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Author(s): D. B. Jarrell

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This document was prepared primarily for preliminary or internal use. It has not received full review and approval. Since there may be substantive changes, this document should not be considered final.

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Prepared for
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Washington, D.C. 20555

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INTERIM REPORT

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PROJECT NO. P 394

for U.S. Nuclear Regulatory Commission

QUICK-LOOK REPORT ON LOFT NONNUCLEAR EXPERIMENT L3-0

DONALD B. JARRELL

July 1979

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

506 002

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INTERIM REPORT

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G. D. McPherson, Acting Chief, LOFT Research Branch,
Division of Reactor Safety Research, USNRC

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Idaho Falls, Idaho 83401

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Idaho Operations Office
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INTERIM REPORT

506 003

QUICK LOOK REPORT ON LOFT NONNUCLEAR EXPERIMENT L3-0

Approved:

L. P. Leach, Manager
LOFT Experimental Program Division

N. C. Kaufman, Director
LOFT

The information contained in this summary report is preliminary and incomplete. Selected pertinent data are presented in order to draw preliminary conclusions and to expedite the reporting of research results.

QLR-L3-0

QUICK LOOK REPORT ON LOFT NONNUCLEAR EXPERIMENT L3-0

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SUMMARY

The preliminary evaluation has been completed of the results from nonnuclear Loss-of-Coolant Experiment (LOCE) L3-0, which was successfully conducted on May 31, 1979, in the Loss-of-Fluid Test (LOFT) facility. In order to permit blind predictions[a] of experimental results using RELAP4/MOD6, RELAP4/MOD7, RELAP5, and TRAC computer codes, data from LOCE L3-0 was withheld until June 25, 1979. LOCE L3-0, the first experiment in the LOFT Small and Intermediate Break Series L3, simulated a small break at the top of the LOFT pressurizer by opening the power operated pressure relief valve.

For this experiment, the nuclear core remained installed and in a shutdown condition. The initial conditions and plant configuration were similar to previous nuclear LOCEs performed in experiment Series L2 with the exception of the primary system being isothermal due to the lack of reactor heat input. Selected data, presented in this report, confirm that the objectives of LOCE L3-0 were successfully achieved.

Significant initial conditions for LOCE L3-0 were: reactor decay heat - 4.2 $\pm$ 1 kW, system pressure - 14.74 $\pm$ 0.07 MPa, hot leg temperature - 556.7 $\pm$ 3.0 K; and intact loop flow rate - 201.0 $\pm$ 17 kg/s. The emergency core cooling system, including high-pressure and low-pressure injection and accumulators, was not allowed to actuate until the transient was terminated. Power to the primary coolant pumps was tripped at transient initiation, and the pumps were allowed to coast down.

The experiment was initiated by opening the power operated pressure relief valve which allowed fluid from the top of the pressurizer vessel to blow down through pressurizer system piping to the pressure suppression tank. The transient was slow and remained under manual control until its termination at 3.53 $\pm$ 0.2 MPa, 2460 s after

a. Calculation of experimental results using measured initial conditions but without benefit of experimental data.

initiation. System depressurization was rapid until 48 s, when primary system saturation occurred at 6.8 MPa; further gradual pressure reduction continued until the transient was terminated.

Core thermal response was completely benign throughout the transient. The core was not uncovered at any time, nor was any temperature increase indicated on fuel rod cladding thermocouples. No fuel rod degradation occurred during LOCE L3-0.

System hydraulics were characterized by pressurizer blowdown to primary saturation pressure, followed by a refill of the pressurizer to the top of its indicating range by 84 s due to vapor generation in the primary system. The pressurizer continued to indicate "liquid full" until approximately 1350 s, when the liquid level slowly dropped back into the indicating range.

Computer calculations were made using RELAP4/MOD6, RELAP4/MOD7, RELAP5, and TRAC codes to predict system performance during LOCE L3-0. Considering the short time allowed to create these predictions they appear to compare reasonably well with LOCE L3-0 data. None of the codes predicted the core to become uncovered and all displayed good system pressure decay. More detailed thermal-hydraulic phonomena such as pressurizer level, surge line flow, and break flow were less accurately predicted. Only RELAP4/MOD6 predicted complete refill of the pressurizer.

LOFT LOCE L3-0, the first experiment in the LOFT Small and Intermediate Break Series L3, provided experimental data on isothermal hydraulic behavior during the blowdown and plant recovery phases of a loss-of-coolant accident in a pressurized water nuclear reactor. The intensive analysis of LOCE L3-0 data currently underway will result in additional understanding of loss-of-coolant accidents and together with results from other Nuclear Regulatory Commission experimental programs will contribute to the data base required for development and assessment of analytical models for licensing commercial pressurized water reactors.

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FIGURES

TABLES

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QUICK LOOK REPORT ON LOFT NONNUCLEAR EXPERIMENT L3-0

I. INTRODUCTION

The Loss-of-Fluid Test (LOFT) facility[1] is a 50 MW(t) volumetrically scaled pressurized water reactor (PWR) system designed to study the response of the engineered safety features (ESF) in commercial PWR systems during the postulated loss-of-coolant accident (LOCA). With recognition of the differences in commercial PWR designs and inherent distortions in reduced scale systems, the design objective for the LOFT facility was to produce the significant thermal-hydraulic phenomena that would occur in commercial PWR systems in the same sequence and with approximately the same time frames and magnitudes. The objectives of the LOFT experimental program are:

(1) To provide data required to evaluate the adequacy and improve the analytical methods currently used to predict the LOCA response of large PWRs. The performance of the ESFs, with particular emphasis on emergency core cooling systems (ECCS), and the quantitative margins of safety inherent in the performance of the ESF are of primary interest.

(2) To identify and investigate any unexpected event(s) or threshold(s) in the response of either the plant or the ESF and develop analytical techniques that adequately describe and account for such unexpected behavior.

The information acquired from loss-of-coolant experiments (LOCE) is thus used for evaluation and development of LOCA analytical methods and assessment of the quantitative margins of safety of ESFs in response to a LOCA.

LOCE L3-0, the first experiment in the LOFT Small and Intermediate Break Series L3, was successfully completed May 31, 1979.

The specific objectives[2] for LOCE L3-0 are as follows:

(1) Provide data to assess the transient pressure, temperature, and density for comparison with predictions from the RELAP4/MOD6, RELAP4/MOD7, RELAP5, and TRAC small break computer models

(2) Determine the break flow from the available pressurizer pressure and level data

(3) Determine if chugging occurs in the suppression tank during the small break blowdown

(4) Provide operator training in performing small break experiments.

This report presents a preliminary examination of the plant performance (Section II) and a summary of the results from LOFT LOCE L3-0 (Section III). Section IV presents conclusions reached from this preliminary examination of results. Data plots are presented in Section V to allow preliminary evaluation of LOCE L3-0 relative to the experiment objectives. The data plots presented include comparisons of LOCE L3-0 data with LOCE L3-0 pretest calculations[3] using the RELAP4/MOD6[4], RELAP4/MOD7[5], and RELAP5[6] computer codes and LOCE L3-0 pretest calculation made by Los Alamos Scientific Laboratory[7] using the TRAC computer code.

LOCE L3-0 was an isothermal nonnuclear simulation of an unisolable break in the pressurizer and pressure relief line. The LOCE was initiated by opening the LOFT power operated relief valve. The LOFT system geometry is shown in Figure 1, and a representation of the core configuration illustrating the instrumentation and position designations is shown in Figures 2 and 3, respectively. Figure 4 shows the LOFT pressurizer geometry and operating volumes. Additional details of the core and system design are given in Reference 1.

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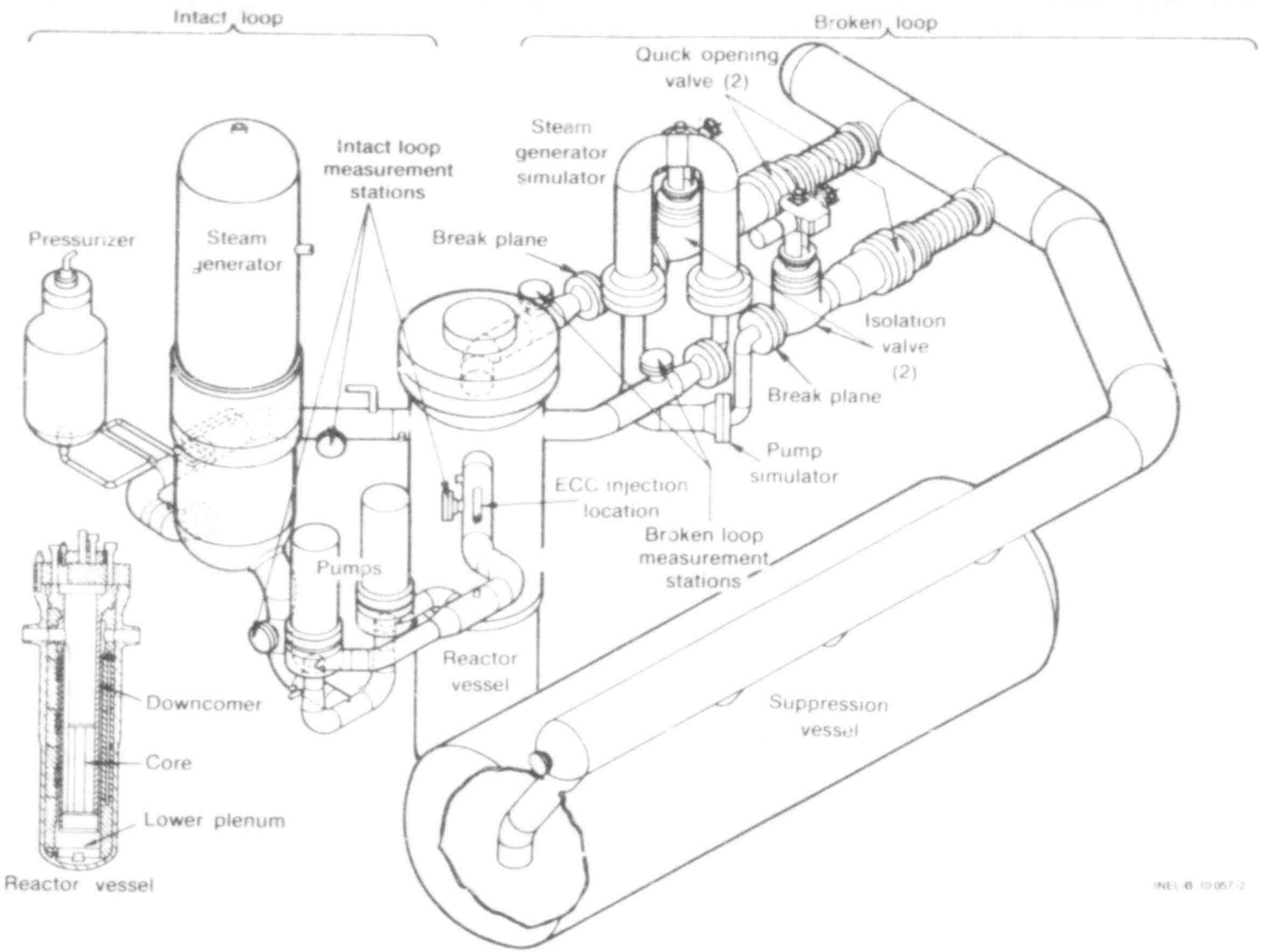

Fig. 1 Axonometric projection of LOFT system.

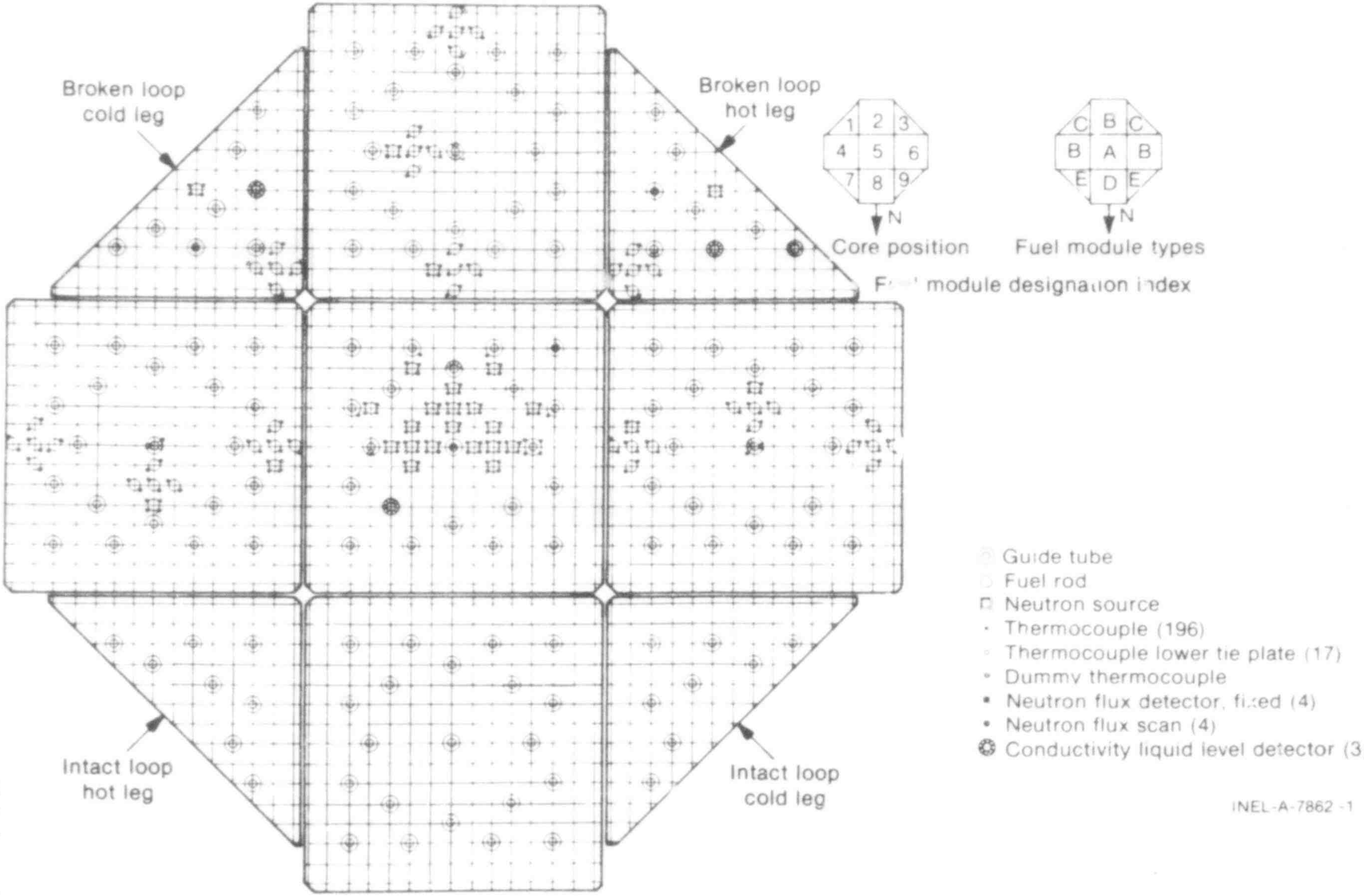

Fig. 2 LOFT core configuration and instrumentation.

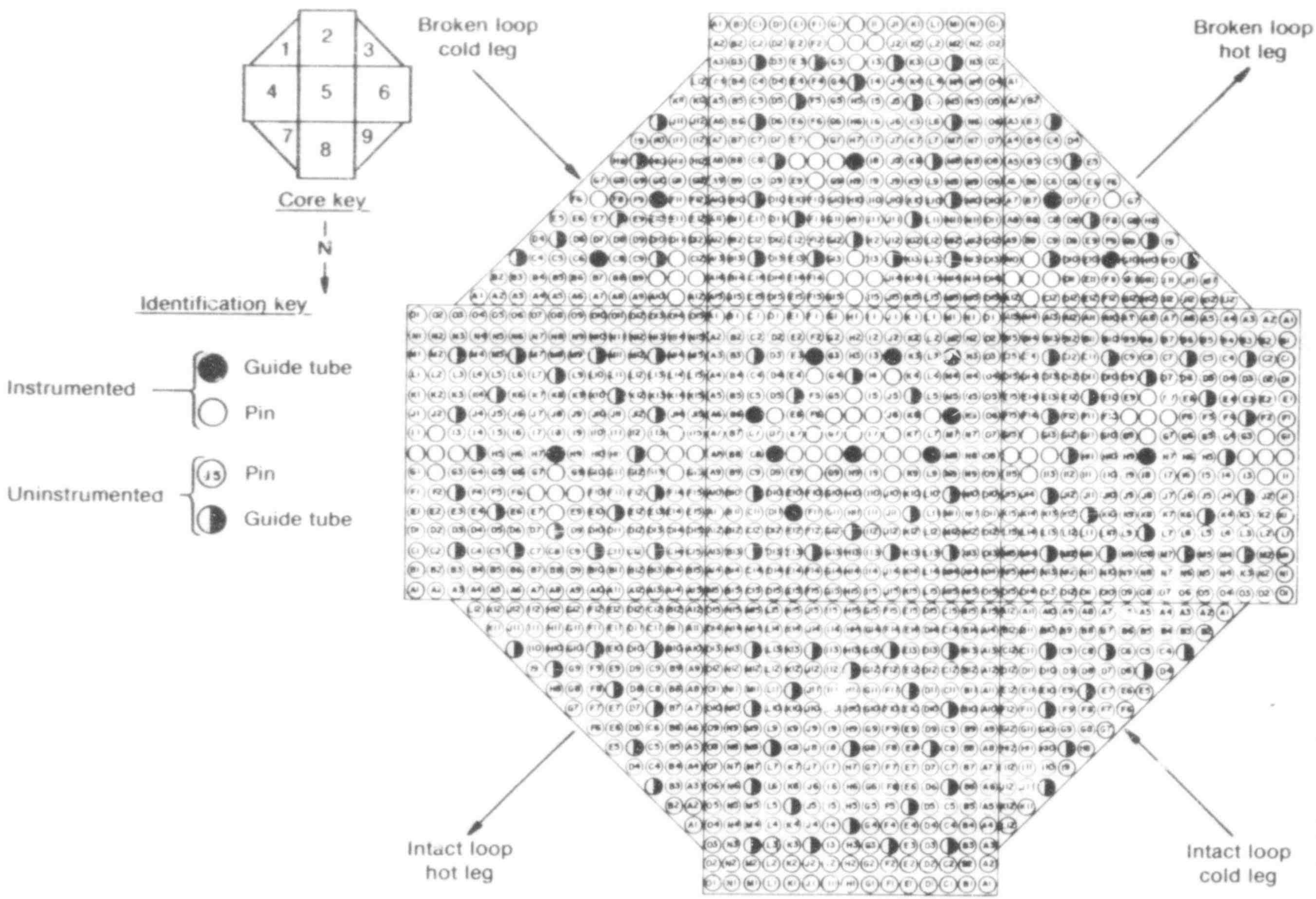

Fig. 3 LOFT core map showing position designations.

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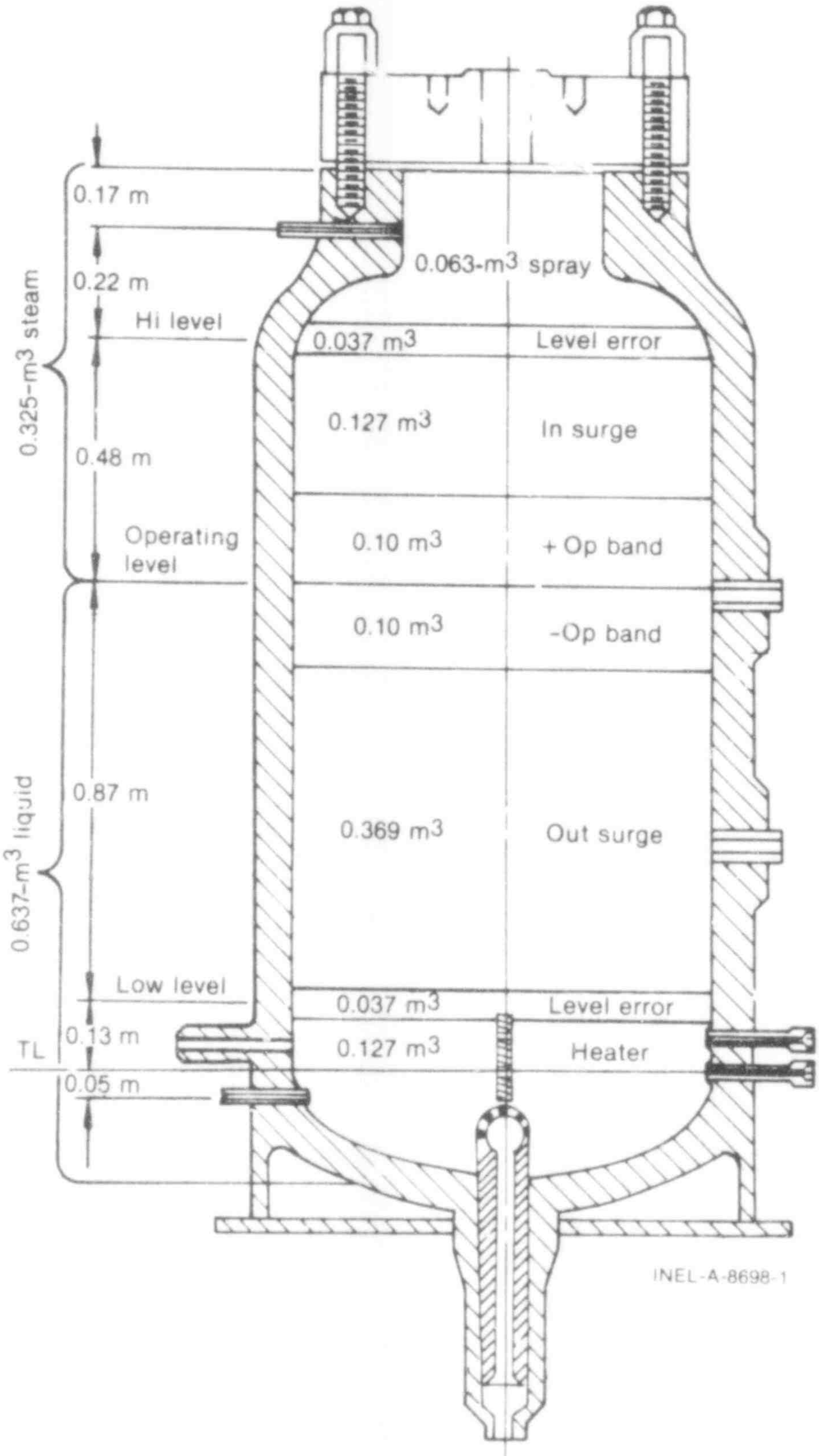

Fig. 4 Pressurizer operating levels and volumes.

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II. PLANT EVALUATION

An evaluation of plant performance is presented. The discussion summarizes the initial experimental conditions, the identifiable significant events, and the instrumentation performance for LOCE L3-0.

1. INITIAL EXPERIMENTAL CONDITIONS

A summary of the specified and measured system conditions immediately prior to LOCE L3-0 blowdown initiation is given in Table I.

The measured average initial primary system temperature was 558.2 ± 3 K, the initial mass flow rate in the primary coolant loop was 201.0 ± 17 kg/s, and the pressurizer pressure was 14.74 ± 0.07 MPa. The reactor was fully shut down (control rods seated and unlatched) and was generating 4.2 ± 1 kW of decay heat.

It was determined that the primary system leakage rate was approximately 30 ml/s and the secondary (steam) leakage was approximately 70 g/s.

TABLE I

INITIAL CONDITIONS FOR NONNUCLEAR LOCE L3-0

Parameter	EOS Specified Value[2]	Measured Value
Primary Coolant System		
Mass flow rate (kg/s)[a,b]	189.4 ± 8.8	201.0 ± 17
Pressure (MPa)	14.89 ± 0.34	14.74 ± 0.07
Temperature, T_h (K)	555.39 ± 2.8	556.7 ± 3
Boron concentration (ppm)	As required	3481 ± 4
Cold leg temperature (K)	555.38 ± 2.8	559.7 ± 3
Leakage rate (l/s)	--	0.03 ± 0.02
Heat loss (kW)	--	248 ± 60

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TABLE I (continued)

Parameter	EOS Specified Value[a]	Measured Value
Reactor Vessel		
Power level (kW) (decay heat)	<11	4.2 ± 1
Control rod position	Rods seated and unlatched	Rods seated and unlatched
Pressurizer		
Steam volume (m^3)	--	0.3840 ± 0.008
Water volume (m^3)	--	0.5816 ± 0.008
Water temperature (K)	As required to establish pressure	611.1 ± 3
Pressure (MPa)	14.89 ± 0.34	14.74 ± 0.07
Level (m)	1.13 ± 0.18	1.03 ± 0.05
Broken Loop		
Hot leg fluid temperature (K)	555.4 ± 13.9	
Near vessel	--	555.7 ± 4
Near break	--	553.2 ± 5
Cold leg fluid temperature (K)	555.4 ± 13.9	
Near vessel	--	557.4 ± 4
Near break	--	553.2 ± 5
Steam Generator Secondary Side[c]		
Water level (m)[b]	3.16	2.90 ± 0.1
Water temperature (K)	--	557.3 ± 3
Pressure (MPa)	--	6.8 ± 0.12
Mass flow rate (kg/s)	Secondary flow secured	Minimum valve leakage (0.065 ± 0.03)

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TABLE I (continued)

Parameter	EOS Specified Value[2]	Measured Value
ECCS (system not used)		
Suppression Tank		
Liquid level (m)	1.27 ± 0.025	1.25 ± 0.04
Gas volume (m^3)	--	54.2 ± 0.59
Pressure (gas space) (MPa)	0.086 ± 0.014	0.099 ± 0.01
Water temperature (K)	316.5	306.9 ± 3
Liquid volume (m^3)	--	28.69 ± 0.59

a. Calculated.

b. Out of specification, but did not affect results.

c. Not controlled.

2. CHRONOLOGY OF EVENTS

Identifiable significant events that occurred during LOCE L3-0 are listed in Table II. For LOCE L3-0, the emergency core coolant (ECC) injection from the high-pressure injection system (HPIS), low-pressure injection system (LPIS), and accumulators was manually controlled, and initiation did not occur until the transient was terminated. Pressurizer spray and heaters were deenergized prior to the LOCE initiation.

TABLE II

CHRONOLOGY OF EVENTS FOR NONNUCLEAR LOCE L3-0

Event	Time After LOCE Initiation (s)
LOCE initiated	0
PSMG[a] power tripped	11
PCP[b] coastdown completed	15
Pressurizer reached minimum indication	48
Primary system reached saturation pressure	48
Pressurizer indicated full	73
Pressurizer returned to indicating range	1420
Blowdown loop isolation valves opened	2416
Quick-opening blowdown valves opened	2460
End of saturation blowdown	2490
LPIS initiated	2535

a. PSMG - primary system motor generator.

b. PCP - primary coolant pump.

3. INSTRUMENTATION PERFORMANCE

The instrumentation used for LOCE L3-0 was essentially the same instrumentation used for the large break (200% double-ended offset shear) experiments (experiment Series L1 and L2). Some of the instrumentation designed to measure large break transient phenomena does not provide useful data for a long-duration, small break experiment. However, sufficient instrumentation existed to provide the necessary data to meet the experimental objectives.

During the short time between the completion of LOCE L2-3 and the initiation of LOCE L3-0, a low-range (0- to 25-psid) differential pressure instrument was substituted in place of a high-range (0- to 1500-psid) instrument in the pressurizer surge line. The data

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obtained from this instrument were used to determine the mass flow rate at the break. No other instrumentation changes were made; however, changes were made in the data recording system which increased the available recording time and permitted observation of the slow transient response. The aggregate sample rate for the data acquisition system was decreased to 4000 samples per second; approximately a tenfold decrease from that used for large break experiments. Analysis of the data indicated that these modifications yield usable long-term data.

The gamma densitometer instruments are recorded on a separate system, which currently has a maximum recording time of 5 minutes. Consequently, during LOCE L3-0 there was a 2-to-3-minute gap in densitometer data every 5 minutes while the recording tape was being changed.

Plans are being implemented to change the densitometer recording system to continuous recording over the entire duration of a small break experiment. Also studies are currently underway which will use the data obtained from LOCE L3-0 to determine areas where new instruments can be designed and installed to provide small break data on mass flow and velocity.

4. FUEL PERFORMANCE

The fuel rods were not damaged during LOCE L3-0. Chemistry samples taken from the suppression system after the experiment indicated no fission products were relased into the blowdown effluent. The lack of fission products in the suppression system is a strong indication that no cladding perforation occurred during the experiment.

Following the experiment the center fuel module was removed and preliminary inspections revealed no cladding deformation.

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III. EXPERIMENTAL RESULTS FROM LOCE L3-0

The experimental results from LOCE L3-0 are summarized in the following sections. The section number corresponds to the objective being addressed in that section.

1. PRIMARY SYSTEM THERMAL-HYDRAULICS

The LOFT experimental instrumentation worked well measuring fluid pressures, temperatures, and densities. Mass flow rates could not be determined beyond primary coolant pump coastdown due to the extremely low flow rates encountered (see Figure 5). The measurements obtained did, however, allow a determination of the major thermal-hydraulic phenomena occurring during LOCE L3-0.

The system hydraulics were characterized by pressurizer blowdown to the primary system saturation temperature, followed by a complete refill of the pressurizer due to vapor generation in the primary system. Primary system saturation pressure was reached at 48 s (see Figure 6) with a more gradual saturated cooldown depressurization continuing to 2460 s, where the experiment was terminated at 3.53 MPa as required in Reference 2. As shown in Figure 7, the pressurizer level decreased during the pressurizer blowdown phase with inward mass flow through the surge line (from system depressurization as shown in Figure 8) being exceeded by outward mass flow through the pressure relief valve.

Evaporative cooling reduced pressurizer temperature and pressure to the saturation conditions of the remainder of the primary coolant system at 48 s, allowing vapor generation (flashing) at locations having high metal mass (vessel head, filler, etc.) or areas of slightly higher temperature (intact loop cold leg). This flashing increased the mass flow to the pressurizer (see Figure 8) such that the pressurizer indicated liquid full at 73 s (see Figure 9).

Flashing continued to reduce the remaining coolant inventory in the primary system until the experiment was terminated at approximately 3.53 MPa by opening the quick-opening blowdown valves (QOBV) at 2460 s and initiating the ECCS at 2535 s. Saturated blowdown continued for an additional 30 s (see Figure 10), followed by refill of the system using the degraded LPIS A system (orificed flow).

Preliminary examination of raw gamma densitometer data indicate that the intact loop hot leg density remained constant until approximately 150 s into the transient. Based on this observation, the surge line differential pressure data shown in Figure 8 give a direct indication of surge line flow for that period.

Core cladding thermocouples in support of previously stated liquid level indication indicate that for this low decay heat generation rate, the core was never uncovered. Consequently, fuel cladding temperatures decreased along a saturation curve with primary pressure following transient initiation and never exceeded the initial values (see Figures 11 through 15). The low value of the decay heat level in the core is illustrated by the fact that the guide tube temperature shown in Figure 15 is approximately equal to the fuel cladding temperatures shown in Figures 11, 12, 13, and 14.

The ECCS performed as expected, refilling the primary system in a controlled evolution without causing excessive thermal stress in the vessel head from a rapid cold water quench.

Computer predictions for LOCE L3-0 were made using RELAP4/MOD6, RELAP4/MOD7, RELAP5, and TRAC during the time the data was withheld (May 31 to June 25, 1979). No single parameter, such as, peak cladding temperature, can be effectively used to judge computer prediction capability; therefore, a comparison of the predictions to several actual data parameters taken during LOCE L3-0 is discussed. Note that RELAP4/MOD7 data is available to 82 s only.

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1.1 Primary System Pressure (Figure 16)

The onset of primary system saturation was predicted very accurately by all four codes, both in time (43 to 60 s versus 48 s $\pm$ 1 actual) and pressure (6.8 to 6.95 MPa versus 6.85 $\pm$ 0.07 MPa actual). The trend of the pressure decrease was followed reasonably well, with only RELAP4/MOD6 underpredicting the actual pressure late in the transient.

1.2 Pressurizer Liquid Level (Figure 17)

The initial level reduction followed by a filling trend in the first 100 s of the transient was predicted by all codes. TRAC did not include the graphics for pressurizer level. The actual filling and duration of the indicated full condition were not accurately predicted. Only RELAP4/MOD6 actually calculated the pressurizer to be liquid full during the transient.

1.3 Pressurizer Surge Line Flow (Figures 8 and 18)

The large influx of fluid into the pressurizer due to system flashing between 50 and 100 s was predicted by all four codes. The exact curve shape and flow instabilities were not accurately predicted, and in all cases the total fluid influx was underpredicted resulting in inaccurate modeling of the pressurizer liquid level, as stated above. The RELAP4/MOD7 run was inconclusive in this respect due to its short run time.

1.4 Core Temperature Response (Figure 19)

Core thermal response was uniform and well predicted by all codes. The core remained covered and essentially followed the saturated cooldown observed in Figure 16.

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2. LOCE BREAK FLOW RATE

LOCE L3-0 break flow must be calculated using a mass balance on the pressurizer vessel since no direct measurement method is available. An accurate determination of surge line flow, required for the mass balance, must account for changes in density or fluid phase. Since density measurements are not yet available, raw gamma densitometer data were used to show that up to 150 s the primary system fluid density was approximately constant. The break flow could only be calculated up to the point of known fluid density or 150 s (see Figure 8).

Initially, single-phase vapor from the steam space in the upper section of the pressurizer (see Figure 4) displayed choked flow response to the change in system pressure. A sharp incre se in flow rate occurred, shown in Figure 8, as the pressurizer refilled from primary system flashing and liquid replaced the steam effluent. Further reduction in system pressure and liquid sity caused the mass flow to reduce as the transient progressed with an apparent return to the indicating pressurizer liquid level range shown in Figure 7.

3. BLOWDOWN SUPPRESSION TANK RESPONSE

Suppression tank pressure, temperature, and level response (see Figures 20, 21, and 22, respectively) to the mass flow described in Section 2 did not show indications of cyclic oscillations characteristic of chugging during the blowdown. Suppression tank spray flow was activated at approximately 1880 s (see Figure 23) to maintain pressure within acceptable limits.

4. OPERATOR TRAINING

The conduct of LOCE L3-0 provided valuable operator training. The entire scenario of system subcooled and saturated depressurization and recovery went as anticipated. The operators were able to monitor the depressurization and opened the QOBVs as planned. The experience gained in the conduct of LOCE L3-0 will be extremely useful in the more demanding LOCEs to follow in experiment Series L3 with the nuclear core at power.

506 025

IV. CONCLUSIONS

The conduct of LOFT LOCE L3-0 and the experimental data acquired concerning integral systems phenomena associated with a loss of coolant are considered to have met the objectives as defined by the experiment operating specifications[2] and discussed in Section III. Conclusions based on the preliminary analyses and experiment assessment are:

(1) Transient response during LOCE L3-0 was slow enough to be completely controlled by manual methods.

(2) Additional flow and density instrumentation will be required to completely characterize small break phenomena.

(3) The predictions compared reasonably well with LOCE L3-0 system response data. Deviations from measured pressurizer thermal-hydraulic behavior indicate that further refinements will be required to accurately predict pressurizer response.

(4) No core uncovery or fuel damage result from a LOFT low decay heat, small break transient.

(5) Instrumentation indicated that the pressurizer was completely filled with liquid from the primary system due to vapor generation as a result of depressurization.

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V. DATA PRESENTATION

This section presents selected preliminary data from LOCE L3-0 LOCE L3-0 data are overlayed with data from LOCE L3-0 pretest calculations using the RELAP4/MOD6[4], RELAP4/MOD7[5], RELAP5[6], and TRAC computer codes. A listing of the data plots is presented in Table III. Table IV gives the nomenclature system used in instrumentation identification. A complete list of the LOFT instrumentation and data acquisition requirements for LOCE L3-0 is given in Reference 2.

The maximum uncertainties in the reported data are $\pm$ 3 K for temperature and $\pm$ 0.07 MPa for pressure measurements.

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TABLE III

LIST OF DATA PLOTS

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TABLE III (continued)

Figure	Title	Measurement Identification	Page
19	Calculated and measured core temperature response	TE-5F4-30	36
20	Pressure in blowdown suppression tank	PE-SV-55	37
21	Temperature in blowdown suppression tank	TE-SV-3	38
22	Liquid level in blowdown suppression tank	LT-P138-33	39
23	Flow rate in pressure suppression tank spray system	FE-P138-139	40

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TABLE IV

NOMENCLATURE FOR LOFT INSTRUMENTATION

Designations for the different types of transducers:[a]

TE	- Temperature element	LT	- Liquid level transducer
PE	- Pressure transducer	FE	- Coolant flow transducer
PdE	- Differential pressure transducer	DE	- Densitometer
		ME	- Momentum flux transducer

Designations for the different systems, except the nuclear core:

PC	- Primary coolant intact loop	SV	- Suppression tank
BL	- Broken loop	P138	- Broken loop and pressure suppression system
RV	- Reactor vessel	P139	- Intact loop

Designations for nuclear core instrumentation:

Transducer location (inches from bottom of fuel rod)
Fuel assembly row
Fuel assembly column
Fuel assembly number
Transducer type

TE-3B11-28

a. Includes only instruments discussed in this report.

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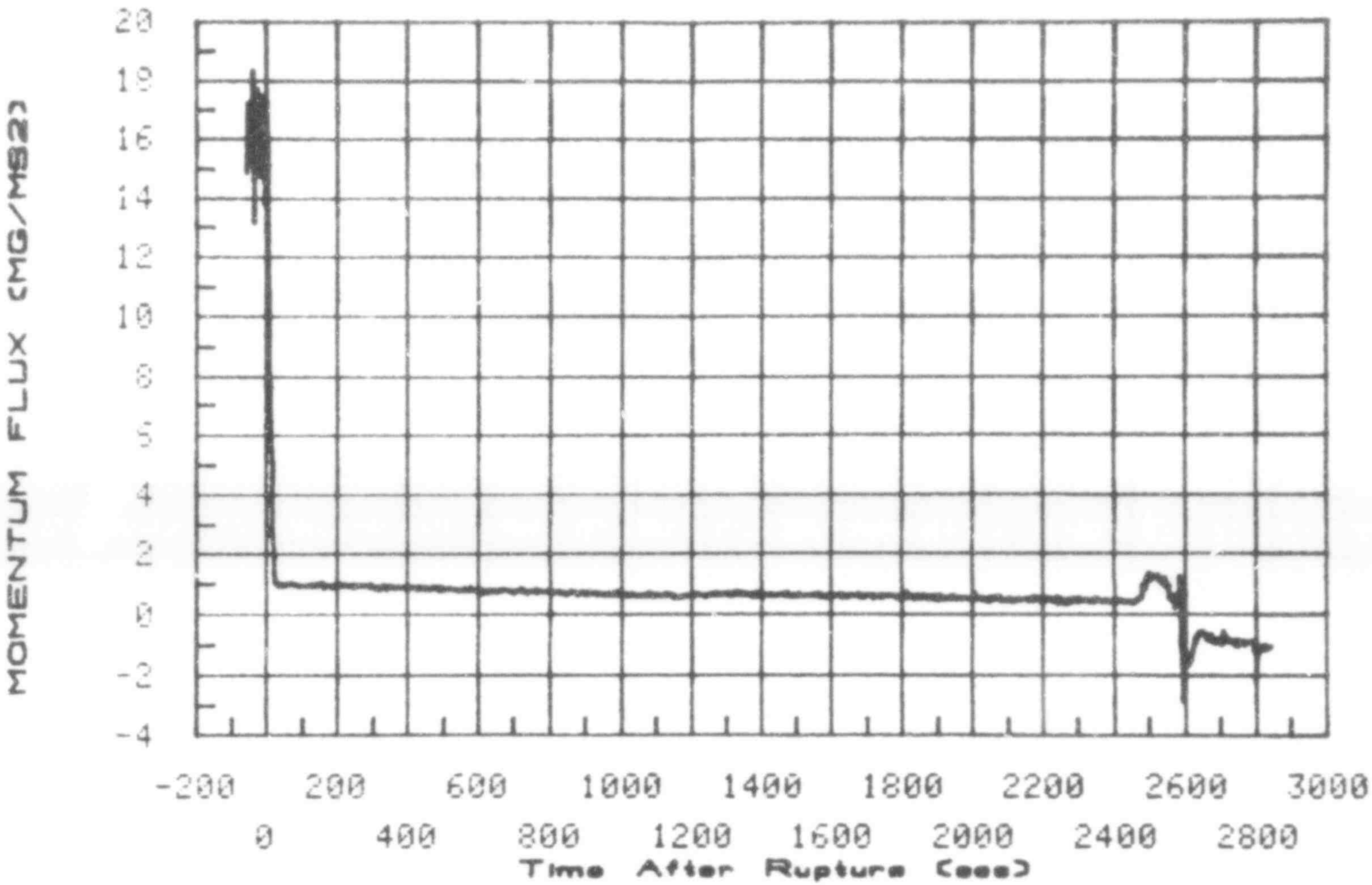

Fig. 5 Momentum flux in primary system.

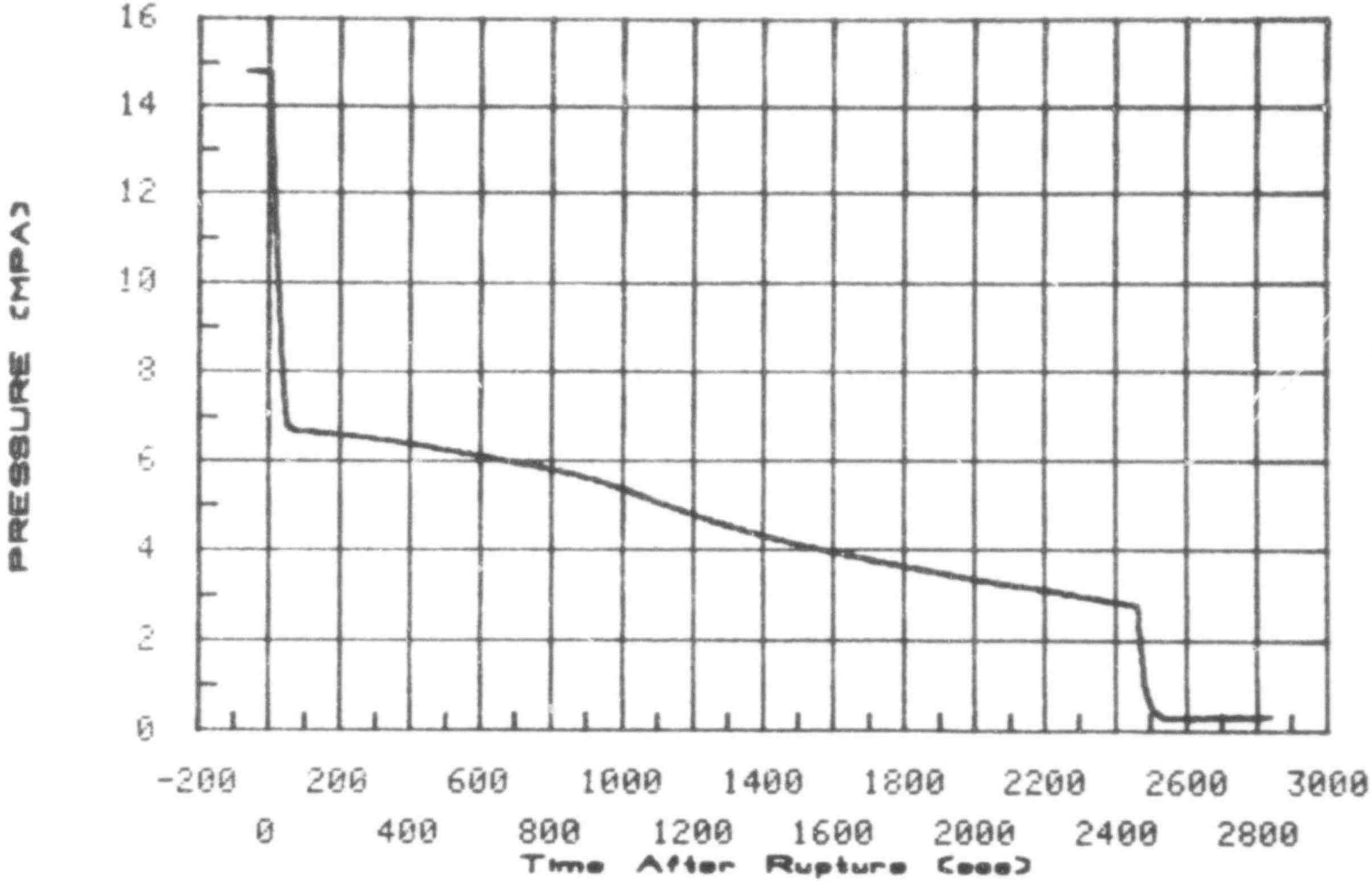

Fig. 6 Pressure in primary system from 0 to 2600 s.

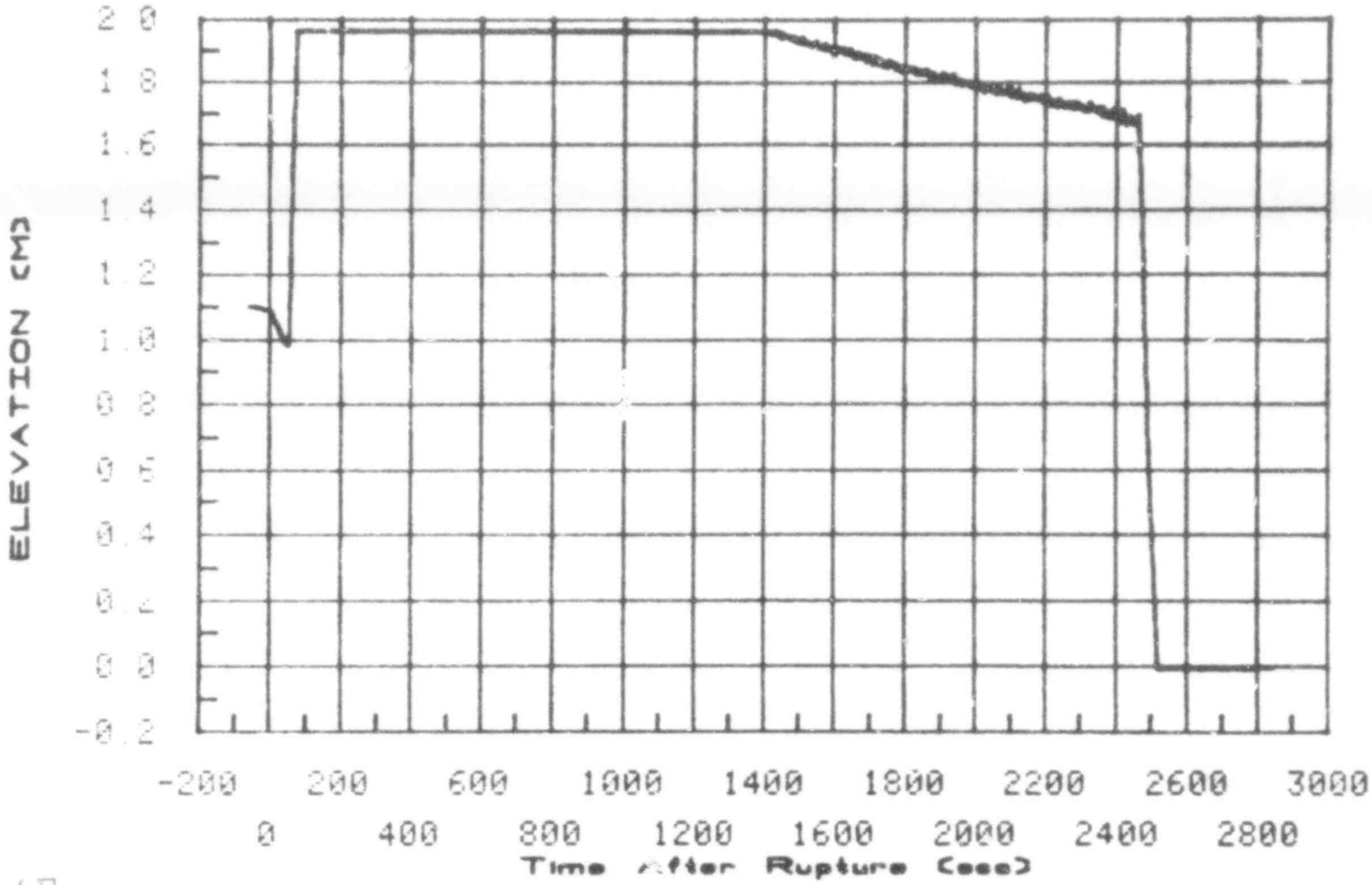

Fig. 7 Liquid level in pressurizer from 0 to 2600 s.

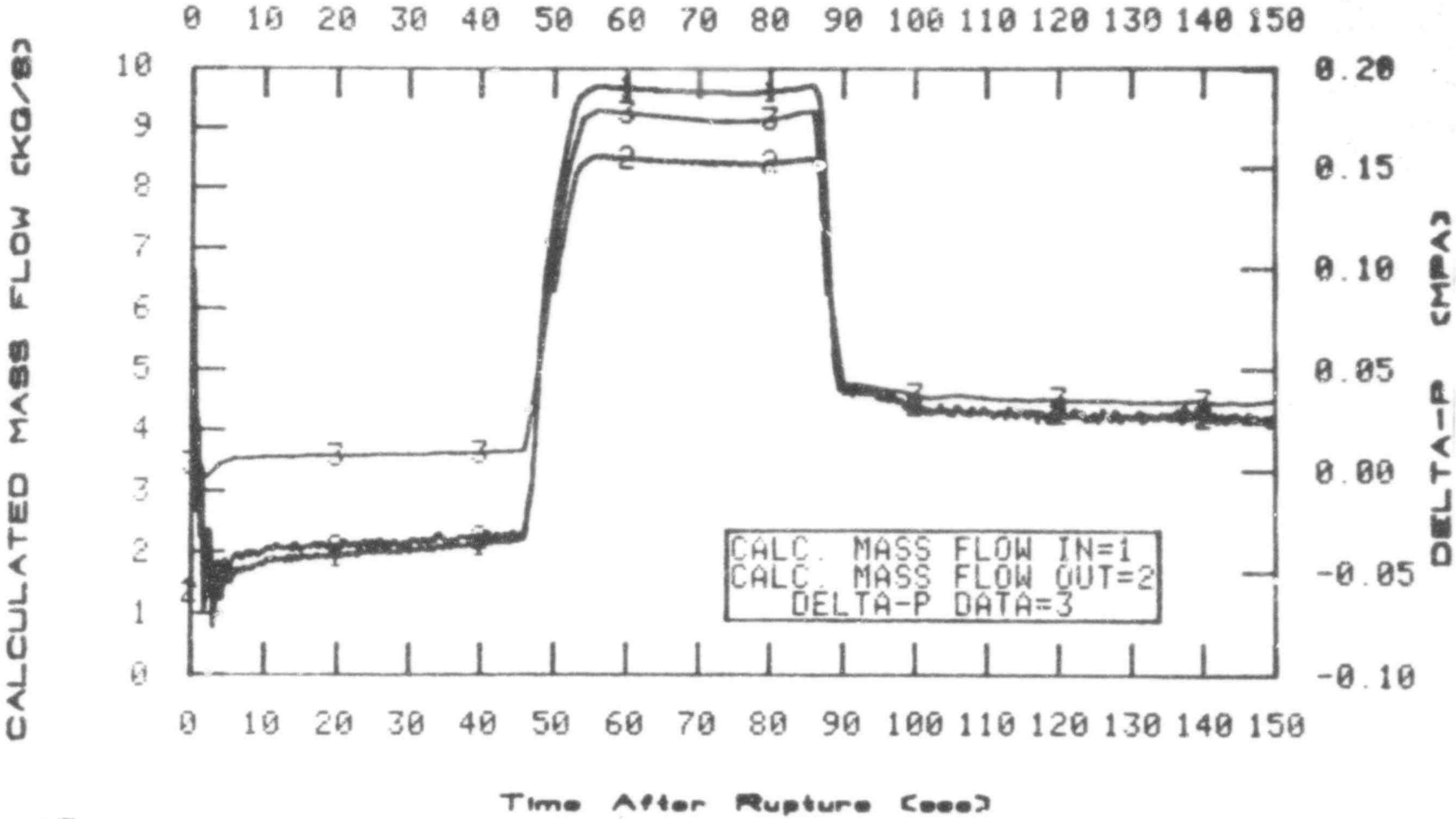

Fig. 8 Differential pressure and mass flow rate in surge line and pressurizer break flow rate from 0 to 150 s.

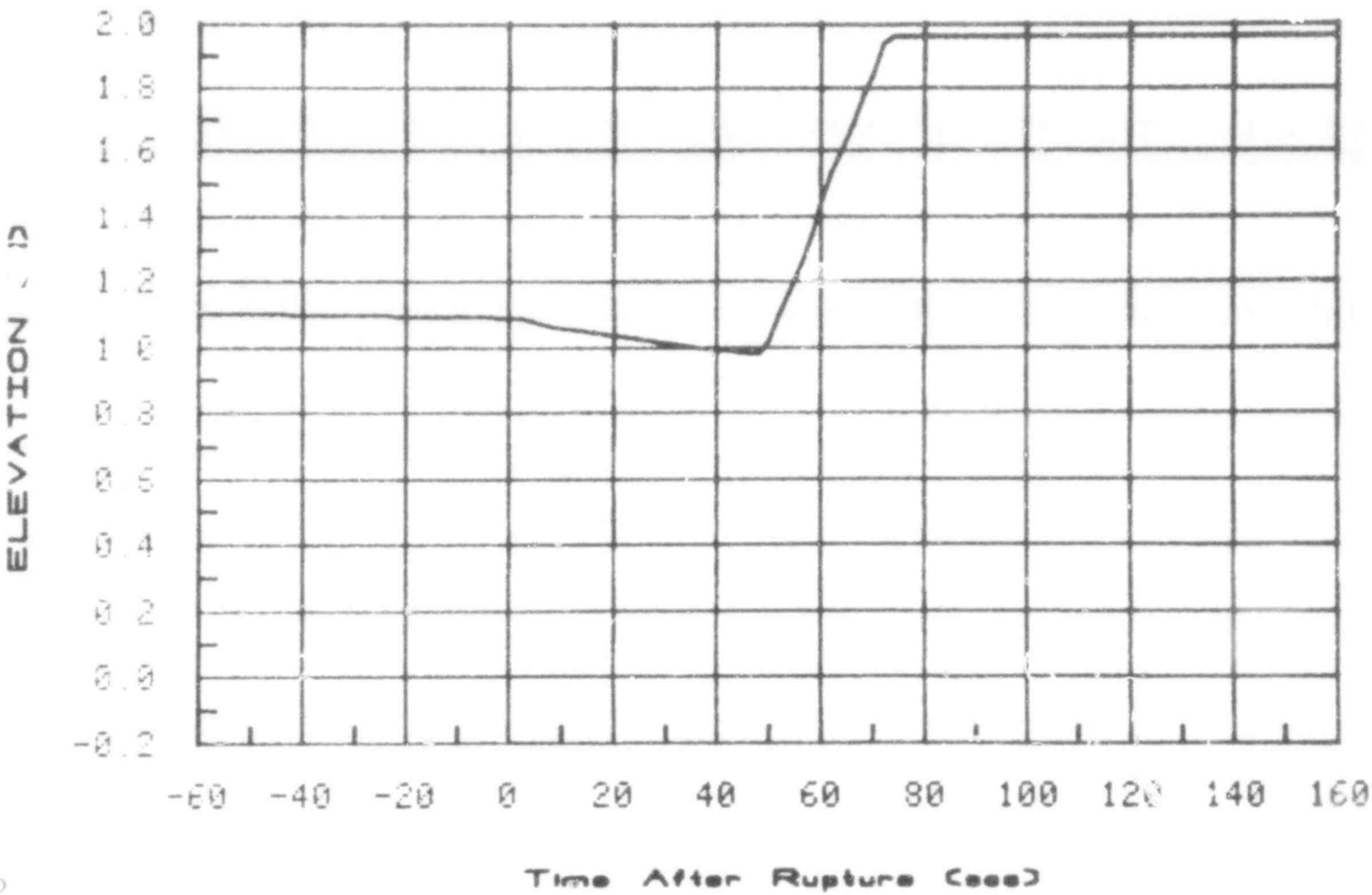

Fig. 9 Liquid level in pressurizer from to 150 s.

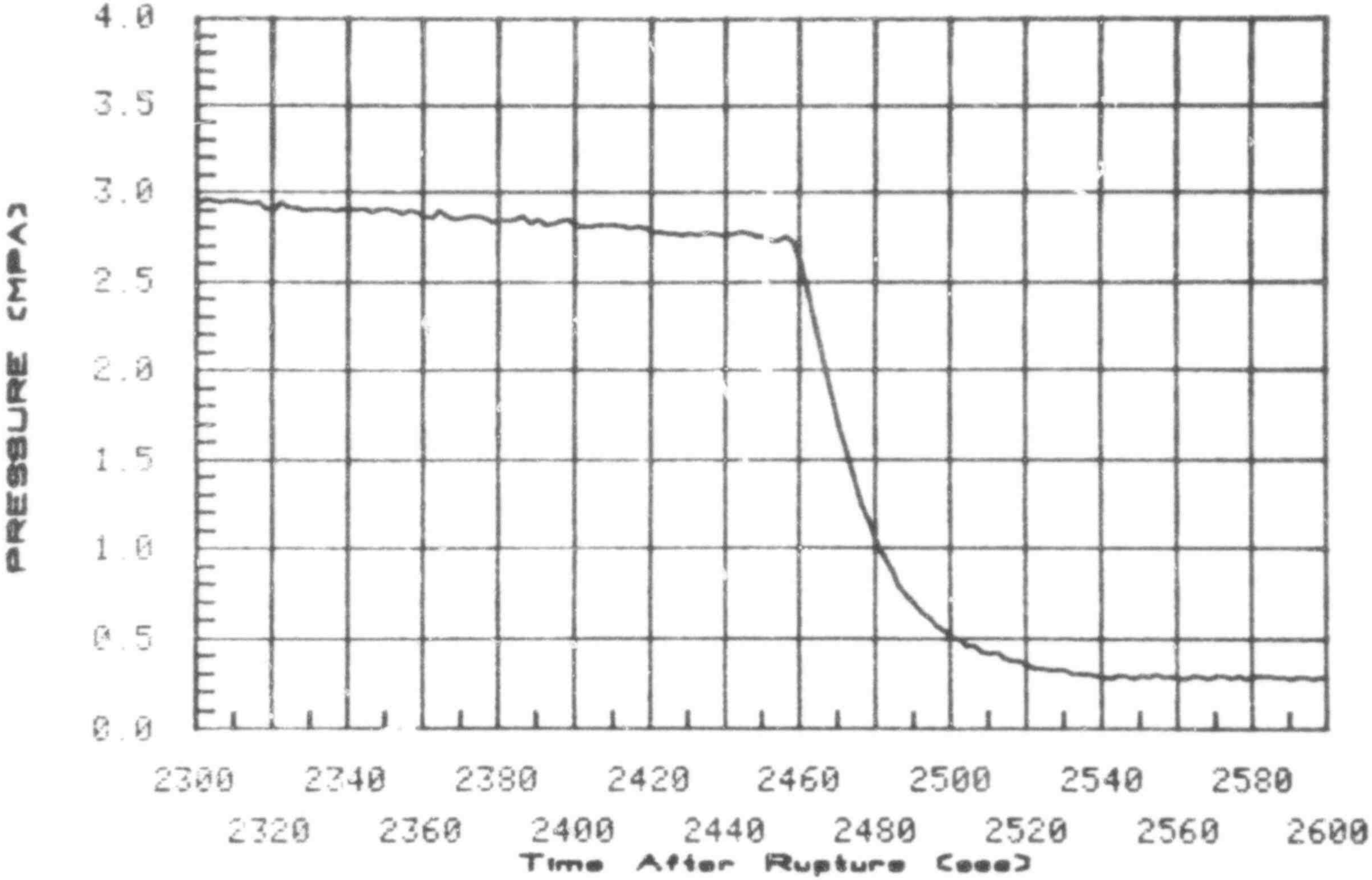

Fig. 10 Pressure in primary system from 2300 to 2600 s.

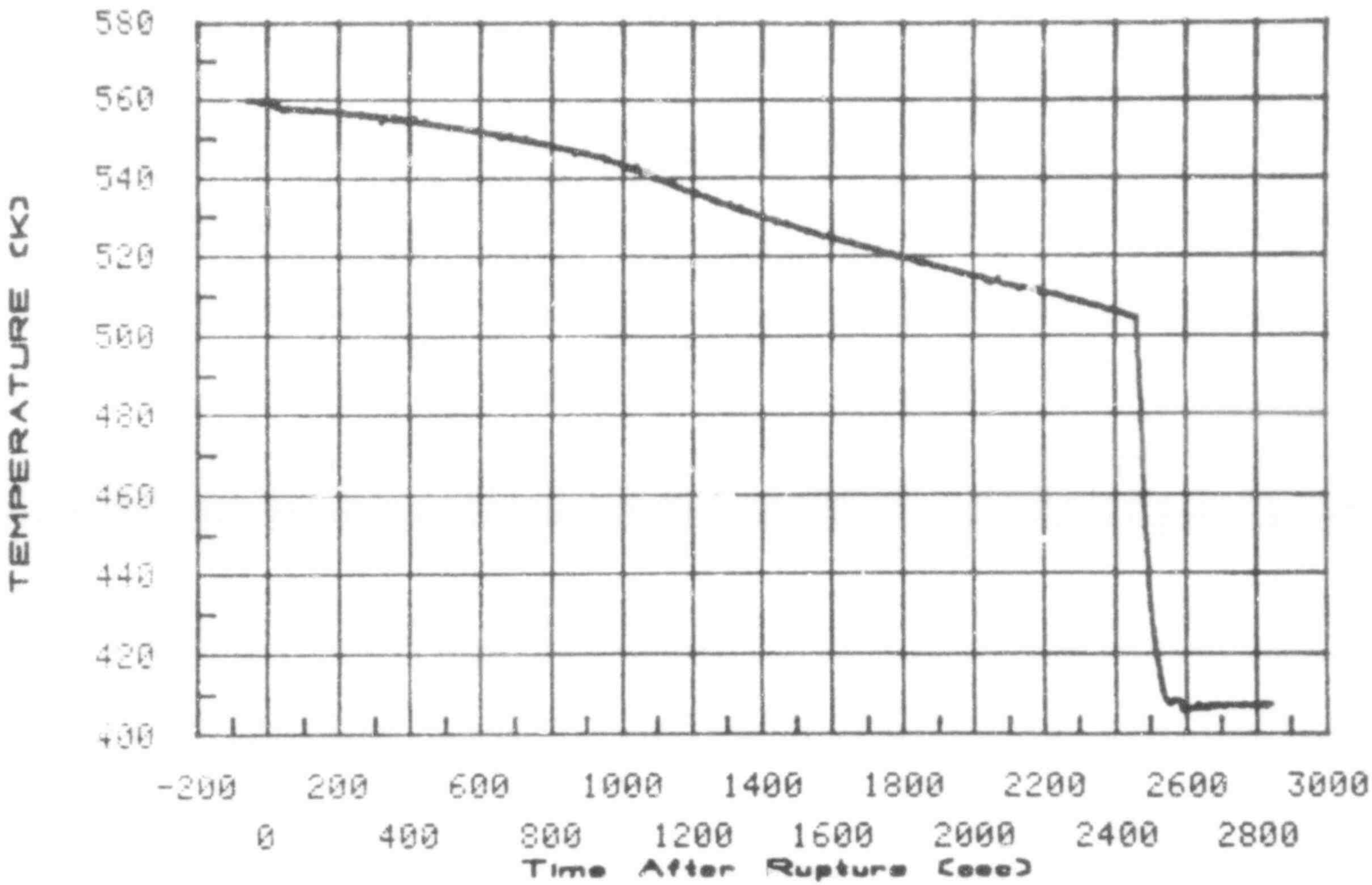

Fig. 11 Cladding temperature in fuel Module 6 at 0.28-m core elevation.

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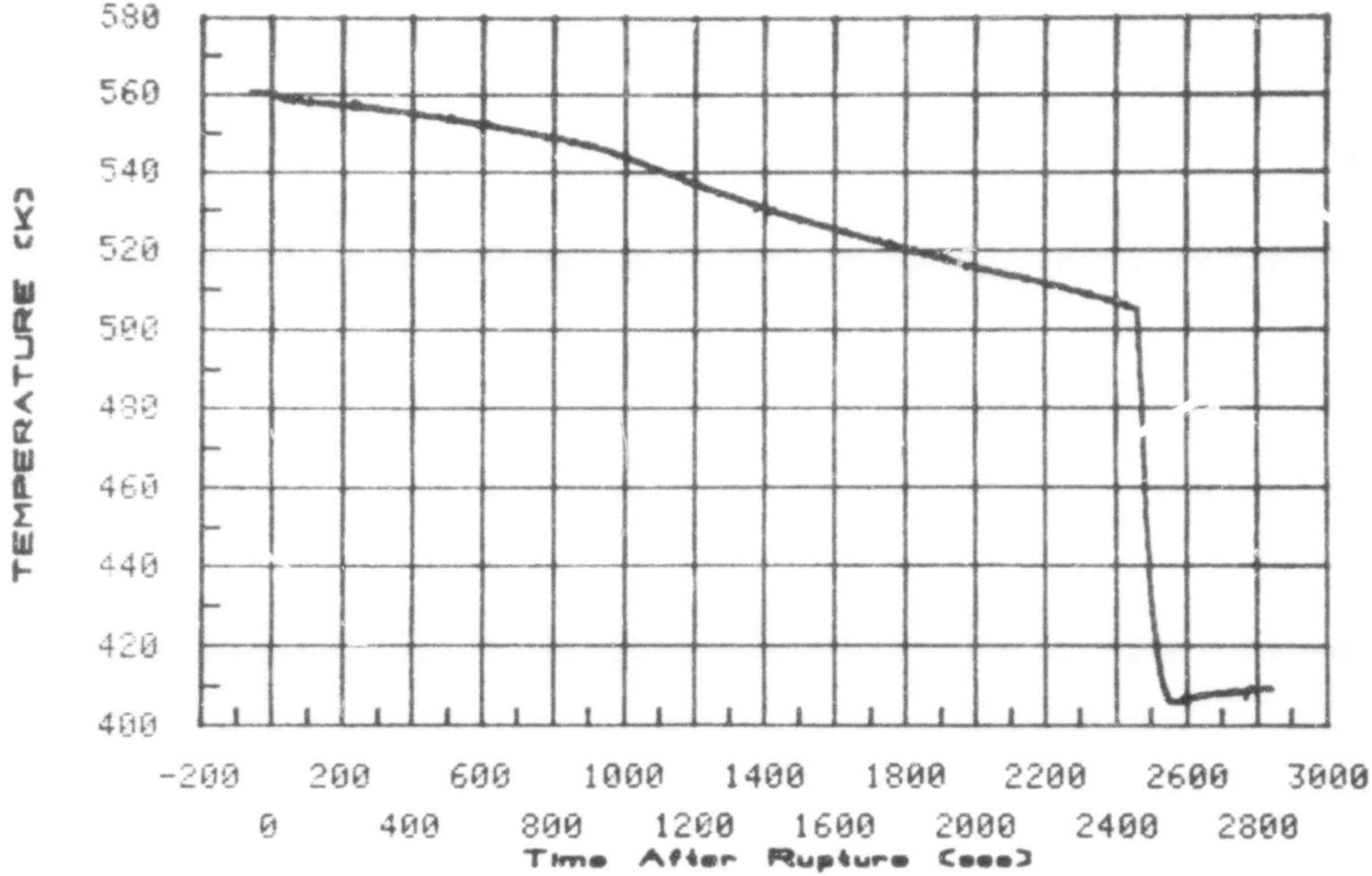

Fig. 12 Cladding temperature in fuel Module 4 at 0.71-m core elevation.

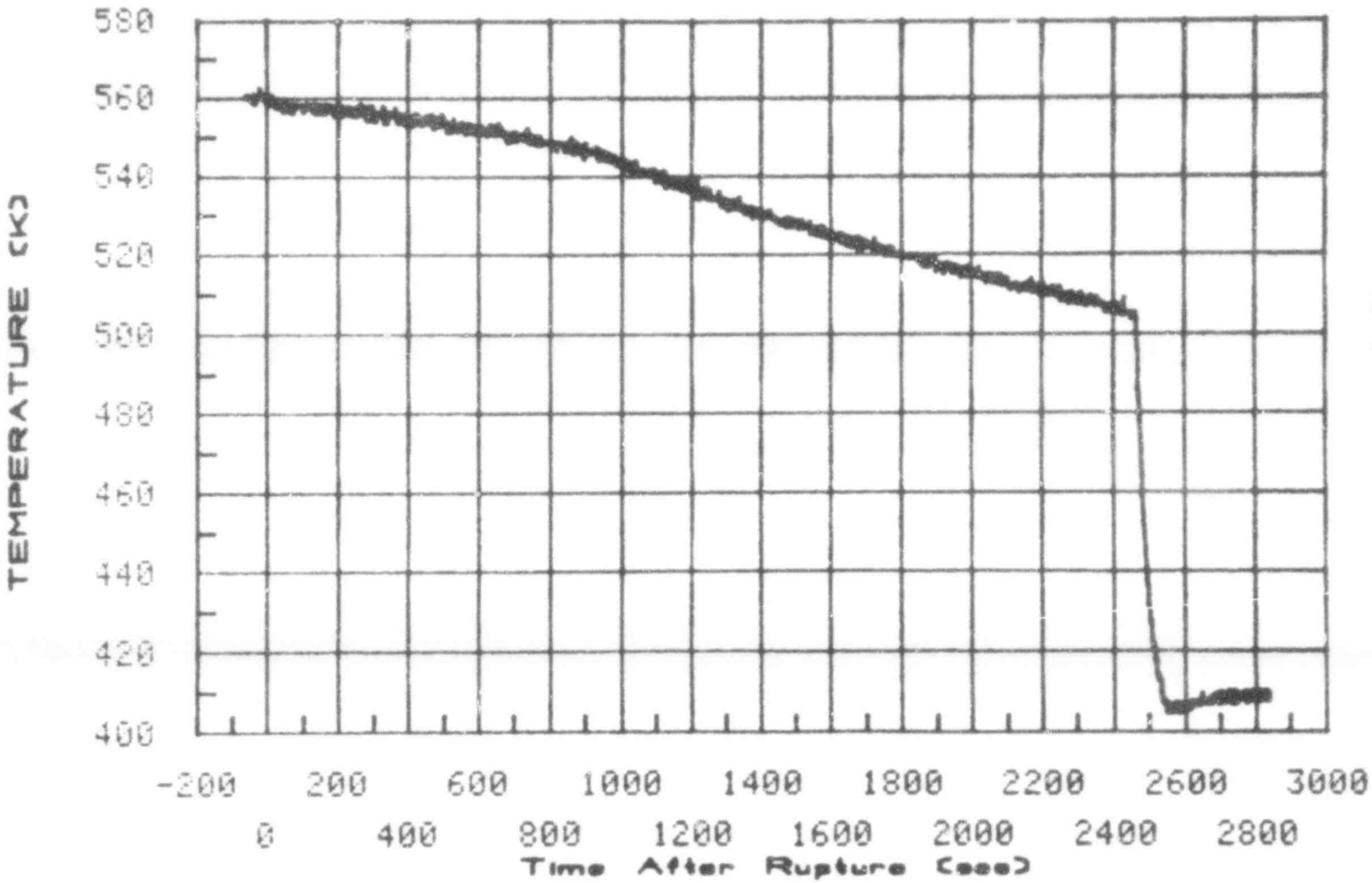

Fig. 13 Cladding temperature on hot rod in fuel Module 5 at 0.76-m core elevation.

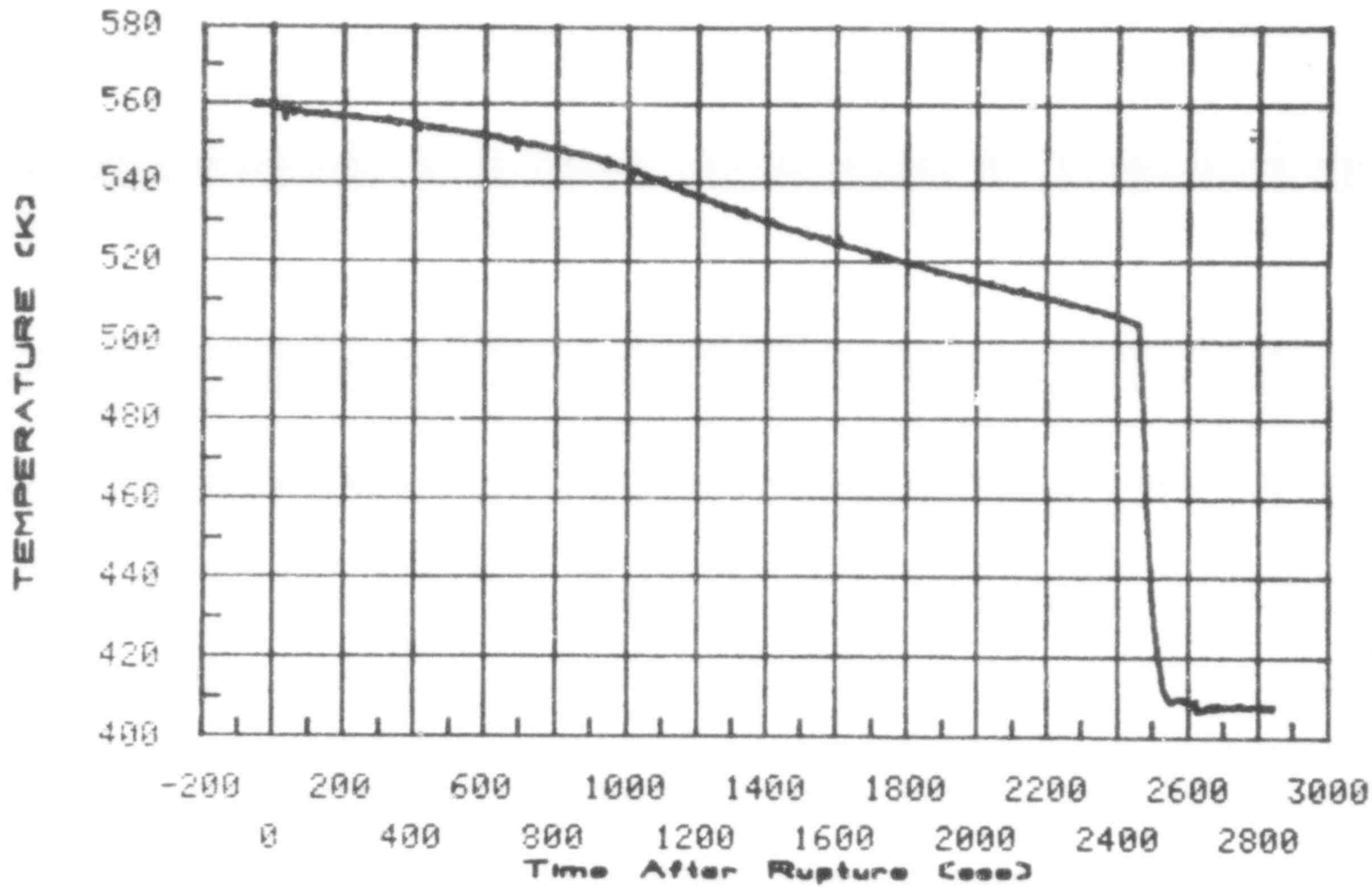

Fig. 14 Cladding temperature in fuel Module 6 at 1.14-m core elevation.

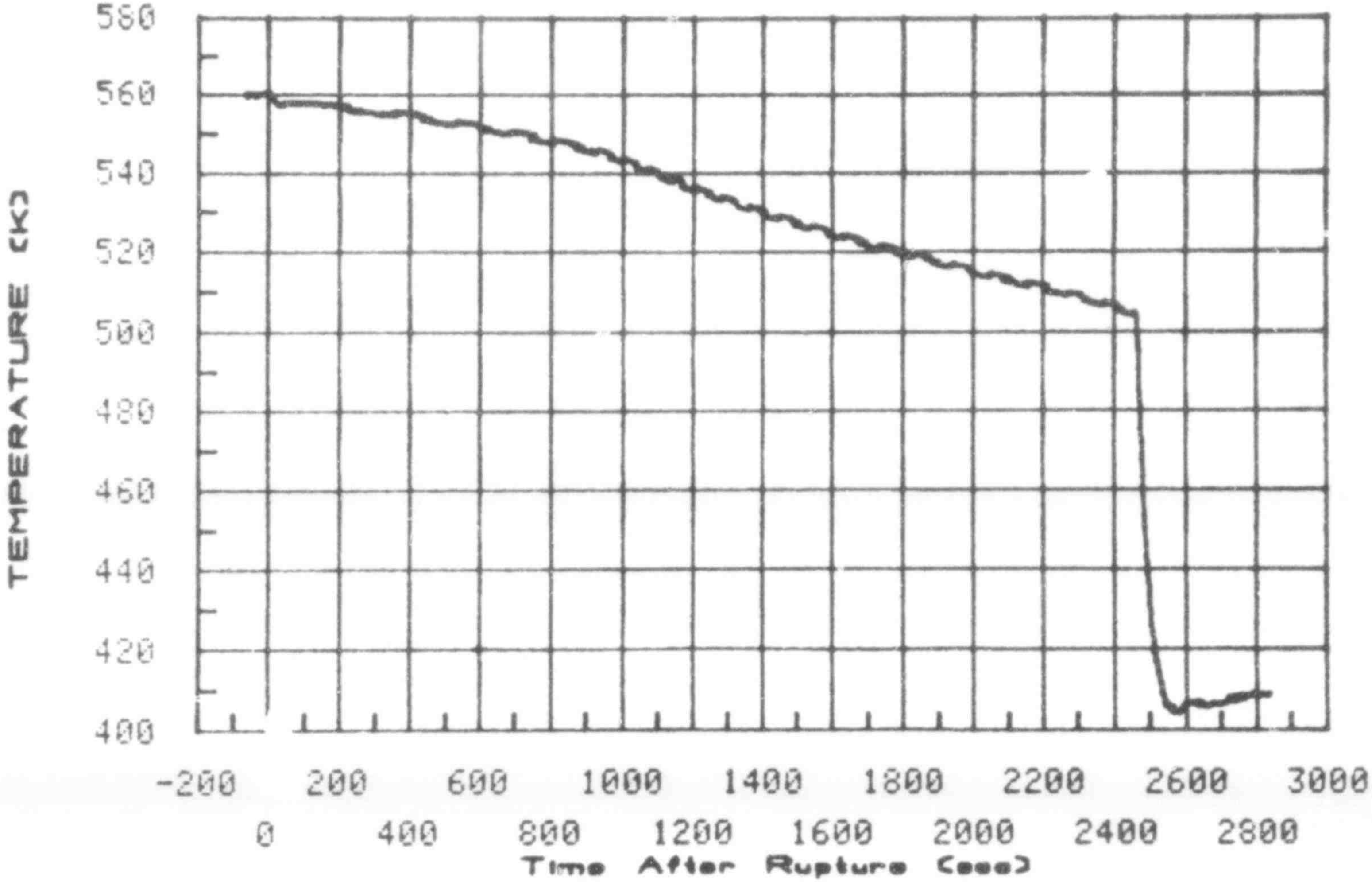

Fig. 15 Guide tube temperature in fuel Module 5 at 0.61-m core elevation.

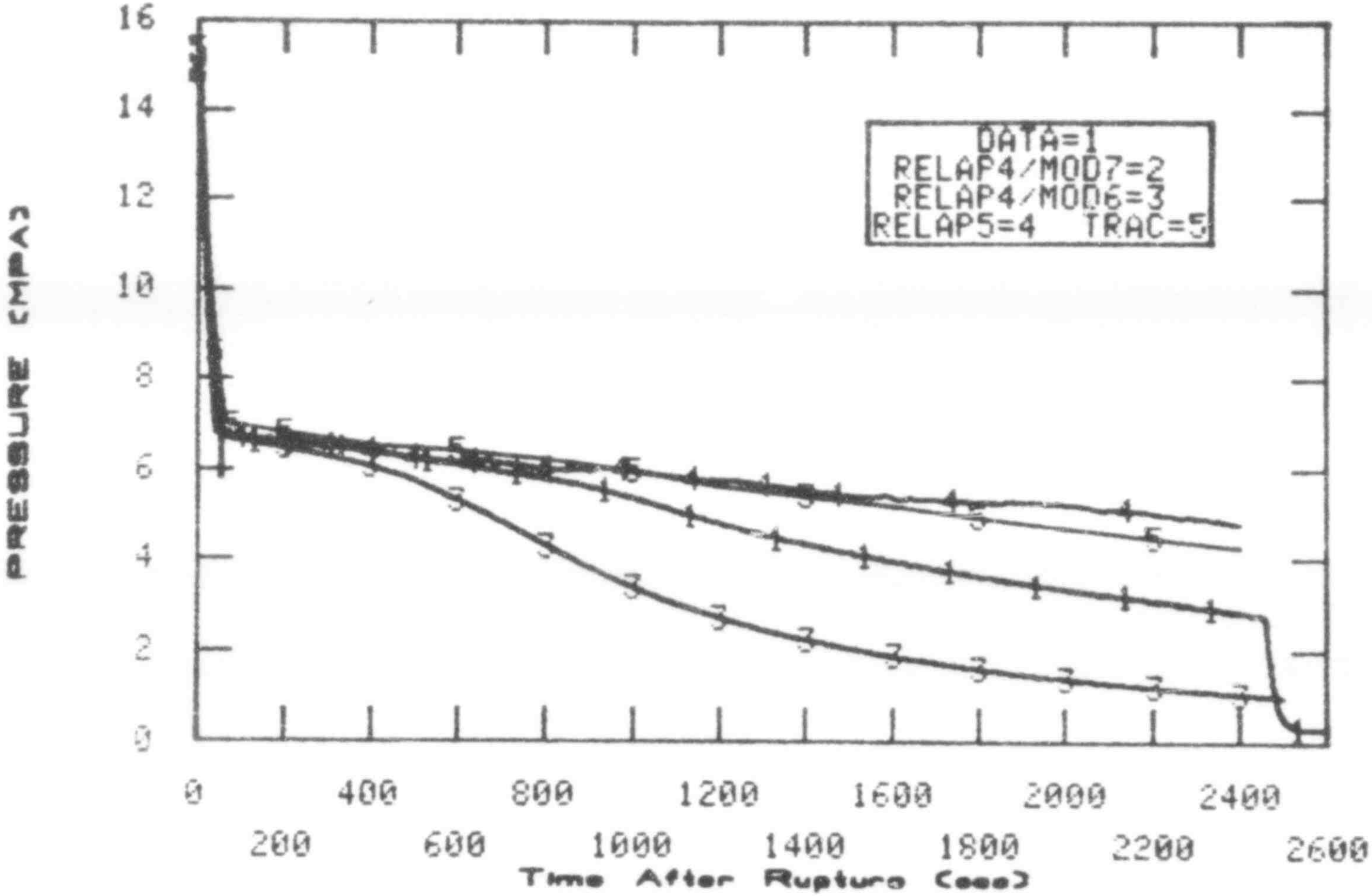

Fig. 16 Calculated and measured primary system pressure.

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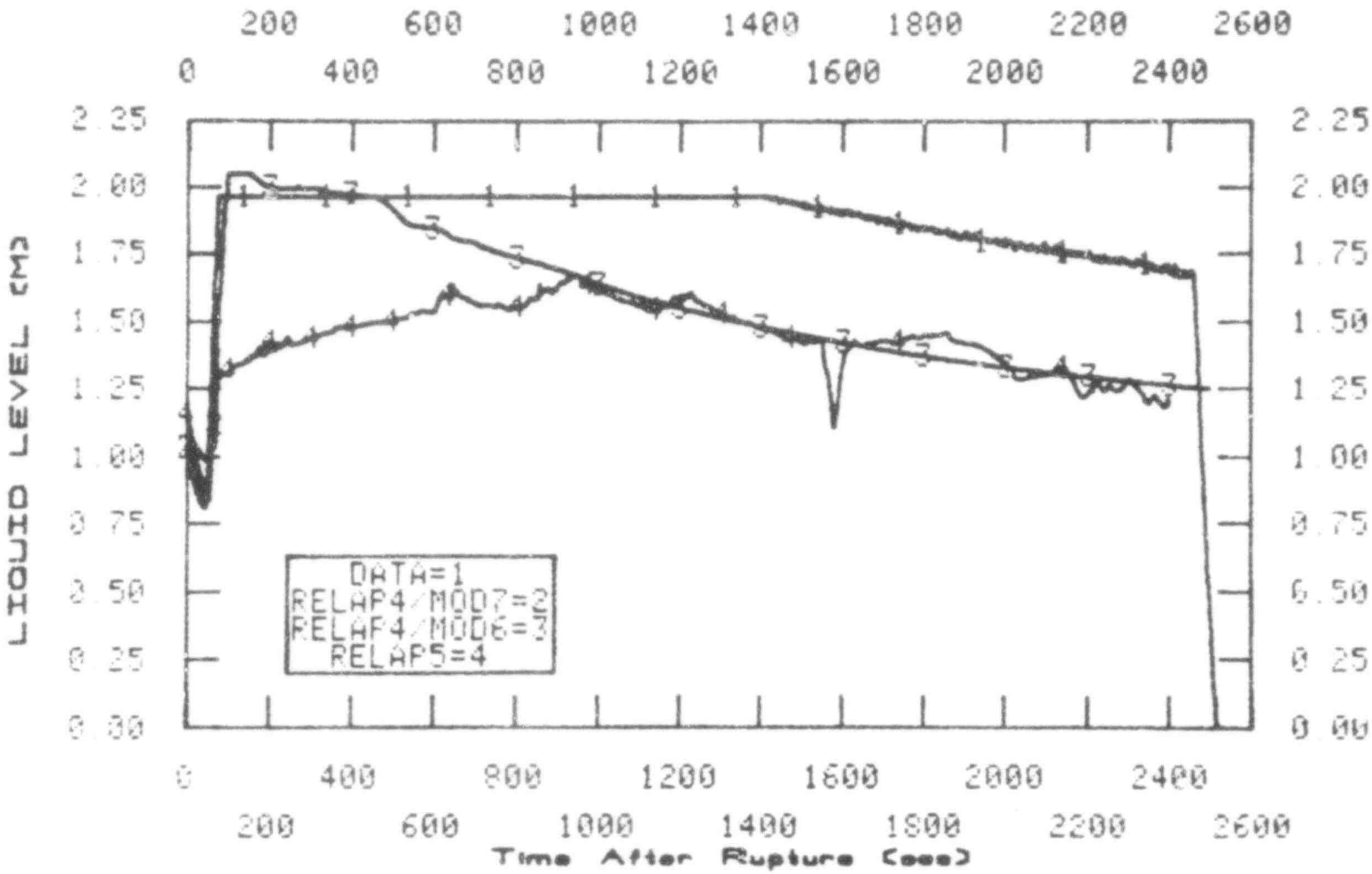

Fig. 17 Calculated and measured liquid level in pressurizer.

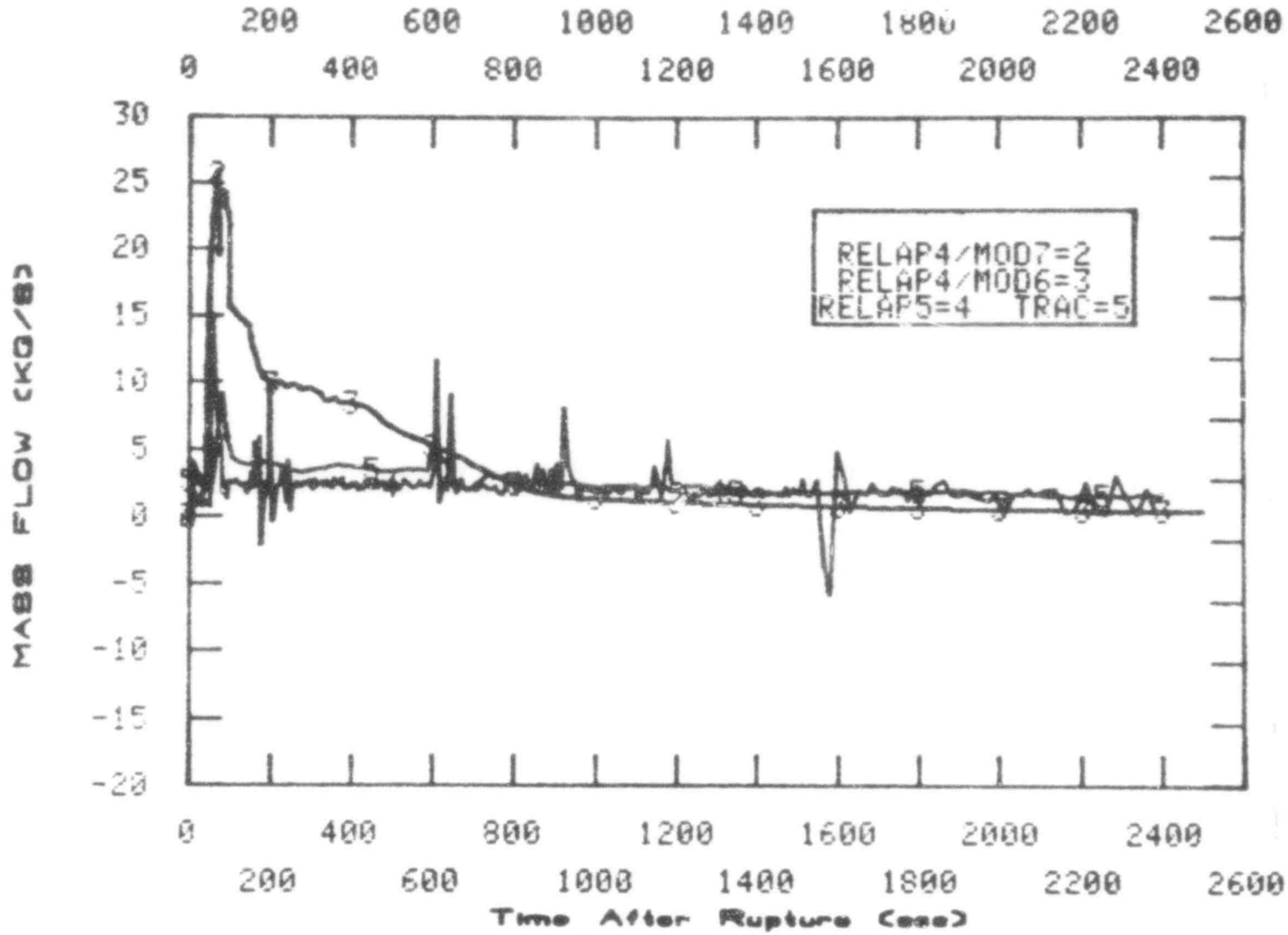

Fig. 18 Calculated flow in pressurizer surge line.

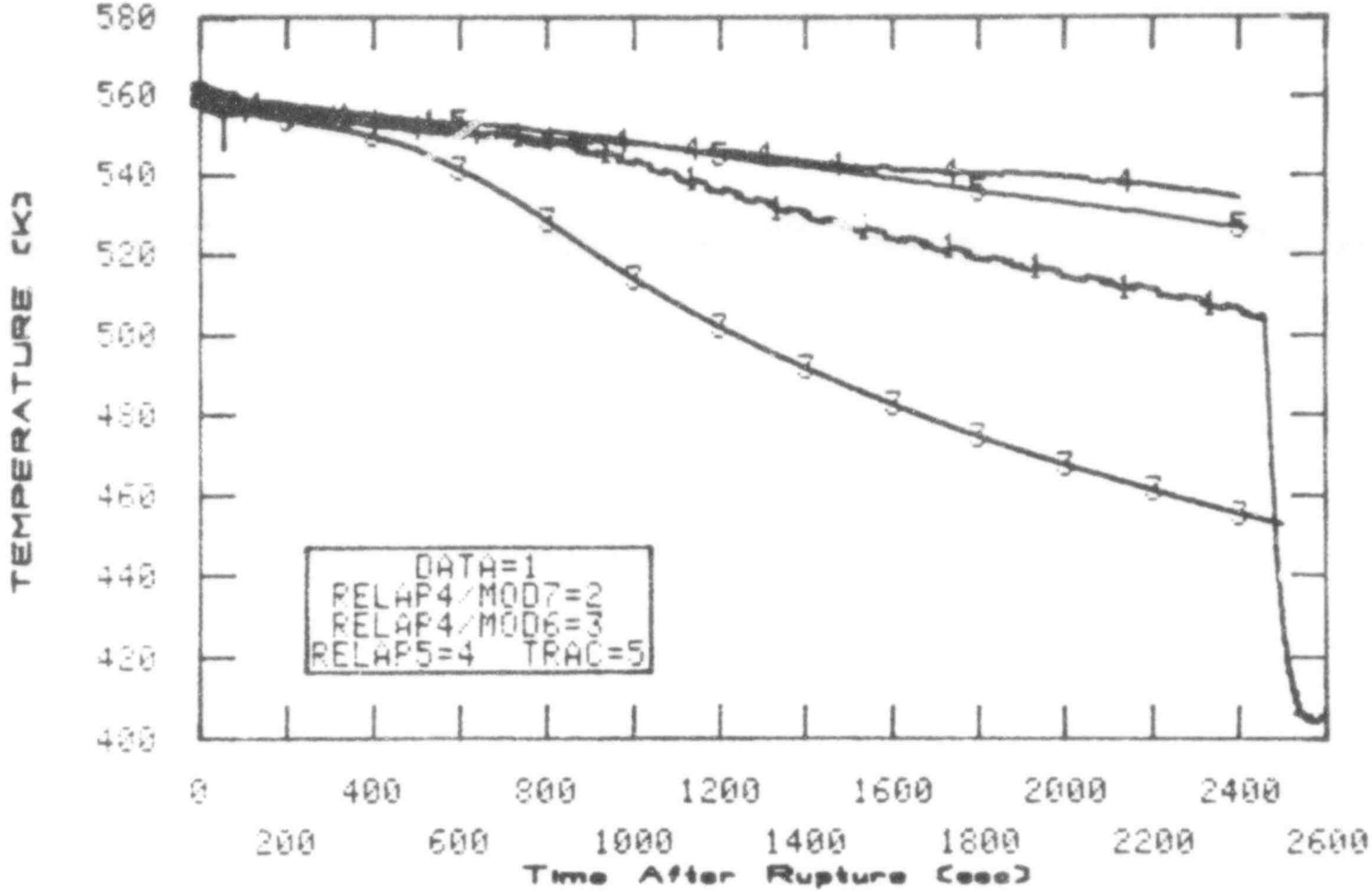

Fig. 19 Calculated and measured core temperature response.

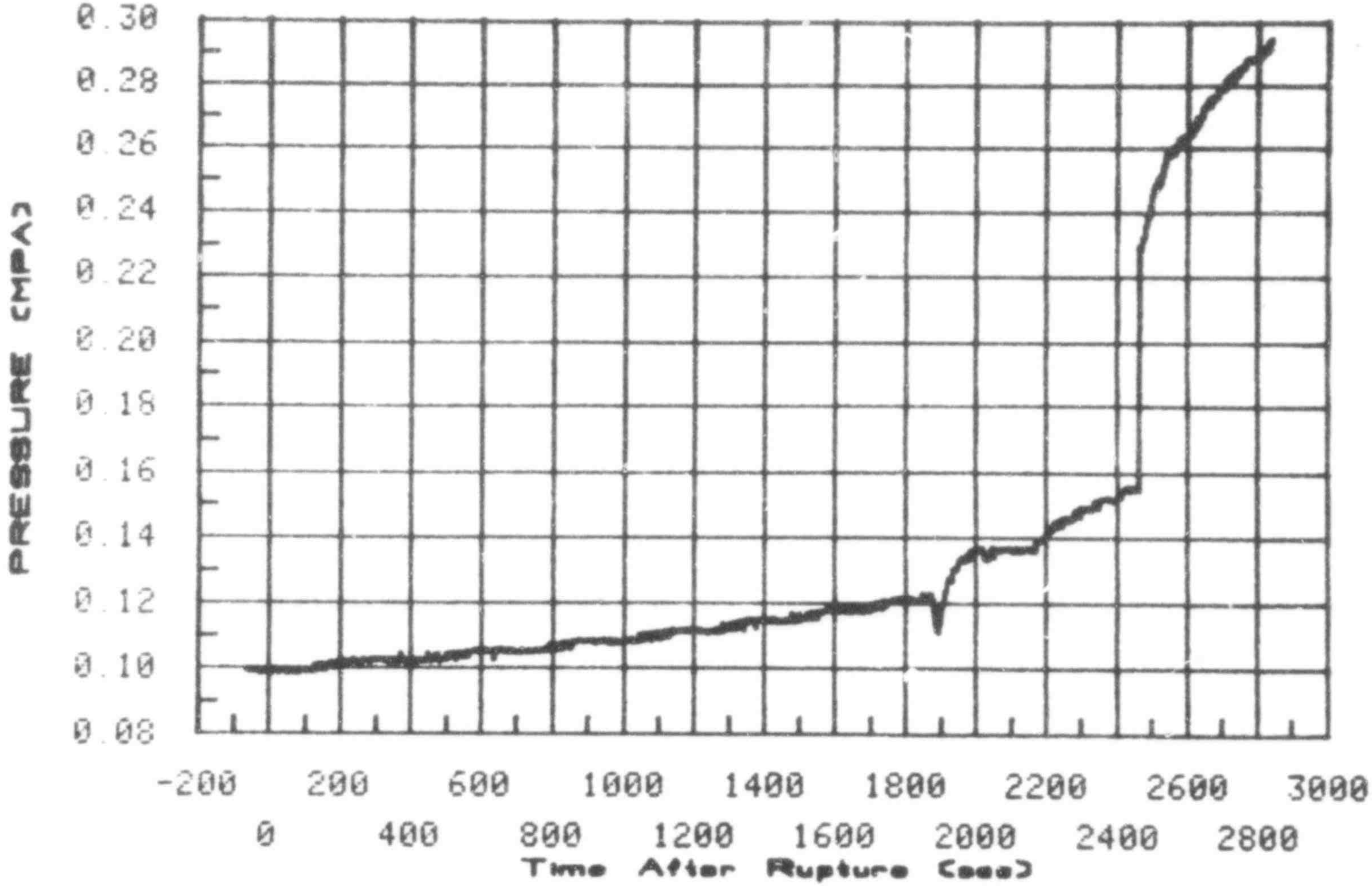

Fig. 20 Pressure in blowdown suppression tank.

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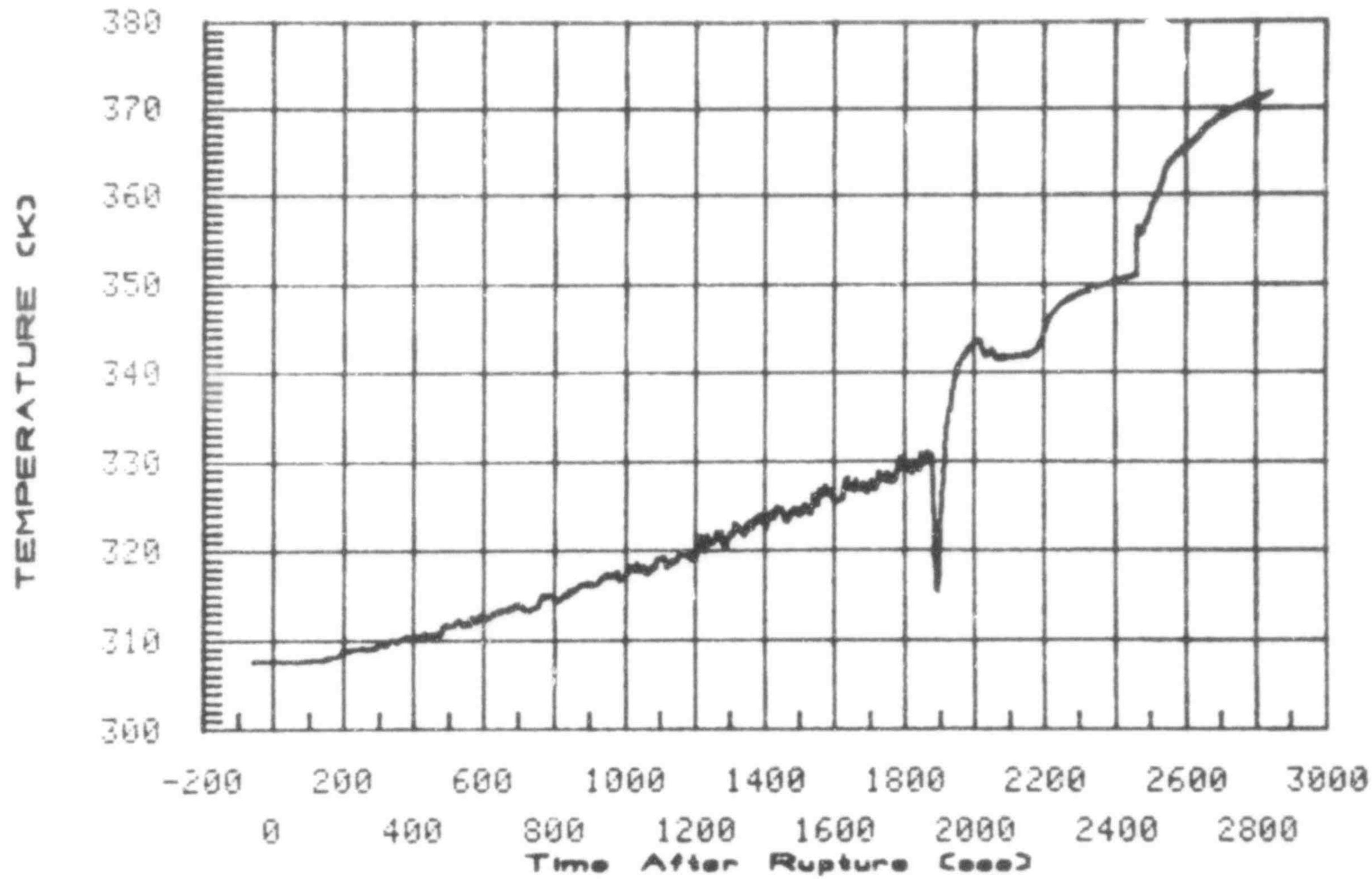

Fig. 21 Temperature in blowdown suppression tank.

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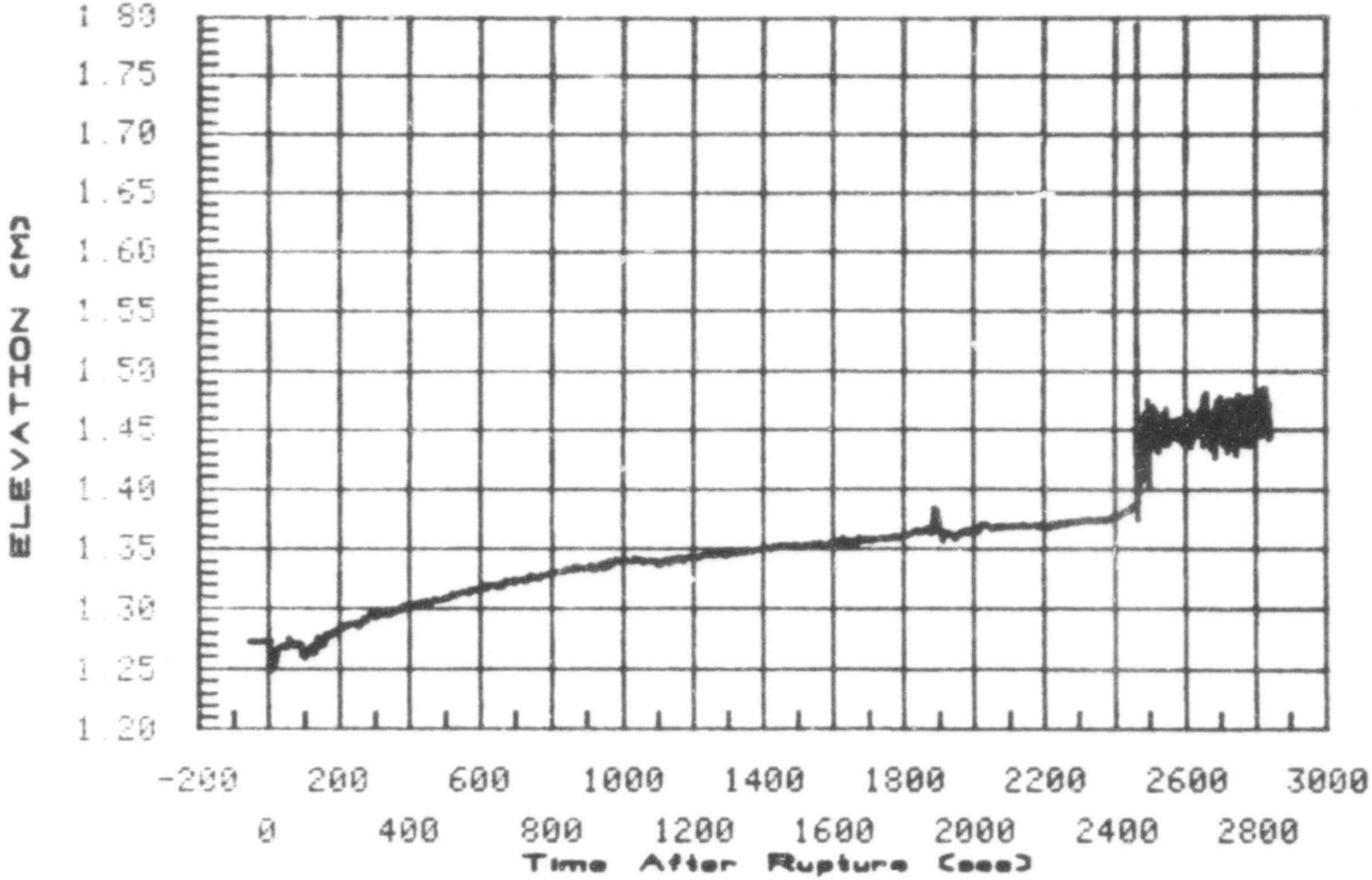

Fig. 22 Liquid level in blowdown suppression tank.

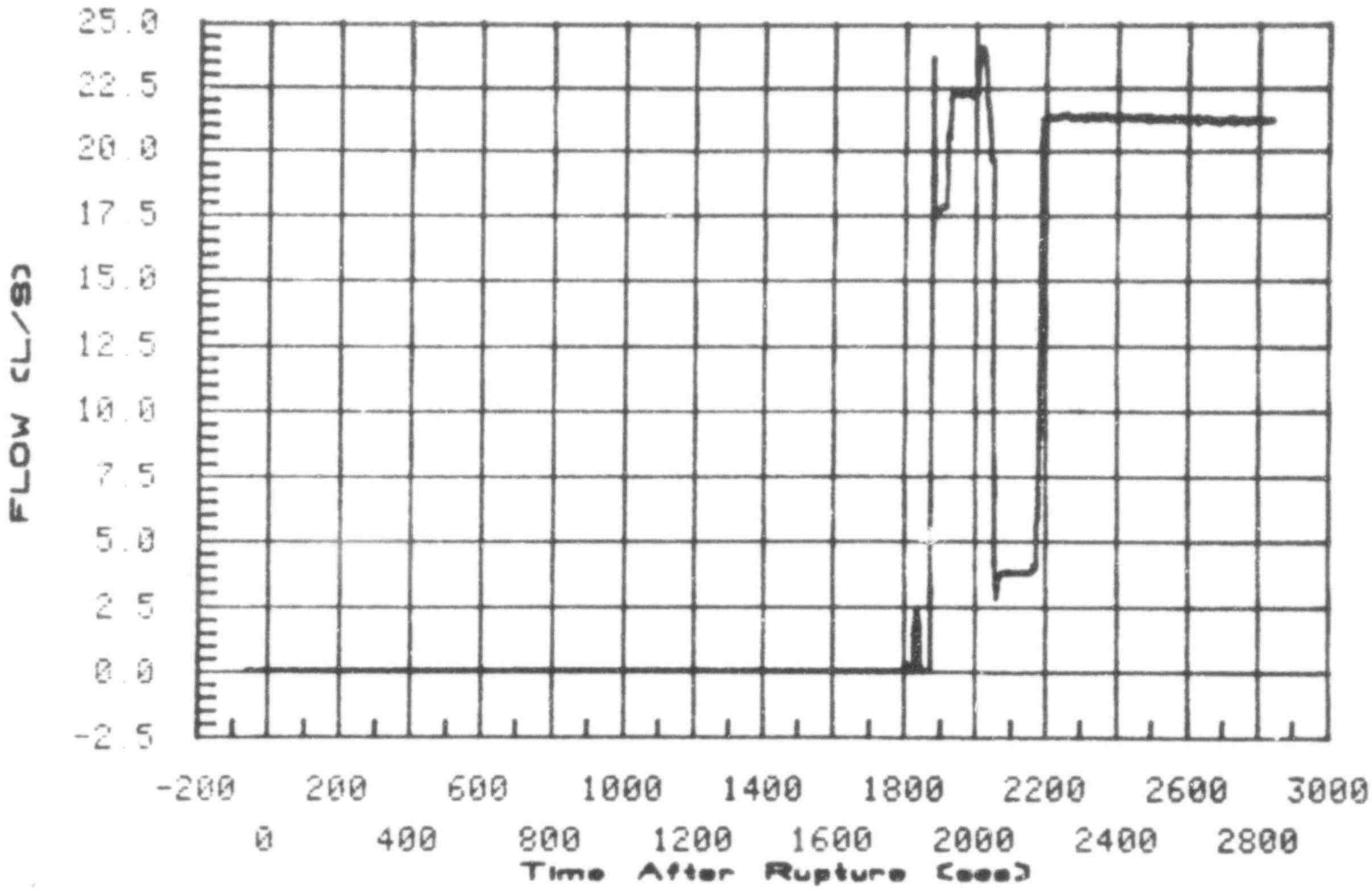

Fig. 23 Flow rate in pressure suppression tank spray system.

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