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AN ANALYSIS OF CSNI STANDARD PROBLEM NO.6 BY ALARM-BI COMPUTER CODE

October 1979

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AN ANALYSIS OF CSNI STANDARD PROBLEM NO.6 BY ALARM-B1 COMPUTER CODE

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Presented in this report are the results of a computer simulation of the CSNI International Standard Problem NO.6 (ISP6) by the ALARM-B1 code.

The aim of this standard problem is particularly to examine the capability of analytical models relating to the two-phase mixture level and the discharge mass flow rate using the individual participants' computer codes.

The theoretical predictions were performed to explore the separate effects during the initial three seconds attended with a non-equilibrium physical phenomenon.

The ISP6, which is based on the Battelle Frankfurt experiment duplicating a BWR steam line break accident, might not be appropriate as a bench mark problem of the ALARM-B1 program (version 2), because it contains an unreasonable demand treating a thermal non-equilibrium process with an equilibrium model.

Apart from the pressure history arising from the non-equilibrium feature, the transient steam-water interface in the vessel was tracked sufficiently by using the bubble-rise-model incorporated in the ALARM-B1 code. In addition, the calculated mass flow rate at the exit plane during the steam phase blowdown was correct within the 15 % experimental error bands.

Key words

NEA-CSNI, Standard Problem, ALARM-B1 Code, BWR-LOCA, Bubble-rise Model, Non-equilibrium Phemomenon, Carry-over, Flashing, Slip, Metastable, Entrainment

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計算コード ALARM-B 1 による CSNI 標準問題 No. 6 の解析

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BWR 用 LOCA 解析コード ALARM-B 1 による CSNI 国際標準問題 No. 6 の解析結果をまとめたものである。問題の趣旨は，特にブローダウン後の液位上昇や流出流量を計算するモデルの妥当性を検証することにおかれた。今回の計算は，非平衡現象が存在する初期の phase に対して実行された。西ドイツ Battelle 研究所で実施された本実験は，平衡モデルの計算コードにより非平衡現象を解明しようとする無理があるため，本コードのサンプル問題としては，必ずしも適当ではないが，当該コードによる解析結果が，実際の非平衡現象にどの程度肉薄するものか注目された。圧力容器内での非平衡性による圧力の一時的不一致がみられたが，後半に両者は近づいた。液位の上昇は，コードのもつ分離モデルでよく説明され更に流出流量も 15 %の実験誤差範囲内で，ほぼ正しく予測された。

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1. Introductory Remarks

OECD NEA Standard Problem NO.6 was adopted at the fourth meeting of the CSNI (Committee on the Safety of Nuclear Installations) Ad Hoc Working Group on Emergency Core Cooling in December 1976.

It is based on one of a series of multifarious vessel blowdown tests already carried out at the Battelle Institute in Frankfurt (May, 1976) in order to study a hypothesized loss-of-coolant process following the rupture of a pipe. These tests series were designed to investigate the fundamental thermal-hydraulic phenomena pertaining to the decompression process of two types of light water cooled reactors; PWR (Pressurized Water Reactor) which contains hot subcooled water only, and BWR (Boiling Water Reactor) which contains saturated water in the vapor region. The present experiment called SWR-2R TEST simulates an instantaneous 100 % main steam line rupture of BWR accidents. During the blowdown, the power was not supplied because of the isothermal test condition. The main objectives of this standard problem were to check the water level and the discharge flow models in existing computer codes, and in addition, to scrutinize the behaviors of the coolant pressure and temperature at the specified locations.

The ISP6 was defined as the open-type problem; that is, all the participants know the results of the experiment in question before their analyses.

Especially interest was centered around the non-equilibrium phenomenon during the early period of the depressurization as a separate effect test.

From the viewpoint of the code analysis, it was also of concern how far the non-equilibrium state can be explained in terms of the current analytical model. The computer program employed in the analysis of the CSNI LOCA standard problem 6 was the ALARM-B1 and the computation was executed on a FACOM-230/75 computer. So far, checkout runs for this code have been scarcely performed because appropriate sample problems or published experimental data were missing. In the prediction of the proposed experiment, it was considered to be an unreasonable calculational exercise for an early phase analysis of blowdown by the equilibrium code such as the ALARM-B1, since there existed a noticeable non-equilibrium characteristics in the vessel. Hence, there was no reason to expect that the predictions would trace the experimental behaviors thoroughly. The most fundamental properties of the code used were to assume a thermal equilibrium between the two phases.

Although any physical models with respect to a non-equilibrium are not introduced in the ALARM-B1 code, checkout runs was done as a good chance to assess the validity or applicability of this code. This report presents a short description of the experimental apparatus and of the ALARM-B1 applied and system modelling, input data and results for the calculation. Including comparisons with some extracted results of the top blowdown experiment, a brief discussion was given about their individual areas of an agreement and also a disagreement.

A disagreement provides, in general, a useful information to analytical model development and improvement as a basis for the verification of codes. The lack of agreements was evidenced

in the pressure data or the incipient water level. After disappearance of the non-equilibrium phenomenon in the pressure vessel, the prediction gradually tends to agree with results of test. Three seconds later, the two was nearly in the agreement. That is to say, it might be expected that this code is capable of predicting the system behaviors adequately within a stabilized saturation regime. It was confirmed that a marked difference of the pressure in the initial phase was the discrepancy caused by the modelling limitations. Also, the bubble-separation model in the ALARM-B1 made the water level rise reasonably.

This calculation has required CPU Time 102 seconds for physical time 3.75 seconds.

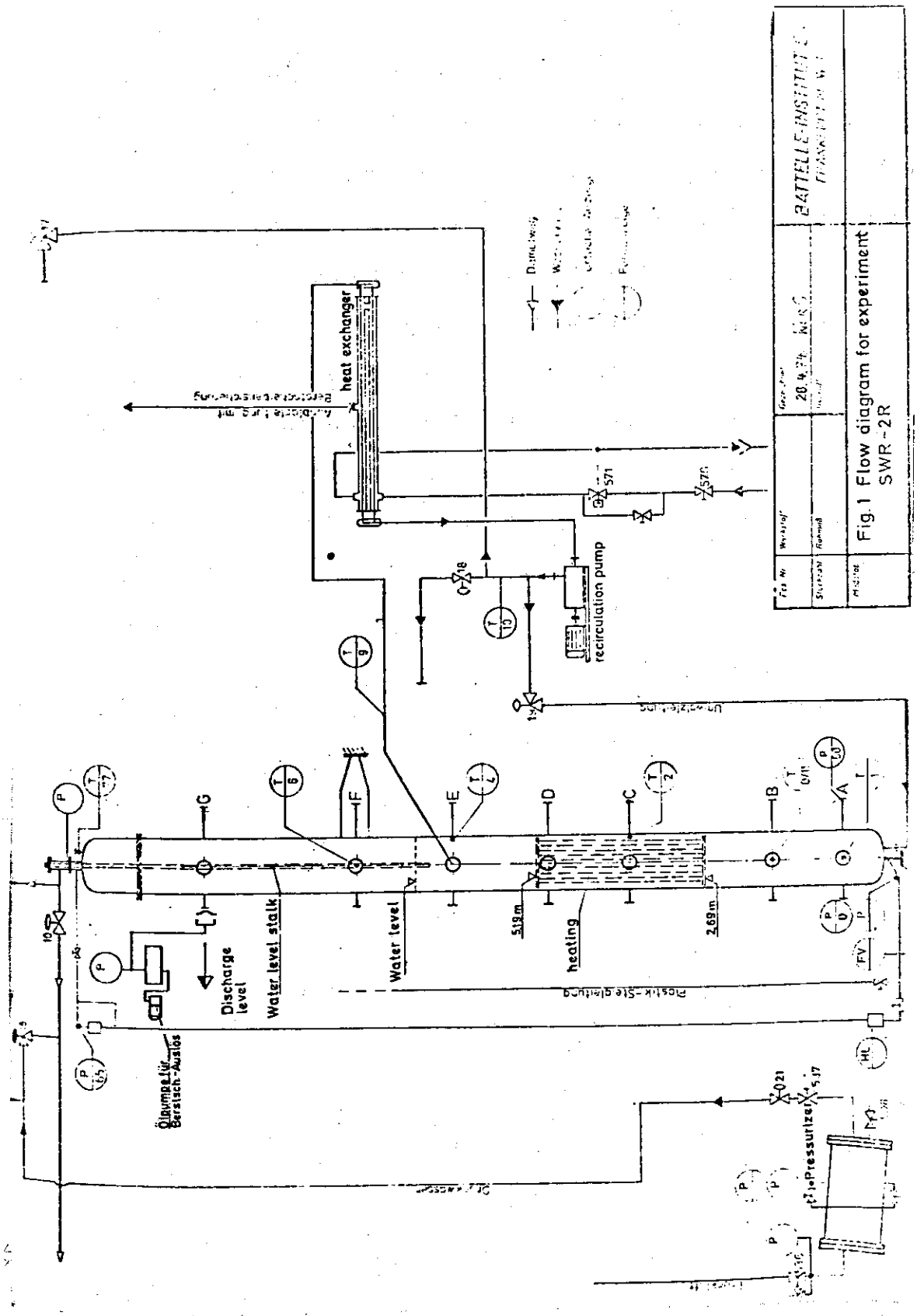
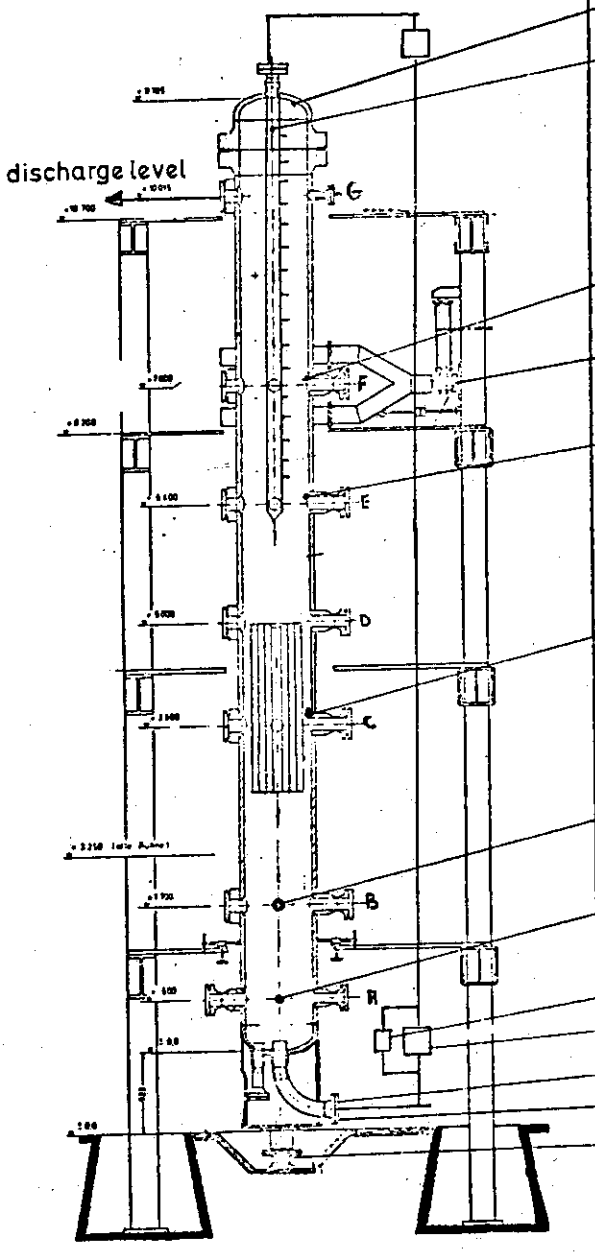


Fig. 1 Flow Diagram for Experiment SWR-2R



Meßstellenbezeichnung	MK
PL 1118BS	5/3 115
Water level stalk	direkt
TL 800BI180-T6	direkt
FH 780BA 180	4/1 121
TL 640 BI 180-T4	direkt
TL380BI270-T2	direkt
TL 170BIMIT-T0	direkt
TL 060BIMIT-T1	direkt
HS-67/1118	1/2 116
HL-67/1118	direkt
PL-67 AK	1/1 114
PM-67 BS	direkt
FV-67 BAMIT	1/3 120

Fig. 2 Pressure Vessel with Supporting Frame Work

2. Experimental Facility Description

Safety studies simulating the discharge process after a postulated piping rupture of a BWR were conducted in a simple vessel. Figures 1 to 2 represent the schematic view for the SWR-2R experimental reactor simulator.

The full description of the facility is given in the reference.[1]*

In short, this vessel has an inner diameter of 0.77 m, a volume of 5.2 m^3 and a height of 11.19 m, which is almost the height of a commercial power reactor core. In the middle of the vessel, there is only a simulated core (2.5 m in effective length) with electrical resistance heating. The test was made with pressure vessel with no internals.

The heater furnishes an electrical power (about 600 KW), which is necessary to adjust the incipient water temperature distributions in the pressure vessel. The heating is then turned off, when the desired temperature was established. The nozzles at the six different elevations A to G indicated in the figure, are equipped in order to perform the blowdown simulation tests for both a PWR and a BWR under the various conditions.

One of them was used as a break nozzle and at the other elevations the measurements of the pressure and the temperature were made. The discharge nozzle for the run SWR-2R was located at the level G, 10.015 m above the vessel base. The configuration of the nozzle is shown in Fig.3. As such, the experiment in question was done to simulate the main steam line rupture of BWR's. The break was simulated by the orifice behind the

* References are associated with numbers in brackets.

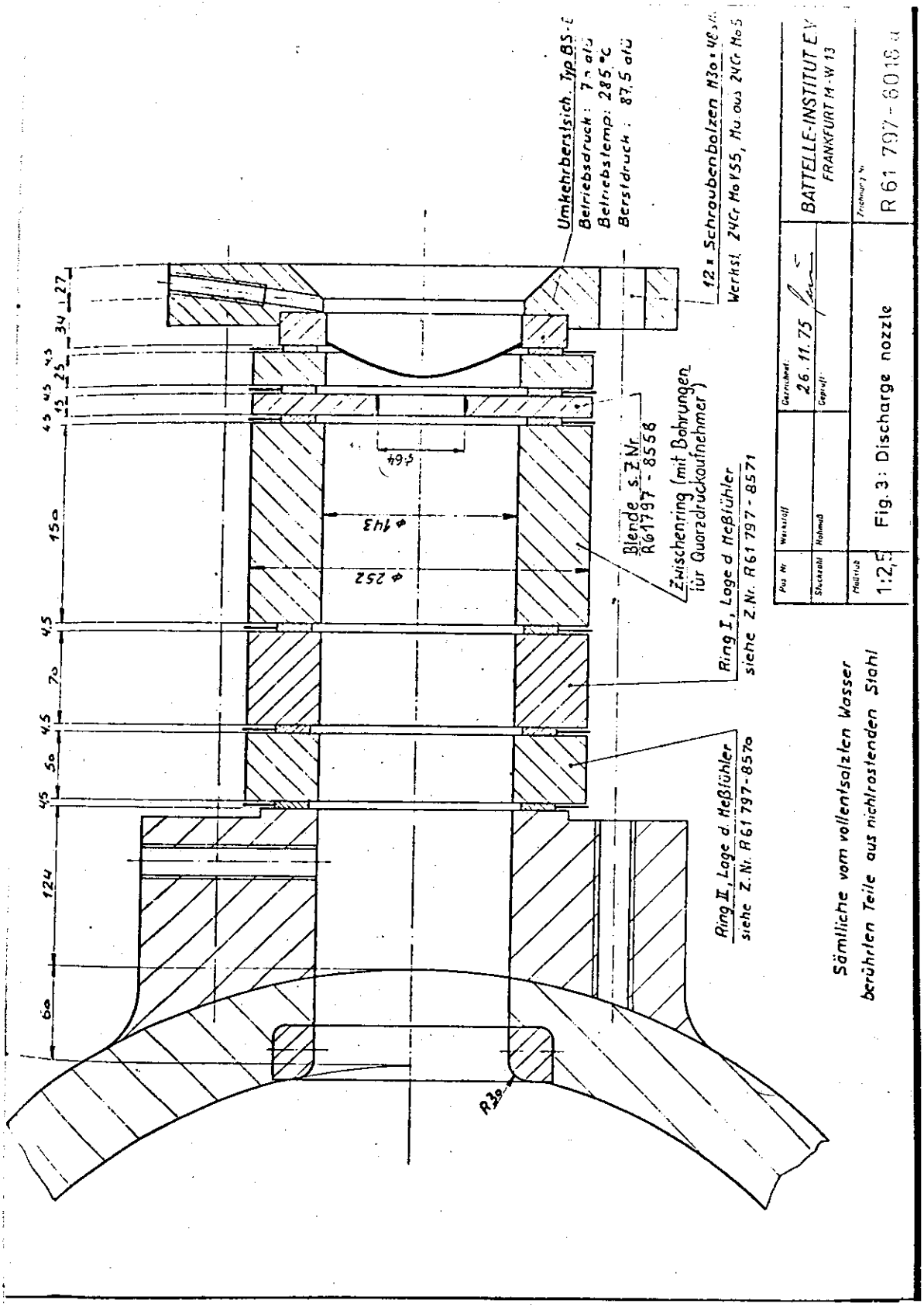


Fig. 3 Discharge Nozzle

concave rupture disc. In this isothermal test, a sharp edged orifice plate with an inner diameter of 64 mm was installed to the steam line duct. By destroying this rupture disc, a LOCA experiment is started. High pressure two-phase flow behaviors were observed through the fluid discharge from a top nozzle in the steam zone. The measurement instruments of the temperature and the pressure are indicated in Table 1. Additionally, the pressure gauges in the nozzle were measured at the eight different positions, while the temperature gauges at the four locations. The measurement of the fluid temperature was made by means of the two types of gauges — "slow resistance thermometers" and "fast thermoelements" —: the former is installed to control the stationary temperature stratification while the latter to measure the transient temperature.

The fluid density in the nozzle was determined from γ-ray absorption method. The discharge mass flow was determined from the density results and drag force measurement. The accuracy of the mass flow rate data was reported to be within approximately 10 through 15 %.

Transient liquid level was observed by a stalk equipped with electrical contacts. When the water level wets a contact, current flows between the electrodes, producing the electrical signals. It has ±2 cm measurement errors. The principal initial conditions specified for the problem are the following:

Pressure	71.1 bar	at the position PL-67 AK
Temperature	285.5 °C	at the position A (TL-060-BIMIT)
	289.4 °C	at the position B (TL-170-BIMIT)
	289.5 °C	at the position C (TL-380-BI270)
	288.0 °C	at the position E (TL-640-BI180)
Water level	7.07 m	above the vessel base (285 °C water temperature)

They are made to be within a range of the typical reactor condition to investigate the various effects arising from the blowdown.

Level	Pressure Gauge	Temperature Gauge	
		(Slow)	(Fast)
A	PS060 BIMIT	TL060 BIMIT	TS060 BIMIT
B	PS170 BI000 PS170 BI180	TL170 BIMIT	TS170 BI000 TS170 BI180
C	PS380 BI000 PS380 BI180	TL380 BI270	TS380 BI000 TS380 BI180
E	PS640 BI000 PS640 BI180	TL640 BI180	TS640 BI000 TS640 BI180
F	PS780 BI180	TL800 BI180	TS780 BI180
G	PS999 BI180		TS999 BI180
Relative accuracy	~ 1 %	~ 1 °C	~ 2 °C

Table 1 Measurement Instrument of Pressure and Temperature

3. Brief Description of ALARM-B1 code

The calculation procedure for predicting the thermal-hydraulic response of the BWR LOCA with a large break has been newly developed for the FACOM-230 series in JAERI. This code ALARM-B1 is a one-dimensional node and junction type (lumped parameters) loop code in which the heat transfer from the fuel rod to the fluid during the blowdown is provided by input data.

In the calculation model, the primary reactor system of current GE type BWR's with jet pumps is simulated by some control volumes with junctions.

Based on the thermal equilibrium assumption, the one dimensional mass, energy and momentum conservation equations are solved in the individual volume nodes simultaneously. At the present version Update 2, the momentum flux term is neglected in the flow equation. Concerning to the hydrodynamics in the control volumes, the selection as to whether homogeneous or separate is quite optional as in ALARM-P1.[13] No slip between the phases is taken into account for the present. For the jet pump behavior, the conservation equations are solved for six cases in accordance with whether the drive, suction and throat flow are in the normal or reverse flow condition. The characteristics of the recirculation pump is calculated by the homologous law using a set of input performance curves.

At the present stage, the heat transfer in the core region is treated in detail by another code (e.g., HYDY). That is, the ALARM-B1 only presents the boundary conditions at the core inlet and outlet. The details of ALARM-B1 are treated in the code manuals.[2].

In the program, a calculational frame work in modelling, such as the transient heat transfer or ECCS problem is still under way. Furthermore, premature parts in this code as the ECCS evaluation code are the major tasks to be improved as soon as possible.

As an extension of current version, above problems will be self-contained in the forthcoming version ALARM-B2.

4. Simulation Model for ALARM-B1 code

The ALARM-B1 noding diagram used to carry out the computation for the Standard Problem NO.6 is shown in Fig.4.

As is seen, the pressure vessel was divided into three control volumes with three junctions. A very simple nodarization scheme was accepted here, though several different proposals have been tried in modelling of experimental equipment. The initial water depth in the vessel is 7.07 m, which is above the region 2 (control volume 2). The discharge nozzle connected to the vessel was ignored in modelling because of a small volume.

A rupture has started the blowdown at time 0.0001 seconds. It was treated as a leak junction and simulated by a 64 mm diameter orifice at 9.96 m above the bottom of the pressure vessel. Leak data were input as a function of time vs. fluid cross section. The sink pressure was assumed to be atmospheric.

A multiplier for the Moody's two-phase critical flow model was set to 0.75. It is an arbitrary number to adjust the maximum flow through the discharge nozzle.[7][8] A bubble rise model applied only to the control volume 3 was determined from ALPH = 2.0 for a bubble slope parameter (density gradient) and VBUB = 4 (ft/sec) for a bubble escape velocity[2] (a bubble data submitted to CSNI). A value of 1.0 for the bubble density gradient stands for a homogeneous mixture. The velocity is the rate of separation of the rising vapor bubbles into the steam dome. The other nodes were assumed to be homogeneous in order to avoid the physical inconsistency called "layer cake situation".

It should be noticed that the separation models in vertically

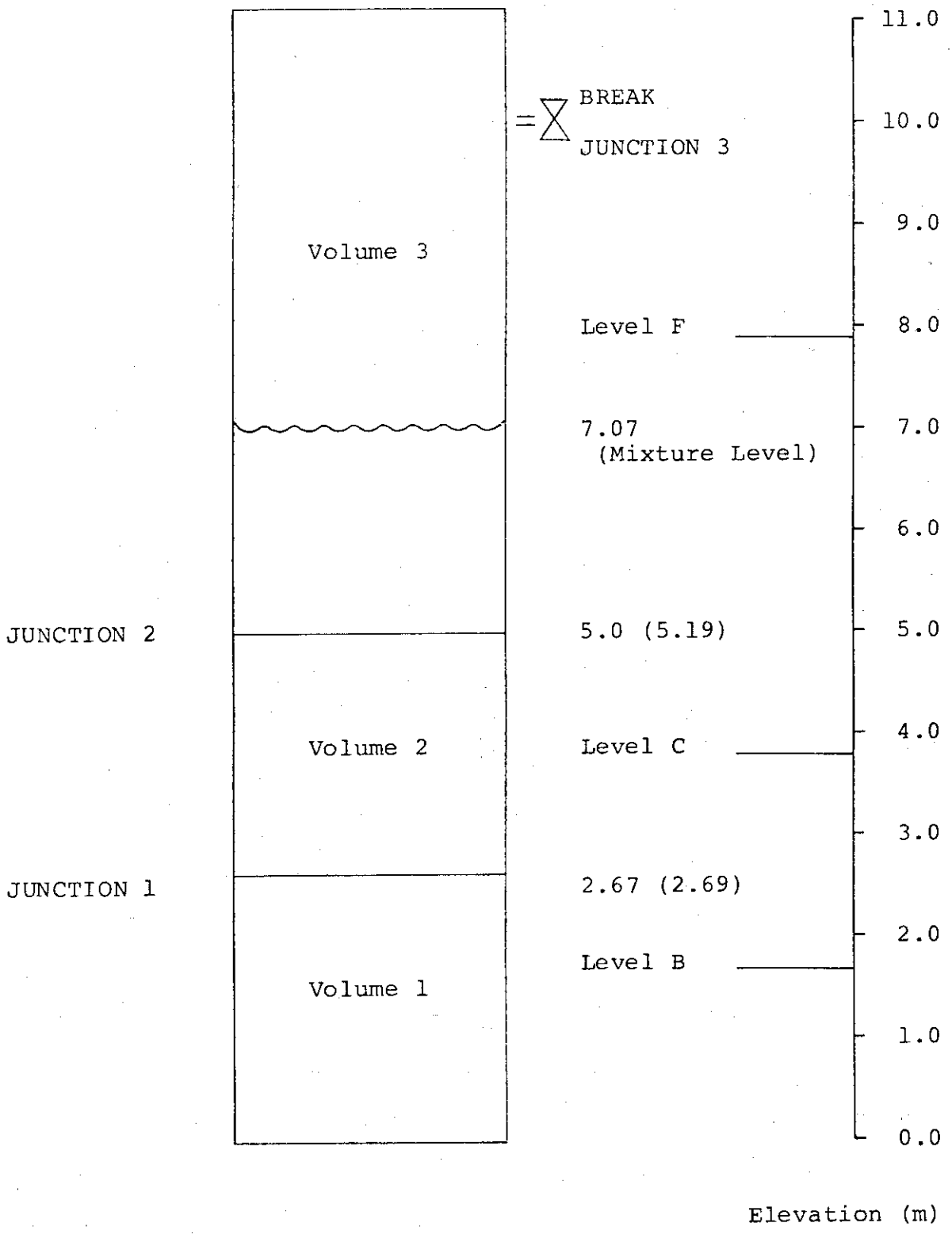


Fig. 4 Noding for ISP6

(Bracket stands for re-analysis data)

stacked control volumes, often provide some physically unrealistic results with regard to the water level. For instance, when this model was applied in volume 2 and 3, there is a mixture level in the two control volumes at the same time. Hence, such a model is only available to the top node.

The whole movement of the free surface between the vapor and two-phase mixture in the vessel was calculated as the sum of the transient mixture level in the volume 3 plus its elevation (5.0 m or 5.19 m).

As the present calculation was performed with a very simple noding method, the experimental measured data at the specified locations and the prediction may be consistent or not. It is difficult to obtain for the current ALARM-B1 three volume model all the required outputs related to the pressure and the temperature as a CSNI request.

When taking the results of neighboring positions, the calculational results correspond to the SWR-2R apparatus data at the following measurement positions.

PRESSURE GAUGE STATION	NODE	INITIAL CONDITIONS
PS170 BI000 (Level B)	VOLUME 1	72.369 (kg/m^2)
PS380 BI000 (Level C)	VOLUME 2	72.232 (kg/m^2)
PS780 BI180 (Level F)	VOLUME 3	72.205 (kg/m^2)
TEMPERATURE GAUGE STATION	NODE	INITIAL CONDITIONS
TS170 BI000 (Level B)	VOLUME 1	289 (°C) (282)*
TS380 BI000 (Level C)	VOLUME 2	sat. (284)*
TS780 BI180 (Level F)	VOLUME 3	sat.

Table 2 Relation between Calculated Modelling and Measured data

In the table, the pressure or temperature recorded by means of station PS170 BI000 or TS170 BI000 correspond to the predictions of the control volume 1. The mass flow rate within the vessel was initially assumed to be zero (stagnant). The liquid and vapor throughout the system were also assumed to be saturated and in equilibrium. Therefore, the non-equilibrium effect is impossible to be treated without further improvement of the current mathematical model of the ALARM-B1.

No heat transfer with the structures was taken into consideration, because the observed run time was short.

Time step sizes employed in the analysis are:

$t \leq 0.5$ (sec)	$\Delta t = 0.0001$ (sec)
$0.5 < t \leq 1.0$	$\Delta t = 0.0005$
$1.0 < t \leq 3.75$	$\Delta t = 0.001$

The principal focus in the calculation was exclusively placed on the rising rate of the interface between the steam and two-phase region, and the discharge flow rate through the exit duct, which were to some extent feasible to control by a few input parameters.

In this analysis submitted to CSNI Ad hoc group, a slight error about the geometry (elevation) was discovered. Moreover, the temperature distribution in the vessel was looked again. That is, the experimental temperature and pressure profiles showed that the liquid was initially subcooled below the water level. Hence, the temperature of the volume 1 and 2 was modified. And the volume 3 was assumed to be composed of the saturated water and vapor.

After the correction of input data, re-analysis was carried out right away on a FACOM 230-75 computer. Seeing the results, the deviation in the pressure data was somewhat reduced. Significant differences between the first and second case were not observed. Geometrical configuration modelled is as follows:

VOLUME DATA			
NO.	VOLUME (m^3)	HEIGHT (m)	ELEVATION (m)
1	1.2433 (1.2526)*	2.67 (2.69)*	0.0
2	0.5998 (0.6436)*	2.33 (2.50)*	2.67 (2.69)*
3	2.8801 (2.8016)*	6.185 (6.00)*	5.00 (5.19)*
JUNCTION DATA			
NO.	ELEVATION (m)	FLOW AREA(m^2)	
1	2.67 (2.69)*	0.2574	
2	5.00 (5.19)*	0.2574	
3	9.983 (9.96)*	0.003217	

Table 3 Control Volume and Junction Identification for ISP 6

* Numbers in bracket represent modified data used in re-analysis

5. Results and Discussions

By using the computer code ALARM-B1, are demonstrated herein the calculational results for the ISP6, including the comparisons with the Battelle experimental data. Several key parameters specified at NEA CSNI were also shown in Figs.5 to 25, compared with the measured values.

A listing of the ALARM-B1 input data described in the preceding chapter is given in Appendix 1 in MKS units.

Appendix 2 is input data of re-analysis. Appendix 3 exhibits the comparisons of the observed data with a wide variety of participants' predictions of the pressure and the temperature at the selected positions, of the mixture level in the vessel and of the mass flow rate in the discharge nozzle.[3] (see Figs.26 to 31) In these figures, the extent of deviations around the experimental values are shown for understanding the current status of predictions using the similar models as ALARM-B1. In addition, the contents of the calculational results and their modellings of participants in different countries are shown in the Tables 4 to 5, with an attention on the difference of computer simulation models.[3]

The computer run for the ALARM-B1 was terminated at 3.75 seconds. In order to present the calculational results pursuant to the predesignated formats, the plotter routine in the ALARM-B1 source program was partly modified as shown in Appendix 4.

Some short discussion of outputs and of problems encountered are given in this section.

5.1 Pressure history

The pressure transient following a guillotine steam line break was computed here.

Of particular interest in this sample problem, was the calculated pressure behavior compared with the measured one.

The ALARM-B1 theoretical prediction of the pressure was considerably higher than the Battelle-Frankfurt experimental values during the blowdown as shown in Figs.5 to 7. This experimental depressurization rate was initially large. From these figures, the pressure differential within the vessel is considered to be quite small.

In particular, the undershooting and recovery phenomenon over the first 0.50 seconds of the transient, which are due to a time delay of a steam bubble formation in the liquid portion, could not be accounted for by using the present equilibrium model.

Judging from this bubble delay behavior, it is likely that the fluid in the vessel was initially subcooled contrary to the problem conditions of saturation. On the other hand, the calculated pressure decreased at a slow pace under the saturated conditions. The transient behavior at the pressure vessel exit and interior is conceived as follows: A high temperature and high pressure fluid flow being expelled through the vessel duct, the resulting pressure falls off slowly along the saturation curve, provided that the system fluid temperature is saturated. In reality, this thermodynamical relationship of the temperature versus pressure is apt to be invalid temporarily at the very early period of the blowdown transient,

because the propagation speed of a pressure wave equivalent to a sonic velocity is faster than the phase change within the vessel.

At this time, the liquid in the vessel becomes super-saturated at the local region together with a sharp reduction of the pressure.

In succession, a steam bubble generation occurs producing the saturated water and vapor.

As a result , a metastable supersaturated state in the vessel disappears in a short time. As can be seen in the figures, a sudden decompression caused by such an initial subcooled flow regime lasts up to 0.3 seconds from the initiation of the accident, the resulting system pressure dropping below the saturation point because of a delayed bubble nucleation, i.e., a time retardation of saturated water flashing to steam.

The rate of depressurization gradually decreases by the expansion of the coolant. The departure from a supersaturated state to saturated — transition region — continued for 0.2 seconds in the figures. After recovering to the saturated point, the whole system pressure decreases smoothly with the saturation from that time on. The calculated results provide the predictions which the liquid-vapor mixture is on the saturation line, showing the gradual variations from beginning to end. The initial small oscillations result from the fluctuations through the medium. The slight increase in the pressure after reaching the two-phase mixture region was impossible to be predicted well.

Perhaps this is because the analysis models preclude the volume of the discharge nozzle. The distinguished difference

between the prediction and the experimental data becomes smaller with time and three seconds later the two is well-balanced.

In the post-case analyses, the calculational results got nearer to the measured data since the pressure drops faster than those in the previous test run.(See Figs.13 to 15) At several checkout calculations, the initial conditions with some subcoolings were given in the fluid of the volume 1 or 2 in order to approach the incipient depressurization rate in the experimental data. However, this attempt was ineffective enough to change the entire behaviors owing to the lack of the non-equilibrium model.

The pressure transient response was no different than the expected gradual change in the large. Unfortunately the first pressure drop and recovery could not be reproduced correctly.

The prediction seems to be scarcely influenced due to the change of the bubble parameters, showing that the increase in the bubble rise velocity accelerates slightly the pressure reduction at the two-phase mixture region.(See Fig.23) A useful correlation of predicting the bubble delay time will be necessary to present more exact pressure profiles in the early stages of decompression. As a few predictive methods, the experimental or theoretical formulas to compute a bubble growth is reported in the reference.[4][9][10][11]

For reference, the initial pressure gradient derived from the isentropic expansion of the vapor phase was determined from the following hand calculation. Namely, using the assumption of the adiabatic law

$$P\ v^k = P_o\ v_o^k = \text{constant} \quad ,$$

the initial decompression rate is calculated as follows:

By differentiating the above formula,

$$\dot{P}_o = - k \frac{P_o}{v_o} \dot{v}_o = - k \frac{P_o}{V_s}(\dot{V}_s)_o = - k P_o \left(\frac{W_s}{\rho_s V_s}\right)_o ,$$

The maximum flow rate through the duct is

$$W_s = \sqrt{\frac{k}{R}\left(\frac{1}{k+1}\right)^{\frac{k+1}{k-1}}} A \frac{P_o}{\sqrt{T_o}}$$

Hence, $$\dot{P}_o = - \frac{k}{V_s} \sqrt{\frac{k}{R}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \frac{A P_o^2}{\rho_s \sqrt{T_o}}$$

From the initial state data

$$\begin{cases} P_o = 72.0 \times 10^4 \ (kgf/m^2) \\ A = 3.217 \times 10^{-3} \ (m^2) \\ v_o = 0.0271 \ (m^3/kgm) \\ V_s = 2.88 \ (m^3) \\ k = 1.4 \end{cases}$$

$$\dot{P}_o = - k \sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \frac{A P_o}{(V_s)_o} \sqrt{\frac{P_o}{v_o}} \quad \text{(from ideal gas equation)}$$

$$= - 1.4 \sqrt{1.4 \left(\frac{2}{2.4}\right)^{\frac{2.4}{0.4}}} \frac{A P_o}{(V_s)_o} \sqrt{\frac{P_o}{v_o}}$$

$$= - 1.4 \sqrt{1.4 \cdot 9.8 \left(\frac{2}{2.4}\right)^6} \frac{A P_o}{(V_s)_o} \sqrt{\frac{P_o}{v_o}}$$

$$= - 3.0096 \cdot \frac{72 \cdot 10^4 \cdot 3.217 \cdot 10^{-3}}{2.88} \sqrt{\frac{72 \cdot 10^4}{0.0271}}$$

$$= - 33.7 \ (kgf/m^2 \cdot sec)$$

On the other hand, the experimental pressure gradient is

$$-(72-67)/0.15 = -33.3 \text{ bar} = -34 \ (\text{kgf/m}^2 \cdot \text{sec})$$

A comparison of the values between the two is in the excellent concurrence.

NOMENCLATURE : P = pressure
T = temperature
v = specific volume
k = ratio of specific heats
V = volume
A = flow area at duct exit
R = universal gas constant
W = mass flow rate

Subscript "O" and "S" mean the initial time and steam space, respectively. Dot means differential with respect to time.

5.2 Temperature history

The fluid temperature profiles were relatively fair between the calculated and measured values, although the former is about 6~7 °C higher than the latter at the initial stages.(see Figs.8 to 10) This small discrepancy might be caused by the inconsistency of the reported experimental conditions. The experimental was certainly below the saturation temperature during the first 0.50 seconds. Due to some subcooling in the liquid portion, it resulted in a rapid decrease in the pressure as already stated.

The temperature recovers to the saturation point 0.50 seconds later, then remaining there. On the other hand, the calculated temperature was saturated throughout the blowdown.

Since the initial temperature distributions have possessed the uncertainty considerably, more exact temperature profiles should be given as the recommendation to this experiment.

Re-calculations had bettered the temperature more or less except in node 3.(see Figs.16 to 18)

5.3 Liquid level history

The rise of the interface between the initial steam and the saturated two-phase mixture was predicted in Fig.11.

As already indicated in the pressure behaviors, an identical difference attributable to the thermo-dynamical non-equilibrium feature was also observed with reference to this parameter. It is obvious that the experimentally measured water level in the vessel during the early time of the blowdown transient did not significantly swell owing to the evaporation delay and incompressibility. From this fact, it was confirmed that the water level rising and pressure recovery are so closely linked. After about 0.3 seconds, the steam-water mixture level increases almost linearly from the initial 7.07 m together with growth of steam bubbles. The rising velocity of the calculated liquid level is 1.133 (m/sec) while the one of the measured exihits 1.344 (m/sec). At 2.55 seconds the calculated water level reaches the height of the discharge line.

A slip ratio between the phase, which is not incorporated in the ALARM-B1 homogeneous model, (slip ratio is 1.0 due to equal fluid velocity) would exert influence on the water level in the transient like a bubble-rise velocity.

In the experimental data, it is noted that there was a

small discrepancy between the time (about 2.5 seconds) when the mixture front reaches the outlet nozzle (G) and the time (about 2.2 seconds) when the effluent flow increases abruptly.

The latter is slightly fast compared with the former. It is presumably due to the fact that entrained droplet was present above the free surface and that liquid flowed through the blow-down nozzle.

The calculational model in ALARM-B1 does not treat such entrainment phenomena, therefore there was no significant difference between these prediction times in contrast with observed in the experimental data. That is, an increase in the liquid level to the height of the discharge line coincides with a step change in the mass flow rate. The saturated mixture in ALARM-B1 predictions begins to carry over into the steam line inlet at 2.55 seconds. The calculation of the liquid level in the control volume strongly depends on the bubble rise parameters given by constant input data during the blowdown.(See Fig.24)

In practice, a bubble rising in the vessel would be affected by the degree of some subcoolings and the amount or location of subcooled water. Thus, the selection of bubble parameters was difficult and determined by rule of thumb criteria derived from the previous experience.[7][11][13]

Aside from this analytical method, for instance, the Wilson's model representing the bubble velocity as a function of mixture void fraction would help handling more exact bubbling phenomena.[12]

In general, a higher bubble rise velocity results in the lower liquid level swelling. The reason is; By the increase of this velocity or slip ratio, steam bubbles in the liquid

becomes low. Hence, the expansion of the mixture, i.e., flooding rate is suppressed down. Since the calculation was initiated at the saturation condition, flashing occurs immediately in the vessel. Accordingly, it reduces to an instantaneous rising in the mixture level as well as a slower continuous decrease in the pressure. In this way void formation due to flashing is the only contribution to water level rise. Throughout some check runs, an optimum bubble rise velocity was 3 ft.(Fig.19, Fig.24)

Additionally it should be noted that the water level also depends on even the Moody's coefficient, which was set to 0.75 at the current analyses. When adopting a small discharge factor, a lower decompression rate results in a reduced rate of flashing within the vessel and a reduced rate of level rising.

5.4 Discharge mass flow rate history

A discharge flow transient was divided into three phases: the vapor flow, the transition from the vapor to saturated two-phase mixture flow and the subsequent mixture flow.

As illustrated in Fig.12, a comparison of the predicted effluent flow rate and the experimentally measured data at the exit duct is quite good through the transient within the 10~15 % instrument error bands, except for the first short period of the blowdown (0~0.05 seconds) and for the two-phase mixture region. The non-equilibrium effect was not, in fact, identified in the behavior of the discharge flow. The calculated result with a Moody's contraction coefficient of 0.75 was in excellent agreement with the observed value.

Immediately after the rupture, the steam flow rate increases

to the maximum value permitted by choking at the outlet junction. This break has made a large pressure drop across the outlet because of the high vapor flow rate. The ALARM-B1 was not capable of predicting the first peak (about 36~7 kg/sec) shown in the experimental curve.

Through the orifice, the steam discharge lasts till 2.55 seconds, thereafter carry-overed two-phase mixture flow does.

When the water level increases to as far as the elevation of the discharge nozzle G, the blowdown flow rate ascends suddenly due to the transition from the vapor to the steam-water mixture. This change invides a reduction of the flow quality at the exit plane.(see Fig.21) By outflowing of the steam flow, a moisture begins to carry-over into the steam dome.

The transition from the steam to mixture gives a step change in the ALARM-B1 model. On the other hand, this characteristic in the experimental occurs over a period of approximately 0.2 seconds.

A marked discrepancy between the two does result from the inability of this code to simulate the entrainment phenomenon. This change from the steam to the mixture flow has a slight effect of reducing the vessel depressurization rate as reflected by the small variation in slope of Fig.7.

During the discharge of the mixture flow, a peculiar behavior in the ALARM-B1 is due to the partial presence of a bubbly-flow produced by a decompression in the intervals of steam-water mixture flow. Transient two-phase flow predicts as if its flow pattern is of slug flow. As shown in the outflowing of the mixture, the amount of effluent two-phase flow agrees

with that of the measured on the average.

Fig.22 shows the mass inventory transient in the vessel. As already stated, lower bubble rise velocity results in smaller mass hold up.

The post calculations almost agrees with the first one. When the bubble-slope parameter decreases, the resulting two-phase discharge flow increased.(see Fig.25)

6. Summary

The Standard Problem NO.6 based on a high pressure and a high enthalpy blowdown test SWR-2R was analyzed by the ALARM-B1 code.

Comparative studies were made with the theory and experimental data. The predictions indicated that homogeneous equilibrium models applied to the initial fluid behavior in the vessel were inadequate to explain the measured pressure or liquid level.

However, by and large, this test runs to make certain the analytical models of the ALARM-B1 were apparently successful with a few exceptional behaviors arising from the non-equilibrium. Namely, the current calculational work was useful for the purpose of checking the program and obtaining more experiences for its use. The measured rapid depressurization, consequent recovery and delayed liquid level rise appear to be associated with the thermal non-equilibrium effects accompanied by the bubble-nucleation delay.

These parameters showed relatively poor agreements between the calculational and measured values. The large pressure waves occurred in the early stages of the blowdown might cause a damage to the pressure vessel owing to the great thrust force. Accordingly, the prediction of such pressure waves seems to be important to the safety assessement of the plant in some cases.

In the present analysis, the initial temperature distribution is especially important because the transient system states, thereby, were determined. In the experiment, there were inconsistent differences between the reported initial temperature

distribution in the vessel and the experimentally measured temperature distribution. Probably, the desired temperature could not have established in the beginning. Full detailed temperature characteristics should be given. To minimize the deviations between the predictions and the experimental results, the adjustable parameters to approach the measured data were only limited to the bubble slope data and the discharge coefficient.

From the parameter studies performed, the water level rise was greatly influenced by the variations in the bubble rise velocity.

An increase in the value of this parameter caused a delay in the liquid level swelling. An increase in the bubble density gradient caused a decrease in the maximum value of the discharge mass flow.

On checking the experimental results, new aspects such as the liquid superheat, bubble nucleation delay or the relaxation time proved to be necessary to trace the phenomenon more realistically.

Nevertheless the first part of system behavior with the principal attention on non-equilibrium might be, in a sense, unnecessary to concentrate more energies from the standpoint of the long term blowdown analysis, because the system performance for the saturation blowdown calculations was adequate in the large by using the current equilibrium code. In that case, needless to say, it is of vital importance to keep in mind the assumptions or the limitations lying behind its use.

Speaking of time step sizes used, they did not lead to numerical instability throughout this calculation.

7. Concluding Remarks

On the whole, the comparison of the theoretical predictions and the measured data for the ISP6 did not show the satisfactory agreements. The main differences would be attributable to the deficiency of the non-equilibrium model in the computer code. The following conclusions can be drawn from this verification run.

(1) The discharge flow model in the ALARM-B1 was reasonably good compared with the measured data. The Moody's model for this critical flow with a contraction coefficient of 0.75 was sufficient in the steam region of the transient, but predicted a bit highly in the two-phase mixture flow region.

(2) The use of a bubble-rise model to predict the swelling of the liquid level was tracked adequately within the capability of the equilibrium code. Although the measured gradient was somewhat steeper than the computed one, the agreement related to the time reaching the top nozzle is considered to be good. An introduction of the bubble growth mechanism within the vessel would play a central role in the analysis of the non-equilibrium phenomenon.

(3) A rapid decompression history attributed to the non-equilibrium properties could not be reproduced well. It shows that the saturated two-phase fluid assumed in the vessel was not, in fact, initially at the equilibrium due to the local subcooled liquid portion. Starting with the saturation in the ALARM-B1 analysis, did produce a slow continuous decrease in the pressure. As well, the consequent recovery was not predicted within restrictions in

this code.

As concluded, it might be highly expected that further examinations of the analytical models such as non-equilibrium phase change, entrainment, slip velocity, or bubble growth mechanism would contribute to give better results.

Acknowledgement

Much appreciation is expressed to Mr. K. Sato, the chief of Reactor Safety Code Development Laboratory, and to Mr. M. Akimoto for their useful suggestions in writing this paper.

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Table 5 Important Features of Simulation Models Using Equilibrium Codes

Country	Australia	Germany	Italy	Italy		Japan
Code	NAIAD (with vessel model)	BRUCH-S	RELAP-UK	RELAP4/MOD5 *		ALARM1-B1
discharge model	HEM	Moody		Moody	Moody	Moody
discharge coefficient	contraction pressure loss coefficient $\frac{fL}{D} = 0.1$	1.0	1.0	0.7	0.7	0.75
number of nodes (liquid/steam/discharge nozzle)	$\frac{1}{2}$ / $\frac{1}{2}$ / 11	$7\frac{1}{2}$ / $\frac{1}{2}$ / 0	6	1/1/0	4/1/0	$2\frac{1}{2}$ / $\frac{1}{2}$ / 0
bubble rise velocity ($\frac{m}{s}$)	0.9	according to Wilson, up to 0.9	0.91	0.15	0.03	1.22
bubble rise gradient parameter	0	quality gradient 3	0.8	0	0.7	2.0
slip	no	no	yes		yes	
number of heat slabs		none		-		
initial liquid subcooling; maximum temperature difference (K)	yes, 2.2	no		no	yes, 4.4	
time step size Δt(sec)	$1 \cdot 10^{-4}$-$1 \cdot 10^{-2}$	varying, $5 \cdot 10^{-1}$-3 10^{-2}		$0 \leq t \leq 0.5 : 0.0001 \leq \Delta t \leq 0.01$ $0.5 \leq t \leq 3.0 : 0.0005 \leq \Delta t \leq 0.05$		$0 \leq t \leq 0.5 \Delta t = 0.0001$ $0.5 \leq t \leq 1.0 \Delta t = 0.0005$ $1.0 \leq t \leq 3.0 \Delta t = 0.001$

f = Fanning friction factor
t = problem time (sec)
D = diameter
L = length

* calculations submitted after deadline to the workshop on CSNI Standard Problems at Carching, April 11-14, 1978

Table 5 (cont.): Important, features of simulation models using equilibrium codes

Country	Sweden	Switzerland		United Kingdom	United Kingdom	United States	France
Code	RELAP4/MOD3 (95) (with liquid cevel modifica-tion)	RELAP4/MOD2	RELAP4/MOD5**	RELAP-UK MKIII	RELAP4/MOD3 (WREM)	RELAR4/MOD5(2)	RELAP4/MOD5
discharge model			HEM	MEM	Moody	HEM	Moody
discharge coefficient		1.0	0.7	0.7	1.0	0.67	0.8
number of nodes (liquid/ steam/discharge nozzle)	4/1/0	6/1/0	6/1/0	$\frac{1}{2}$ / $\frac{1}{2}$ / 1	4/1/1	6/2/1	5/1/0
bubble rise velocity ($\frac{m}{s}$)	0.91	0.91	0.15	0	0.91	0.15	0.30
bubble rise gradient parameter	1.0	0.8	0.0	0	0.8	0	0.8
slip		no	no			yes	yes
number of heat slabs					5	none	none
initial liquid subcooling maximum temperature difference (K)	yes, 6.7		yes, 3.0			yes, 6.8	
time step size Δt(sec)	$0 \leq t \leq 0.05$: $\Delta t = 0.00068$ $0.05 \leq t \leq 0.5$: $\Delta t = 0.00197$ $0.5 \leq t \leq 3.0$: $\Delta t = 0.0098$	$0 \leq t \leq 0.04$: $10^{-3} > \Delta t > 10^{-4}$ $0.04 < L \leq 1.6$: $10^{-2} > \Delta t > 10^{-3}$ $1.6 \leq t \leq 3.0$: $10^{-2} > \Delta t > 10^{-4}$			$0 \leq t \leq 0.5$: $0.01 > \Delta t > 0.0001$ $0.5 \leq t \leq 3.0$: $0.05 > \Delta t > 0.0005$	$0 \leq t \leq 0.5$: $\Delta t \leq 0.005$ $0.5 \leq t \leq 2.1$: $\Delta t \leq 0.001$ $2.1 \leq t \leq 2.6$: $\Delta t \leq 0.01$ $2.6 \leq t \leq 5.0$: $\Delta t \leq 0.0005$	$t \leq 0.1$: $0.0001 \leq \Delta t \leq 0.001$ $0.1 < t < 4$: $0.001 < \Delta t < 0.005$

t = problem time (sec)

* calculations submitted after deadline to the workshop on CSNI LOCA Standard Problems at Carching, April 11-14, 1978

** post calculation

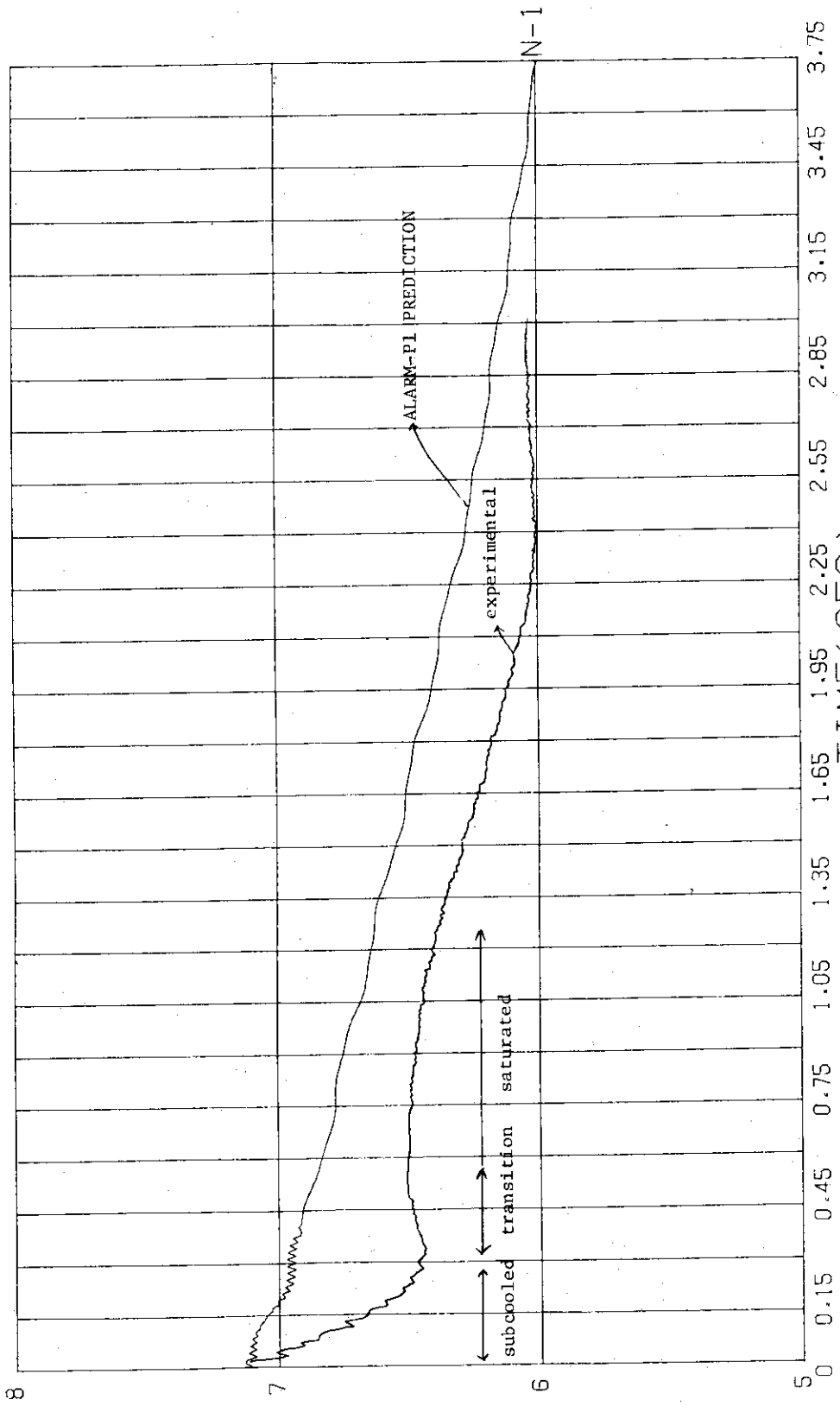

Fig. 5 Pressure in the Vessel at Level B

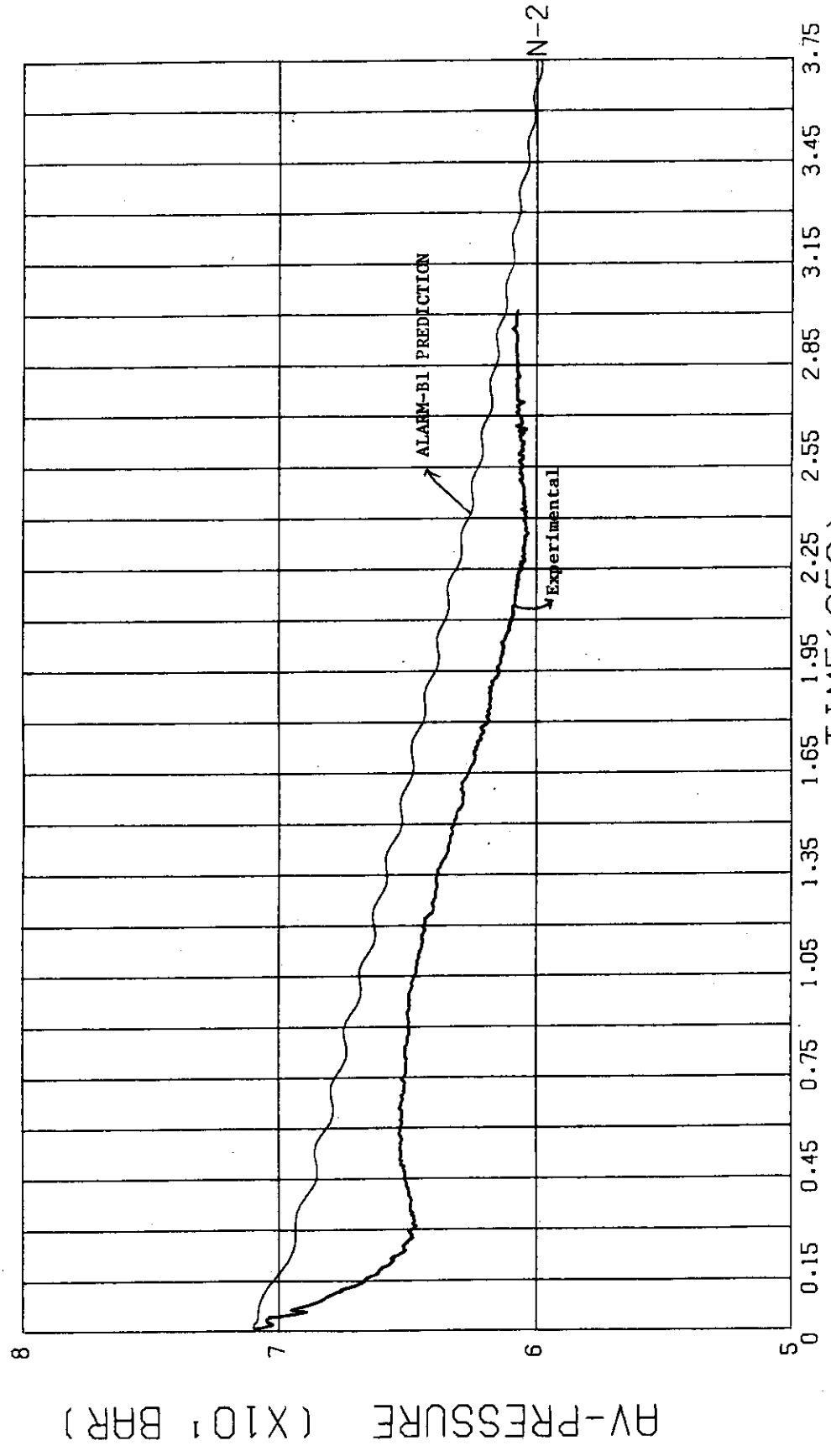

Fig. 6 Pressure in the Vessel at Level C

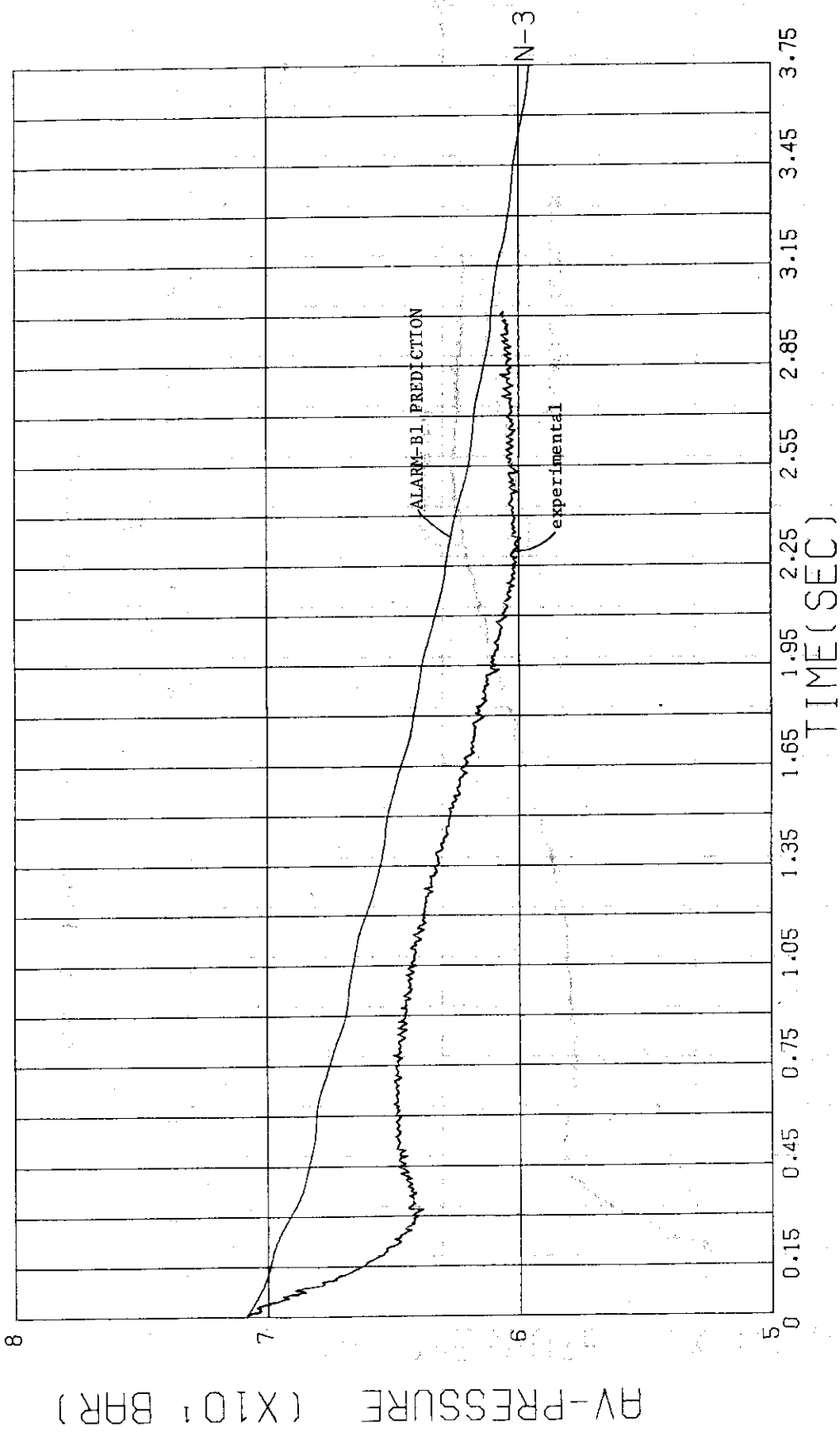

Fig. 7 Pressure in the Vessel at Level F

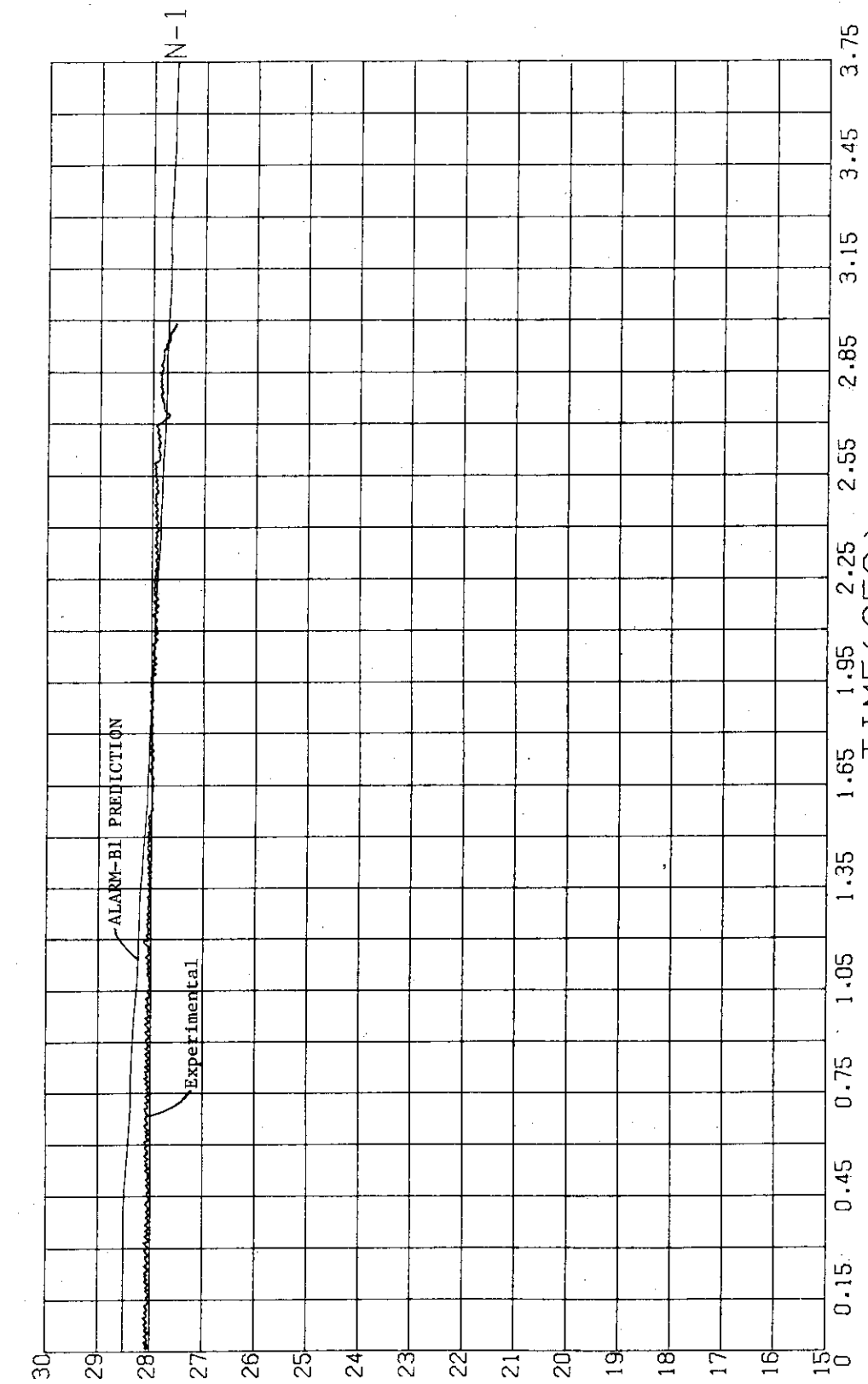

Fig. 8 Temperature in the Vessel at Level B

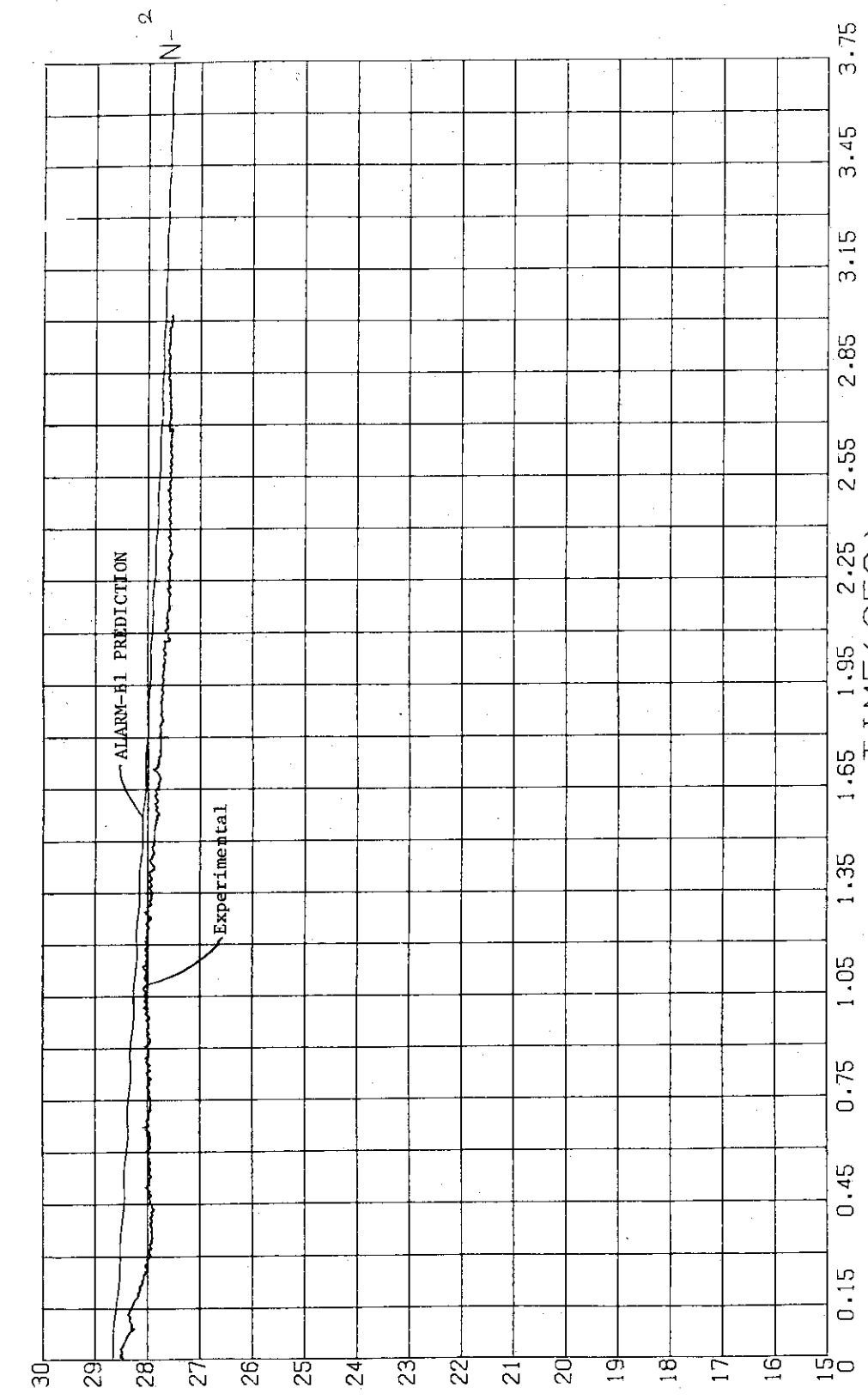

Fig. 9 Temperature in the Vessel at Level C

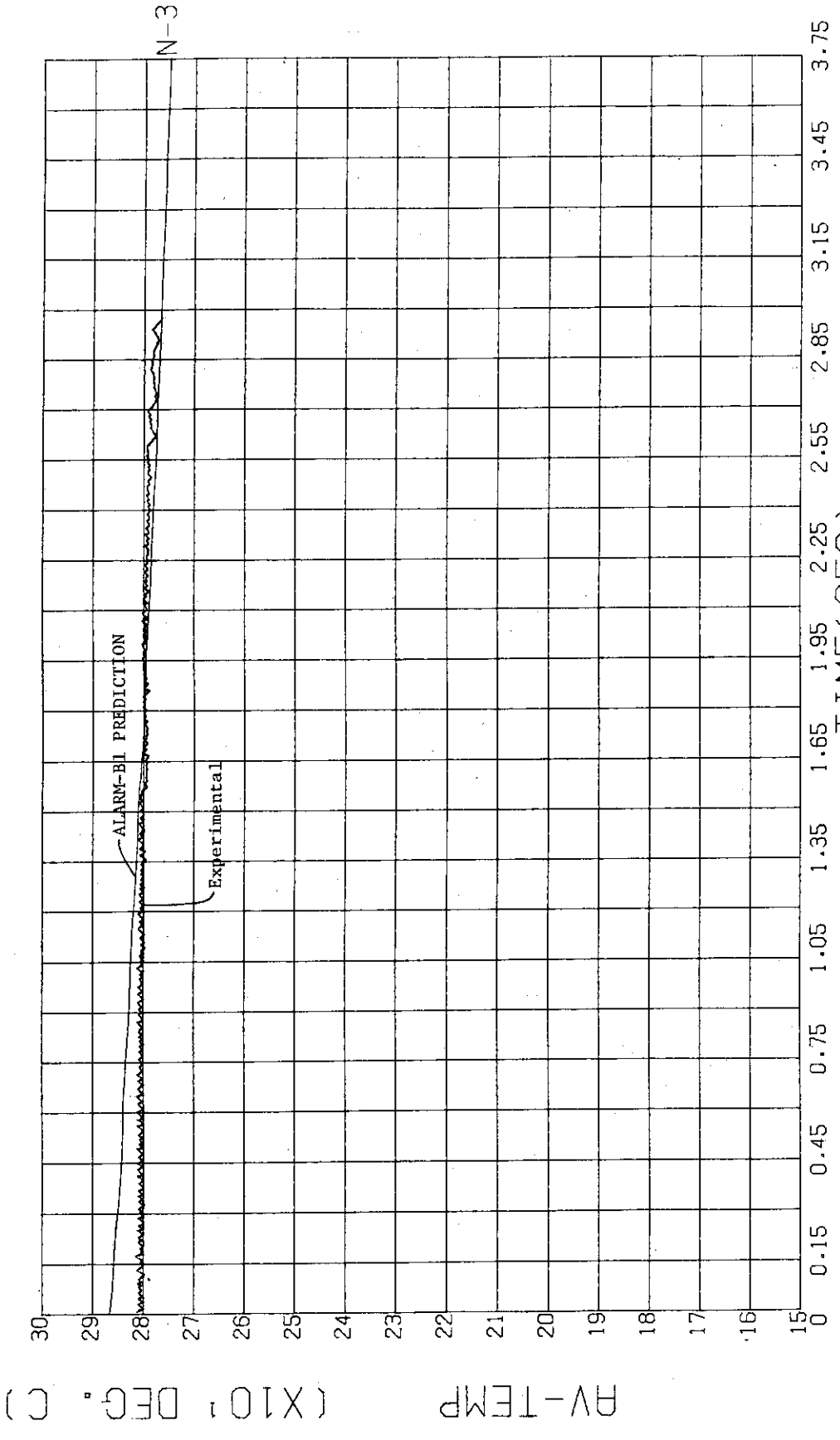

Fig.10 Temperature in the Vessel at Level F

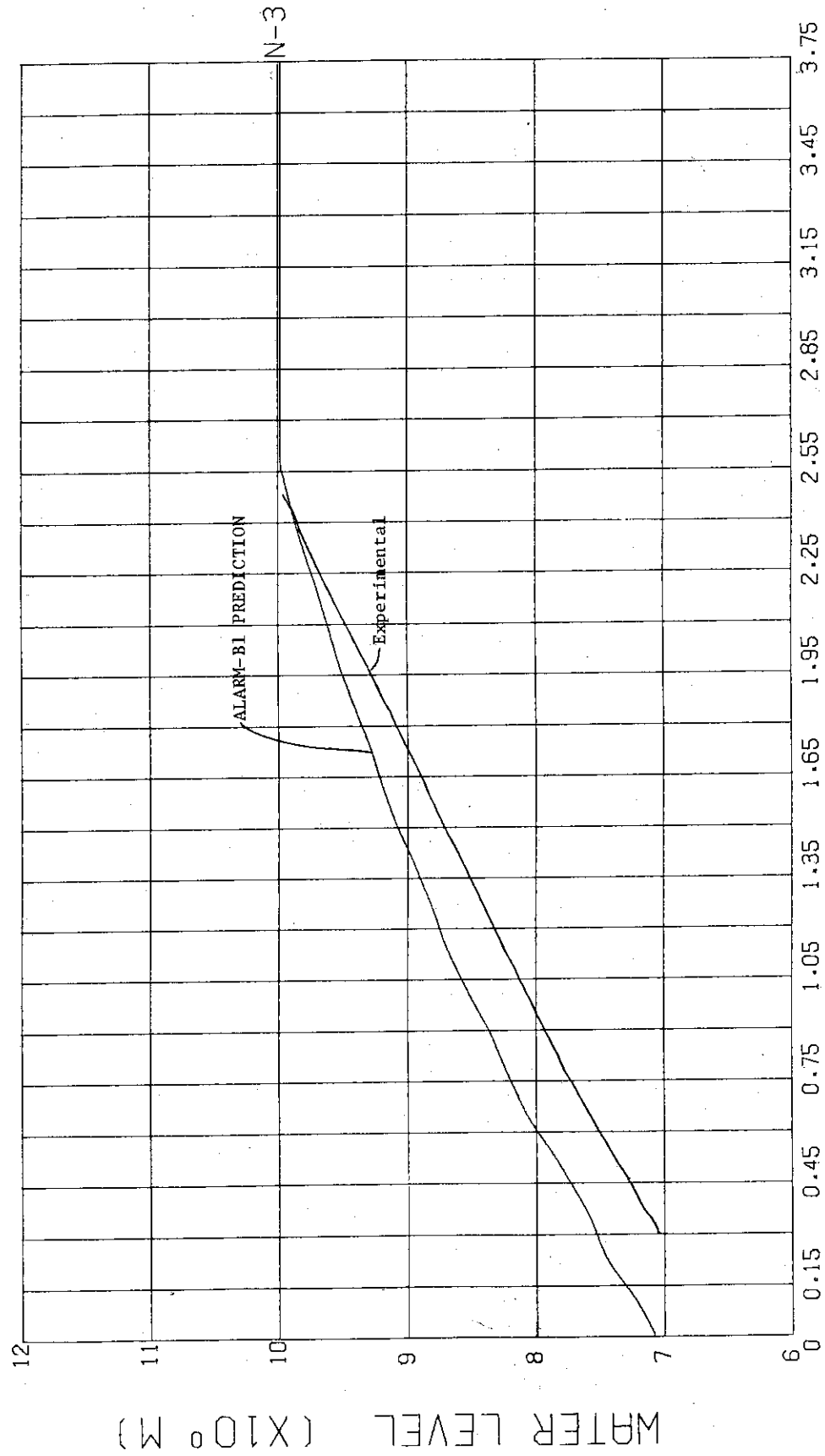

Fig.11 Liquid Level in the Vessel

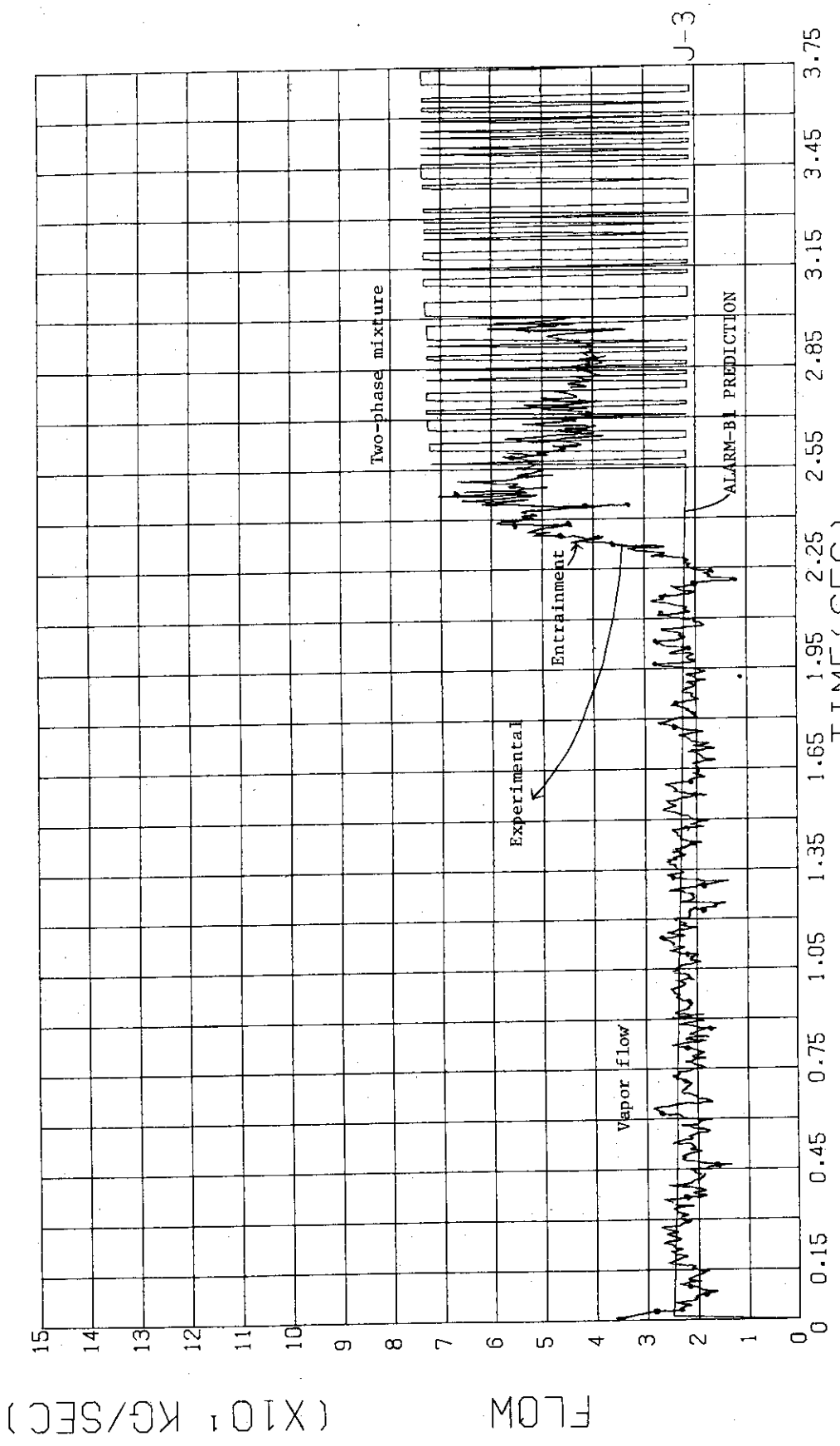

Fig.12 Discharge Mass Flow Rate

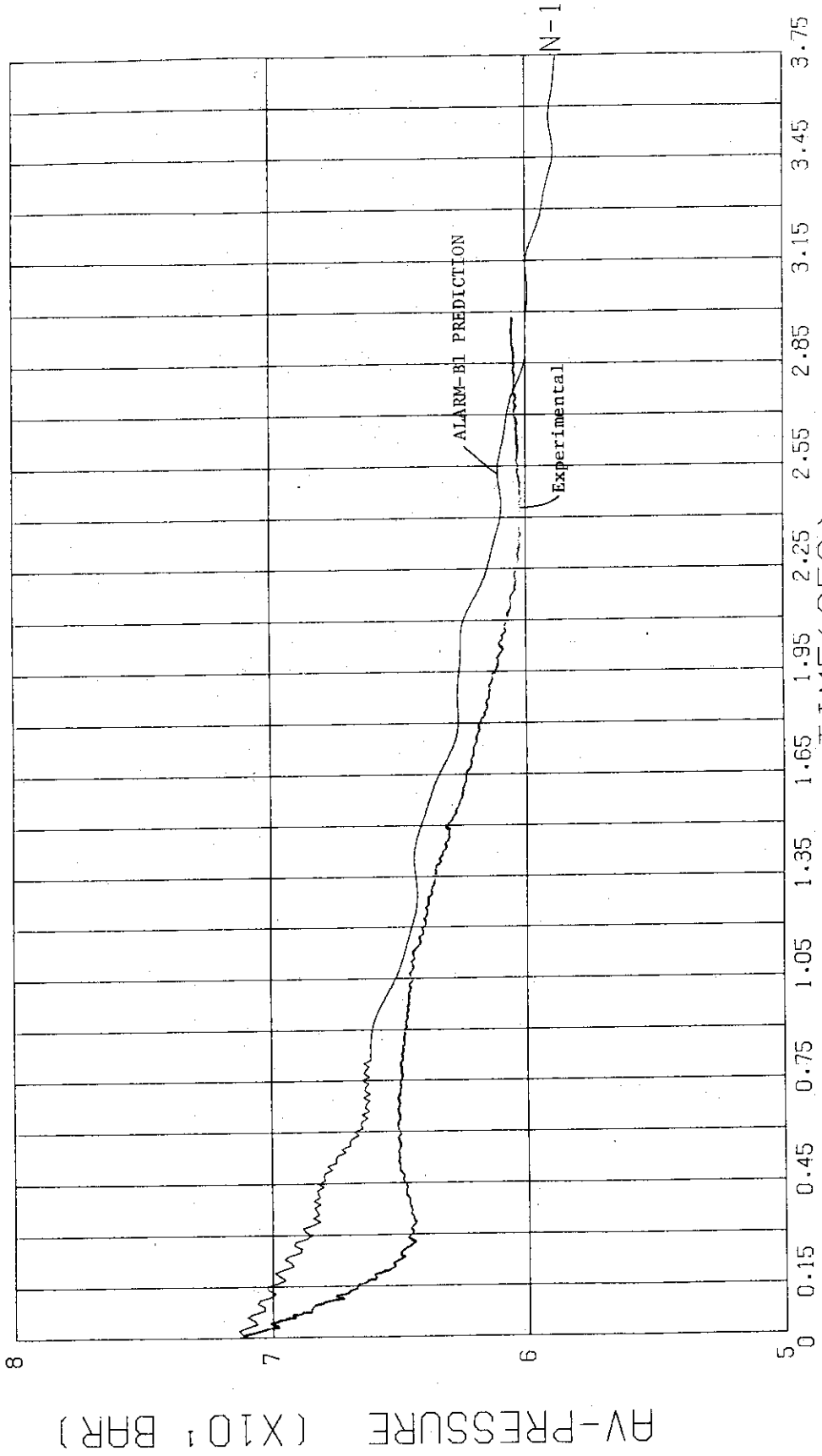

Fig.13 Pressure in the Vessel at Level B (Re-analysis)

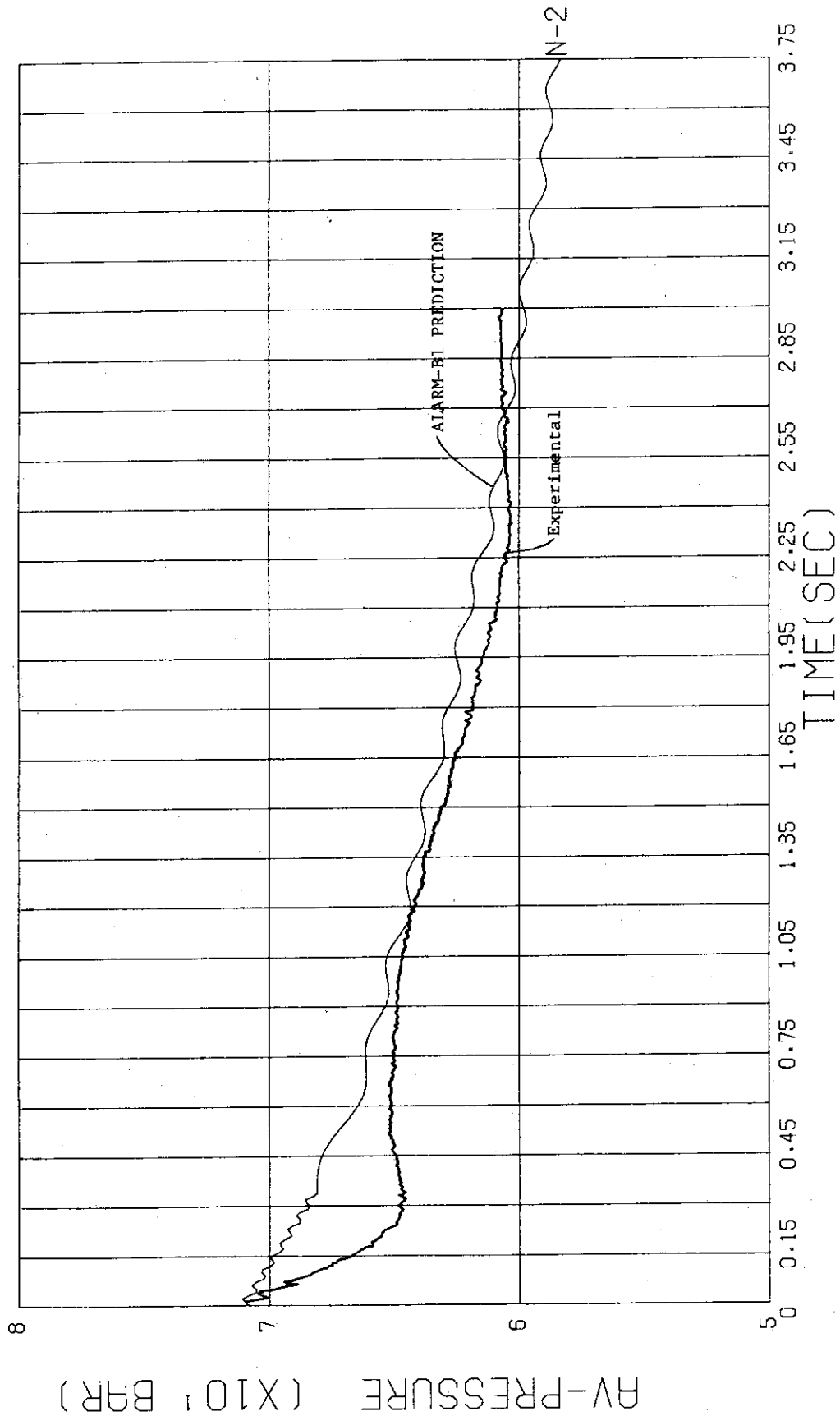

Fig.14 Pressure in the Vessel at Level C (Re-analysis)

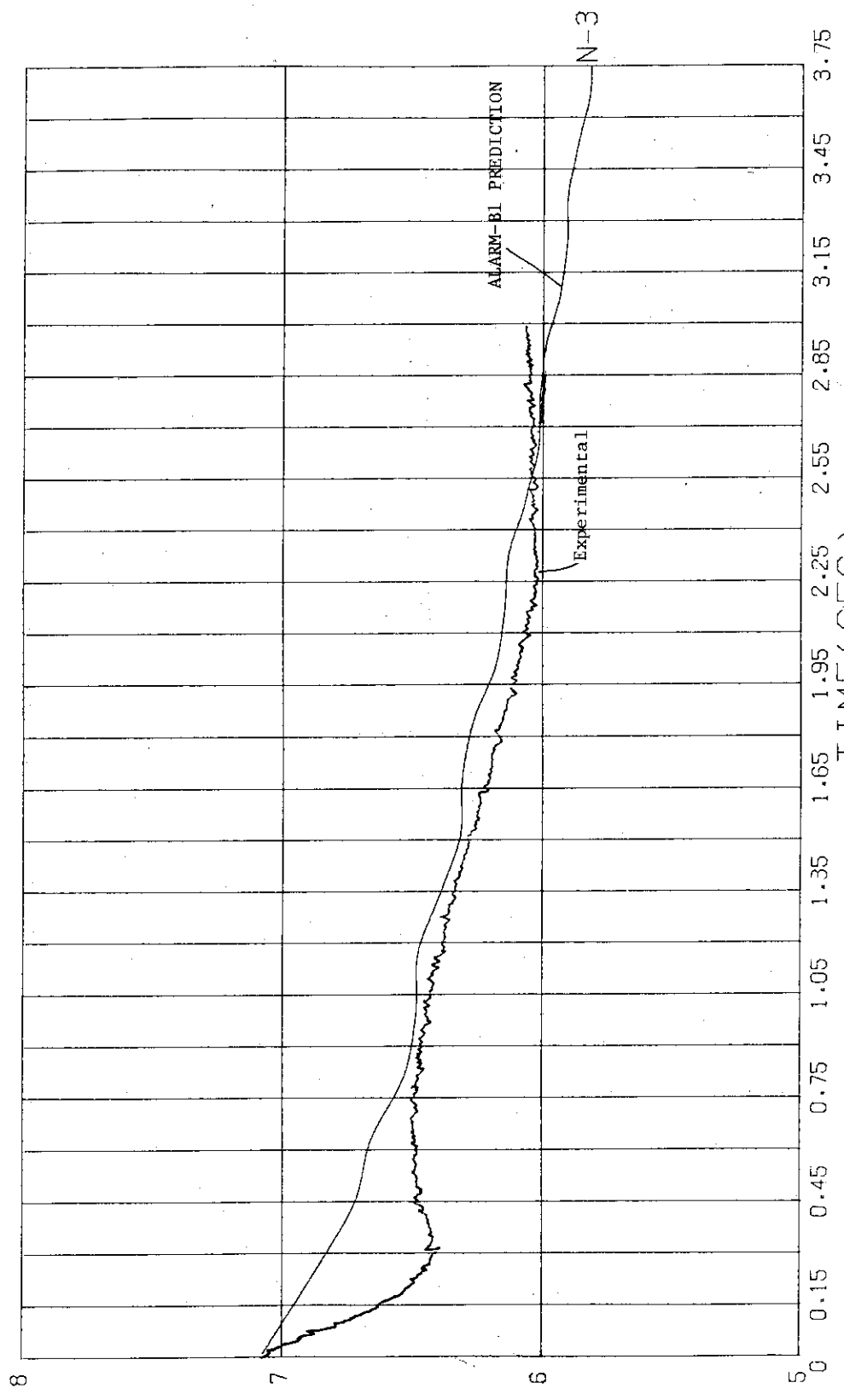

Fig.15 Pressure in the Vessel at Level F (Re-analysis)

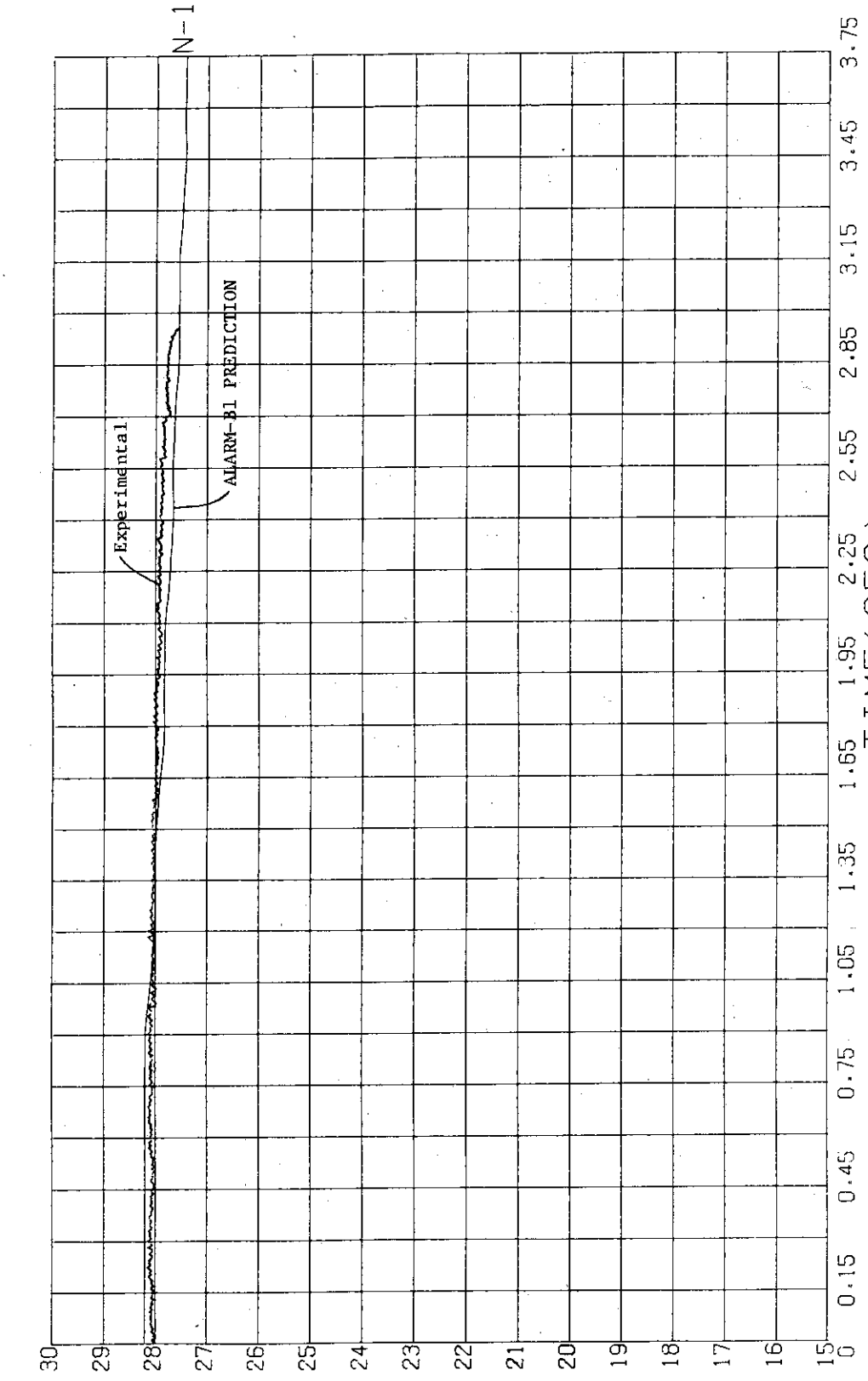

Fig.16 Temperature in the Vessel at Level B (Re-analysis)

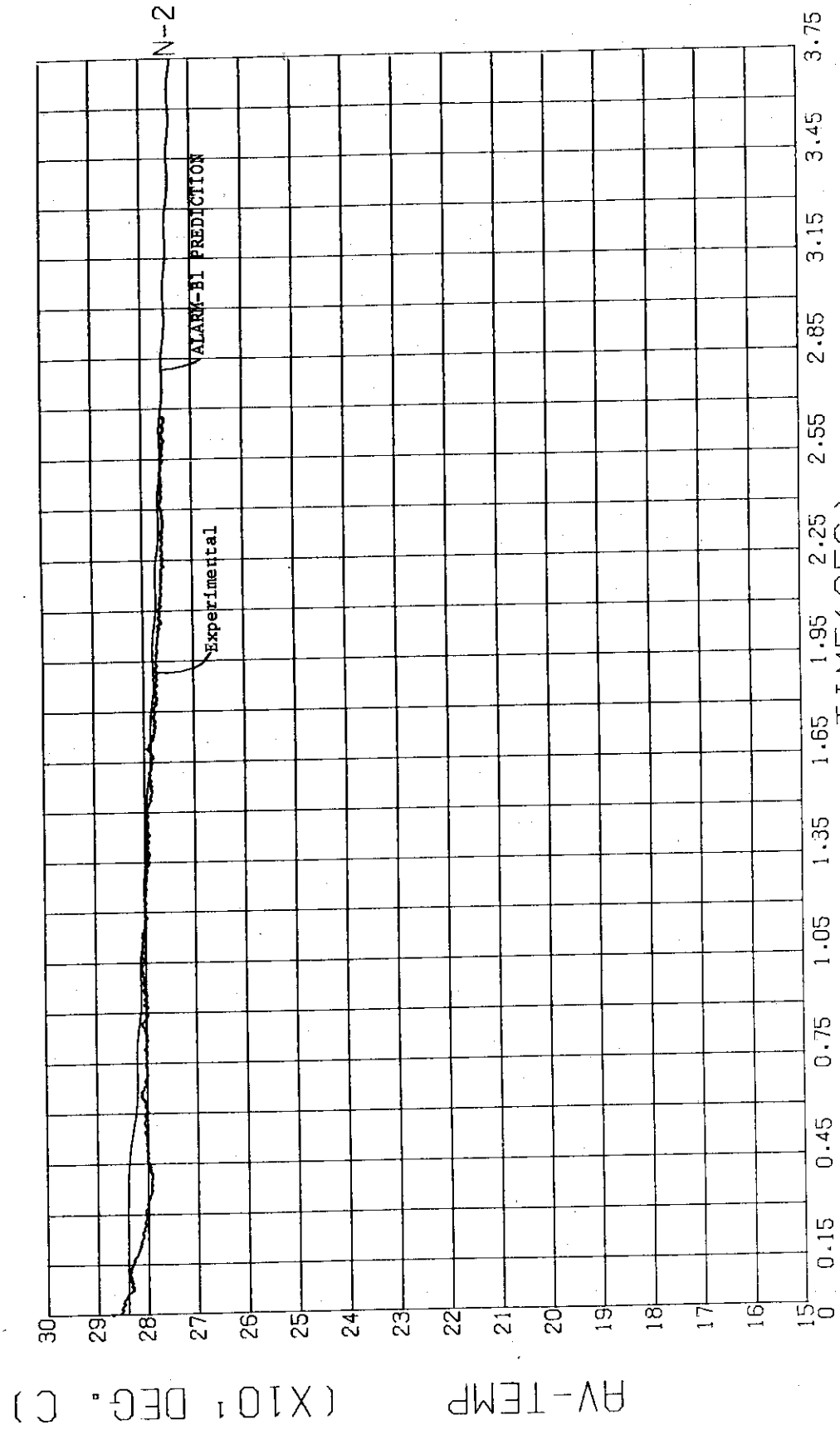

Fig.17 Temperature in the Vessel at Level C (Re-analysis)

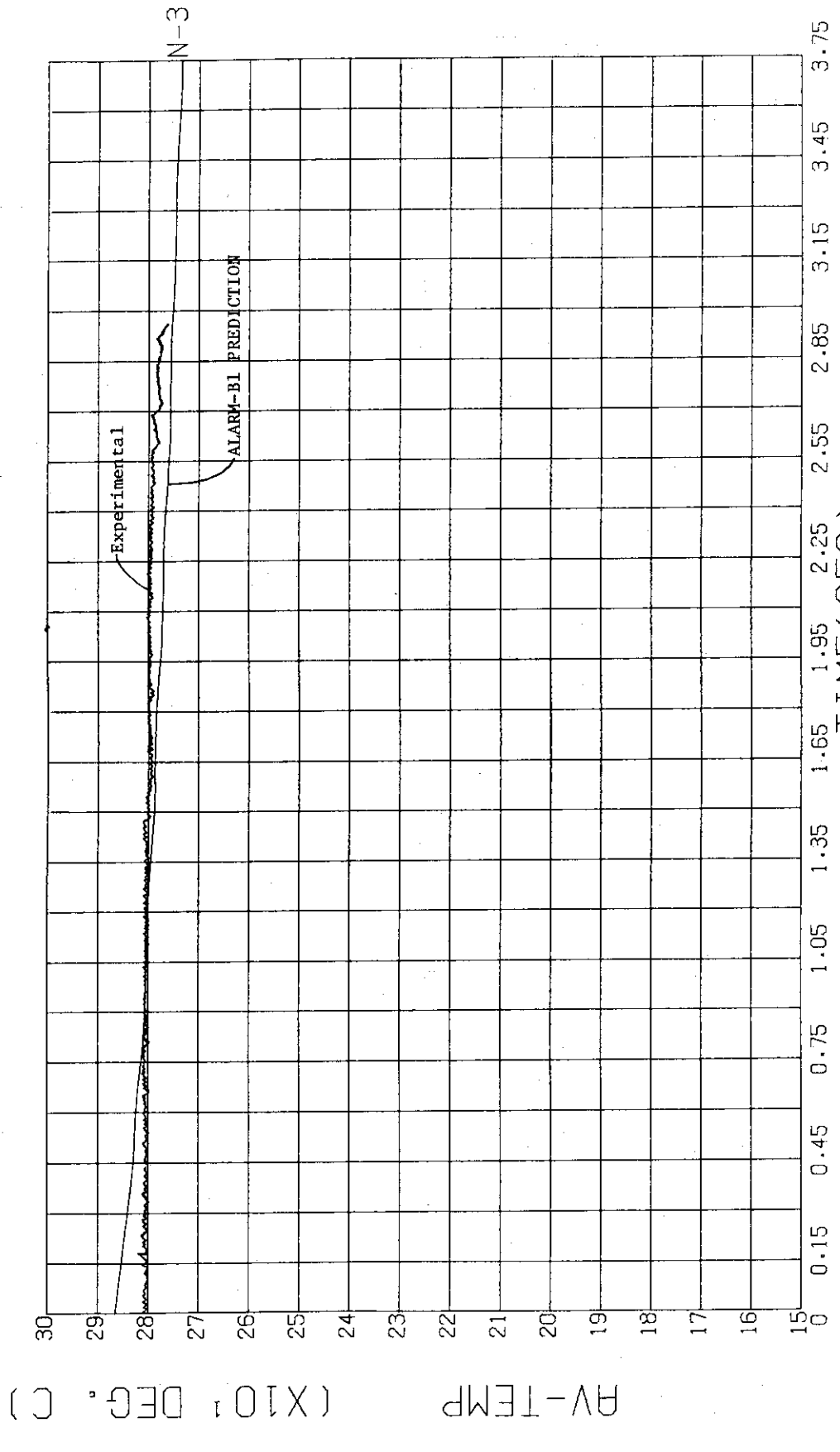

Fig.18 Temperature in the Vessel at Level F (Re-analysis)

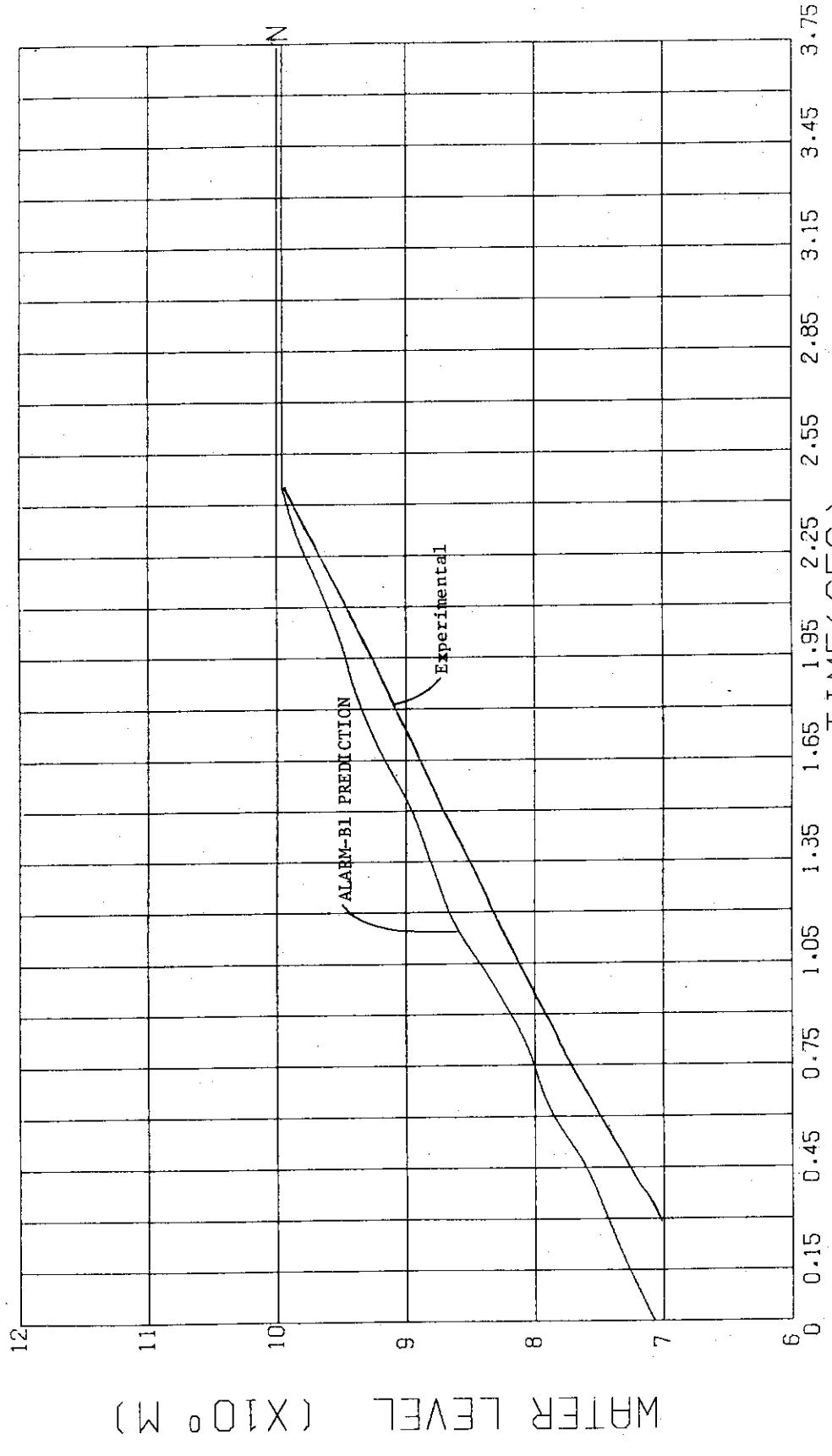

Fig.19 Liquid Level in the Vessel (Re-analysis)

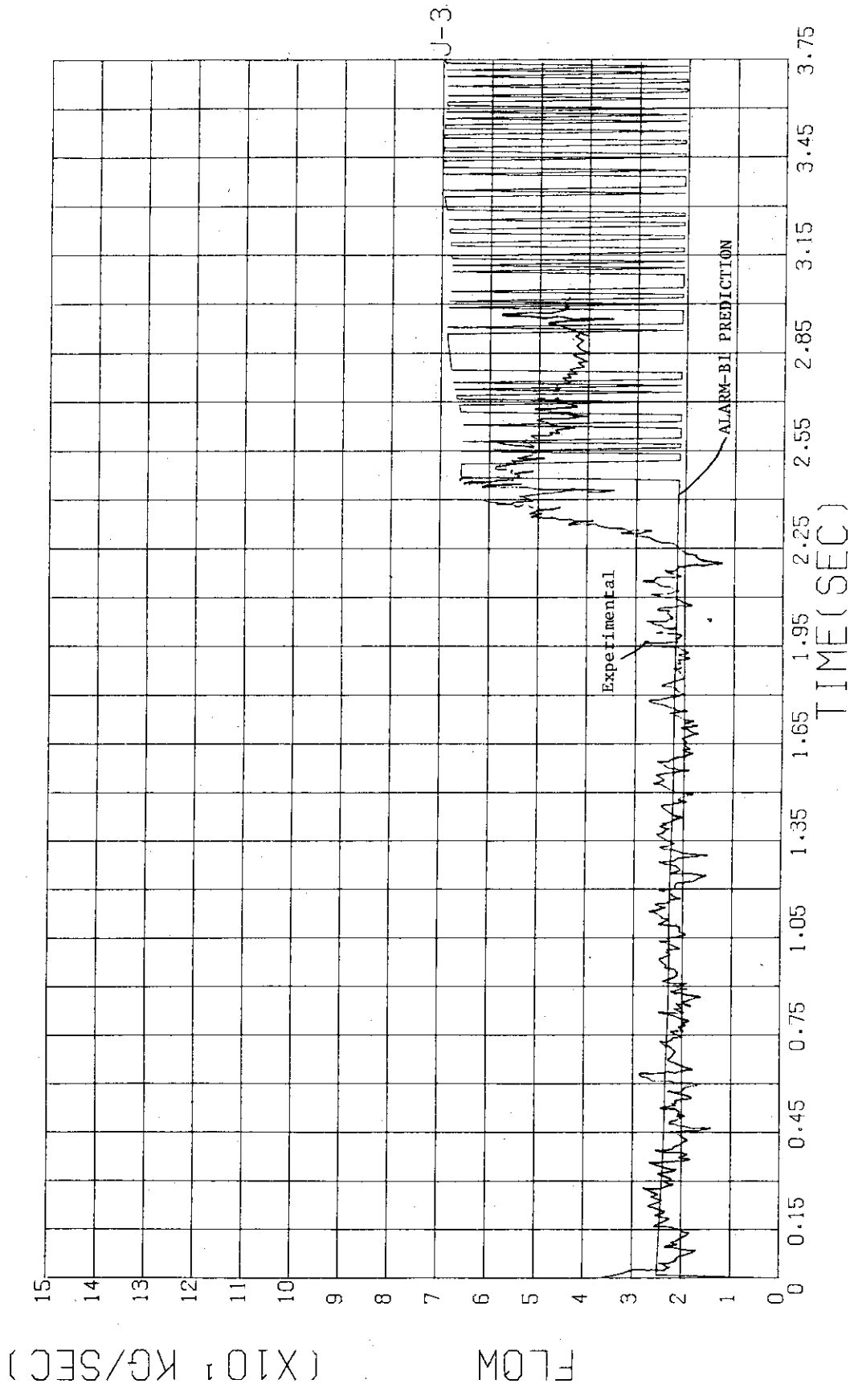

Fig.20 Discharge Mass Flow Rate (Re-analysis)

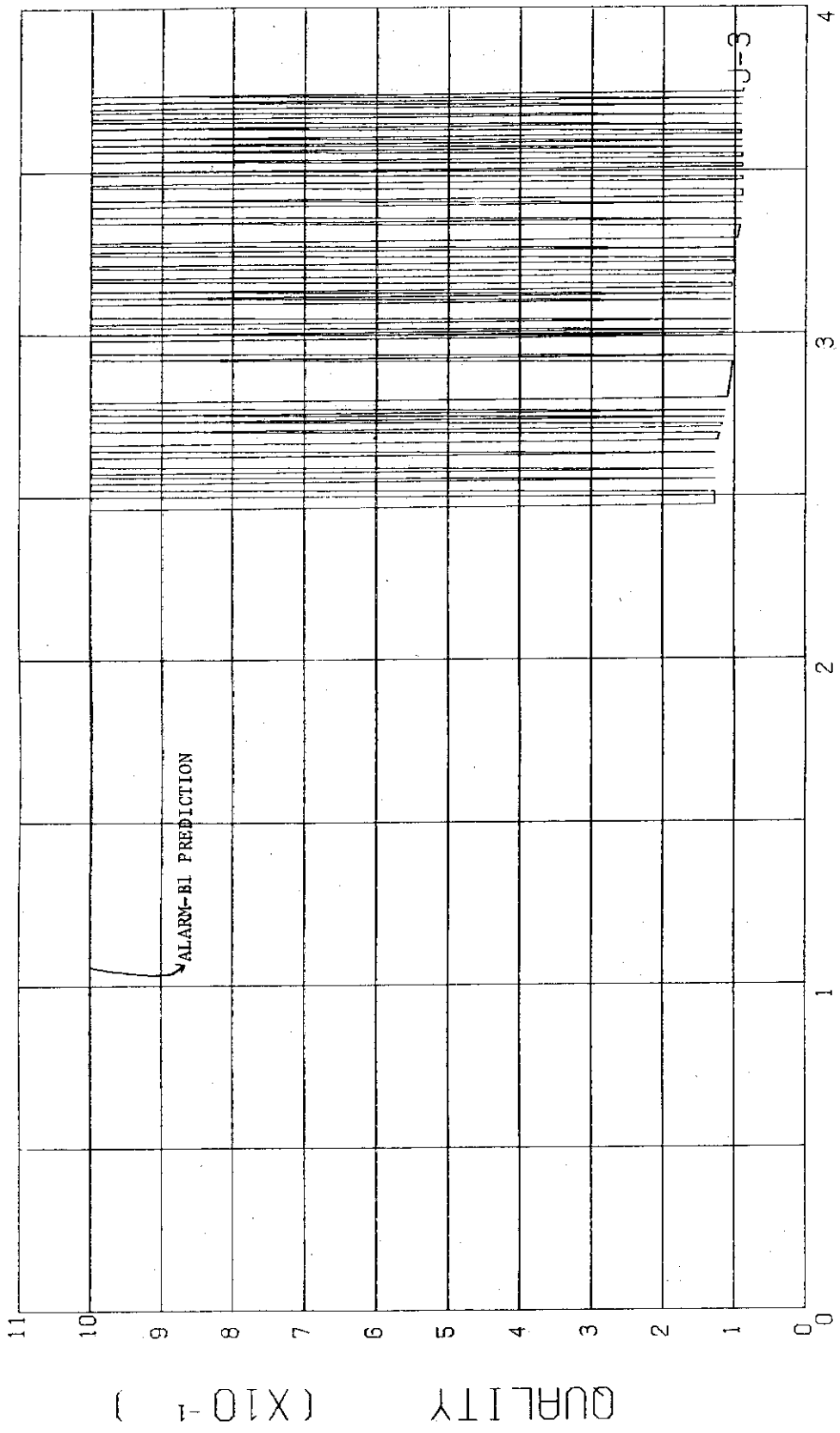

Fig.21 Flow Quality at Outlet (Re-analysis)

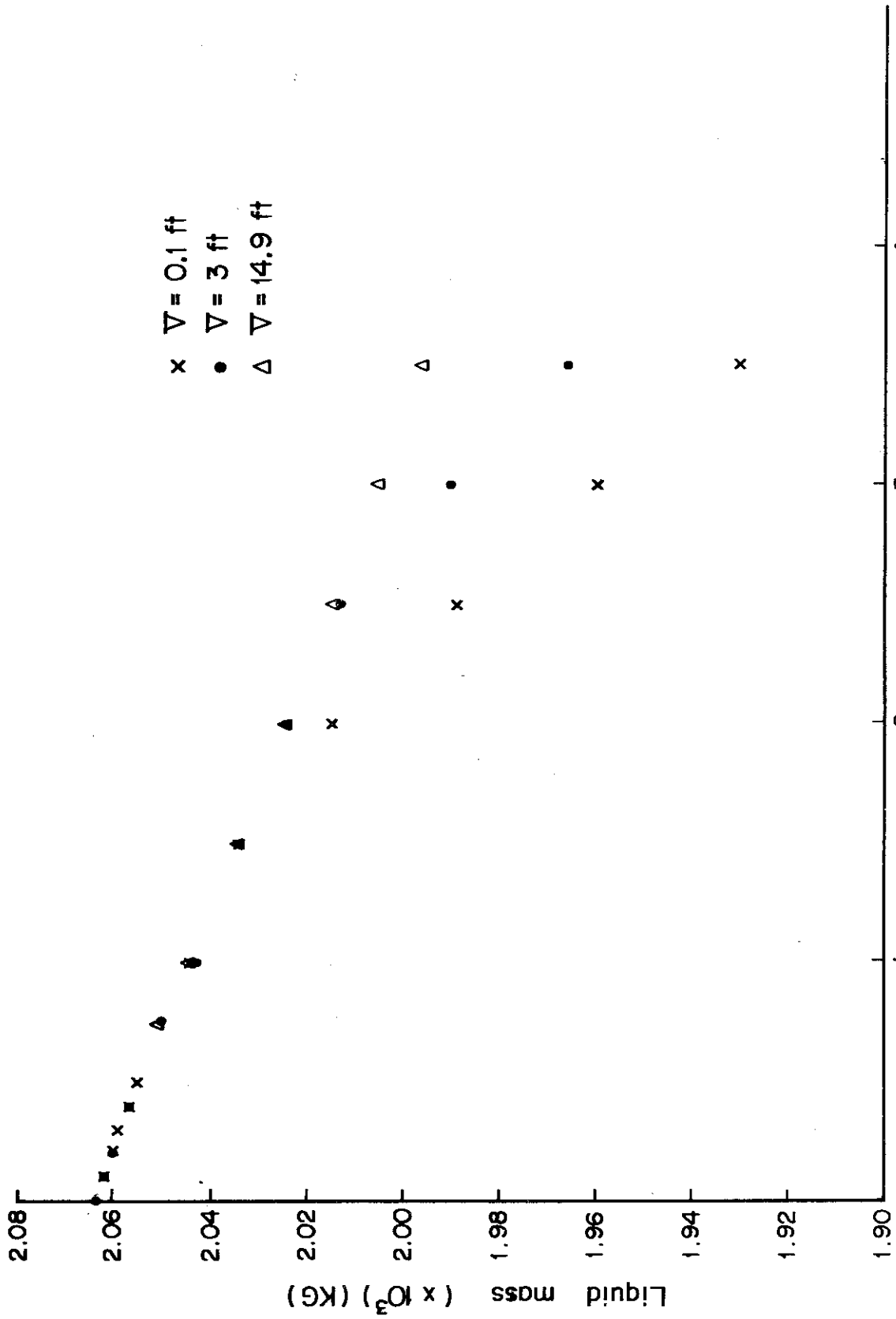

Fig.22 Mass Inventory in the Vessel (Re-analysis)

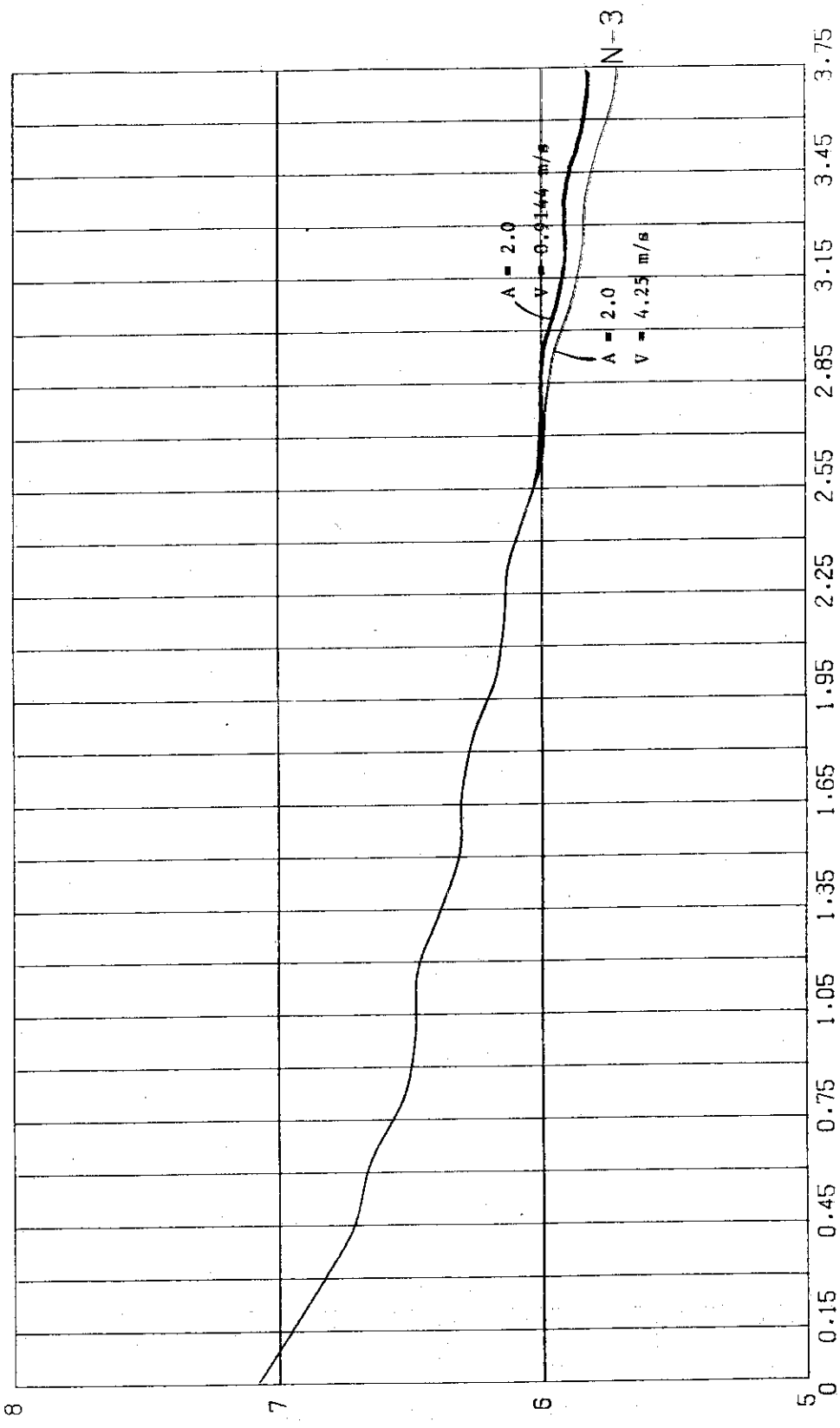

Fig.23 Pressure Profiles due to Bubble Parameters (Re-analysis)

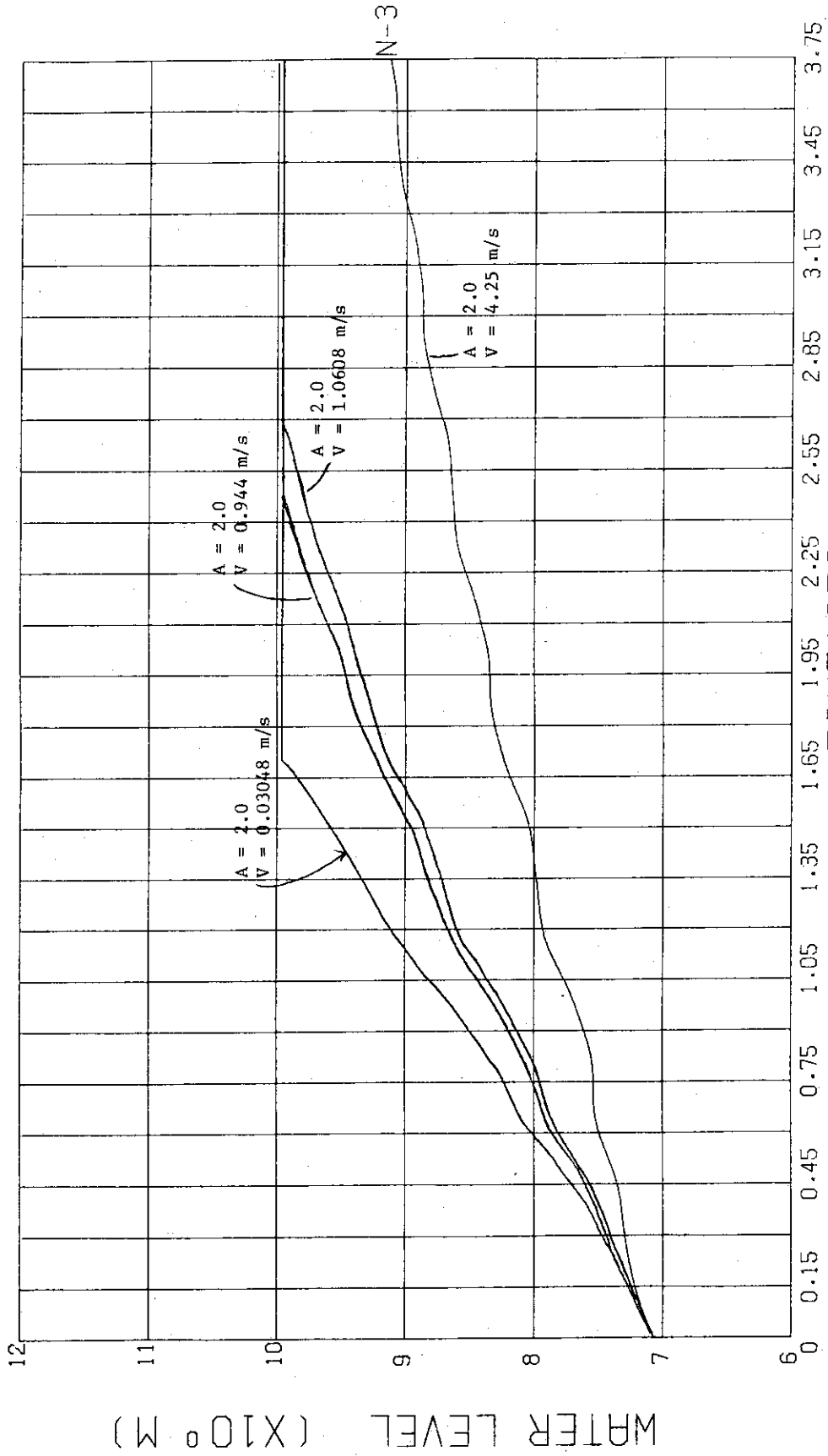

Fig.24 Water Level Profiles due to Bubble Parameters (Re-analysis)

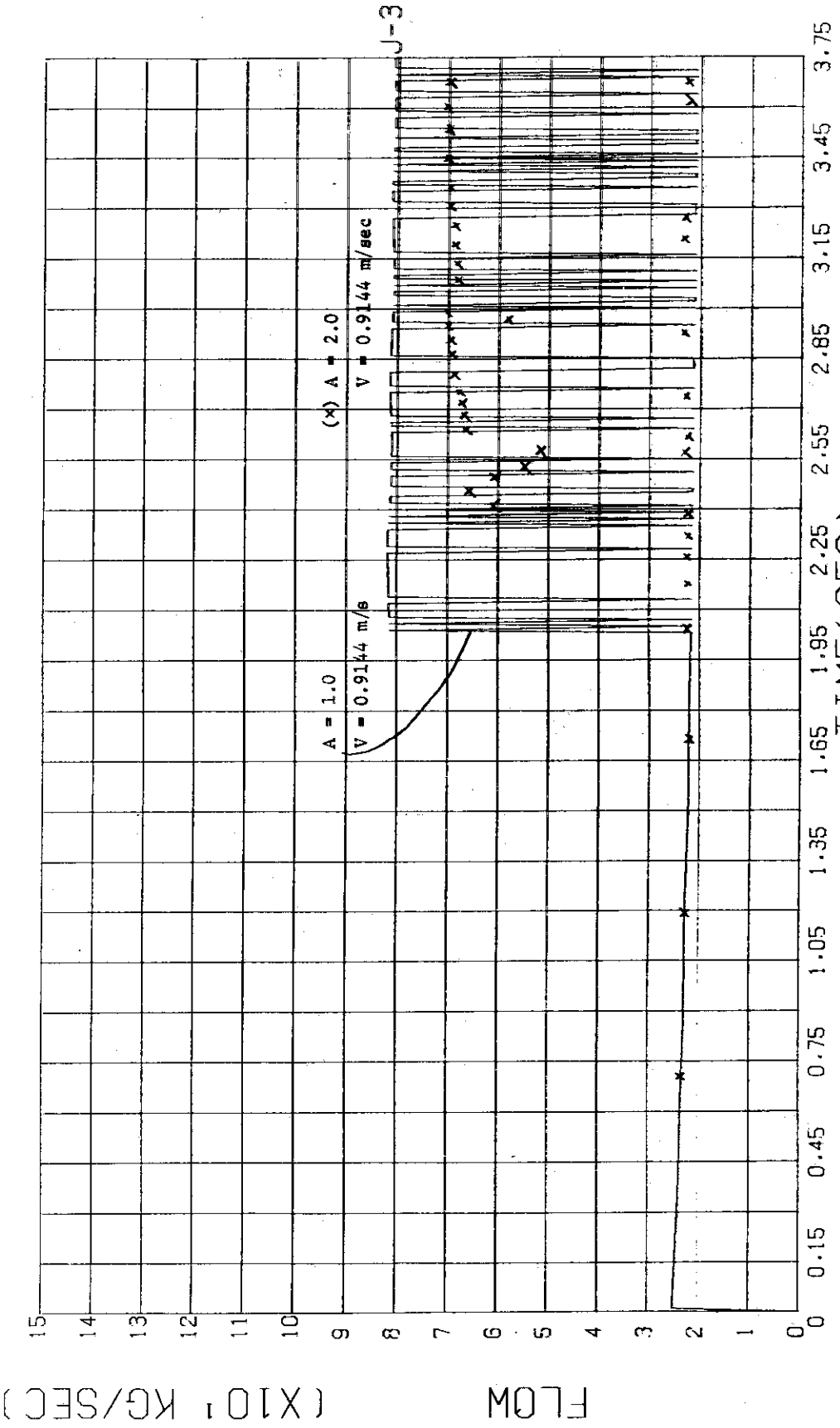

Fig.25 Dishcarge Flow Profiles due to Bubble Parameters
(Re-analysis)

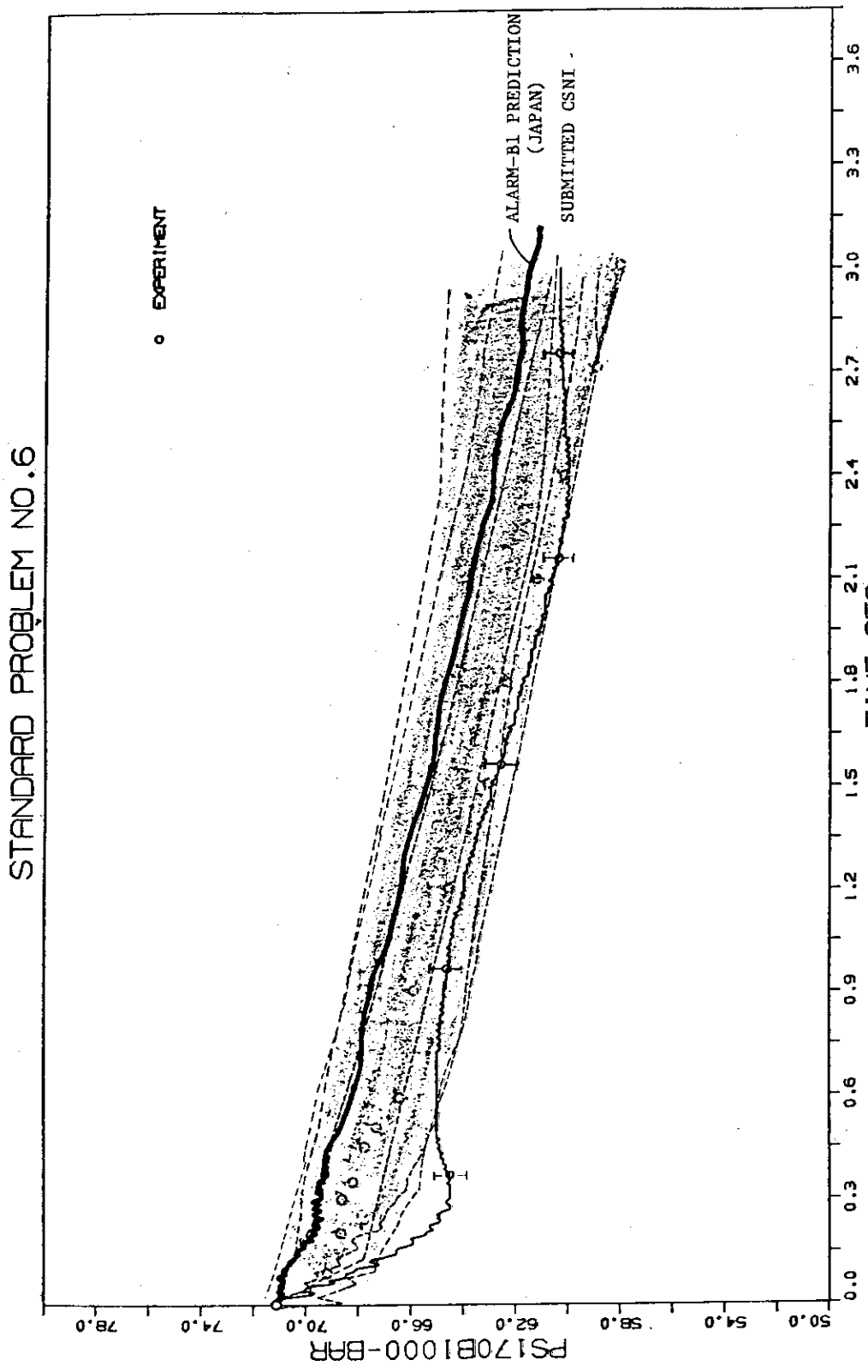

Fig.26 Envelope of Pressure Predictions at Level B

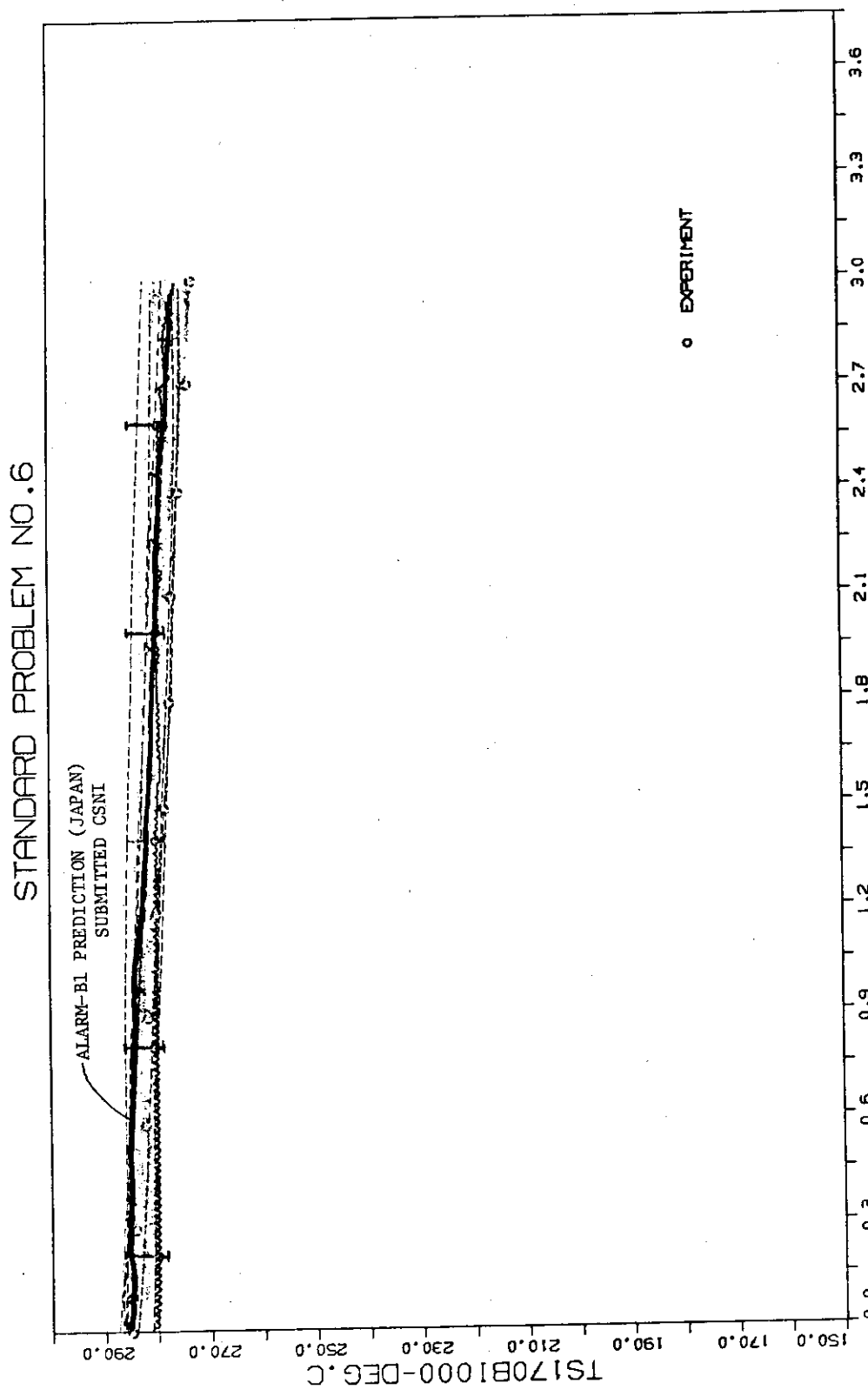

Fig.27 Envelope of Temperature Predictions at Level B

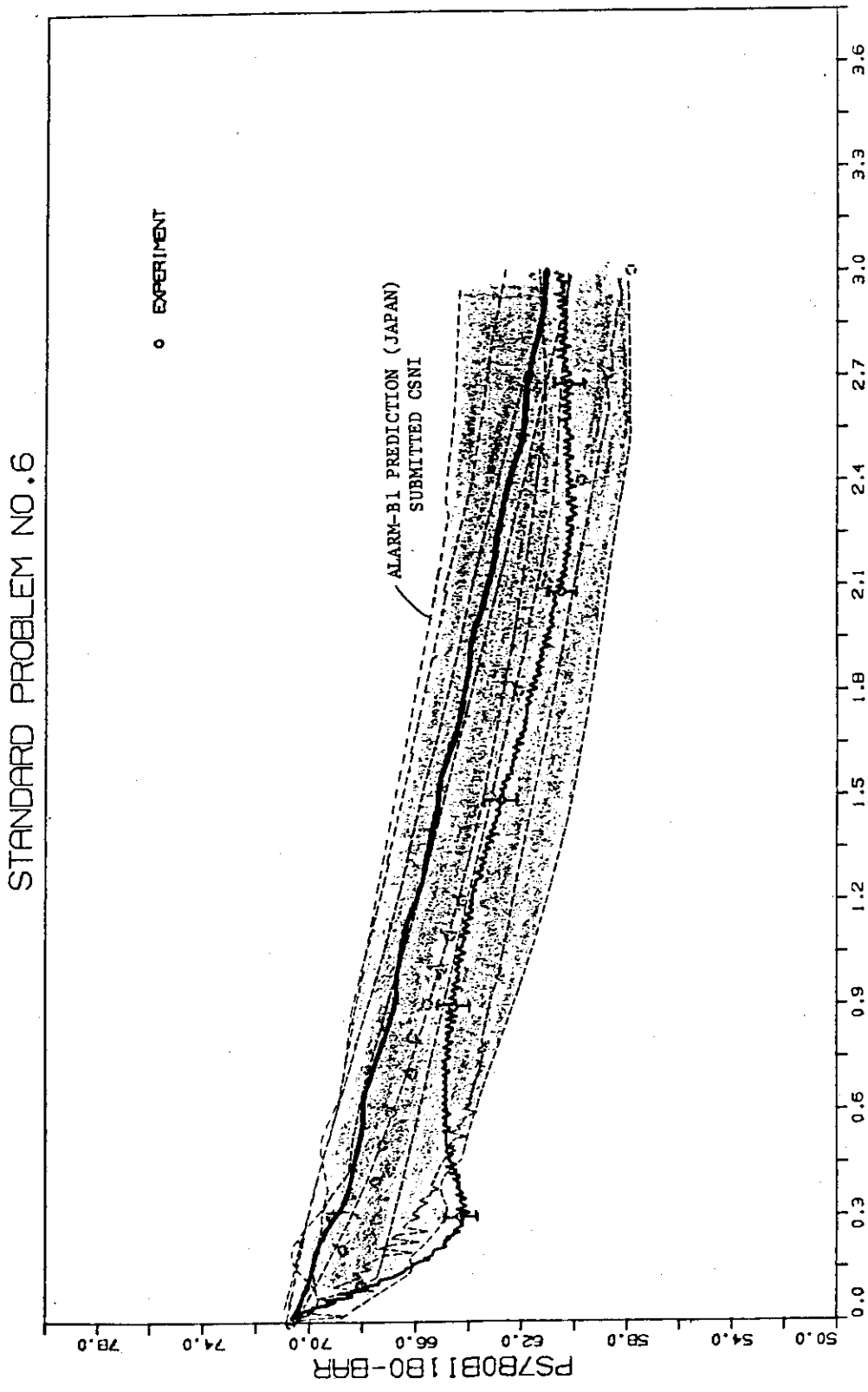

Fig.28 Envelope of Pressure Predictions at Level F

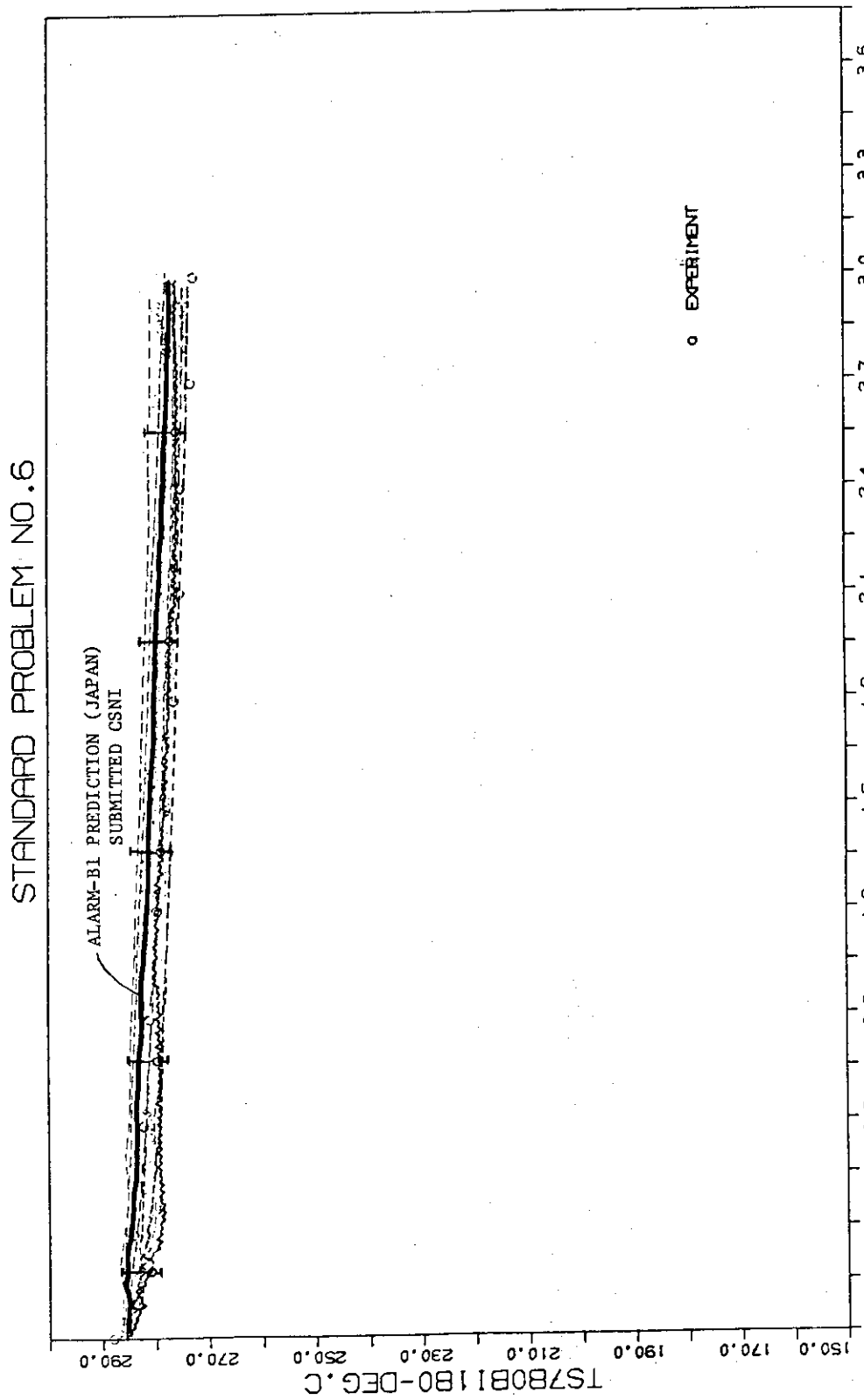

Fig.29 Envelope Temperature Predictions at Level F

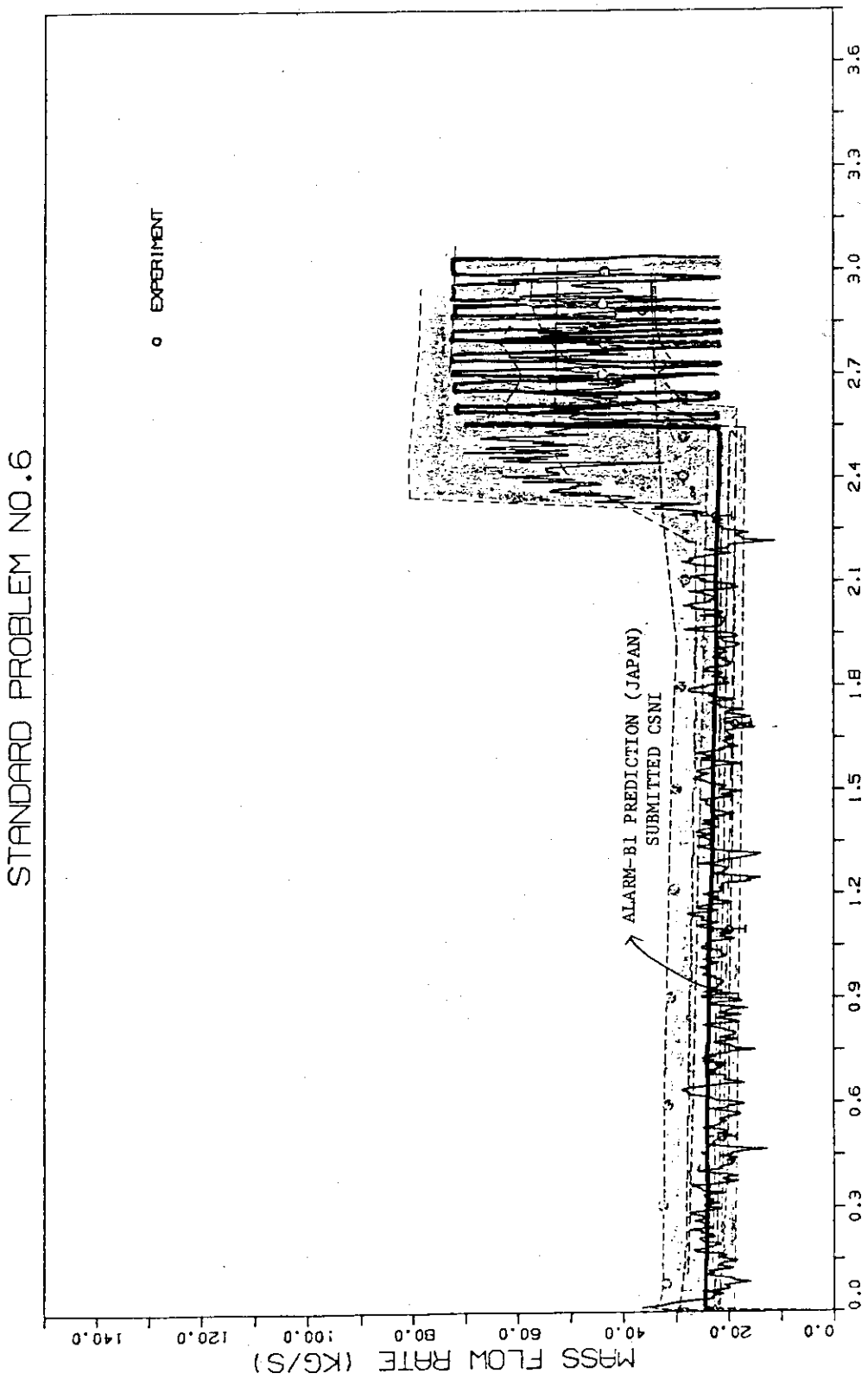

Fig.30 Envelope of Mass Flow Rate Predictions in the Discharge Nozzle

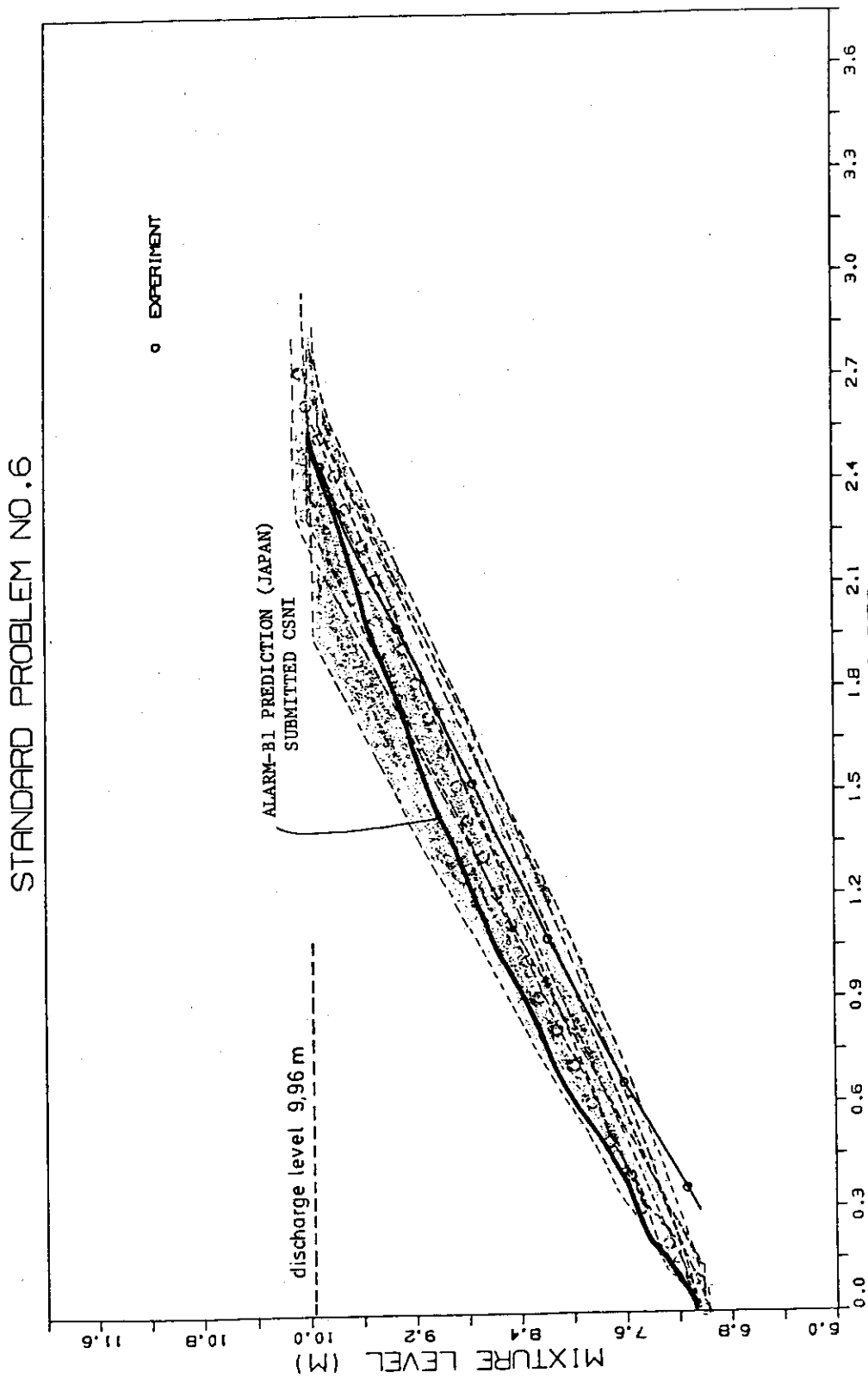

Fig.31 Envelope of Mixture Level Predictions

Appendices

(1) ALARM-B1 input data

(2) ALARM-B1 input data (Re-analysis)

(3) Calculated results of participants

(4) ALARM-B1 plotter routine

Appendix 1. ALARM-B1 input data

```
                    *****    LISTING OF INPUT DATA     *****

NO.       ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

 1                CSNI STANDARD PROBLEM NO.6 ANALYSIS BY ALARM-B1                    ISP60000
 2        /*       PRESSURE  GAUGES                                                  ISP60010
 3        /*         PS170B1000     =    PRESSURE OF NODE1                          ISP60020
 4        /*         PS380B1000     =    PRESSURE OF NODE2                          ISP60030
 5        /*         PS780B1180     =    PRESSURE OF NODE3                          ISP60040
 6        /*                                                                         ISP60050
 7        /*       TEMPERATURE  GAUGES                                               ISP60060
 8        /*         TS170B1000     =    TEMPERATURE OF NODE1                       ISP60070
 9        /*         TS380B1000     =    TEMPERATURE OF NODE2                       ISP60080
10        /*         TS780B1180     =    TEMPERATURE OF NODE3                       ISP60090
11             1  /   PROBLEM DIMENSION                                             ISP60100
12               0   6  3   2   3   1   3   0   1   5(0)    8   160                ISP60110
13        /*                                                                        ISP60120
14             2  /   EDIT VARIABLE                                                 ISP60130
15        /*                                                                        ISP60140
16        AP  N1  AP  N2  AP  N3  AT  N1  AT  N2  AT  N3  ZM  N3  JF  J3           ISP60150
17        /*                                                                        ISP60160
18                                                                                 ISP60170
19             3  /   TIME STEP                                                    ISP60180
20        /*                                                                       ISP60190
21               100      5      0      100        0.0001       0.5               ISP60200
22                50     10      0       20        0.0005       1.0               ISP60210
23                10     50      0       10        0.001        3.75              ISP60220
24        /*                                                                       ISP60230
25             4  /   TRIP CONTROL                                                 ISP60240
26        /*                                                                       ISP60250
27                1      1      0       0        4.00         0.0               ISP60260
28                2      1      0       0        0.0001       0.0               ISP60270
29        /*                                                                       ISP60280
30             5  /   VOLUME                                                      ISP60290
31        /*                                                                       ISP60300
32               0   0   0   0   0   72.369E4   285.0   1.2433  2.67  2.67  2(0.0)ISP60310
33               0   0   0   0   0   72.232E4     0.0   0.5998  2.33  2.33        ISP60320
34               2.67   0.0                                                      ISP60330
35               1   0   0   0   0   72.205E4     0.0   2.8801  6.185 2.07        ISP60340
36               5.00   0.0                                                      ISP60350
37        /*                                                                       ISP60360
38             6  /   BUBBLE DATA                                                 ISP60370
39        /*                                                                       ISP60380
40                  2.0       1.21920                                            ISP60390
41        /*                                                                       ISP60400
42             7  /   JUNCTION  DATA                                              ISP60410
43        /*                                                                       ISP60420
44           1  2  0  0  0.0  0.2574  0.078  0.2574  2.67  2.67  7.39  2(0.0)    ISP60430
45           2  3  0  0  0.0  0.2574  0.078  0.2574  2.33  5.00 10.32  2(0.0)    ISP60440
46           3 -1  1  0  0.0 3.217E-3 0.064 3.217E-3 5.40  9.983 5.80  2(0.0)    ISP60450
47        /*                                                                       ISP60460
48             11 /   LEAK DATA                                                    ISP60470
49        /*                                                                       ISP60480
50              3     0      1.0E4      0.75                                      ISP60490
51              0.0      0.0              0.0001       1.0   5.0       1.0        ISP60500
52        /*                                                                       ISP60510
53             15 /   PLOT DATA                                                    ISP60520
54        /*                                                                       ISP60530
55                  250.0       150.0                                            ISP60540
56        AP  N1  AP  N2  AP  N3  AT  N1  AT  N2  AT  N3  ZM  N3  JF  J3          ISP60550
57        0                                                                        ISP60560
58        END                                                                      ISP60570

                              END OF INPUT DATA
```

Appendix 2. ALARM-B1 input data (Re-analysis)

```
                    *****     LISTING OF INPUT DATA     *****

NO.       ....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

  1               CSNI STANDARD PROBLEM NO.6 ANALYSIS BY ALARM-B1                    ISP60000
  2       /*       PRESSURE  GAUGES                                                  ISP60010
  3       /*         PS170BI000     =    PRESSURE OF NODE1                          ISP60020
  4       /*         PS380BI000     =    PRESSURE OF NODE2                          ISP60030
  5       /*         PS780BI180     =    PRESSURE OF NODE3                          ISP60040
  6       /*                                                                         ISP60050
  7       /*       TEMPERATURE  GAUGES                                               ISP60060
  8       /*         TS170BI000     =    TEMPERATURE OF NODE1                       ISP60070
  9       /*         TS380BI000     =    TEMPERATURE OF NODE2                       ISP60080
 10       /*         TS780BI180     =    TEMPERATURE OF NODE3                       ISP60090
 11            1  /   PROBLEM DIMENSION                                             ISP60100
 12              0   8  3   2   3   1   3   0   1   5(0)    8   160                 ISP60110
 13       /*                                                                        ISP60120
 14            2  /   EDIT VARIABLE                                                 ISP60130
 15       /*                                                                        ISP60140
 16       AP  N1  AP  N2  AP  N3  AT  N1  AT  N2  AT  N3  ZM  N3  JF  J3           ISP60150
 17       /*                                                                        ISP60160
 18                                                                                 ISP60170
 19            3  /   TIME STEP                                                     ISP60180
 20       /*                                                                        ISP60190
 21              100       5      0       100         0.0001        0.5            ISP60200
 22               50      10      0        20         0.0005        1.0            ISP60210
 23               10      50      0        10         0.001         3.75           ISP60220
 24       /*                                                                        ISP60230
 25            4  /   TRIP CONTROL                                                 ISP60240
 26       /*                                                                        ISP60250
 27                1       1      0         0         4.00          0.0            ISP60260
 28                2       1      0         0         0.0001        0.0            ISP60270
 29       /*                                                                        ISP60280
 30            5  /   VOLUME                                                       ISP60290
 31       /*                                                                        ISP60300
 32              0   0   0   0   0   72.369E4   282.0   1.2526  2.69  2.69  2(0.0)ISP60310
 33              0   0   0   0   0   72.232E4   284.0   0.6436  2.50  2.50        ISP60320
 34              2.69   0.0                                                       ISP60330
 35              1   0   0   0   0   72.205E4     0.0   2.8016  6.000 1.88        ISP60340
 36              5.19   0.0                                                       ISP60350
 37       /*                                                                        ISP60360
 38            6  /   BUBBLE DATA                                                  ISP60370
 39       /*                                                                        ISP60380
 40                 1.0       0.9144                                              ISP60390
 41       /*                                                                        ISP60400
 42            7  /   JUNCTION  DATA                                              ISP60410
 43       /*                                                                        ISP60420
 44          1  2  0  0  0.0  0.2574  0.082  0.2574  2.69  2.69 12.43  2(0.0)     ISP60430
 45          2  3  0  0  0.0  0.2574  0.082  0.2574  2.50  5.19 17.97  2(0.0)     ISP60440
 46          3 -1  1  0  0.0 3.217E-3 0.064 3.217E-3 5.27  9.96 44.45  2(0.0)     ISP60450
 47       /*                                                                        ISP60460
 48            11 /   LEAK DATA                                                    ISP60470
 49       /*                                                                        ISP60480
 50              3     0      1.0E4      0.75                                      ISP60490
 51             0.0      0.0              0.0001       1.0    5.0       1.0        ISP60500
 52       /*                                                                        ISP60510
 53            15 /   PLOT DATA                                                    ISP60520
 54       /*                                                                        ISP60530
 55                  250.0       150.0                                            ISP60540
 56       AP  N1  AP  N2  AP  N3  AT  N1  AT  N2  AT  N3  ZM  N3  JF  J3           ISP60550
 57       0                                                                         ISP60560
 58       END                                                                       ISP60570

                              END OF INPUT DATA
```

Appendix 3

Table 4 Calculated Results of Participants

Country	Code	Calculated results for: pressure at level B	C	E	F	G	temperature at level B	C	E	F	G	pressure in discharge nozzle	temperature in discharge nozzle	mixture level	discharge mass flow rate
	a) non-equilibrium														
Finland	NORA	X	X	X	X	O	X	X	X	X	O	O	O	X	X
Germany	DRUFAN	X	X	X	X	X	X	X	X	X	X	X	X	X	X
UK (UKAEA)	FROTH2	O	O	X →	O	O	O	O	X	O	O	X	X	X	X
	b) equilibrium														
Australia	NAIAD	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Germany	BRUCH-S	X AK PL67-	O	O	O ←	X BS PL1218	X TS060	O	O	O ←	X	O	O	X	X
Italy (CNEN)	RELAP-UK	O ←	X	X	X	O	X	X	X	X	O	X	X	X	X
Italy (Nuclital)	RELAP4/MOD5	O ←	X	O	O ←	X	O ←	X	O	O ←	X	O	O	X	X
	RELAP4/MOD5*	X	X	X	X	X	X	X	X	X	X	O	O	X	X
Japan	ALARM-B1	X	X	O	X	O	X	X	O	X	O	O	O	X	X
Sweden	RELAP4/MOD3(95)	X	X	X	O	X	X	X	X	O ←	X	O	O	X	X
Switzerland	RELAP4/MOD2	X	X	X	X	X	X	X	X	X	X	O	O	X	X
UK (UKAEA)	RELAP-UK Mk III	O	O	X →	O	O	O	O	X	O	O	X	X	X	X
UK (Strathclyde)	RELAP4/MOD3(WREM)	X	X	X	O ←	X	X	X	X	O ←	X	X	X	X	X
US	RELAP4/MOD5(2)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
France*	RELAP4/MOD5	X	X	X	X	O	X	X	X	X	O	O	O	X	X
		↑			↑		↑			↑		↑	↑	↑	↑

X = calculated
O = not calculated
↑ = taken for comparison

* calculations submitted after deadline to the workshop on CSNI LOCA Standard Problems at Garching, April 11-14, 1978

** post calculation

Appendix 4. ALARM-B1 plotter routine

```
FACOM 230-75 (M7)        L I B E  77.11.21   ( V-03  L-12 )          79/05/29          PAGE-0002

          SOURCE ELEMENT LIST (8BIT MODE)

ELEMENT NAME  ((PLOTER  ))     ESTABLISHED  78.09.28

                      SUBROUTINE PLOTER ( XPLOT,XMIN,XMAX,LSEQ,NSEQ,NBF,NEDP,NEDP1,      PL000010
                     *   LSEQN,NSEQN,NUM,YLAST,TLAST)                                    PL000020
                      REAL*8  YLAST,TLAST,TIME,DAT                                       PL000030
                      COMMON / PDIM /                                                    PL000040
                     1     NREST , NEDIT , NTSC  , NTRIP , NVOL  , NBUB  , NJUN  ,     PL000050
                     2     NPUMP , NLP   , NFILL , NSUB  , NJETP , NTSUR , NJEGRP      PL000060
                     *  ,NEDITP , NBUF , NEDTP1                                         PL000070
                      COMMON /TCNT/  KSTEP , NTRAN , TIME                                PL000080
                      COMMON / FORM /                                                    PL000090
                     *    EDUMV( 3,15), EDUMJ( 3, 7), EDUMS( 3, 3), EDUMT( 3, 5)        PL000100
                      COMMON /COMPLT/ KPLT,LPLT,XLEN,YLEN                                PL000110
                      COMMON /TAPE/ ITAPER,ITAPEP,ITAPE*                                 PL000120
                      COMMON  TITLE(18),DUMY(40),DAT                                     PL000130
                      DIMENSION  NUM(1),YLAST(1),TLAST(1),IAUX(100)                      PL000140
                      DIMENSION  xPLOT( NBF,NEDP1) , XMIN(NEDP),XMAX(NEDP) ,             PL000150
                     *   LSEQ(NEDP) , NSEQ(NEDP) , LSEQN(   1) , NSEQN(   1)           PL000160
                      COMMON / UNIT / PWR,UNITV(2,15),UNITJ(2, 4),UNITT(3, 2)            PL000170
                C                                                                        PL000260
                C     PLOTTING ROUTINE                                                   PL000270
                C                                                                        PL000280
                      DIMENSION  IBUF(1)                                                 PL000290
                C                                                                        PL000300
                      REWIND ITAPER                                                      PL000310
                C                                                                        PL000320
                C                                                                        PL000330
                C                                                                        PL000340
                      CALL PLOTS(IBUF,IALARM)                                            PL000350
                C                                                                        PL000360
                      ISW = 0                                                            PL000370
                      IF ( NREST.LT.0 .AND. NEDITP.EQ.0 ) NEDITP=NEDP                    PL000380
                C                                                                        PL000390
                      IX = 0                                                             PL000400
                      DO 1 I=1,NEDITP                                                    PL000410
                      DO 2 J=1,NEDP                                                      PL000420
                      IF ( LSEQN(I).EQ.LSEQ(J) .AND. NSEQN(I).EQ.NSEQ(J) ) GO TO 3       PL000430
                    2 CONTINUE                                                           PL000440
                      GO TO 1                                                            PL000450
                    3 CONTINUE                                                           PL000460
                      IX = IX + 1                                                        PL000470
                      IAUX(IX) = J                                                       PL000480
                    1 CONTINUE                                                           PL000490
                C                                                                        PL000500
                C                                                                        PL000510
                      IF ( IX.EQ.0 ) GO TO 999                                           PL000520
                C                                                                        PL000530
                      IAX = 0                                                            PL000540
                      I = 1                                                              PL000550
                      J = 1                                                              PL000560
                C                                                                        PL000570
                      XX = XMAX( IAUX(1) )                                               PL000580
                      XN = XMIN( IAUX(1) )                                               PL000590
                      LO = LSEQ( IAUX(1) )                                               PL000600
```

Appendix 4. (continued)

```
FACOM 230-75 (M7)        L I B E  77.11.21   ( V=03  L=12 )          79/05/29          PAGE=0003

 SOURCE ELEMENT LIST (8BIT MODE)

            NO = NSE@( IAUX(1) )                                                    PL000610
      100 I = I + 1                                                                 PL000620
      C                                                                             PL000630
            IF ( I.GT.IX ) GO TO 200                                                PL000640
            K = IAUX( I )                                                           PL000650
      C                                                                             PL000660
      200 CONTINUE                                                                  PL000670
            IAX = IAX + 1                                                           PL000680
            NUM(IAX) = J                                                            PL000690
            XMIN(IAX) = XN                                                          PL000700
            XMAX(IAX) = XX                                                          PL000710
            IF ( I.GT.IX ) GO TO 300                                                PL000720
            J = 1                                                                   PL000730
            LO = LSE@( K )                                                          PL000740
            NO = NSE@(K)                                                            PL000750
            XN = XMIN(K)                                                            PL000760
            XX = XMAX(K)                                                            PL000770
            GO TO 100                                                               PL000780
      300 CONTINUE                                                                  PL000790
      C                                                                             PL000800
            DT = 10.0                                                               PL000810
            IF ( TIME.LT.100.0 ) DT=5.0                                             PL000820
            IF ( TIME.LT.10.0 ) DT=0.5                                              PL000830
            IF ( TIME.LT.1.0 ) DT=0.05                                              PL000840
            NDX = TIME/DT + 1                                                       PL000850
            IF ( MOD(NDX,2).NE.0 ) NDX=NDX+1                                        PL000860
      C                                                                             PL000870
            DX = XLEN / ( NDX*DT )                                                  PL000880
            DT=0.15                                                                 PL000881
            NDX=25                                                                  PL000882
            DX=10./0.15                                                             PL000883
      C                                                                             PL000890
      C                                                                             PL000900
      C     PLOTTING                                                                PL000910
      C                                                                             PL000920
            K = 0                                                                   PL000930
      C                                                                             PL000940
            CALL PLOT(0.,0.,3)                                                      PL000945
            DO 400 I=1,IAX                                                          PL000950
      C                                                                             PL000960
      C                                                                             PL000970
      C     SET DX,DY ACCORDING TO XMIN(I),XMAX(I)                                  PL000980
      C                                                                             PL000990
            LPLT1=LPLT                                                              PL001000
            K=K+1                                                                   PL001002
            L=IAUX(K)                                                               PL001004
            LL=LSE@(L)                                                              PL001006
            IF(NSE@(L).GT.0.AND.LL.EQ.1)    GO TO 111                               PL001010
            IF(NSE@(L).GT.0.AND.LL.EQ.3)    GO TO 121                               PL001012
            IF(NSE@(L).GT.0.AND.LL.EQ.8)    GO TO 131                               PL001014
            IF(NSE@(L).LT.0.AND.LL.EQ.1)    GO TO 141                               PL001016
            STOP  9999                                                              PL001030
      111 CONTINUE                                                                  PL001035
            XMIN(I)=50.0                                                            PL001040
```

Appendix 4. (continued)

```
FACOM 230-75 (M7)        L I B E  77.11.21   ( V-03  L-12 )          79/05/29          PAGE-0004

 SOURCE ELEMENT LIST (8BIT MODE)

                NDY2=8                                                              PL001045
                NDY1=5                                                              PL001050
                XS=10.0                                                             PL001055
                NX=NDY2-NDY1                                                        PL001060
                XMAX(I)=YLEN/(NX*XS)                                                PL001065
                GO TO 11111                                                         PL001070
            121 CONTINUE                                                            PL001075
                XMIN(I)=150.0                                                       PL001080
                NDY2=30                                                             PL001085
                NDY1=15                                                             PL001090
                XS=10.0                                                             PL001095
                NX=NDY2-NDY1                                                        PL001100
                XMAX(I)=YLEN/(NX*XS)                                                PL001105
                GO TO 11111                                                         PL001110
            131 CONTINUE                                                            PL001115
                XMIN(I)=6.0                                                         PL001120
                NDY2=12                                                             PL001125
                NDY1=6                                                              PL001130
                XS=1.0                                                              PL001135
                NX=NDY2-NDY1                                                        PL001140
                XMAX(I)=YLEN/(NX*XS)                                                PL001145
                GO TO 11111                                                         PL001150
            141 CONTINUE                                                            PL001152
                XMIN(I)=0.0                                                         PL001154
                NDY2=15                                                             PL001156
                NDY1=0                                                              PL001157
                XS=10.0                                                             PL001159
                NX=NDY2-NDY1                                                        PL001160
                XMAX(I)=YLEN/(XS*NX)                                                PL001162
          11111 CONTINUE                                                            PL001163
          C                                                                         PL001170
                X = XLEN                                                            PL001180
                CALL PLOT ( X,0.,2 )                                                PL001190
                DO 480 N=1,NDX                                                      PL001200
                CALL PLOT(X,YLEN,3)                                                 PL001210
                CALL PLOT(X,0.  ,2)                                                 PL001220
                IF ( MOD(N,2).EQ.0 ) GO TO 481                                      PL001230
                CALL NUMBER ( X-3.,-5.,3., (NDX-N+1)*DT ,0., 2 )                    PL001240
            481 CONTINUE                                                            PL001250
                X = X-DT*DX                                                         PL001260
            480 CONTINUE                                                            PL001270
          C                                                                         PL001280
                CALL NUMBER (-3.,-5.,3.,0.,0.,-1 )                                  PL001290
          C                                                                         PL001300
                DY = YLEN / NX                                                      PL001310
                RNDY1 = FLOAT(NDY1)                                                 PL001320
                CALL NUMBER ( -5.,-1.,3.,RNDY1,0.,-1 )                              PL001330
                DO 485 N=1,NX                                                       PL001340
                X = DY * FLOAT(N)                                                   PL001350
                IF ( NDY1+N.EQ.0 ) GO TO 486                                        PL001360
                CALL PLOT(XLEN,X,3)                                                 PL001370
                GO TO 487                                                           PL001380
            486 CONTINUE                                                            PL001390
                CALL PLOT ( XLEN,X,3 )                                              PL001400
```

Appendix 4. (continued)

```
FACOM 230-75 (M7)        L I B E  77.11.21   ( V-03  L-12 )          79/05/29          PAGE-0005

 SOURCE ELEMENT LIST (8BIT MODE)

      487 CONTINUE                                                                    PL001410
          CALL PLOT(0.,X,2)                                                           PL001420
          RNDY1 = FLOAT(NDY1+N)                                                       PL001430
          CALL NUMBER ( -5.,X-1.,3.,RNDY1,0.,-1 )                                     PL001440
      485 CONTINUE                                                                    PL001450
          Pw = ALOG10(XS)                                                             PL001460
C                                                                                     PL001470
          CALL PLOT ( 0.,YLEN,3 )                                                     PL001480
          CALL PLOT ( 0.,0.,2 )                                                       PL001490
          ISW=0                                                                       PL001500
C                                                                                     PL001530
      470 CONTINUE                                                                    PL001540
          READ(ITAPEP,END=509) XPLOT                                                  PL001550
          LPLT1=LPLT1-NBF                                                             PL001560
C                                                                                     PL001570
          DY = XMAX( I )                                                              PL001580
C                                                                                     PL001590
          NM = NUM(I)                                                                 PL001600
C                                                                                     PL001610
          DO 500 J=1,NM                                                               PL001620
          L = IAUX( K )                                                               PL001630
          IF ( ISW.NE.0 .OR. J.NE.1 ) GO TO 505                                       PL001640
          LL = LSE@( L )                                                              PL001650
          IF ( NSE@( L ) ) 502,503,501                                                PL001660
      501 CONTINUE                                                                    PL001670
          CALL SYMBOL ( -15.0,YLEN/7.,6.0,EDUMV(1,LL),90.,12 )                        PL001680
          GO TO 504                                                                   PL001690
      502 CONTINUE                                                                    PL001700
          CALL SYMBOL ( -15.0,YLEN/7.0,6.0,EDUMJ(1,LL),90.,12 )                       PL001710
          GO TO 504                                                                   PL001720
      503 CONTINUE                                                                    PL001730
          CALL SYMBOL ( -15.0,YLEN/7.,6.0,EDUMT(1,LL),90.,12 )                        PL001740
      504 CONTINUE                                                                    PL001750
          CALL SYMBOL ( -15.0,YLEN/7.0+72.0,6.0,PWR,90.,4 )                           PL001760
          IF ( NSE@(L) ) 702,704,701                                                  PL001770
      701 CONTINUE                                                                    PL001780
          IF (LL.EQ.1 .OR. LL.EQ.14) Pw=Pw                                            PL001790
          CALL NUMBER ( -18.0,YLEN/7.0+94.0,3.0,Pw,90.,-1 )                           PL001800
          CALL SYMBOL ( -15.0,YLEN/7.0+102.0,6.0,UNITV(1,LL),90.,8 )                  PL001810
          GO TO 707                                                                   PL001820
      702 CONTINUE                                                                    PL001830
          IF (LL.LT.4) GO TO 703                                                      PL001840
          Pw = Pw                                                                     PL001850
          LL = 4                                                                      PL001860
      703 CALL NUMBER ( -18.0,YLEN/7.0+94.0,3.0,Pw,90.,-1 )                           PL001870
          CALL SYMBOL ( -15.0,YLEN/7.0+102.0,6.0,UNITJ(1,LL),90.,8 )                  PL001880
          GO TO 707                                                                   PL001890
      704 CONTINUE                                                                    PL001900
          IF (LL.EN.3 .OR. LL.EQ.5) GO TO 705                                         PL001910
          LL = 1                                                                      PL001920
          GO TO 706                                                                   PL001930
      705 LL = 2                                                                      PL001940
      706 CALL NUMBER ( -18.0,YLEN/7.0+94.0,3.0,Pw,90.,-1 )                           PL001950
          CALL SYMBOL ( -15.0,YLEN/7.0+102.0,6.0,UNITT(1,LL),90.,9 )                  PL001960
```

Appendix 4. (continued)

```
FACOM 230-75 (M7)        L I B E  77.11.21   ( V-03  L-12 )          79/05/29          PAGE-0006

 SOURCE ELEMENT LIST (8BIT MODE)

          707 CONTINUE                                                                  PL001970
              CALL SYMBOL ( XLEN/2.-10.0.-13.0.6..'TIME(SEC)'.0..9 )                    PL001980
          505 CONTINUE                                                                  PL001990
              IF ( ISW.EQ.0 ) GO TO 510                                                 PL002000
              XLST = TLAST( K )                                                         PL002010
              YLST = YLAST( K )                                                         PL002020
              NS = 1                                                                    PL002030
              GO TO 520                                                                 PL002040
          510 CONTINUE                                                                  PL002050
              IF(NSE@(L).GT.0.AND.LL.EQ.1) XPLOT(1.L)=XPLOT(1.L)/1.01972E4              PL002052
              IF(NSE@(L).GT.0.AND.LL.EQ.8) XPLOT(1.L)=XPLOT(1.L)+5.19                   PL002054
              XLST = XPLOT ( 1.NEDP1 )                                                  PL002060
              YLST = XPLOT ( 1.L )                                                      PL002070
              TIME0 = XLST                                                              PL002080
              NS = 2                                                                    PL002090
          520 CONTINUE                                                                  PL002100
              X = DX*XLST                                                               PL002110
              Y = DY*( YLST-XMIN(I) )                                                   PL002120
          C                                                                             PL002130
              CALL PLOT( X.Y.3 )                                                        PL002140
          C                                                                             PL002150
              NB = NBF                                                                  PL002160
              IF ( LPLT1.LE.0 ) NB=LPLT1+NBF                                            PL002170
          C                                                                             PL002180
              DO 600 N=NS.NB                                                            PL002190
              IF(NSE@(L).GT.0.AND.LL.EQ.1) XPLOT(N.L)=XPLOT(N.L)/1.01972E4              PL002192
              IF(NSE@(L).GT.0.AND.LL.EQ.8)  XPLOT(N.L)=XPLOT(N.L)+5.19                  PL002196
              X = DX*XPLOT( N.NEDP1 )                                                   PL002200
              Y = DY*( XPLOT(N.L)-XMIN(I) )                                             PL002210
              CALL PLOT ( X.Y.2 )                                                       PL002220
          600 CONTINUE                                                                  PL002230
              TLAST( K ) = XPLOT( NB.NEDP1 )                                            PL002240
              YLAST( K ) = XPLOT ( NB.L )                                               PL002250
              IF ( LPLT1.GT.0 ) GO TO 508                                               PL002260
              IF ( NSE@( L ) ) 507.508.506                                              PL002270
          506 CONTINUE                                                                  PL002280
              CALL SYMBOL ( X+1..Y-1..4..'N=',0..2 )                                    PL002290
              RNSE@ = FLOAT(NSE@(L))                                                    PL002300
              CALL NUMBER ( X+8..Y-1..4.RNSE@.0..-1 )                                   PL002310
              GO TO 508                                                                 PL002320
          507 CONTINUE                                                                  PL002330
              CALL SYMBOL ( X+1..Y-1..4..'J-',0..2 )                                    PL002340
              RNSE@ =-FLOAT(NSE@(L))                                                    PL002350
              CALL NUMBER ( X+8..Y-1..4.RNSE@.0..-1 )                                   PL002360
              GO TO 508                                                                 PL002370
          508 CONTINUE                                                                  PL002380
          C                                                                             PL002390
          500 CONTINUE                                                                  PL002400
              ISW=1                                                                     PL002410
              GO TO 470                                                                 PL002420
          509 CONTINUE                                                                  PL002430
              REWIND ITAPEP                                                             PL002440
              CALL PLOT ( XLEN+50.0.0..-3 )                                             PL002450
              CALL PLOT(0..0..777)                                                      PL002451
```

Appendix 4. (continued)

```
FACOM 230-75 (M7)        L I B E  77.11.21   ( V-03  L-12 )          79/05/29          PAGE-0007

 SOURCE ELEMENT LIST (8BIT MODE)

                CALL PLOT(0.,0.,888)                                              PL002452
                CALL PLOT(0.,0.,666)                                              PL002453
          C                                                                       PL002460
            400 CONTINUE                                                          PL002470
          C                                                                       PL002480
            999 CONTINUE                                                          PL002490
                CALL PLOT ( 0.,0.,999 )                                           PL002500
                RETURN                                                            PL002510
                END                                                               PL002520
```