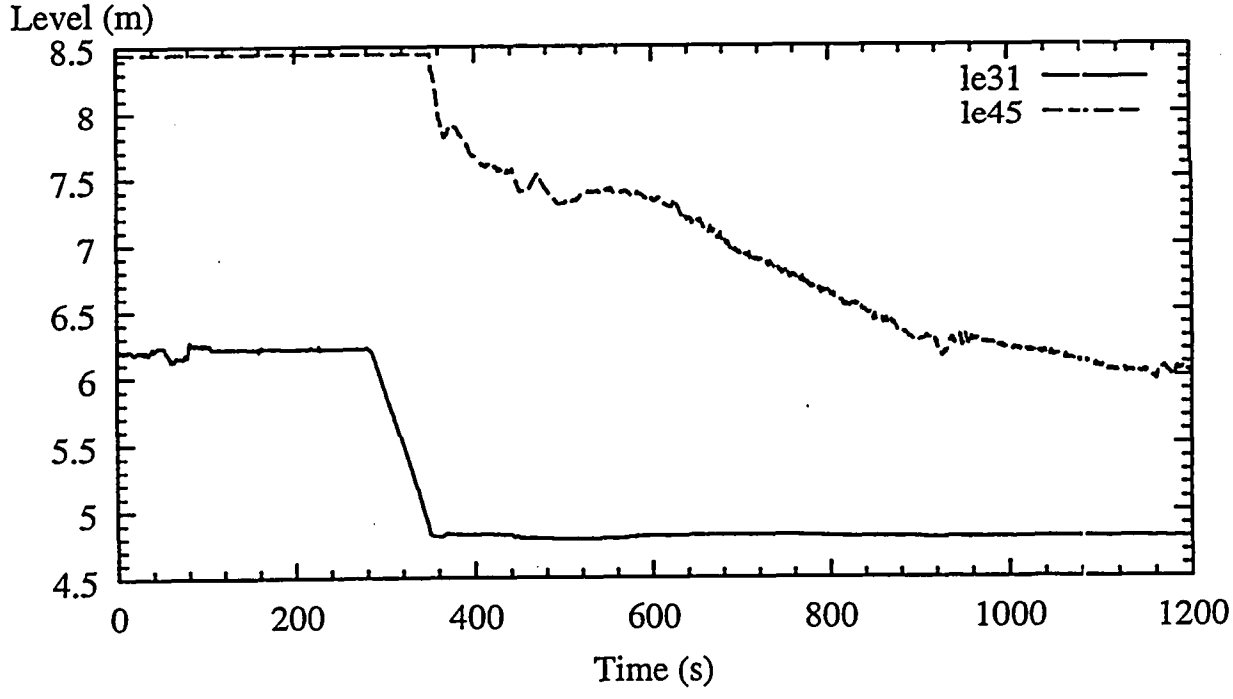
PMK-2 CAMP EXPERIMENT

Fig. 4.5 Hot Leg Loop Seal Level



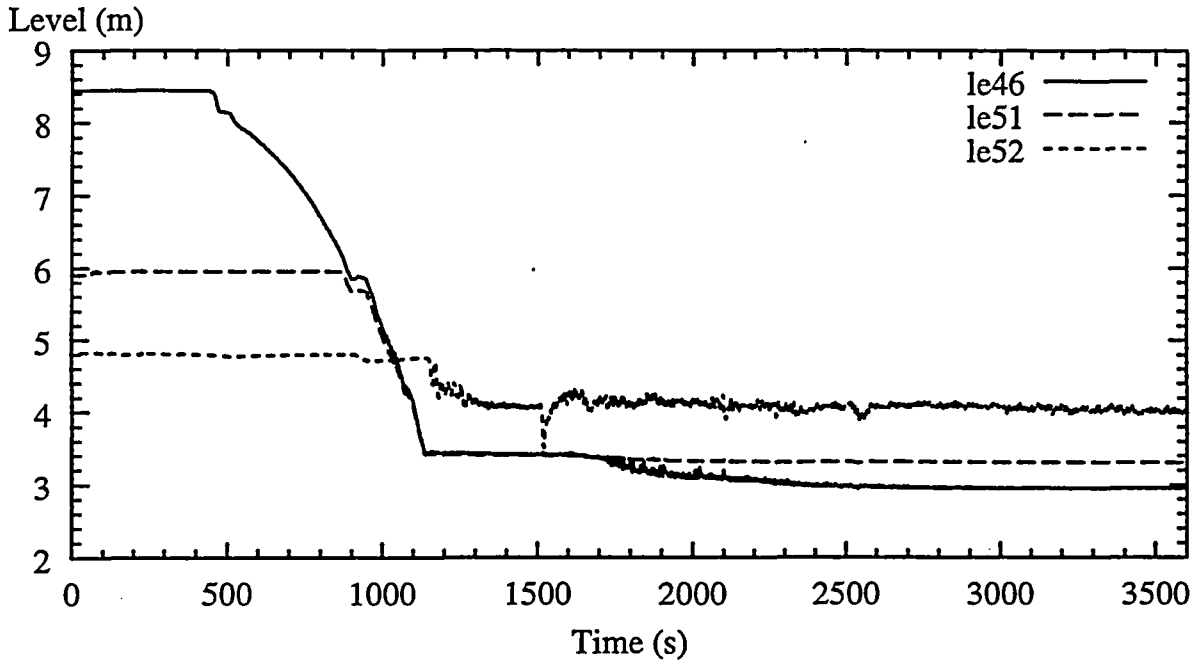
PMK-2 CAMP EXPERIMENT

Fig. 4.5z Hot Leg Loop Seal Level



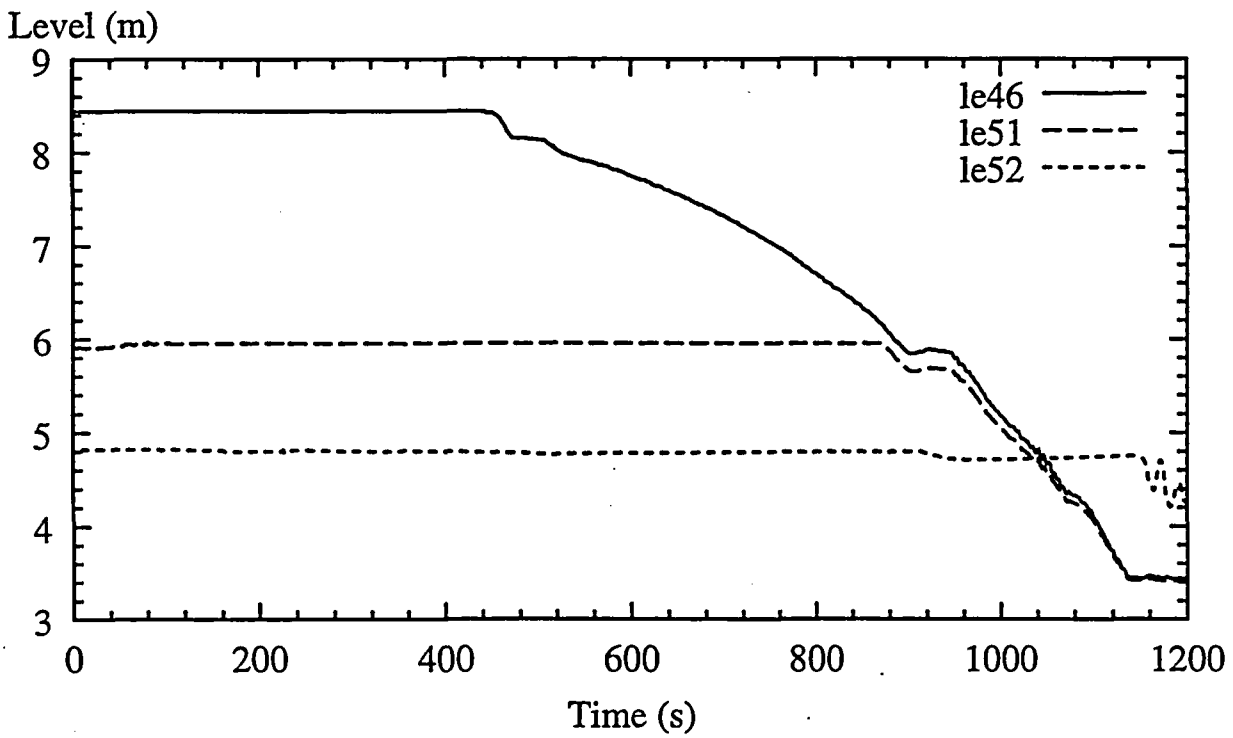
PMK-2 CAMP EXPERIMENT

Fig. 4.6 Cold Leg Loop Seal Levels



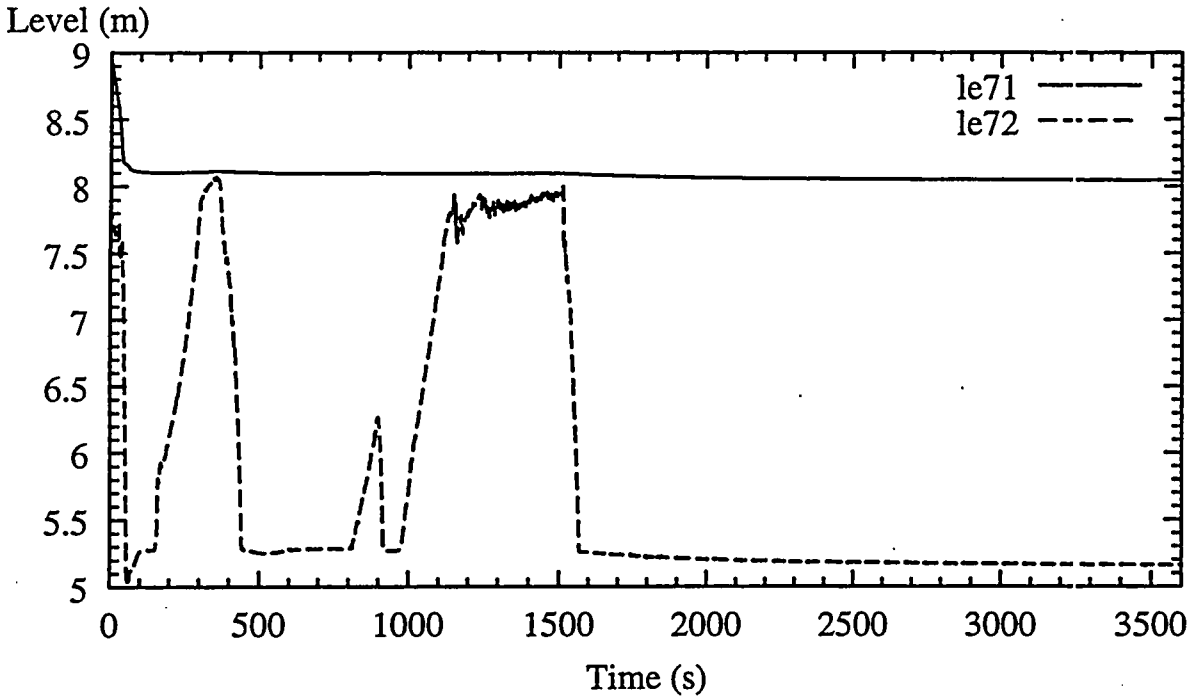
PMK-2 CAMP EXPERIMENT

Fig. 4.6z Cold Leg Loop Seal Levels



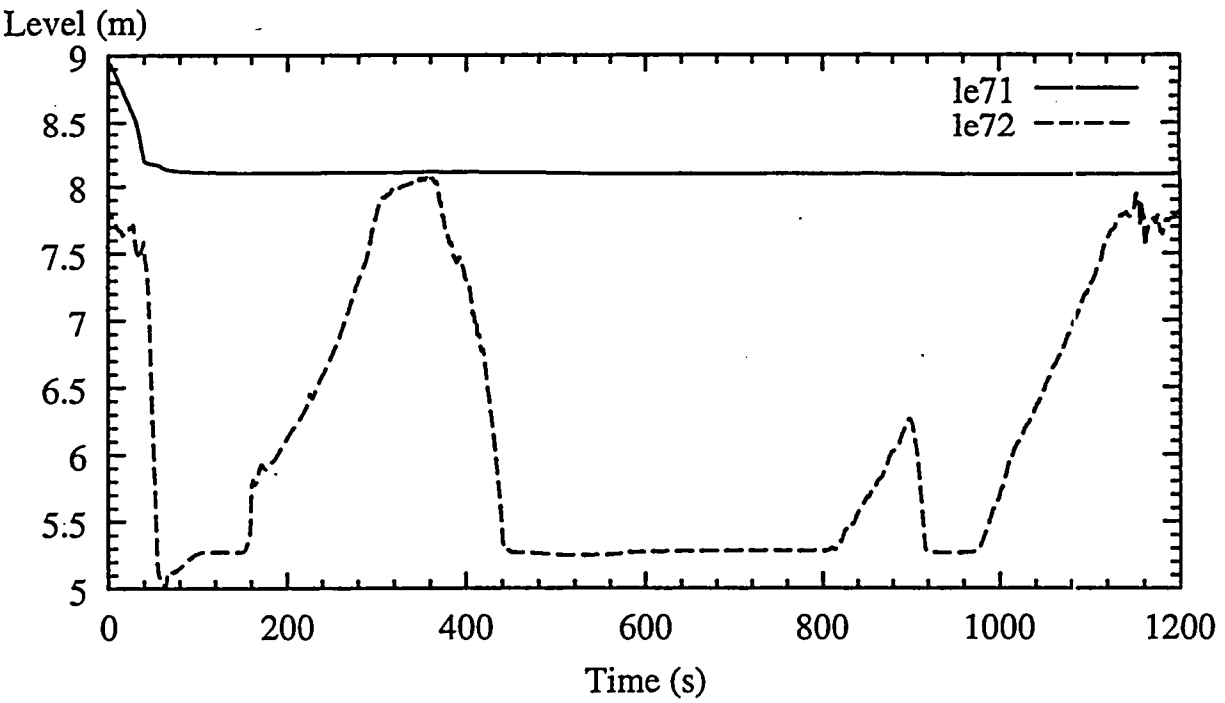
PMK-2 CAMP EXPERIMENT

Fig. 4.7 Pressurizer and Surge Line Level



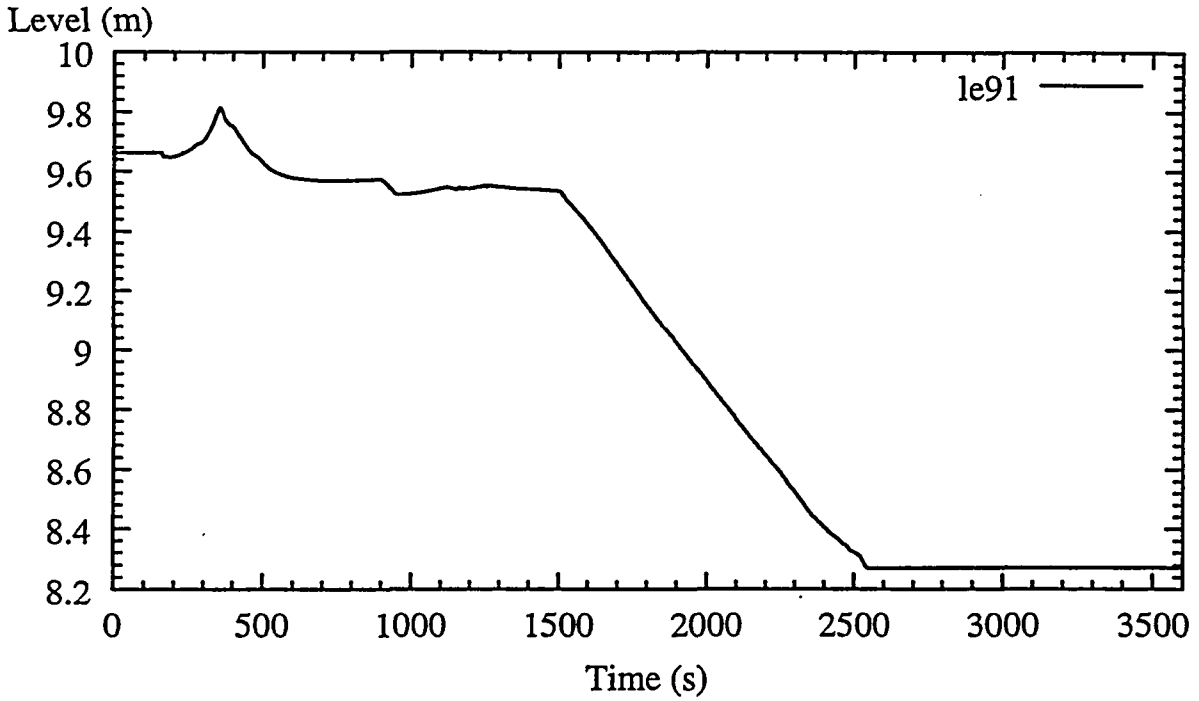
PMK-2 CAMP EXPERIMENT

Fig. 4.7z Pressurizer and Surge Line Level



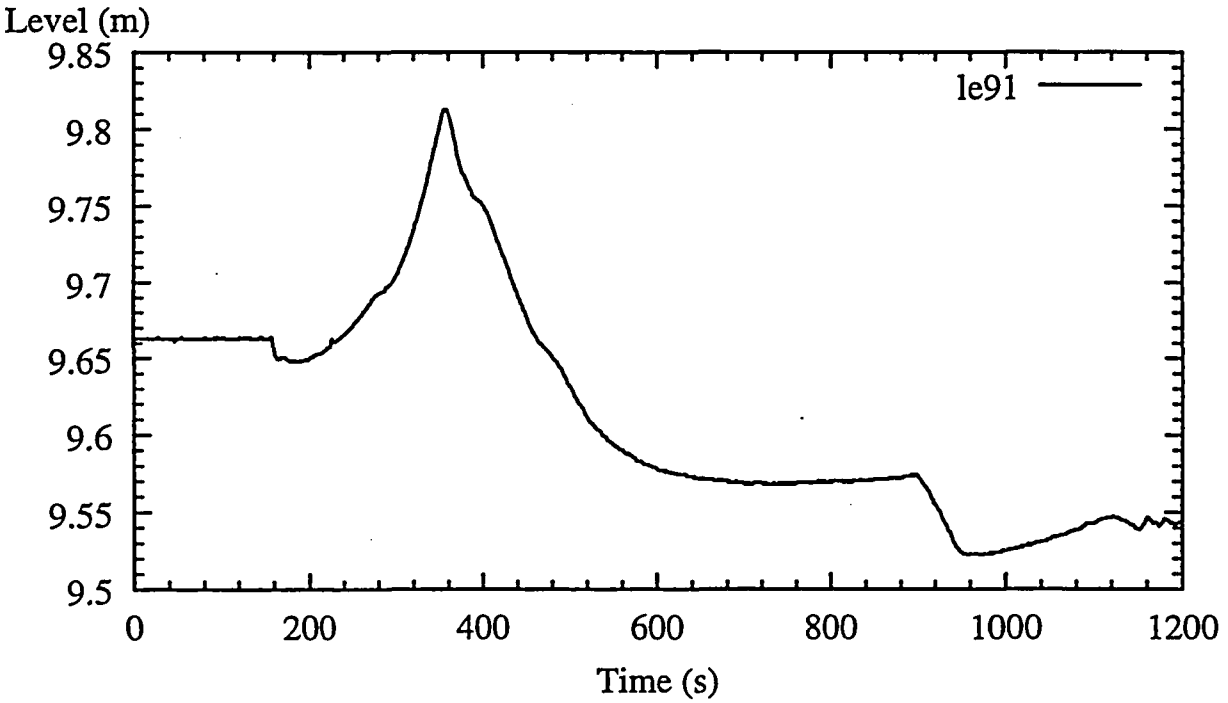
PMK-2 CAMP EXPERIMENT

Fig. 4.8 Hydroaccumulator Level



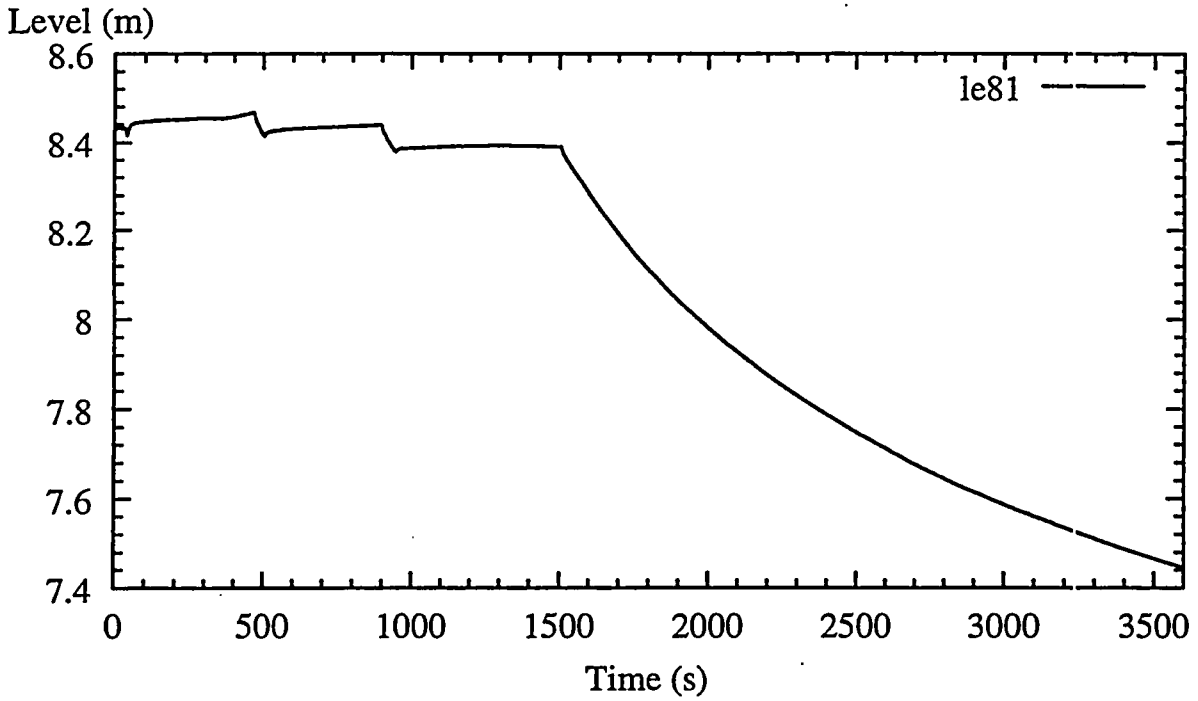
PMK-2 CAMP EXPERIMENT

Fig. 4.8z Hydroaccumulator Level



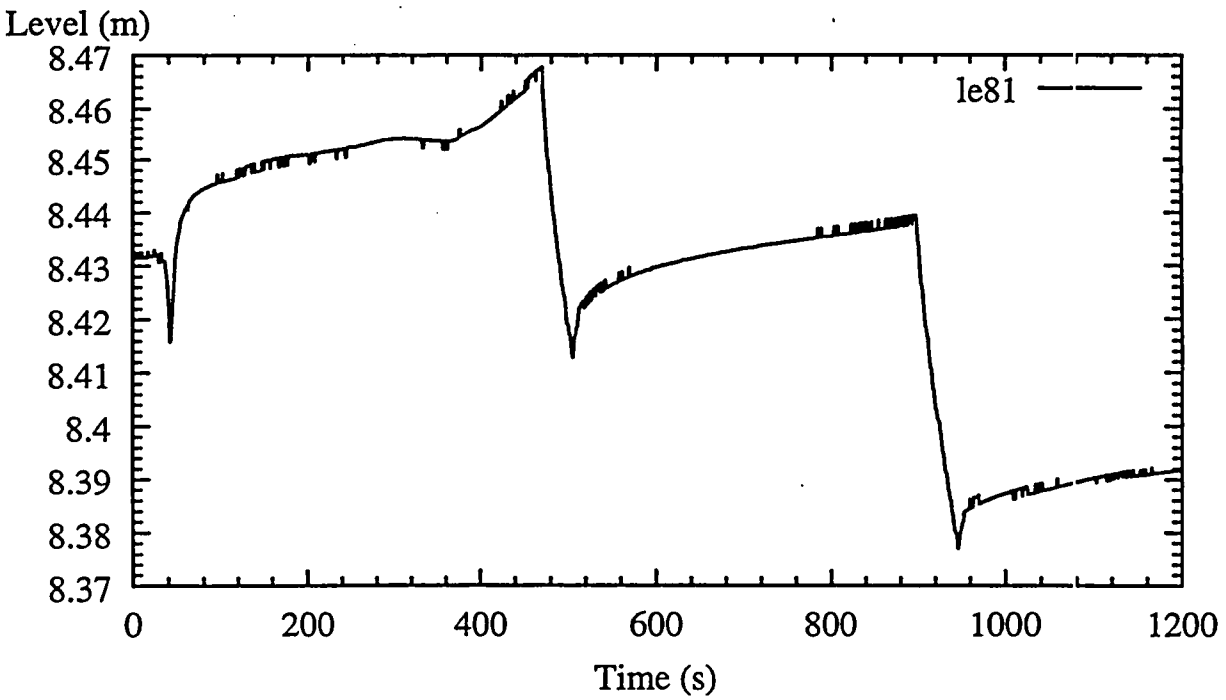
PMK-2 CAMP EXPERIMENT

Fig. 4.9 SG Secondary Level



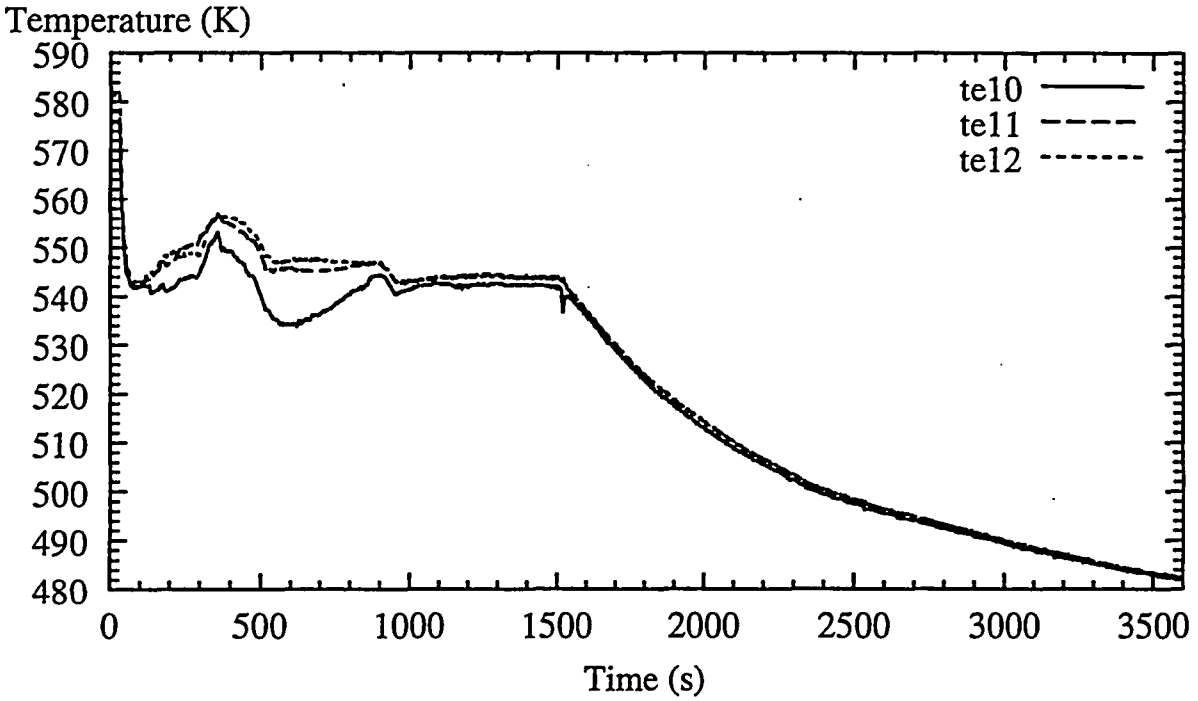
PMK-2 CAMP EXPERIMENT

Fig. 4.9z SG Secondary Level



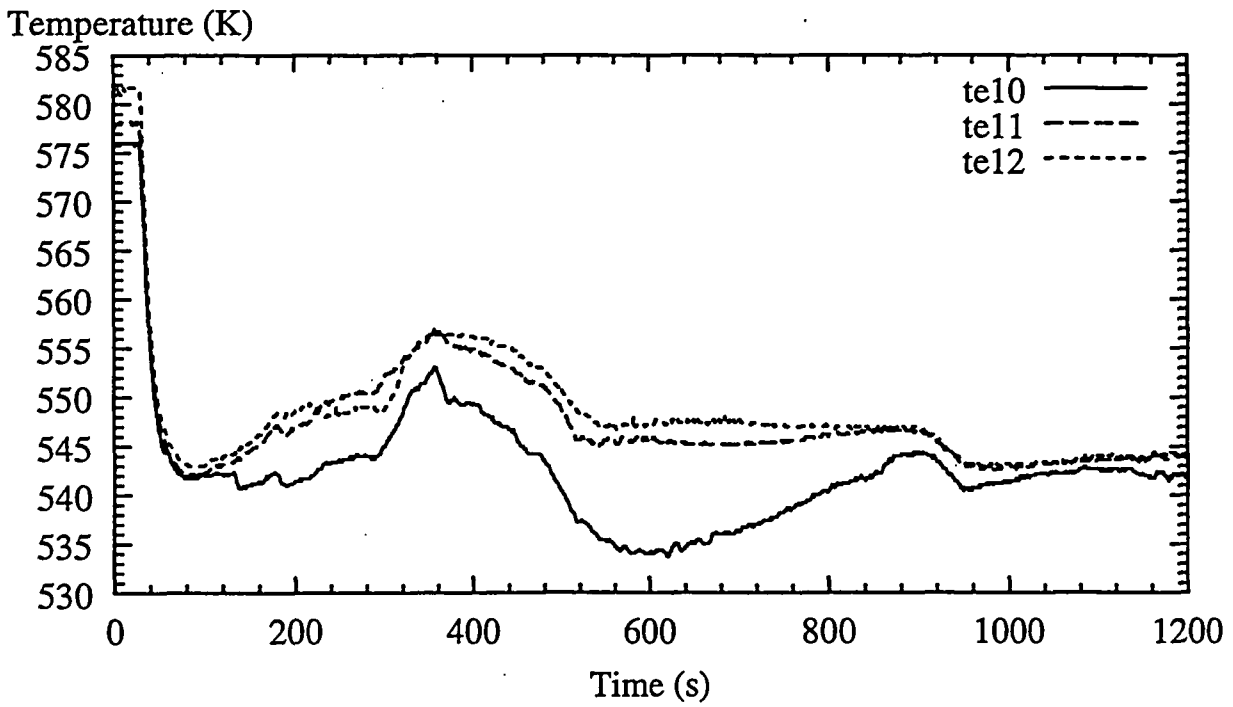
PMK-2 CAMP EXPERIMENT

Fig. 4.10 Heater Rod Temperatures



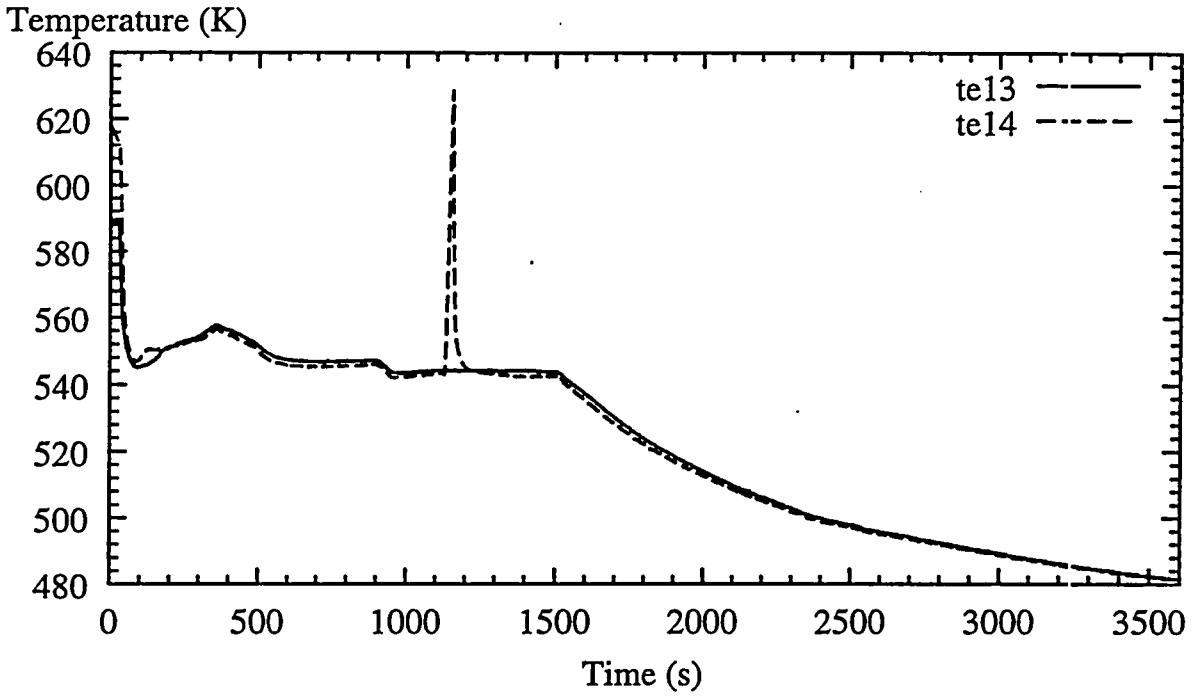
PMK-2 CAMP EXPERIMENT

Fig. 4.10z Heater Rod Temperatures



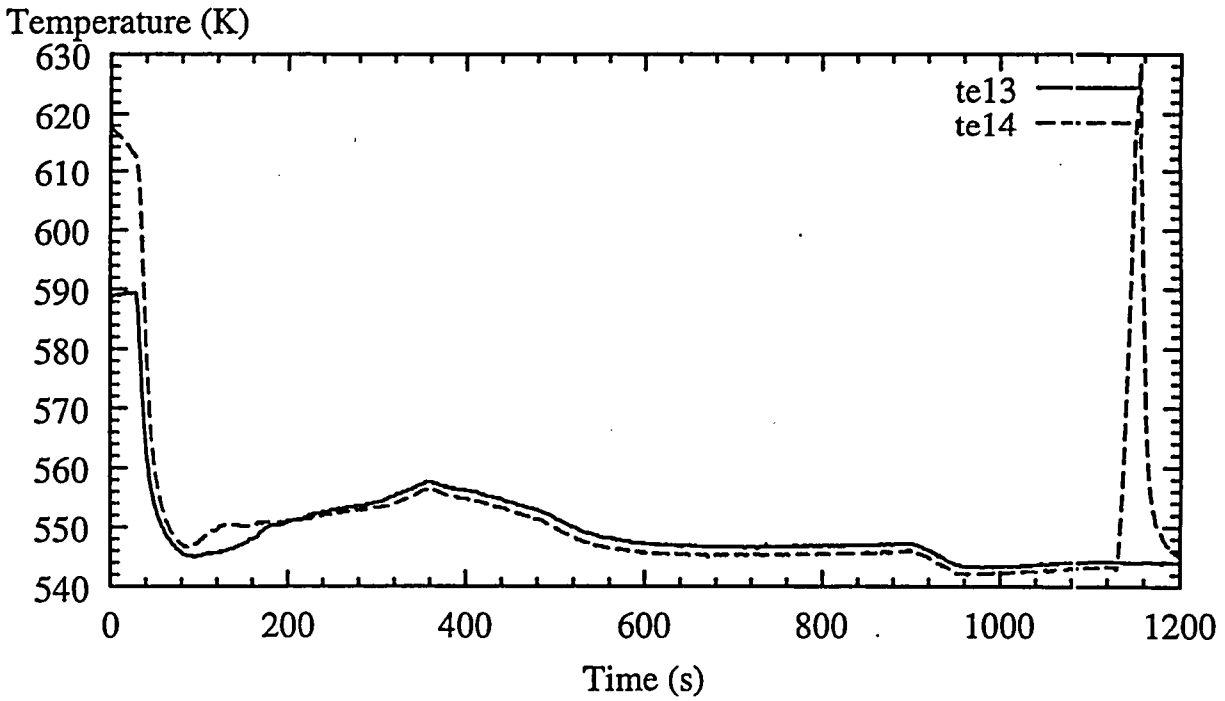
PMK-2 CAMP EXPERIMENT

Fig. 4.11 Heater Rod Temperatures



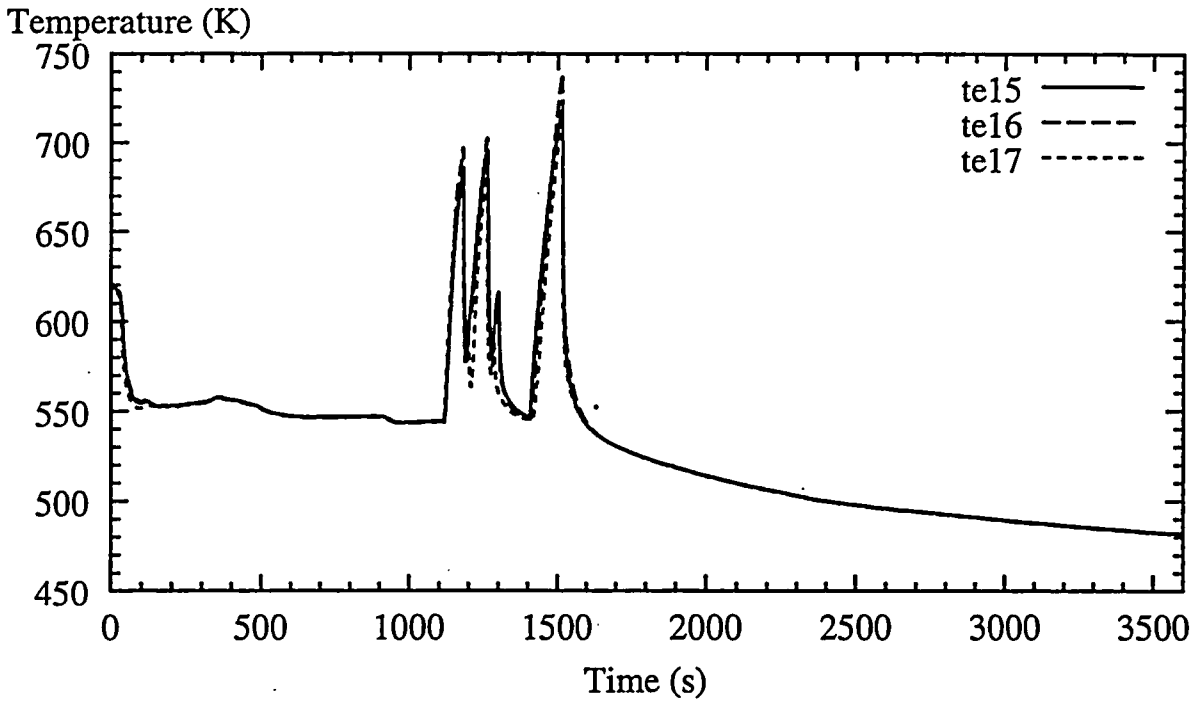
PMK-2 CAMP EXPERIMENT

Fig. 4.11z Heater Rod Temperatures



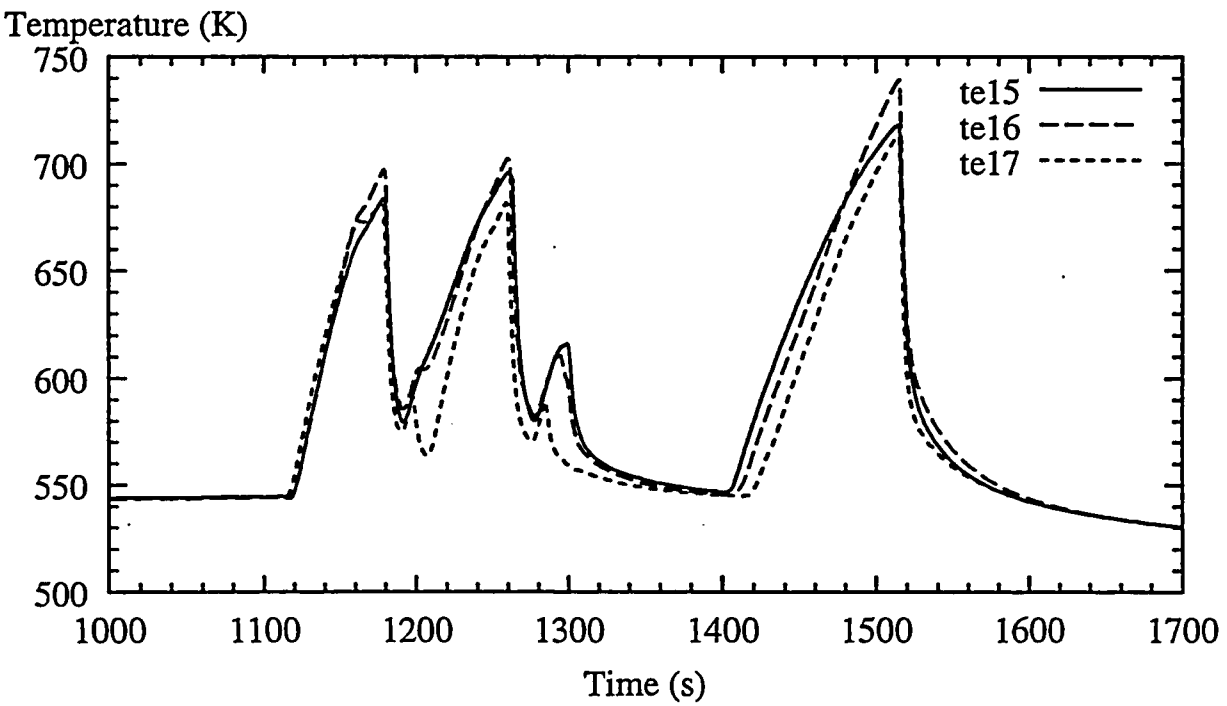
PMK-2 CAMP EXPERIMENT

Fig. 4.12 Heater Rod Top Temperatures



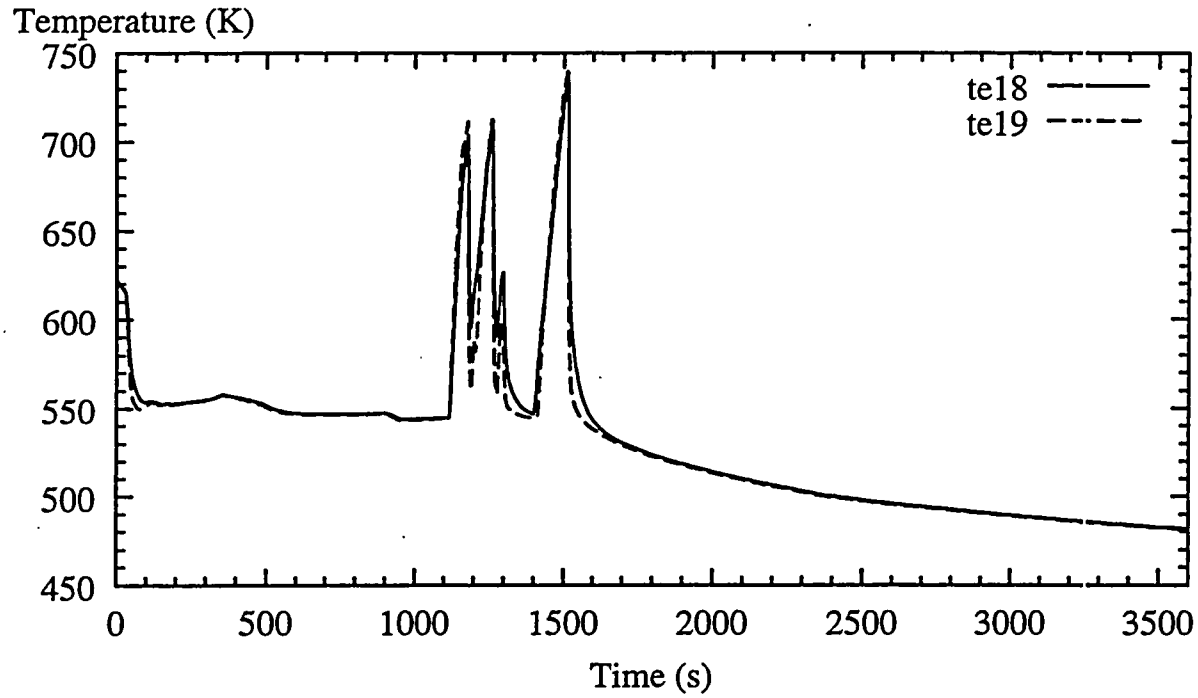
PMK-2 CAMP EXPERIMENT

Fig. 4.12z Heater Rod Top Temperatures



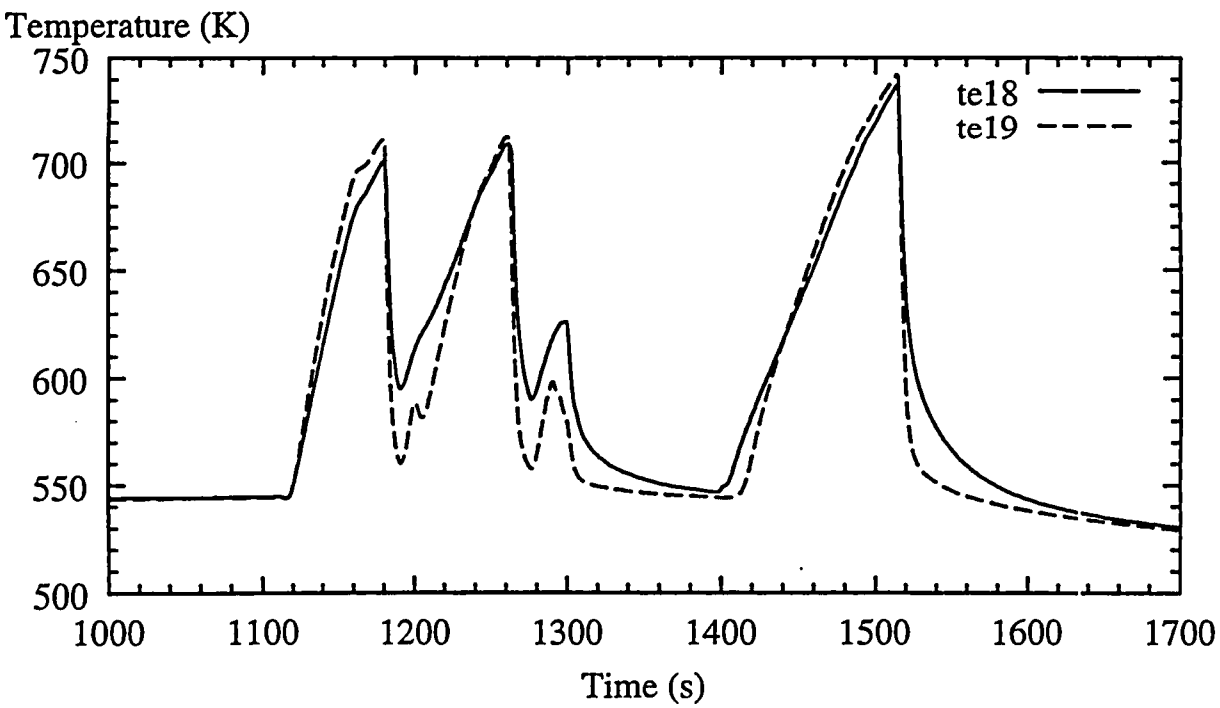
PMK-2 CAMP EXPERIMENT

Fig. 4.13 Heater Rod Top Temperatures



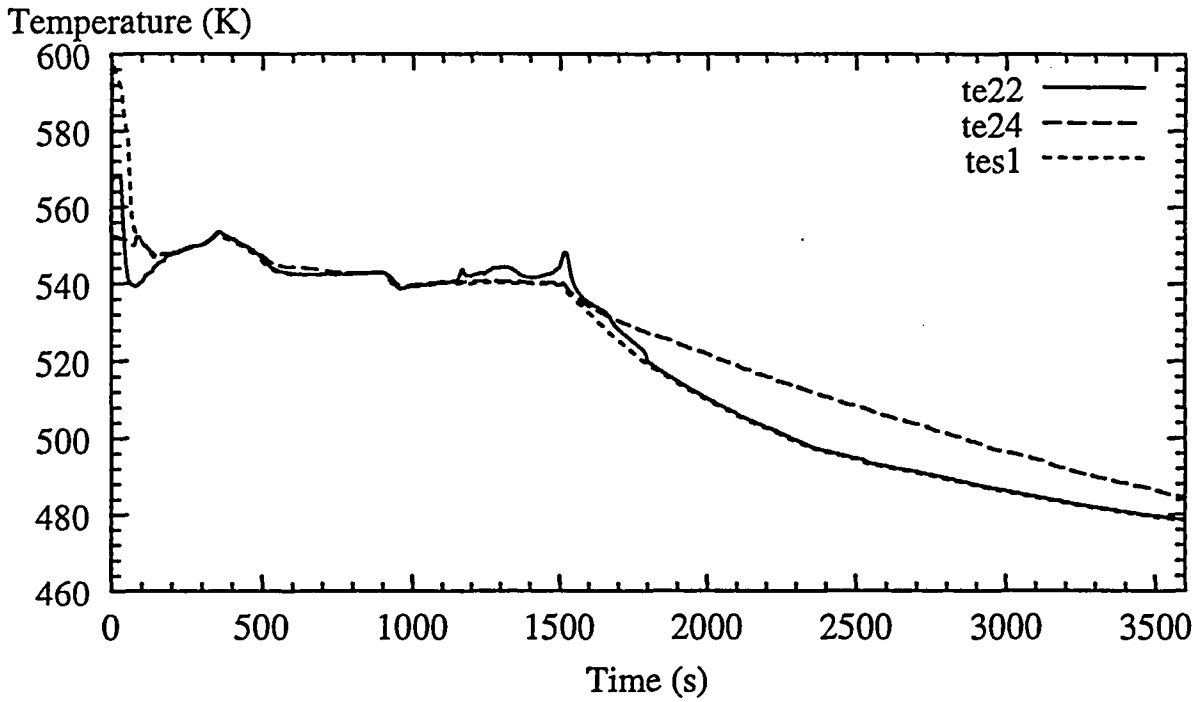
PMK-2 CAMP EXPERIMENT

Fig. 4.13z Heater Rod Top Temperatures



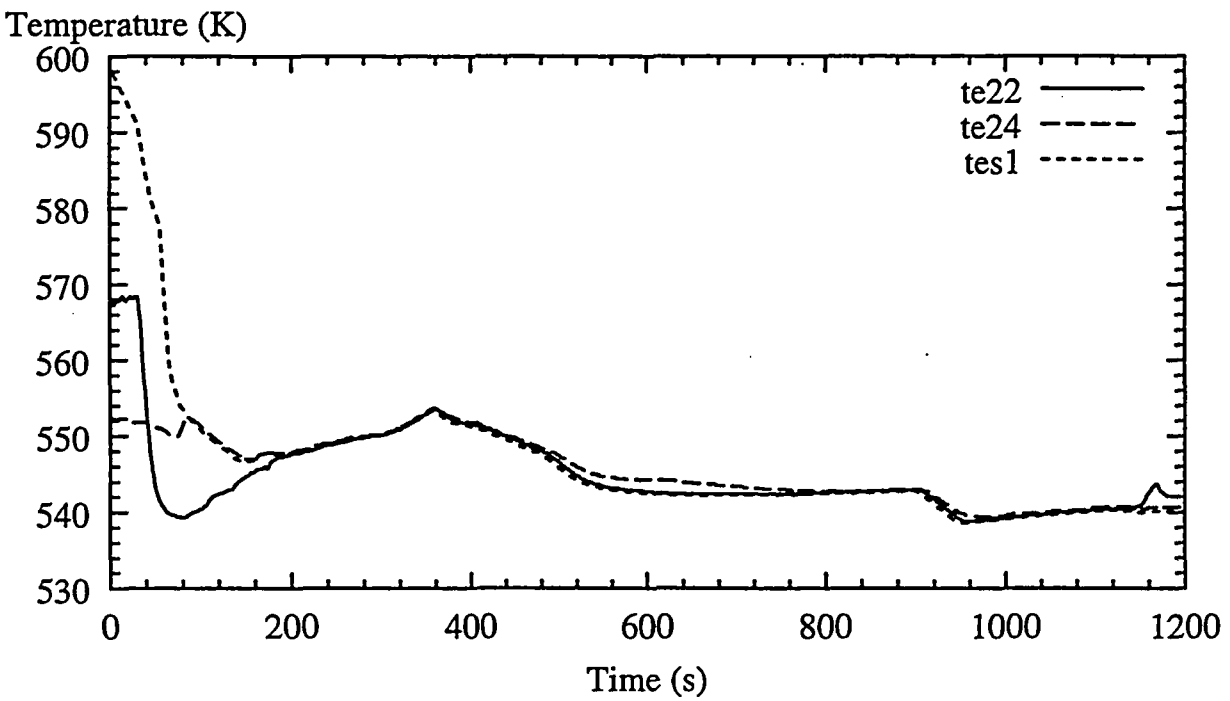
PMK-2 CAMP EXPERIMENT

Fig. 4.14 Vessel Temperatures



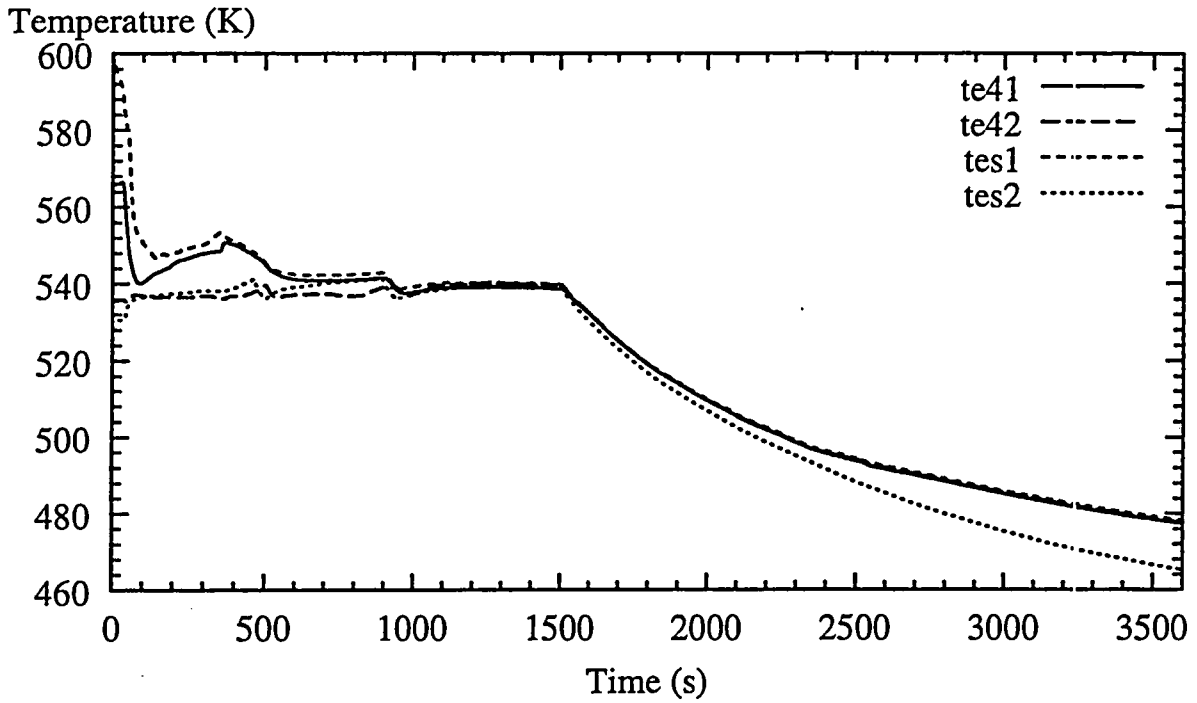
PMK-2 CAMP EXPERIMENT

Fig. 4.14z Vessel Temperatures



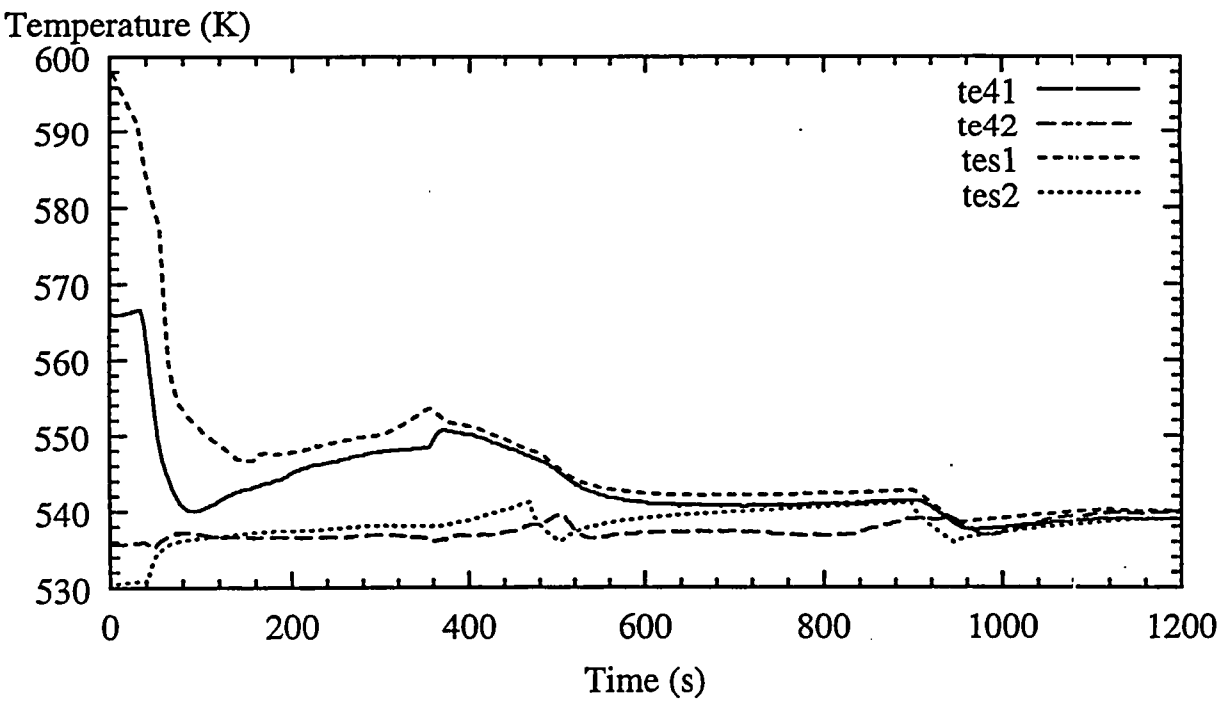
PMK-2 CAMP EXPERIMENT

Fig. 4.15 SG Inlet and Outlet Temperatures



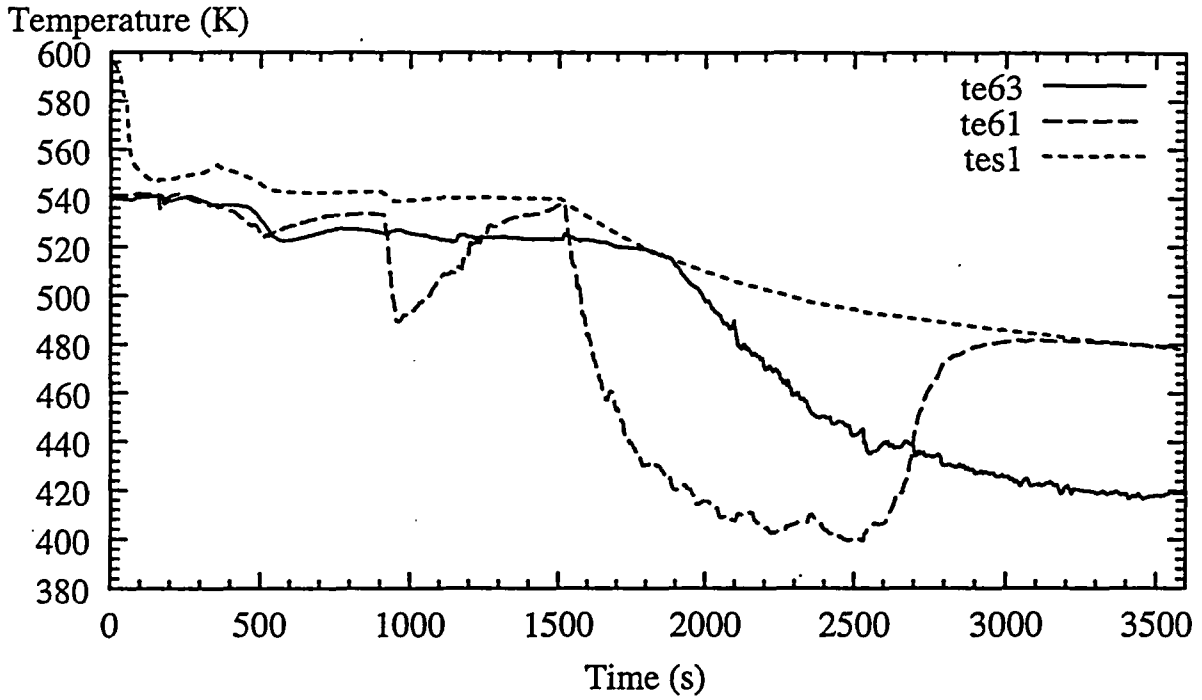
PMK-2 CAMP EXPERIMENT

Fig. 4.15z SG Inlet and Outlet Temperatures



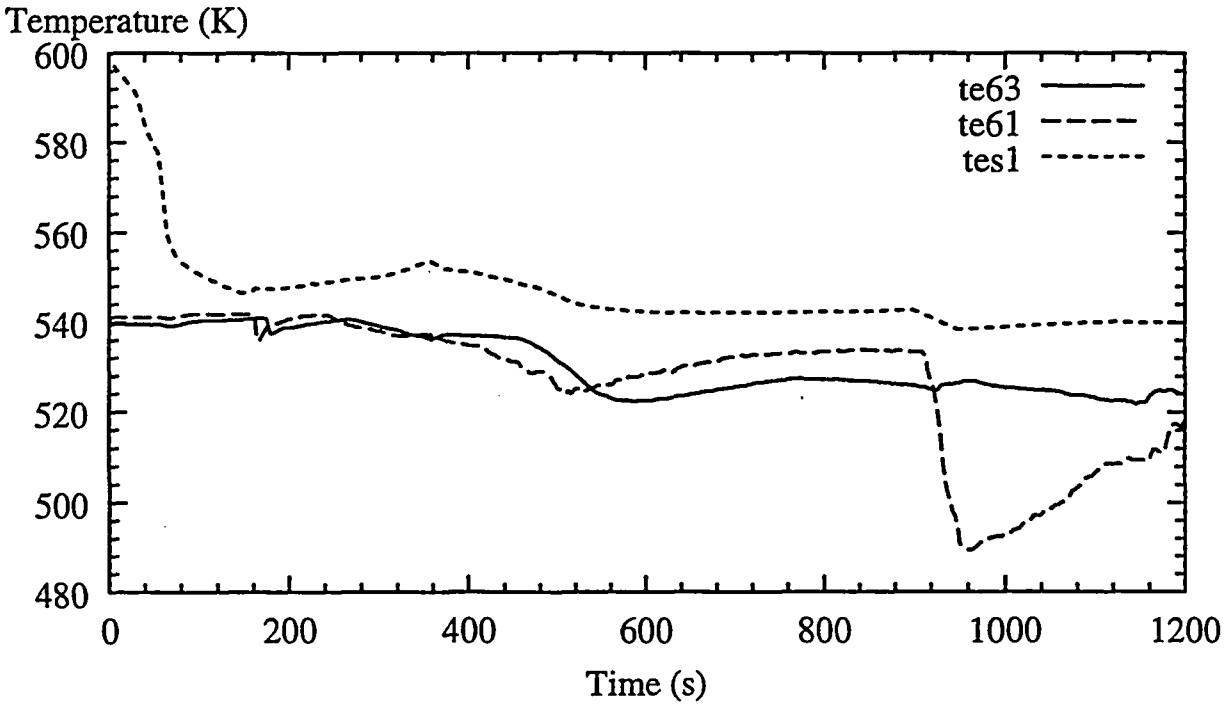
PMK-2 CAMP EXPERIMENT

Fig. 4.16 Cold Leg Temperatures



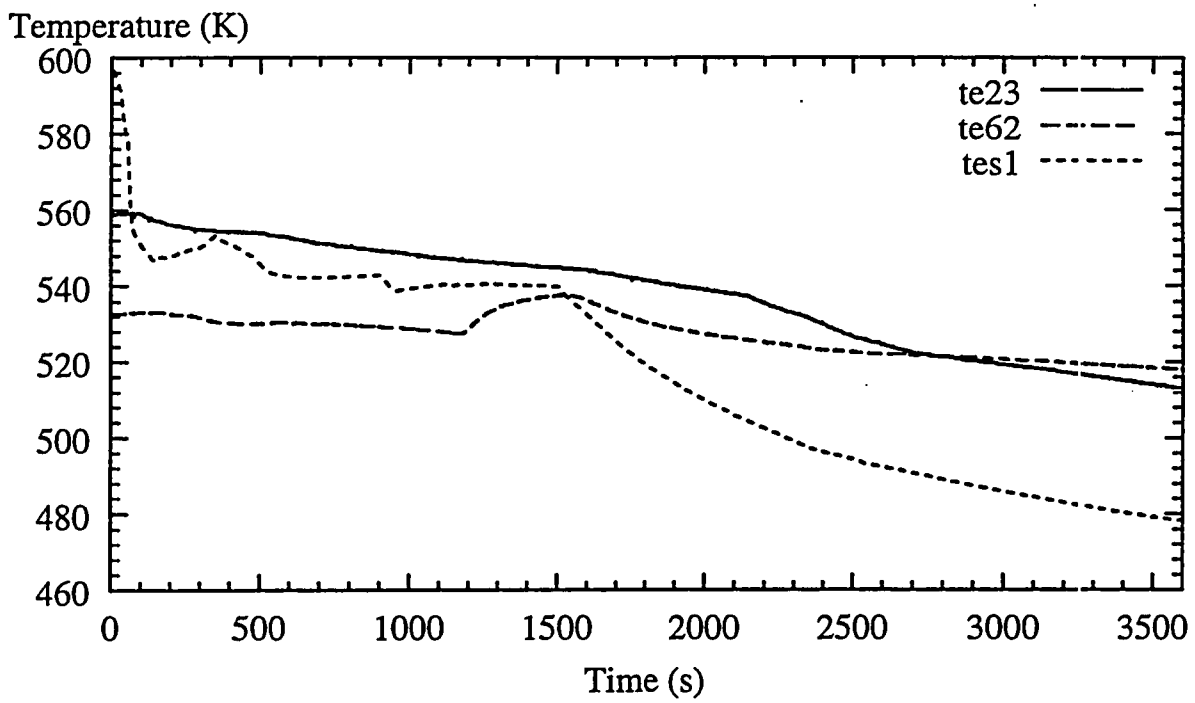
PMK-2 CAMP EXPERIMENT

Fig. 4.16z Cold Leg Temperatures



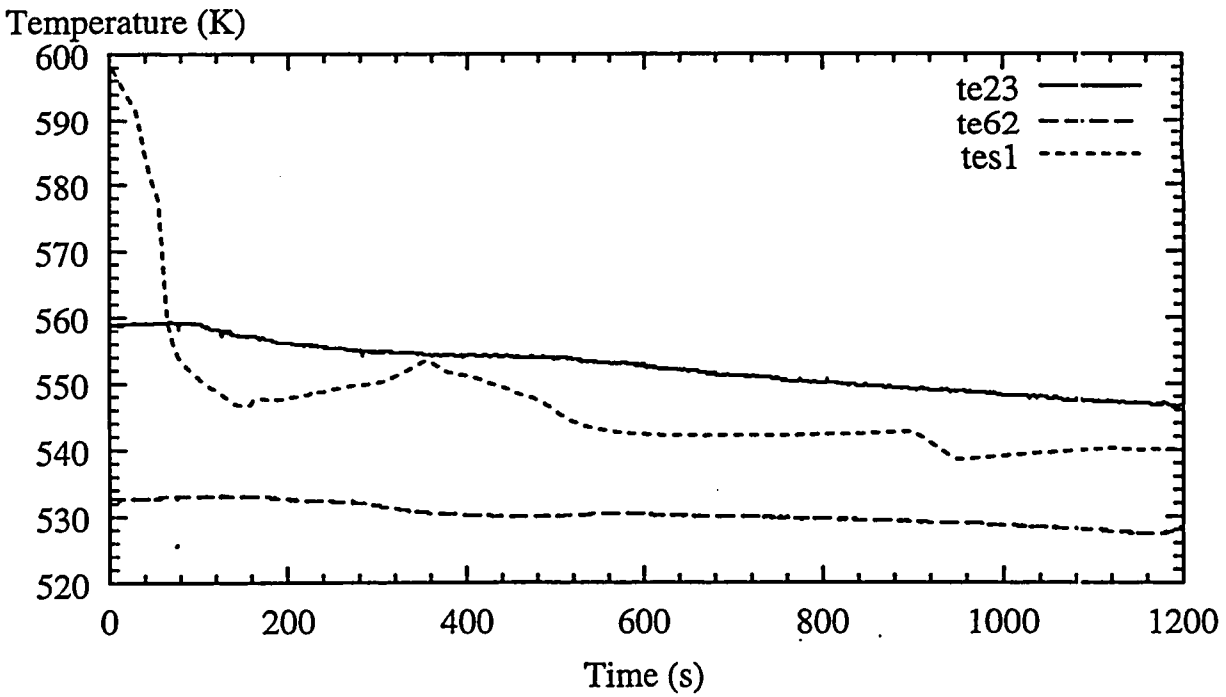
PMK-2 CAMP EXPERIMENT

Fig. 4.17 Upper Plenum and Downcomer Wall Temperatures



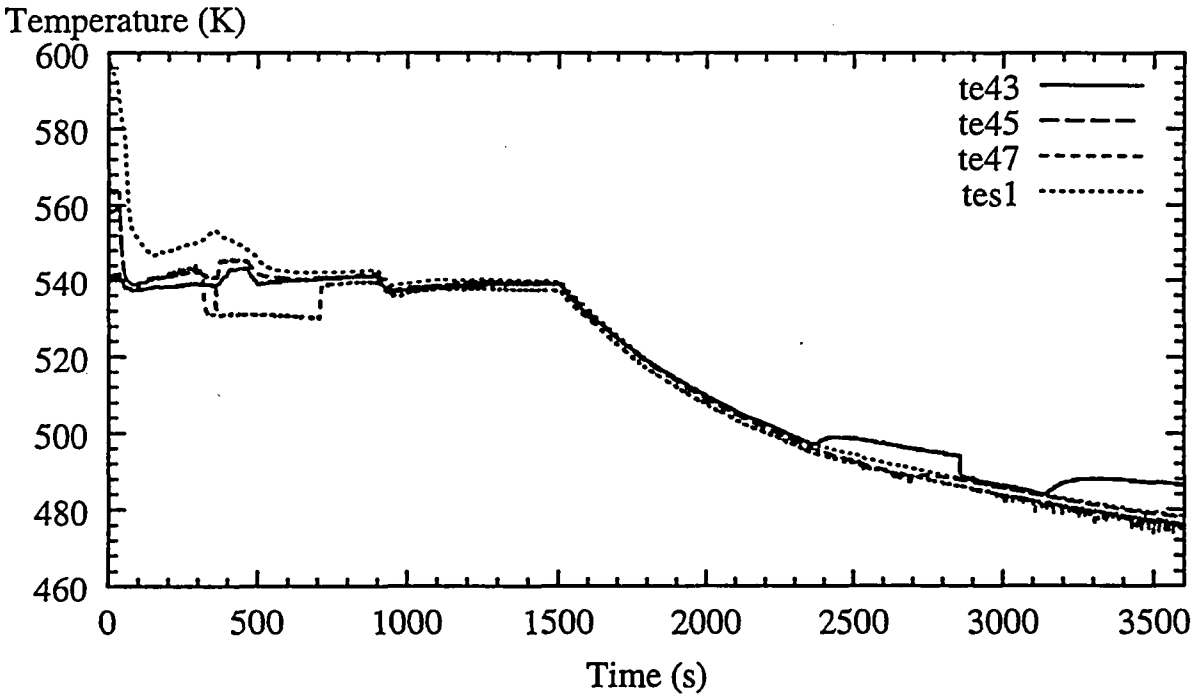
PMK-2 CAMP EXPERIMENT

Fig. 4.17z Upper Plenum and Downcomer Wall Temperatures



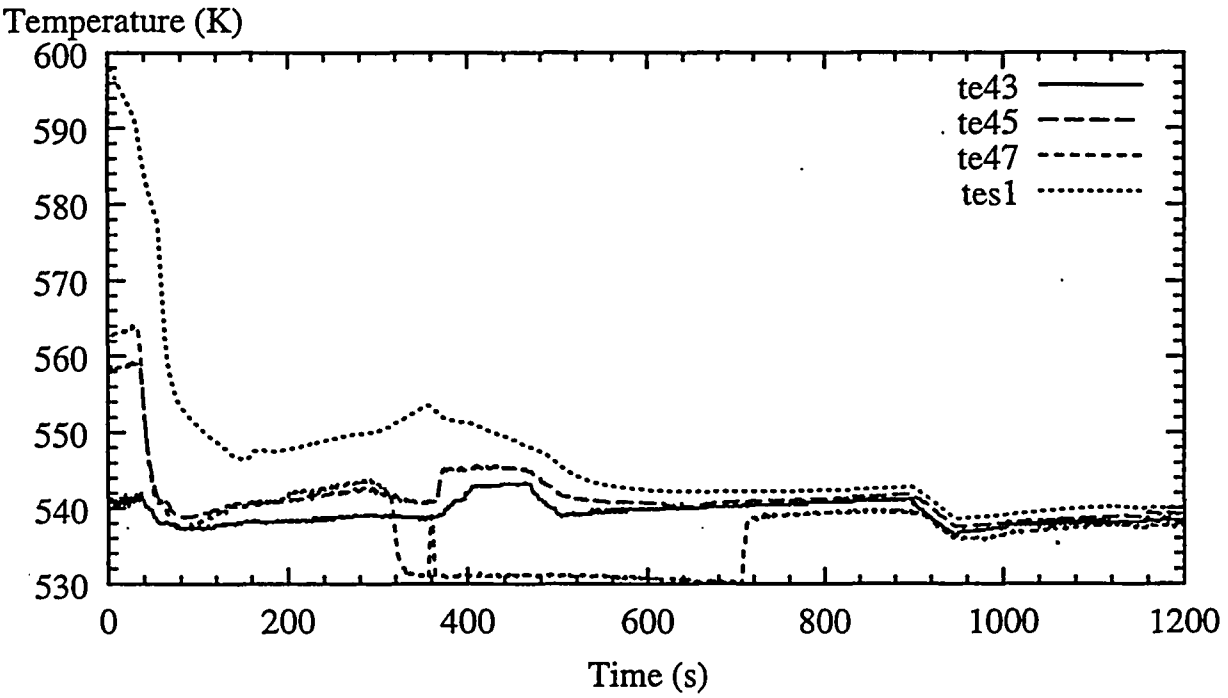
PMK-2 CAMP EXPERIMENT

Fig. 4.18 SG Hot Collector Temperatures



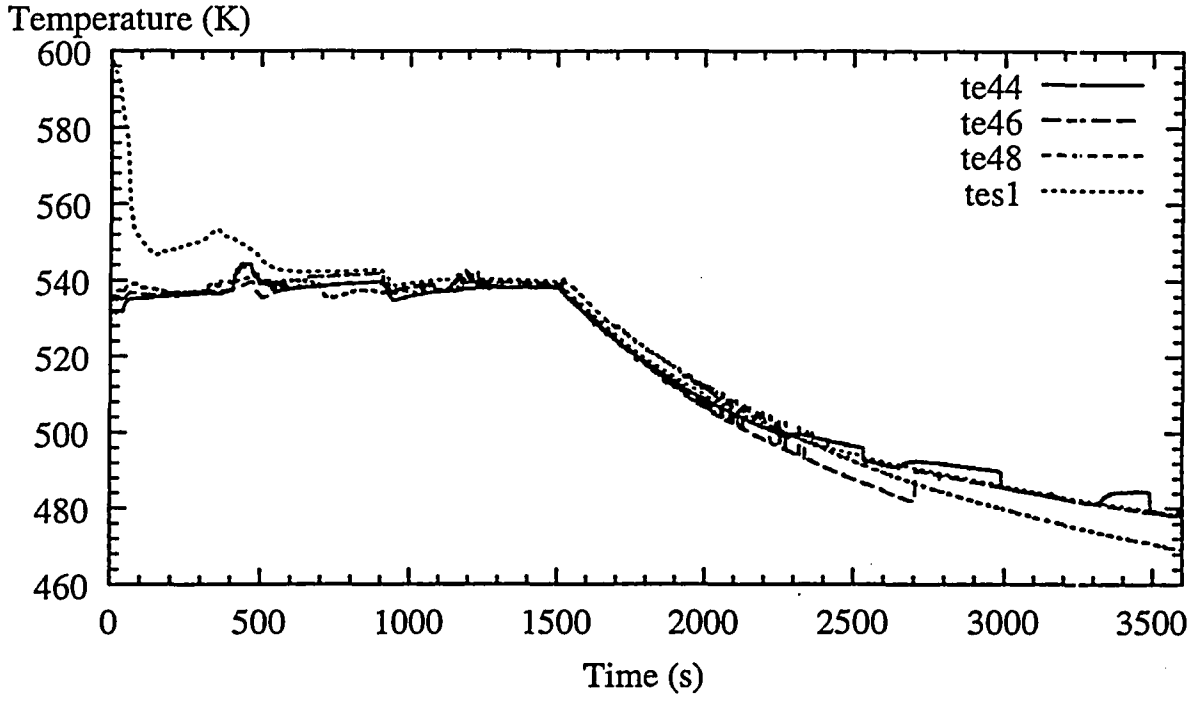
PMK-2 CAMP EXPERIMENT

Fig. 4.18z SG Hot Collector Temperatures



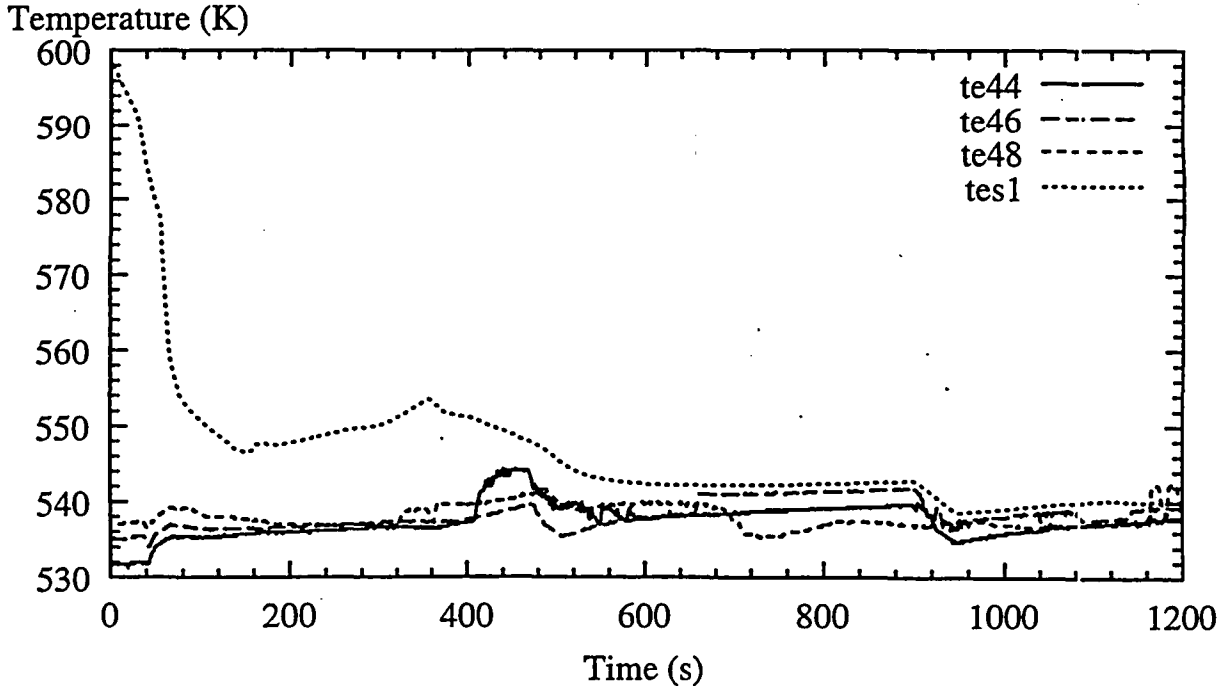
PMK-2 CAMP EXPERIMENT

Fig. 4.19 SG Cold Collector Temperatures



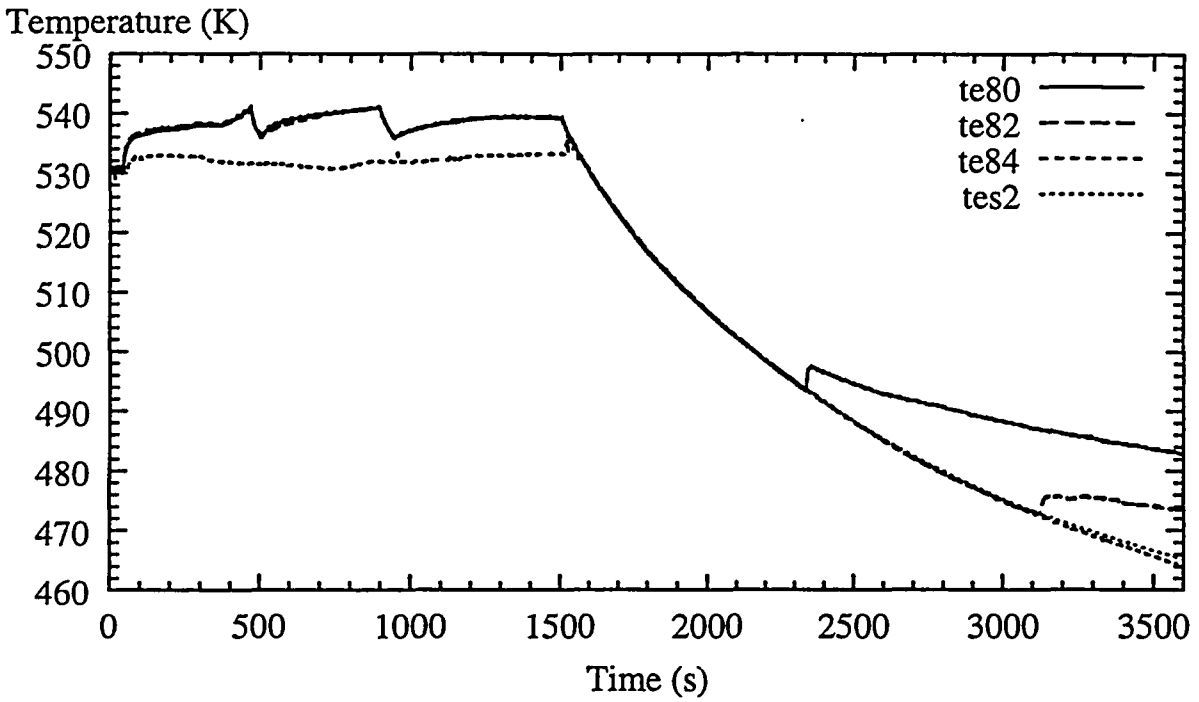
PMK-2 CAMP EXPERIMENT

Fig. 4.19z SG Cold Collector Temperatures



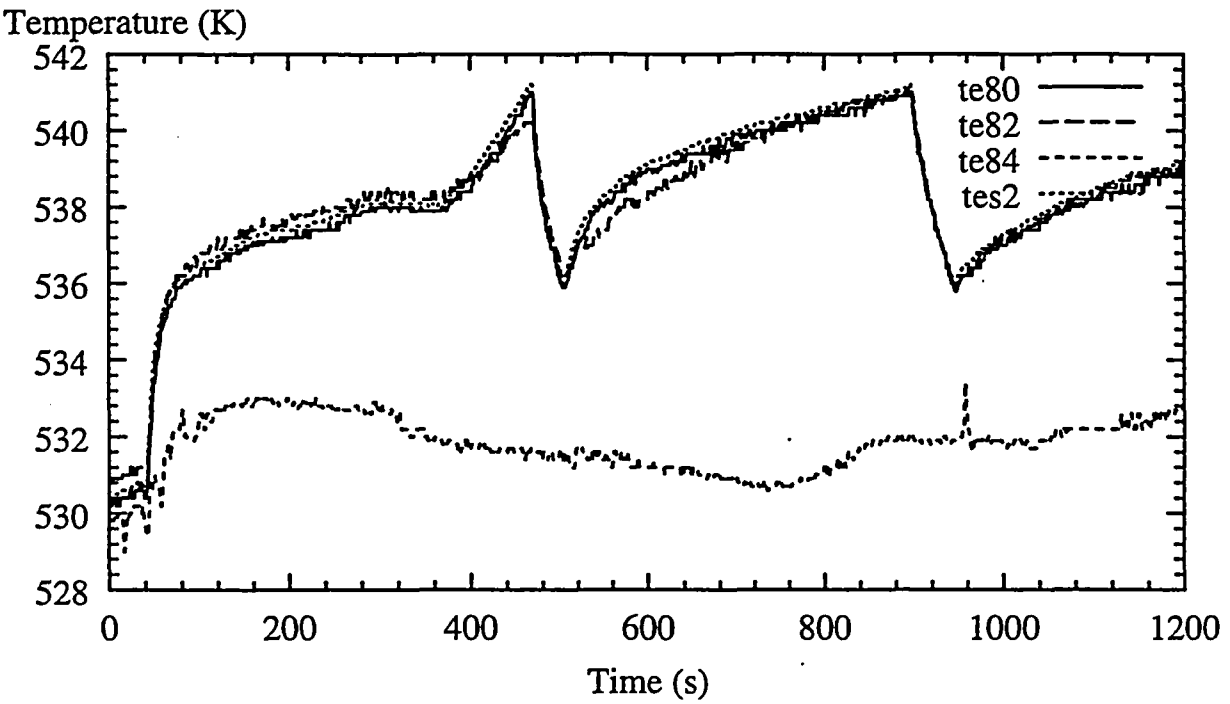
PMK-2 CAMP EXPERIMENT

Fig. 4.20 SG Secondary Temperatures at Hot Collector



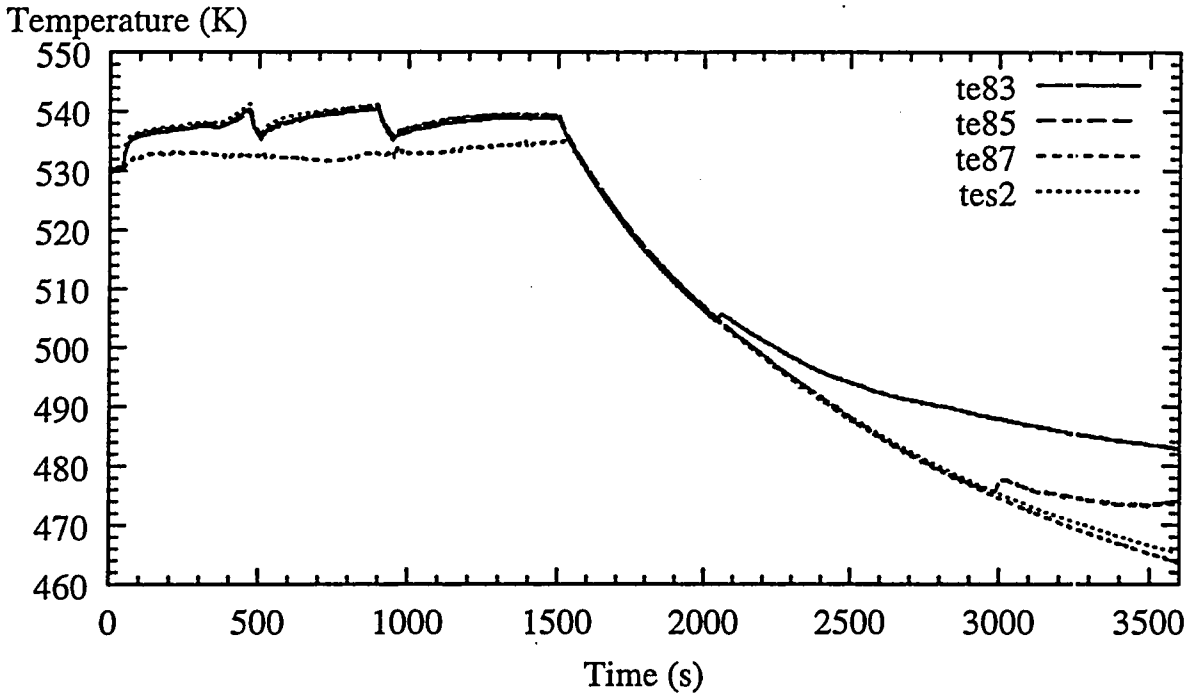
PMK-2 CAMP EXPERIMENT

Fig. 4.20z SG Secondary Temperatures at Hot Collector



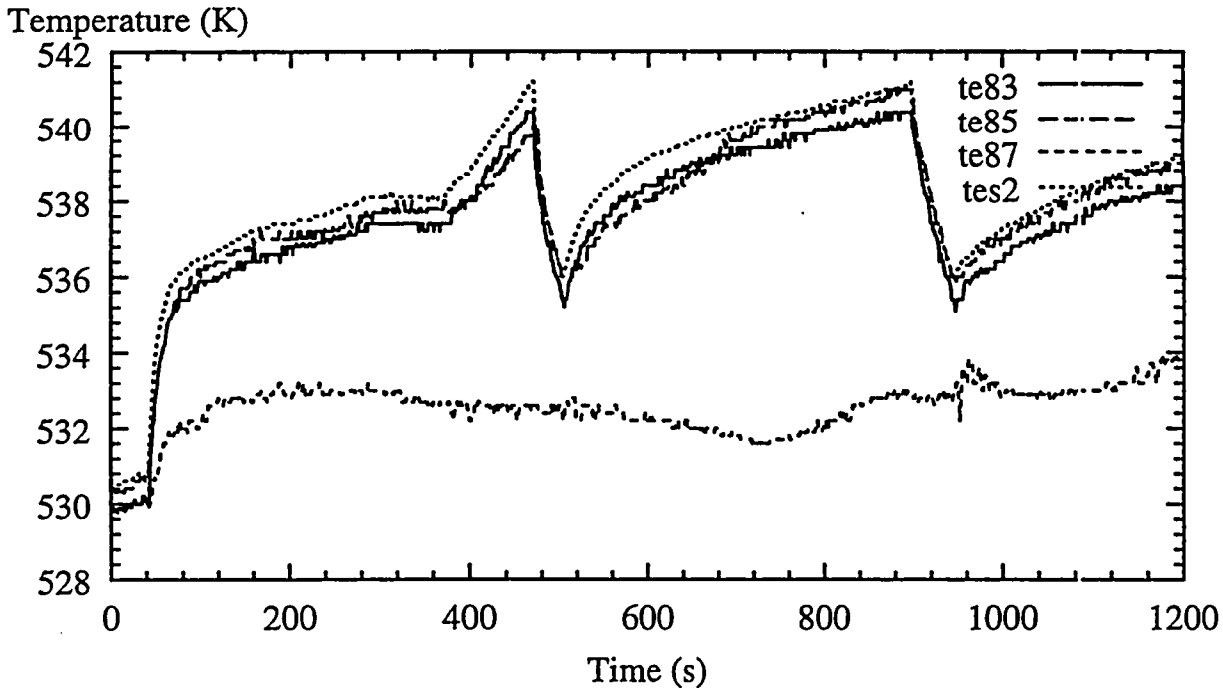
PMK-2 CAMP EXPERIMENT

Fig. 4.21 SG Secondary Temperatures in Axis



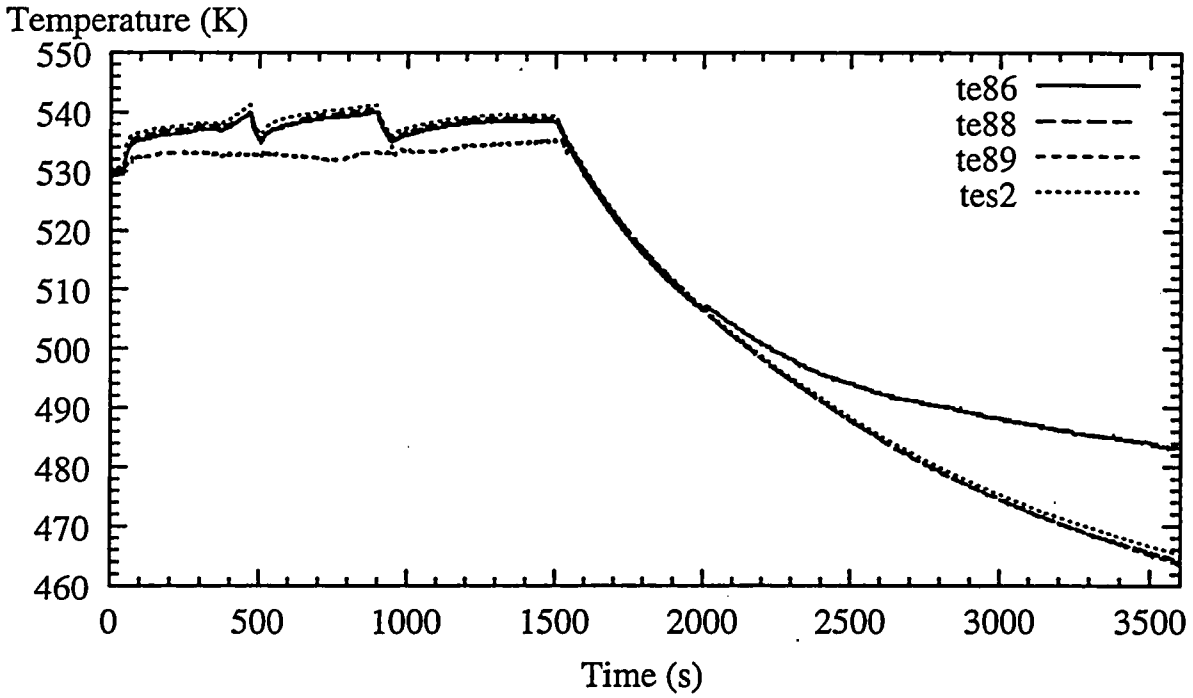
PMK-2 CAMP EXPERIMENT

Fig. 4.21z SG Secondary Temperatures in Axis



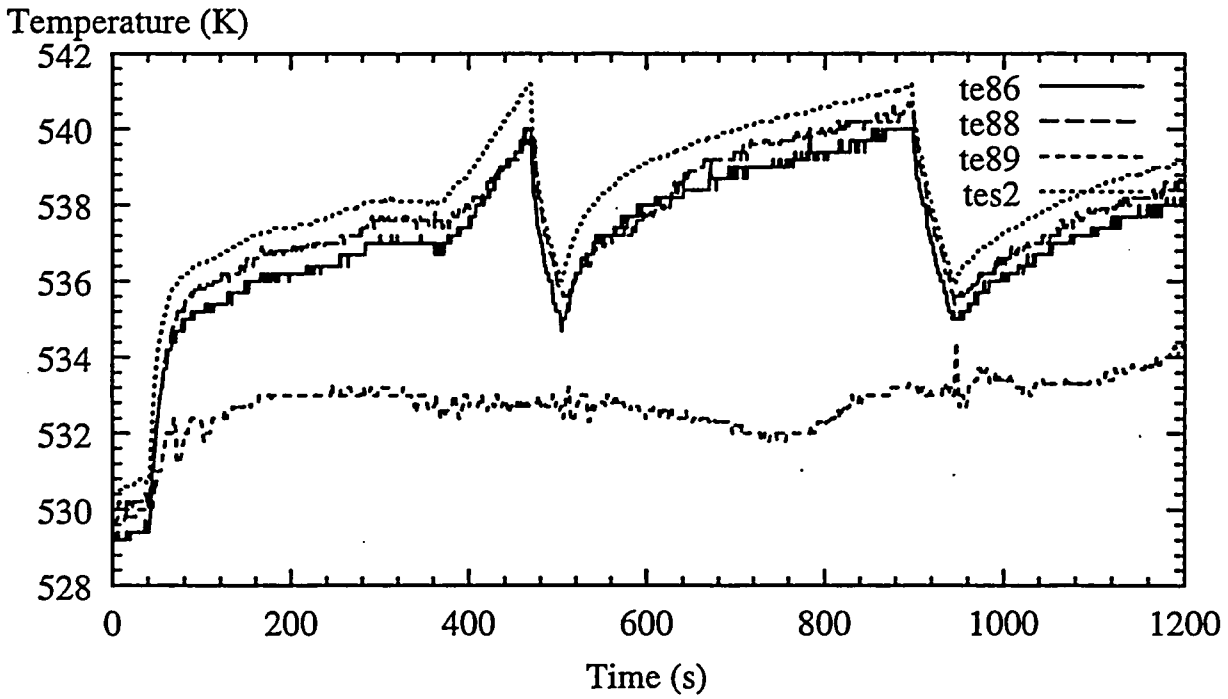
PMK-2 CAMP EXPERIMENT

Fig. 4.22 SG Secondary Temperatures at Cold Collector



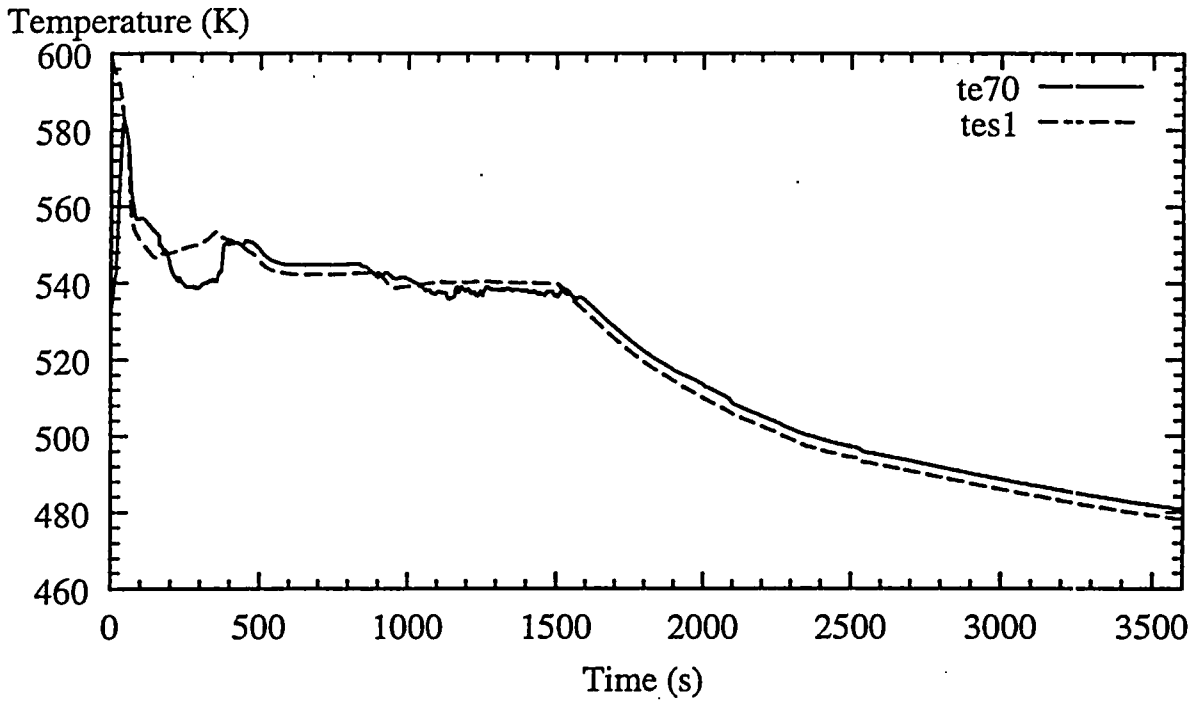
PMK-2 CAMP EXPERIMENT

Fig. 4.22z SG Secondary Temperatures at Cold Collector



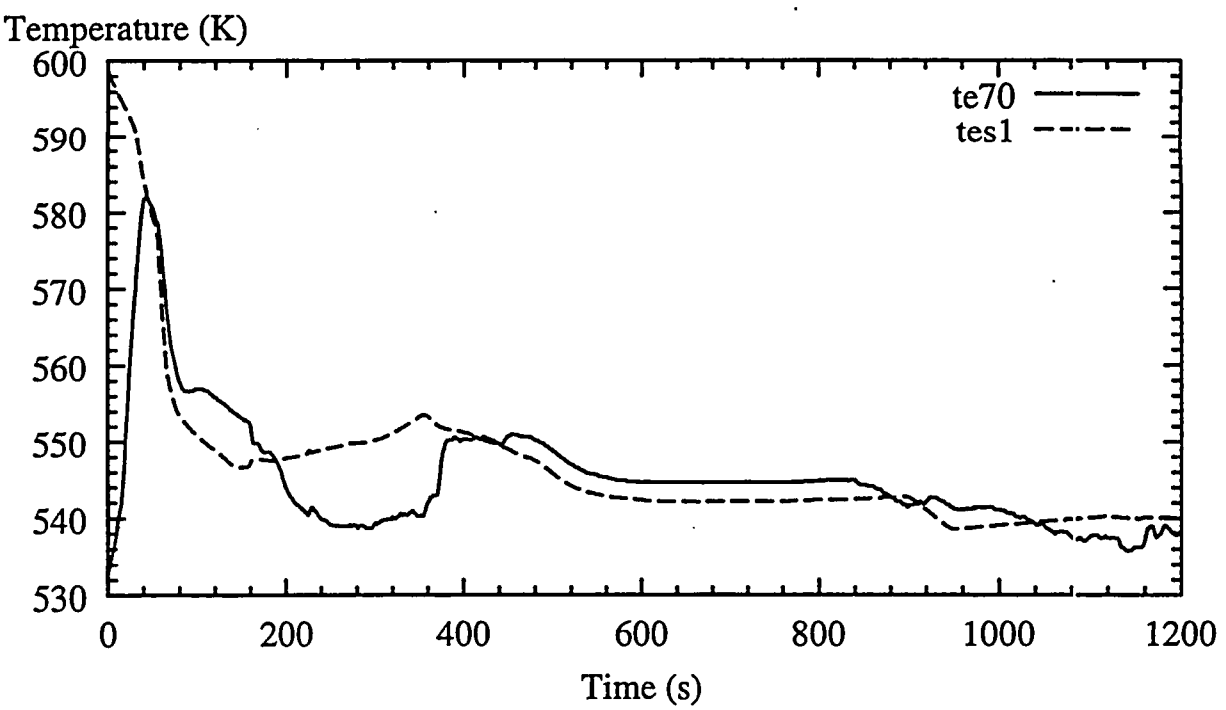
PMK-2 CAMP EXPERIMENT

Fig. 4.23 Temperature in Surge Line



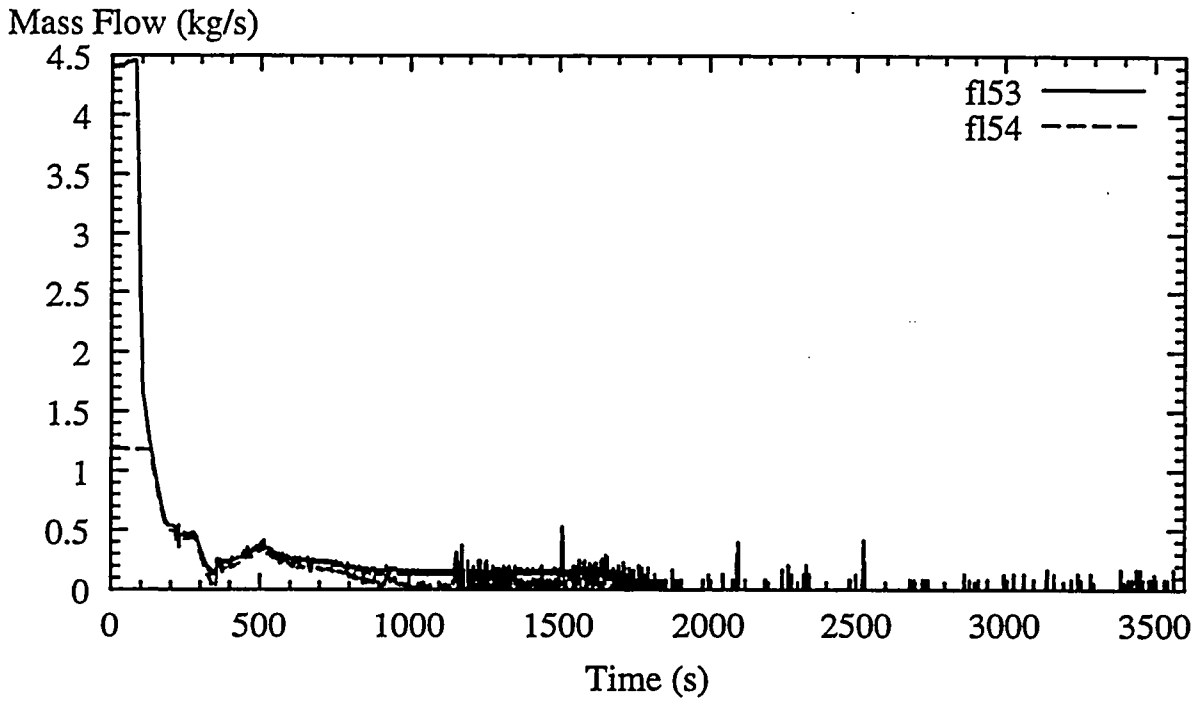
PMK-2 CAMP EXPERIMENT

Fig. 4.23z Temperature in Surge Line



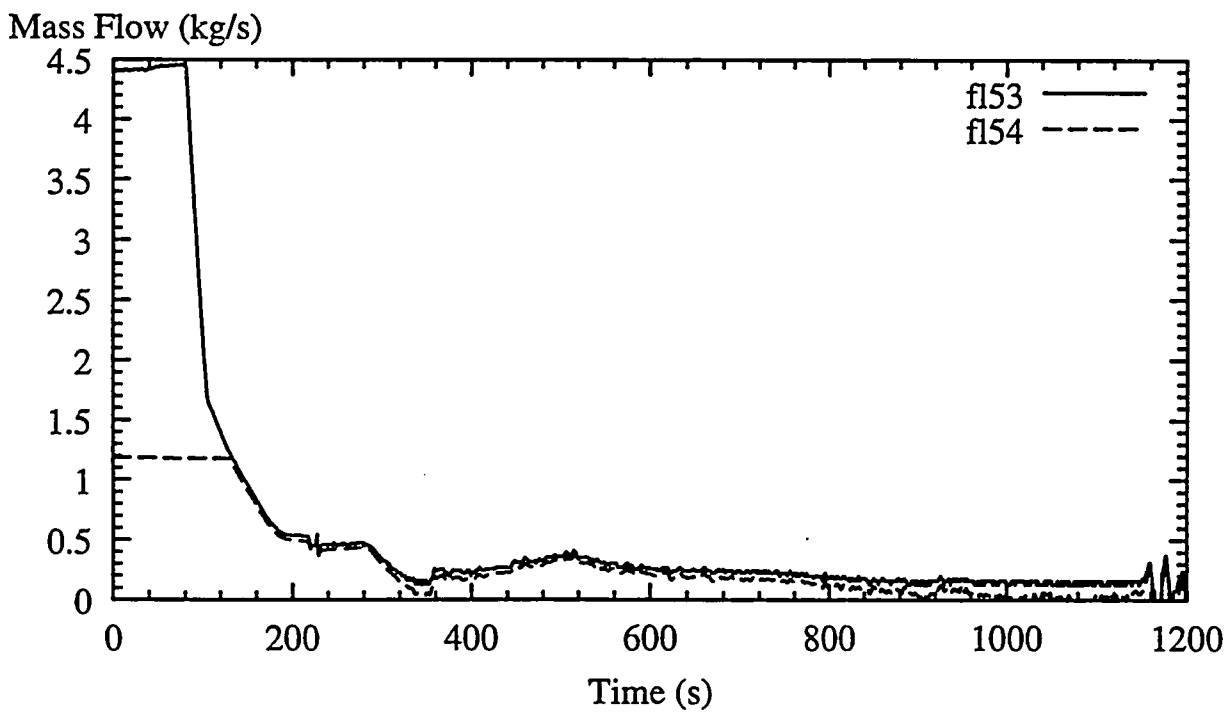
PMK-2 CAMP EXPERIMENT

Fig. 4.24 Cold Leg Mass Flow Rate



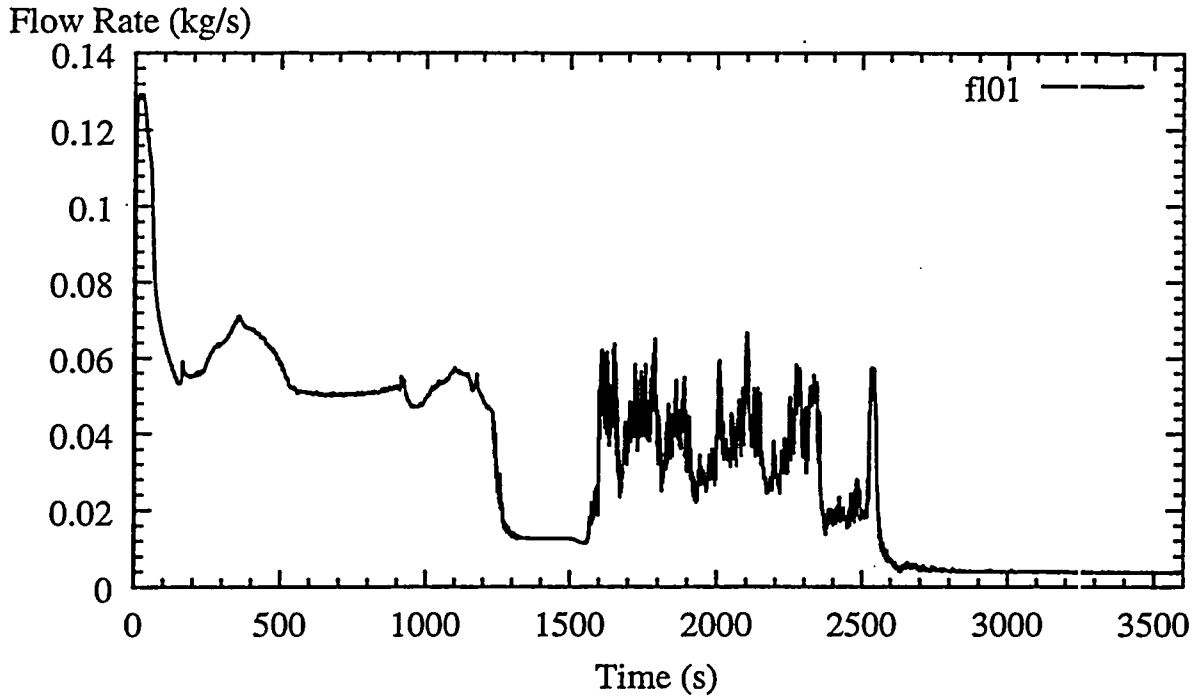
PMK-2 CAMP EXPERIMENT

Fig. 4.24z Cold Leg Mass Flow Rate



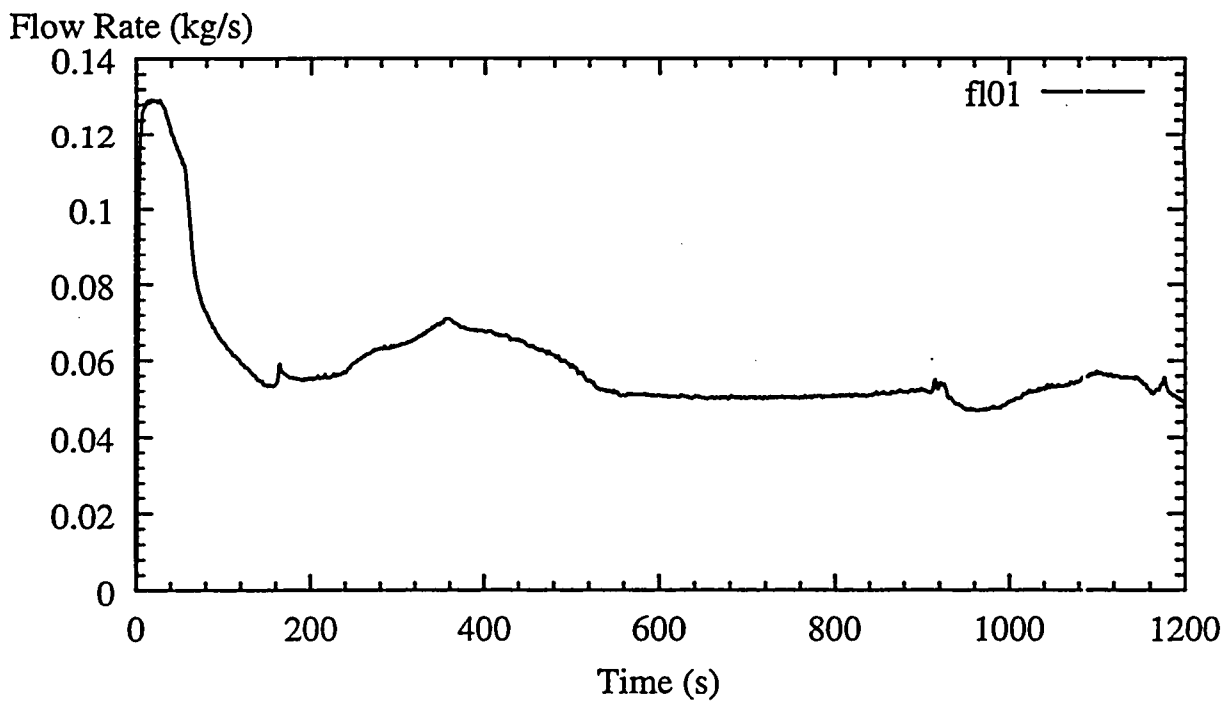
PMK-2 CAMP EXPERIMENT

Fig. 4.25 Break Flow



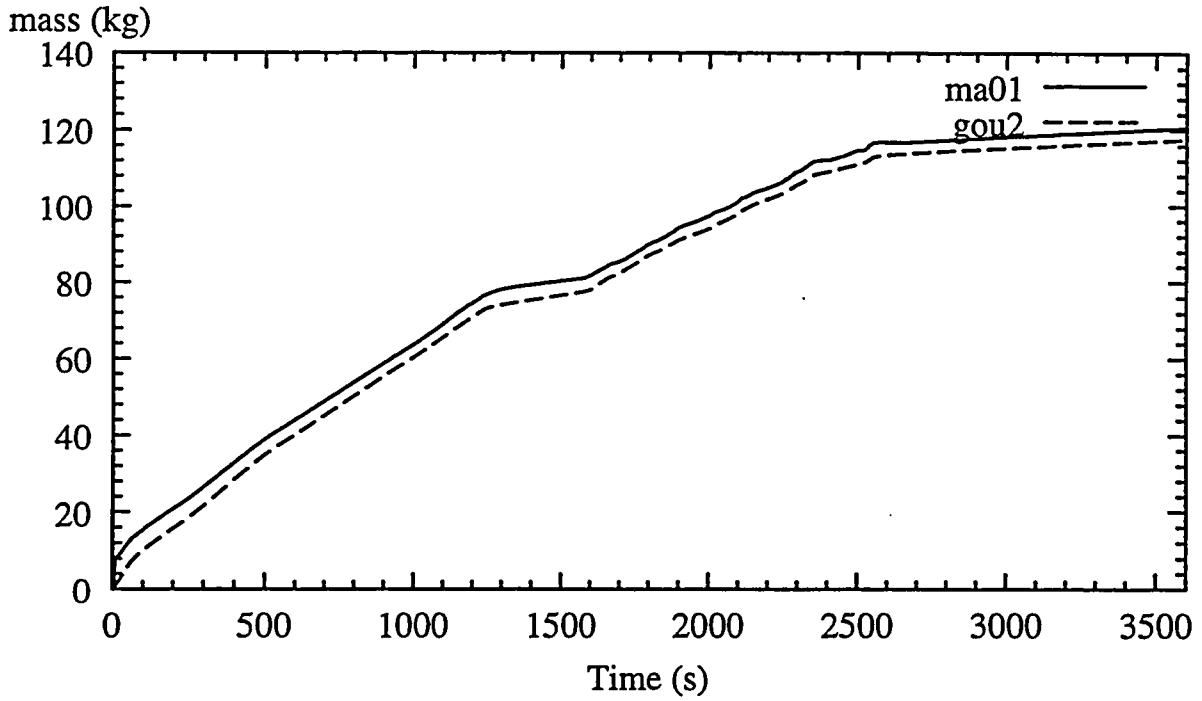
PMK-2 CAMP EXPERIMENT

Fig. 4.25z Break Flow



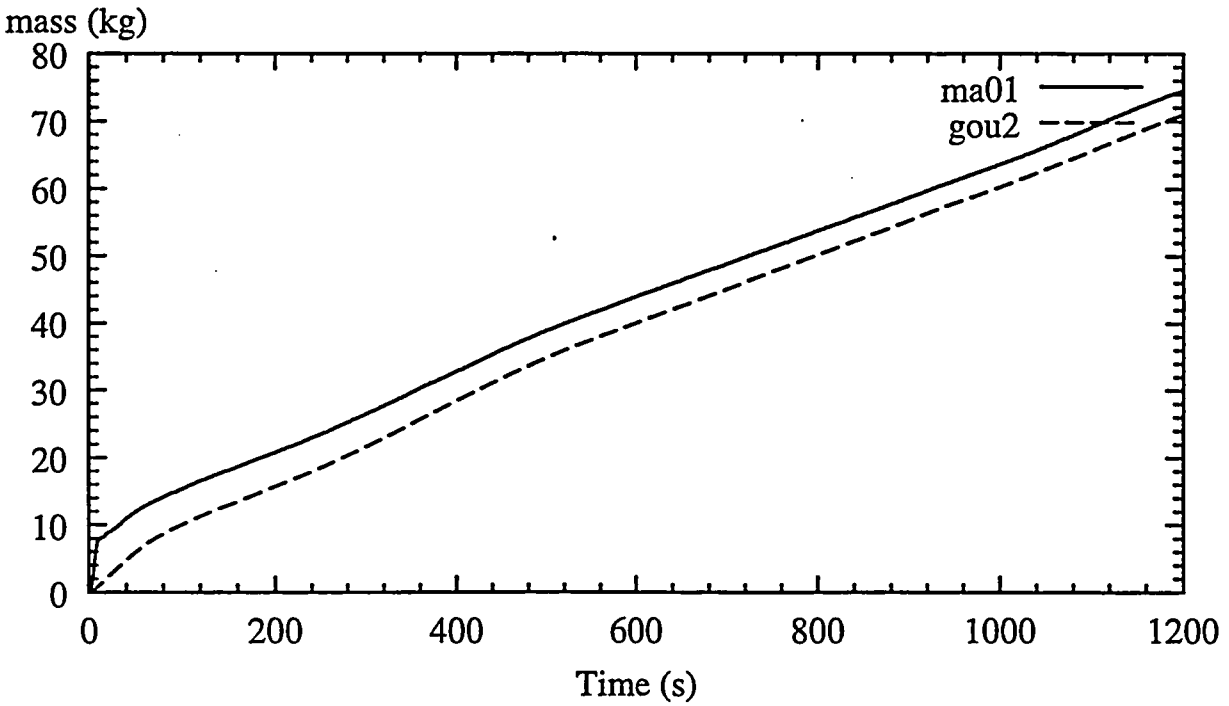
PMK-2 CAMP EXPERIMENT

Fig. 4.26 Break Outflow



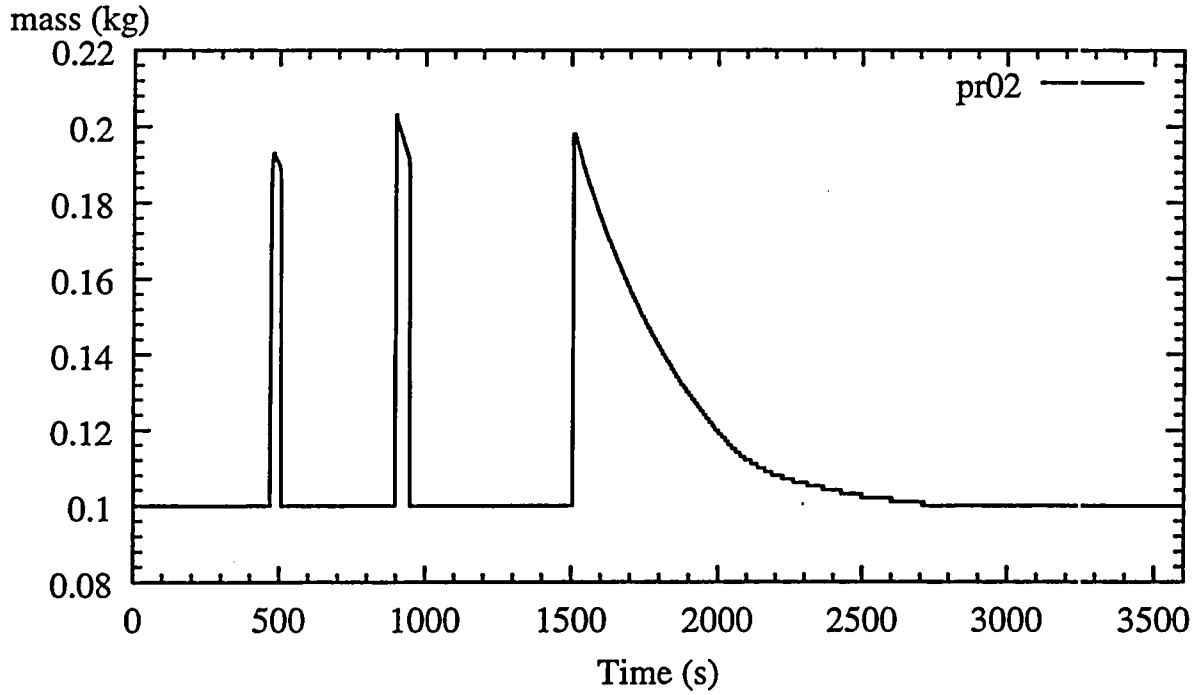
PMK-2 CAMP EXPERIMENT

Fig. 4.26z Break Outflow



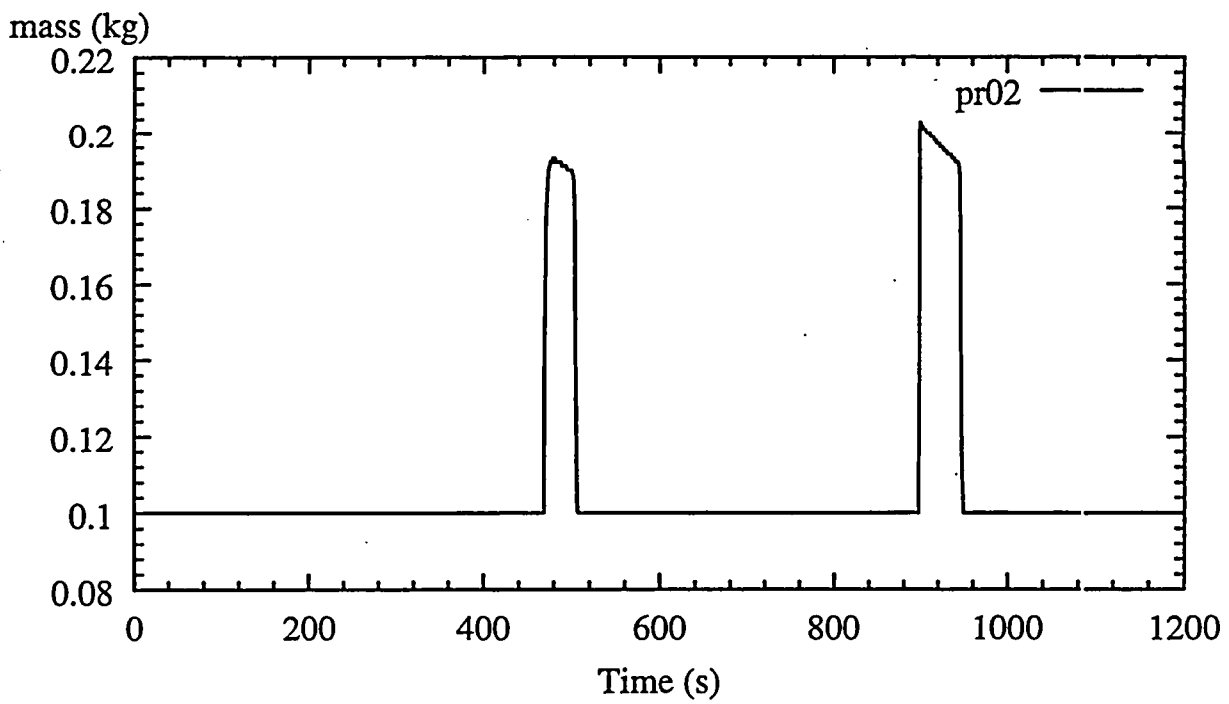
PMK-2 CAMP EXPERIMENT

Fig. 4.27 BRU-A Pressure



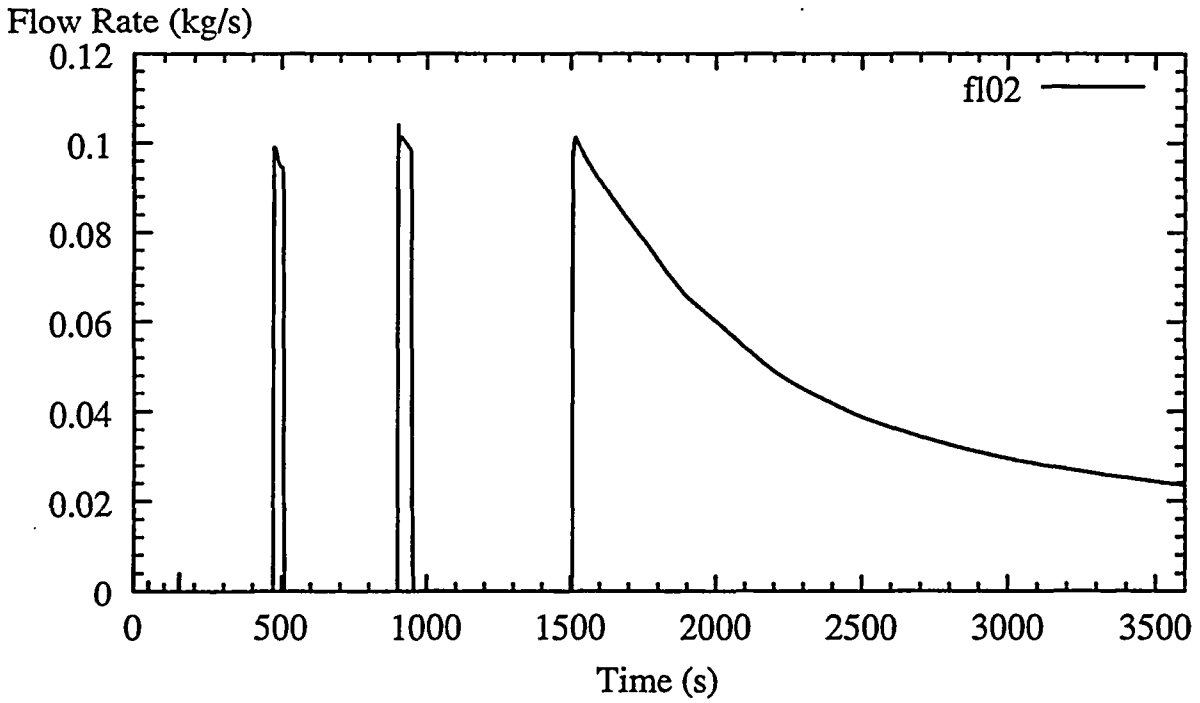
PMK-2 CAMP EXPERIMENT

Fig. 4.27z BRU-A Pressure



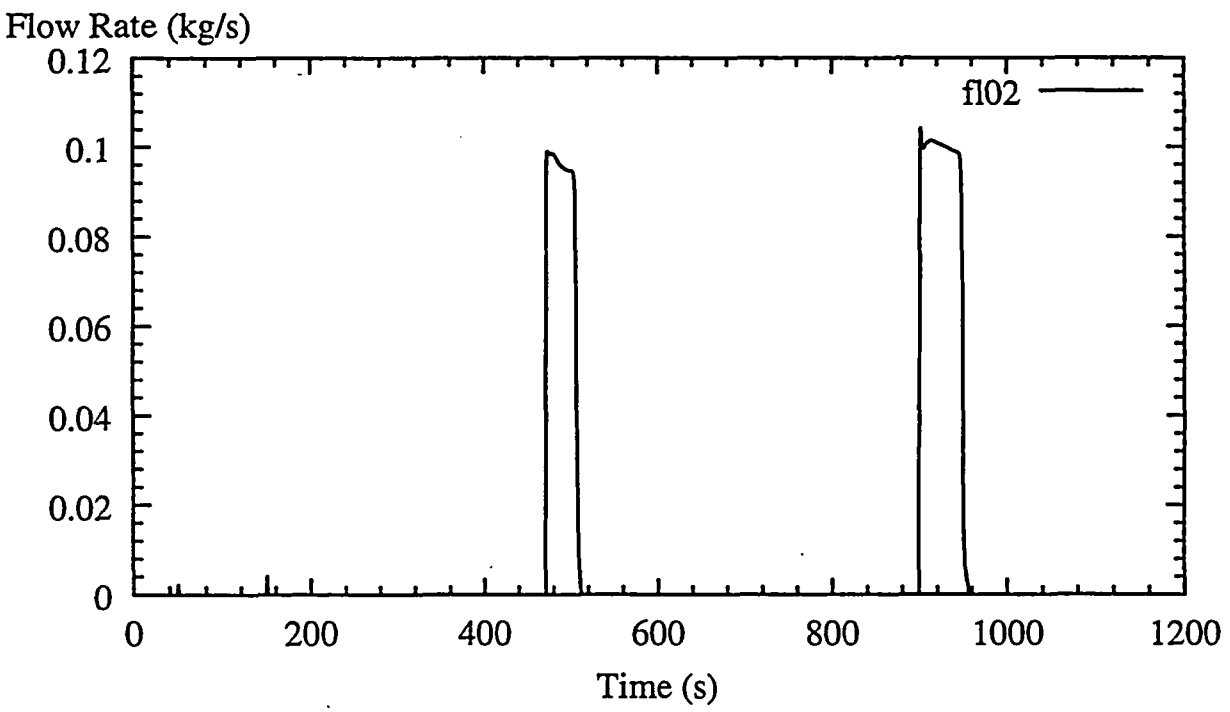
PMK-2 CAMP EXPERIMENT

Fig. 4.28 BRU-A Flow



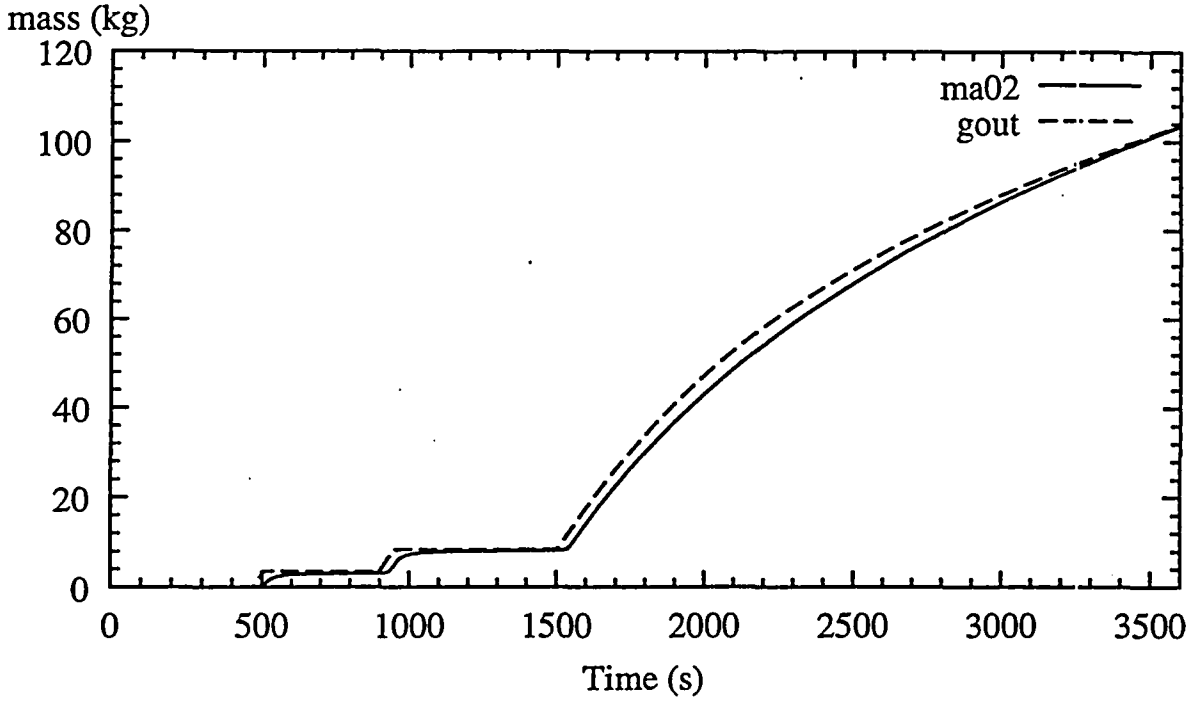
PMK-2 CAMP EXPERIMENT

Fig. 4.28z BRU-A Flow



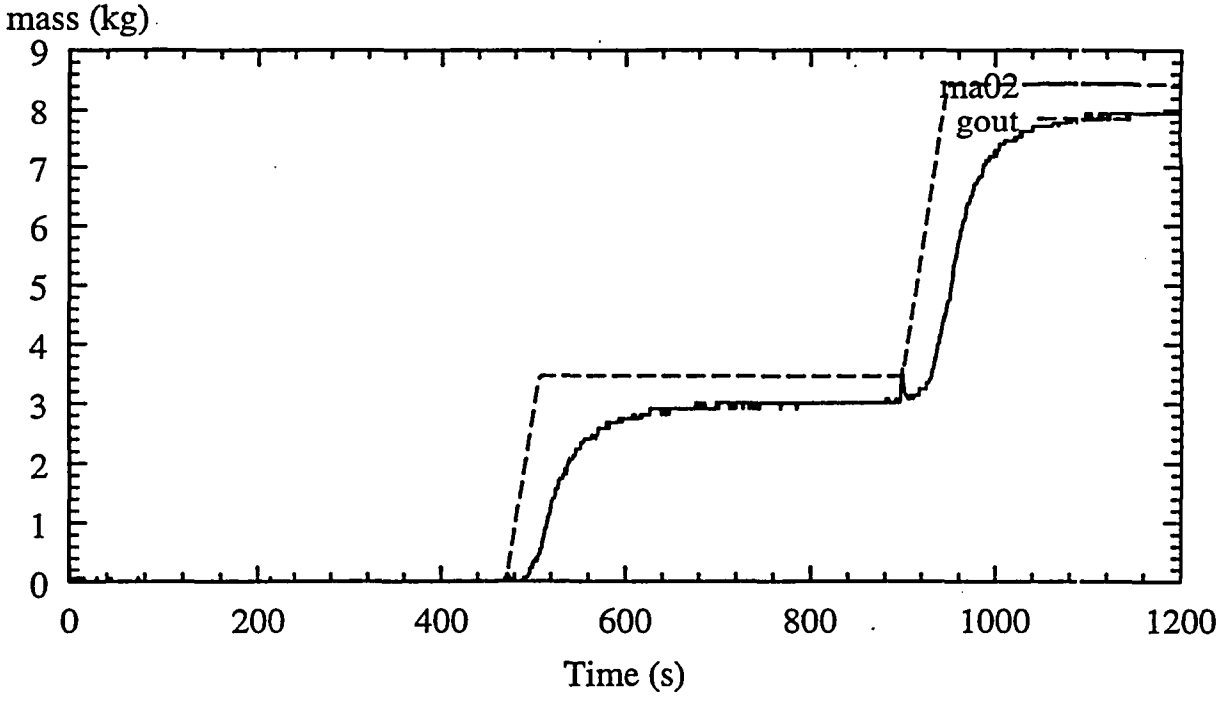
PMK-2 CAMP EXPERIMENT

Fig. 4.29 BRU-A Outflow



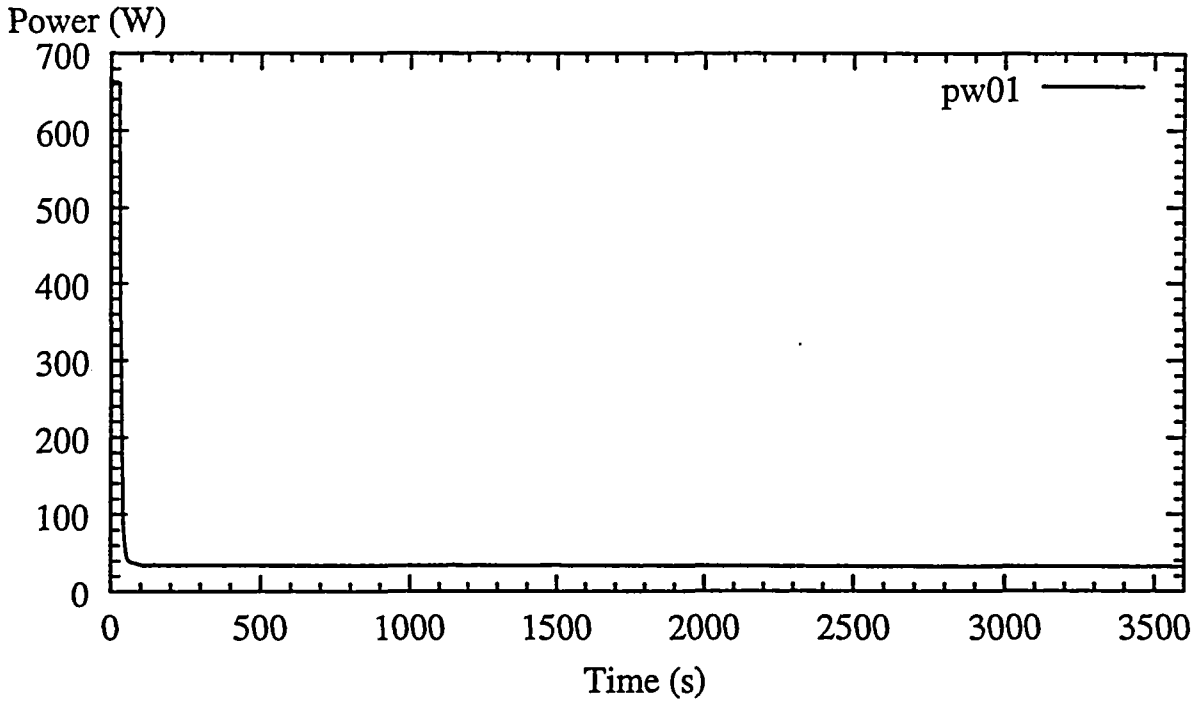
PMK-2 CAMP EXPERIMENT

Fig. 4.29z BRU-A Outflow



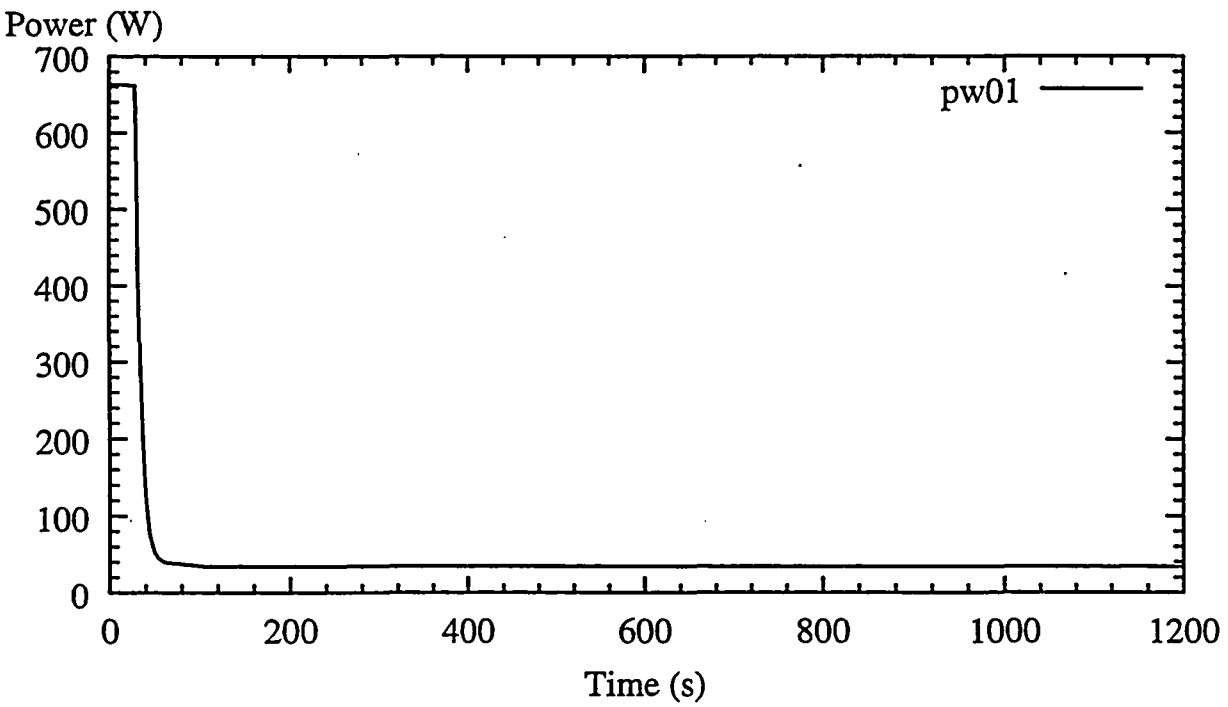
PMK-2 CAMP EXPERIMENT

Fig. 4.30 Reactor Power



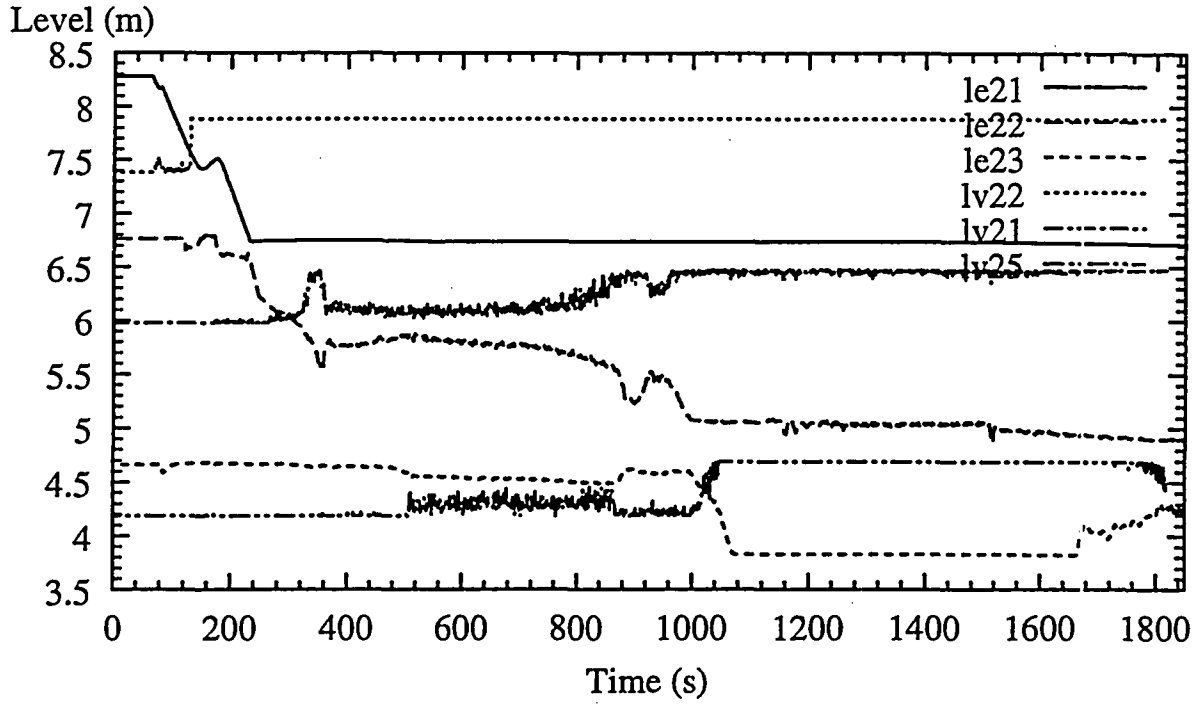
PMK-2 CAMP EXPERIMENT

Fig. 4.30z Reactor Power



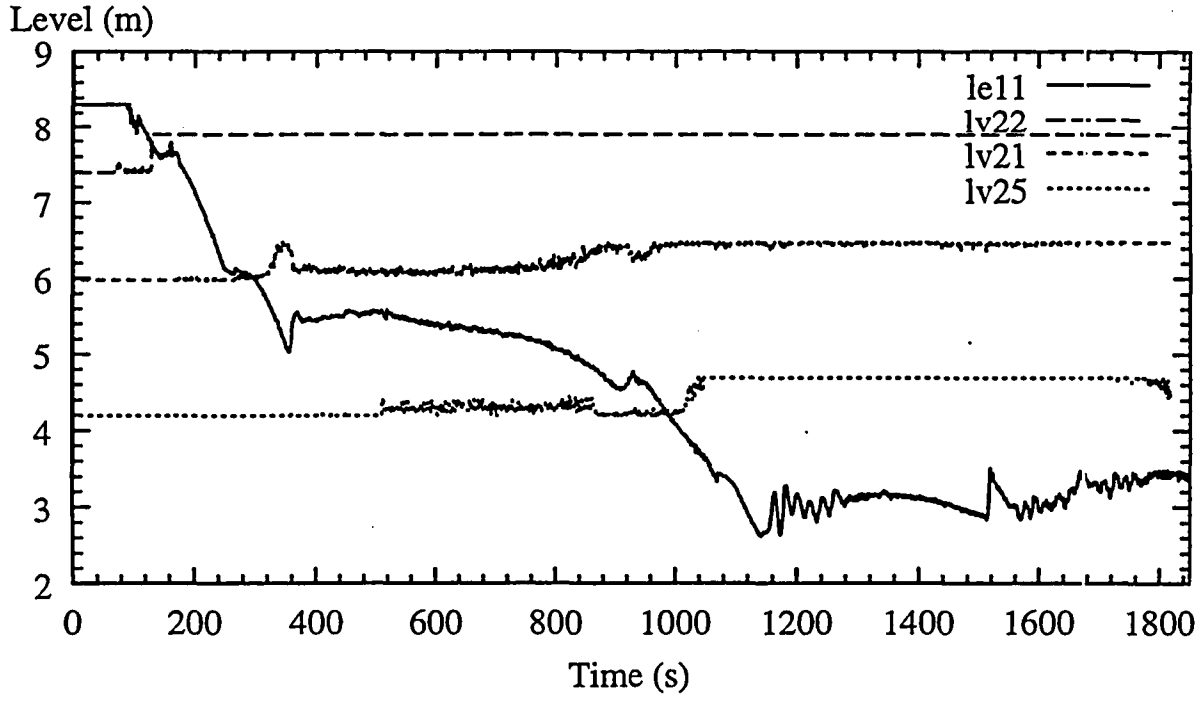
PMK-2 CAMP EXPERIMENT

Fig. 4.31 Levels in the Vessel



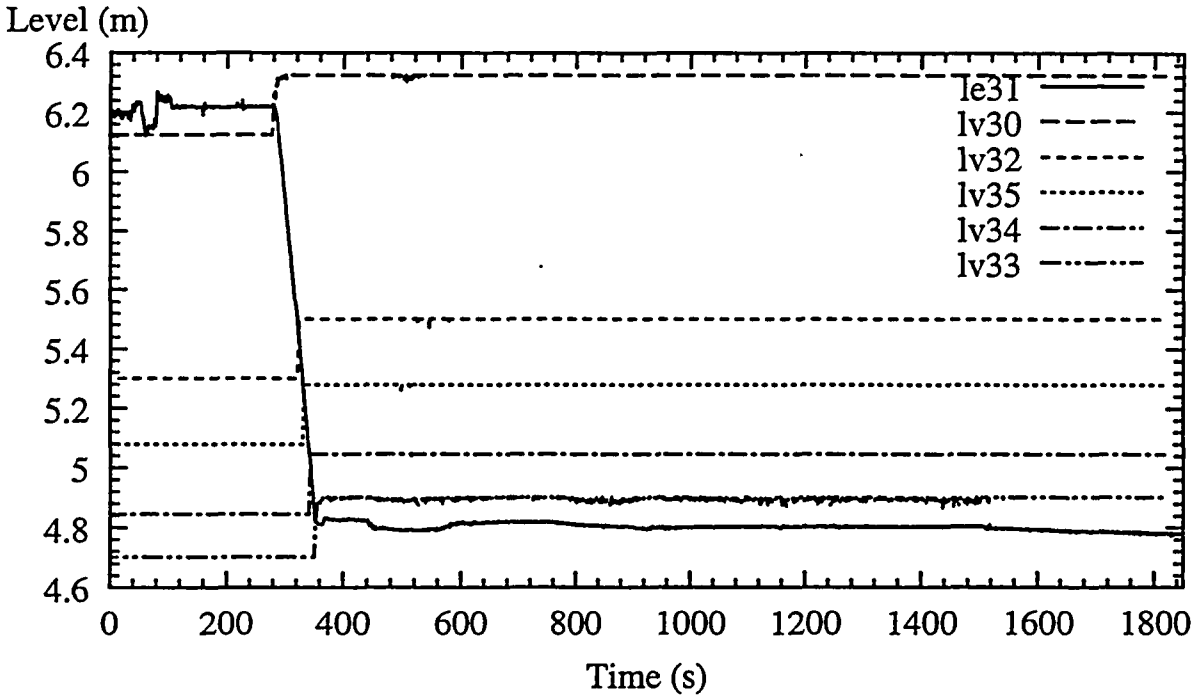
PMK-2 CAMP EXPERIMENT

Fig. 4.32 Levels in the Vessel



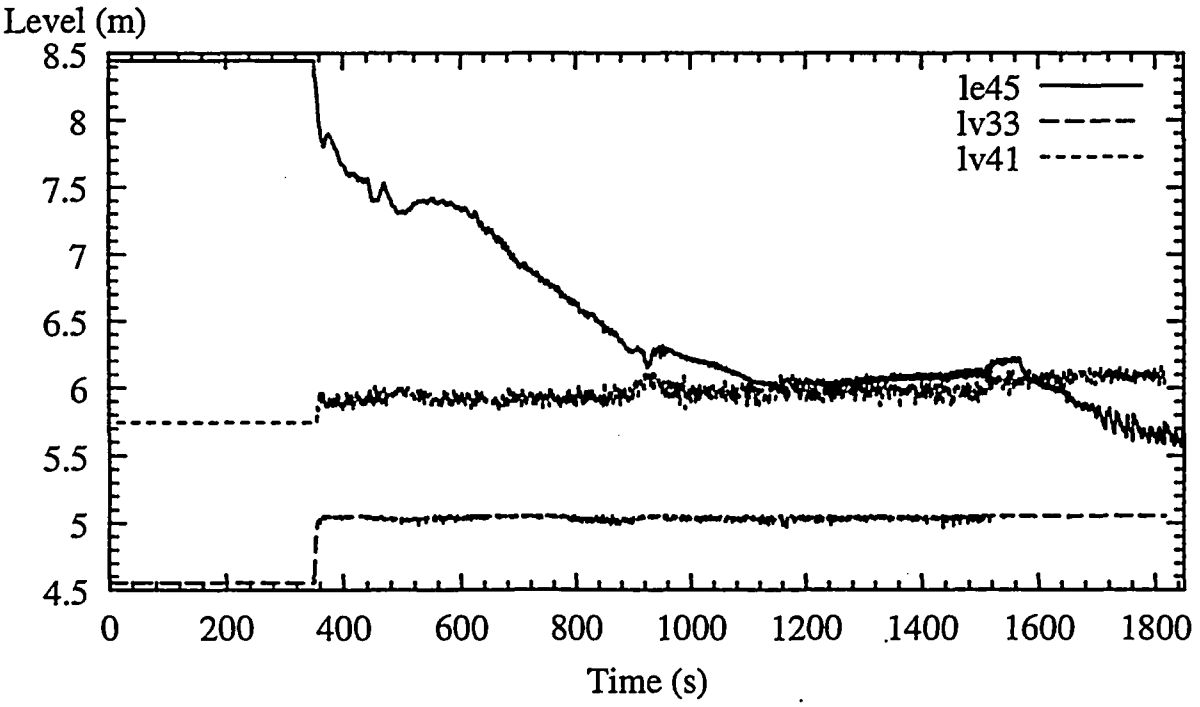
PMK-2 CAMP EXPERIMENT

Fig. 4.33 Hot Leg Loop Seal Level



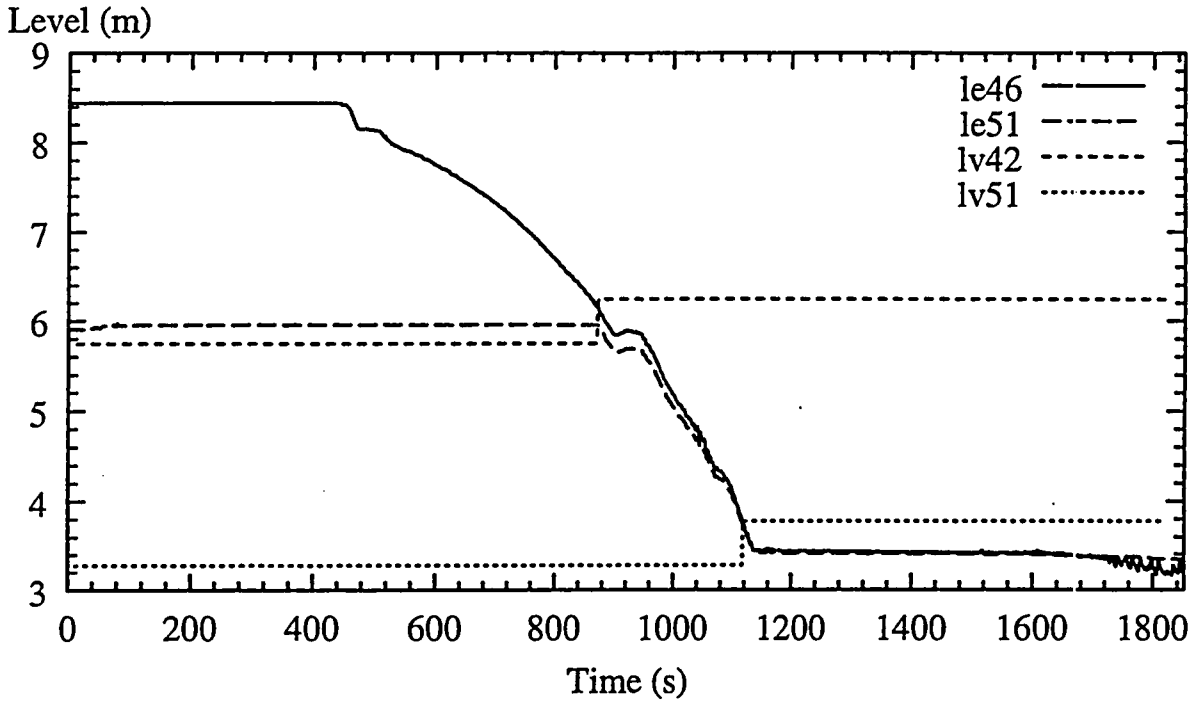
PMK-2 CAMP EXPERIMENT

Fig. 4.34 SG Hot Collector Level



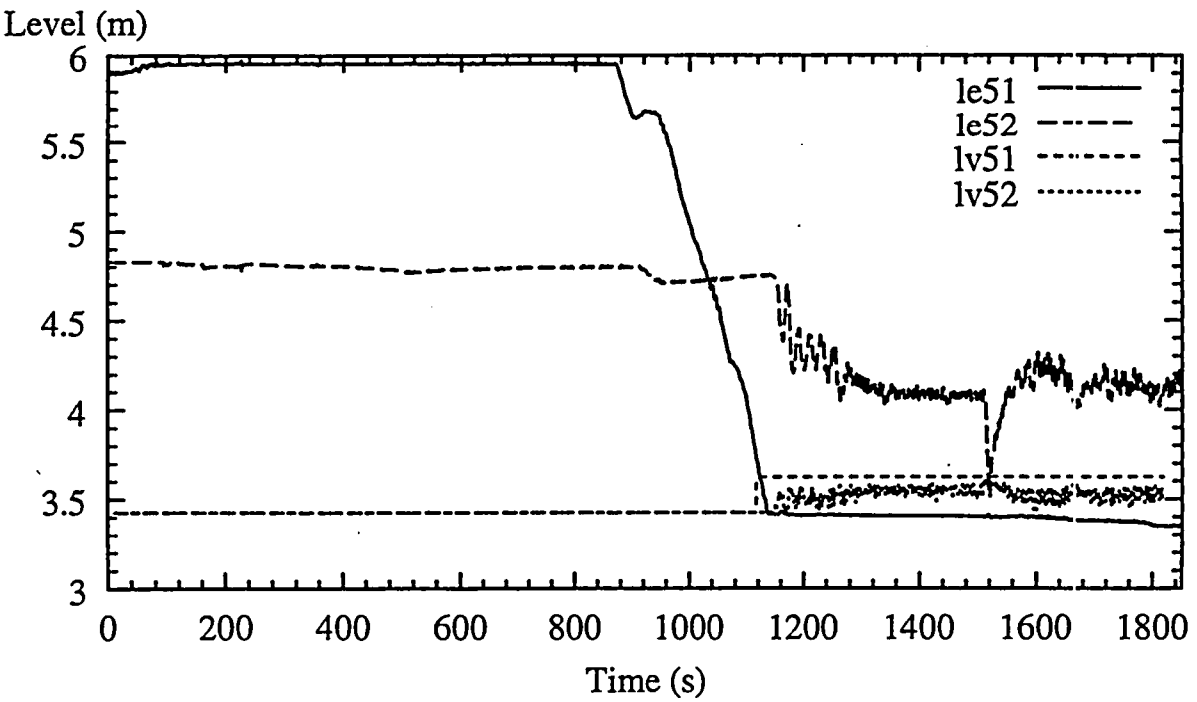
PMK-2 CAMP EXPERIMENT

Fig. 4.35 SG Cold Collector Levels



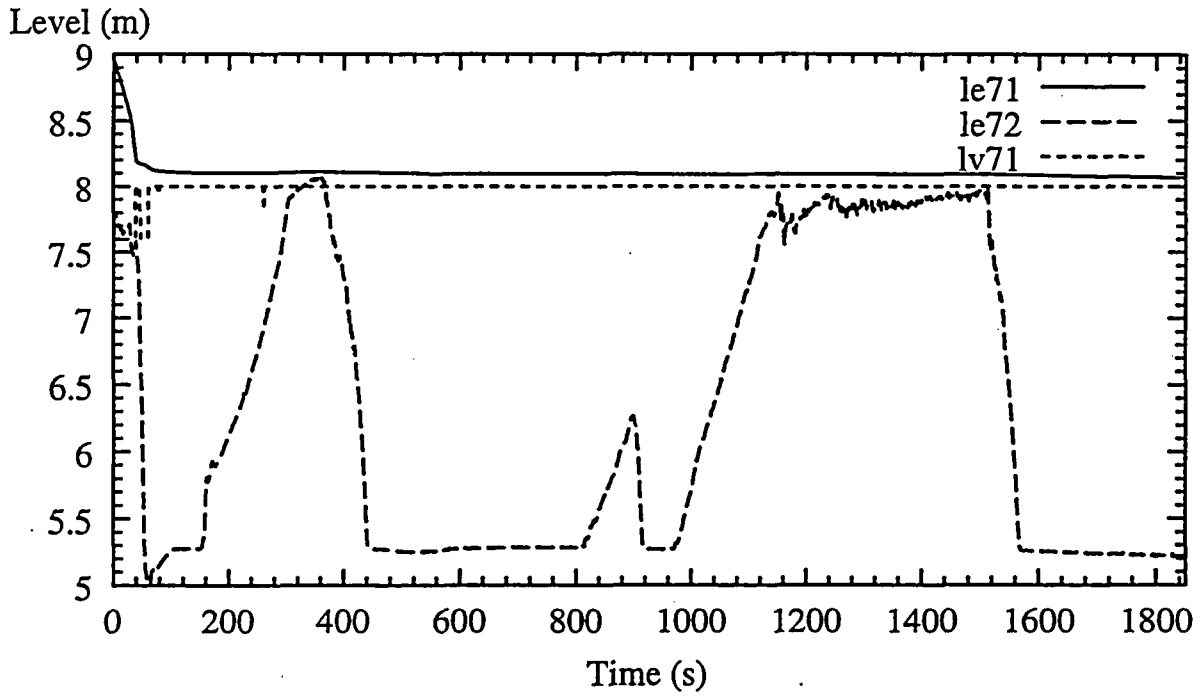
PMK-2 CAMP EXPERIMENT

Fig. 4.36 Cold Leg Levels



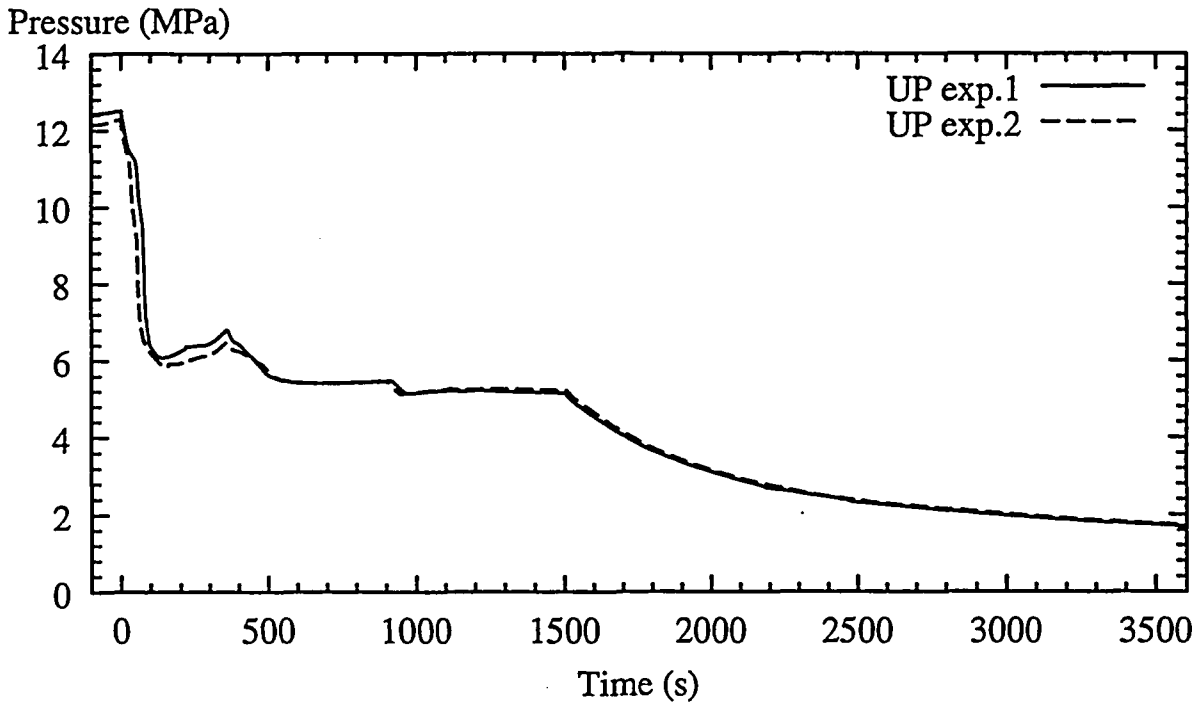
PMK-2 CAMP EXPERIMENT

Fig. 4.37 Pressurizer and Surge Line Level



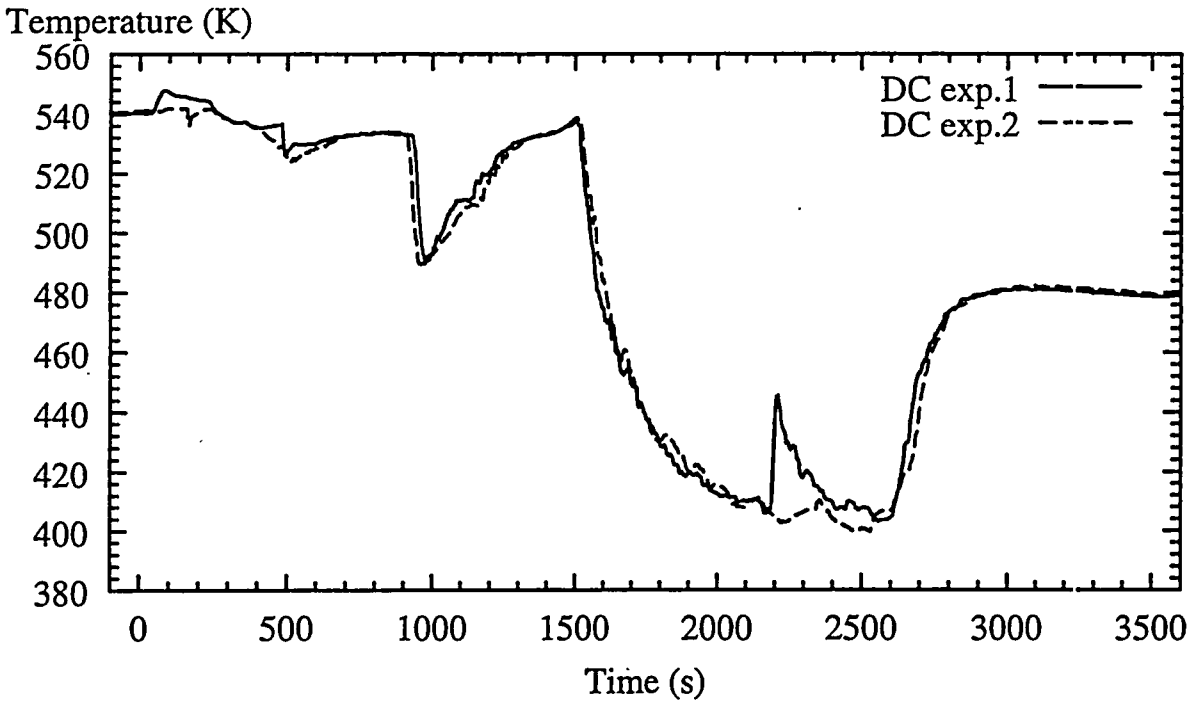
PMK-2 CAMP EXPERIMENT

Fig. 4.38 Primary Pressure



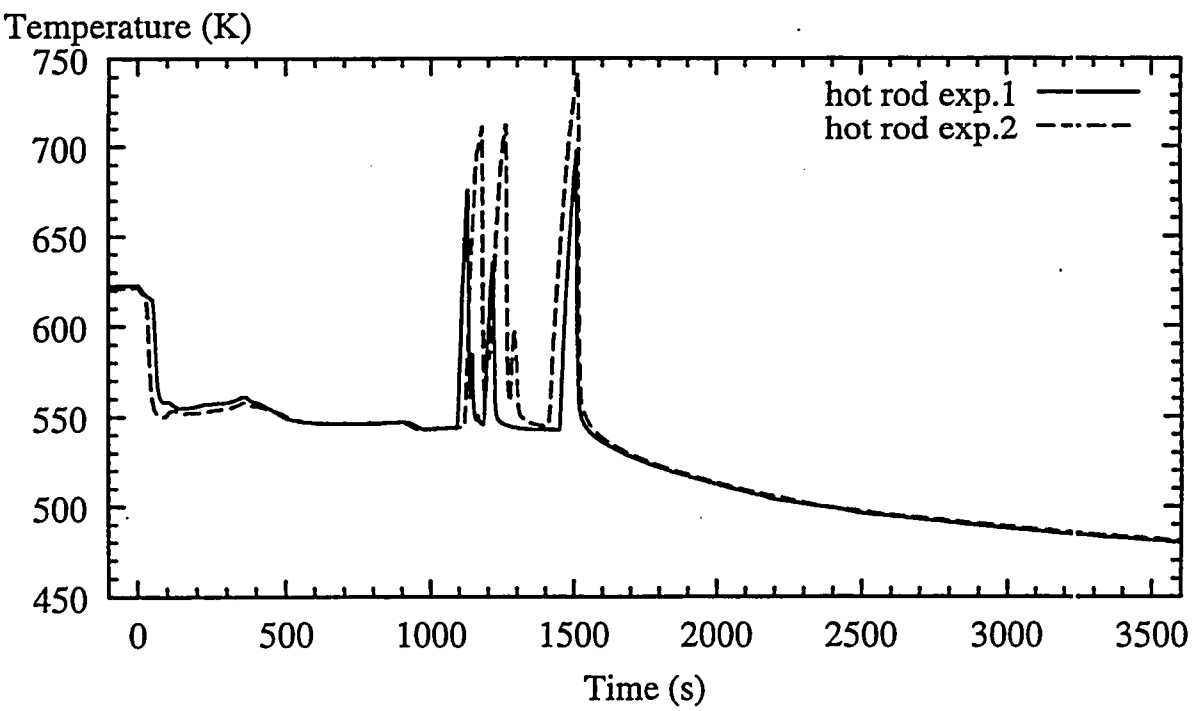
PMK-2 CAMP EXPERIMENT

Fig. 4.39 Down-comer Temperature



PMK-2 CAMP EXPERIMENT

Fig. 4.40 Cladding Temperature



APPENDIX 2

Fig 6.1 Primary Pressure

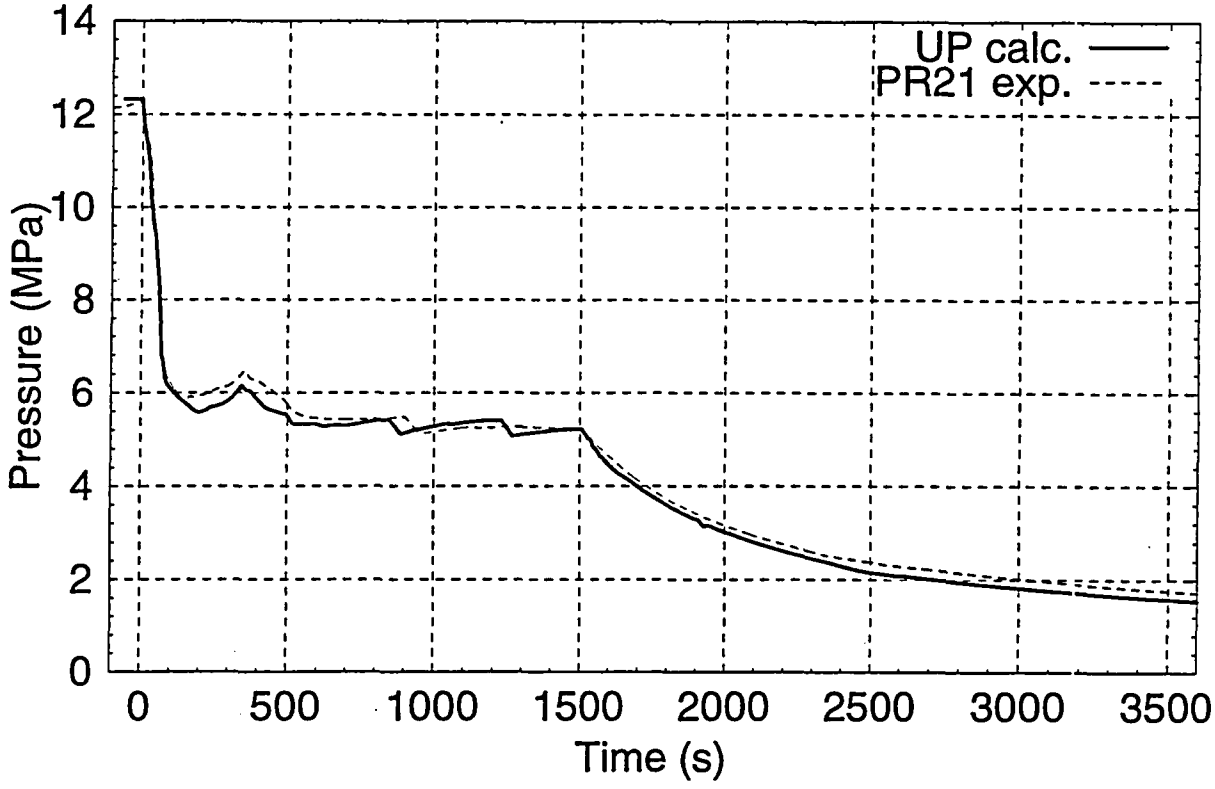


Fig 6.2 Secondary Pressure

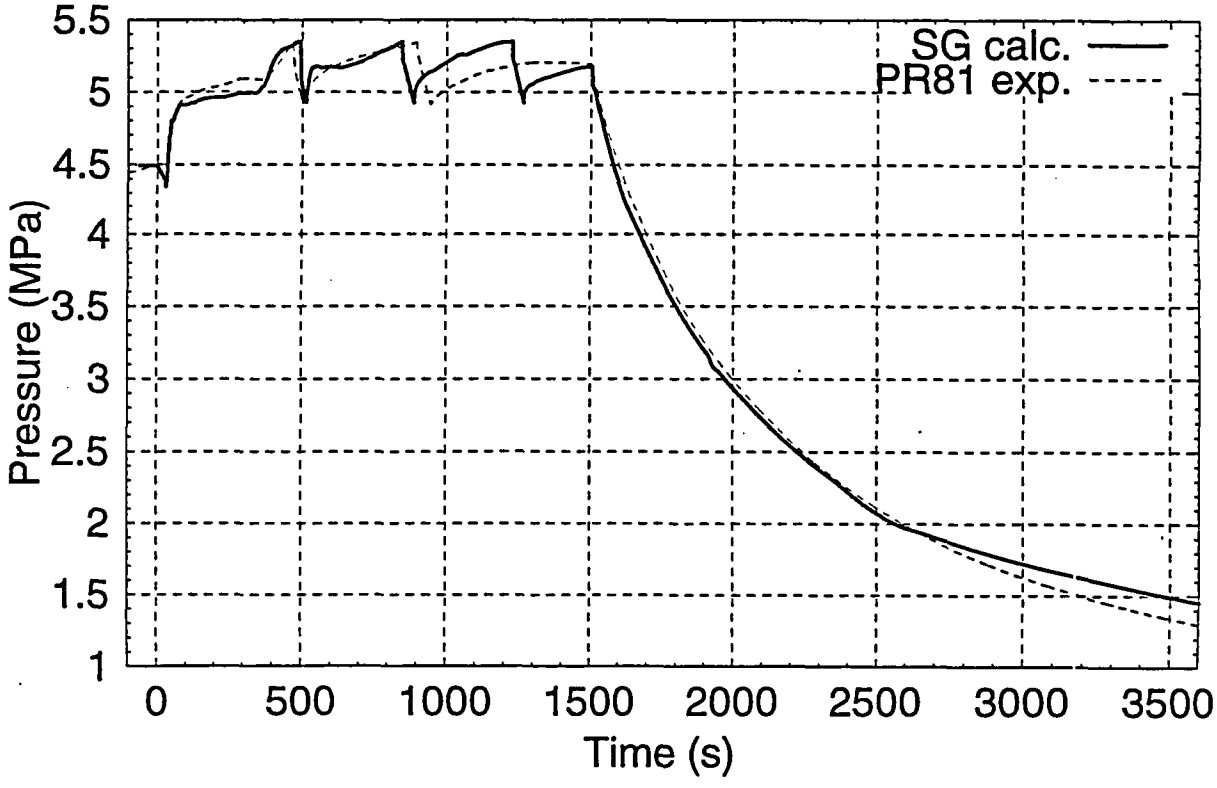


Fig 6.3 Break Mass Flow Rate

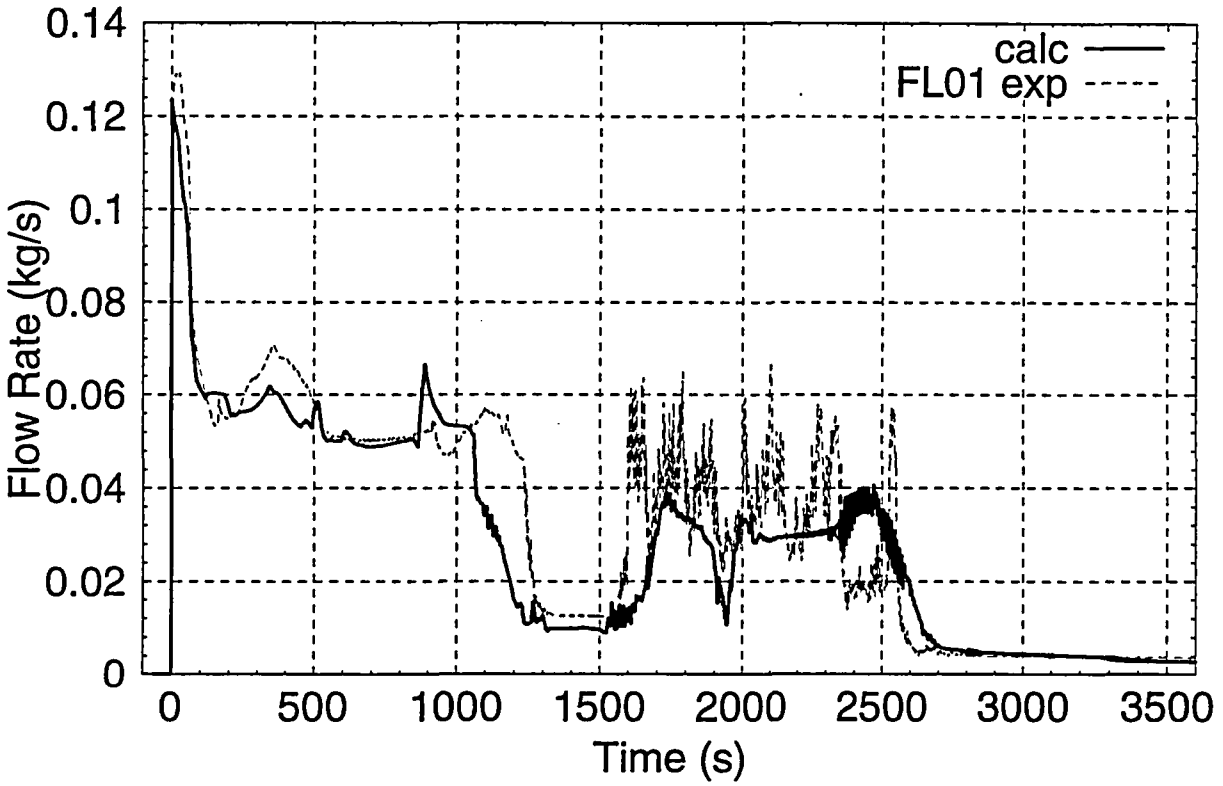


Fig 6.4 Integrated Break Mass Flow

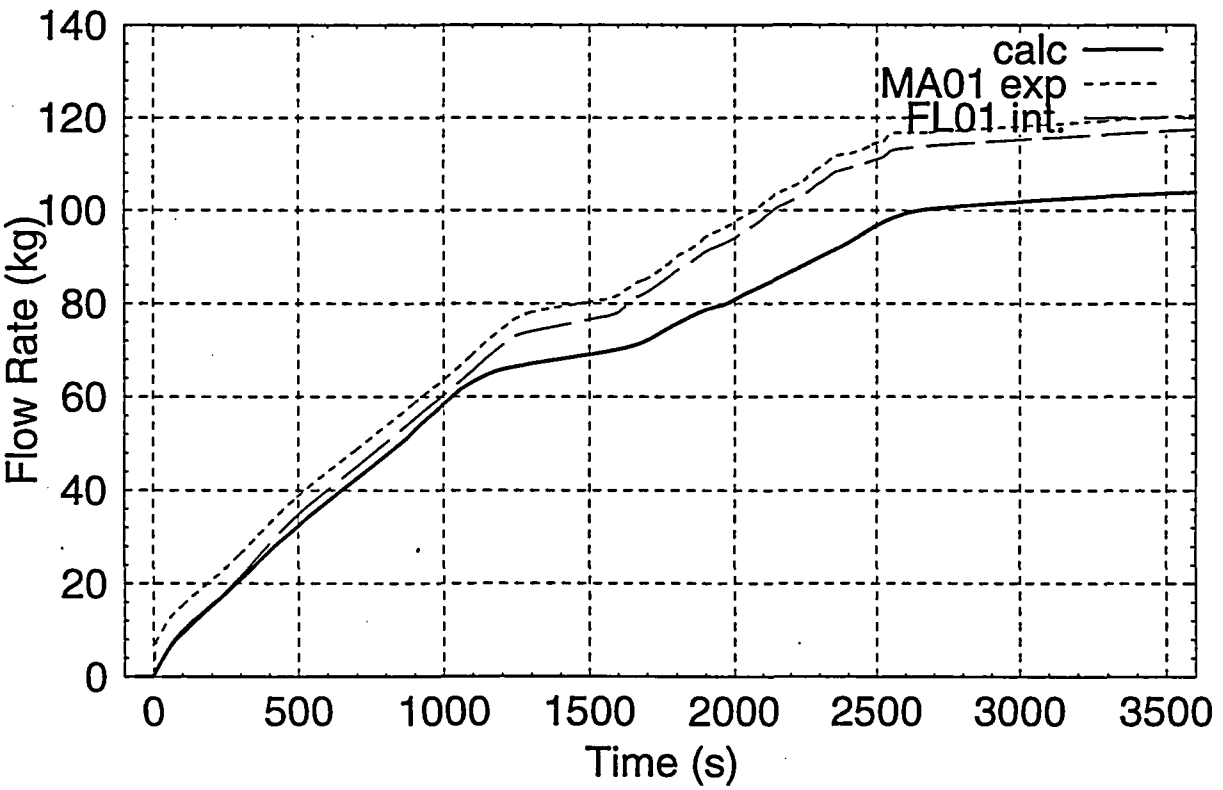


Fig 6.5 Core Energy

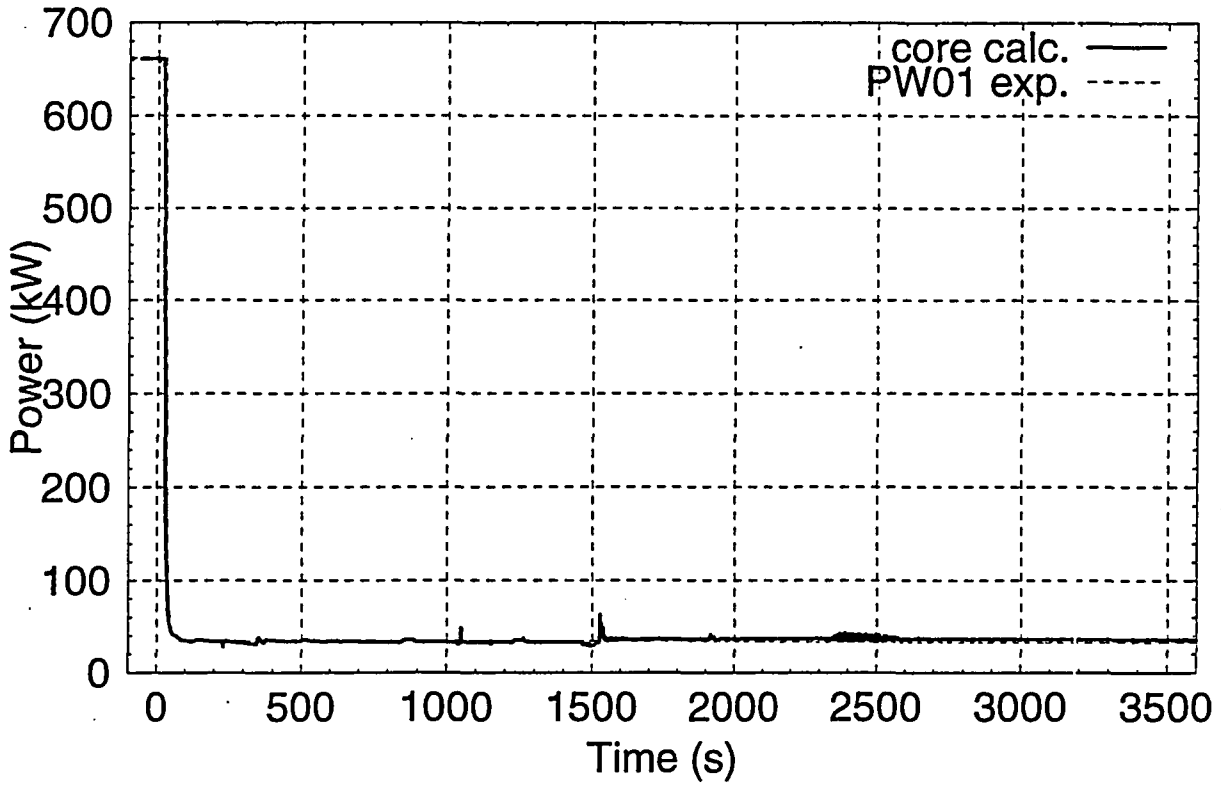


Fig 6.6 Primary Mass Flow

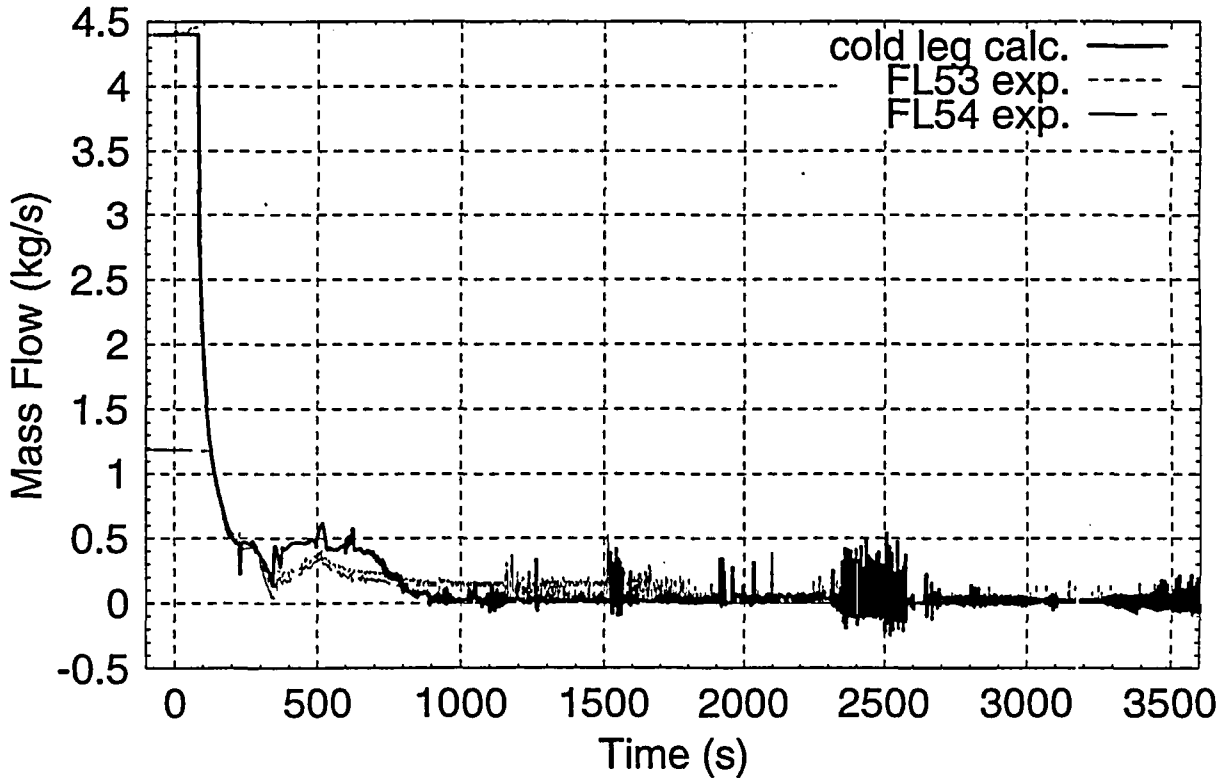


Fig 6.7 Hydroaccumulator Pressure

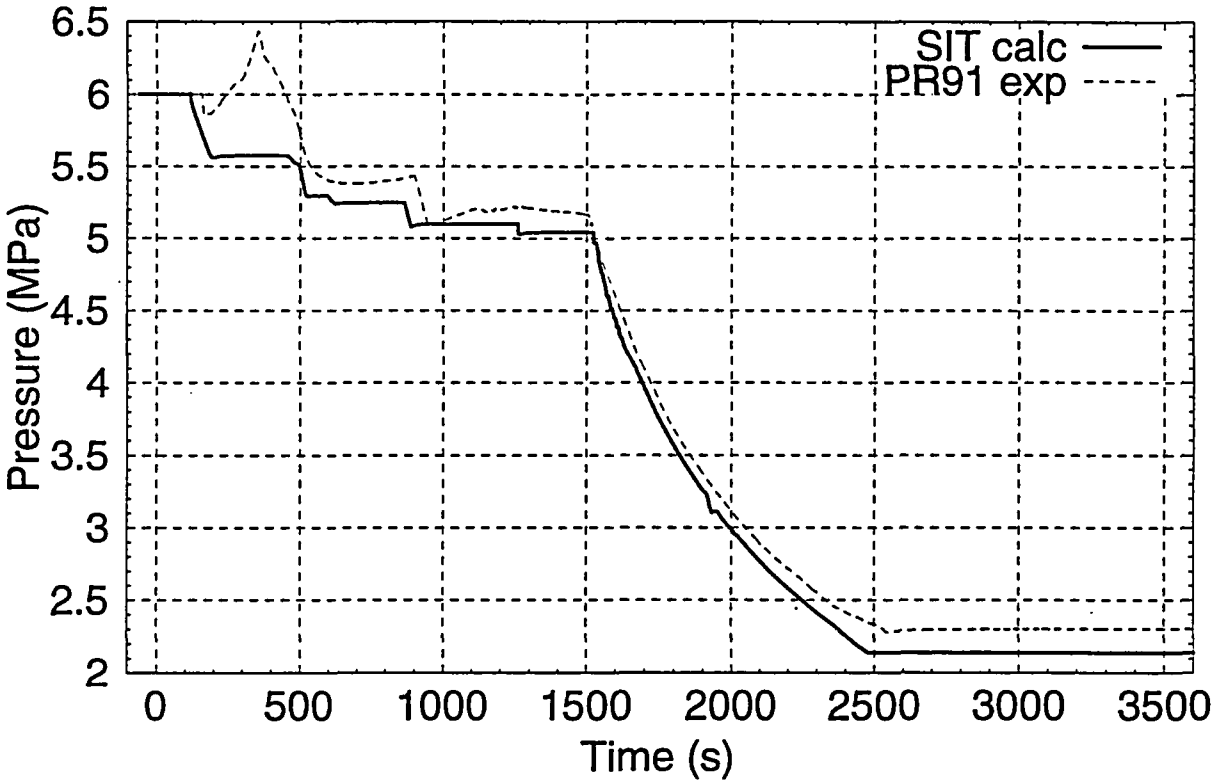


Fig 6.8 Hydroaccumulator Level

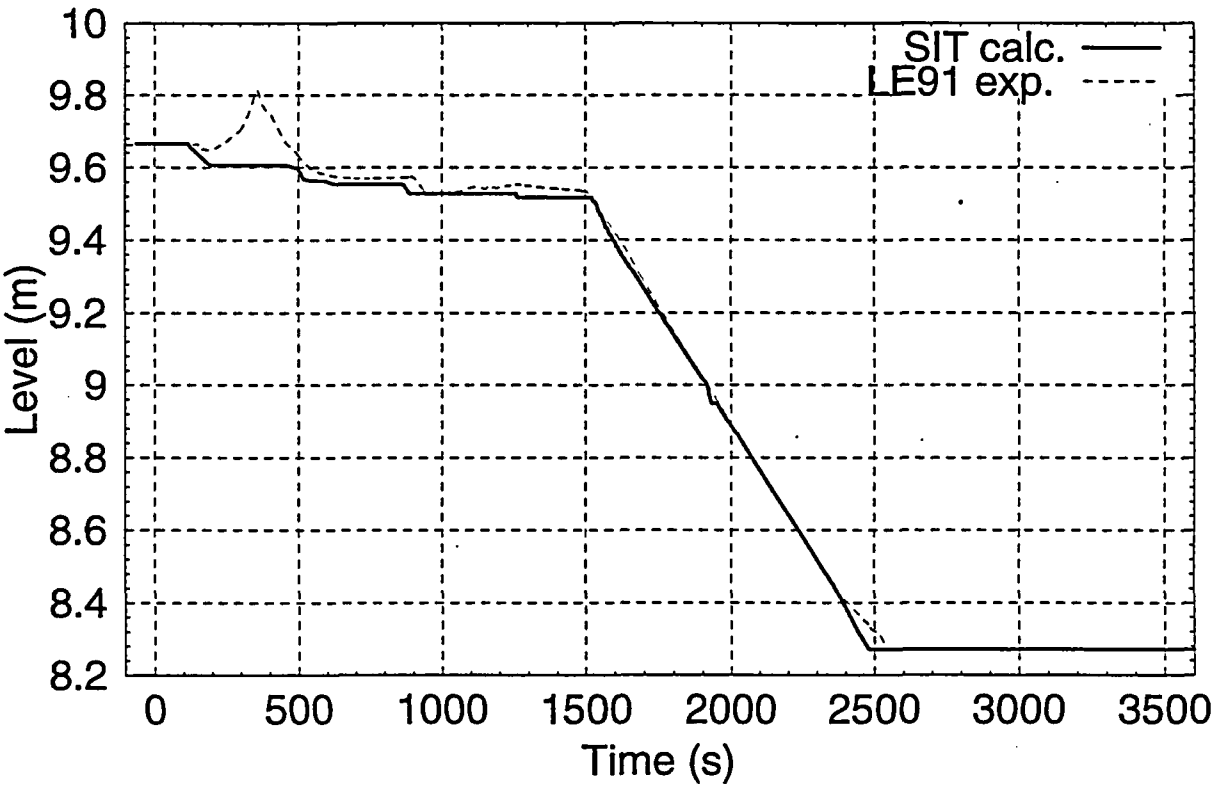


Fig 6.9 Steam Dump Mass Flow

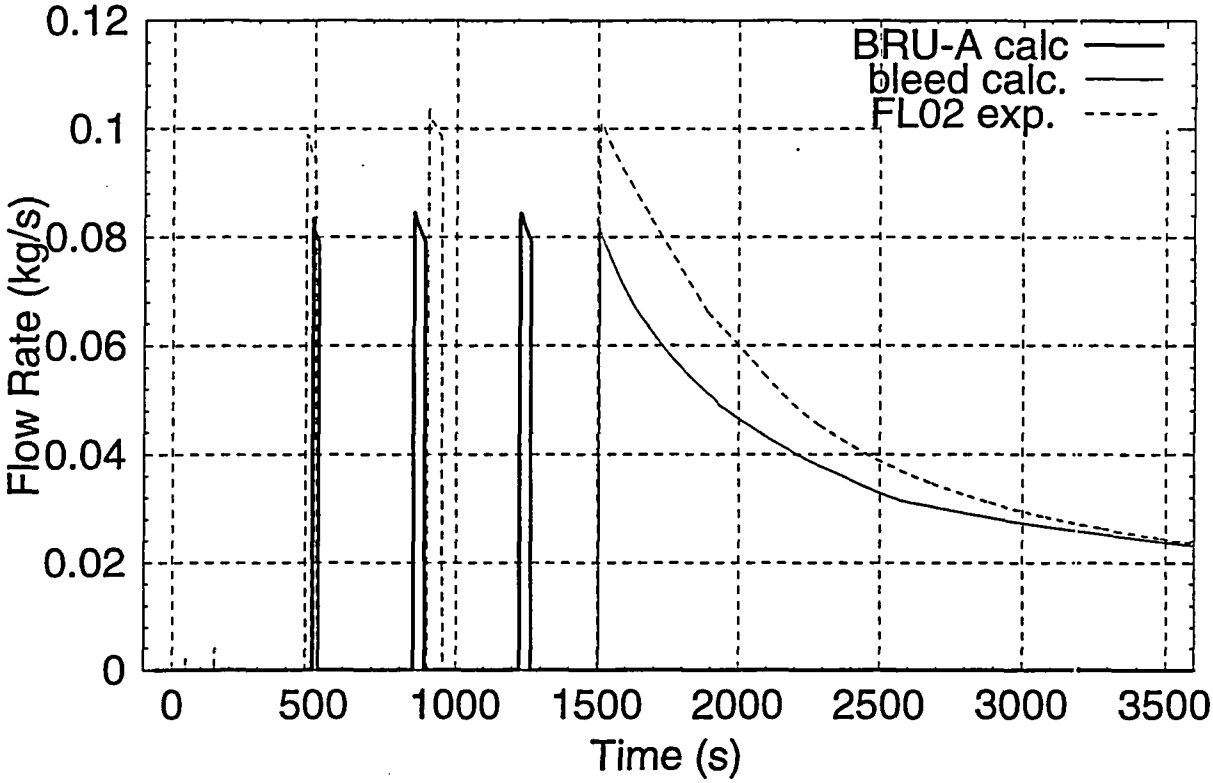


Fig 6.10 Pressurizer Collapsed Level

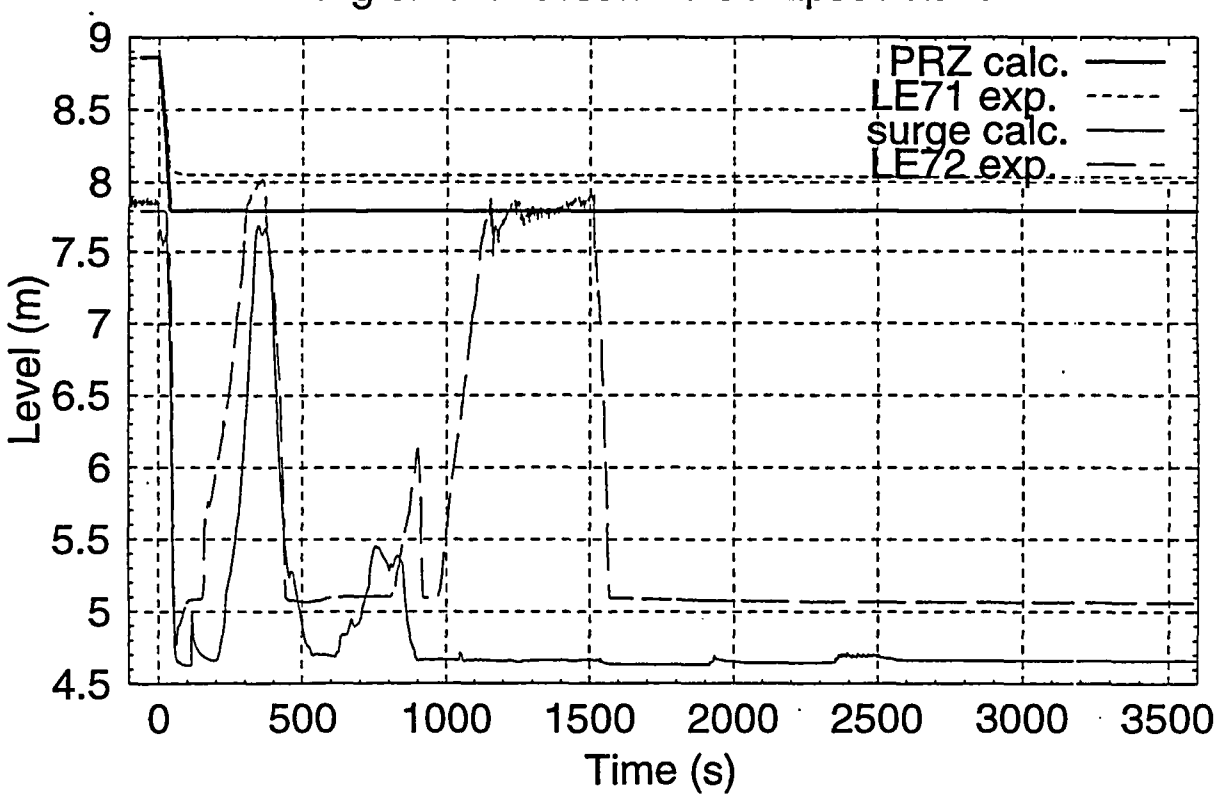


Fig 6.11 Collapsed Level in Reactor Vessel

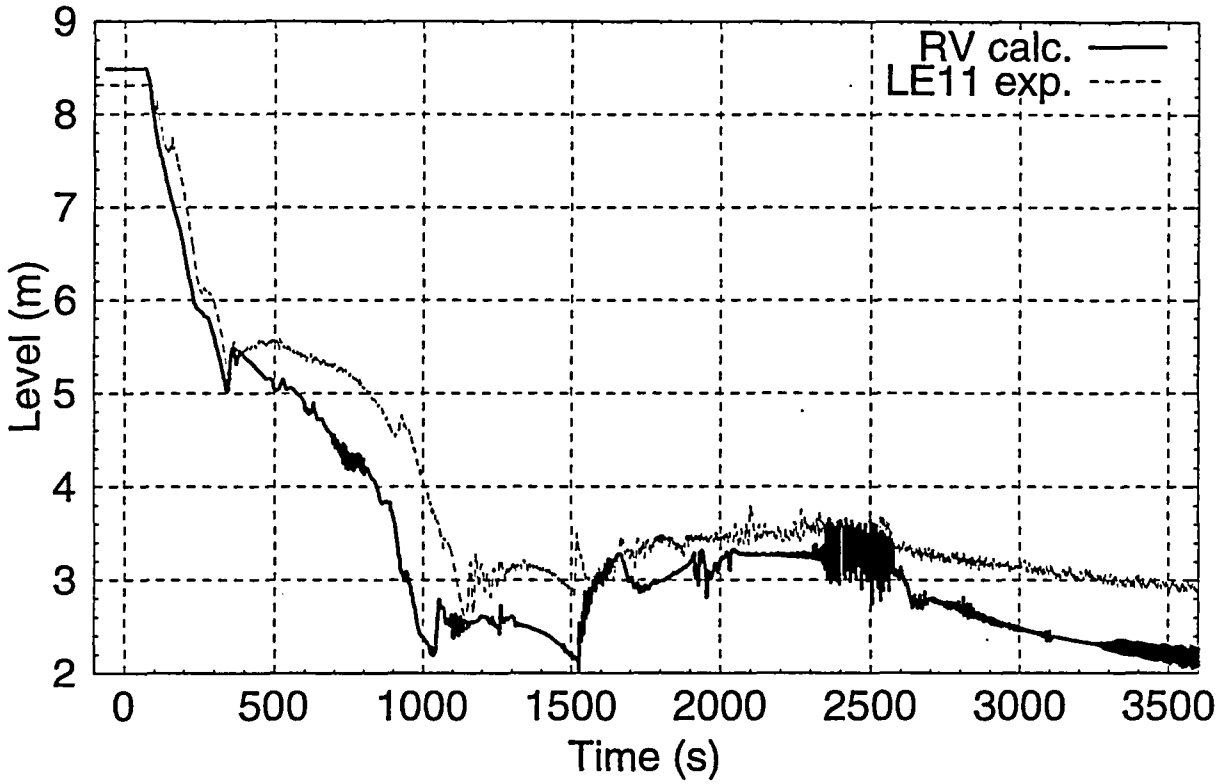


Fig 6.12 Primary Mass Inventory

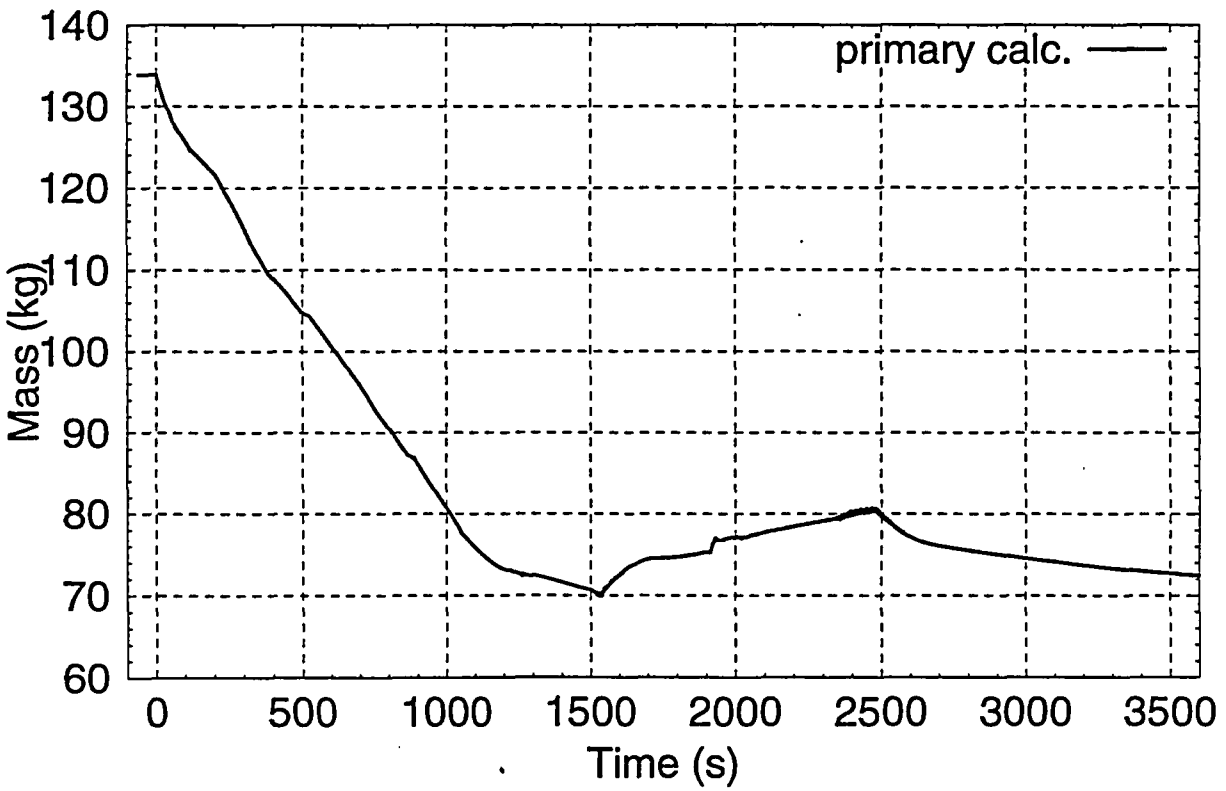


Fig 6.13 Collapsed Levels in Hot Leg Loop Seal

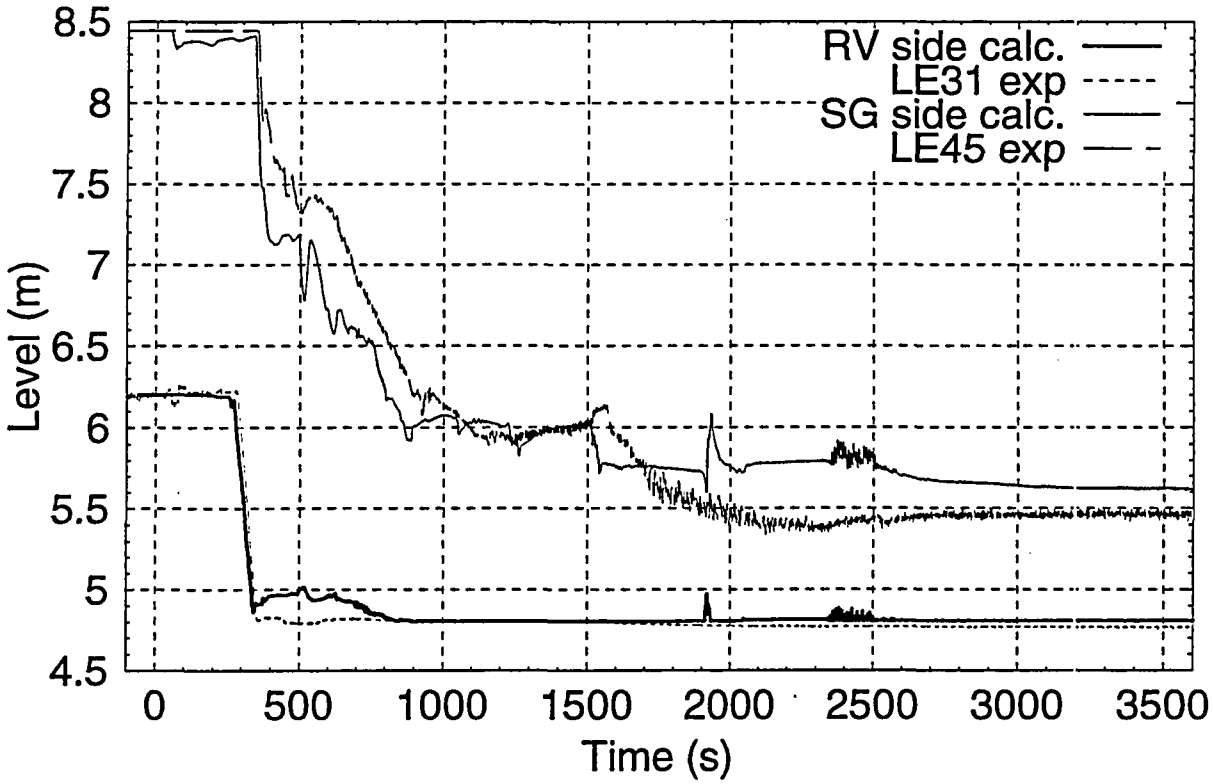


Fig 6.14 Collapsed Levels in Cold Leg Loop Seal

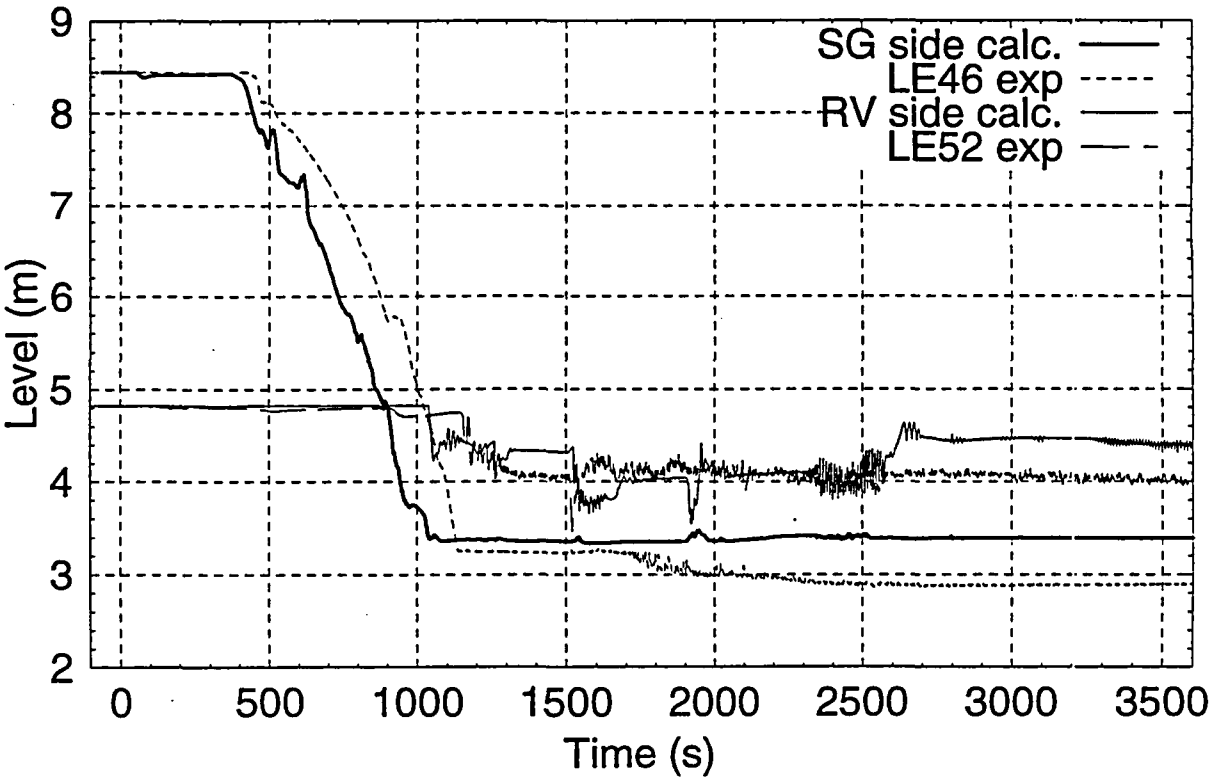


Fig 6.15 Down Comer Temperature

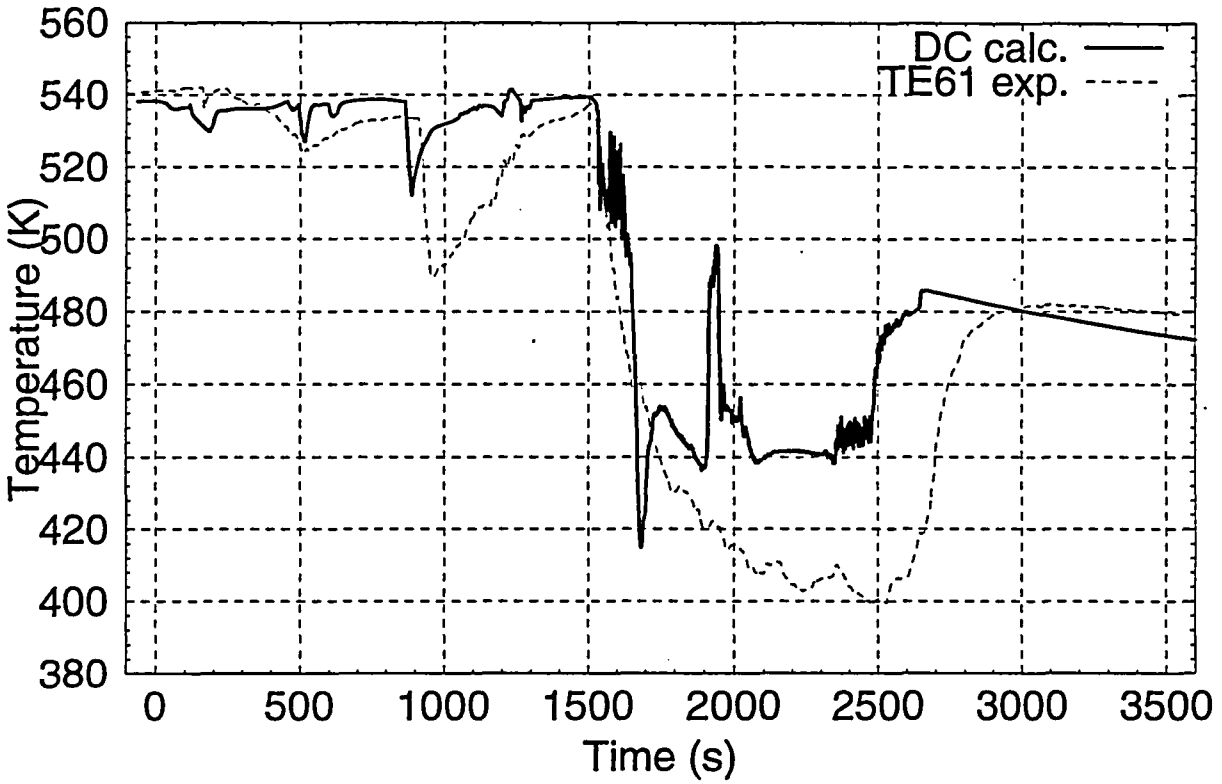


Fig 6.16 Core Inlet Temperature

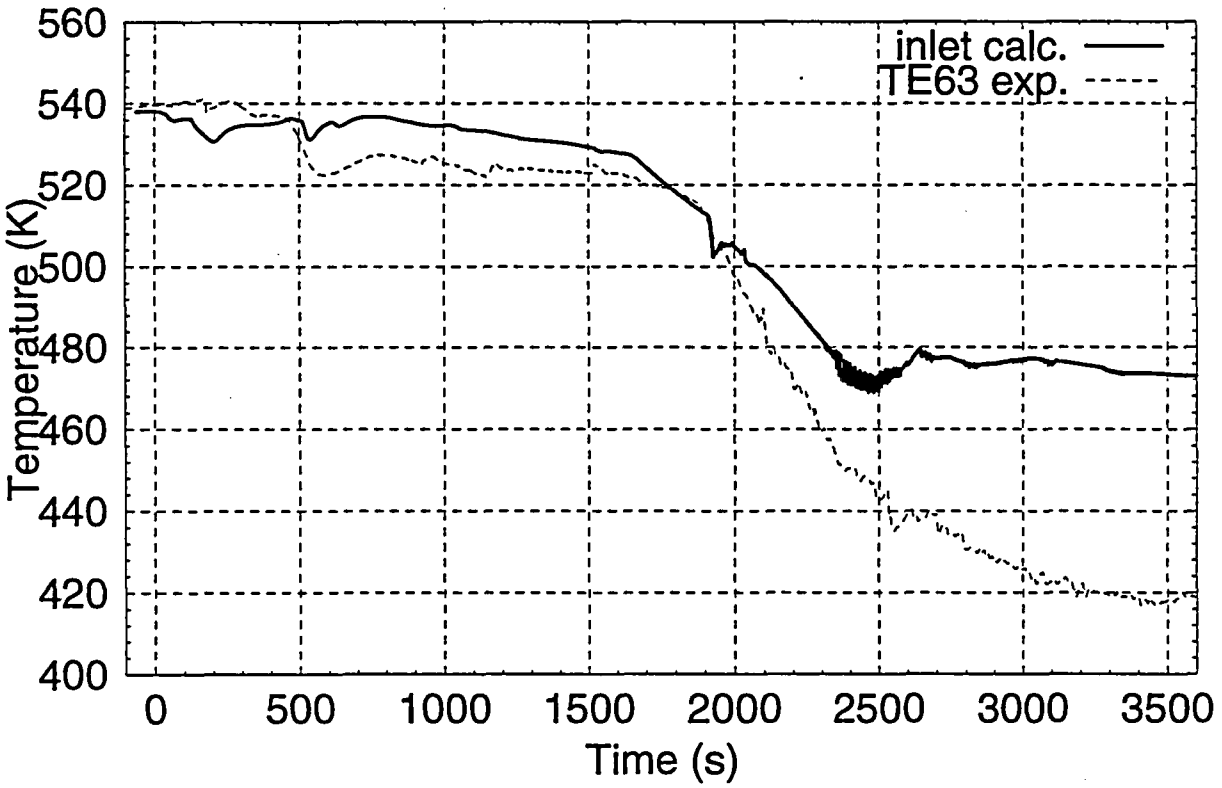


Fig 6.17 Core Outlet Temperature

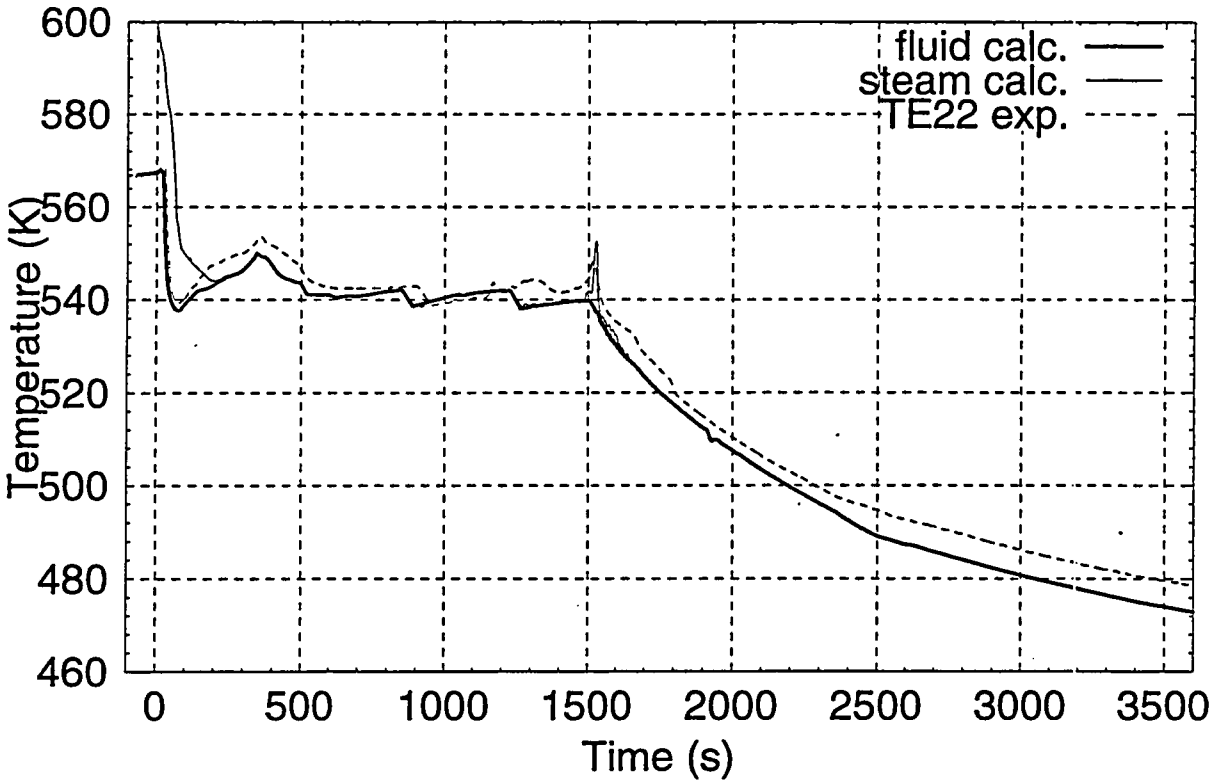


Fig 6.18 Collapsed Level in SG Secondary Side

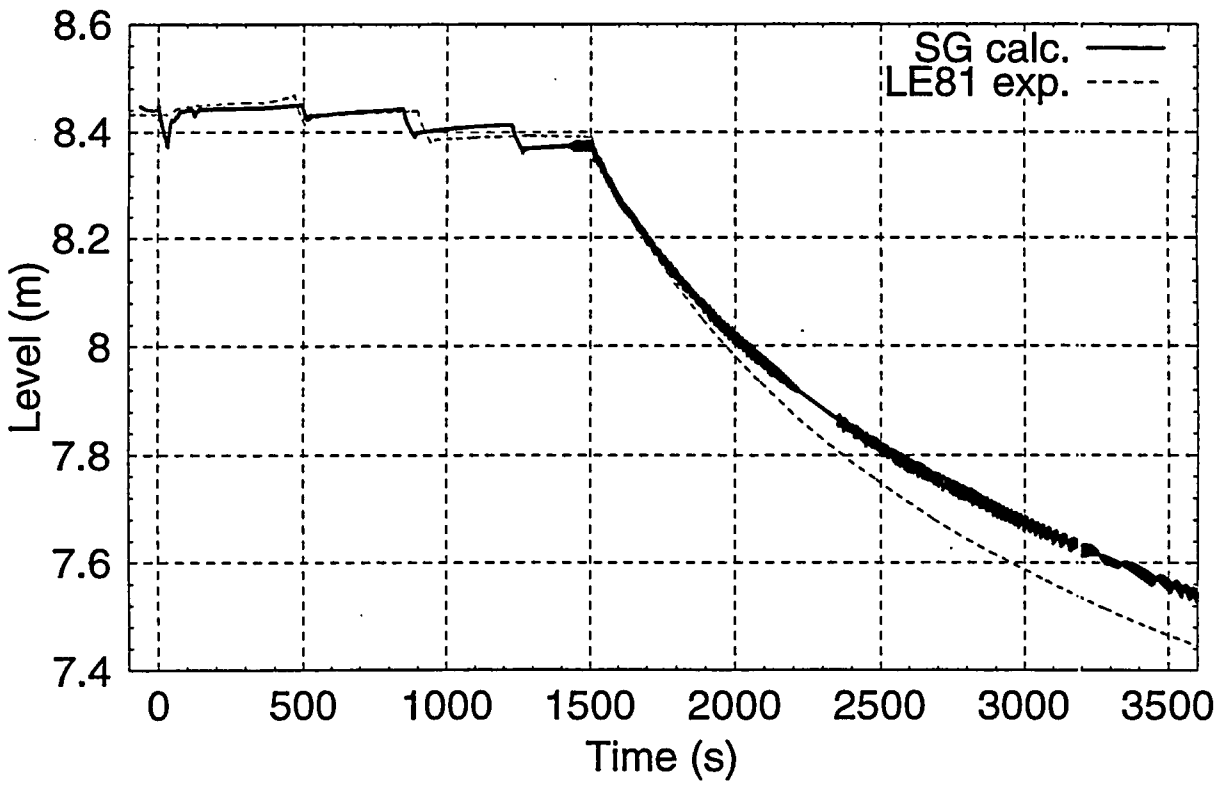


Fig 6.19 Cladding Temperatures at 3 m

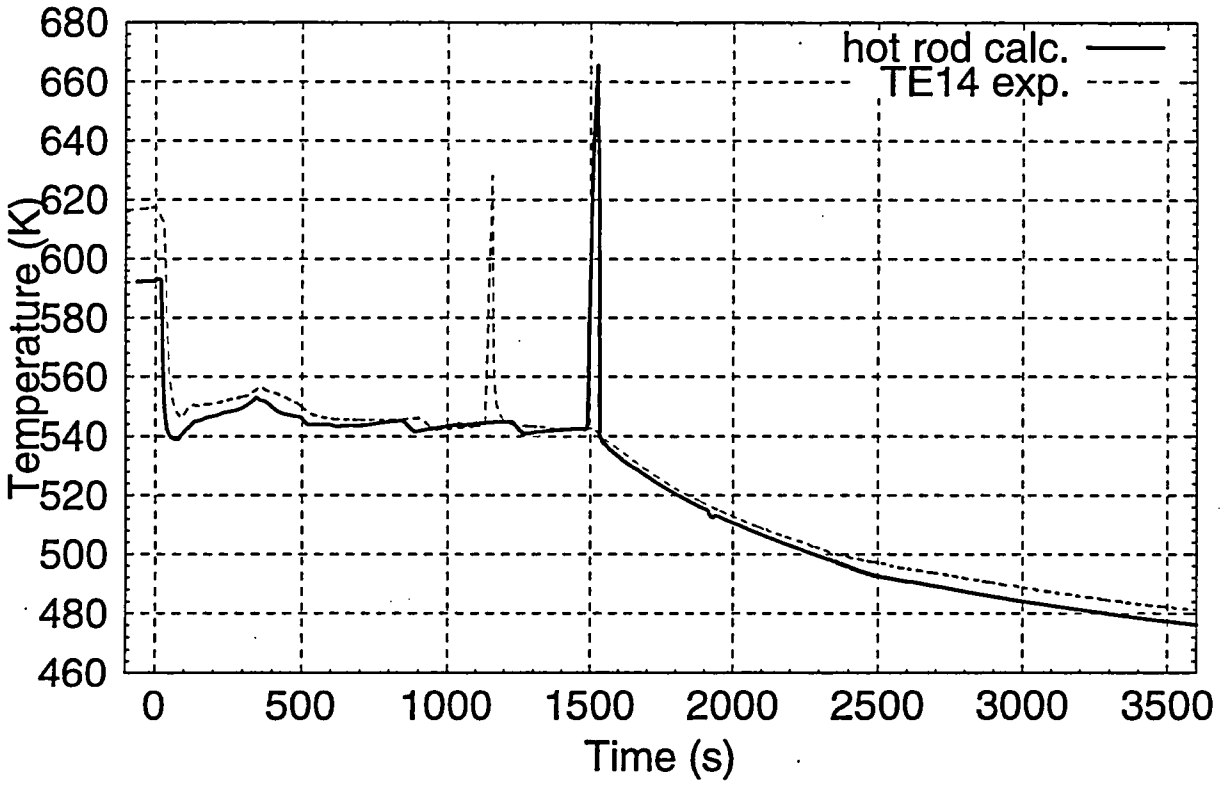


Fig 6.20 Cladding Temperatures Top

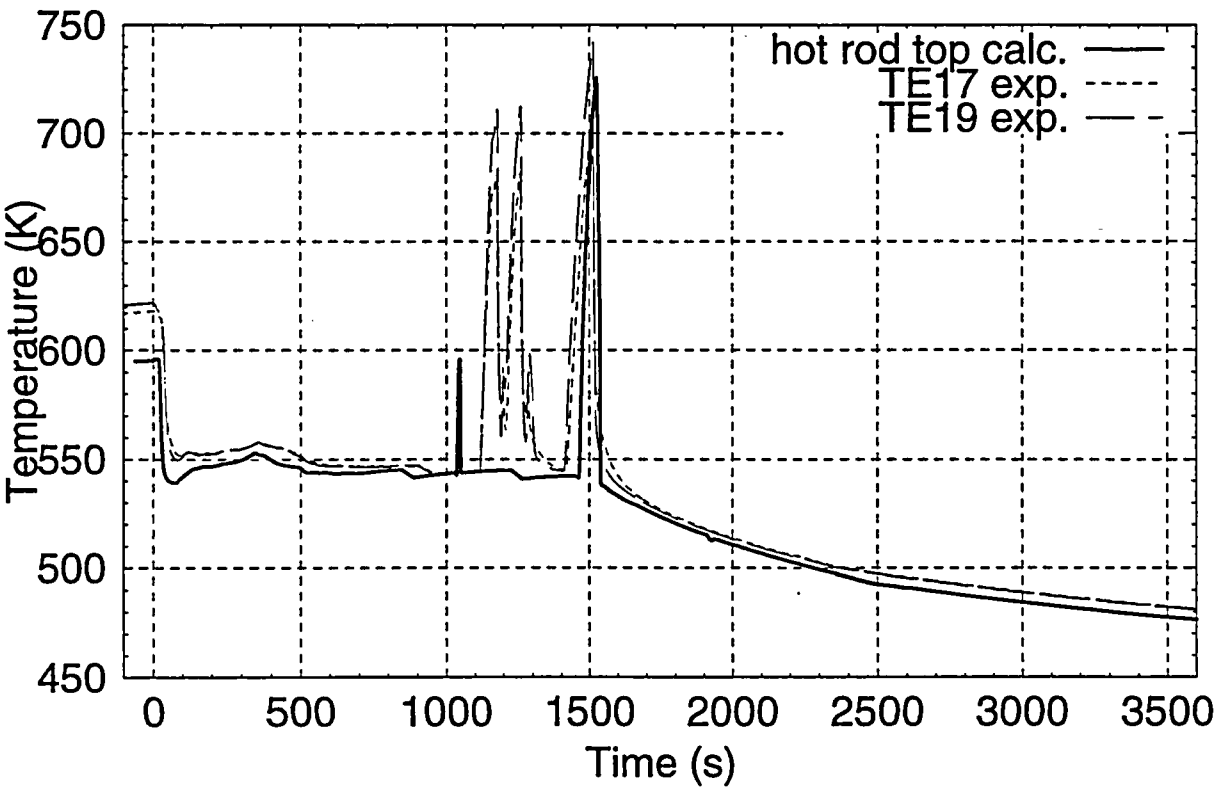


Fig 7.1 Steam Dump Mass Flow

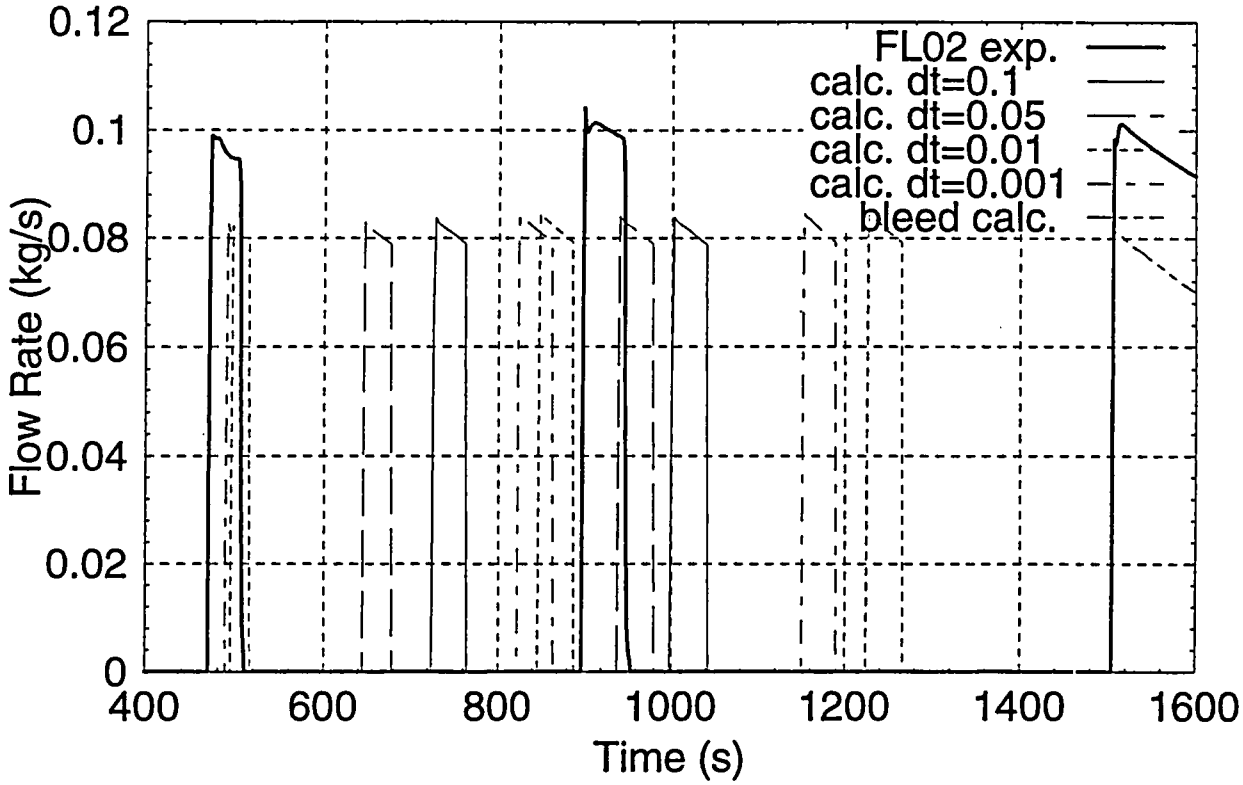


Fig 7.2 Secondary Pressure

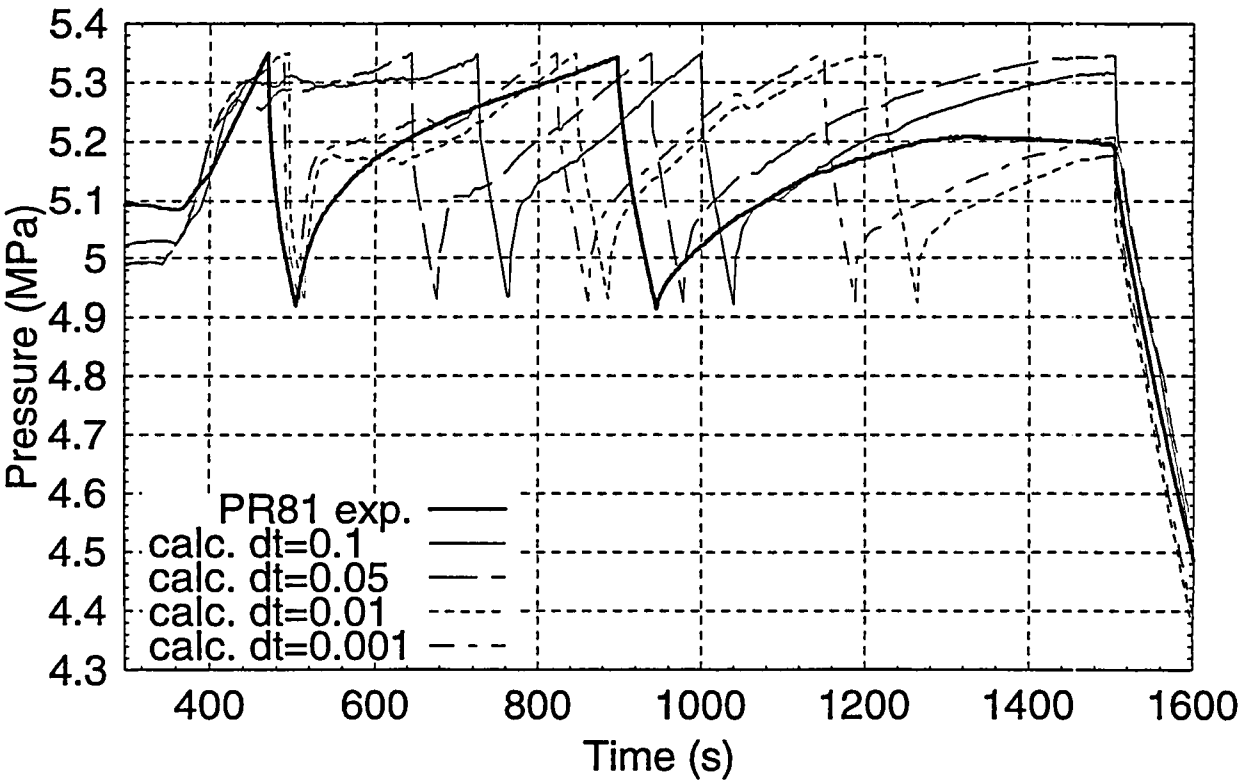


Fig 7.3 Collapsed Level in Reactor Vessel

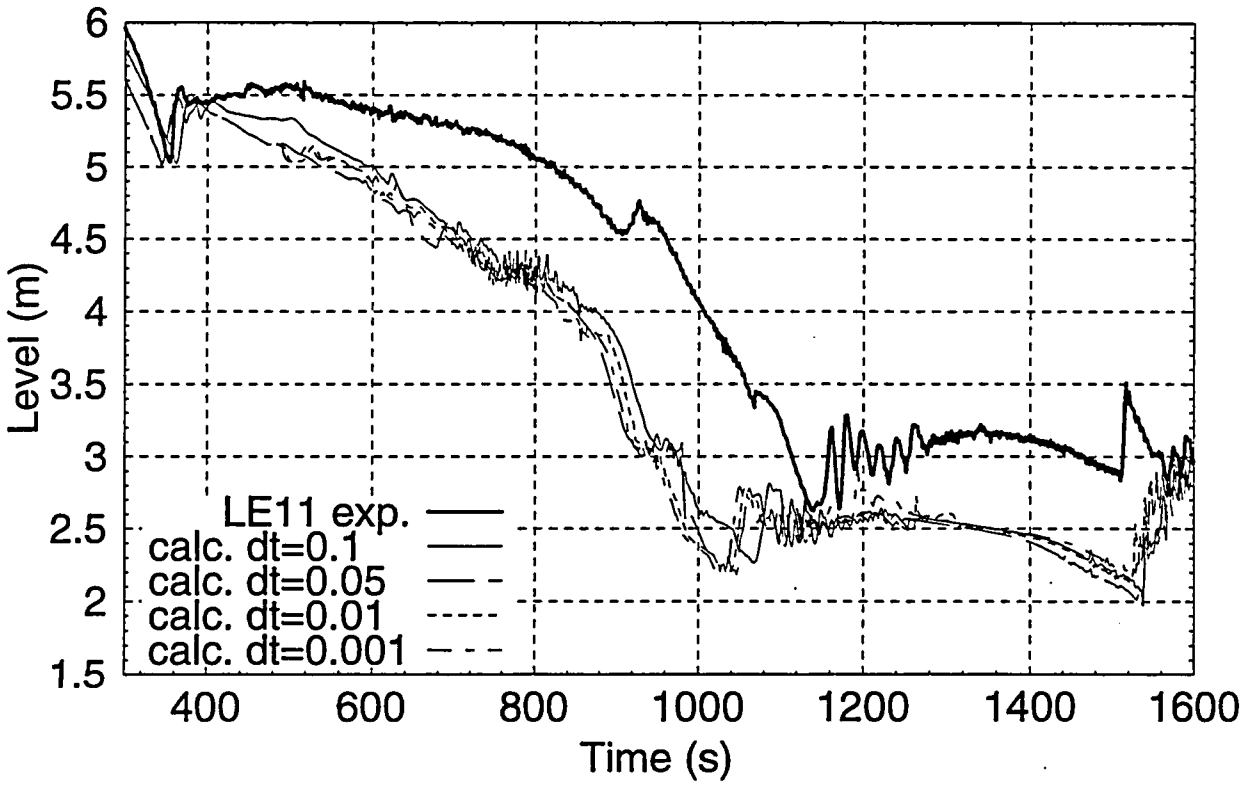


Fig 7.4 Cladding Temperature

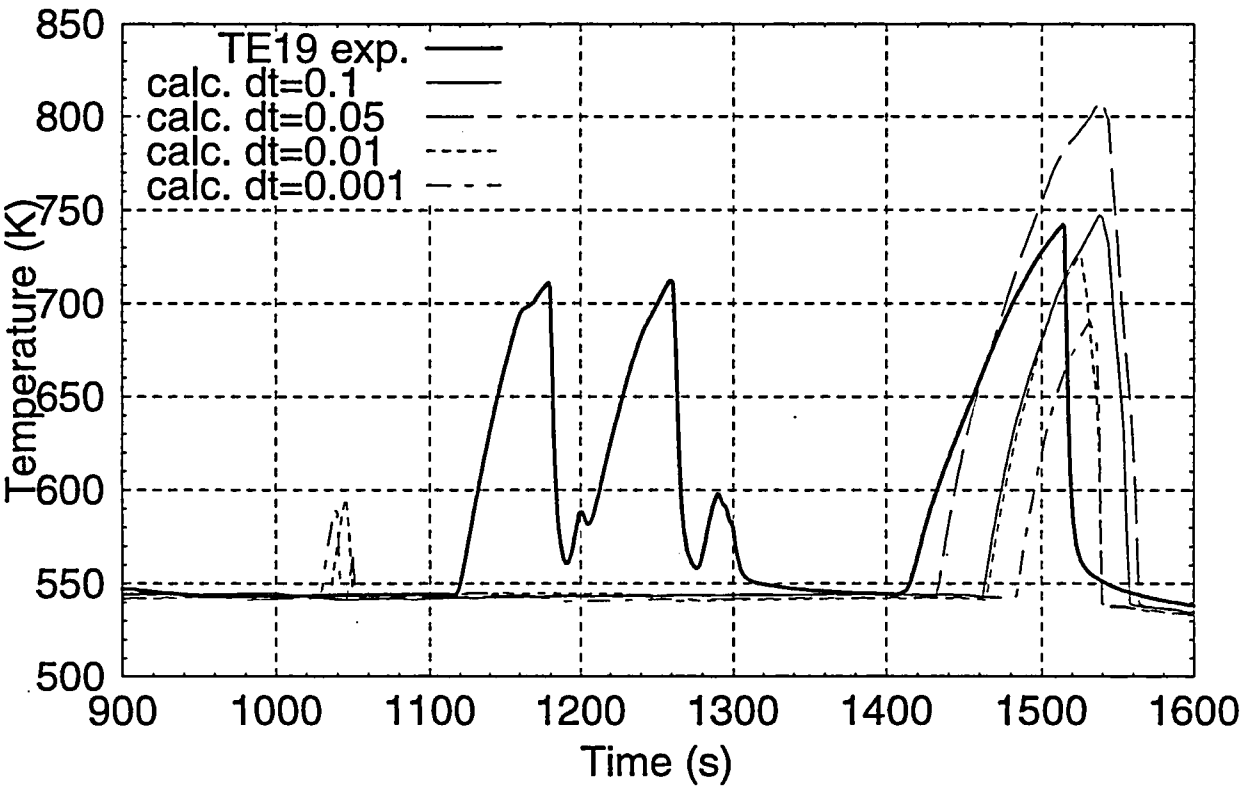


Fig 7.5 Steam Dump Mass Flow

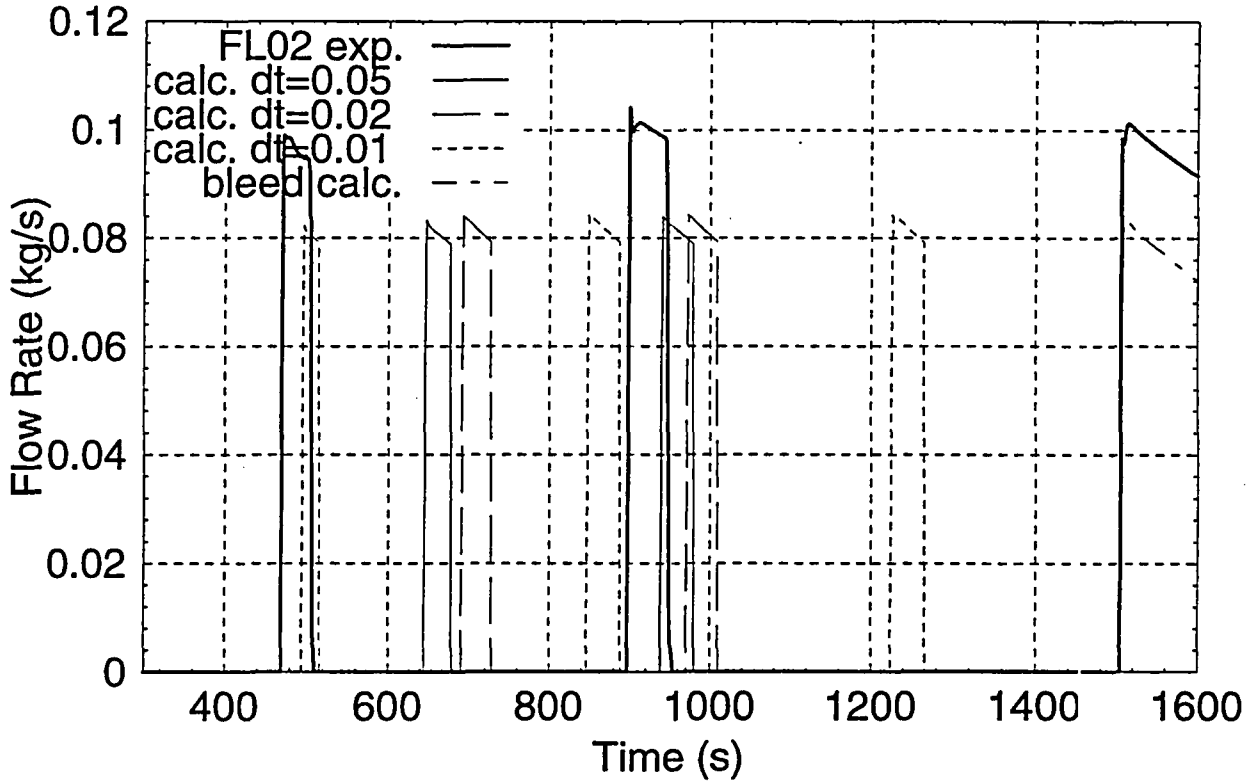


Fig 7.6 Collapsed Level in Reactor Vessel

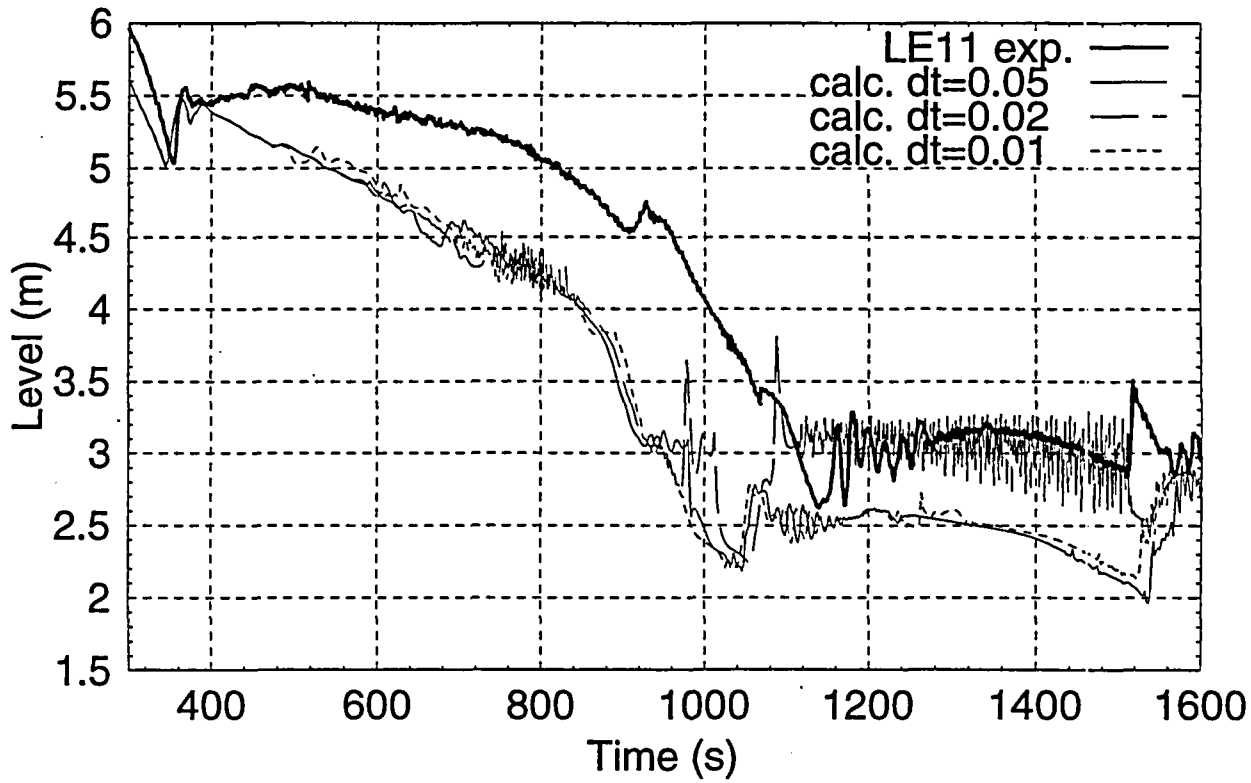


Fig 7.7 Cladding Temperature

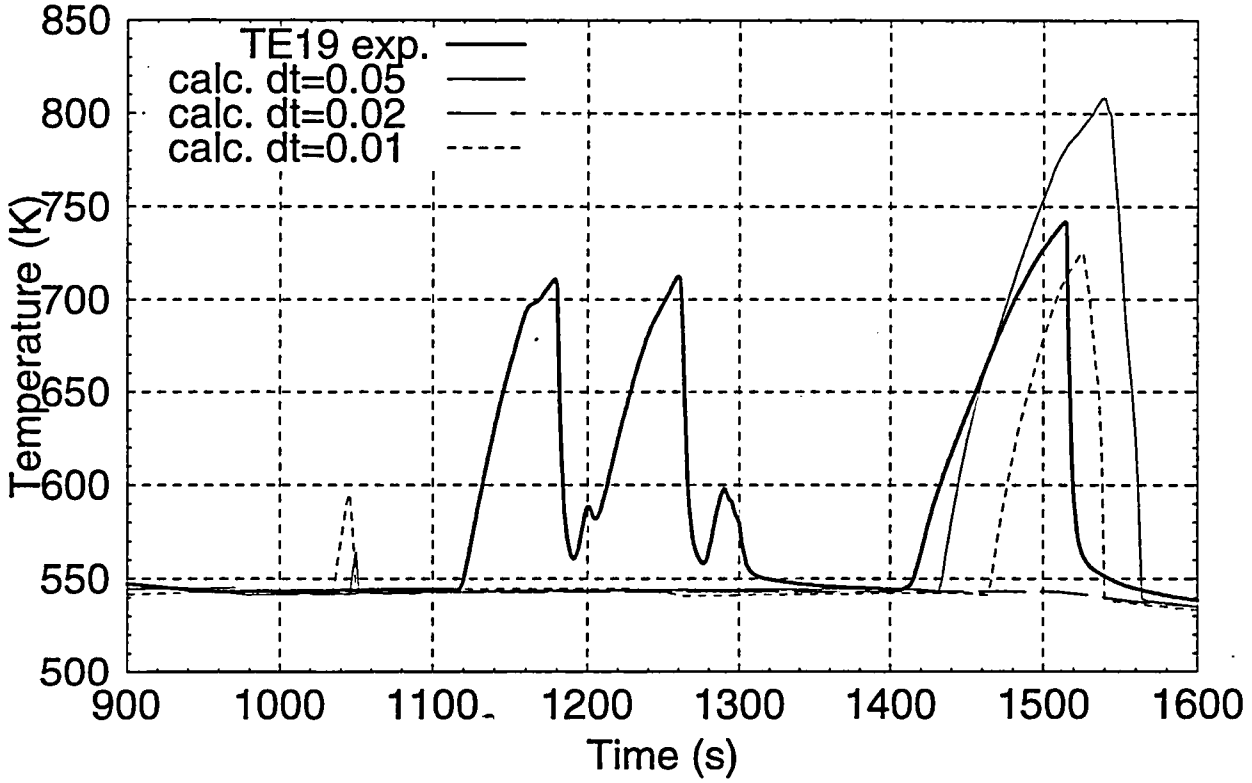


Fig 7.8 Steam Dump Mass Flow

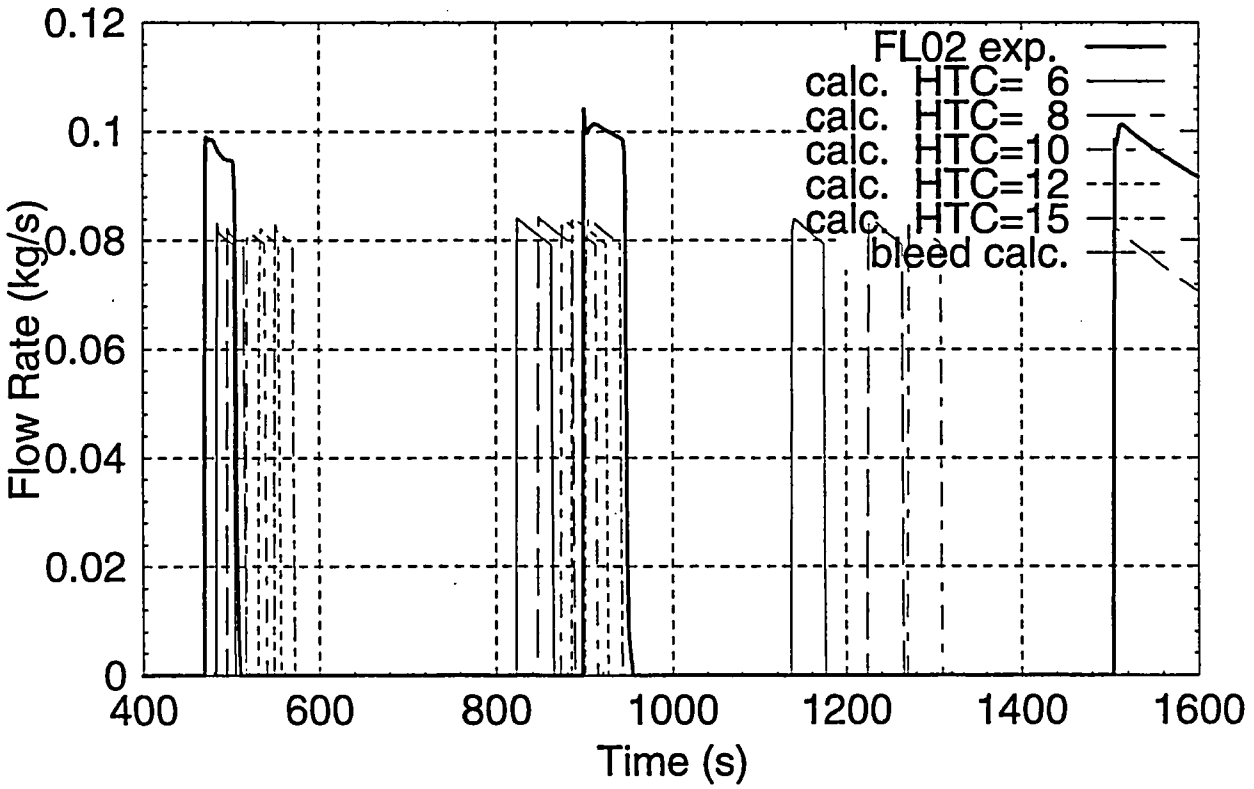


Fig 7.9 Secondary Pressure

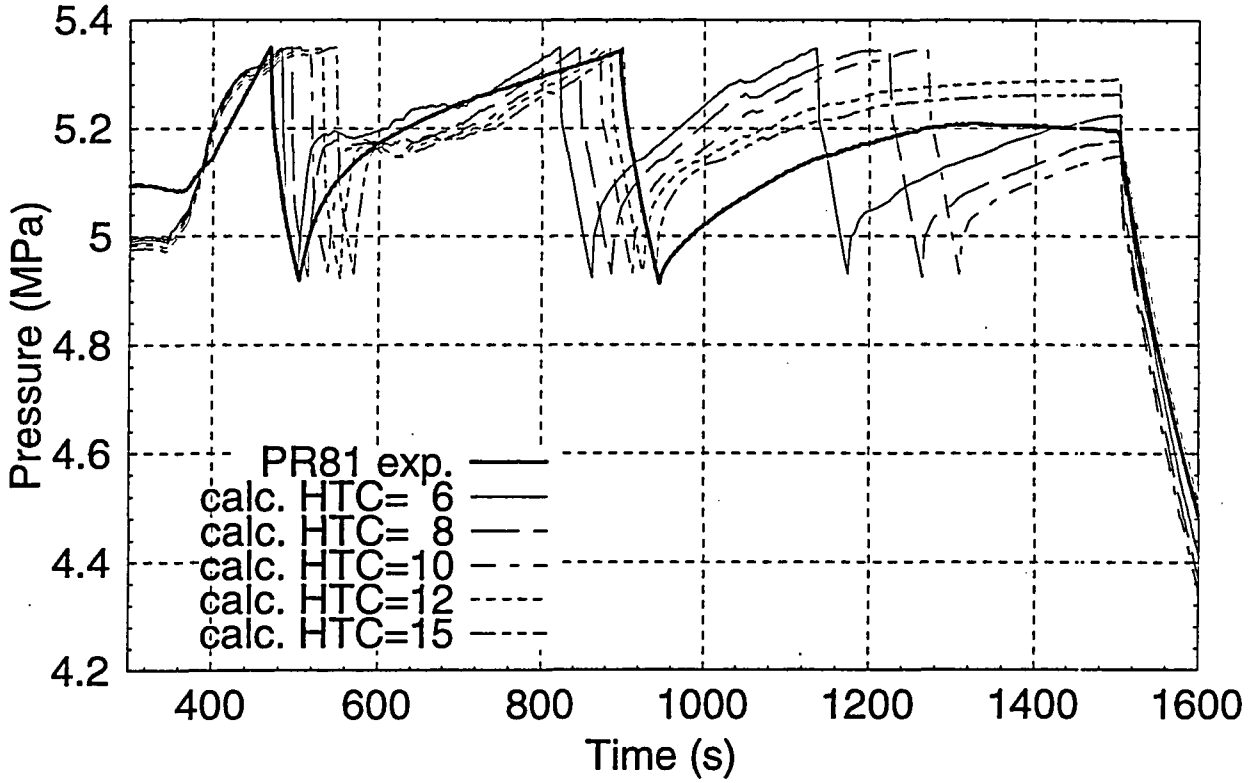


Fig 7.10 Collapsed Level in CLLS SG Side

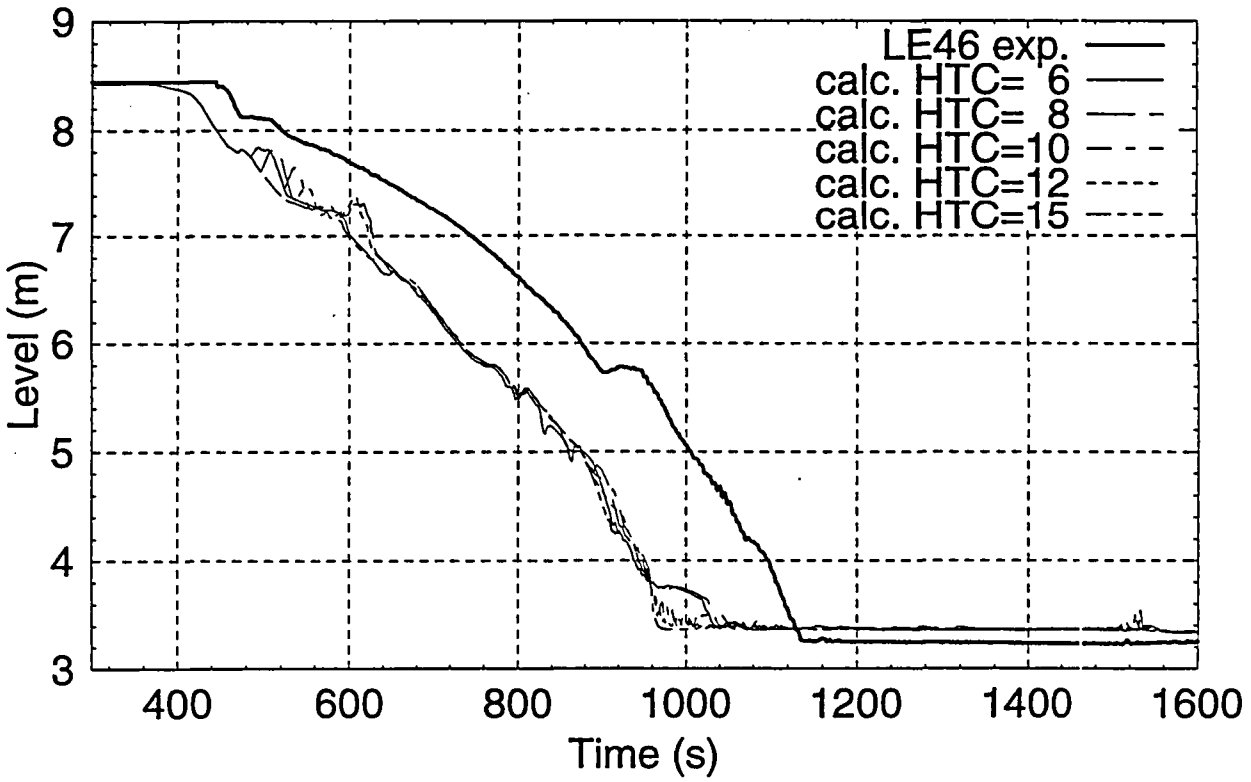


Fig 7.11 Collapsed Level in CLLS Vessel Side

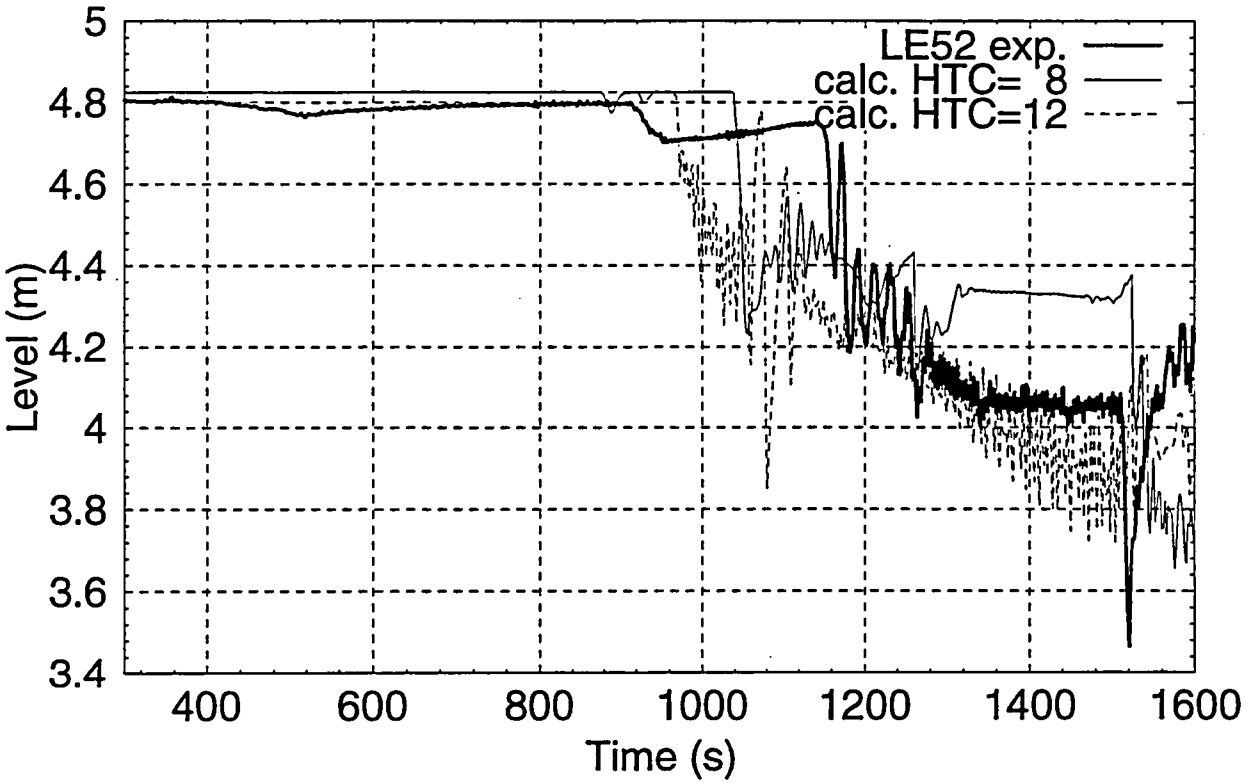


Fig 7.12 Collapsed Level in Reactor Vessel

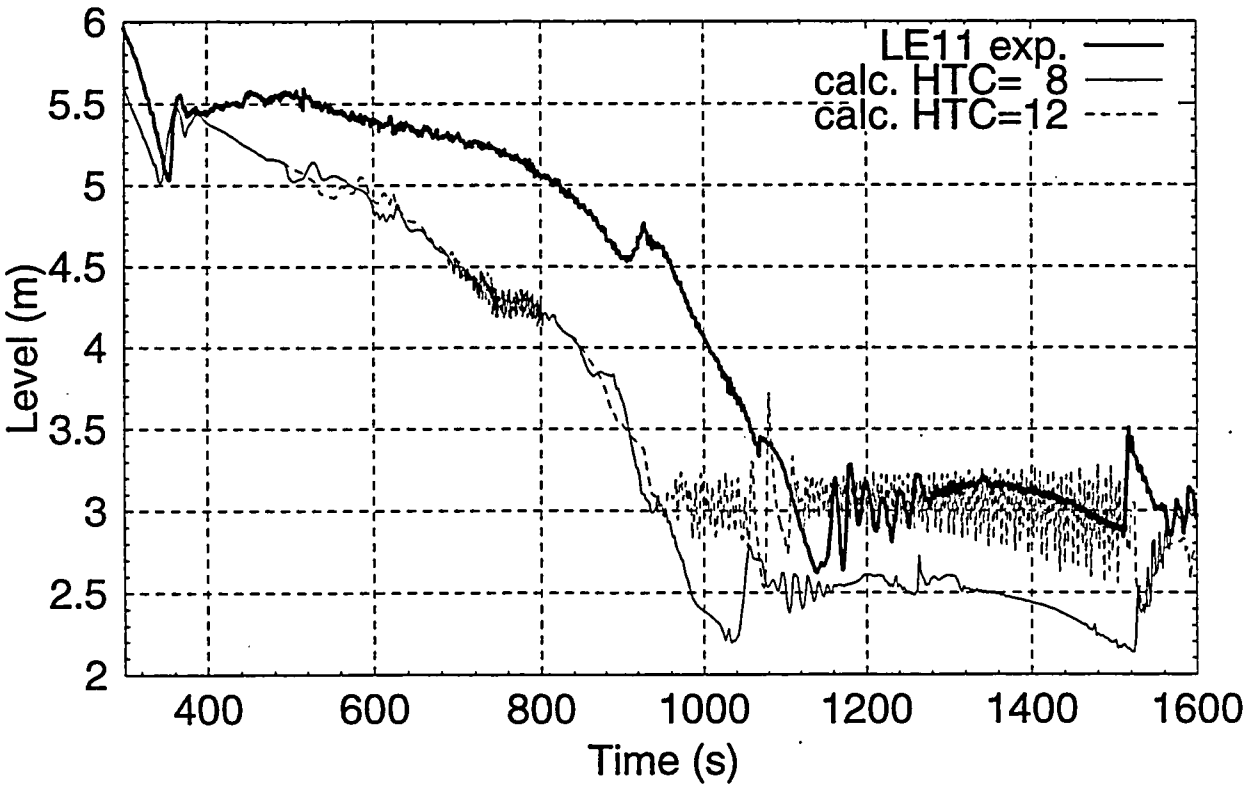


Fig 7.13 Primary Mass Flow

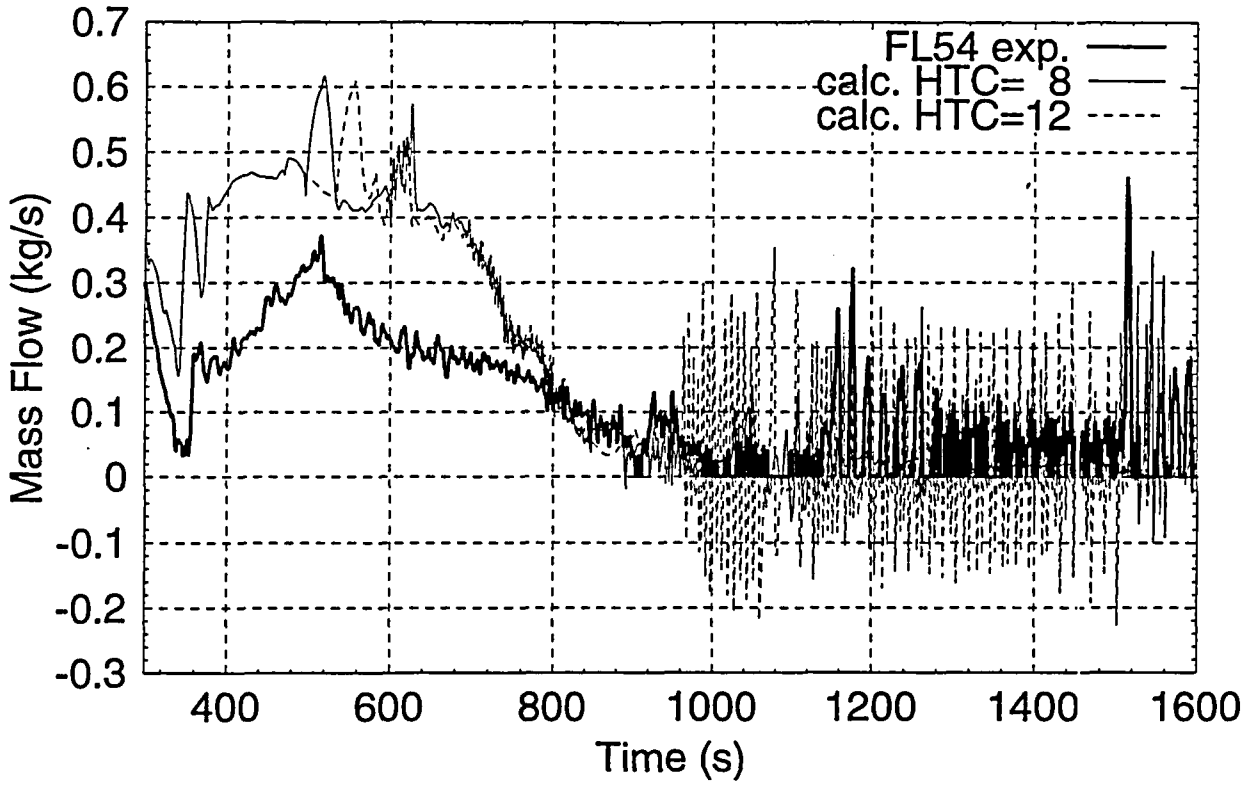


Fig 7.14 Cladding Temperature

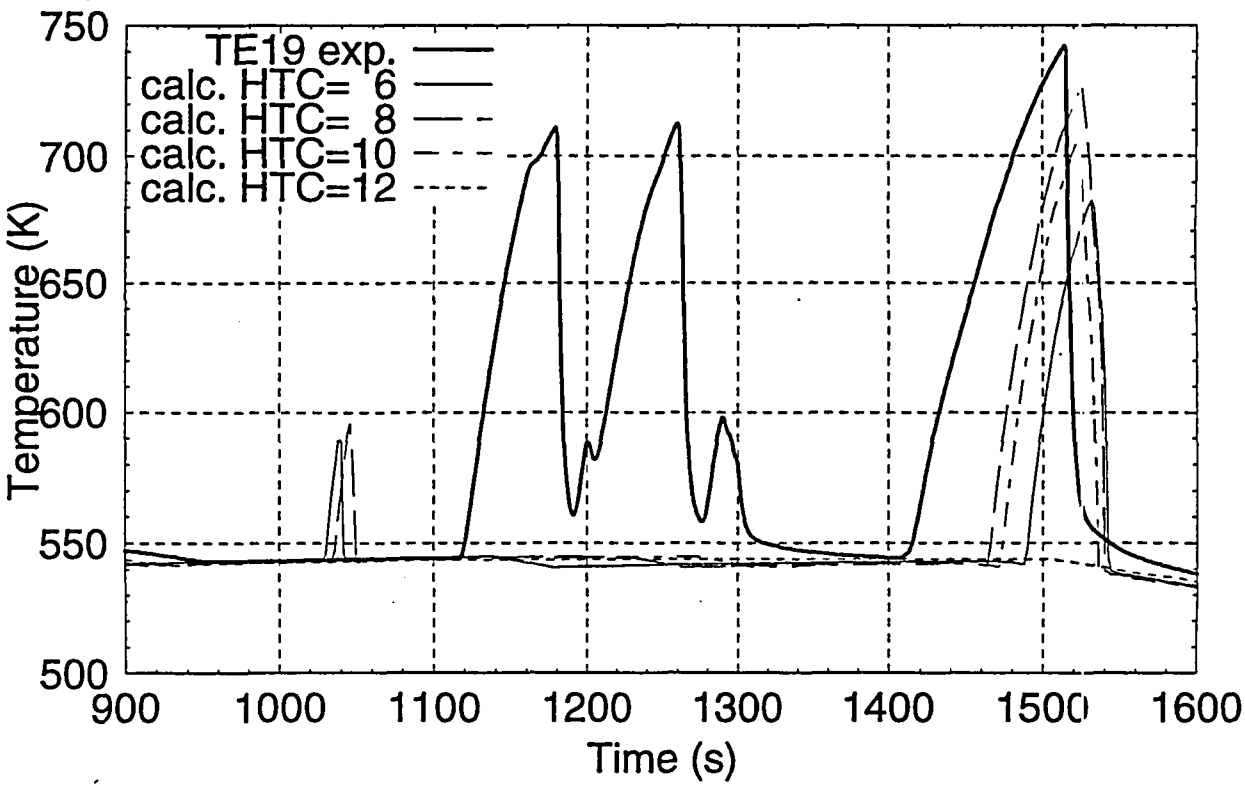


Fig 7.15 Break Mass Flow

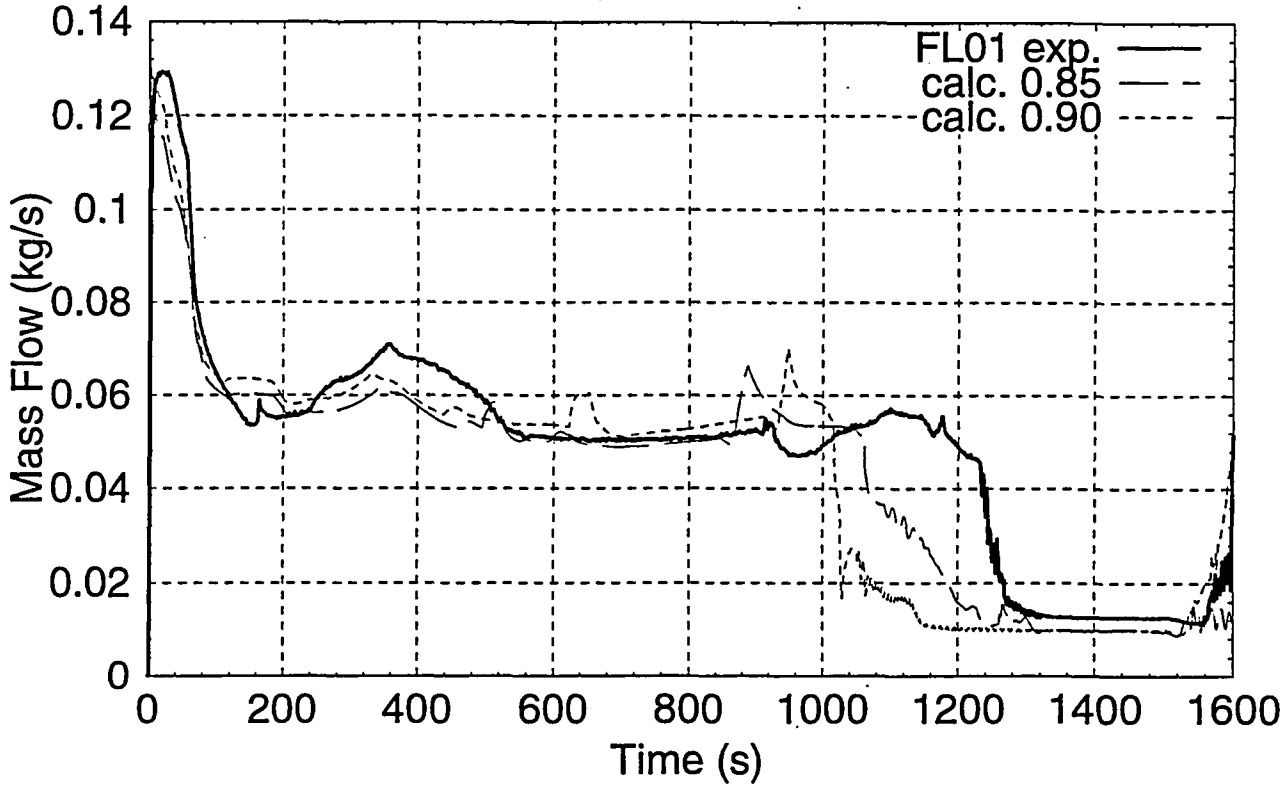


Fig 7.16 Steam Dump Mass Flow

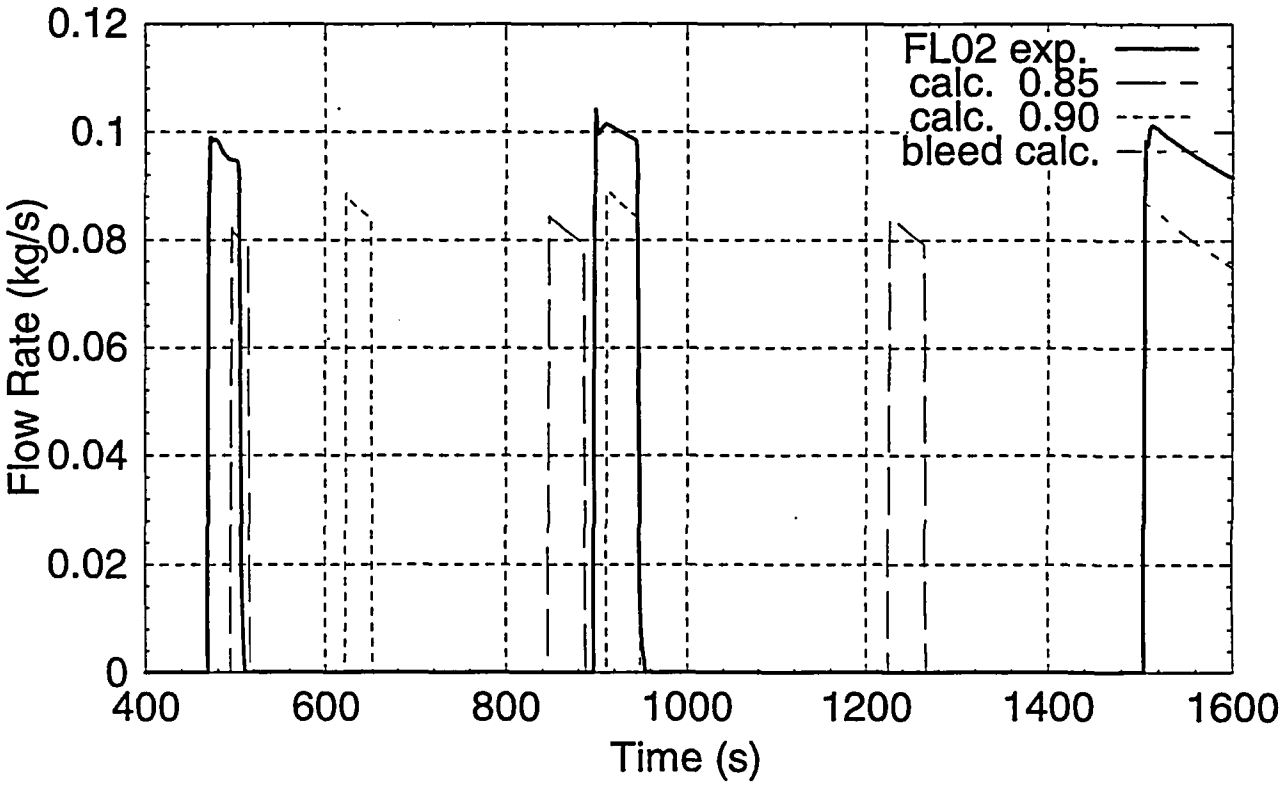


Fig 7.17 Secondary Pressure

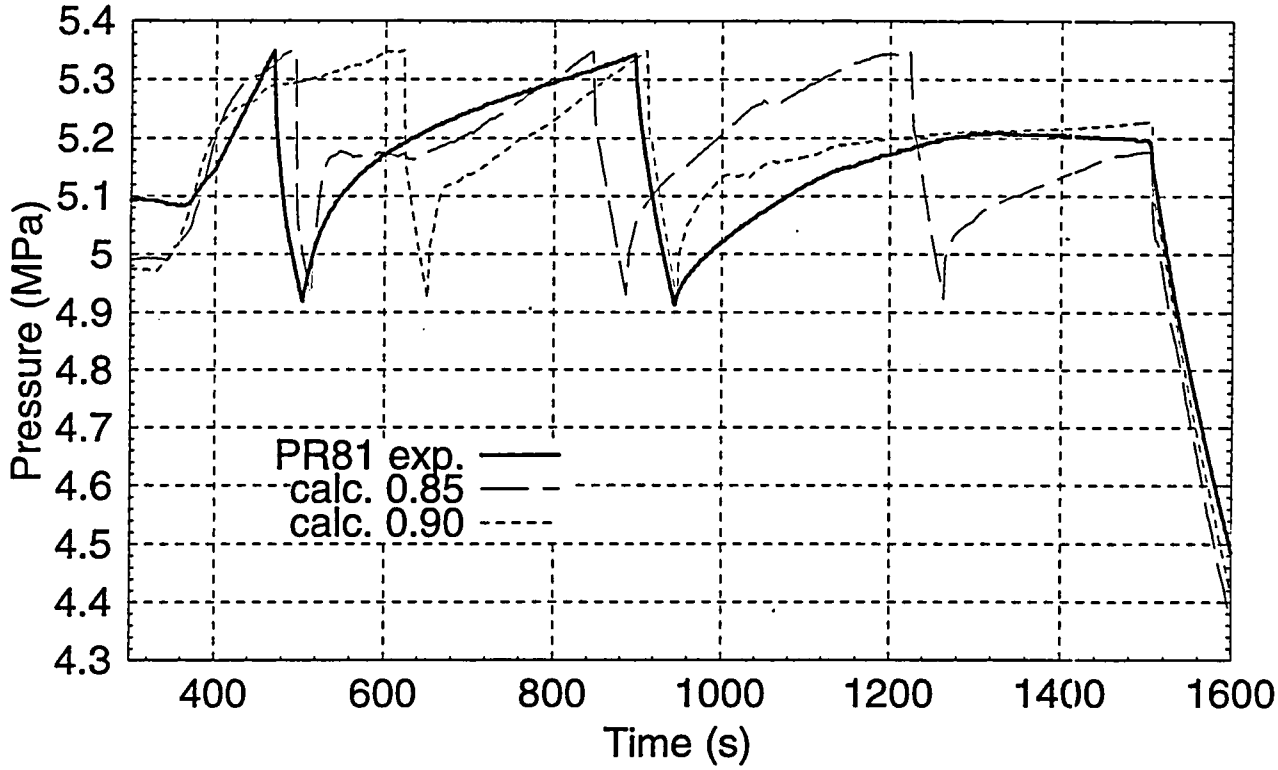


Fig 7.18 Collapsed Level in Reactor Vessel

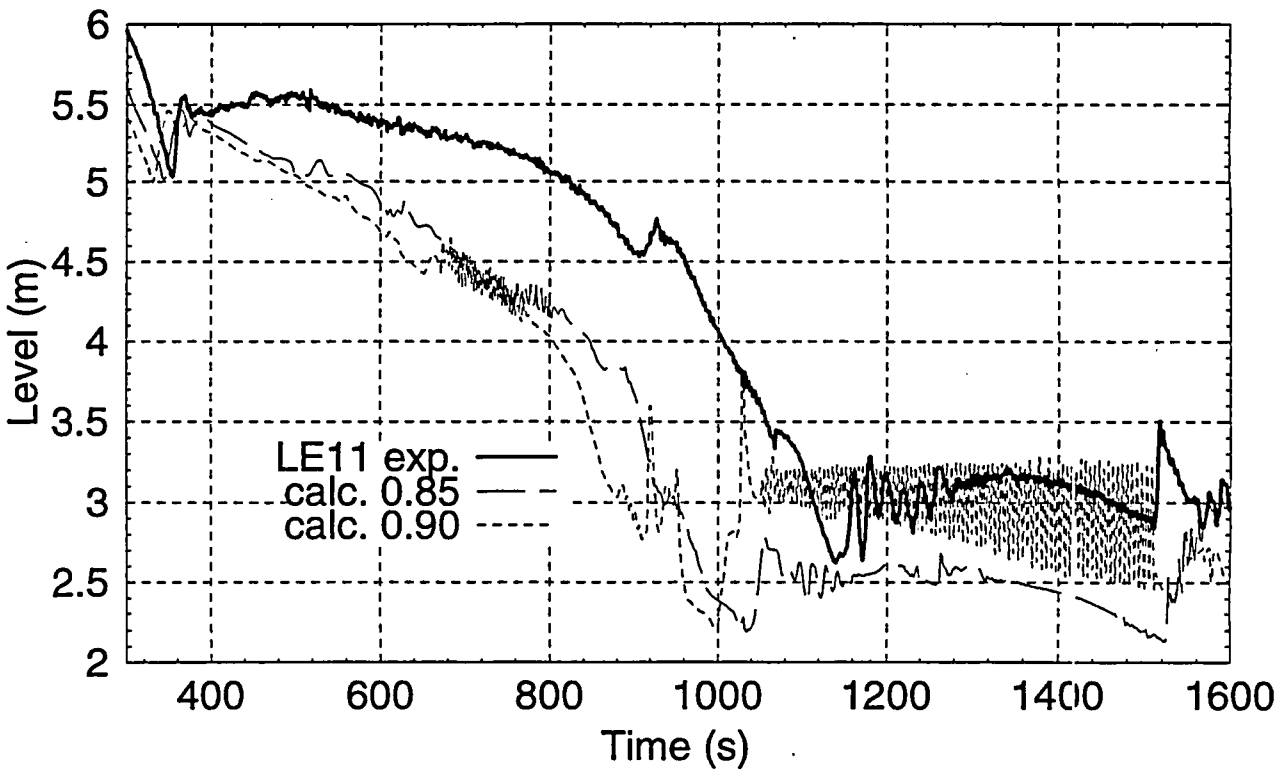


Fig 7.19 Collapsed Level in CLLS SG Side

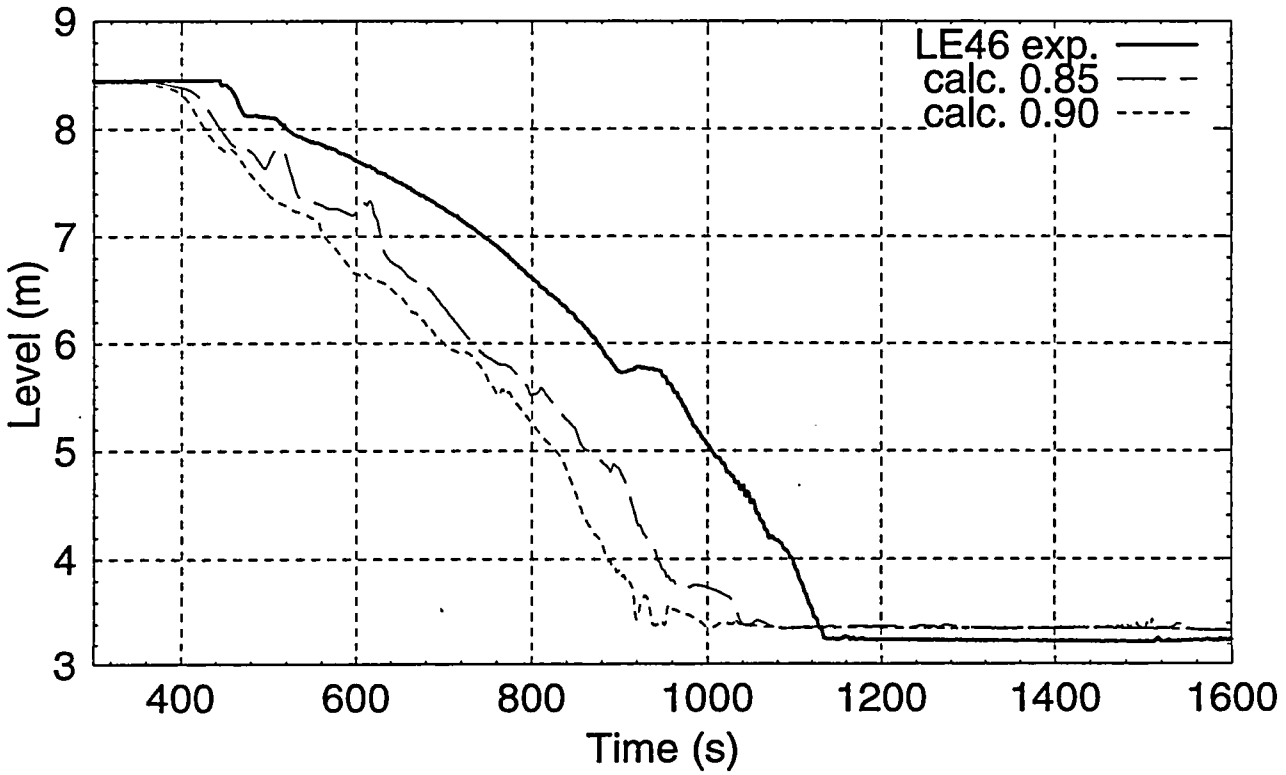


Fig 7.20 Collapsed Level in CLLS Vessel Side

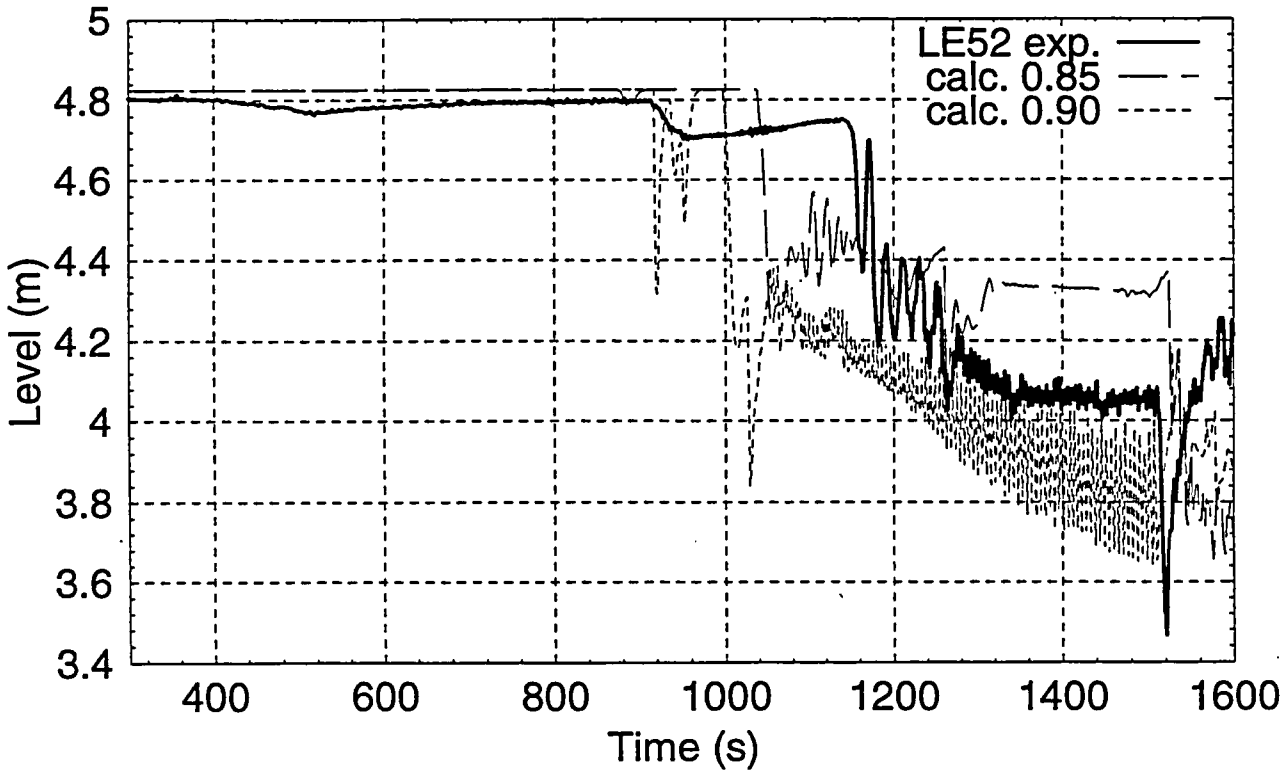


Fig 7.21 Primary Mass Flow

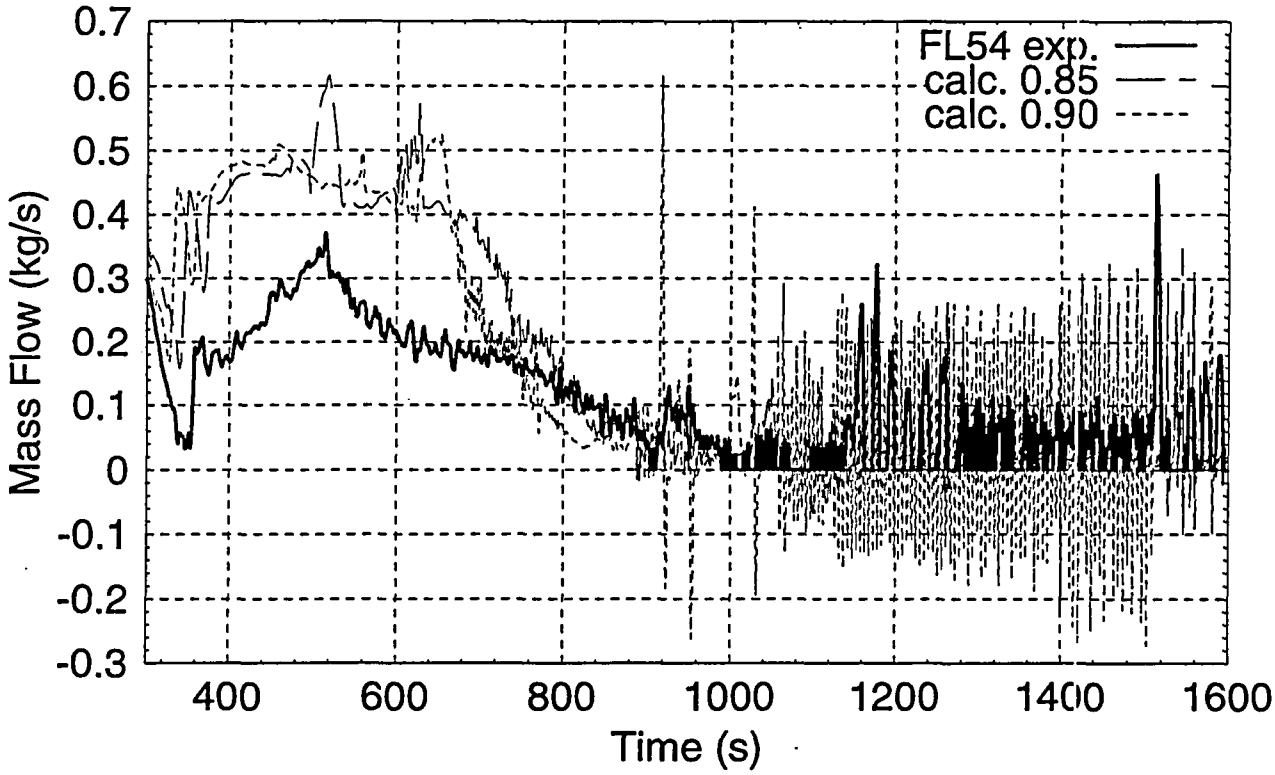
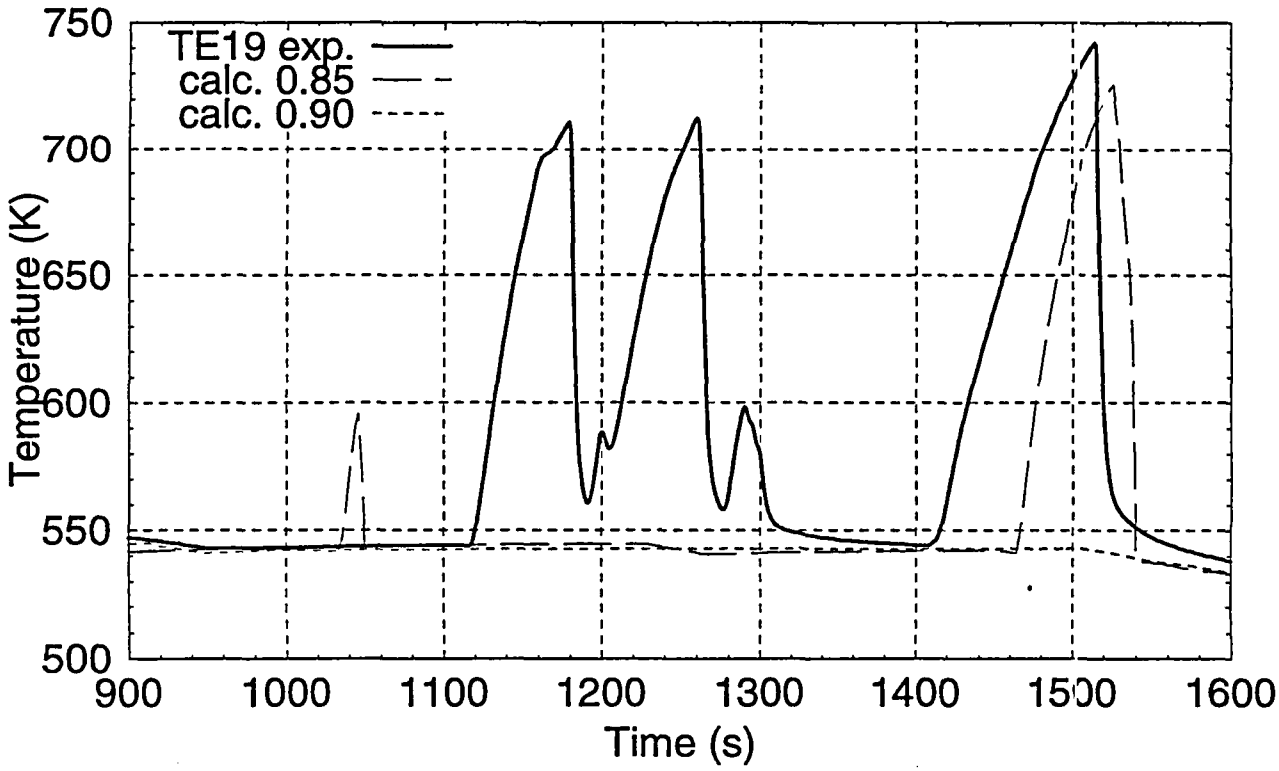


Fig 7.22 Cladding Temperature



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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

There is a general interest to validate best estimate (BE) reactor safety system codes for VVER-type reactors. The OECD-VVER code validation matrix is used for the selection of tests in support of accident management (AM) and to eliminate "white spots" in the matrix. Based on this matrix - test types not yet covered - a proposal was made at the 12th (Spring '98) CAMP meeting in Ankara:

. perform VVER-440/213 related experiment on the Hungarian PMK-2 test facility
. validate RELAP5/mod 3.2 code.

The CAMP-CLB test is an AM-type experiment with small leak in the primary coolant system needing secondary side heat removal. The break size is 2%, heat removed by break is insufficient to depressurize primary circuit below secondary pressure. Steam dump valve to atmosphere regulates secondary pressure until - as an AM action - secondary bleed is started following core fuel rod simulator overheating which is a consequence of unavailability of the high pressure injection systems.

Report presents a short description of the PMK-2 facility, the initial and boundary conditions of the test followed by an evaluation of the results by measured parameters. After reviewing modelling aspects and results of post-test calculations by RELAP5/mod3.2.2 Gamma a sensitivity study is described. The "bifurcation type" behaviour encountered in parametric studies could be the result of the code calculating by different constitutional models depending on the time step or secondary heat losses. This behaviour needs further investigation and it is reported as a new RELAP5 user problem.

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

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