FINAL

CSNI Report No. 41

COMPARISON REPORT ON OECD-CSNI CONTAINMENT STANDARD PROBLEM No. 1

W. Winkler

Gesellschaft für Reaktorsicherheit (GRS) mbH
Garching near Munich, Germany

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COMPARISON REPORT ON OECD-CSNI CONTAINMENT STANDARD PROBLEM No. 1:

"Steamline Rupture within a Chain of Compartments"

by

W. Winkler

Gesellschaft für Reaktorsicherheit (GRS) mbH
Garching near Munich, F. R. Germany

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Time interval 0 to 50 s

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NOMENCLATURE

A	area
C_D	discharge coefficient
D	diameter (of flow path)
f	Fanning friction factor
H	total enthalpy released at break
htc	heat transfer coefficient
K	drag coefficient
L	length (of flow path)
MW	mass of water
m	mass
n	number of connections into the relevant compartment
P	pressure
PD	pressure difference
R	compartment
T	temperature
t	time
V	volume
w	velocity
Δ	difference
ζ	pressure loss coefficient

1. INTRODUCTION

Starting in 1973 in the USA and in 1975 within the frame of OECD-CSNI* there were performed several Standard Problems in the field of Emergency Core Cooling (ECC), Loss-of-Coolant Accident (LOCA). On CSNI full meeting in November 1977 the Federal Ministry for Research and Technology (BMFT) proposed to perform a similar exercise in the field of Containment Responses after a LOCA in a Light Water Reactor and to sponsor it. The Committee supported the proposal in principle but felt it necessary to hold a preparatory meeting. It took place on May 10/11, 1978 at Battelle-Institut, Frankfurt (FRG) including a visit of the test facility. All experts in the meeting indicated /2/ that they would recommend to their organizations to perform - according to the procedures described in CSNI Report No. 17 /1/ - a Standard Problem based on a test D15 (performance December 20, 1977) out of a series of tests conducted at Battelle-Institut and sponsored by BMFT within the frame of the German Reactor Safety Research Program (RS 50: Pressure Distribution in Containment). Specification /3, 4/ was sent from GRS to possible participants in August 1978. The Standard Problem was approved by the CSNI full meeting in November 1978. After deadline of "blind" German Standard Problem No. 1 (Containment-Standard-Problem) based on the same test, experimental results of test D15 were communicated to participants in December 1978 /5, 6, 7/ this Standard Problem therefore being an "open" one (deadline May 1, 1979).

The technical purpose of the problem is to compare experimental results of history of pressure, temperature, pressure difference, and water mass after a steamline rupture within a chain of six subsequent compartments (simplified integral test) with the corresponding results of best-estimate posttest-calculations from computer codes for three different time intervals.

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* Organization for Economic Cooperation and Development-Committee on the Safety of Nuclear Installations

Finally, in the comparison took part 11 countries with 12 contributions using 11 different computer codes and, partly, several versions (s. Table 1). Contributions arrived from April 10 to May 23, 1979 two of them revised thereafter (arrival of corrected tapes June 11 and July 2, 1979).

The workshop on the results of the Standard Problem was held at GRS, Garching, FRG on September 17/18, 1979. Comparison results and the results of the individual participants were presented and discussed in detail (see /10, 11/).

Supplementary information to and comments on the draft comparison report /12/ came from Australia, Belgium, Canada, Germany, Italy (CNEN/Pisa), Italy (NIRA), the Netherlands, Sweden, and the United States and are far extendingly considered in the present final report.

Comments on submitted results and results of parametric studies (Australia, Germany, Italy (CNEN/Pisa), Italy (NIRA), Sweden, United Kingdom) are content of the appendix.

TABLE 1: Participation

Country (organization)	Contributor	Computer code	Time interval (s)
Australia* (AAEC)	J. Marshall, P. Holland	ZOCO V	0 to 2.5 0 to 50
Belgium (Tractionel)	E. Stubbe	TRAP-SCO	0 to 2.5
		TRAP-CON	0 to 50 0 to 1500
Canada (AECL-EC)	J.E. Dick, J.D. Lovatt, D.R. Pendergast	PRESCON	0 to 2.5 0 to 50 0 to 1500
Finland (VTT)	L.J. Mattila, H. Holmström	RELAP4/MOD6	0 to 2.5 0 to 50
		CONTEMPT-LT/026 (VTT version)	0 to 1500
France (CEA/EDF)	A. Sonnet, A. Mattei/ D. Roy	GRUYER	0 to 2.5 0 to 50 0 to 1500
F.R.Germany (GRS)	Mrs. G.Hellings, A. Berning, G. Mansfeld	COFLOW	0 to 2.5
	D. Risse M. Tiltmann	CONDRU 4	0 to 50 0 to 1500
Italy (CNEN/Pisa Univ.)	R. Romanacci/ 9 authors	RELAP4-MOD5(1)	0 to 2.5 0 to 50
		CONTEMPT LT-026 (Tagami)	0 to 1500
Italy (NIRA)	V. Viotti, A. Hassid, B. Chiantore, A. Pennese	PACO	0 to 2.5 0 to 50 0 to 1500

TABLE 1 (contd.): Participation

Country (organization)	Contributor	Computer code	Time interval (s)
Netherlands (ECN)	J.P.A.van den Bogaard, A. Woudstra	ZOCO V (modif.)	0 to 2.5 0 to 50 0 to 1500
Sweden (Studsvik)	J.E. Marklund	COPTA-5	0 to 2.5 0 to 50 0 to 1500
United Kingdom (UKAEA, AEEW)	W.H.L. Porter	CLAPTRAP II (AEEW-R1108)	0 to 2.5 0 to 50
		CLAPTRAP I (AEEW-R965)	0 to 1500
United States (USNRC/EG&G)	S. Fabic/ C.R. Broadus	BEACON/MOD3	0 to 2.5

* As for all participants the results submitted in May 1979 (deadline) are included in the main part of the report. They are provided with an asterix because the authors declared them invalid when results of additional calculations with revised coating data etc. were performed (data arrival August 27, 1979). Further explanations are given in the appendix.

2. BRIEF DESCRIPTION OF THE PROBLEM

For more details see specification /3, 4/.

2.1. Test facility

The test facility consists of a high pressure system and a model containment. The high pressure system consists of a pressure vessel containing heated water and steam, a piping system connecting the pressure vessel with the location of rupture, and an auxiliary recirculation loop. In this test the containment compartments were chain-type arranged (6 subsequent compartments, s. figs. 1 and 2). Starting in the rupture compartment R6 (longitudinal flow) the fluid flows via a channel with sharp-edged inlet into the first follow-up compartment R8 (longitudinal flow) and via the sharp-edged orifice Ü 78 B (situated on the ceiling at the end of R8) into compartment R7. After passing R7 (longitudinal flow) the fluid enters via sharp-edged orifices compartment R4 (transversal flow), then compartment R5 (longitudinal flow), and finally the big dome compartment R9 working as a sink.

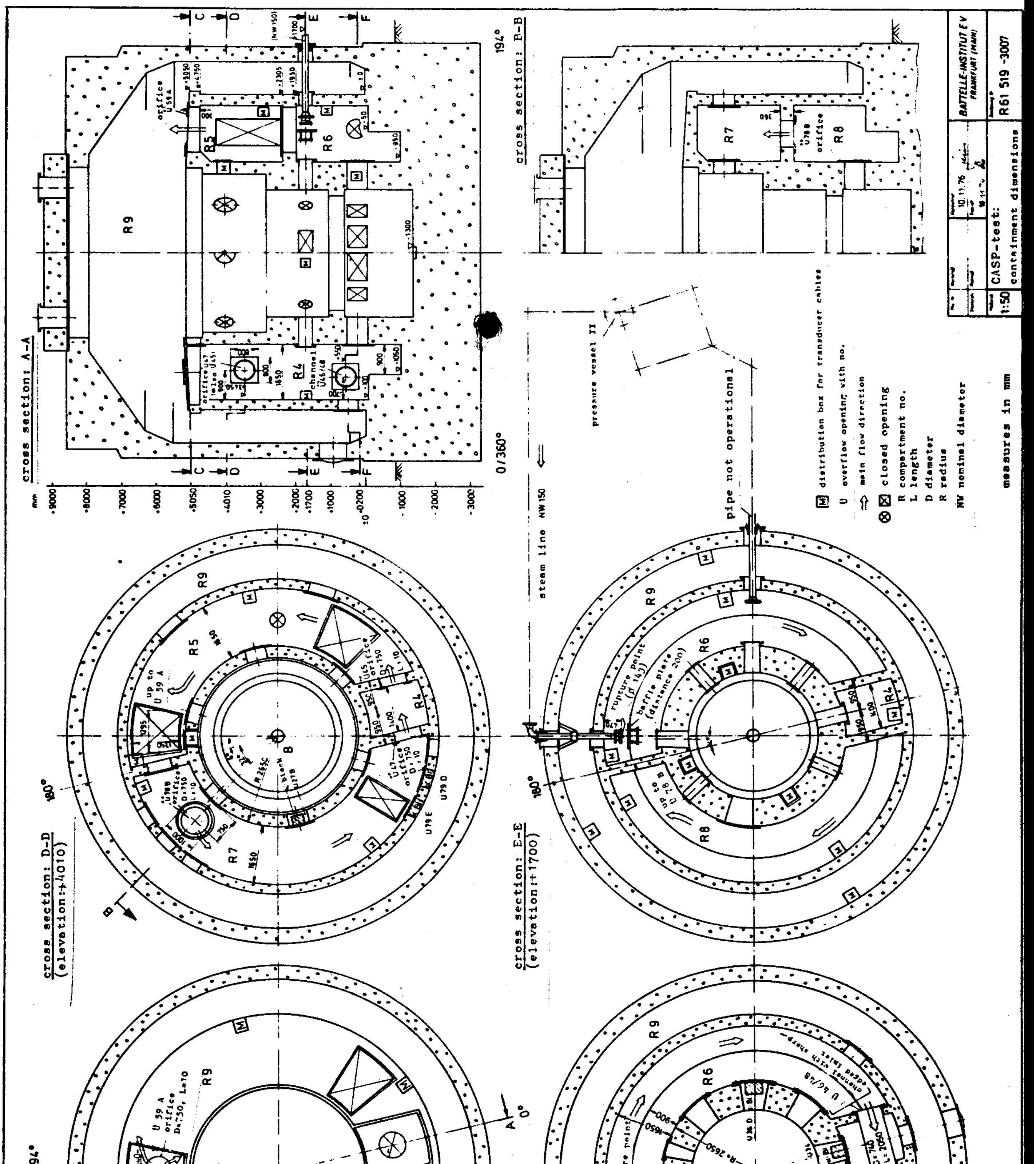

Fig. 1:

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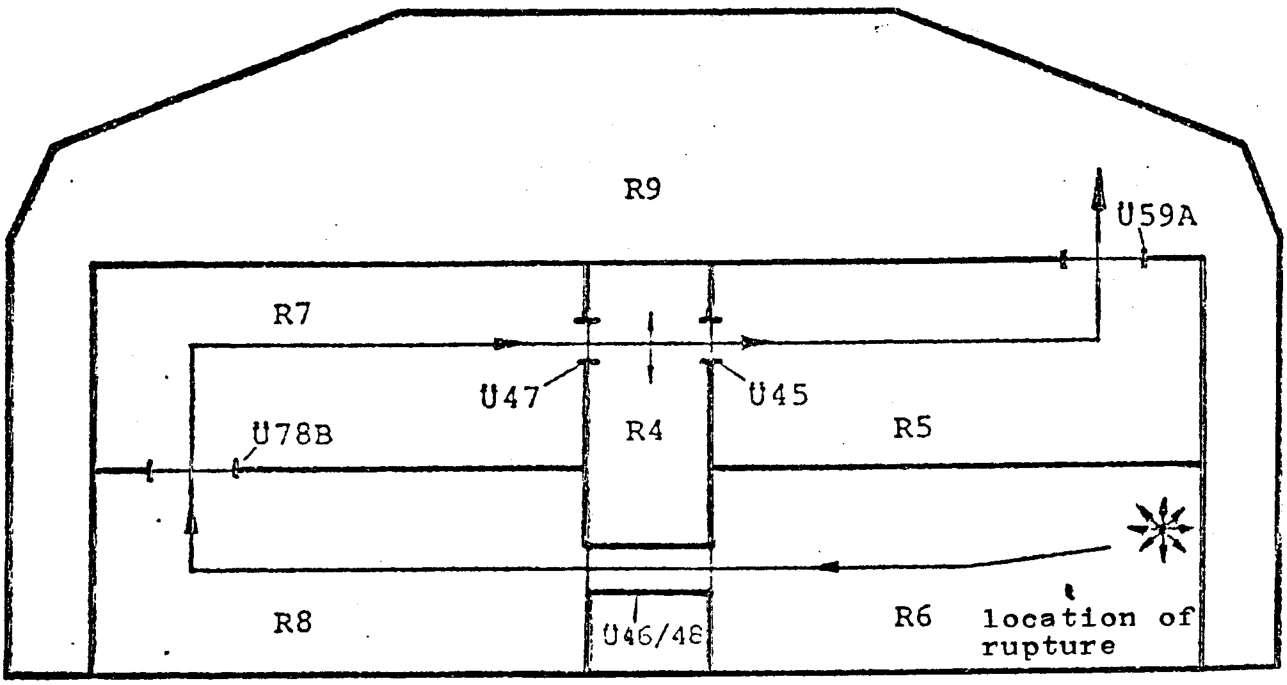


Rupture compartment:	R6
Compartment chain:	R6 - R8 - R7 - R4 - R5 - R9
Flow areas:	Ü 46/48 } circular channel
	Ü 78B, Ü 47, Ü 45, Ü 59A } sharp-edged orifices
Flow path:	R6 - Ü 46/48 - R8 - Ü 78B - R7 - Ü 47 - R4 - Ü 45 - R5 - Ü 59A - R9

Fig.2: Scheme of the Compartment Chain and Associated Flow Paths

2.2 Initial conditions

The measured initial conditions for test D15 before blowdown were as follows:

High pressure system (pressure vessel and lines)

initial pressure	P_o	= 69.8 bar	
initial temperature	T_o	= 285.5 ^oC	(averaged)
mass of steam	m_D	= 126.6 kg	
mass of water	m_W	= 1791.8 kg	

Containment

initial atmospheric pressure		P_o = b	= 1.0152 bar		
R6	initial temperature	T_o	= 10.6	^oC	(averaged)
R8	" " "	T_o	= 9.8	^oC	
R7	" " "	T_o	= 8.4	^oC	
R4	" " "	T_o	= 9.0	^oC	
R5	" " "	T_o	= 9.0	^oC	
R9	" " "	T_o	= 8.7	^oC	
	relative humidity	fr	= 60 % (estimated)		

2.3 Boundary conditions

Boundary conditions for the containment were the mass flow rate and associated specific enthalpy as function of time measured at the rupture point:

<u>Mass flow rate and associated specific enthalpy as function of time</u>

time (s)	mass flow rate (kg/s)	specific enthalpy (kJ/kg)
0	0	2773.7
0.01	50.9	2773.7
0.015	70.7	2773.7
0.065	84.6	2773.7
0.22	66.0	2763.0
0.32	58.9	2760.0
0.75	43.0	2761.5
1.2	45.3	2754.2
2.8	37.0	2731.8
2.92	20.9	2731.8
3.0	68.9	1251.2
3.1	58.2	1280.6
4.0	59.0	1347.9
10.0	39.8	1615.7
15.0	30.4	1753.2
20.0	26.6	1775.9
25.0	21.2	1948.6
30.0	16.3	2136.5
40.0	10.0	2724.7
50.0	6.7	2716.4
70.0	0	2716.4

Above given values for mass flow rate and specific enthalpy are evaluated from measurements without any correction. Specific enthalpy includes kinetic energy $\frac{w2}{2}$. The history of both values shows that up to 2.92 s pure steam is entering the containment.

2.4 Instrumentation

Table 2 shows the designation scheme for the measuring points which also gives information on object of measurement, measured variable and type of sensor, positions of the measuring points, and the kind of installation.

Figures 3 to 8 show the measuring point positions in each compartment of the containment.

The individual values are measured in the following way:

PS static pressure by piezoelectric transducer directly installed at the measuring point (fast)

PL static pressure by strain gauge transducer or piezoresistive transducer (on PMS-basis) installed outside the containment (measuring point connected to transducer by pressure lines, slow)

PD pressure difference by piezoresistive transducer on DMS-basis directly installed at the measuring point position

TF temperature by "unencapsulated" Ni/CrNi thermocouple (30μm d., sensitive to mechanical stresses)

TS temperature by Ni/CrNi thermocouple 0.25 mm o.d., fast)

TL temperature by Ni/CrNi thermocouple (1 to 1.5 mm o.d., slow)

TW temperature by ohmic thermometer

WS water level by capacitive transducer installed outside

TABLE 2: Designation of Measuring Points

for instance	9	P	S	3	1	8	A	Ø	5	M
or	B	T	S	1	Ø	Ø	2	G	2	
	1	2	3	4	5	6	7	8	9	10

1 Object of measurement

2+3 Measured value and type of sensor

4-9 Positions of measuring points

10 Special type of installation

Digit 1: Object of measurement

1 to 9	Containment compartment numbers R1 to R9
Ø	Reactor cavity in containment
B	Pressure vessel
L	Pipeline of long-term cooling system
P	Buffer tank
R	High-pressure pipeline

Digits 2 to 3: Measured value and type of sensor

DG	Density (gamma ray absorption)
DK	Density (capacitative)
FA	Force on mockup (piezoelectric)
FD	Force on drag body (strain gauges)
FP	Force on baffle plate (piezoelectric transducer)
FV	Vertical force on the vessel (strain gauge transducer)
PD	Pressure differential
PL	Static pressure, slow (strain gauge transducer or piezoresistive transducer)
PP	Dynamic pressure (piezoresistive transducer)

TABLE 2 (contd.)

PS	Static pressure, fast (piezoelectric transducer)
TF	Temperature ("unencapsulated" thermocouple, 30 μm)
TL	Temperature, slow (thermocouple 1 to 1.5 mm O.D.)
TS	Temperature, fast (thermocouple 0.25 mm O.D.)
TW	Temperature (ohmic thermometer)
WS	Water level (capacitative)

Digits 4 to 9: Positions of measuring points

I. Designations for pressure vessels (digit 1: "B"):

Digit 4 to 7:	Height in cm, measured from the vessel floor	
Digit 8 + 9:	A1 to A4 . . . . G1 to G2	Horizontal nozzles
	H-	Upper vertical nozzle
	U-	Lower vertical nozzle
	--	Other

II. Designations for containment, buffer tank and pipeline (digit 1: "Ø", "1" to "9", "C", "P" or "R"):

Digits 4 to 6: ØØØ to 36Ø polar angle in angular degrees, of manhole (= 0^o) in clockwise direction

Digit 7:	1 to 9	Installed in wall to compartment R1 to R9
	A	On/in outer wall
	F	In intermediate flange
	I	On/in inner wall
	P	On/in baffle plate
	U	On/in overflow opening
	W	Heat transfer measuring block
	D	On/in steam generator mockup

TABLE 2 (contd.)

Digits 8 + 9:	Height in dm above bottom of the containment compartment in question (in compartments R4, R6, R8 above sump floor, and in the case of pipelines above the sump floor, compartment R6)

III. Designations in the long-term cooling system (digit 1: "L"):

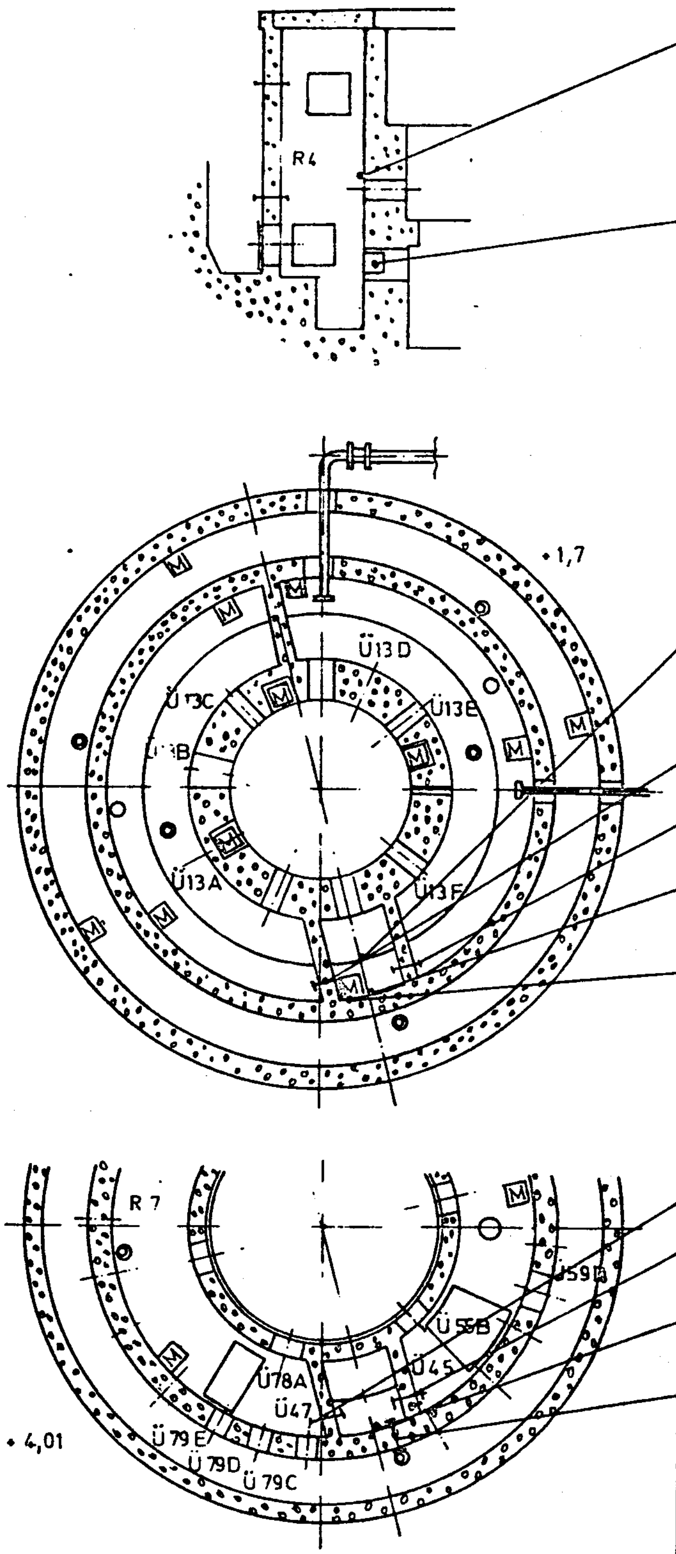
Characteristic word, for instance:

ABLAUF	(drain)
ZULAUF	(feed line)
SPRUEH	(spray system)

Digit 10: Special type of installation

M	In spray protection tube
L	With pressure measurement line
T	In dead-water area
W	In wall
-	Other

test no. D15	measuring point position	compartment R4



designation of measuring points		MUX
4 TS ØØØ I 3Ø		
Alpha-Block:		
4 TL ØØØ W 13 (3,6)		21
4 TL ØØ1 W 13 (24,5)		22
4 TL ØØ2 W 13 (14,2)		23
4 TL ØØ3 W 13 (66,5)		24
4 TL ØØ4 W 13 (107,6)		25
4 TL ØØ5 W 13 (1,0)		26
4 TL ØØ6 W 13 (40,8)		27
4 TL ØØ7 W 13 (7,7)		28
4 TL ØØ8 W 13 (1,0)		29
4 TS ØØØ I 13 (Atm.)		177
4 TS ØØØ M 3Ø		178
4 PD Ø1Ø 8 24 W		148
4 PD 35Ø 6 24 W		146
4 PL ØØØ A 3Ø		129
4 PL ØØ8 A 25 L		130
4 PD 35Ø 7 51 W		147
4 PD Ø1Ø 5 51 W		145
4 PS ØØØ A 5Ø M		162
4 TS ØØØ A 5Ø		179
4 PD 354 9 46 W		149
4 WS		209

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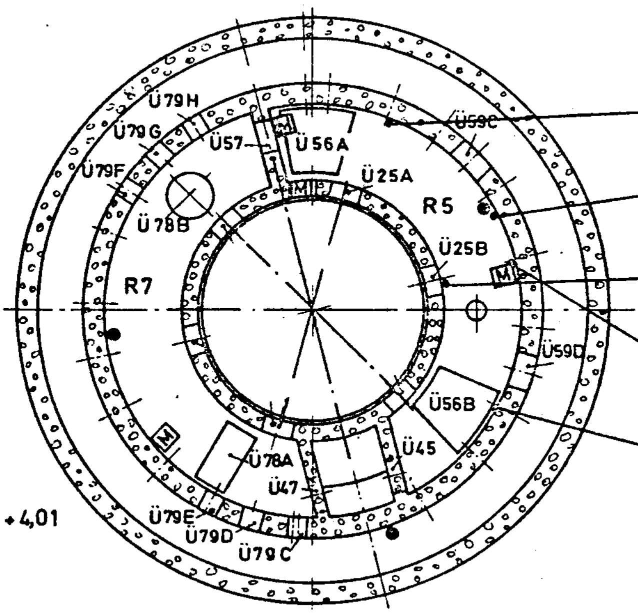
Fig. 3:

MUX=channel no.

test no. D15	measuring point position	
		compartment R5



designation of measuring points		MUX
5 PS 215 A 12		164
5 TS 214 A 12		180
5 PL 255 A 17 L		131
5 PS 27Ø I 15 M		165
5 TS 27Ø I 12		182
5 PD 27Ø 9 15 W		150
5 TS 269 A 12		181
5 PS 312 A 11		166
5 TS 313 A 11		183
5 WS		210

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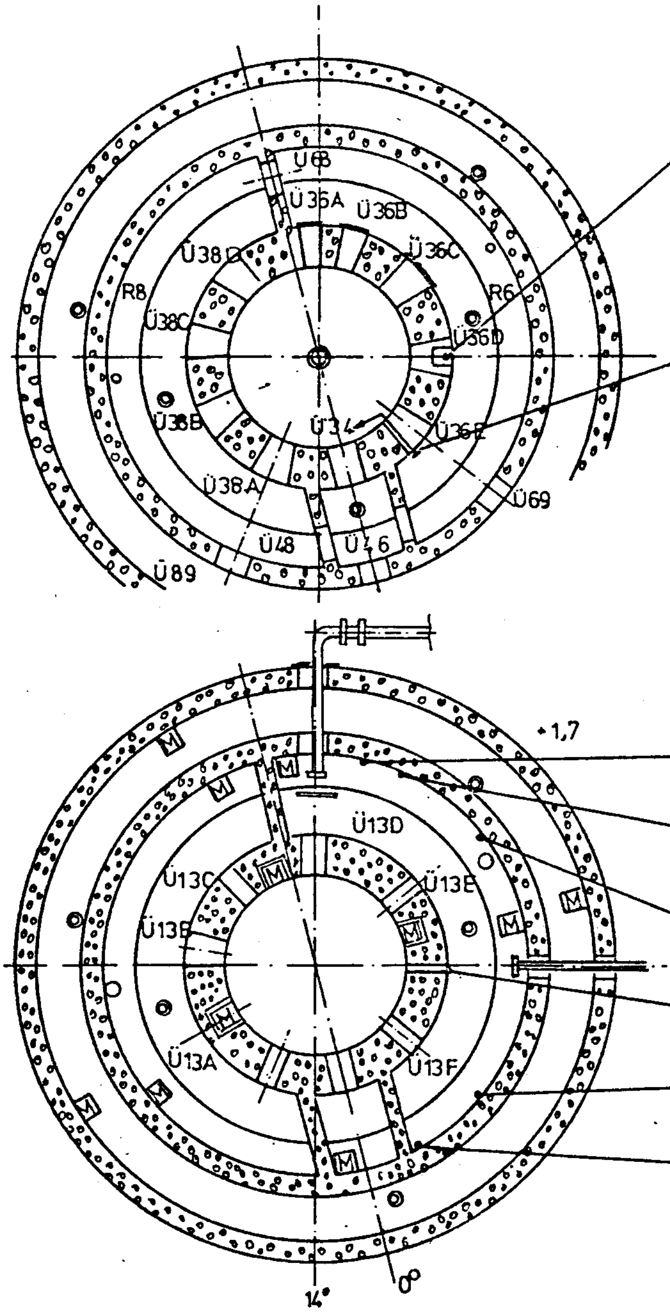
Fig. 4: MUX=channel no.

test no. D15	measuring point position	
		compartment R6



designation of measuring points		MUX
Alpha-Block:		
6 TL 28Ø W 12 (3,6)		12
6 TL 281 W 12 (24,5)		13
6 TL 282 W 12 (14,5)		14
6 TL 283 W 12 (66,6)		15
6 TL 284 W 12 (107,6)		16
6 TL 285 W 12 (1,0)		17
6 TL 286 W 12 (40,8)		18
6 TL 287 W 12 (7,7)		19
6 TL 288 W 12 (1,0)		20
6 TS 284 I 12 (Atm.)		187
6 PD 323 8 1Ø L		151
6 PS 2Ø8 A 21 W		167
6 TF 211 A 21		184
6 PL 255 A 25 L		132
6 PS 245 A 21 W		168
6 TS 246 A 21		186
6 PD 284 9 27 W		152
6 PS 32Ø A 21 W		169
6 TS 318 A 21		185
6 PS 343 A 29 T		174
6 WS		211

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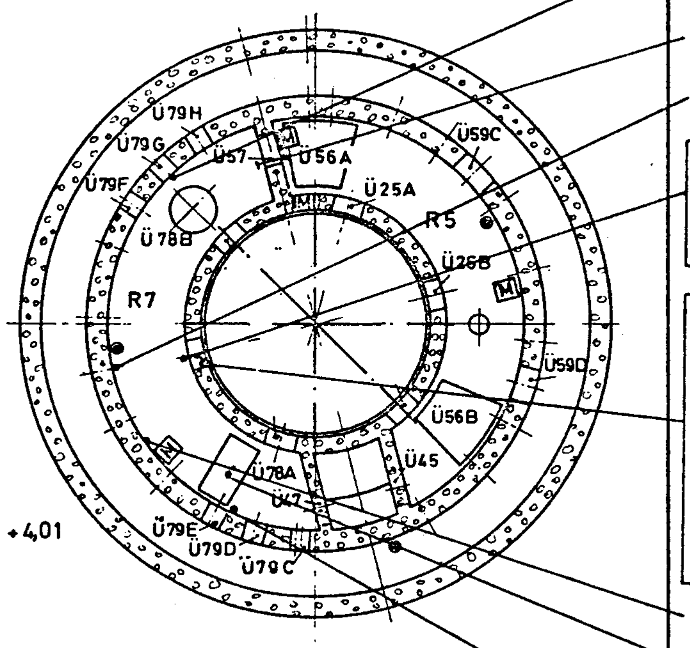
Fig. 5: MUX=channel no.

test no. D15	measuring point position	compartment R7



designation of measuring points		MUX
7 PS 143 A 12 W		173
7 TS 144 A 12		192
7 PD 18Ø 5 19 W		153
7 TS Ø9Ø A 12		190
7 PS Ø89 I 15 M		172
7 PD Ø89 9 15 W		155
7 TS Ø89 I 18		191
Alphablock:		
7 TL Ø9Ø W 17 (3,6)		2
7 TL Ø91 W 17 (24,5)		3
7 TL Ø92 W 17 (14,5)		4
7 TL Ø93 W 17 (66,6)		6
7 TL Ø94 W 17 (107,6)		7
7 TL Ø95 W 17 (1,0)		8
7 TL Ø96 W 17 (40,8)		9
7 TL Ø97 W 17 (7,7)		10
7 TL Ø98 W 17 (1,0)		11
7 PL Ø66 A 12 L		135
7 PD Ø45 8 ØØ W		154
7 PS Ø38 A 12 W		171
7 TS Ø37 A 12		189
7 WS		212

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Fig. 6: MUX=channel no.

test no. D15	measuring point position	
		compartment R8

designation of measuring points		MUX
8 PS 153 A 21 W		176
8 TS 158 A 21		196
8 TS ø9ø I 21		194
8 TS ø9ø A 21		193
8 PD ø75 9 12 W		156
8 PL ø53 A 25 L		136
8 PS ø4ø A 21 W		170
8 TS ø42 A 21		188
8 WS		213

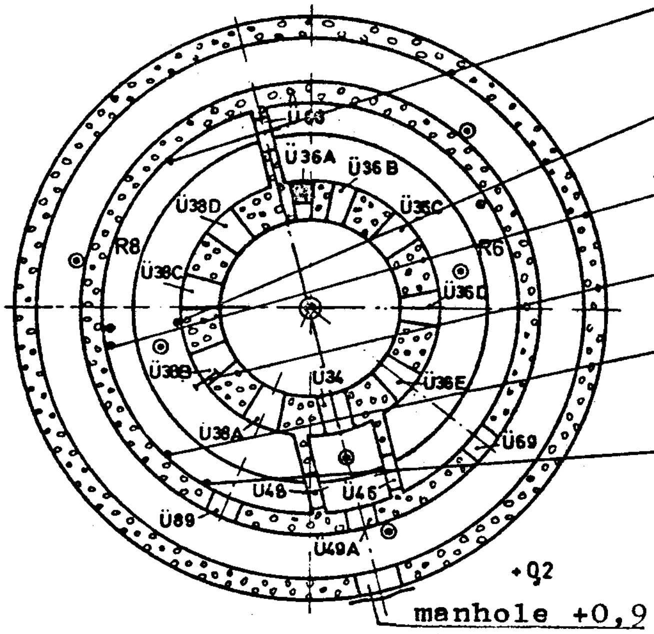

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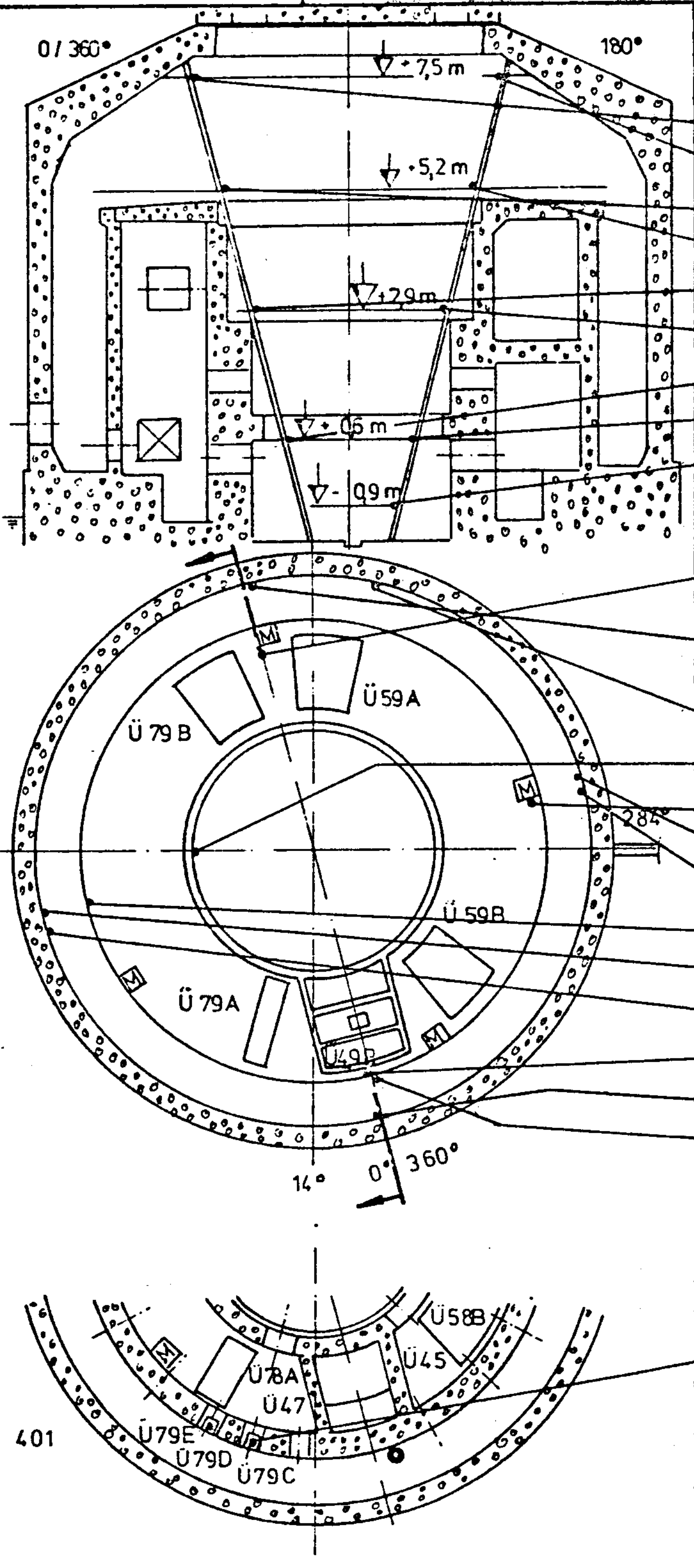
Fig. 7: MUX=channel no.

test no. D15	measuring point position	compartment R9



designation of measuring points		MUX
9 TW ØØØ M 75		41
9 TW 18Ø M 75		42
9 TW ØØØ M 52		43
9 TW 18Ø M 52		44
9 TW ØØØ M 29		45
9 TW 18Ø M 29		46
9 TW ØØØ M Ø6		47
9 TW 18Ø M Ø6		48
9 TW 18Ø M -9		49
9 TW 18Ø A 52		53
9 TW 18Ø A 29		51
9 TW 18Ø A Ø6		52
9 PL 2Ø7 A 16 L		137
9 PL 1Ø3 M 39 L		138
9 TW 27Ø A 52		64
9 TW 27Ø A 29		63
9 TW 27Ø A Ø6		62
9 TW Ø9Ø A 52		56
9 TW Ø9Ø A 29		57
9 TW Ø9Ø A Ø6		58
9 TW ØØØ A 52		59
9 TW ØØØ A 29		60
9 TW ØØ5 A Ø6		61
Alphablock (new):		
9 TL Ø3Ø W 4Ø (8,6)		30
9 TL Ø31 W 4Ø (24,5)		31
9 TL Ø32 W 4Ø (14,2)		32
9 TL Ø33 W 4Ø (66,6)		33
9 TL Ø34 W 4Ø (107,6)		34
9 TL Ø35 W 4Ø (1,0)		35
9 TL Ø36 W 4Ø (40,9)		36
9 TL Ø37 W 4Ø (7,7)		37
9 TL Ø38 W 4Ø (1,0)		38
9 TL Ø3Ø I 4Ø (Amb.)		39
3 WS		208
9 WS		214

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Fig. 8: MUX=channel no.

2.5 Errorbands of the measurements

2.5.1 Errorbands of variables measured in the containment

The following table informs about the probable relative total measuring errors with a statistical accuracy of 96 % (2σ) in percent of the measuring range of the variable. In fact, the given erros are only valid for the time range t≤0 that is the time before start of blowdown. Temperature and pressure effects on transducers and cables during blowdown are not regarded. However, temperature and pressure influence being effective with a certain time delay the given measuring errors are also approximately valid for the time range t > 0 within the given measuring time (s. also /4/).

measured quantity	probable relative total measuring error in ± %	related to measuring time (s)	related to measuring range	delay time for measurement
PS	0.9	0.2!	5 bar	
PL	0.7	1500	5 bar	
PD	1 to 5	2	0.5 bar	
TS	1.1	1500	150 °C	15 to 20 ms
TF	1.1	1500	150 °C	some ms
TL	1.1	1500	150 °C	~ 1 s
TW	0.7	1500	150 °C	~ 1 s
WS (cap.)	2.5 to 10			
WS (U-tube)	1.5 to 5			

In general above given measuring erros are small and most of the time within the oscillatory margins of the measured variables. Therefore experimental errorbands are not shown in the comparative plots. Measuring erros supplementarily communicated by Battelle-Institut are almost of the same order. To improve comparability of experimental errorbands with the calculational bandwidths the experimental errorbands are shown in the comparative plots as bars according to scale.

2.5.2 Errorbands of initial and boundary conditions to be input for containment calculations

The initial conditions (pressure in containment and temperatures in the diverse compartments) are measured with the high accuracy as is valid for the containment measurements at zero time. Relative humidity, less important because of low initial temperatures in the containment, was estimated.

For pure containment problems the uncertainty in calculating mass flow rate and specific enthalpy at the break in the primary system with blowdown codes is atypical. To eliminate this both variables were measured and determined to be the boundary conditions for the containment calculations. These measurements partly have relatively high errors (see figs. 8.1 and 8.2 from /5/). Especially in the regime of two-phase flow the high differences between test D15 and D10 also indicate measuring errors which is supported by the fact that the pressure histories in pressure vessel and at rupture point for both tests do hardly differ.

The influence of errors of the measured initial and boundary conditions on containment calculations is discussed in /9/.

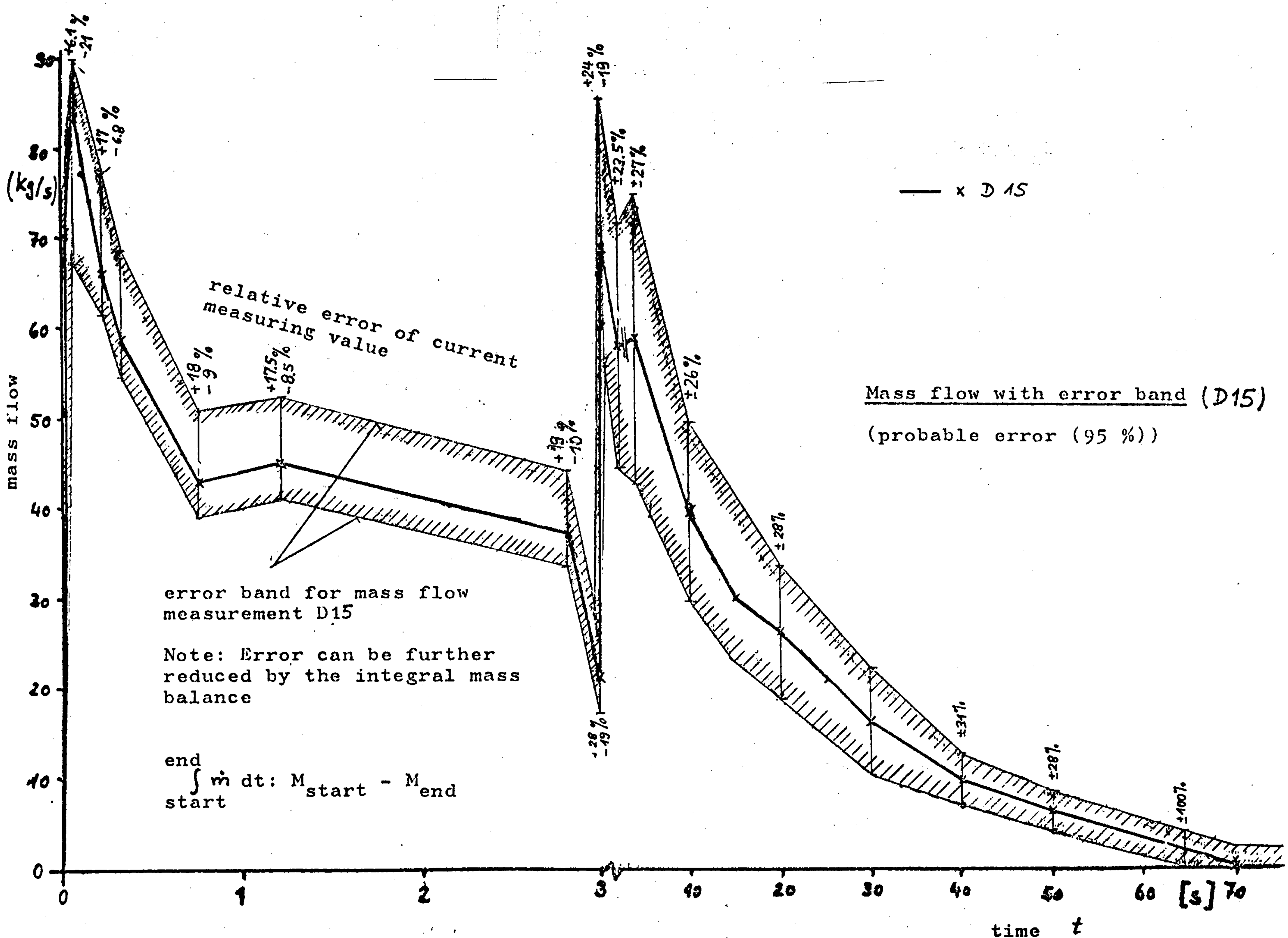

Fig. 8.1: Experiment D 15, mass flow with error band (probable error)

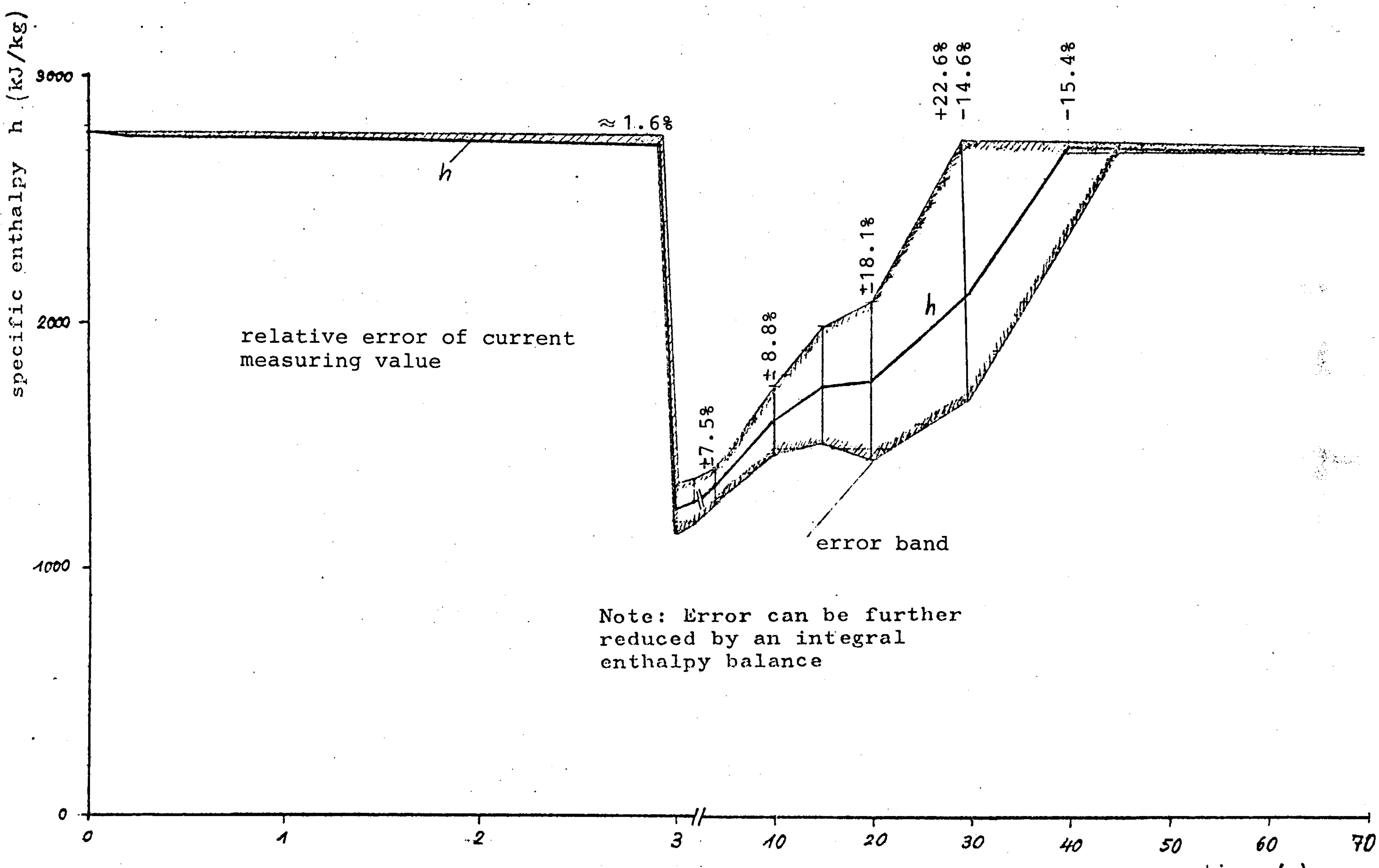

Fig. 8.2: Experiment D15, specific enthalpy with error band (probable error (95%))

2.6 Variables to be calculated

As stated in /3/ each participant should calculate the following variables as function of time

for time interval 0 to 2.5 s:

- 2 pressures in each compartment
- 2 temperatures in compartments R4, R7, R8
  3 temperatures in compartments R5, R6
  5 temperatures in compartment R9
- 13 pressure differences between different compartments

for time interval 0 to 50 s:

- 2 pressures in each compartment
- 2 temperatures in compartments R4, R7, R8
  3 temperatures in compartments R5, R6
  5 temperatures in compartment R9
- water masses in each compartment

for time interval 0 to 1500 s:

- pressure
- temperature
- water mass
  in the containment to be regarded as a single node.

3 PRESENTATION OF RESULTS

3.1 Listing of important features and input parameters of the codes used

In table 3 important features, assumptions, and input parameters of the codes used by the participants are put together for the different time intervals. Information was taken from the reports submitted together with the calculational results.

Calculational results for all three specified time intervals were submitted from all participants but Australia (not for 0 to 1500 s) and USA (not for 0 to 50 s and 0 to 1500 s).

For the long term range, simulating the containment as one node, about half of the participants used other computer codes or other versions than in the short term range calculations (total of 11 different codes and, partly, several versions).

One code (BEACON, advanced code using 1D/2D-mesh concept) is able to account for full non-equilibrium, the others being lumped-parameter codes more or less based on homogeneous models.

TABLE 3 Important features and input parameters

Country	Time interval (s)	Computer code	Model	Number of nodes	Heat transfer			Flow resistances			Water transport?	Kinetic energy considered?	Computer	Computer time (s)	Other remarks
					to structures?	Correlation according to... (htc $\frac{W}{m^2 K}$)	coating considered?	concept	channel R6 - R8	other orifices					
Australia *	0 - 2.5	ZOCO V	.	6	yes	derived htc to fit p_{R6} (0-3s:2800→300 ≈lin. decr.; 3-50s:300=const)	no	compressible flow	C_D = 1.0	C_D=1.0	yes (carry over factor 0.01)	.	.	.	.
	0 - 50	ZOCO V		6	yes	"	no	"	C_D = 1.0	C_D=1.0	"	.	.	.	.
Belgium	0 - 2.5	TRAP-SCO	homogeneous	11(R6:6)	no (reduced (≈7%) energy input + given mass flow rate)	(corresponds to ≈750)	no	onedimensional incompressible unsteady mom. equ. with friction, Fauske critical flow model (C_D=1.0)	$K+f\cdot\frac{L}{D}$= 1.2+0.084	C_D=1.0	yes (carry over fraction 20% =const for all vent paths)	no (U45: contraction coeff. 0.8≙ 20% loss of mom.)	IBM 370	129	.
	0 - 70	TRAP-CON	"	1	yes	Tagami/Uchida (2 x actual energy to match peak pressure) [htc_{max}=1550 (50s), htc=70→15(130-1500s)]	yes	-	-	-	"	-	"	24	.
	0 - 1500	TRAP-CON	"	1	yes	"	yes	-	-	-	flashing fraction 90% after 70s	-	"	121	flashing fraction at break 90%→10% of released water and steam to sump
Canada	0 - 2.5	PRESCON	homogeneous	10(R6,R8, R7, R5:2, R4, R9:1)	yes (not in channel, combined surface areas)	Uchida	.	onedim. mom. equ. with friction factors (for abrupt area changes: reversible and irreversible part of press. drop)	ζ_{in}=0.5 ζ_{out}=1.0 $\zeta_{friction}$=0.4	ζ= 1.7 (except U45: ζ = 0.35)	no (water flashing in source node, unflashed liquid removed)	yes (ζ_{U45}=0.35)	CYBER 170	15	.
	0 - 50	PRESCON	homogeneous	10(R6,R8, R7, R5:2, R4, R9:1)	"	"	.	"	"	"	"	"	"	164	.
	0 - 1500	PRESCON	homogeneous	1	yes	"	.	-	-	-	-	-	"	4	.
Finland	0 - 2.5	RELAP4/MOD6	complete sep. of phases but homogeneous in R4	7(R4:2)	yes (metal, concrete separate)	40 x forced convection	yes	incompr. single stream flow without mom. flux; channel: compr. single stream flow with mom. flux; two-phase multiplier in f; form loss coeff. acc. to Idelchik	.	.	yes	.	IBM 370/3033	35	.
	0 - 50	RELAP4/MOD6	"	7(R4:2)	"	"	yes	"	.	.	yes	.	IBM370/3033	73	.
	0 - 1500	CONTEMPT-LT/026	homogeneous	1	yes	Uchida for R9, other comp.: lin.incr. 45.4→ 10000(0-35s), 10000 = const (35-70s)	no	-	-	-	-	-	IBM370/3033	120	.
France	0 - 2.5	GRUYER	homogeneous	6	yes (steel and painted concrete)	up to 50s:1300=const., then htc=1.5(ΔT)$^{1/3}$; Uchida for warmer walls, 11.3+454 $\frac{m_{steam}}{m_{air}}$ for colder walls	yes (80µm)	steady state adiabatic flow, isentropic expansion, no friction, hom. frozen model	sharp-edged orifice C_D = 1.0	C_D=1.0	.	yes	IBM360-91	122	"a priori" realistic assumptions, heat conduction for planar or cylindrical walls
	0 - 50	GRUYER	homogeneous	6	"	"	"	"	"	"	.	yes	IBM 360-91	400	"
	0 - 1500	GRUYER	homogeneous	1	yes	"	no	-	-	-	-	-	IBM 360-91	32	"

* see footnote on page 5 and App.

Table 3 (contd.)

Country	Time interval (s)	Computer code	Model	Number of nodes	Heat transfer: to structures?	Heat transfer: Correlation according to... (htc $\frac{W}{m^2K}$)	Heat transfer: coating considered?	Flow resistances: concept	Flow resistances: channel R6 - R8	Flow resistances: other orifices	Water transport?	Kinetic energy considered?	Computer	Computer time (s)	Other remarks
F. R. Germany	0 - 2.5	COFLOW	homogeneous	17+1 (R6, R8, R7, R4, R5:3, U68; R9; out-side)	yes	input f(t) for R6, R8, R7 beginning with break node and decreasing slope increasing from 10 to 10000 (up to 5s in R7) for other comp. 10	yes (80µm)	channel and subdiv. of rooms: nonstat. incompr. mom. equ. with flow resistance coeff. ζ; orifices: quasisteady compr. orifice flow equ. with $C_D = C_{D_{inc}} \cdot f(p_2/p_0)$	$\zeta_{in} = 0.42$, $\zeta_{out} = 0.72$	$C_{D_{inc}} = 0.7$ (incompr.)	no	yes	AMDAHL470V/5	120	precalculation results for "blind" German Standard Problem No. 1, heat conduction for planar walls
	0 - 50	CONDRU4	homogeneous	1	yes (steel and concrete)	input f(t)=350→45	no	-	-	-	-	-	AMDAHL470V/5	"	"
	0 - 1500	CONDRU4	homogeneous	1	"	"	"	-	-	-	-	-	AMDAHL470V/5	"	
Italy (CNEN/Pisa)	0 - 2.5	RELAP4-MOD5(1)	Complete separation of phases but homogeneous in U46/48	7 (6+ channel)	yes	50xDittus-Bölter (liqu.forc.conv.)	yes (80 µm)	pressure drop coeff. acc. to Idelchik	$C_D=1.0$	$C_D=1.0$	"	no	IBM 370/158	93	"
	0 - 50	RELAP4-MOD5(1)		7 (6+ channel)	yes	30xDittus-Bölter (liqu. forc. conv.) (380→115 from 0 to 4s), 50xDittus-Bölter (vapor forc.conv.) (115→45.4 from 4s to 50 s)	"	pressure drop coeff. acc. to Idelchik	$C_D=1.0$	$C_D=1.0$	no	no	IBM 370/158	450	"
	0 - 1500	CONTEMPT-LT-026 (Tagami)	compl. sep. of phases	1	yes	Tagami (W-modif.) htc_{max}=2660(40s)	"	-	-	-	no	-	IBM 370/158	681	"
Italy (NIRA)	0 - 2.5	PACO	homogeneous	5 (R4+R5 collapsed)	yes	2100 up to 70s, then Uchida	"	isentropic flow	$C_D = 1.0$	$C_D = 1.0$	no	"	IBM 370/168	100	"
	0 - 50	PACO	homogeneous	5 (R4+R5 collapsed)	yes	"	"	"	$C_D = 1.0$	$C_D = 1.0$	no	"	IBM 370/168	140	"
	0 - 1500	PACO	homogeneous	1	yes	"	"	-	-	-	-	-	IBM 370/168	60	"
Netherlands	0 - 2.5	ZOCO V modif.	homogeneous, not in R6	7 (R6:2)	yes	Henderson/ Marchello	no	steady state incompressible flow	$C_D = 1.0$	$C_D = 1.0$	yes (carry-over factor 0.5)	no	CYBER-175CDC	60	concrete walls between comp. split up and taken as walls inside the comp.
	0 - 50	ZOCO V modif.	"	7 (R6:2)	"	"	"	"	$C_D = 1.0$	$C_D = 1.0$	"	"	CYBER-175CDC	380	"
	0 - 1500	ZOCO V modif.	"	1	"	"	"	-	-	-	-	-	CYBER-175CDC	335	"
Sweden	0 - 2.5	COPTA-5	homogeneous gas mixture, liquid temp. ≠ atm. temp.	5 (R4+R5 combined)	yes	Uchida for R9, 1590 up to 50s for other comp.	no	compressible orifice flow	$C_D = 0.88$	$C_D=0.88$	same composition as gas phase	no	CYBER-172CDC	71	Integration method and time determined by output specification
	0 - 50	COPTA-5	"	"	yes	"	"	"	$C_D = 0.88$	$C_D=0.88$	"	no	"	(2000)	
	0 - 1500	COPTA-5	"	1	yes	Uchida for R9, 1590 up to 50s for other comp.; linear interpolation from 50 to 70s, then 15 = const.	"	-	-	-	-	-	"	161	"
United Kingdom	0 - 2.5	CLAPTRAP II	homogeneous, slip	6	yes	0-50s: 851 $htc=5.48\cdot10^{-7}(\frac{1}{V}\frac{\partial H}{\partial t})^{1.62}$ in R6; vent component $htc=\frac{12.8}{n}\sum_n(\Delta_p\frac{A}{V^{2/3}})^{0.4}$ but > 150	"	adiabatic flow	$C_D = 0.7$	$C_D = 0.8$	yes (carry-over factor 0.035)	yes	"	3180 (0-70 s)	different wall materials can be considered
	0 - 50	CLAPTRAP II	"	6	yes	"	"	"	$C_D = 0.7$	$C_D = 0.8$	"	yes	"	"	"
	0 - 1500	CLAPTRAP I	homogeneous	1	yes	851 up to 70 s, then 100	"	-	-	-	-	-	"	660	different wall materials can be considered
United States	0 - 2.5	BEACON/MOD3	non-equilibrium	178 2D-cells	yes	analogy between heat and mass transfer	yes	1D-meshes, orifices	$C_D = 0.87$	$C_D=0.72$; orifices to and from comp. R4 modeled as 0.193m x 1.65m (decreased area) instead of being square to account for jet effect	yes (negligible)	yes	CDC 7600	~ 1000	modeling of thermocouple to demonstrate differences between pred. gastemp. and measured temp. (for low htc high time lag)

Nodalization (except BEACON with its 1D/2D-mesh concept) was chosen by the different participants in very different manners:

- time interval 0 to 2.5 s (total of 12 participants):
  With regard to pressure measurements in the compartments (see also chapters 3.2 and 3.3) and the licensing important pressure differences between the compartments a simulation one node for one compartment seems sufficient (6 nodes, 3 participants). With regard to specified temperature histories at different locations in one compartment (especially differing slopes in the beginning, not so important for licensing) or pressure waves (appearing especially within about 0 to 0.2 s, not asked for in this Standard Problem) it would be desirable to further subdivide most of the compartments. This was taken into consideration by USA (178 meshes), F.R. Germany (17 nodes), Canada (10 nodes), and partly by Belgium (11 nodes, 6 nodes in R6), Netherlands 7 nodes, 2 nodes in R6), Finland (7 nodes, 2 nodes in R4). While subdividing other compartments these participants also took compartment R9 as one node. This seems to be a good approximation also with regard to temperature history in this time interval (no measuring response of the resistance thermometers because of time lag) and saving computer time. Two participants combined compartments R4 and R5 to one node to account for the negligible pressure difference between R4 and R5.

- time interval 0 to 50 s (total of 11 participants):
  Almost all participants chose the same nodalization as in the short term range except Belgium and F.R. Germany, which lumped all compartments into a single node already during this medium time interval. Simulation of one node per compartment seems to be suitable also with regard to far extending temperature equalization within the compartments except big dome compartment R9, where stable temperature stratification becomes apparent (see also chapters 3.2 and 3.3).

- time interval 0 to 1500 s (total of 10 participants): All participants simulated the whole containment as one node, as was proposed in the specification of the Standard Problem.

One of the most dominant mechanisms in this Standard Problem is heat transfer to the structures. It was considered by all participants in all three time intervals but handled as different as there were different participants. Handling ranged from analogy between heat and mass transfer, use of Tagami- and/or Uchida-correlation (well known from licensing calculations) as well as other correlations, via derived heat transfer coefficients [input f(t) or const(t)] to consider steam front propagation or to fit some pressure histories, to setting dials for forced convection heat transfer correlations (RELAP4 versions). Heat transfer coefficients gained these ways range up to 10 000 $\frac{W}{m^2 K}$ + during steam flow at the location of rupture. Use of Tagami- and/or Uchida-correlation is prevailing for the long term range, especially. Surface coating of the concrete walls was partly considered as specified though little information was found within the participants' reports originally submitted. Influence of coating data revised after deadline of Standard Problem calculations is, as proposed, regarded by some participants in an additional post-analysis (see. App.).

Two concepts for representing flow resistances for the two types of flow paths between neighbouring compartments (channel, sharp-edged orifices) were mainly used: one-dimensional quasi-steady compressible flow with discharge coefficients between 0.7 and 1.0 or/and - to a smaller extent - one-dimensional unsteady incompressible flow (Euler or momentum equation) with friction terms (friction factors or resistance coefficients in a corresponding magnitude as discharge coefficients). Different discharge coefficients respectively resistance coefficients for channel and orifices were used by four participants.

+ UK: up to 48 000 $\frac{W}{m^2 K}$ "attributable to water steam release" (see SINDOC (79)80 in /10/, not communicated originally).

Water transport was considered, to a higher extent only by a few participants. This parameter could have been only of minor to negligible influence on the results, at least during the time period of pure steam flow at the rupture point.

Kinetic energy terms are deemed necessary for more precisely calculating pressure differences. They were considered in most of the codes. This seems to be important especially for simulating jet flow from orifice Ü74 via compartment R4 and short distance orifice Ü45 to compartment R5. Experimentally this results in a negligible pressure difference between R4 and R5. Also other ways were gone to account for this jet effect: smaller resistance coefficient for orifice Ü45, compartments R4 and R5 combined to one node as already stated.

Computer times are inasmuch different as different codes, nodalizations and computers were used.

It should be mentioned that USA modeled a thermocouple to demonstrate differences between predicted gas temperature and measured temperature: especially during gas compression heat transfer coefficients are low, this resulting in a time lag of thermocouple response which is higher than was in general assumed up to now. Further it should be referenced to the fact that the calculational results of F.R. Germany using COFLOW for the time interval 0 to 2.5 s are the same as for the "blind" German Standard Problem No. 1, based on the same test D15.

3.2 Comments on the experimental results and deductions for the comparison (see also /5, 6/)

- Pressure measurements: The pressure measurements with the piezoelectric transducers (PS, fast) directly installed at the measuring point positions partly are without drift only up to 0.2 s (time interval interesting for investigation of pressure waves; afterwards especially near the break an influence of temperature is observed; see also chapter 2.5.1 table). Therefore, for all time intervals the measurement results of external pressure transducers connected to the measuring point positions by pressure lines (PL, slow) are taken for comparison. These are in the time interval 0 to 2.5 s and 0 to 50 s the measuring points

6 PL 255 A 25 L
8 PL Ø53 A 25 L
7 PL Ø66 A 12 L
4 PL ØØ3 A 25 L
5 PL 255 A 17 L
9 PL 2Ø7 A 16 L,

in the time interval 0 to 1500 s the measuring point

9 PL 2Ø7 A 16 l.

For the same measuring channel differences (see fig. 9) can appear for different time intervals of data aquisition (different data aquisition systems).

To illustrate pressure steps (time interval 0 to 2.5 s) and pressure approximation (time interval 0 to 50 s) the pressures of all compartments are plotted together in one figure each. (figs. 10 and 11).

MEASURED VALUES OF CASP-TEST D15 (DEC. 20, 1977)

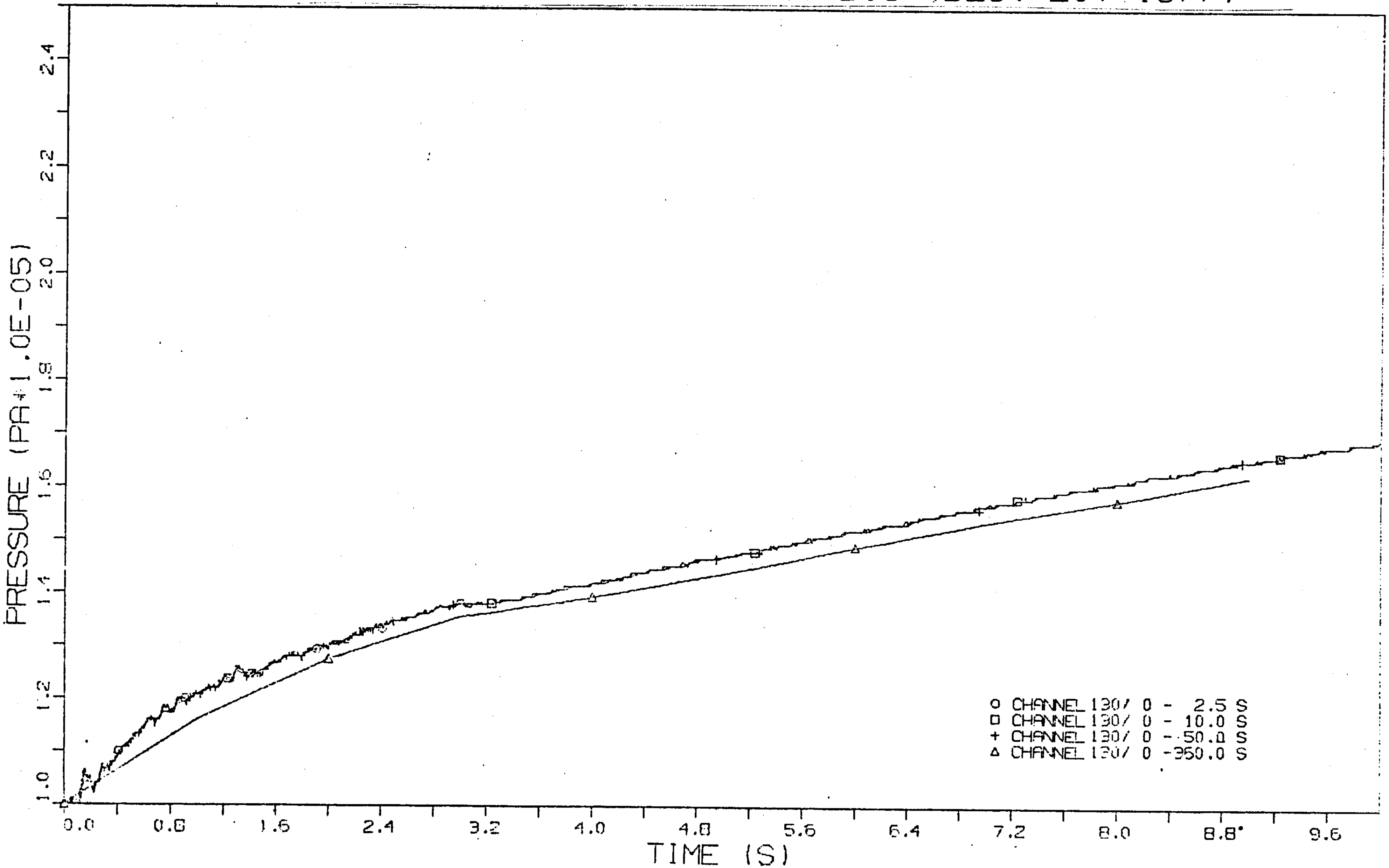

FIG. 9 PRESSURE HISTORY IN COMPARTMENT R4, 4PL008A25L

MEASURED VALUES OF CASP-TEST D15 (DEC. 20, 1977)

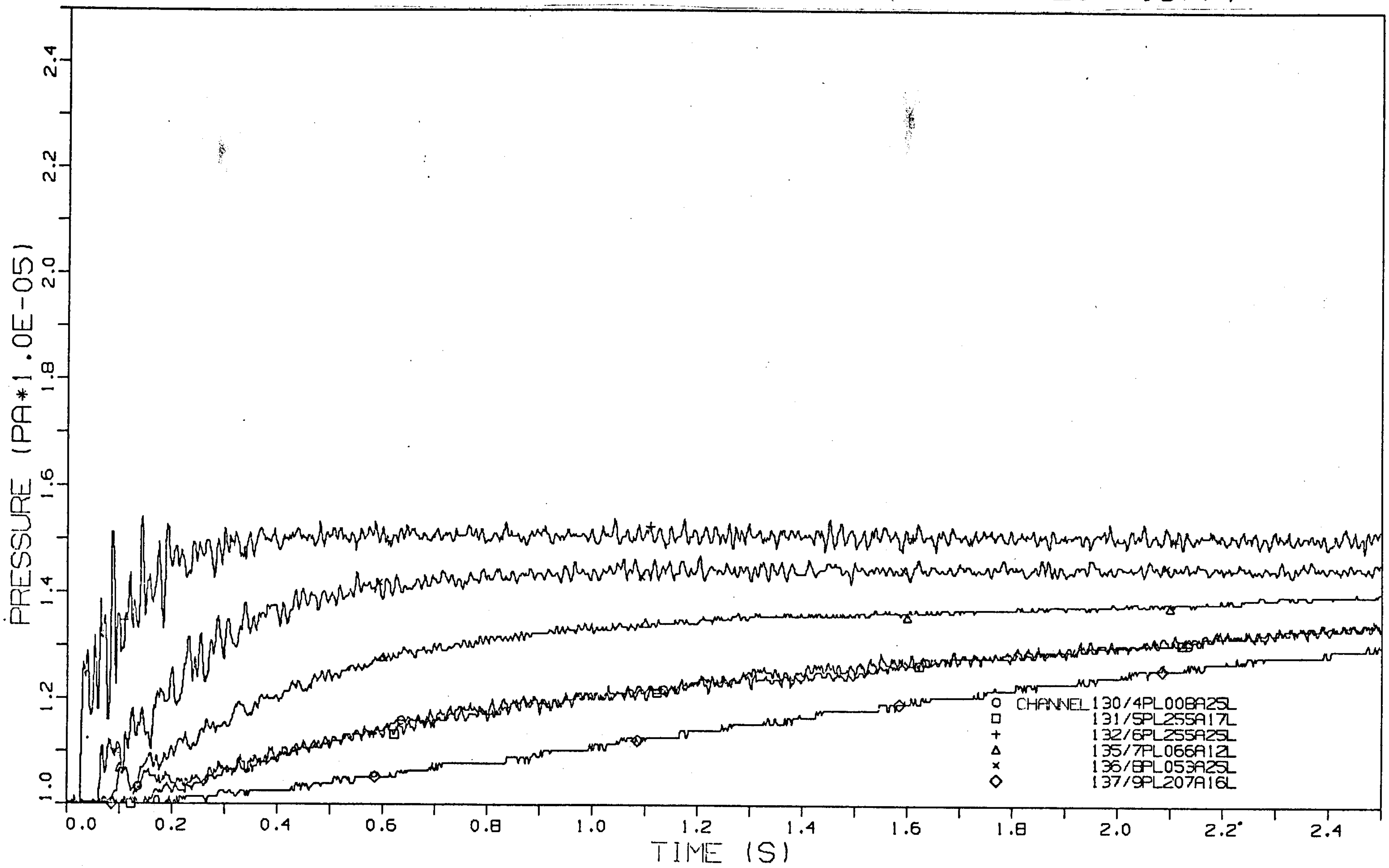

FIG.10 PRESSURE HISTORY IN CONTAINMENT

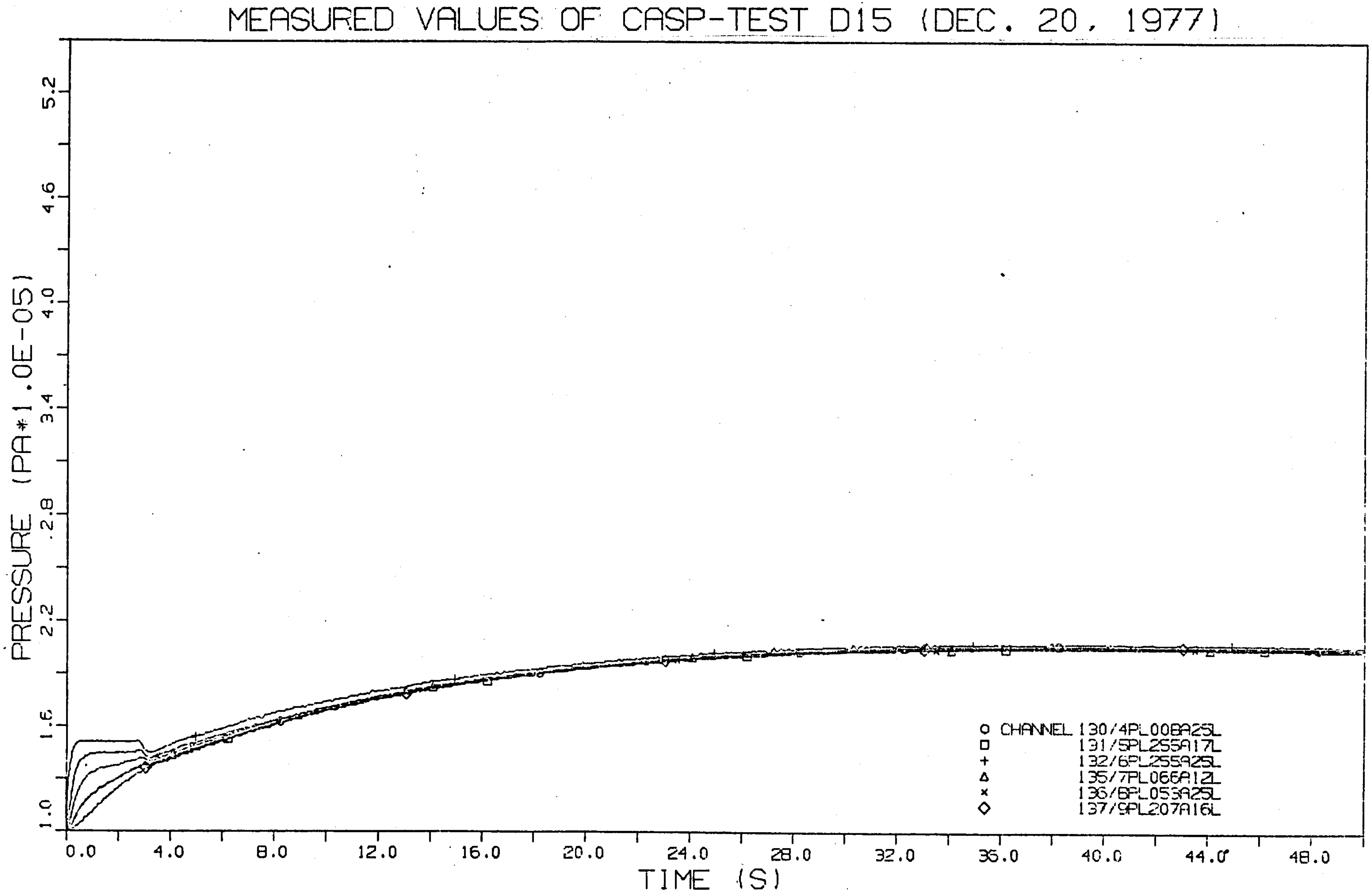

FIG.11 PRESSURE HISTORY IN CONTAINMENT

- Temperature measurements: The measuring point 6 TS 343 A 29 was not connected to the data aquisition system in test D15. Therefore, the nearest measuring point 6 TS 318 A 21 is used for comparison.

  Within the time interval 0 to 2.5 s the resistance thermometers installed in R9 do not yet give an answer. Therefore, no comparison with experimental results can be made.

  In the time interval 0 to 50 s all temperatures in one compartment are almost equal except in R9. Because of this for each compartment a mean temperature (measuring point approximately in the middle of the compartment), in R9 an upper and a lower temperature of the experiment are compared. Temperature deviations in one compartment sometimes are as high as 25 K (see values in parentheses). For comparison purposes the following measuring points are used:

  6 TS 246 A 21 (25K)
  8 TS Ø9Ø A 21 (20K)
  7 TS Ø89 I 18 (5K)
  4 TS ØØØ M 3Ø (10K)
  5 TS 269 A 12 (15K)
  9 TW ØØØ M 75, 9 TW 18Ø M-9.

  In the big dome compartment R9 in the long term range a stable temperature stratification is established. For this reason in the time interval 0 to 1500 s an upper (9 TW ØØØ M 75) and a lower (9 TW 18Ø M-9) measured temperature is used in the comparison, though a therefrom averaged temperature is only partly representative for a mean temperature of the whole containmant (partly higher temperatures in preceding compartments R6 to R5).

  To illustrate the advance of the steam front (time interval 0 to 2.5 s) and the far extending temperature equalization in the compartments (time interval 0 to 50 s) all temperatures of all compartments are plotted together in one figure each (figs. 12 and 13).

MEASURED VALUES OF CASP-TEST D15 (DEC. 20, 1977)

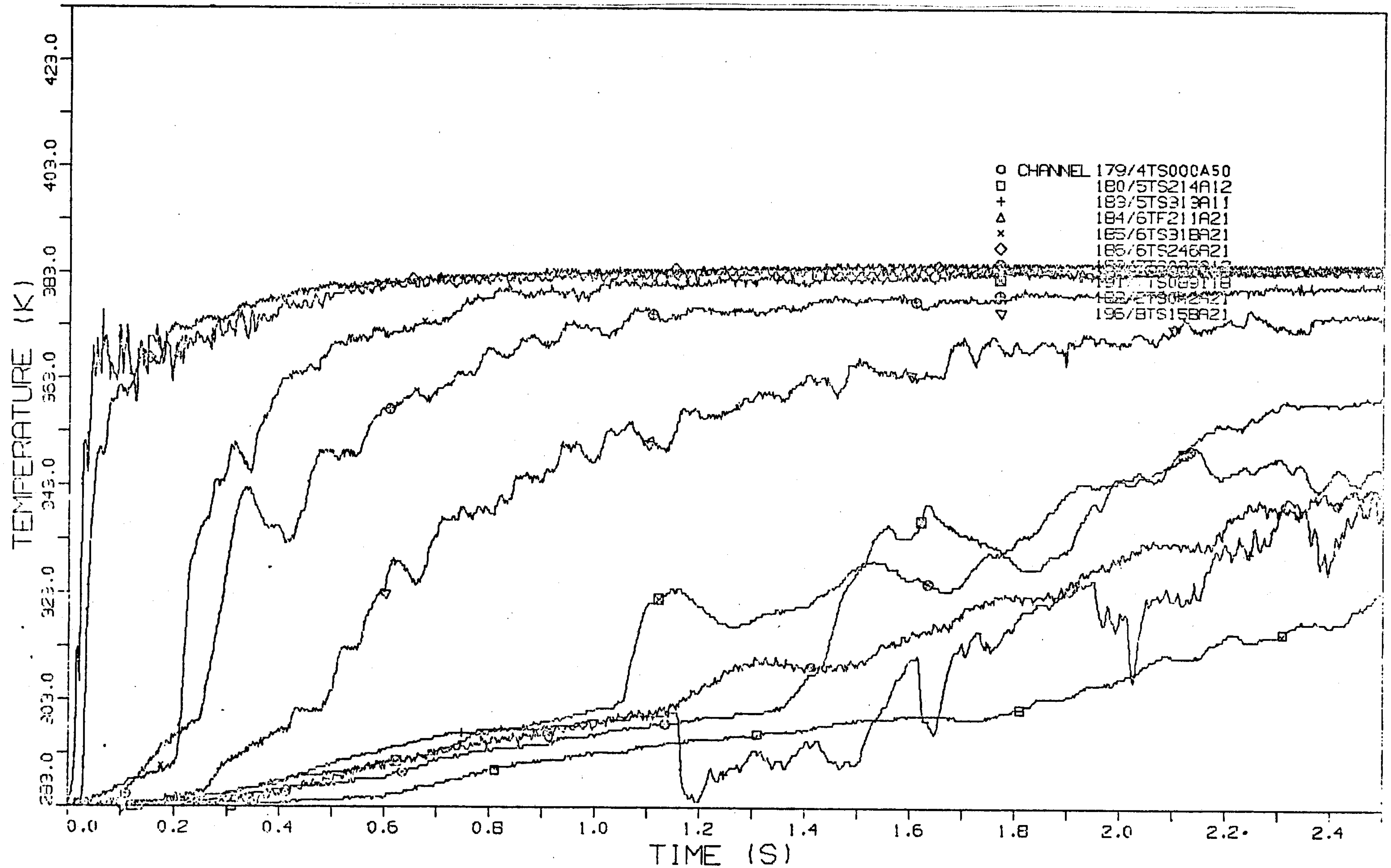

FIG. 12 TEMPERATURE HISTORY IN CONTAINMENT

MEASURED VALUES OF CASP-TEST D15 (DEC. 20, 1977)

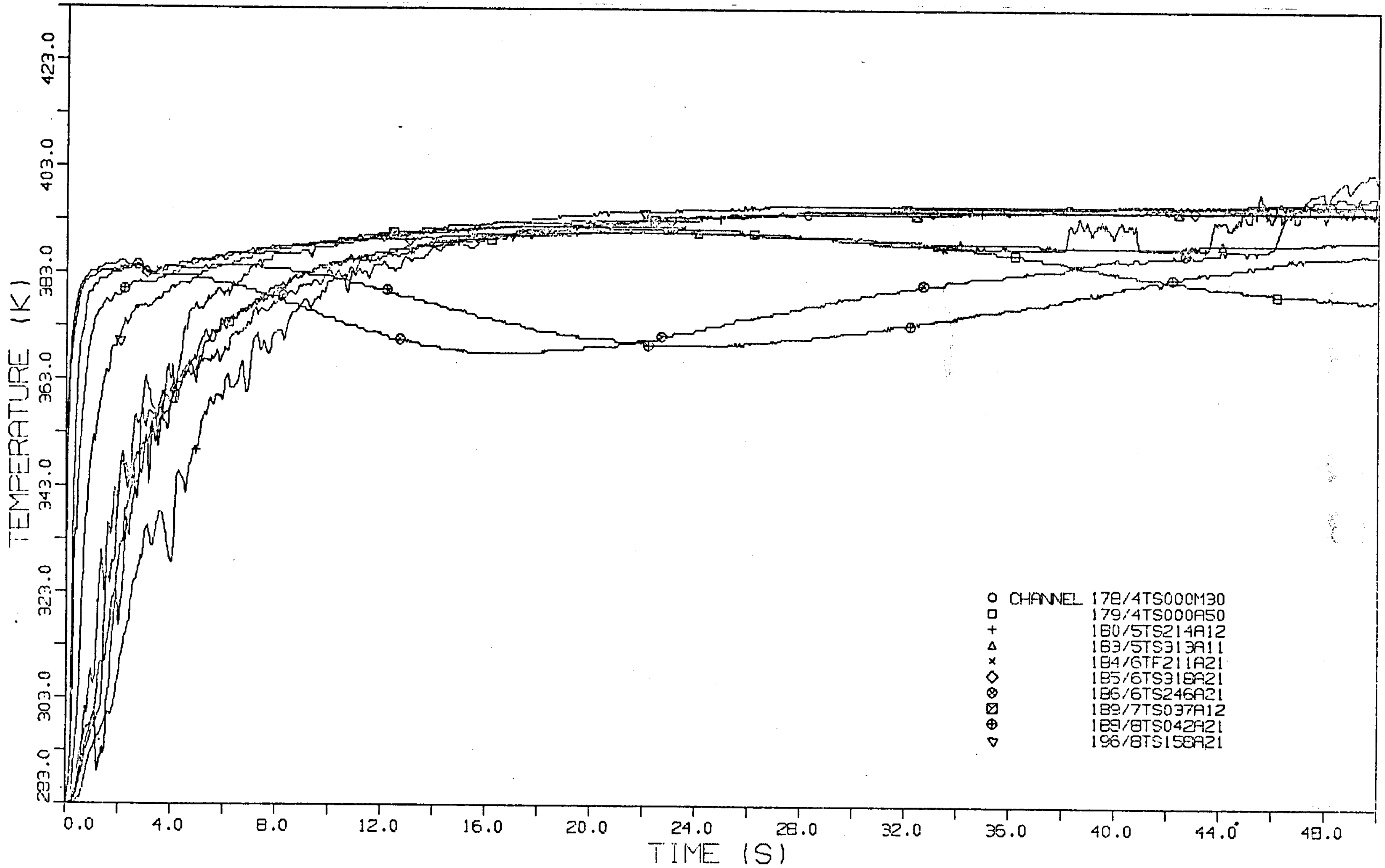

FIG. 13 TEMPERATURE HISTORY IN CONTAINMENT

- Measurements of pressure differences: The specified pressure difference between R5 and R6 was not measured directly. So the difference of the absolute pressure (5 PL 255 A 17 L minus 6 PL 255 A 25 L) is used for comparison. Instead of the specified measuring point 6 PD 18Ø 8 13 W the measuring point 6 PD 323 8 1Ø L was connected to the data acquisition system in test D15. Because of this measuring point being defective the difference of the absolute pressures (6 PL 255 A 25 L minus 8 PL Ø53 A 25 L) is taken for comparison. A comparison between the directly measured pressure difference between R6 and R9 (measuring point 6 PD 284 9 27 W) and the difference of the absolute pressures (6 PL 255 A 25L minus 9 PL 207 A 16 L) is represented in fig. 14 and shows representative for other differences the good agreement between the two measurement techniques.

- Water masses: For the reason of the water levels in the different compartments - manually read or capacitively measured - being only evaluable after end of blowdown (appr. 7o s), a comparison of calculated water masses can only be made in the time interval 0 to 50 s.

MEASURED VALUES OF CASP-TEST D15 (DEC. 20, 1977)

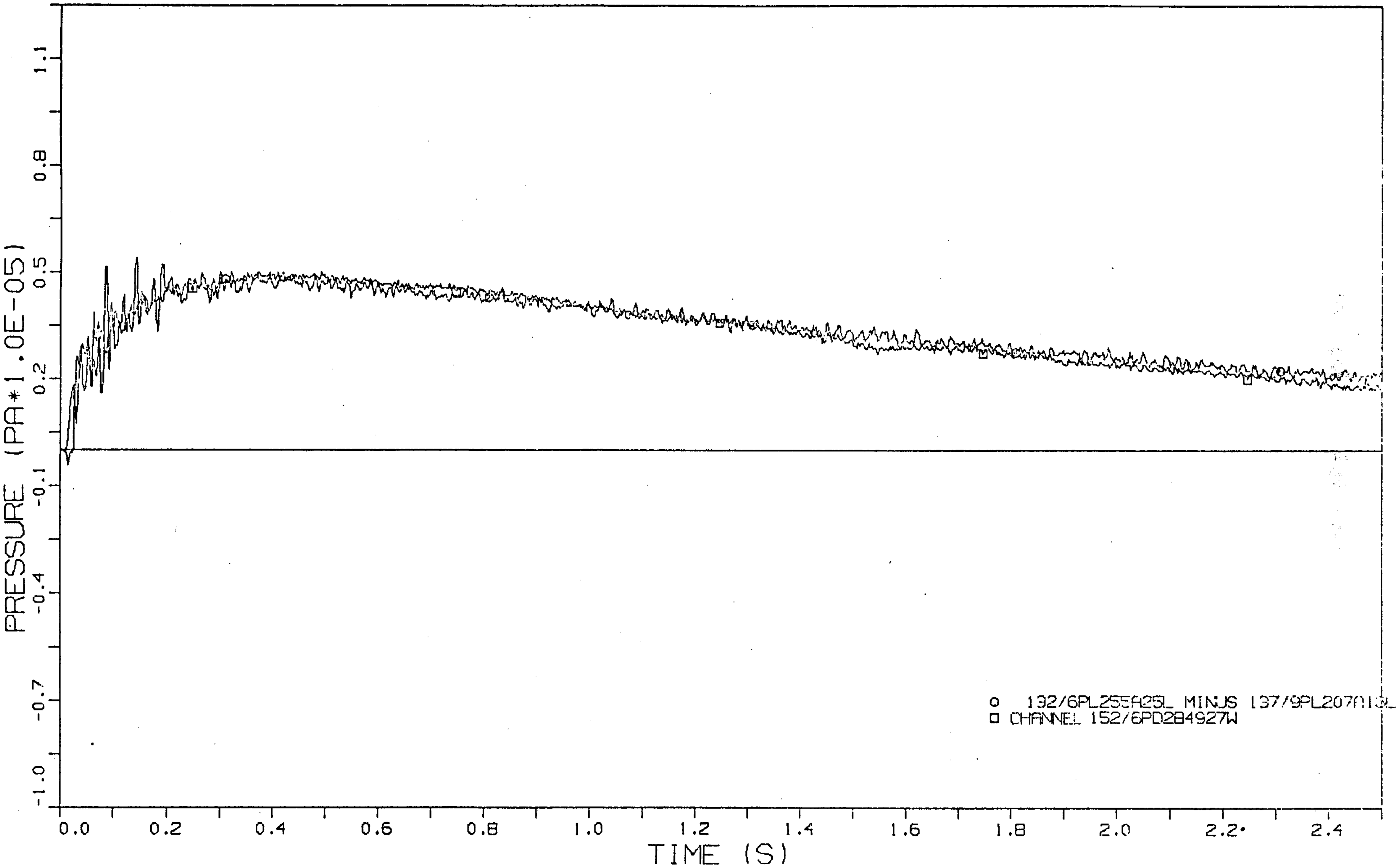

FIG. 14 HISTORY OF PRESSURE DIFFERENCE R6-R9

3.3 Selection of important variables

As stated in the specification a number of variables was to be calculated. For evaluation of the results it seems necessary only to consider important variables. All variables additionally wanted become important, especially when deviations are to be analysed more exactly and more individually. This should be done by each participant himself with the aid of the experimental data in /5, 6/. In the following a brief argumentation for selection made (mostly in parentheses) is given. Fluid temperatures instead of wall temperatures not measured in this test give an approximate indication on the temperature stresses the walls are exposed to.

Time interval 0 to 2.5 s:

Pressure: 1 pressure in each compartment (pressure differences within a compartment are negligibly small, see e.g. fig 15 for the first follow-up compartment R8), so for

- rupture compartment R6 (compartment with the highest pressure built-up)
- first follow-up compartment R8 (pressure built-up highest but one after flow through channel connecting R6 to R8)
- dome compartment R9 (energy sink with slowest and time-delayed pressure built-up)

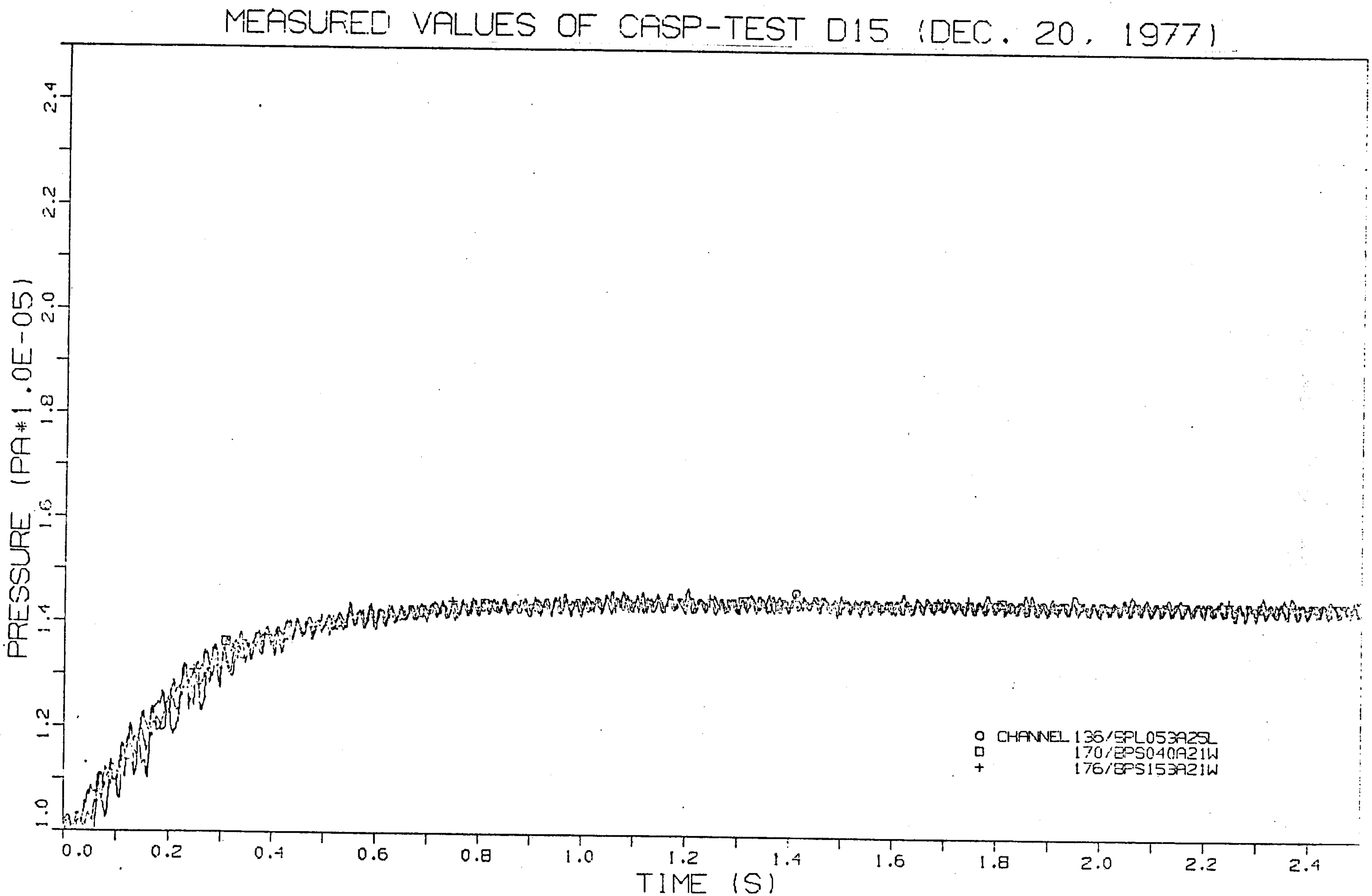

FIG. 15 PRESSURE HISTORY IN COMPARTMENT R8

Temperature: Because of expected differences inside one compartment

- 3 temperatures in the rupture compartment R6 (highest temperature stress, differing initial slopes)

- 2 temperatures in the first follow-up compartment R8 (temperature built-up highest but one)

- 2 temperatures in compartment R4 with transversal flow (differences between upper and lower part)

because of no measuring response seen from slow resistance thermometers and more or less homogeneous air compression is expected

- 1 temperature in dome compartment R9 (slowest temperature built-up)

Pressure difference:

- between R6 and R9 (highest pressure difference)

- between R6 and R8 (information on flow resistance of over-flow channel)

- between R8 and R9 (information on flow resistances of all follow-up orifices)

- between R4 and R5 (flow resistance of orifice Ü45 following in short distance on orifice Ü 47)

Time interval 0 to 50 s:

Pressure: During this interval maximum pressure in the whole containment and pressure equalization between all compartments are to be expected. As important variables the same pressures as in interval 0 to 2.5 s are selected, so pressure

- in rupture compartment R6
- in first follow-up compartment R8
- in dome compartment R9

Temperature: During this interval maximum temperatures and far extending temperature equalization (see fig. 16 for compartment R8) are to be expected in each compartment except R9. Important variables selected are one temperature

- in rupture compartment R6
- in first follow-up compartment R8
- in dome compartment R9

Water mass: History of water mass in all 6 compartments as specified (information on water transport)

Time interval 0 to 1500 s:

According to specification pressure, temperature, and water mass history in the whole containment during the cooling down phase.

MEASURED VALUES OF CASP-TEST D15 (DEC. 20, 1977)

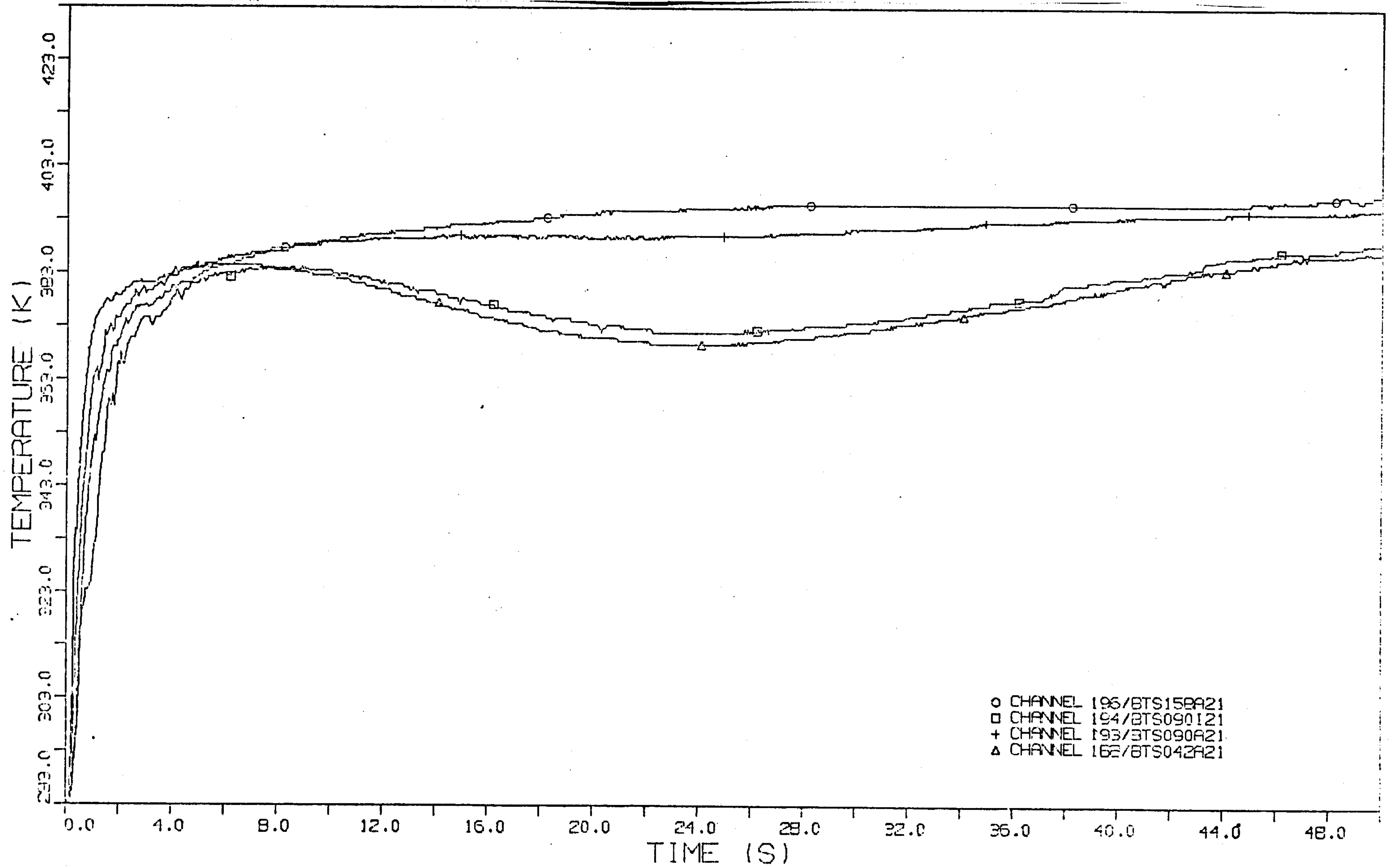

FIG. 16 TEMPERATURE HISTORY IN COMPARTMENT RB

3.4 Comparison of selected variables

For comparison purpose the calculated results of the participants were taken from submitted punched cards (5 participants) and magnetic tapes (7 participants). During data transfer for plotting it became apparent that two participants either had to complete (June 11, 1979) or replace (July 2, 1979) their tapes submitted. Other complications for data processing partly came from not following the specified order of variables, incorrect statements for record lenght and/or blocksize of magnetic tapes by some participants as well as from differences between tape or card data, plots and listings.

3.4.1 Time interval 0 to 2.5 s

Comparing calculated with experimental results it can be seen that for some variables deviations calculated by Canada (Uchida-correlation with small htc) and UK are partly greater than the diverging results of other participants. These being ten one can speak of a more or less statistical "bandwidth of calculations". Though differences in quality can be observed within this "bandwidth" no attempt shall be undertaken to differenciate perhaps in the sense of a ranking of participants'results.

In the following the different variables shall be regarded individually according to the order of selection (see chapter 3.3).

- Pressure in rupture compartment R6 (figs. 17A, 17B):

Pressure built-up is predicted within - 0.02 to + 0.21 bar supposed to the different assumptions of the participants for heat transfer. Related to a measured maximum pressure increase of (1.53 minus 1.02) bar this means a bandwidth of -4 % to + 41 % for these post-calculated results (experimental errorband ± 4%!). Disregarding results of Canada and UK this bandwidth diminishes to -4 % to +24 % what is nearly the same as for "blind" precalculations of German participants in German Standard Problem No. 1. The higher the assumed or calculated heat transfer rates to the structures (highly turbulent steam condensation in this period, long compartments, great ratio of surface area to volume) are the better seems the approach of calculated to experimental results.

- Pressure in first follow-up compartment R8 (figs. 18A, 18B):

  Nearly the same is valid for R8 as for R6. (-0.04 bar to +0.14 bar corresponding to -8 % to +30 % for maximum pressure, experimental errorband ± 5 %).

- Pressure in dome compartment R9 (figs. 19A, 19B):

  Pressure increase is over- and underpredicted by an amount of + 0.11 bar to - 0.14 bar at the maximum. This means + 35 % to - 45 % related to a pressure incrase at the end of the time interval of 0.31 bar (experimental errorband ± 7 %). These relatively high deviations are insofar more engraving as this compartment is the biggest of the chain (450 m^3 of a total of 630 m^3). After all this means either too little or too much energy release from or vice versa energy transport to R9. Eventually less or more energy from preceding compartments is to transport via the overflow vents (smaller or higher mass flow rates). General over-prediction of pressures (e.g. in R6 and R8), despite of partly high heat transfer rates, indicate to use higher discharge coefficients respectively lower pressure loss coefficients than applied in general.

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

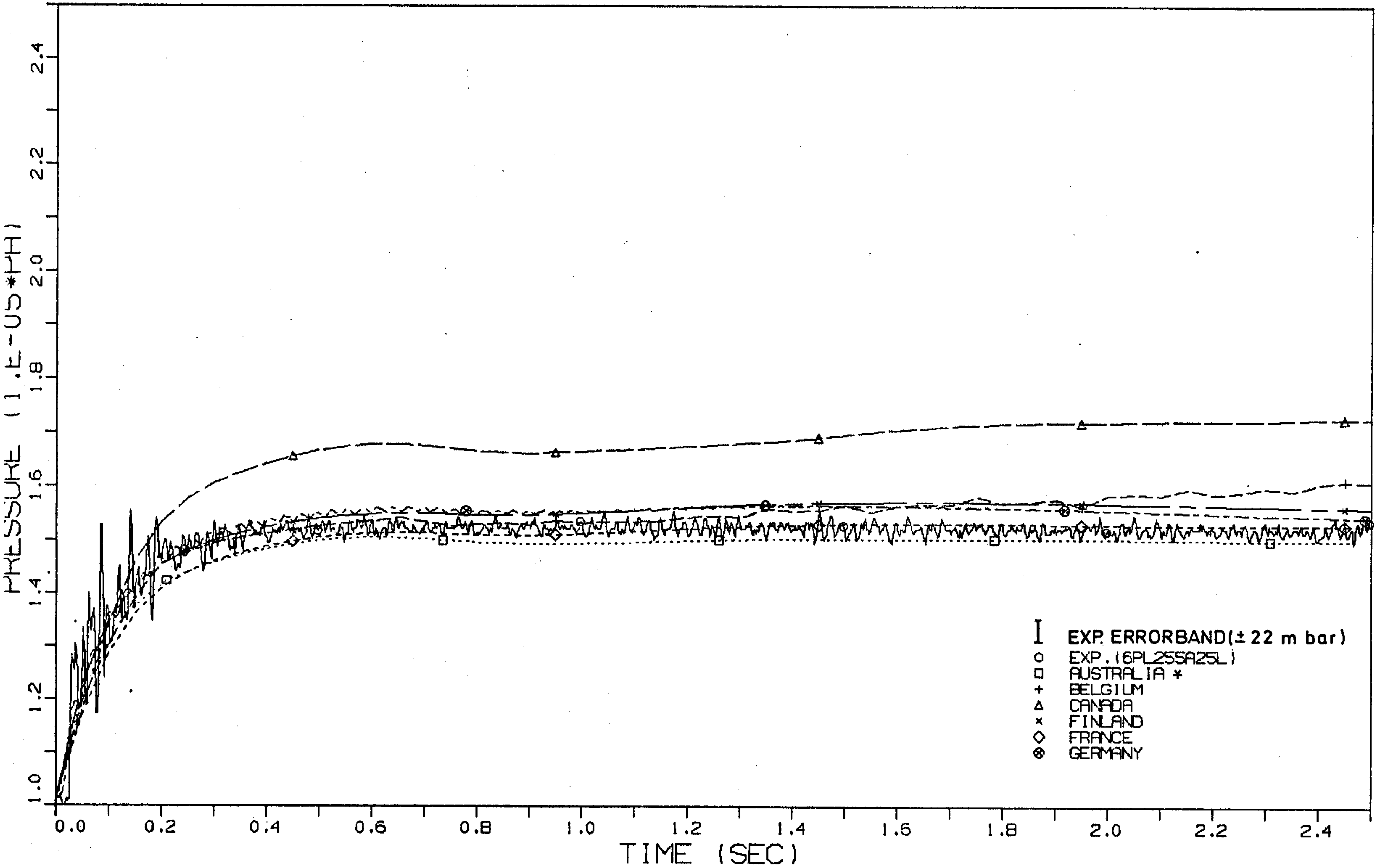

FIG. 17A PRESSURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

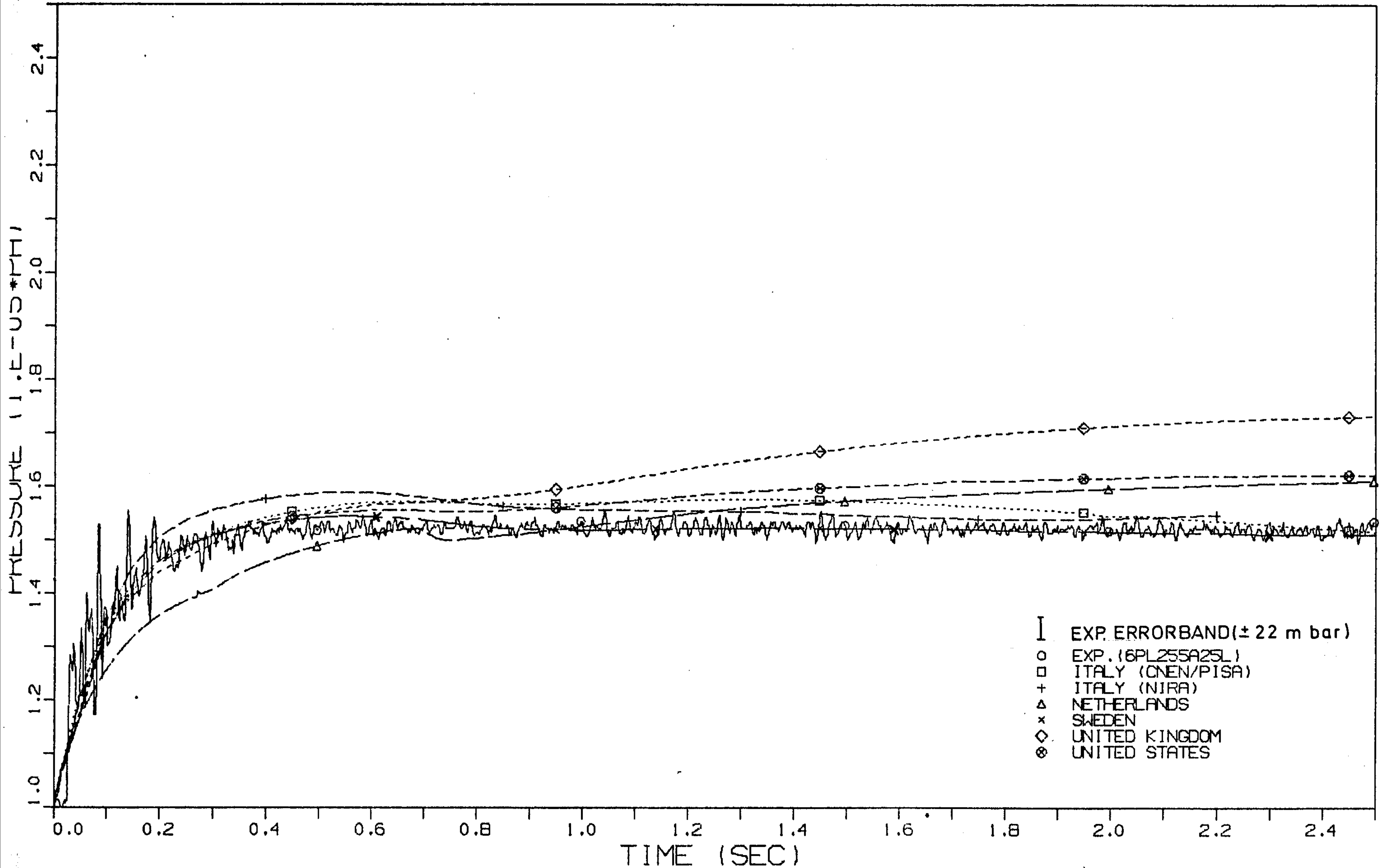

FIG. 17 B PRESSURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

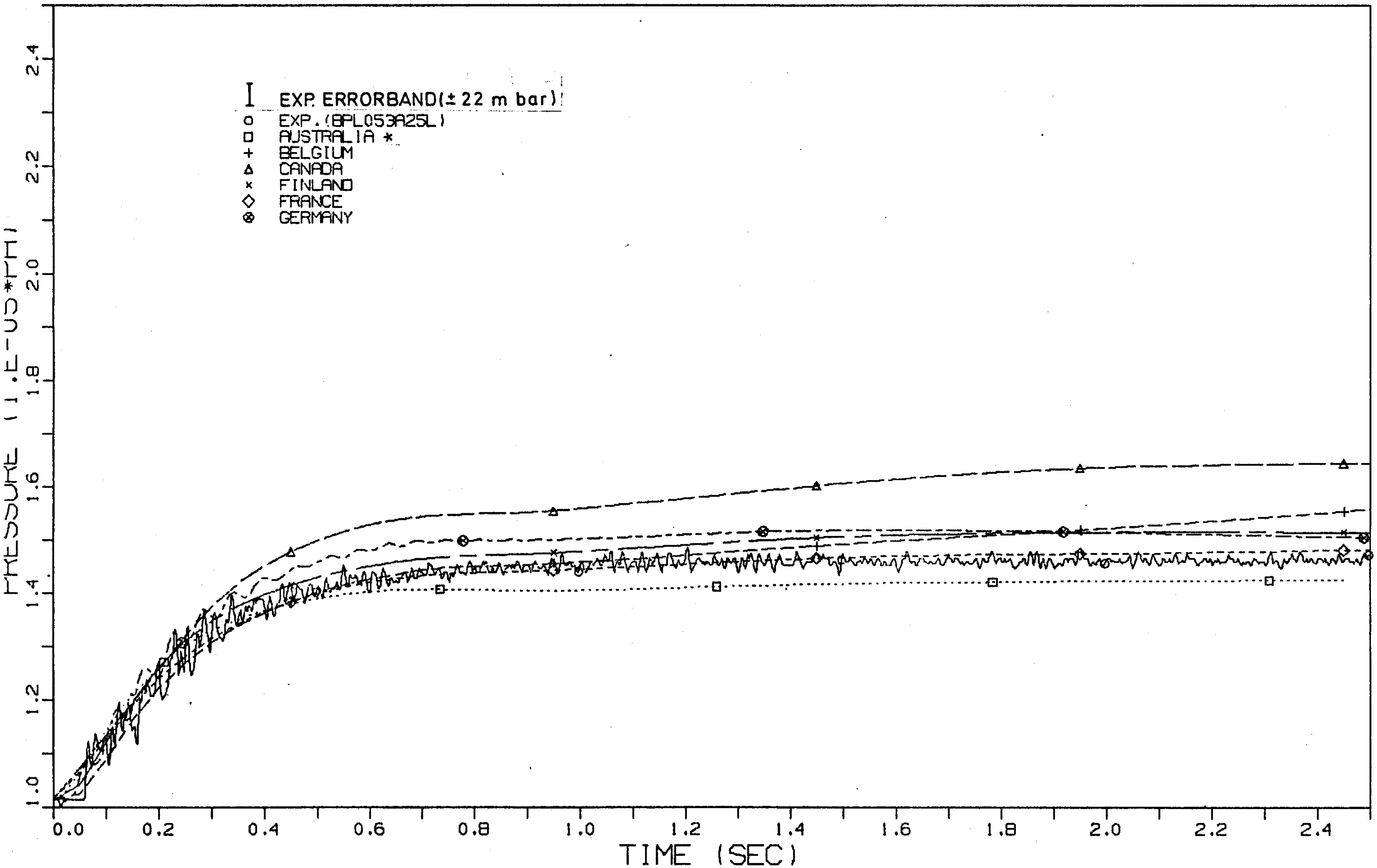

FIG. 18A PRESSURE HISTORY IN COMPARTMENT R8

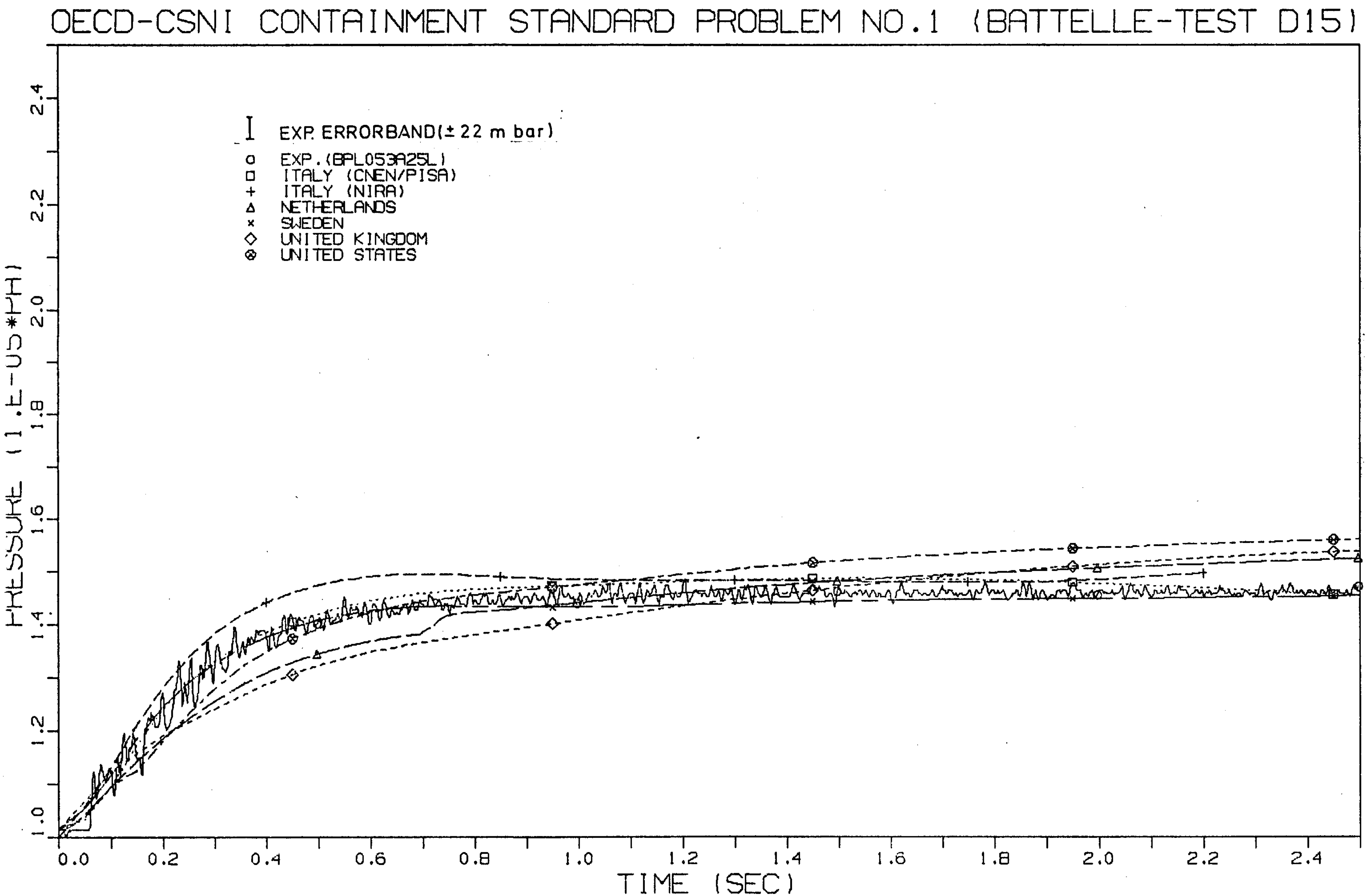

FIG. **18 B** PRESSURE HISTORY IN COMPARTMENT R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

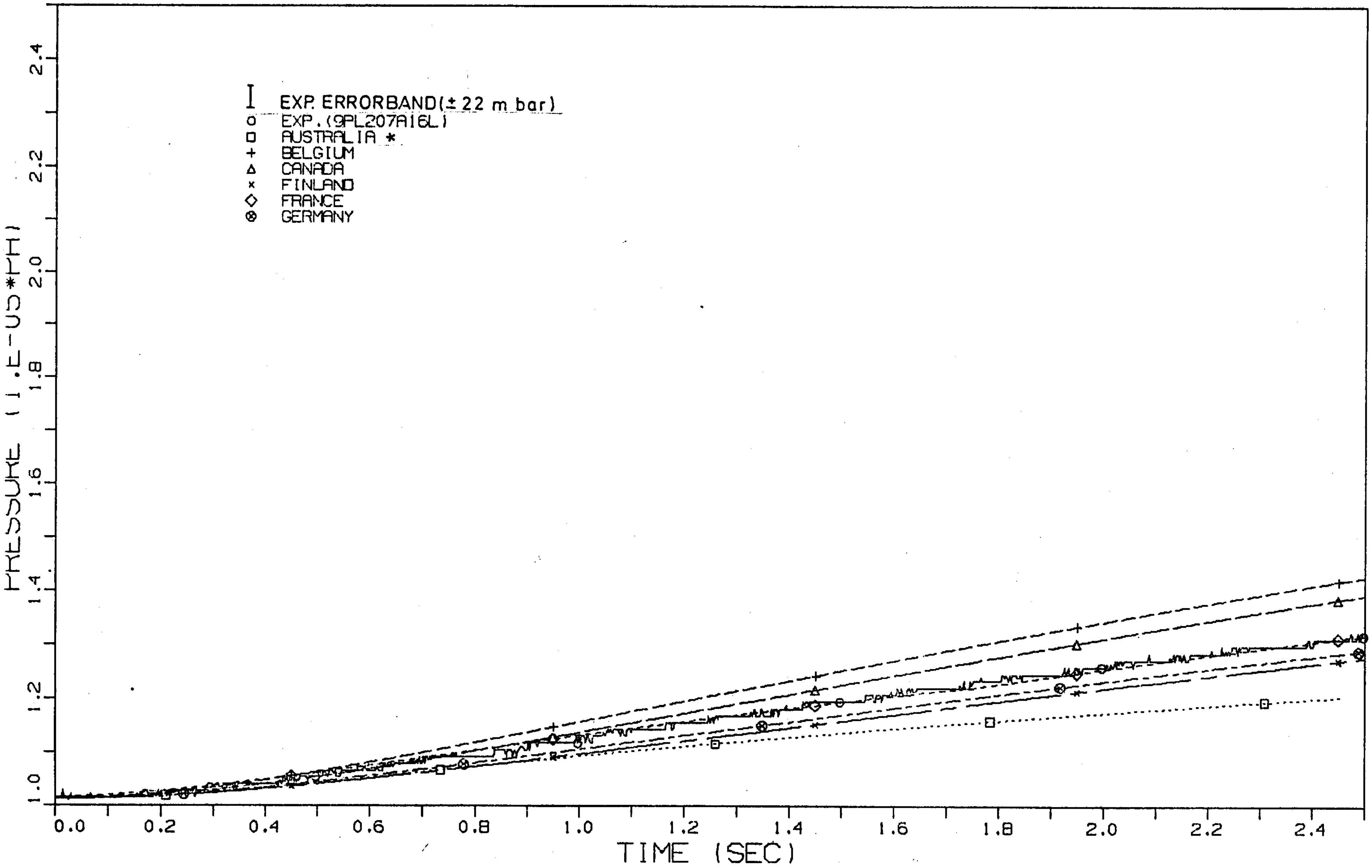

FIG. 19A PRESSURE HISTORY IN COMPARTMENT R9

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

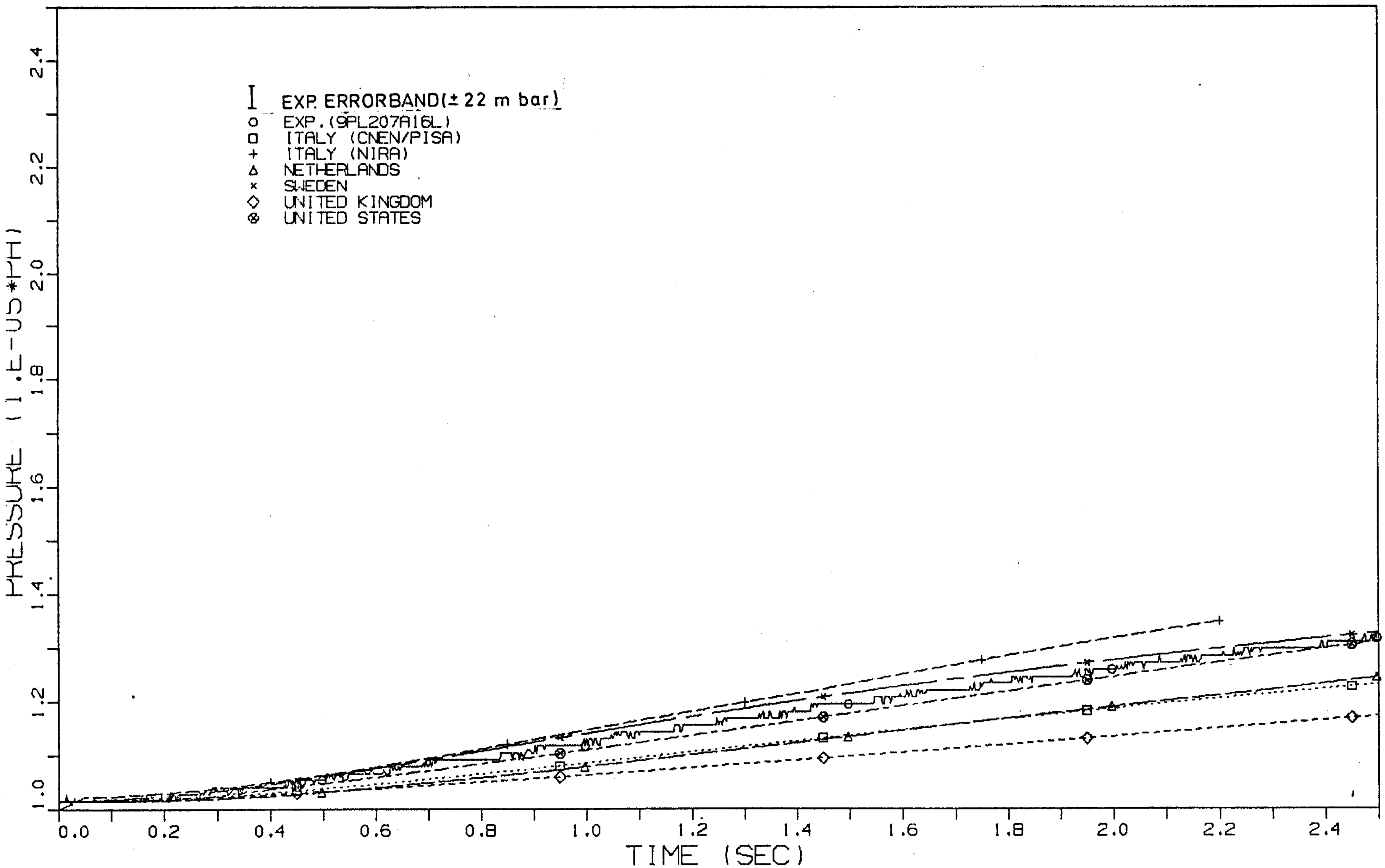

FIG.**19 B** PRESSURE HISTORY IN COMPARTMENT R9

Comparisons of all temperature histories to be calculated in one compartment can only be made for participants subdividing corresponding compartments (5 participants in R6, 3 participants in R8 and R4). Main comparison for the majority of participants simulating a compartment as a node is made with the response of a thermocouple installed in the middle of the compartments.

- Temperatures in the rupture compartment R6 (figs. 20A, 20B, 21, 22):

  The closer to the rupture point thermocouples are (6TF 211 A21 → 6TS 246 A21 → 6TS318 A21) the earlier one observes steep temperature increase caused by steam flow (flat increase means compression of air; pistonlike steam front propagation).

  Participants' calculations follow these gradients except for the thermocouple far away from rupture point (6TS 318 A21). Calculated results of Belgium with a 6-node-simulation for R6 agree well with the experimental results also for this thermocouple. Some participants calculate superheated conditions in the early stages of this period while thermocouples show saturated conditions despite of injection of superheated vapour. Highest measured temperature of about 383K (saturation temperature corresponding to measured pressure) is calculated by all participants within a margin of + 6K to - 5K (related to a temperature increase of 383K minus 273 K + 5 % to - 4.5 %, experimental errorband ± 1.5 %). Higher underprediction for 6TS 318 A21 may result from comparing calculated temperature for the more distant corner thermocouple (6TS 343 A29) with thermocouple 6TS 318 A21.

- Temperatures in first follow-up compartment R8 (figs. 23A, 23B, 24):

  Arrival of steam front in this compartment is less marked. Experimental temperature histories show inhomogenities (temperature oscillations). With exception of a higher underprediction of USA participants in general more under-predict these temperatures (+ 5K to - 13K at the maximum).

- Temperatures in compartment R4 (figs. 24A, 24B, 25):

  It is surprising that measured temperature closer to orifice flow at the outer wall (4 TS ØØØ A 5Ø) is lower than that more distant in the middle of compartment R4. This and the highly oscillatory history indicate equalizing flows within this compartment passed more transversally. This can hardly be simulated therefore the calculated results showing wide divergence.

- Temperatures in dome compartment R9 (figs. 27A, 27B):

  Only comparison of calculated results for one measuring point nearest to the orifice is made because there is no response of the resistance thermometers during this time interval and all participants but one do not subdivide R9. Spread of calculated results is high and high or low results in general correspond to higher overpredictions or higher underpredictions in calculated pressure history in R9 (figs. 19A, 19B).

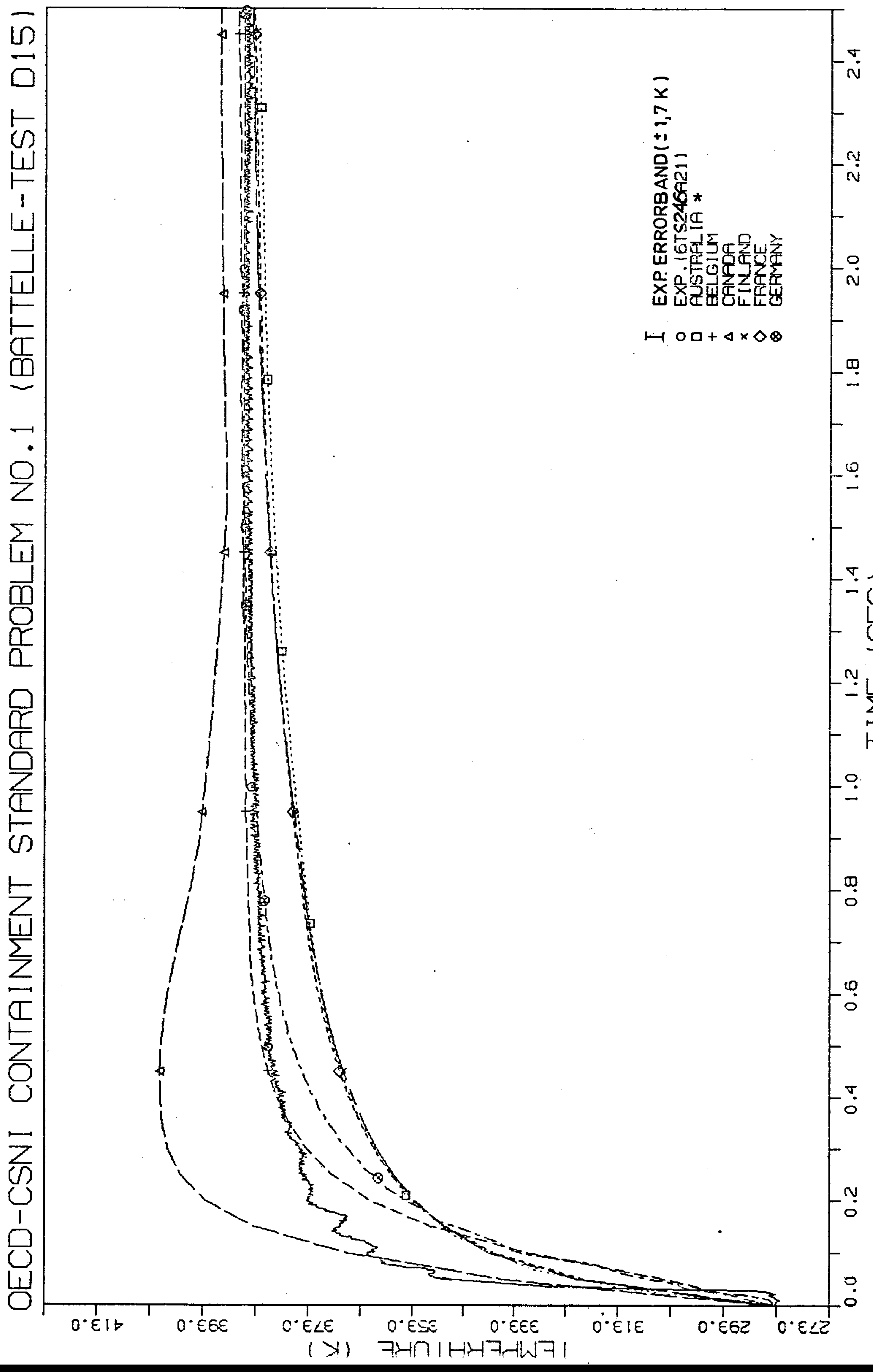

FIG. 20A TEMPERATURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

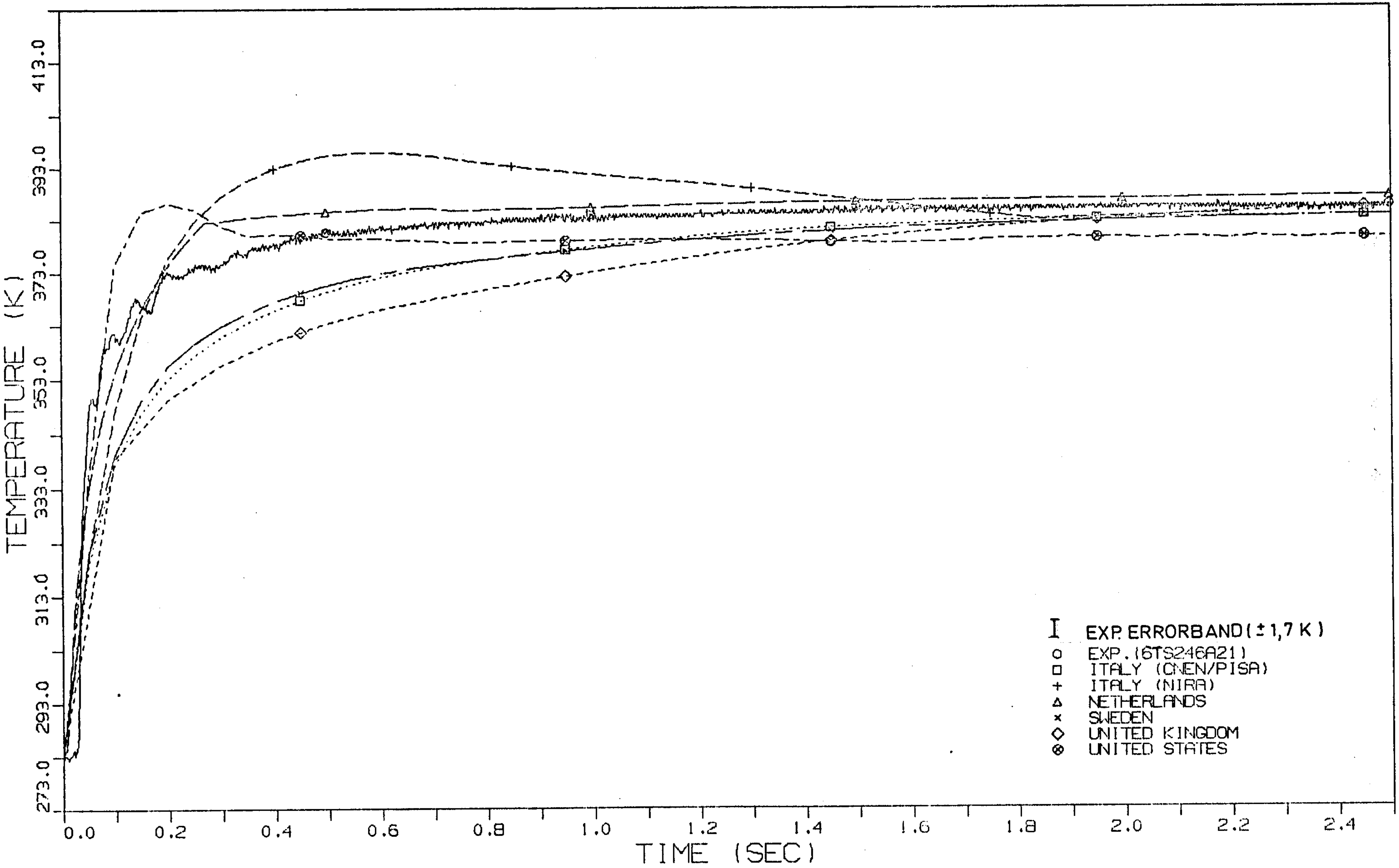

FIG. 20B TEMPERATURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

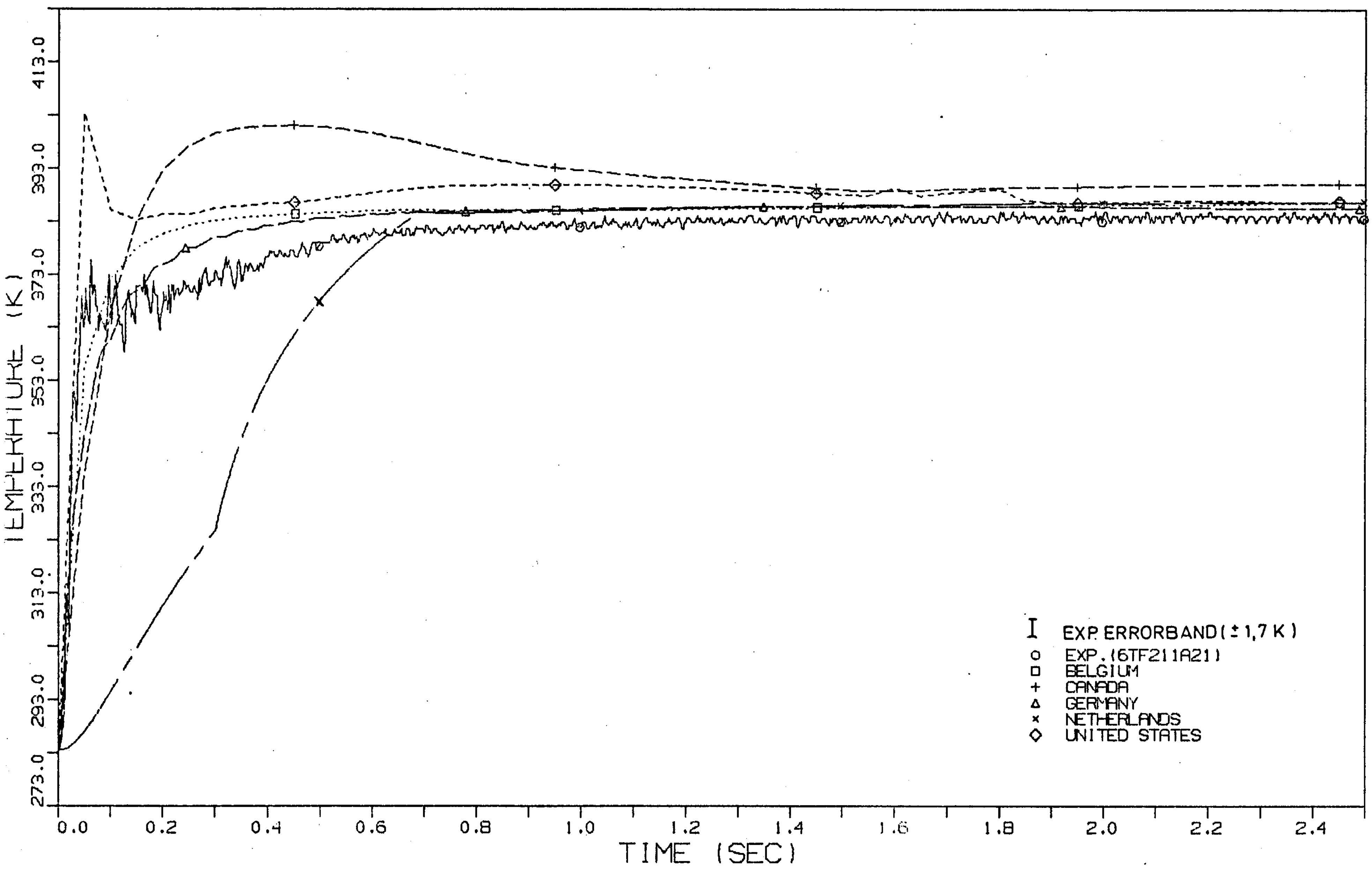

FIG. 21 TEMPERATURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

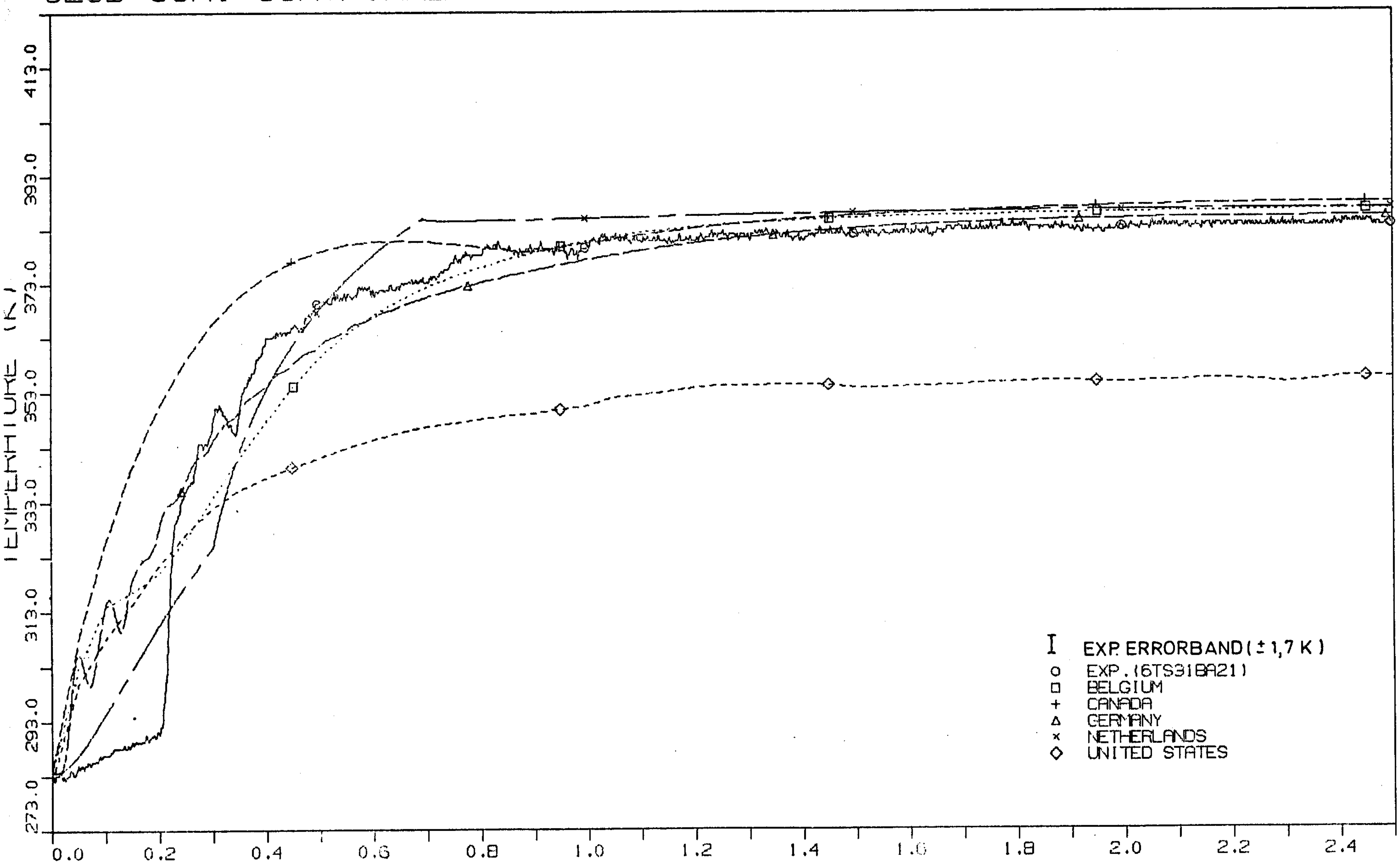

FIG. **22** TEMPERATURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

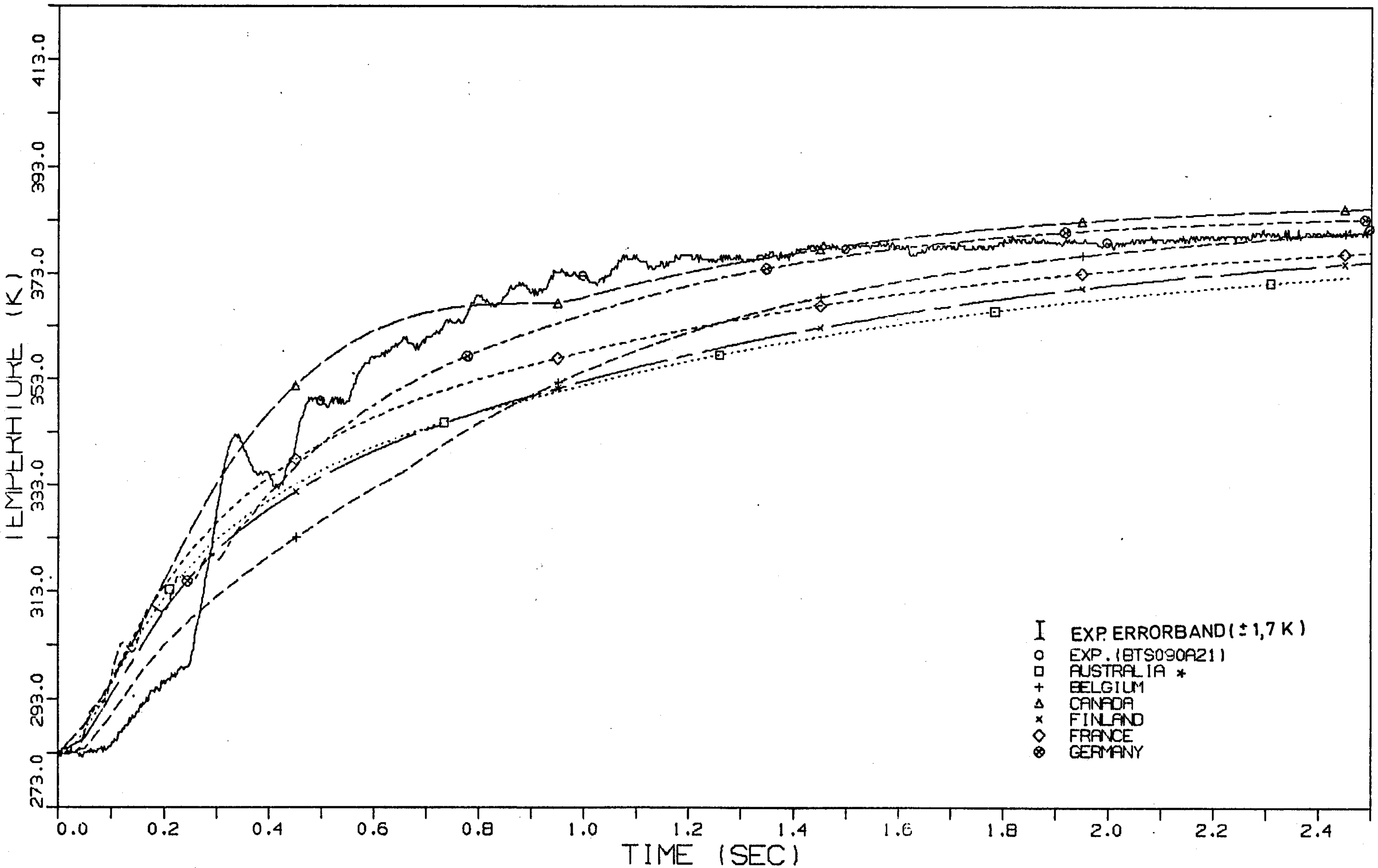

FIG. **23A** TEMPERATURE HISTORY IN COMPARTMENT R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

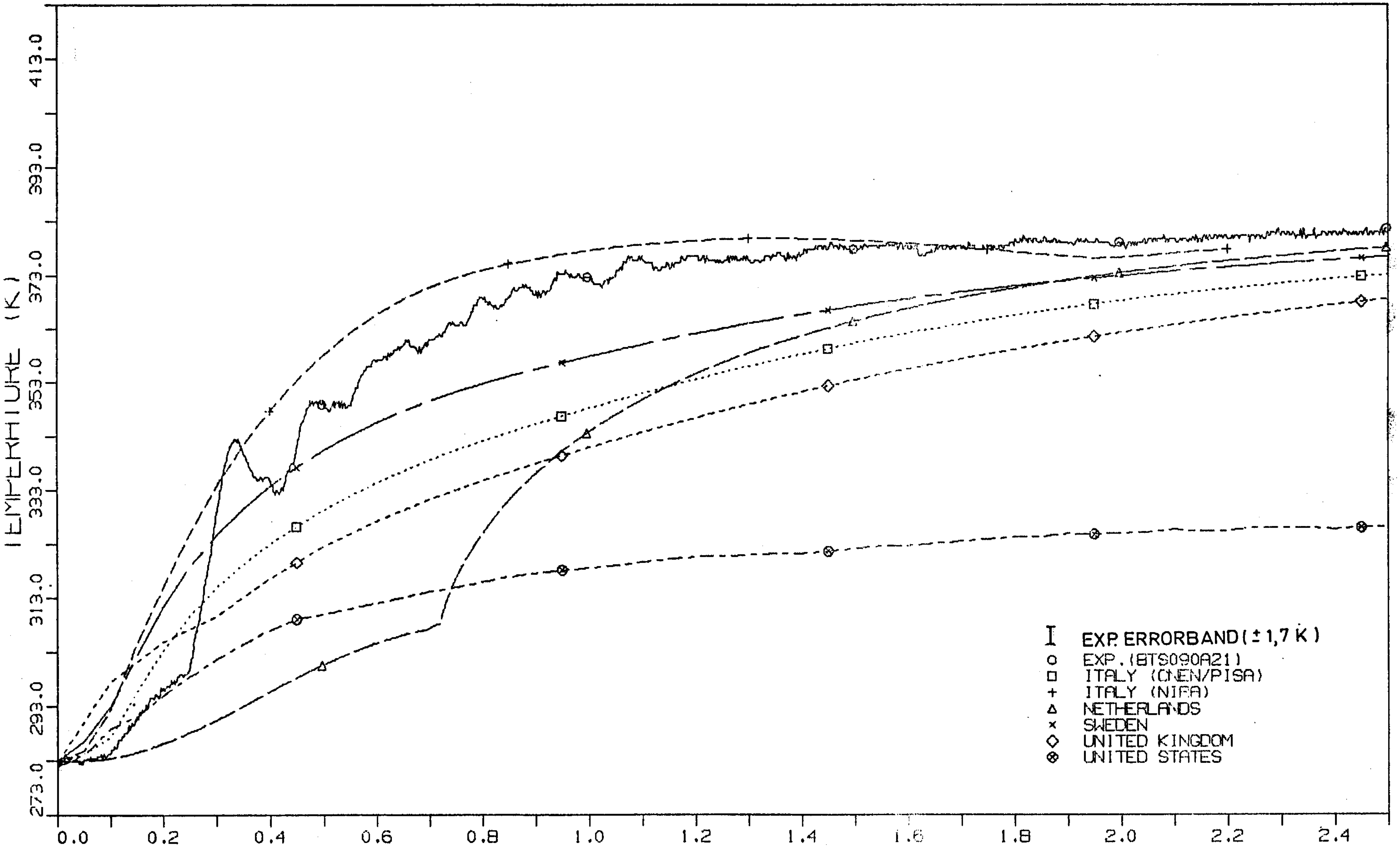

FIG. **23 B** TEMPERATURE HISTORY IN COMPARTMENT R8

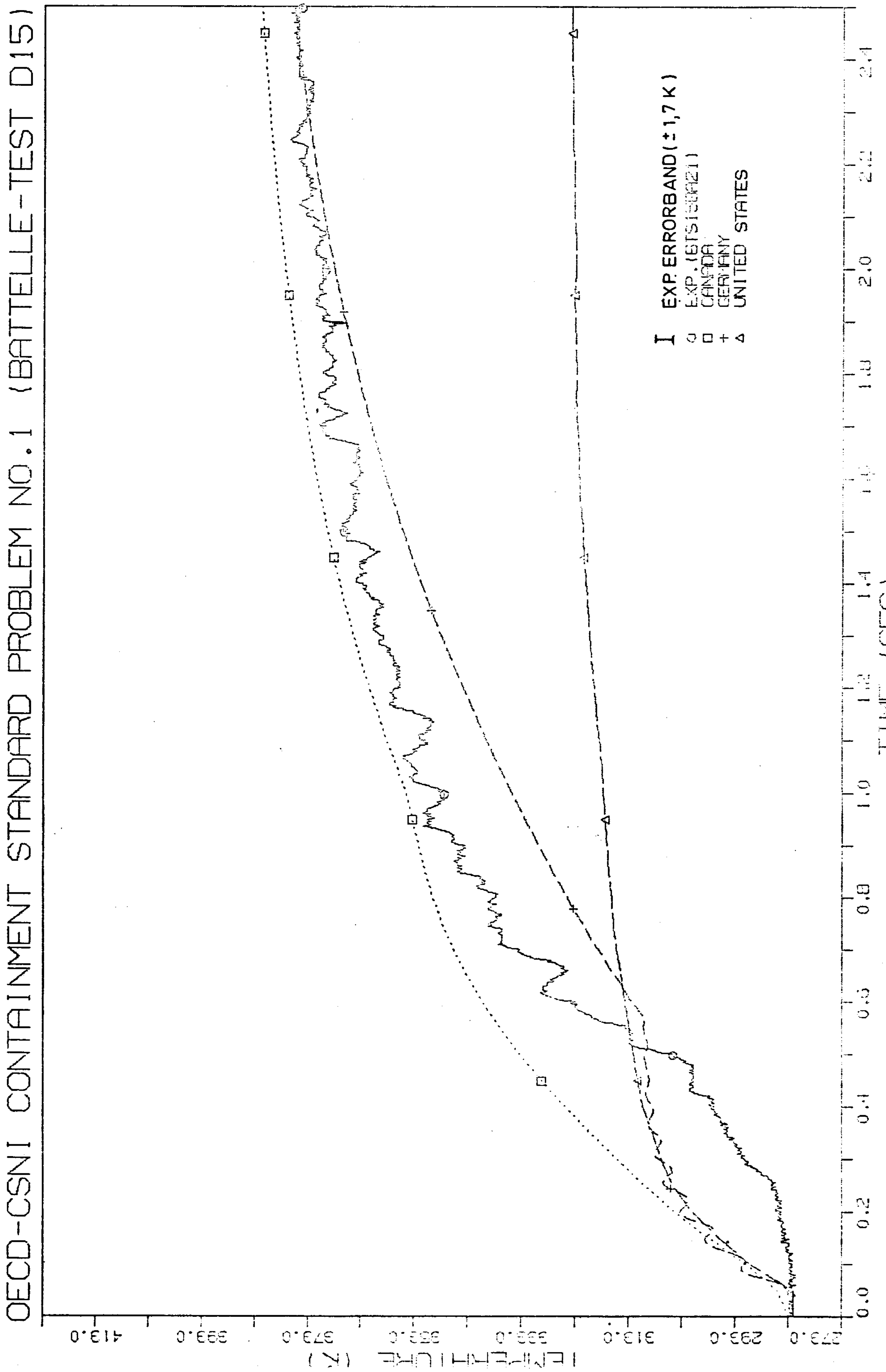

FIG. 24 TEMPERATURE HISTORY IN COMPARTMENT R5

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

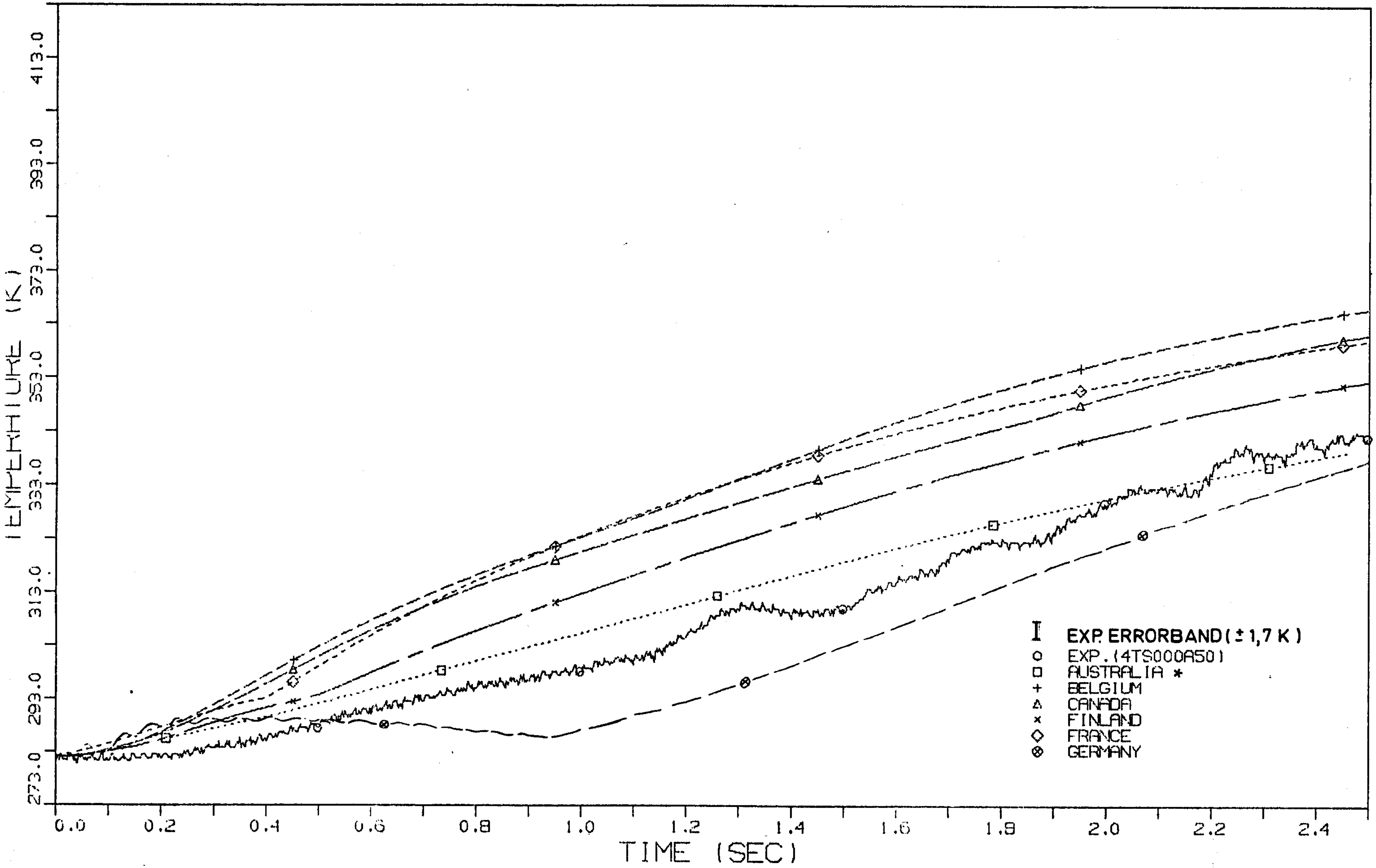

FIG. 25A TEMPERATURE HISTORY IN COMPARTMENT R4

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

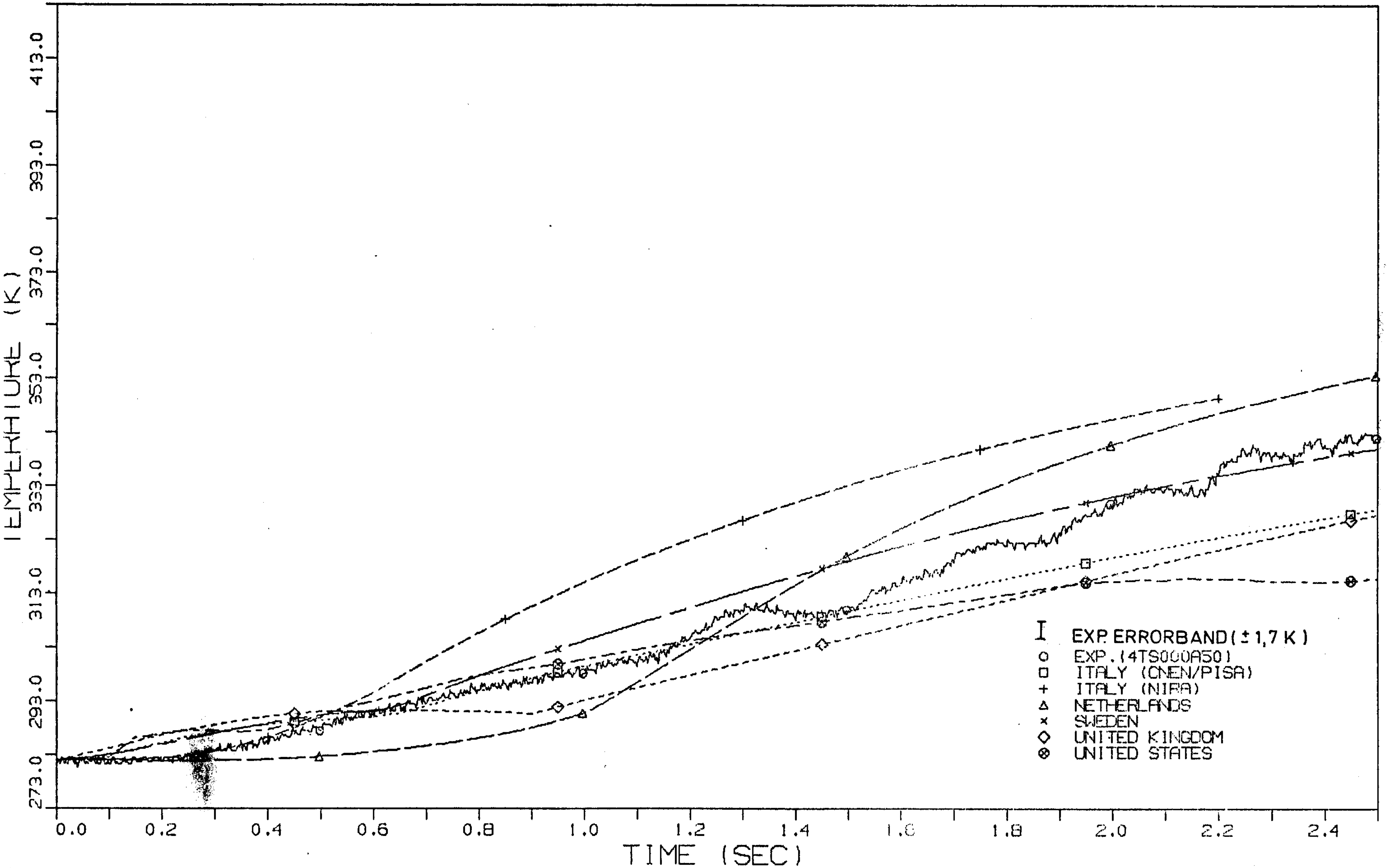

FIG. **25 B** TEMPERATURE HISTORY IN COMPARTMENT R4

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

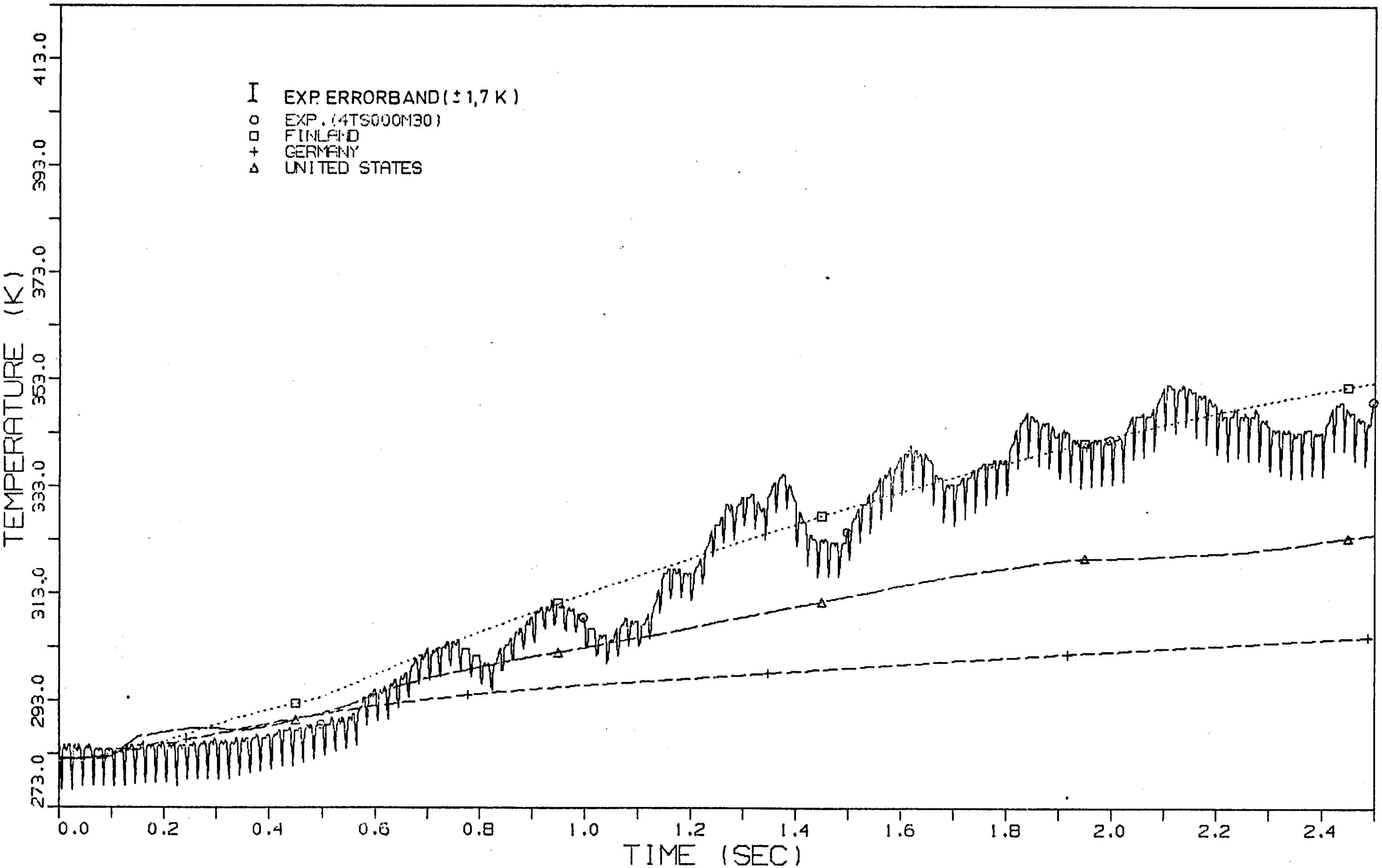

FIG. 26 TEMPERATURE HISTORY IN COMPARTMENT R4

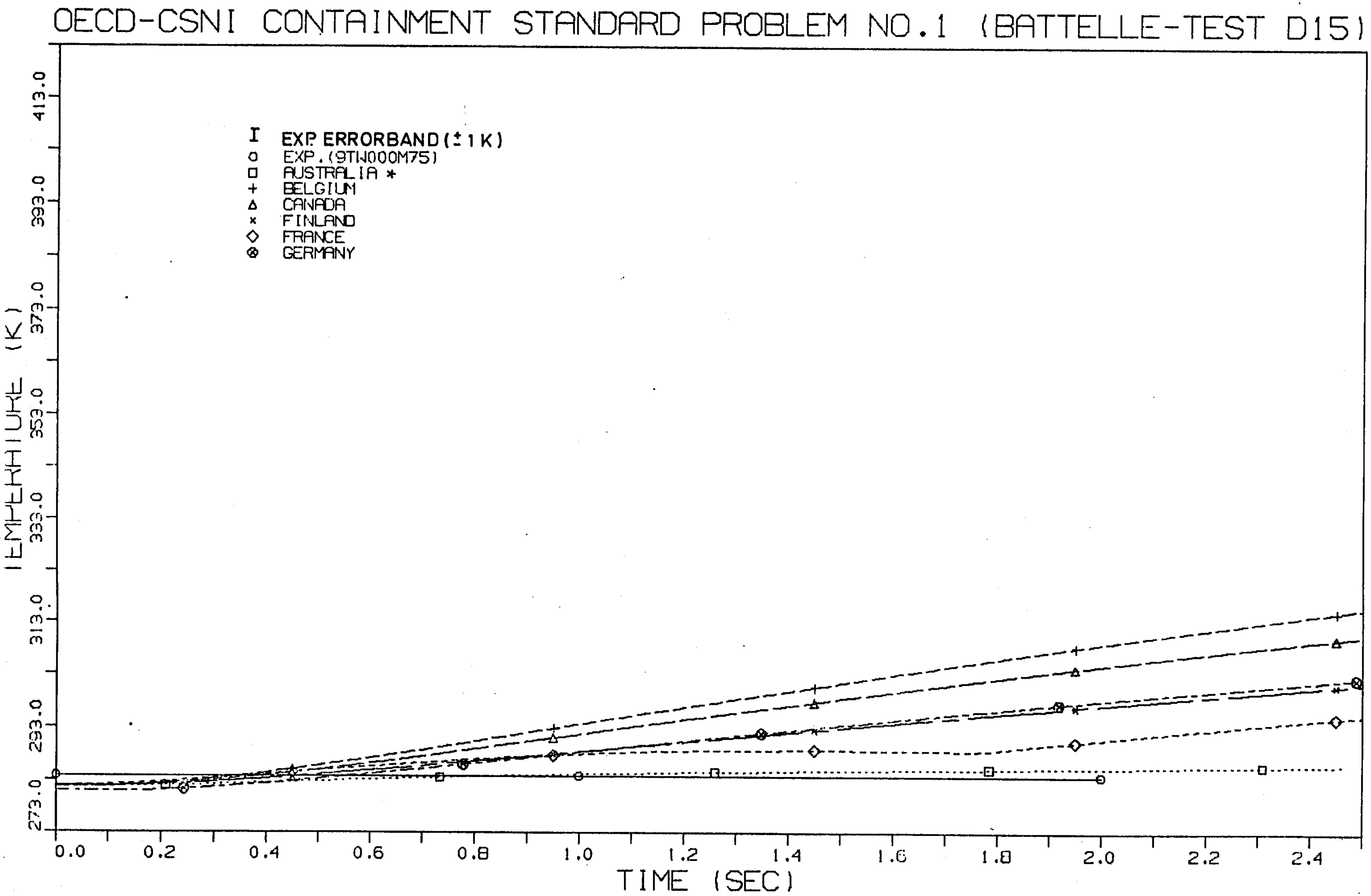

FIG. 27A TEMPERATURE HISTORY IN COMPARTMENT R9

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

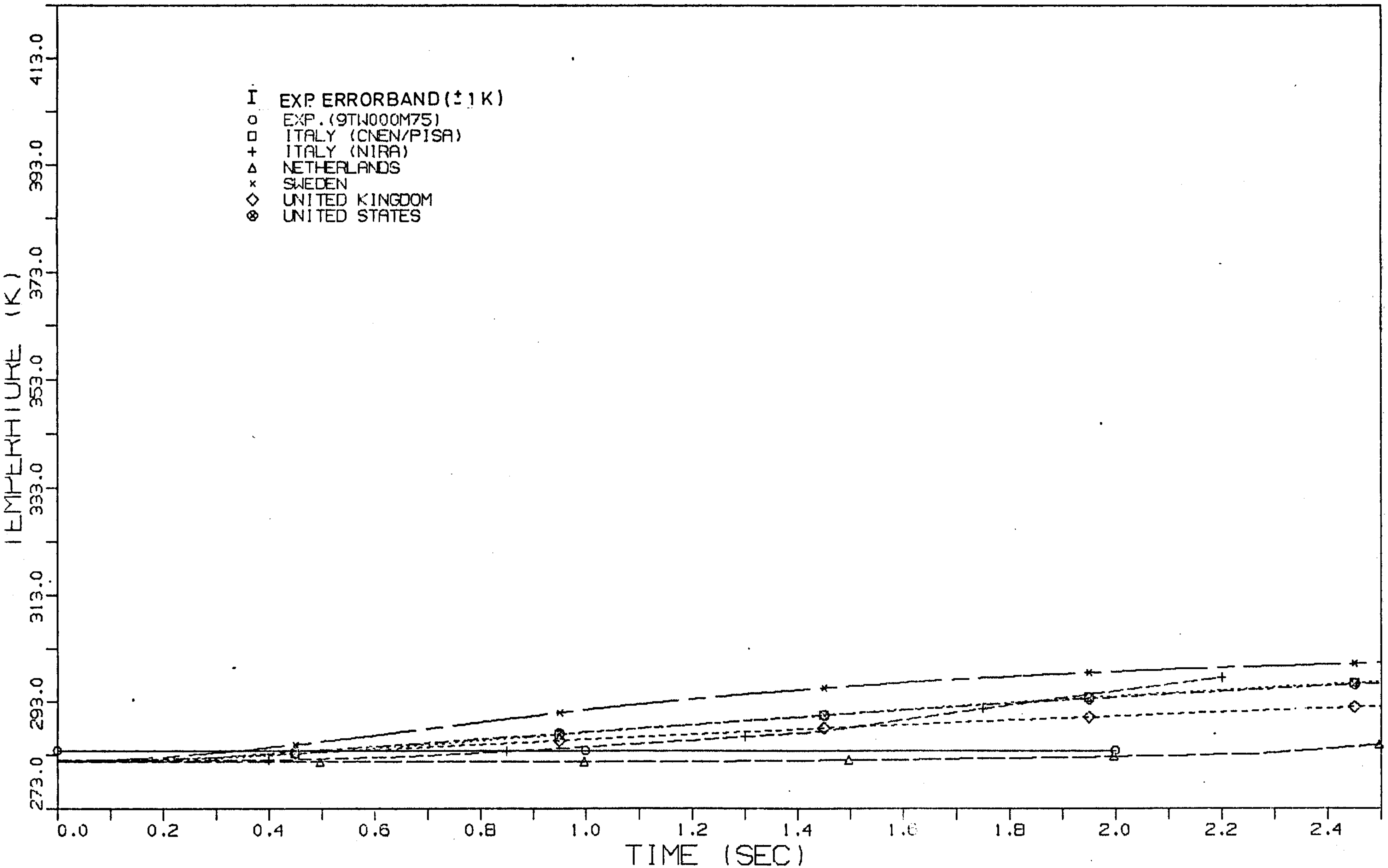

FIG. **27B** TEMPERATURE HISTORY IN COMPARTMENT R9

- Pressure difference between compartments R6 and R9 (figs. 28A, 28B):

  The maximum of the highest pressure difference at all occurring between compartments was calculated within a range of -0.06 bar (-12 %) and +0.13 bar (26 %) partly at different moments. Not including, in this case, the slightly higher deviations of Canada and UK (choice of higher resistance or discharge coefficients) this bandwidth diminishes to - 0.06 bar (-12%) and + 0.04 bar (+ 8 %) (in German SP + 4 % and + 20 %). The more time is increasing the more calculational results, in general, overpredict experimental results and partly diverge. Results of Belgium Italy (NIRA) and Sweden show overall best agreement with experimental data. Belgium's result is insofar interesting as compartment pressures especially in R9 are somewhat over-predicted thus indicating that the assumptions for heat transfer (here relatively small htc) are partly filtered out with regard to pressure differences.

- Pressure difference between compartments R6 and R8 (figs. 29A, 29B):

  This pressure difference essentially informing on the quality of assumptions for flow losses of the channel was calculated within a small bandwidth in the order of the experimental errorband (except UK). A few participants more or less underpredict the maximum. On the average over the whole time interval calculated results of Finland, Germany (oscillations with lower frequency than in the beginning of the experiment), Italy (CNEN/Pisa) and Italy (NIRA) best coincide with experimental results. Lacking or contradictory information on concept or coefficients for channel flow does not enable to find out the best method.

- Pressure difference between compartments R8 and R9 (figs. 30A, 30B):

The sum of the pressure differences across all overflow vents following the channel (4 sharp-edged orifices) is more or less overpredicted by the participants (+ 10 % to + 48 % at the maximum the corresponding values of "blind" German Standard Problem being + 27 % to + 52 %). It seems that flow coefficients differ with respect to main direction of inlet and outlet flow. Regarding the whole history of this pressure difference Belgium's and Sweden's results fit best the experimental results. To further analyse deviations each participant should look at the pressure difference of each orifice. By doing so one may find out which orifice to what an amount is contributing to the deviation.

- Pressure difference between compartments R4 and R5 (figs. 31A, 31B)

As an example for this further analysing orifice Ü 45 (D = 0.75 m) shall be taken. This orifice differs from other overflow openings insofar as it is following orifice Ü 47 (D = 0.75 m) in a short distance of 1.4 m. As measurement results also indicate the core of the flow of orifice Ü 47 passes orifice Ü 45 without touching its edge and thus generating only a negligible pressure difference. 7 of a total of 12 participants take into account this jet effect though in different manners: by considering kinetic energy and/or momentum loss in the codes, by choosing higher discharge respectively lower pressure loss coefficients than for other orifices, and by combining compartments R4 and R5 to a single node.

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

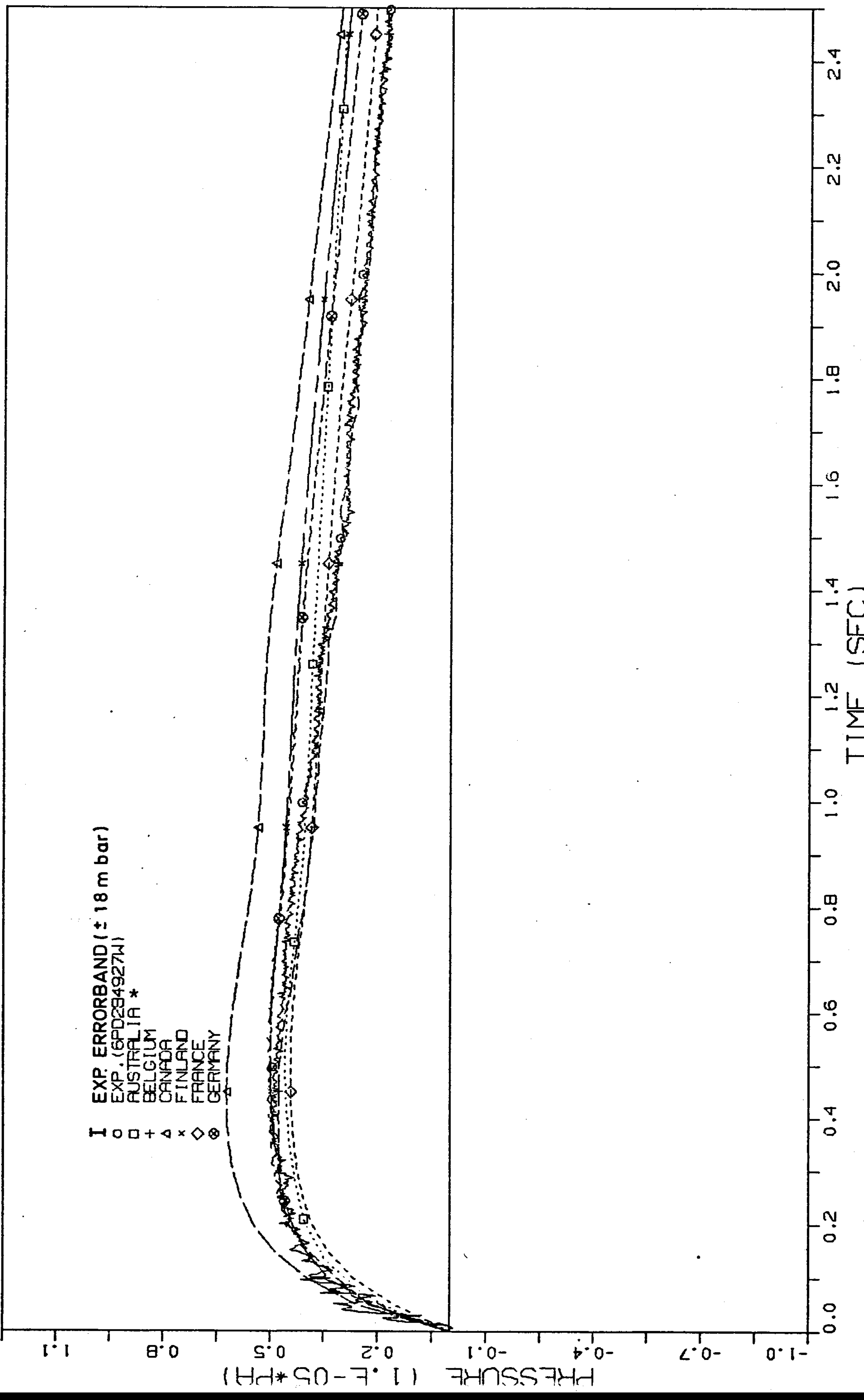

FIG. 28A HISTORY OF PRESSURE DIFFERENCE R6-R9

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

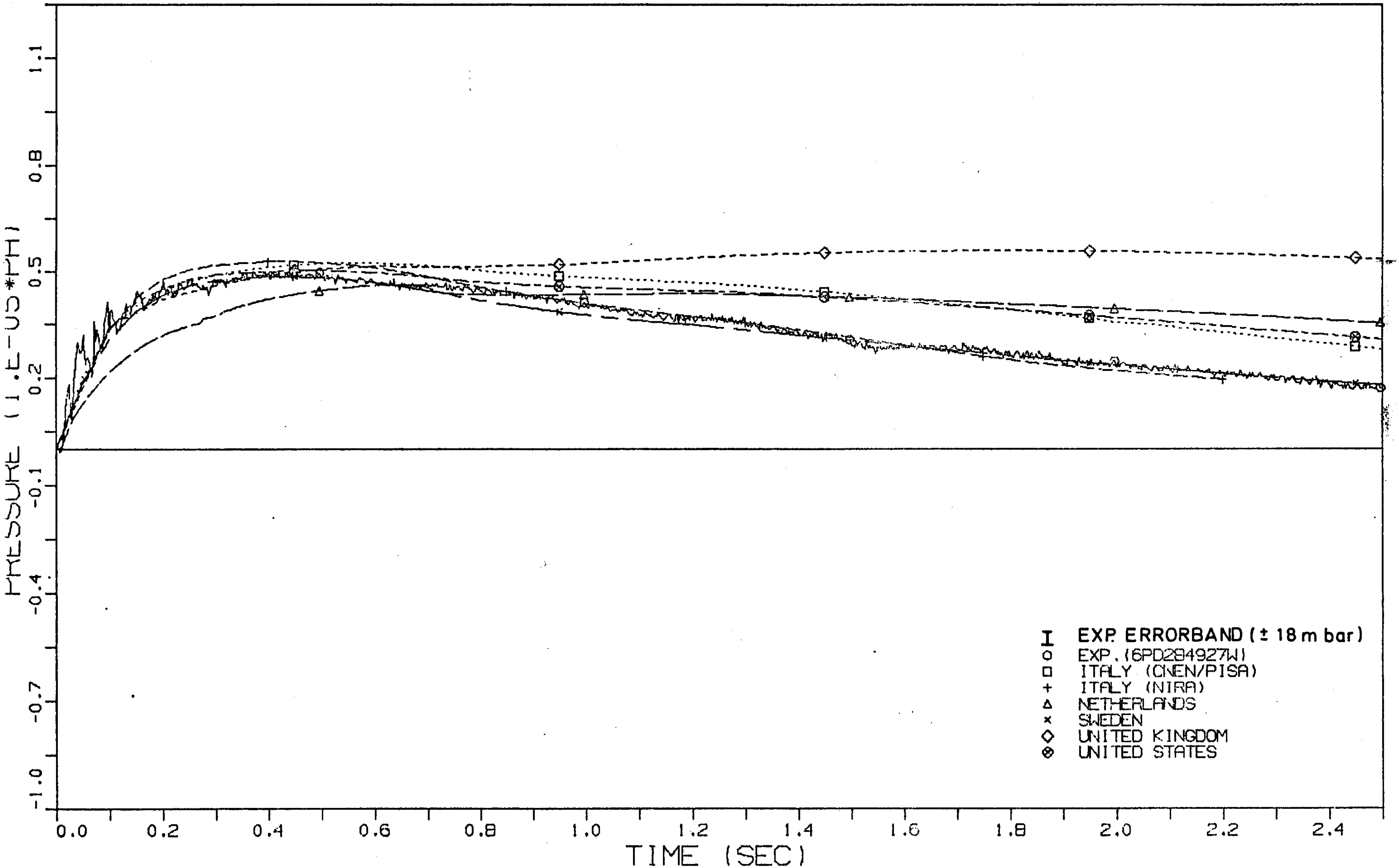

FIG. **28 B** HISTORY OF PRESSURE DIFFERENCE R6-R9

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

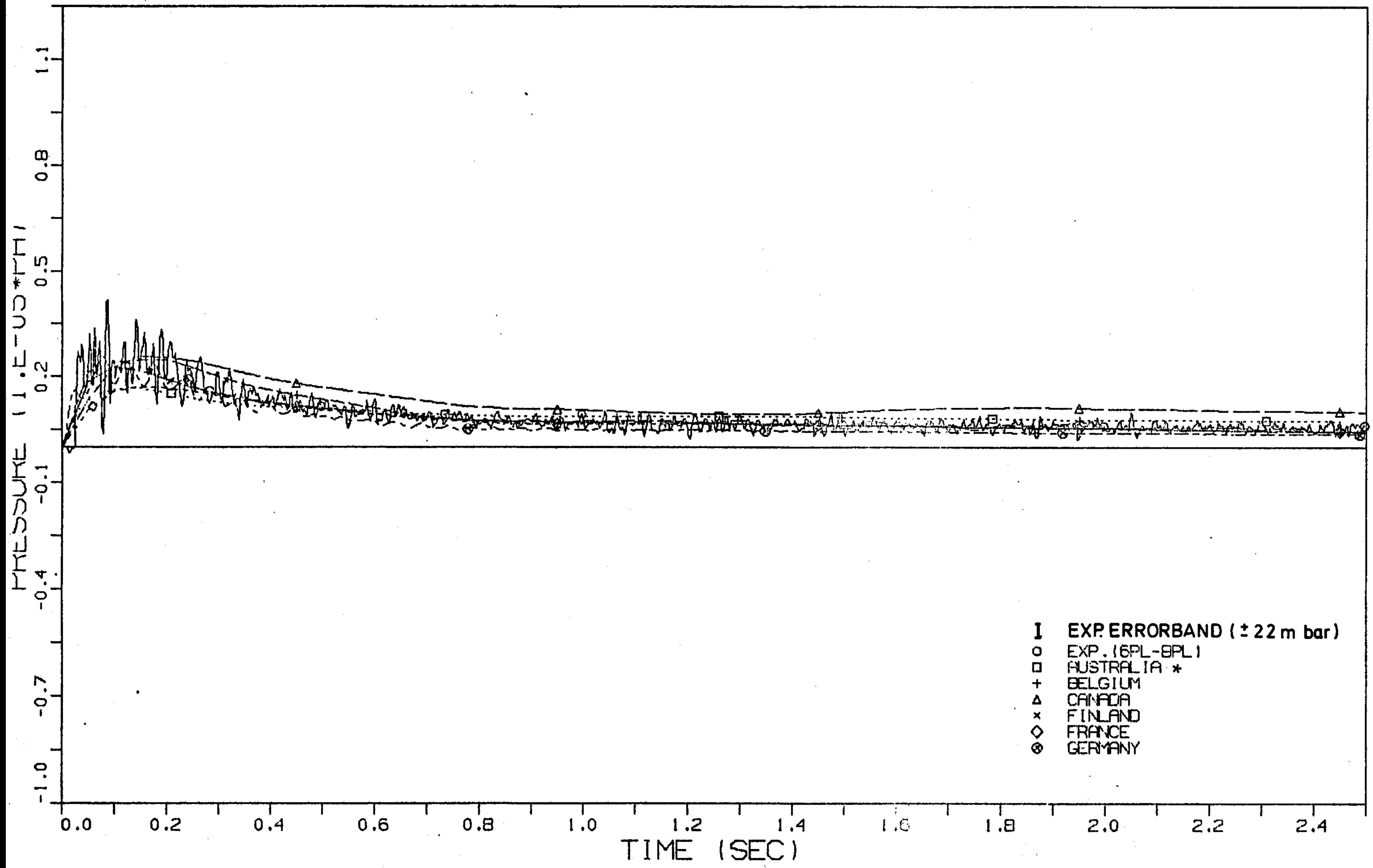

FIG. 29A HISTORY OF PRESSURE DIFFERENCE R6-R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

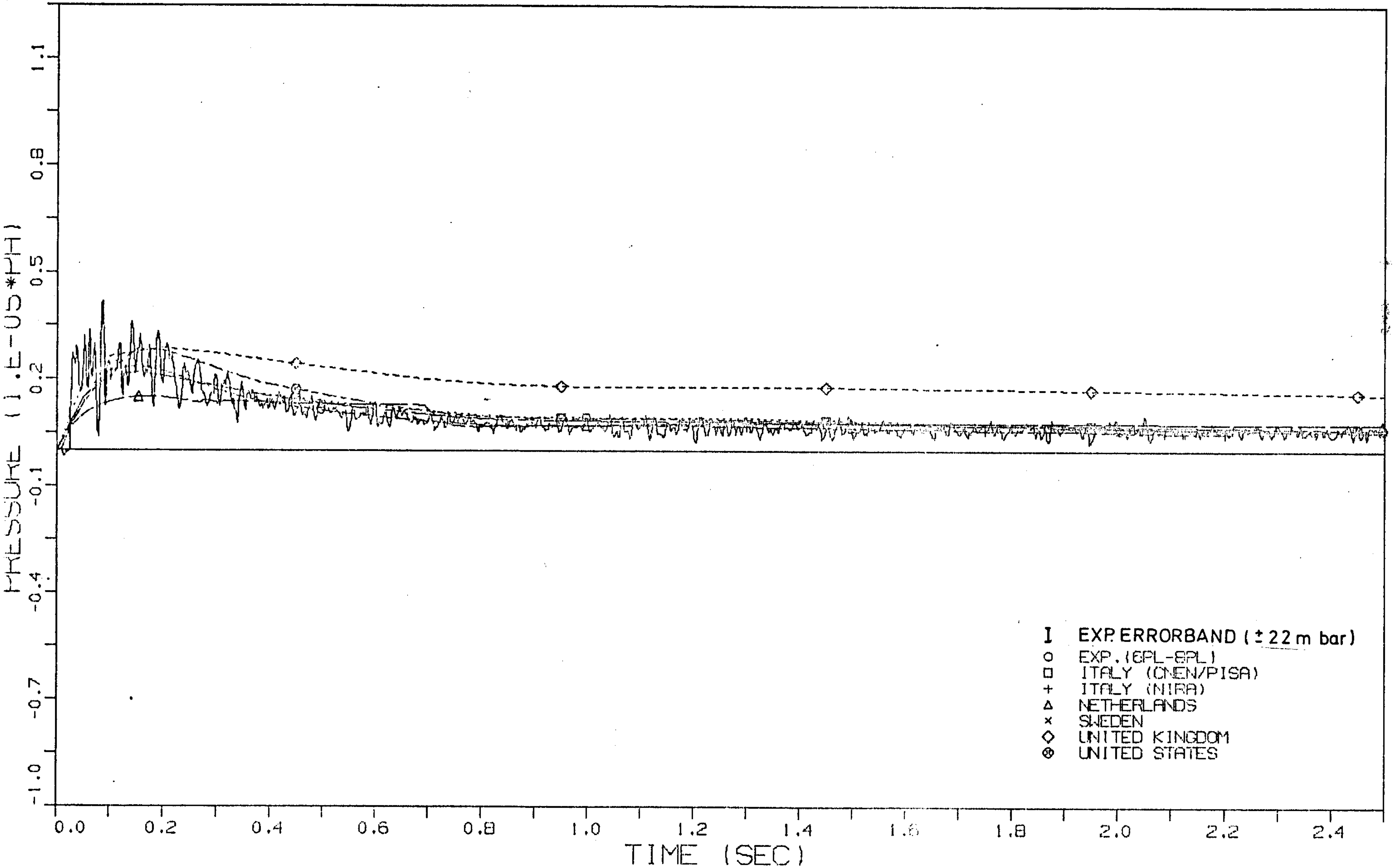

FIG. **29B** HISTORY OF PRESSURE DIFFERENCE R6-R8

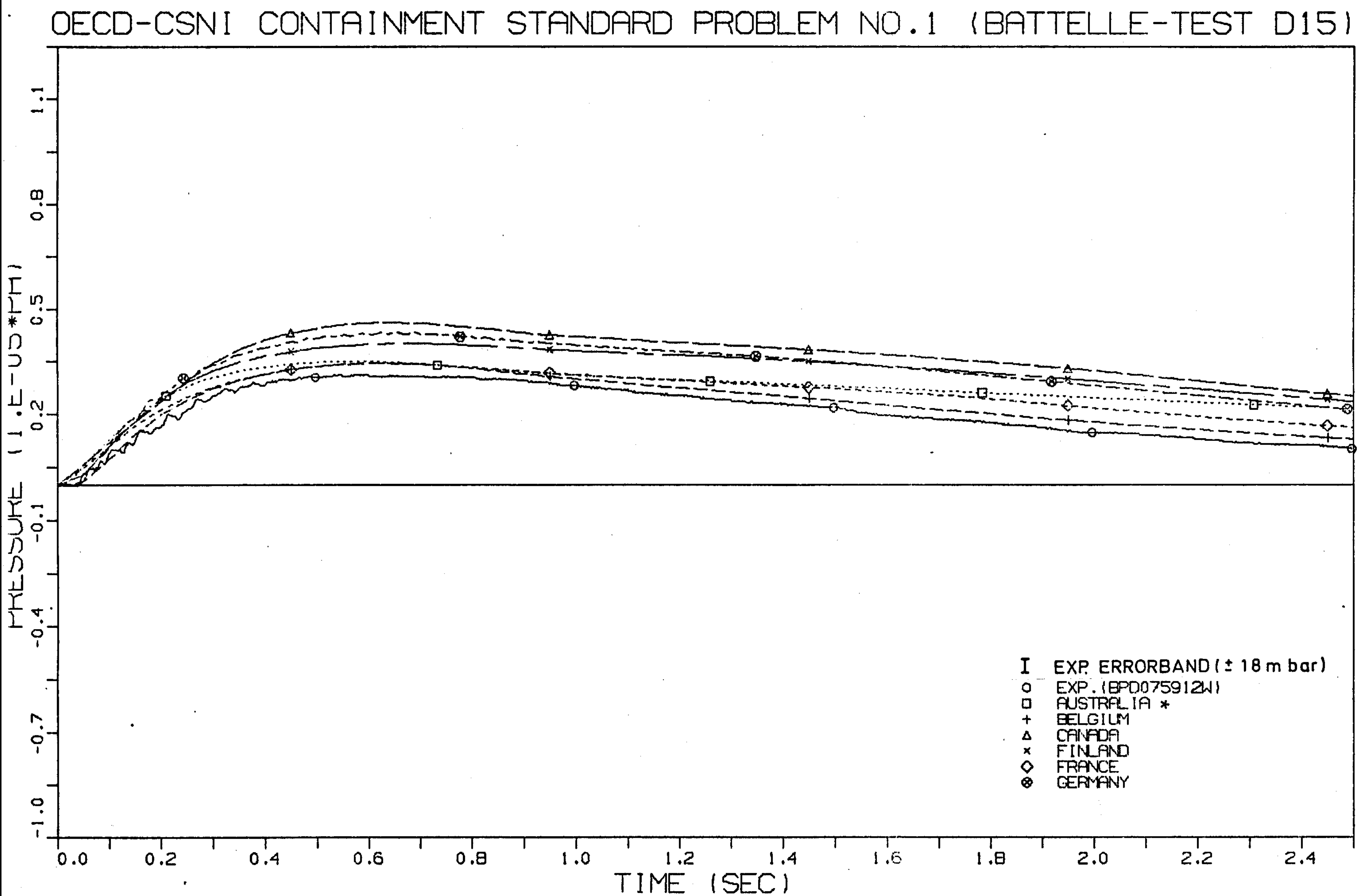

FIG. 30A HISTORY OF PRESSURE DIFFERENCE R8-R9

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

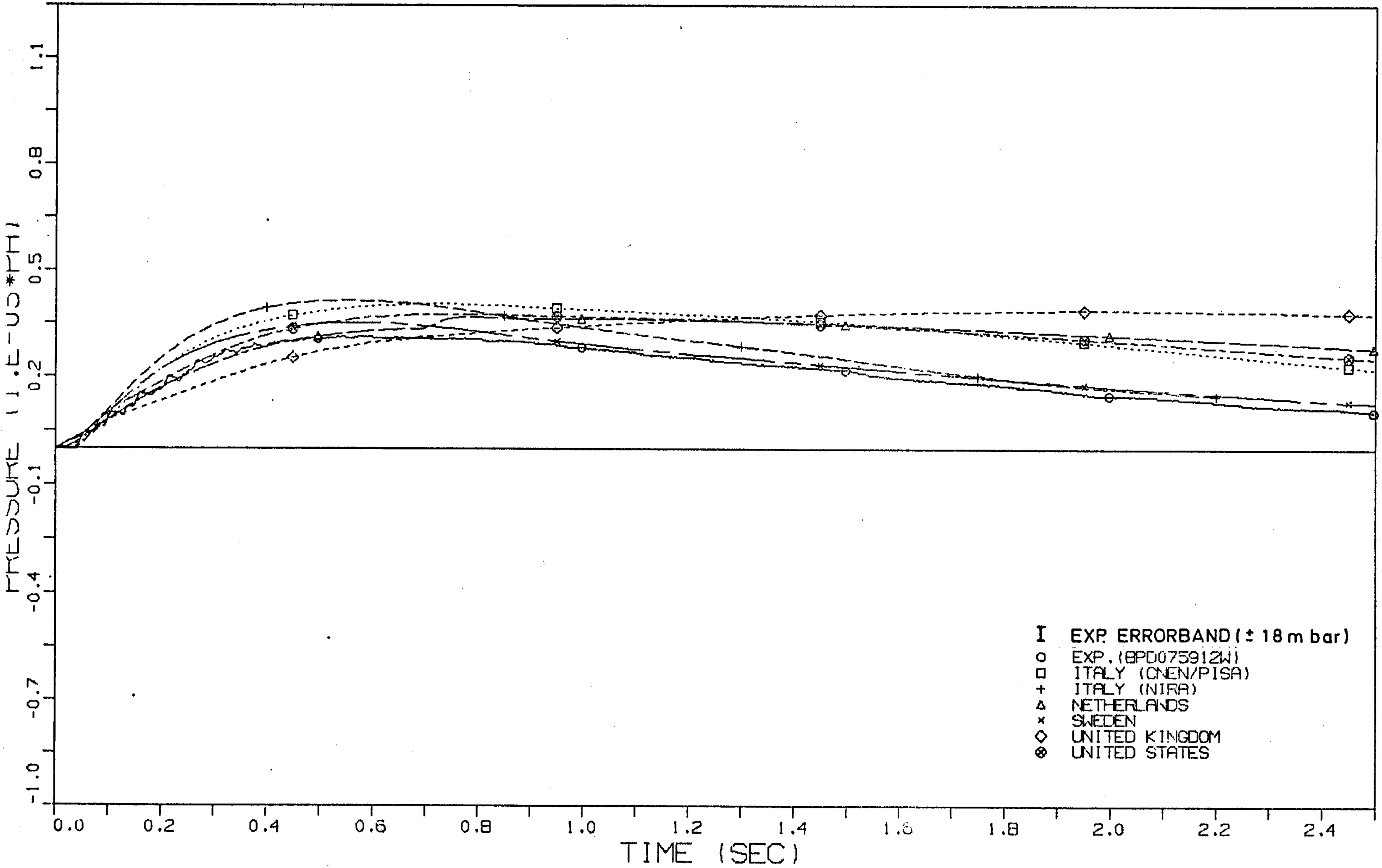

FIG. **30B** HISTORY OF PRESSURE DIFFERENCE R8-R9

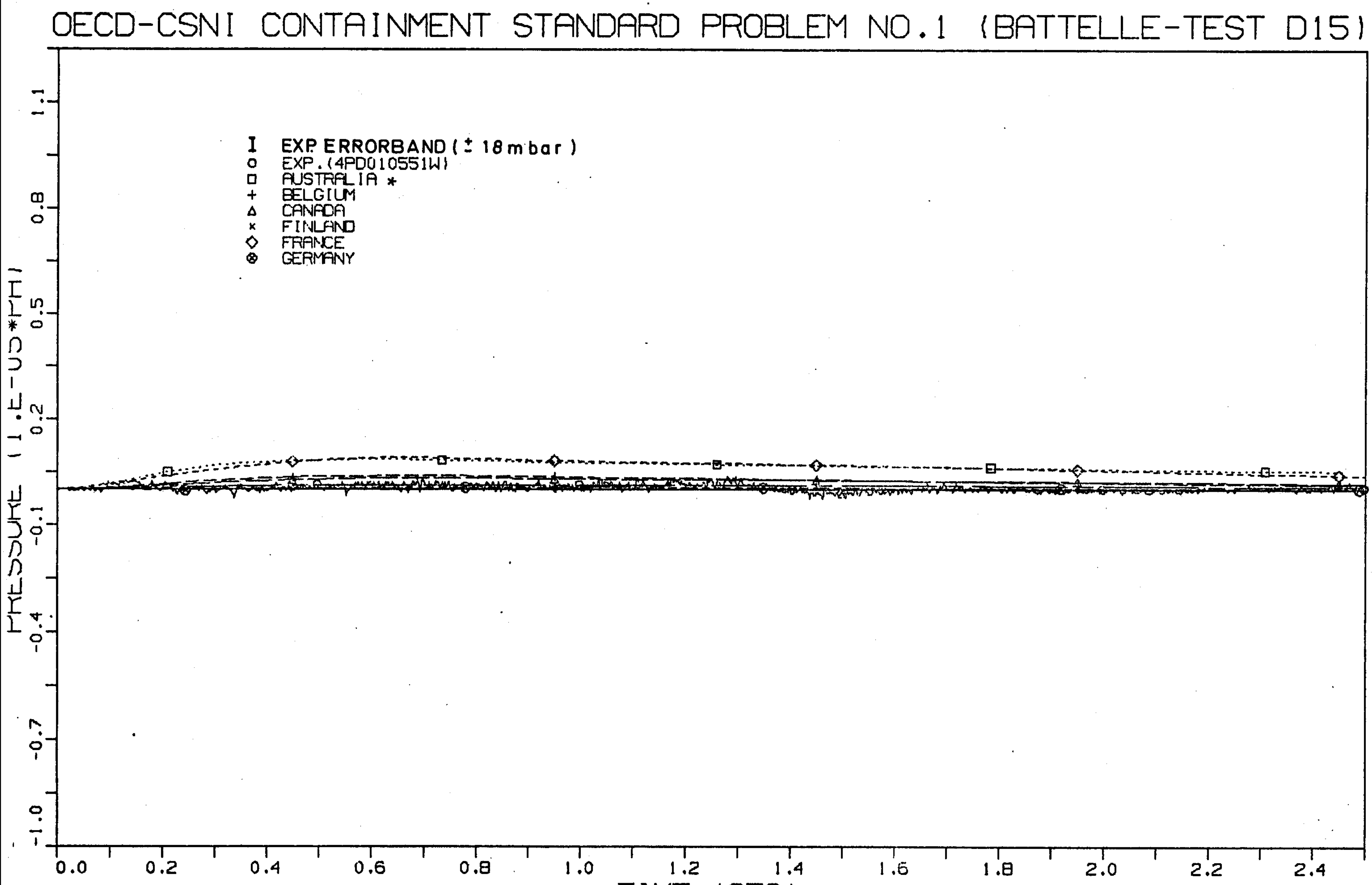

FIG. 31A HISTORY OF PRESSURE DIFFERENCE R4-R5

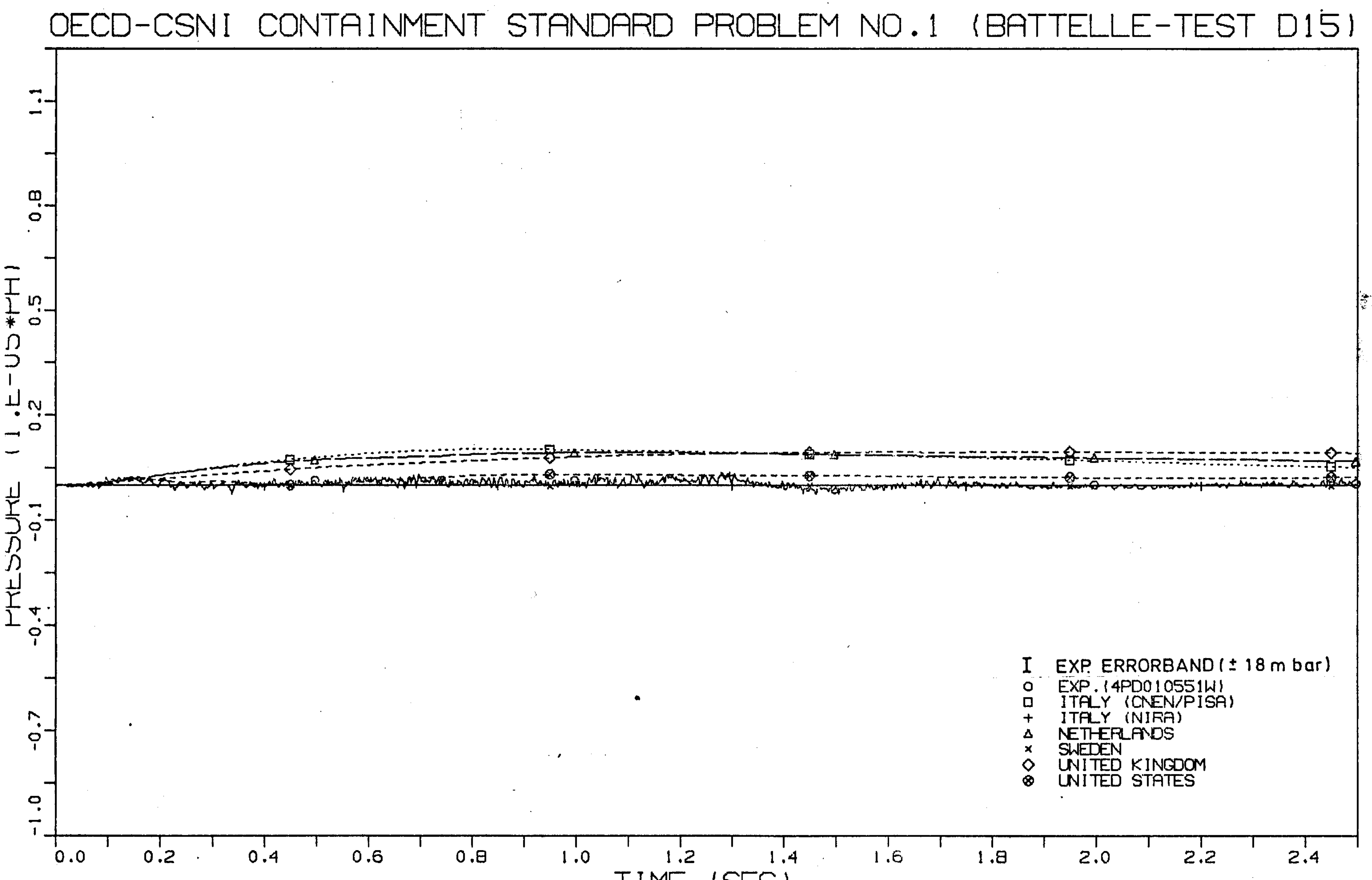

FIG. **31 B** HISTORY OF PRESSURE DIFFERENCE R4-R5

3.4.2 Time interval 0 to 50 s

9 participants subdivide the containment. Already in this time interval Belgium and Germany are simulating the containment as one node. Therefore, in addition, these calculated results are included for comparison of the pressure history in the big dome compartment R9.

Following the selected variables will be regarded more individually.

- Pressure in rupture compartment R6 (figs. 32A, 32B), in first follow-up-compartment R8 (figs. 33A, 33B), and in dome compartment R9 (figs. 34A, 34B):

  With exception of the time period 0 to 4 s experimental pressure histories in the individual compartments do hardly differ and show a maximum especially important for design of a containment (2.06 bar at about 40 s).

  This maximum is calculated by the participants within a range of 1.98 bar to 2.57 bar. This means

$$\frac{-\ 0.08 \text{ to } +\ 0.51}{2.06 \text{ minus } 1.02} = -\ 8\ \% \text{ to } +\ 49\ \%$$

  (corresponding values for German Standard Problem: + 13 % to + 38 %) related to the pressure increase since zero time.

  An essential reason for this great bandwidth of 57 % may be found from the different assumptions for heat transfer to the structures. Australia* within the whole time interval (using derived htc), Belgium (using Tagami/Uchida-correlation but inserting twice the actual energy input to match the peak pressure) and Germany (using a time function for htc) at the maximum fit best the experimental results. Canada

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* see footnote on page 5 and App.

(using Uchida-correlation), Finland (using a dial of 40 to some heat transfer correlation incorporated in the REALP4-version applied), and Italy-NIRA (using htc=2100 $W/(m^2K)$ up to 70 s, then Uchida-correlation) a little more overpredict the peak pressure than other participants.

In connection with this it should be mentioned that, on the other hand, deviations between calculations and experiment can also be attributed to questionable energy release data for test D15 (high errorband for certain time ranges of the test, see figs. 8.1 and 8.2 from /5/). There are inexplicable differences in comparison with other tests (e.g. D10) showing only small differences for pressure history in the pressure vessel.

Also the moment of maximum pressure is partly calculated with less accuracy values ranging from 37 s to 50 s.

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

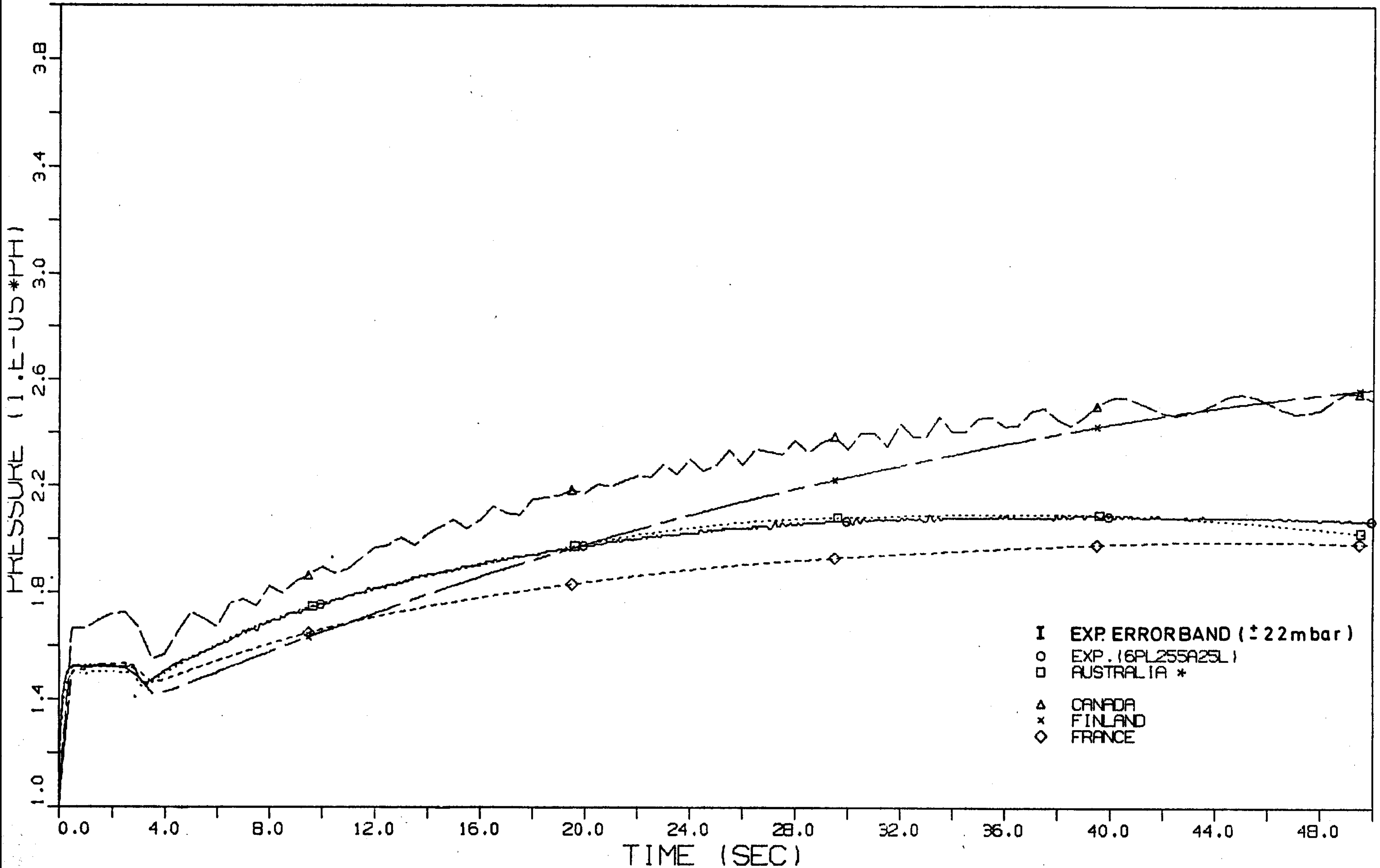

FIG. 32A PRESSURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

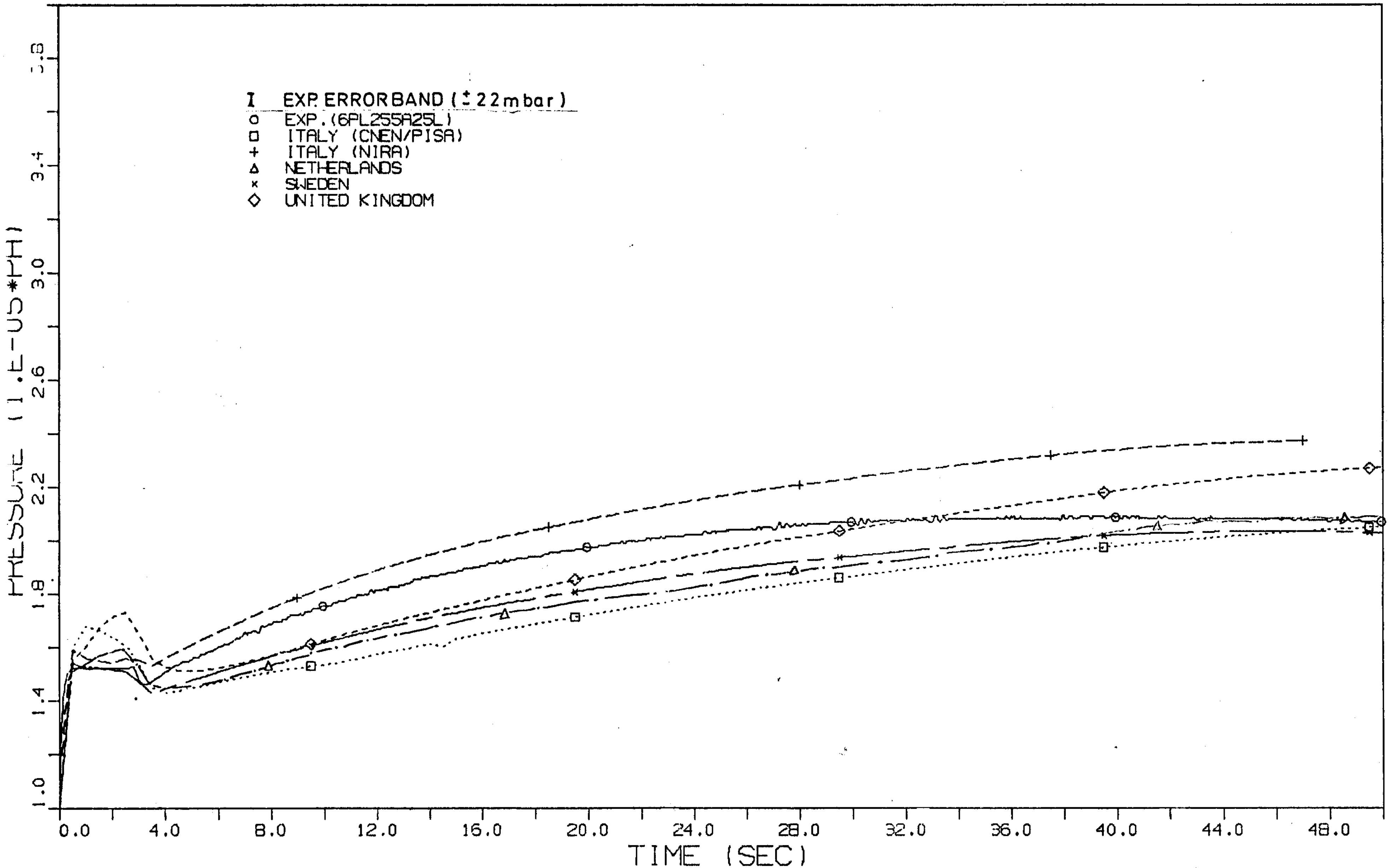

FIG. **32 B** PRESSURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

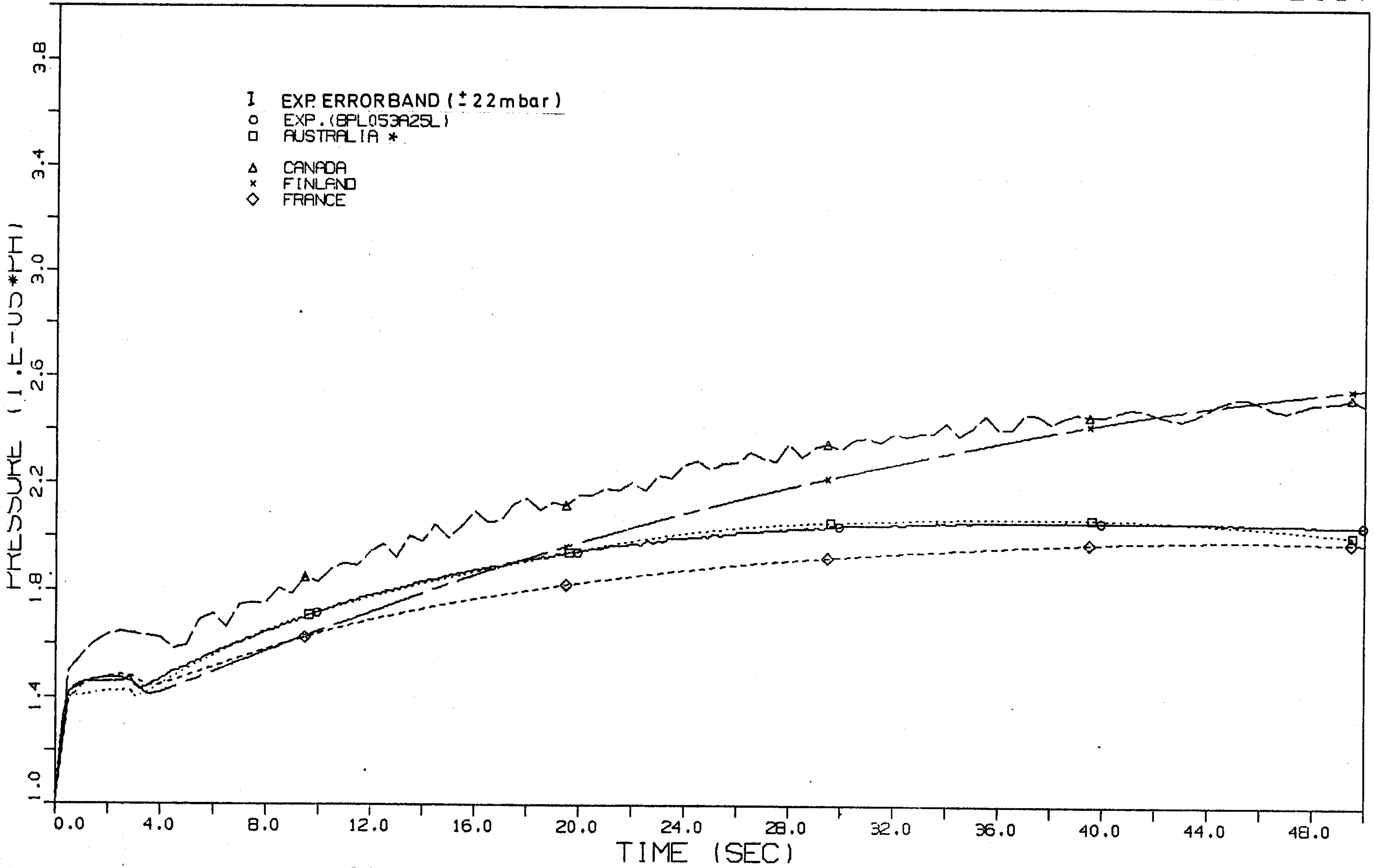

FIG. 33A PRESSURE HISTORY IN COMPARTMENT R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

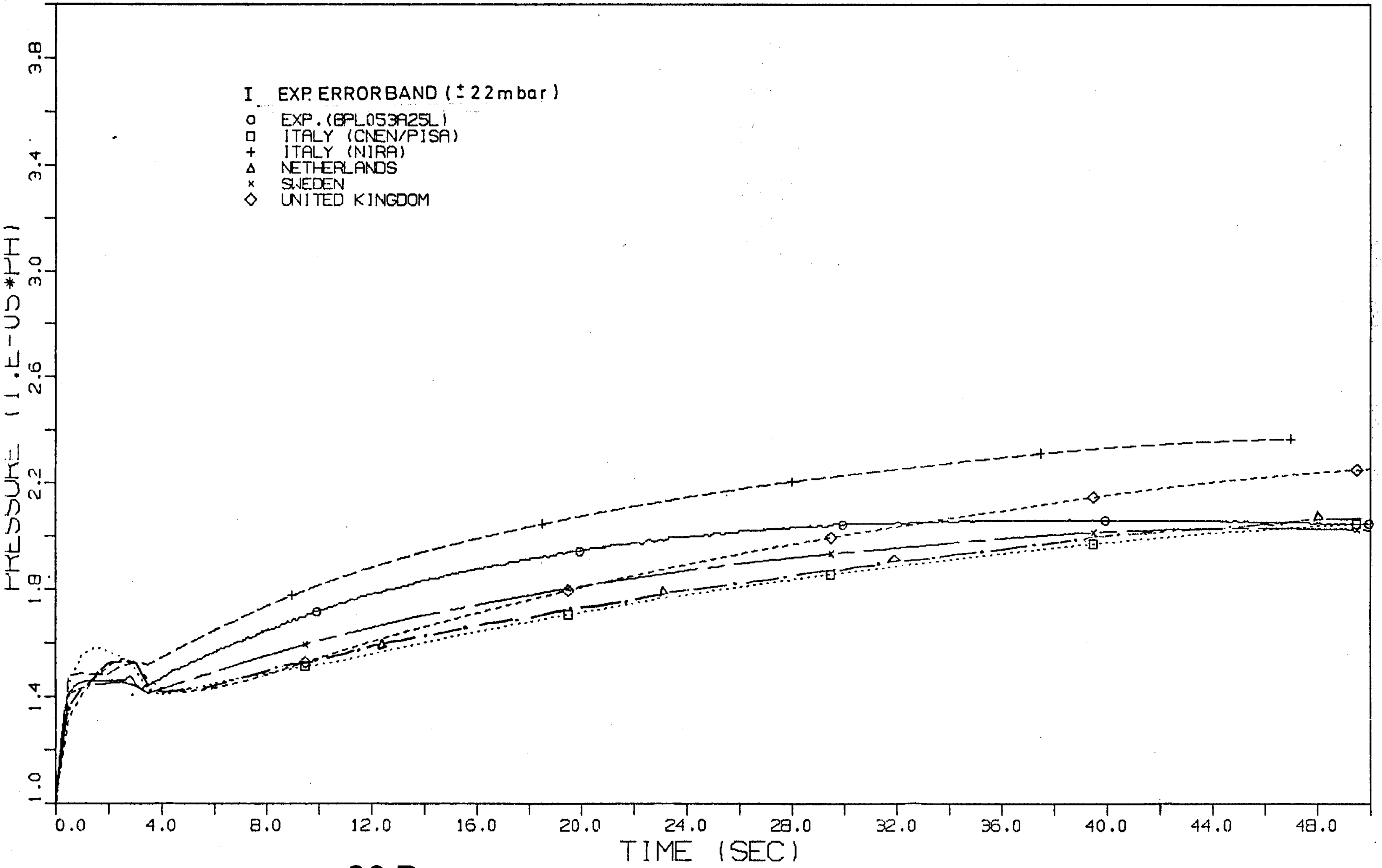

FIG. **33 B** PRESSURE HISTORY IN COMPARTMENT R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

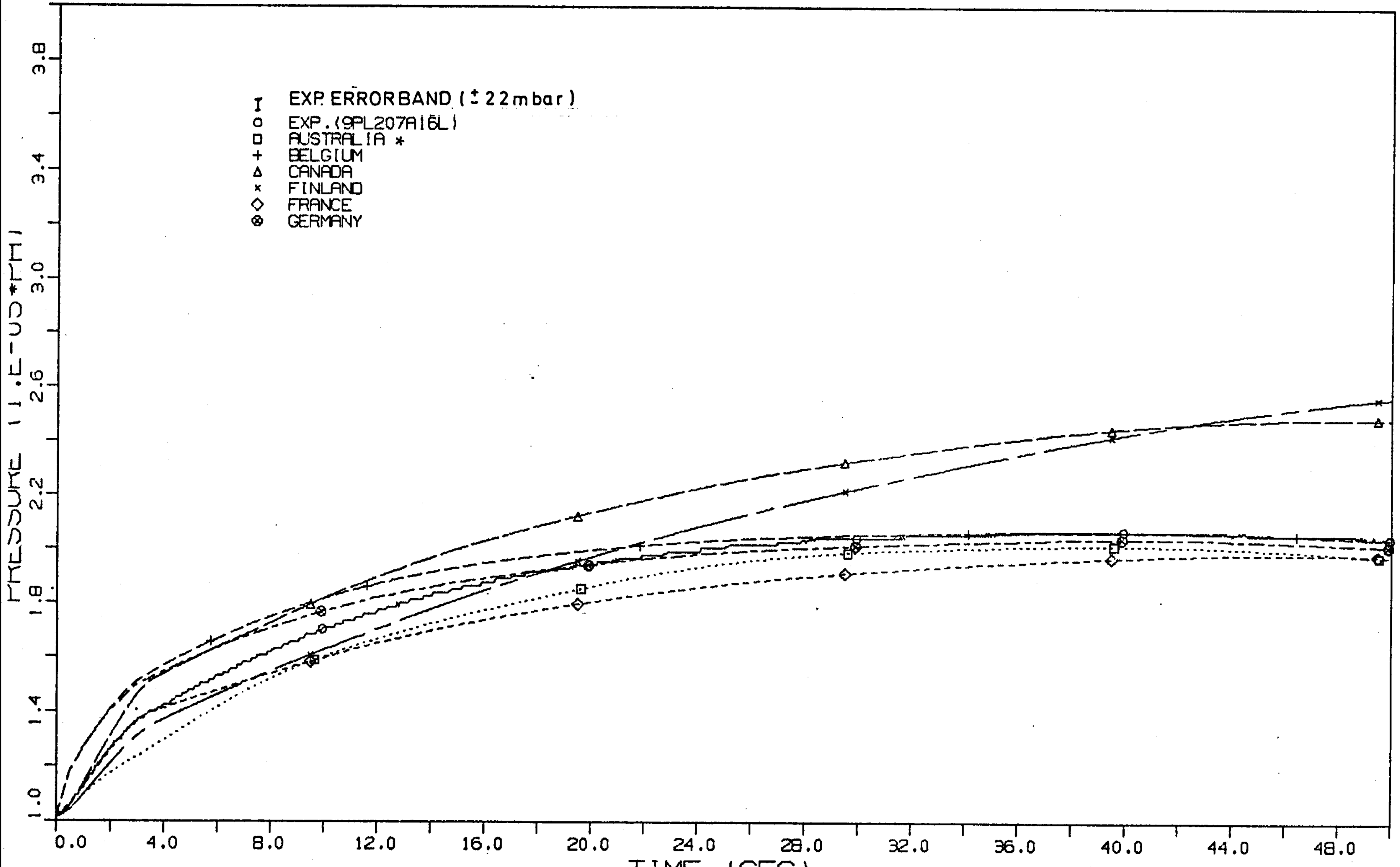

FIG. 34A PRESSURE HISTORY IN COMPARTMENT R9

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

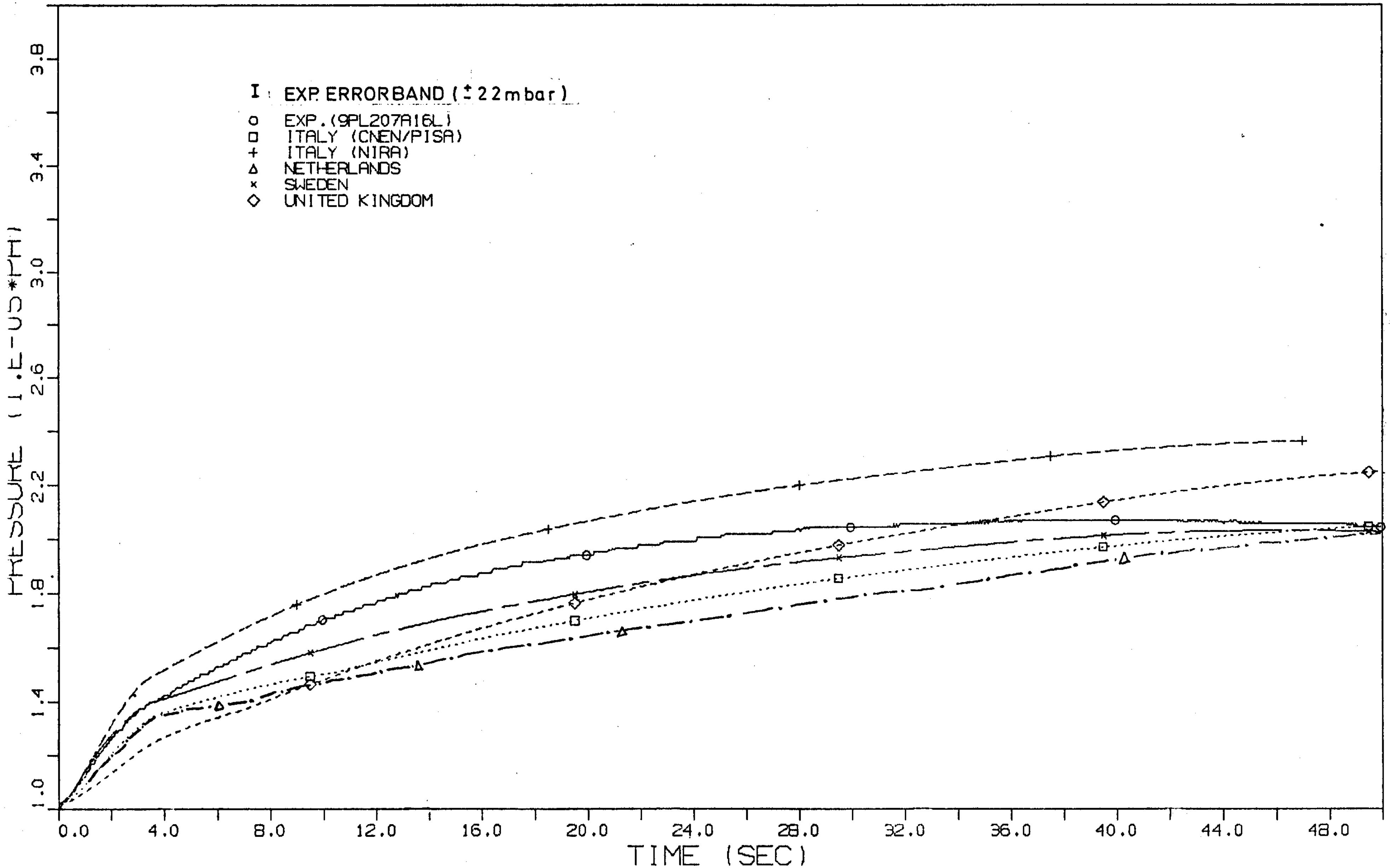

FIG. **34 B** PRESSURE HISTORY IN COMPARTMENT R9

- Temperature in rupture compartment R6 (figs. 35A, 35B):

  It may be deduced from measured temperature histories at other measuring point positions in R6 and in other compartments that a dead flow region was formed at this measuring point position. After cooling down and warming up at 46 s this region seems to be replaced by hotter steam.

  On the average calculations are within a small band of up to 10 K (experimental errorband $\pm$ 1.7 K).

- Temperature in first follow-up compartment R8 (figs. 36A, 36B):

  Nearly the same calculational bandwidth as for R6 is valid here.

- Temperature in dome compartment R9 (figs. 37A, 37B):

  For this compartment it is difficult to attach locally measured temperatures (upper and lower limit are shown) to an integral mean value calculated by the codes. For the reason of the temperature maximum in this compartment not yet being reached it seems less important whether, in general, the temperature of the upper measuring point position is overpredicted in the beginning and then underpredicted.

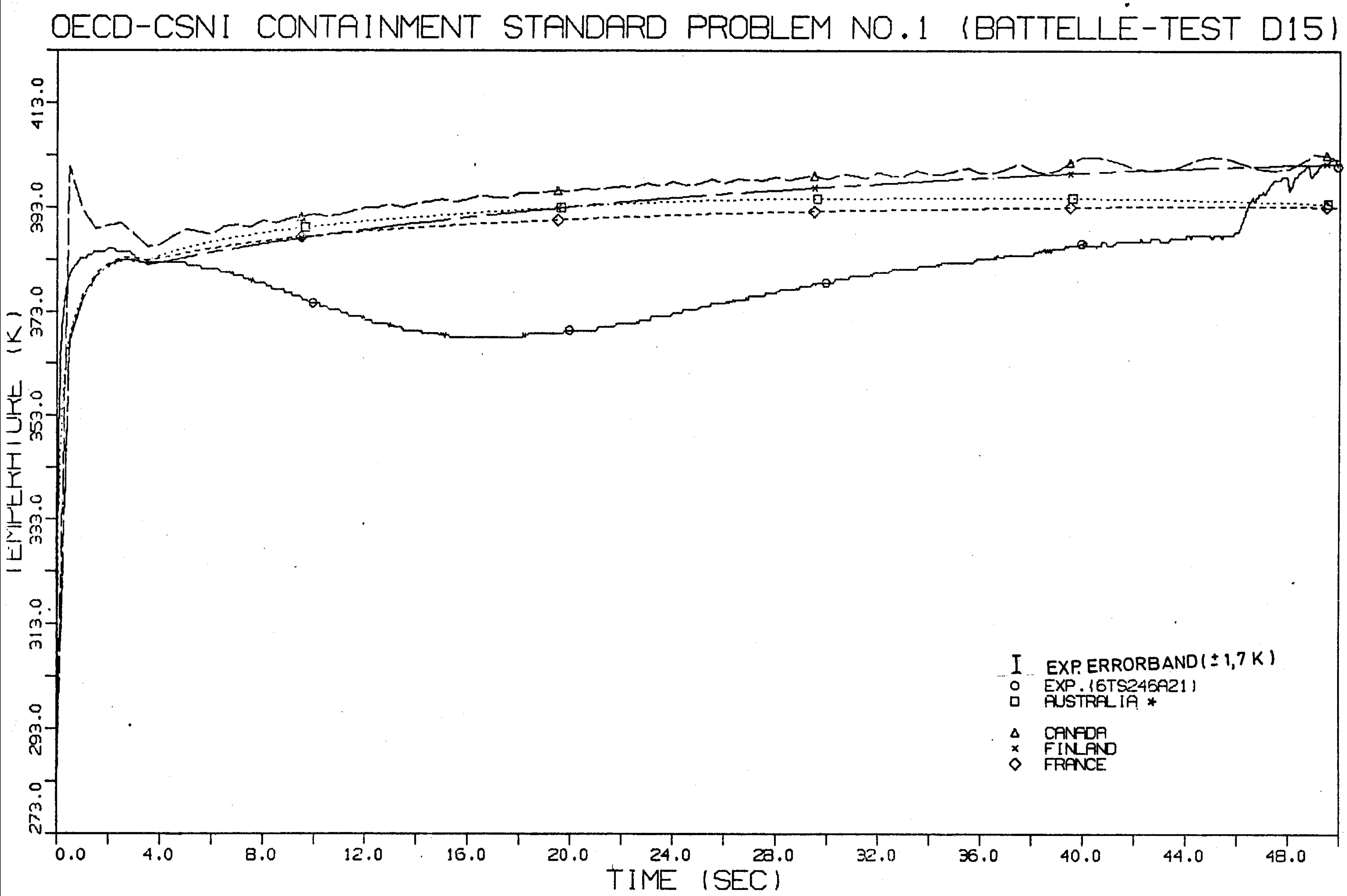

FIG. 35A TEMPERATURE HISTORY IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

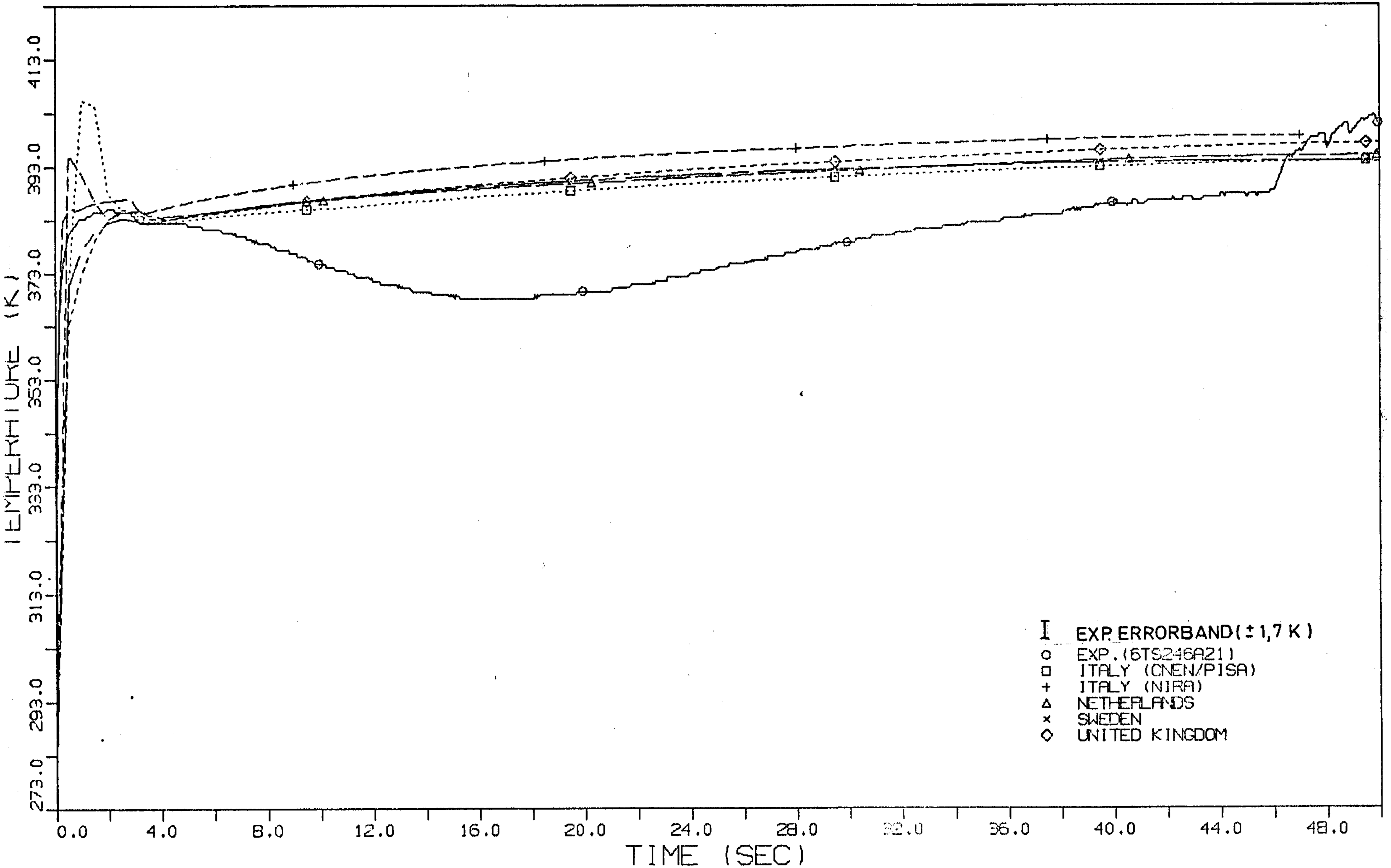

FIG. 35 B TEMPERATURE HISTORY IN COMPARTMENT R6

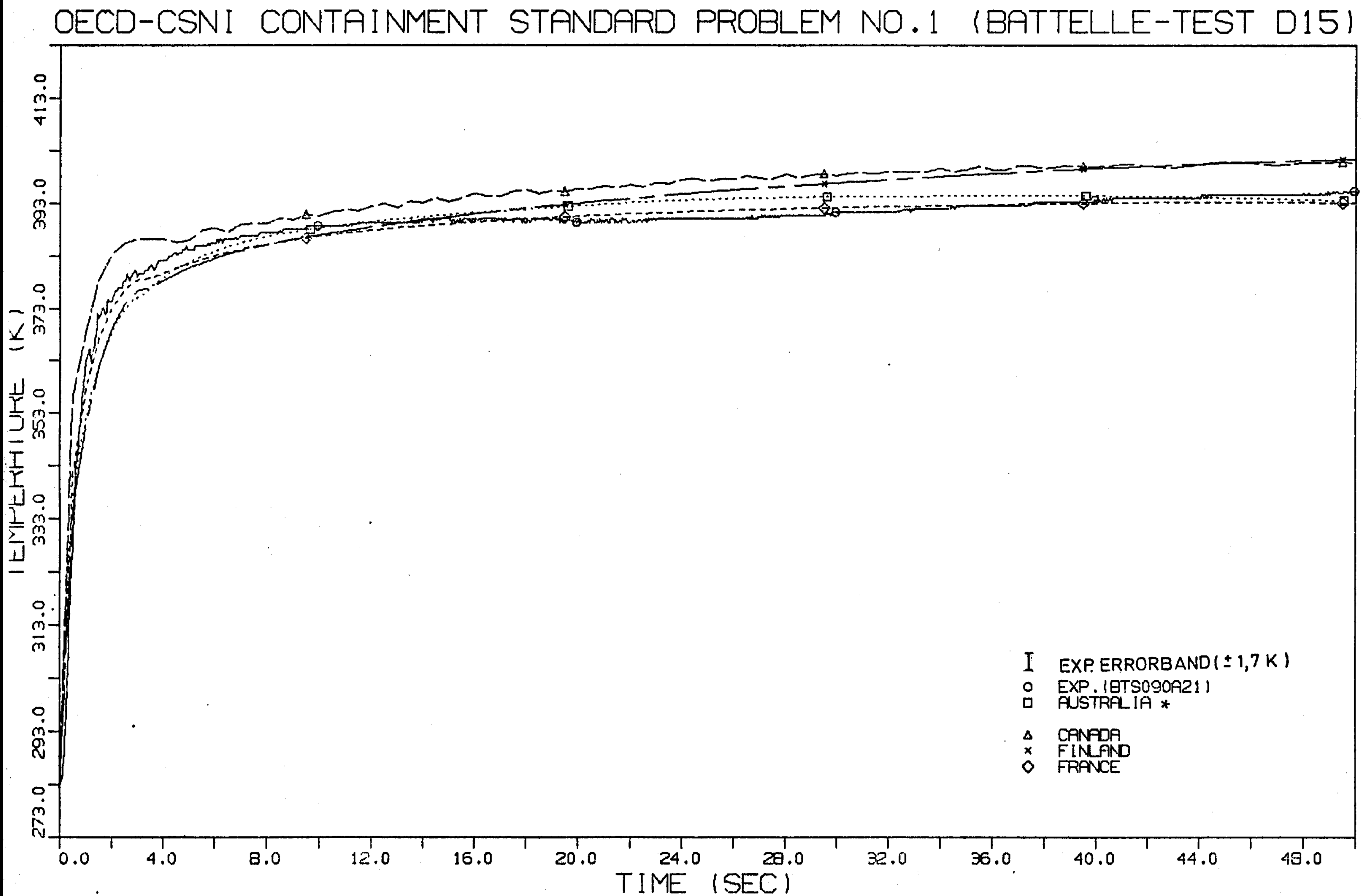

FIG. 36A TEMPERATURE HISTORY IN COMPARTMENT R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

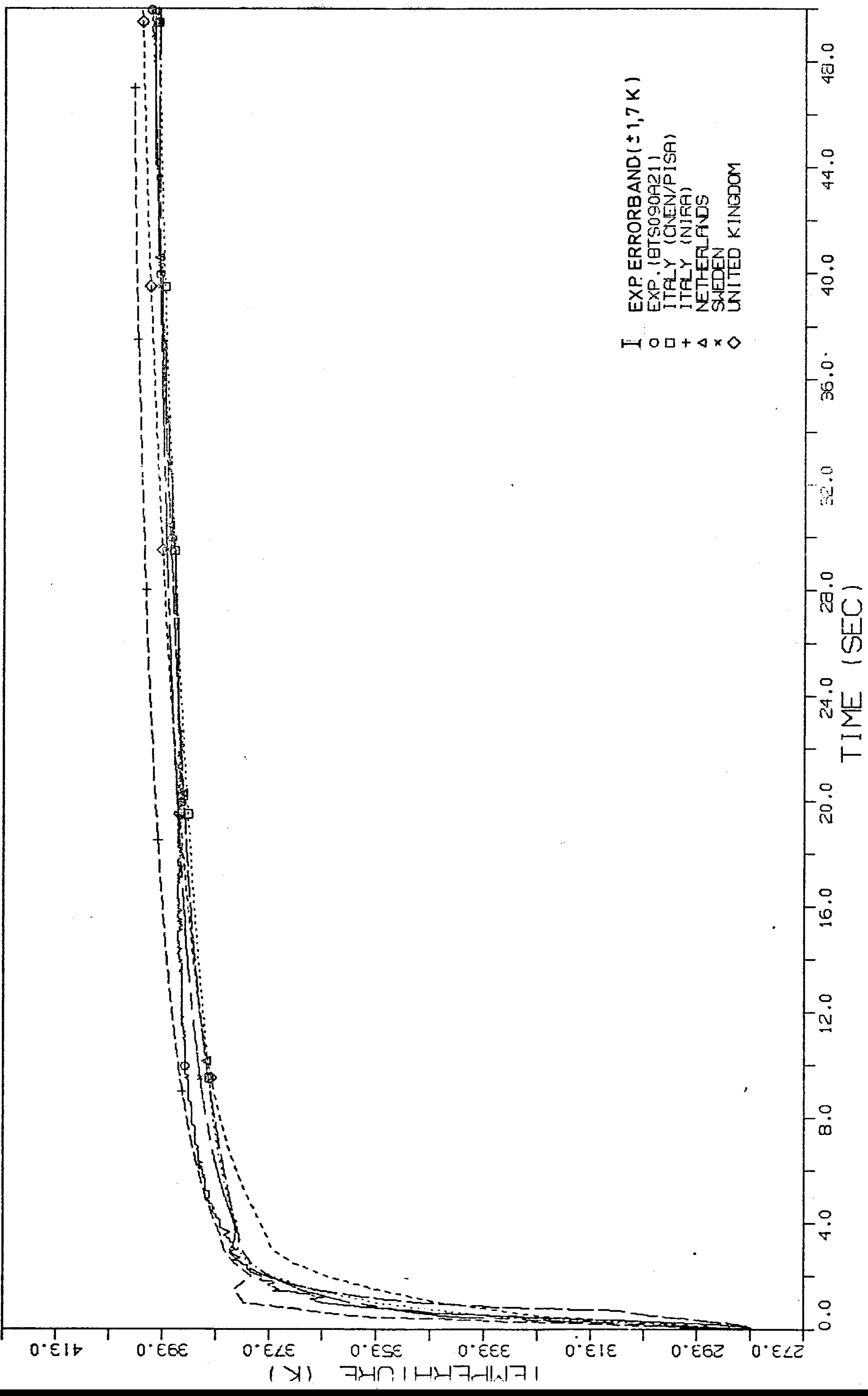

FIG. 36B TEMPERATURE HISTORY IN COMPARTMENT R8

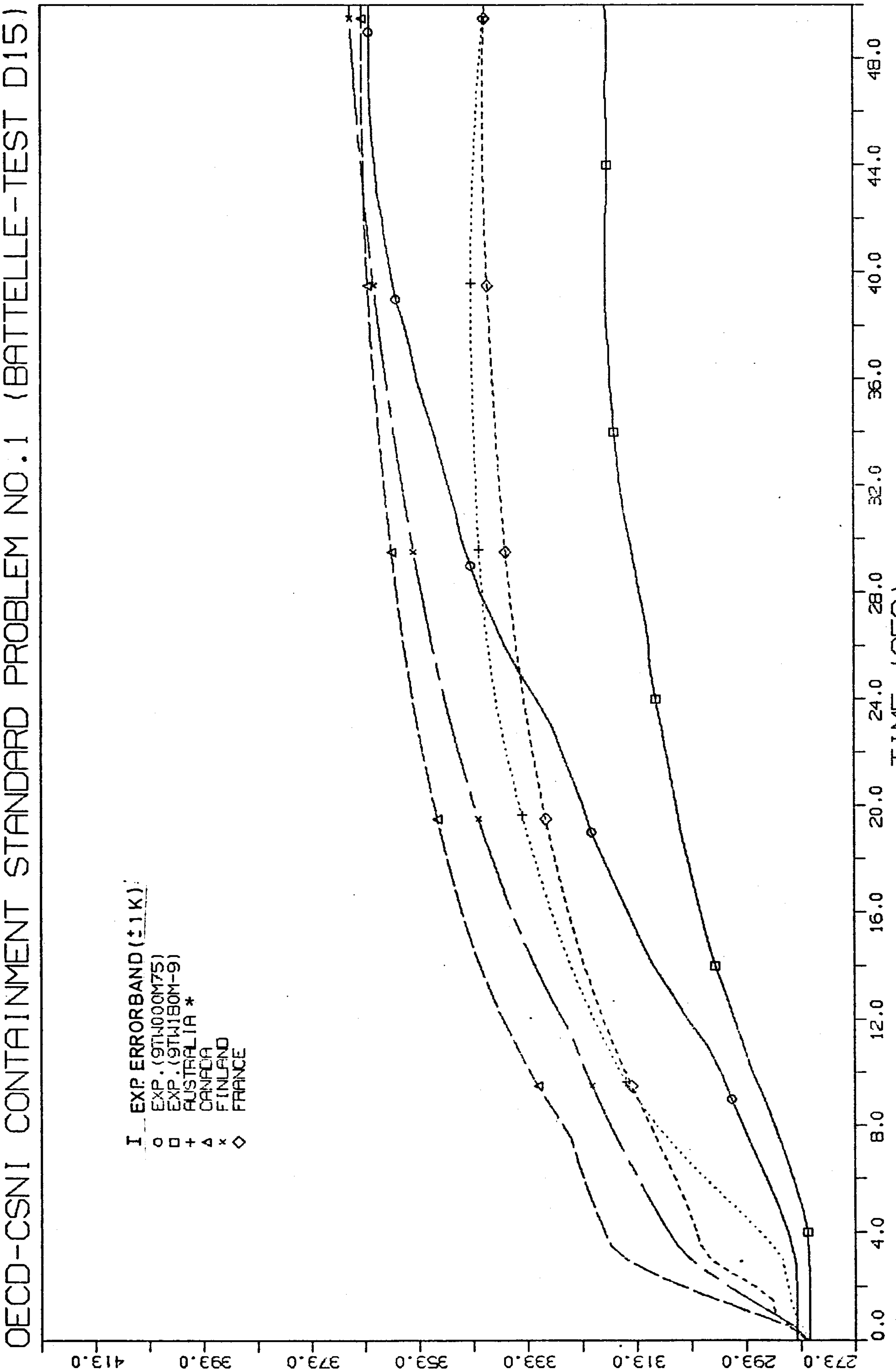

FIG. 37A TEMPERATURE HISTORY IN COMPARTMENT R9

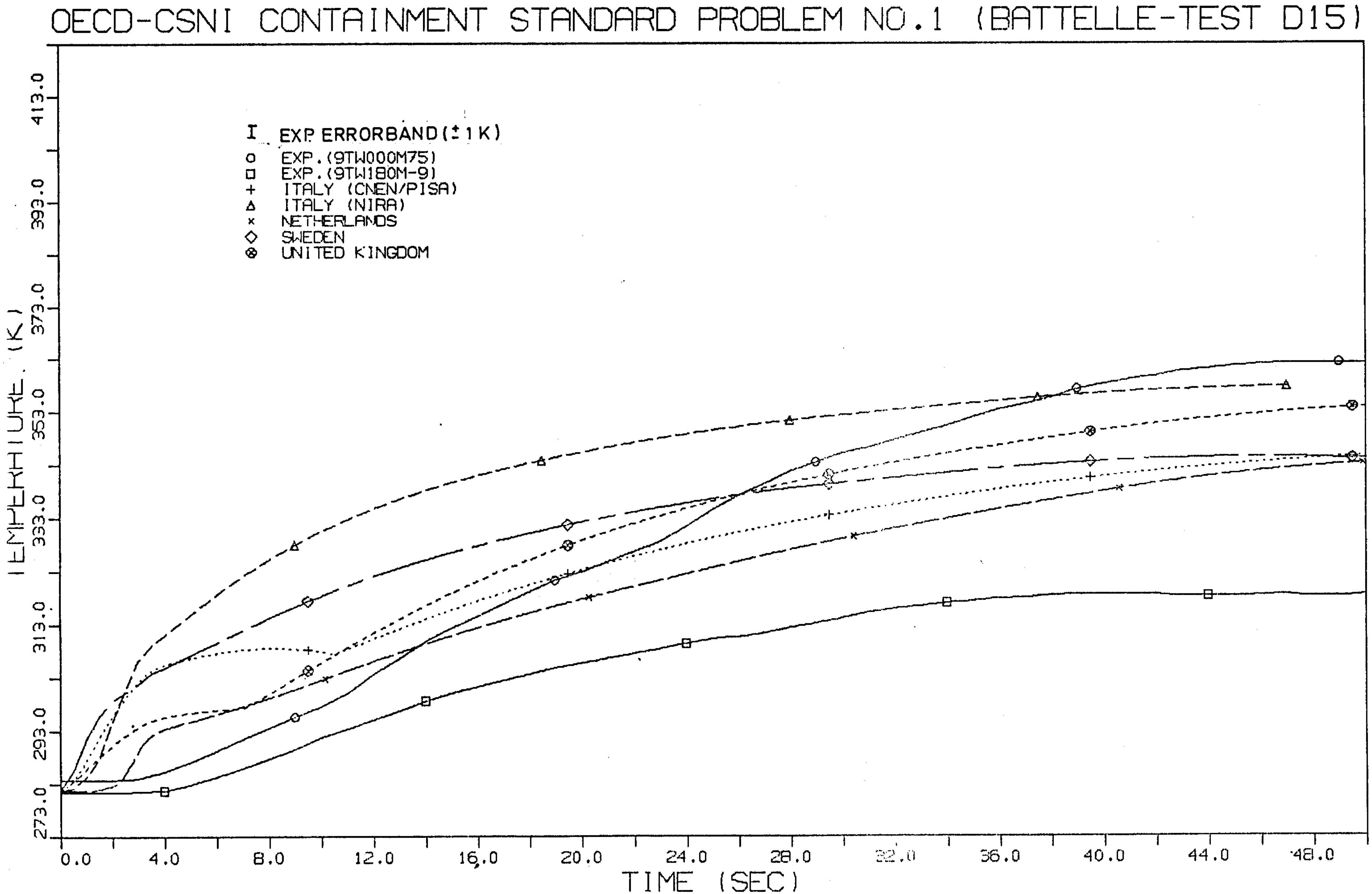

FIG. **37B** TEMPERATURE HISTORY IN COMPARTMENT R9

- History of water mass in compartments R4(figs. 38A, 38B), R5 (figs. 39A, 39B), R6 (figs. 40A, 40B), R7 (figs. 41A, 41B), R8 (figs. 42A, 42B), and R9 (figs. 43A, 43B):

  The widespread calculated results for history of water mass especially in R6 and R9 give a hint that, in general, condensation and water carry-over problems are not yet solved in a reasonable manner. However, from above-mentioned reasons these calculated results cannot be compared to experimental results. Therefore no qualification can be made. To gain an approximate qualitative idea water masses measured at 1500 s are indicated on the plots.

  The mass of water curves of Sweden contain an error (see App.).

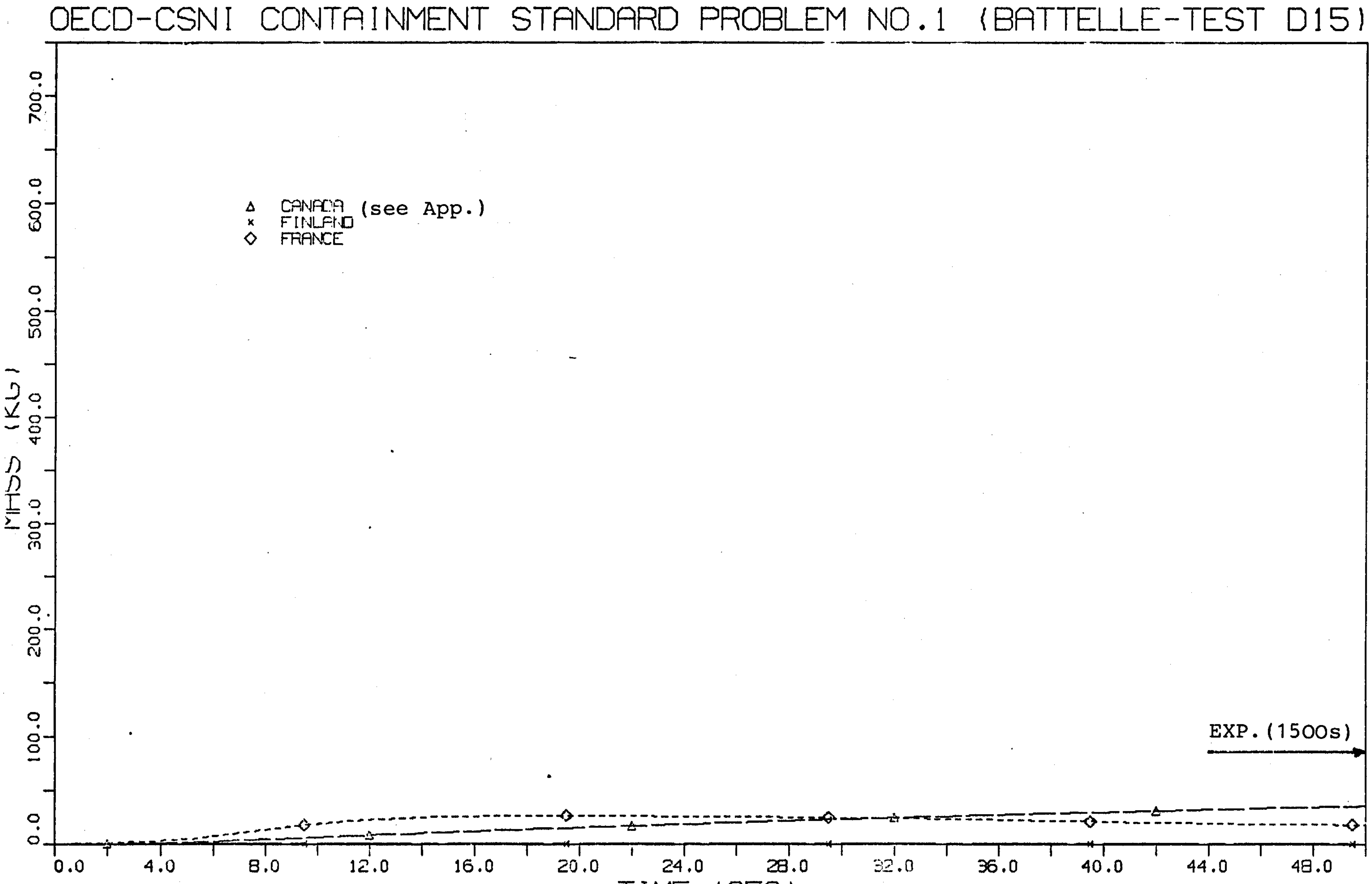

FIG. 38A HISTORY OF WATER MASS IN COMPARTMENT R4

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

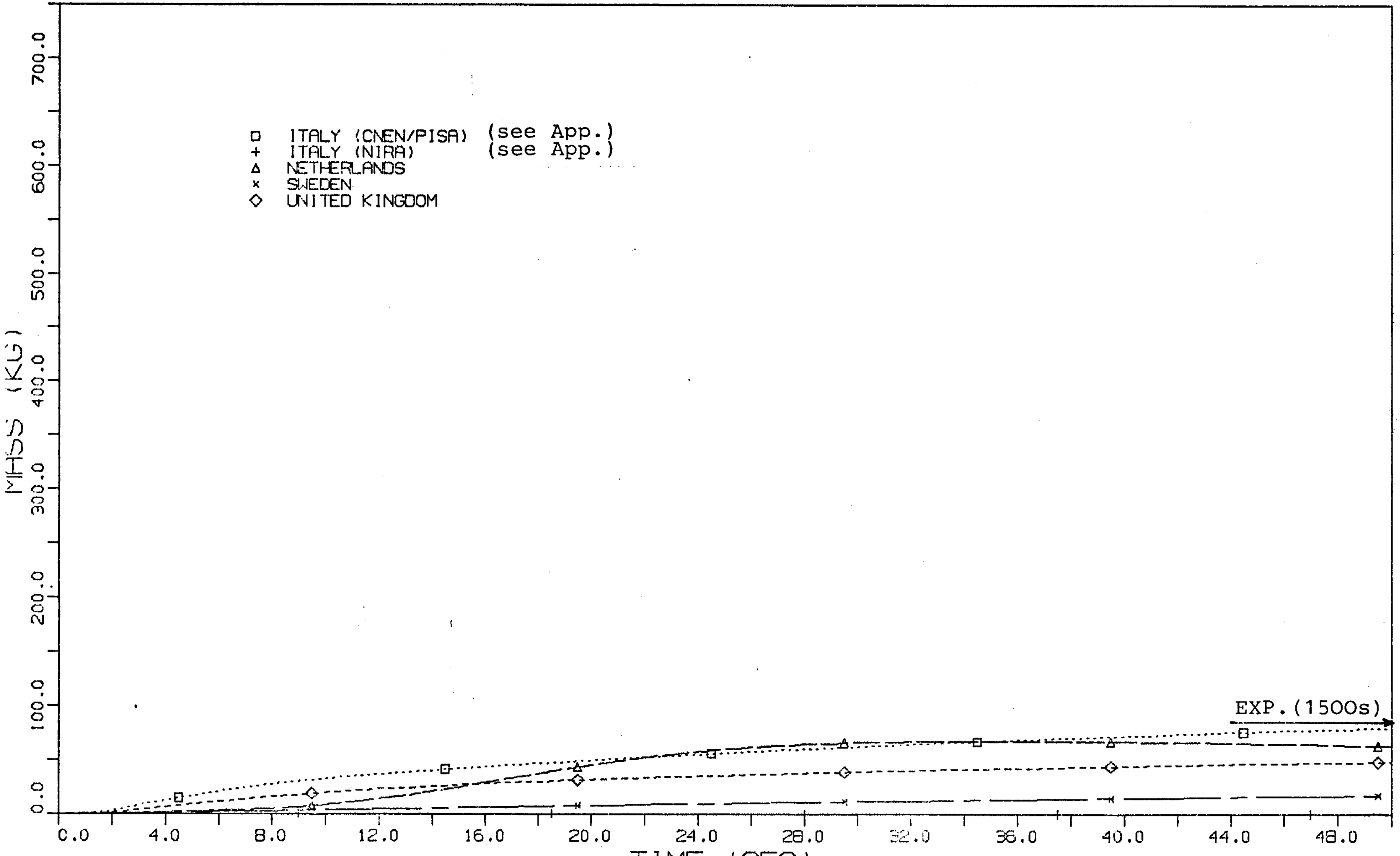

FIG. 38B HISTORY OF WATER MASS IN COMPARTMENT R4

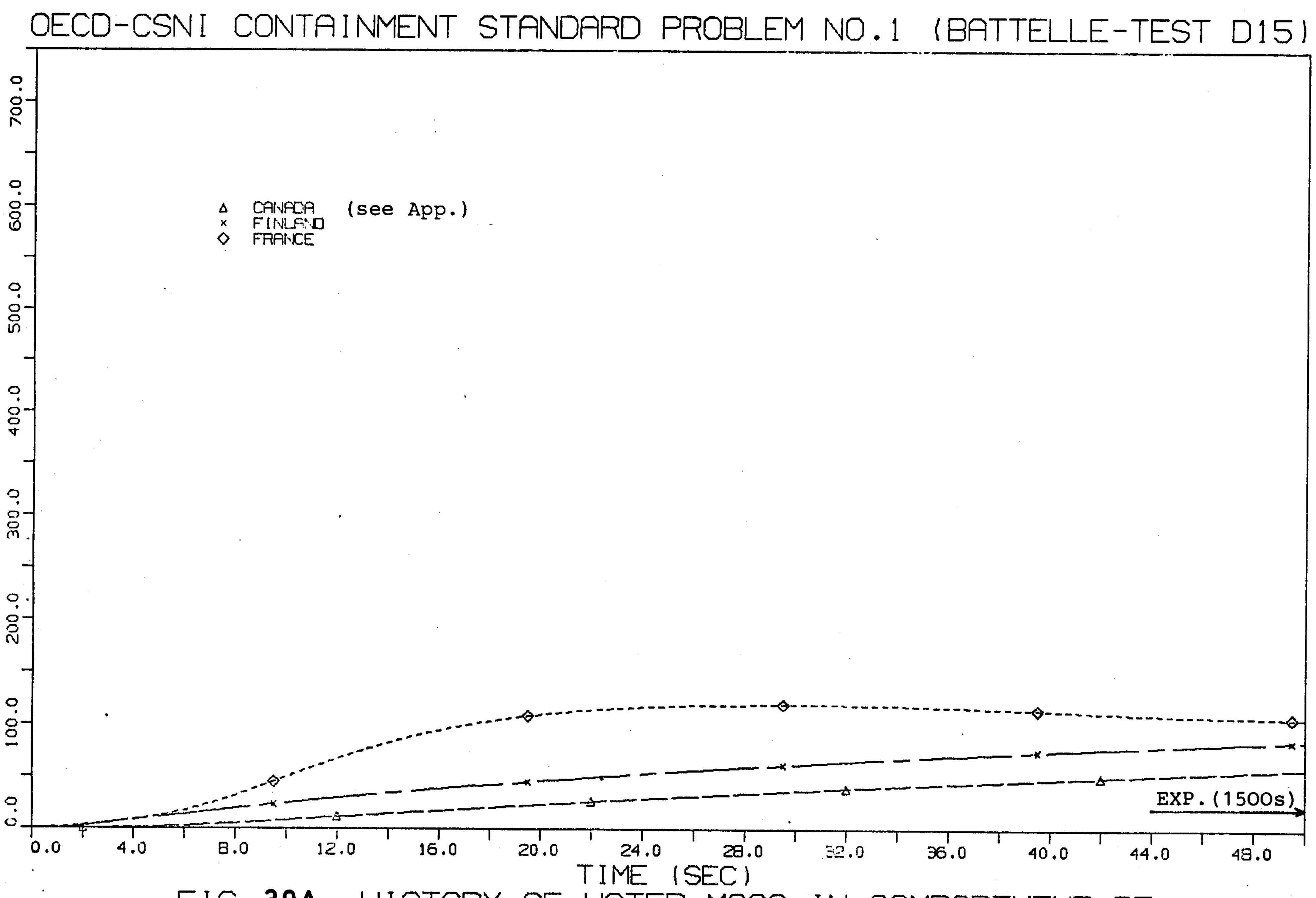

FIG. 39A HISTORY OF WATER MASS IN COMPARTMENT R5

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

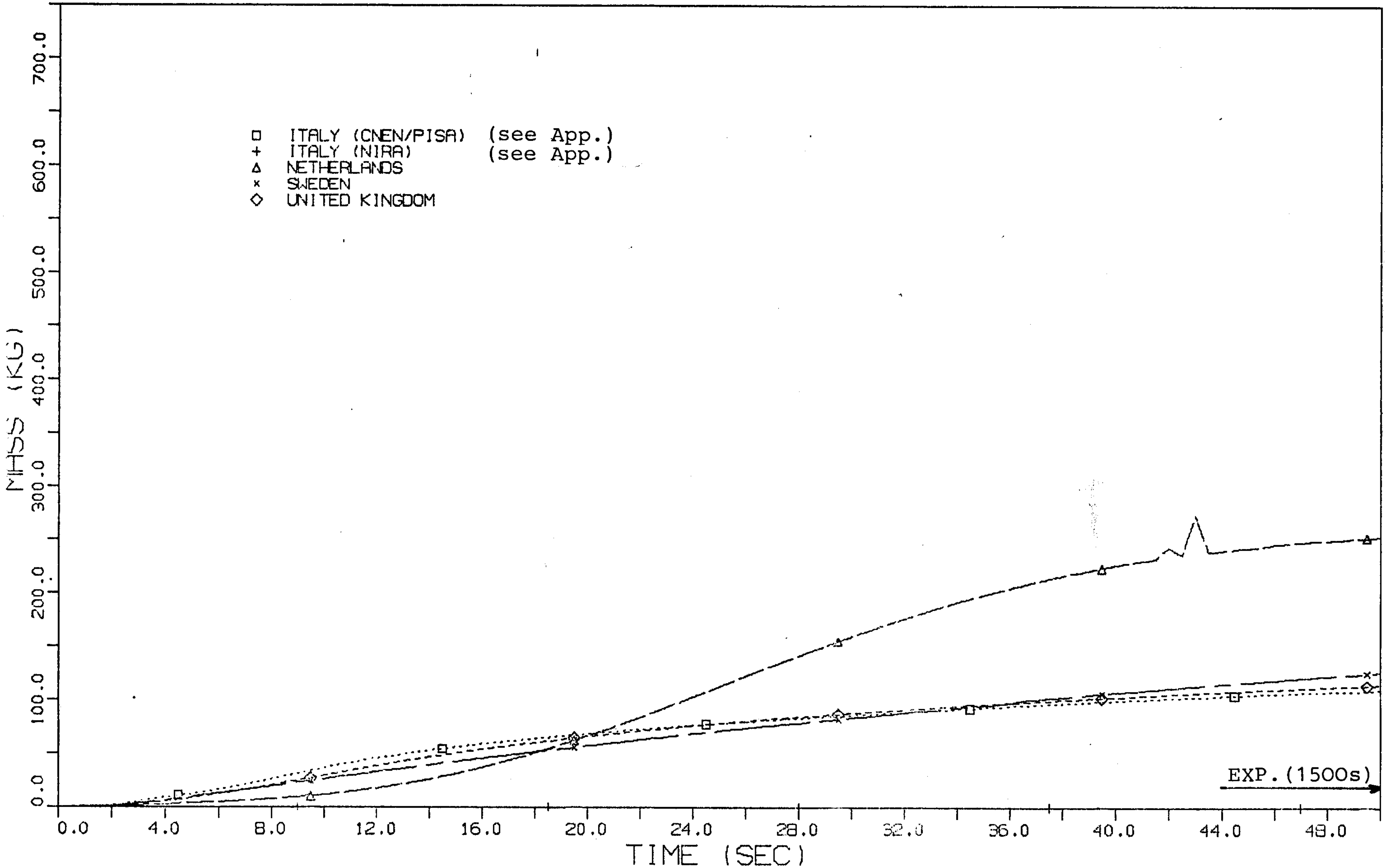

FIG. **39B** HISTORY OF WATER MASS IN COMPARTMENT R5

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

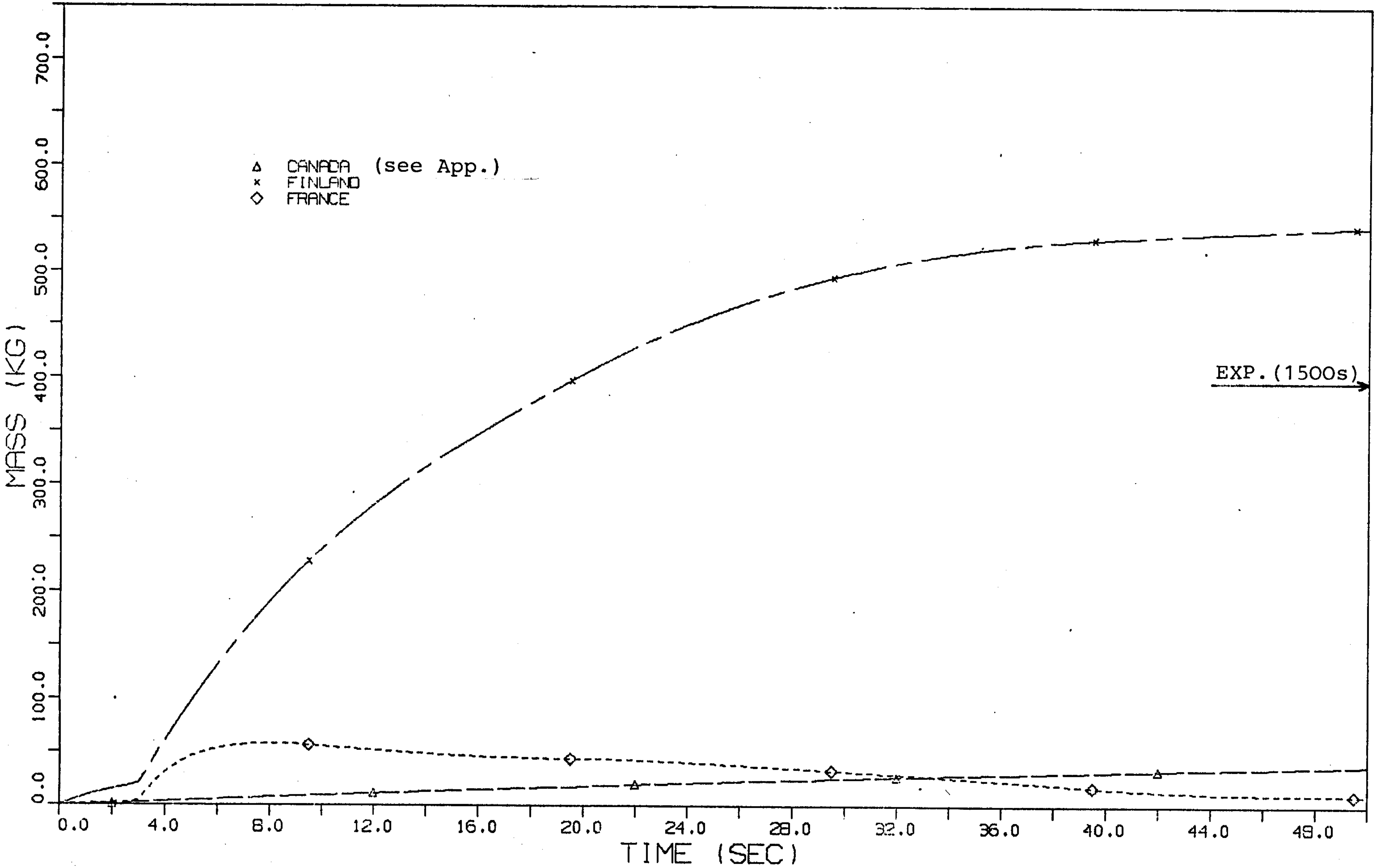

FIG.**40A** HISTORY OF WATER MASS IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

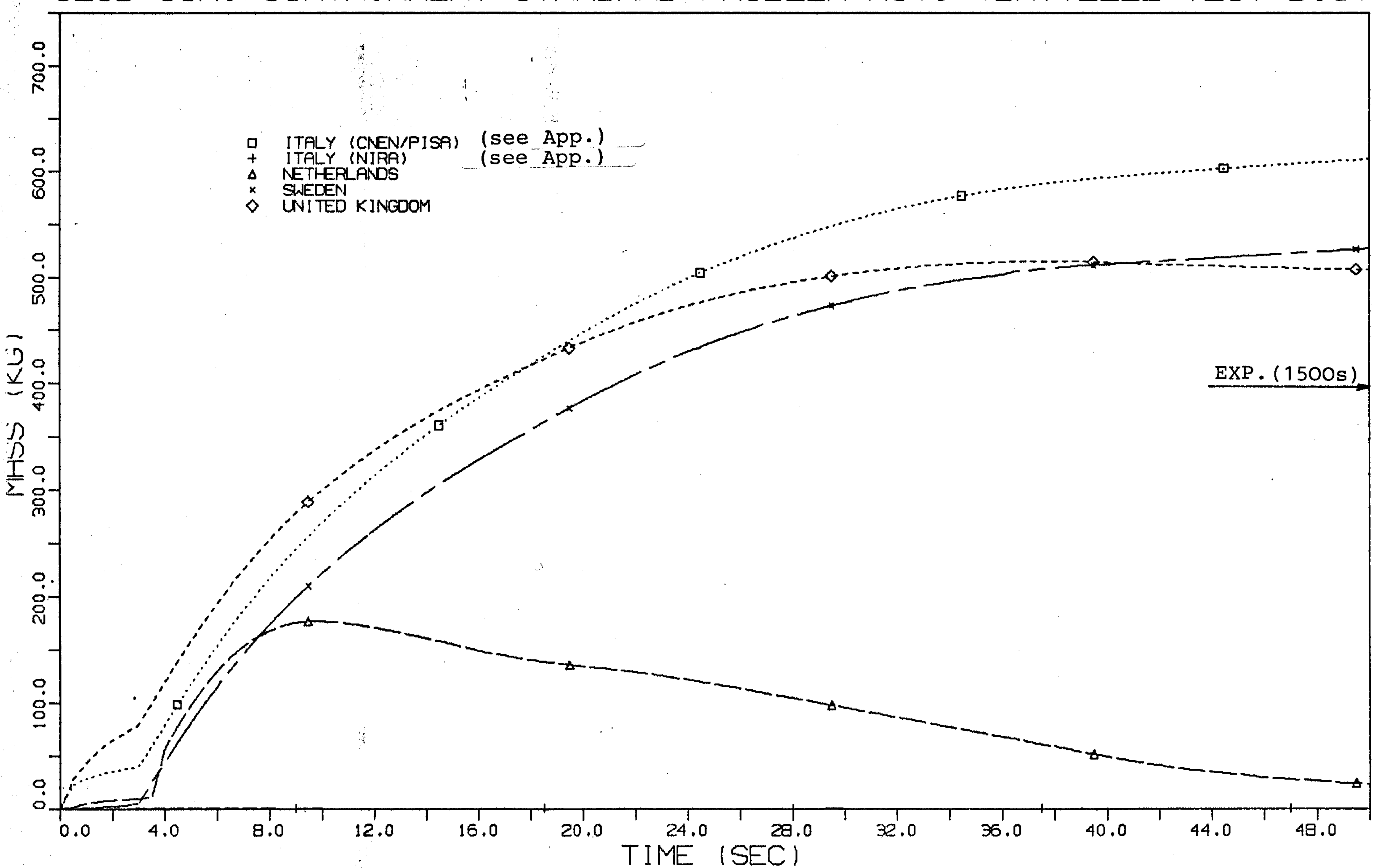

FIG.40B HISTORY OF WATER MASS IN COMPARTMENT R6

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

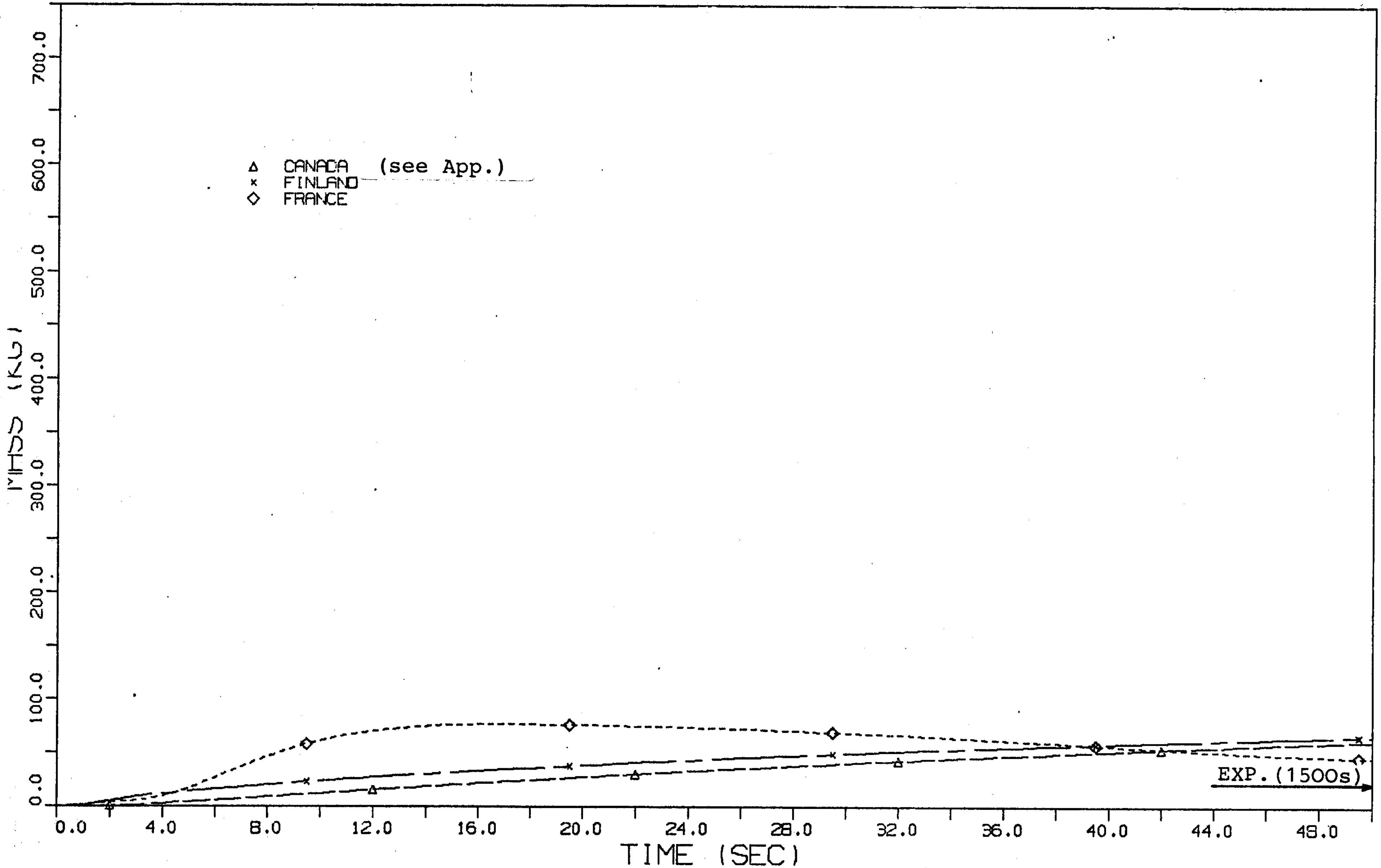

FIG. 41A HISTORY OF WATER MASS IN COMPARTMENT R7

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

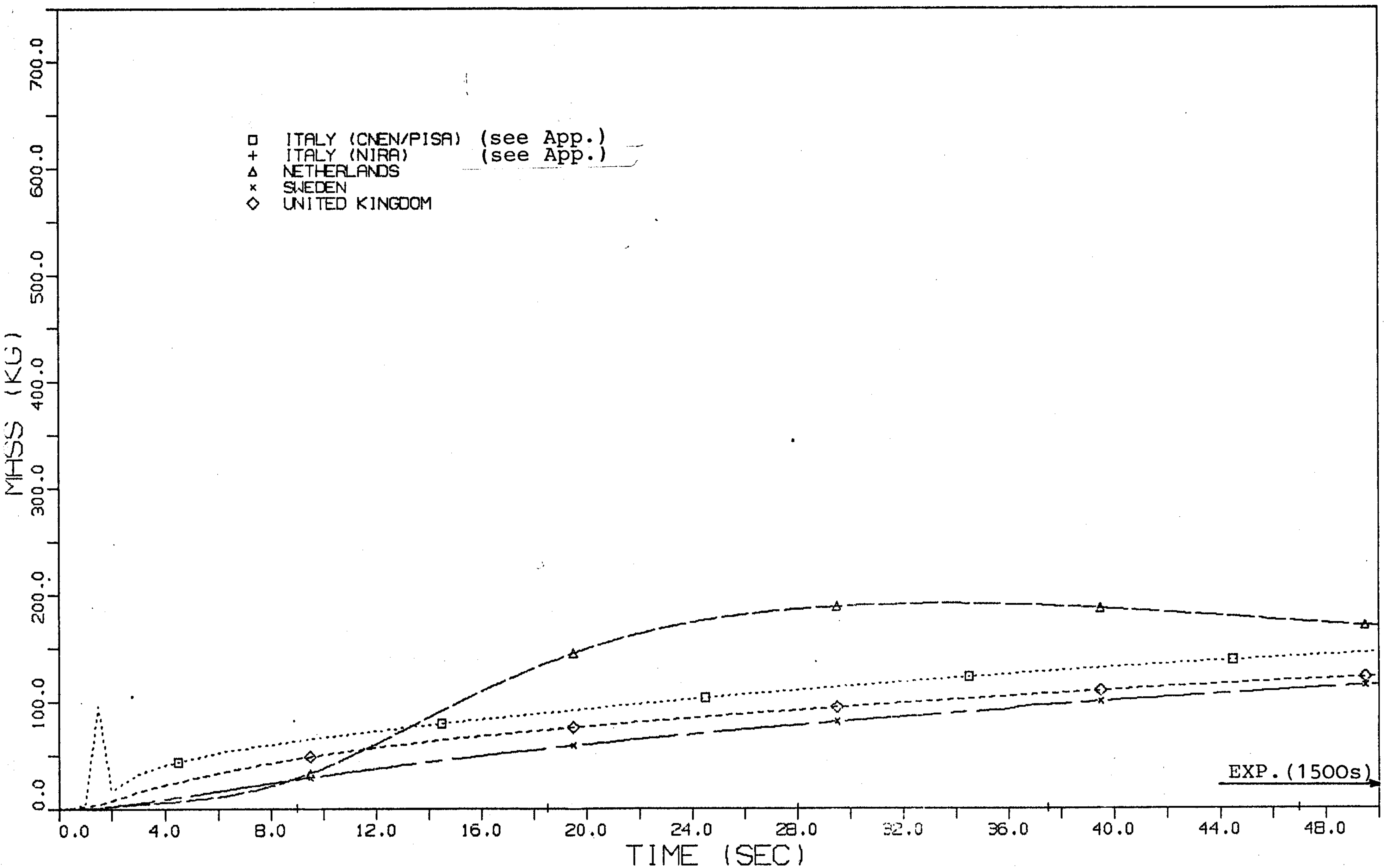

FIG. 41B HISTORY OF WATER MASS IN COMPARTMENT R7

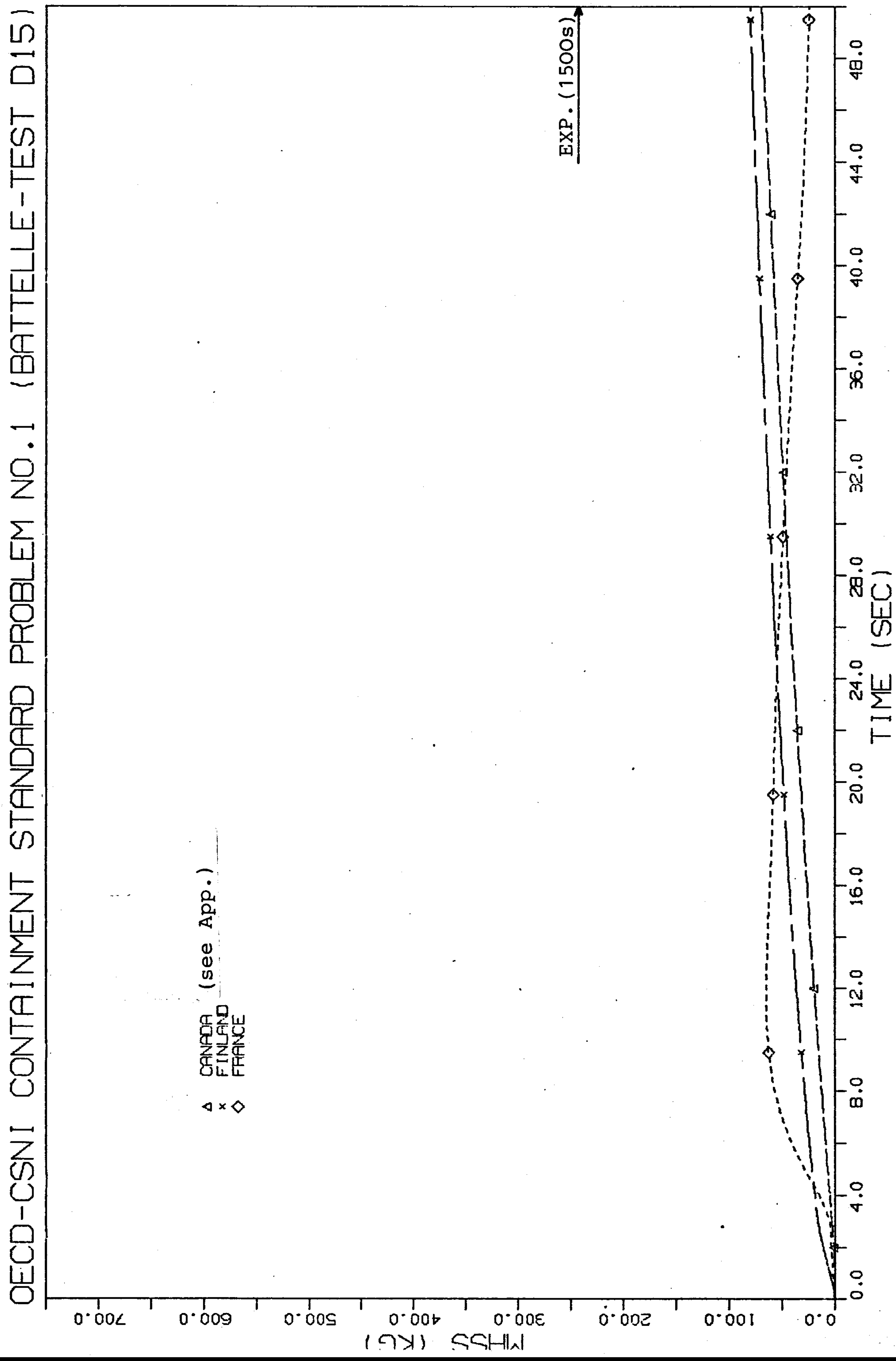

FIG. 42A HISTORY OF WATER MASS IN COMPARTMENT R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

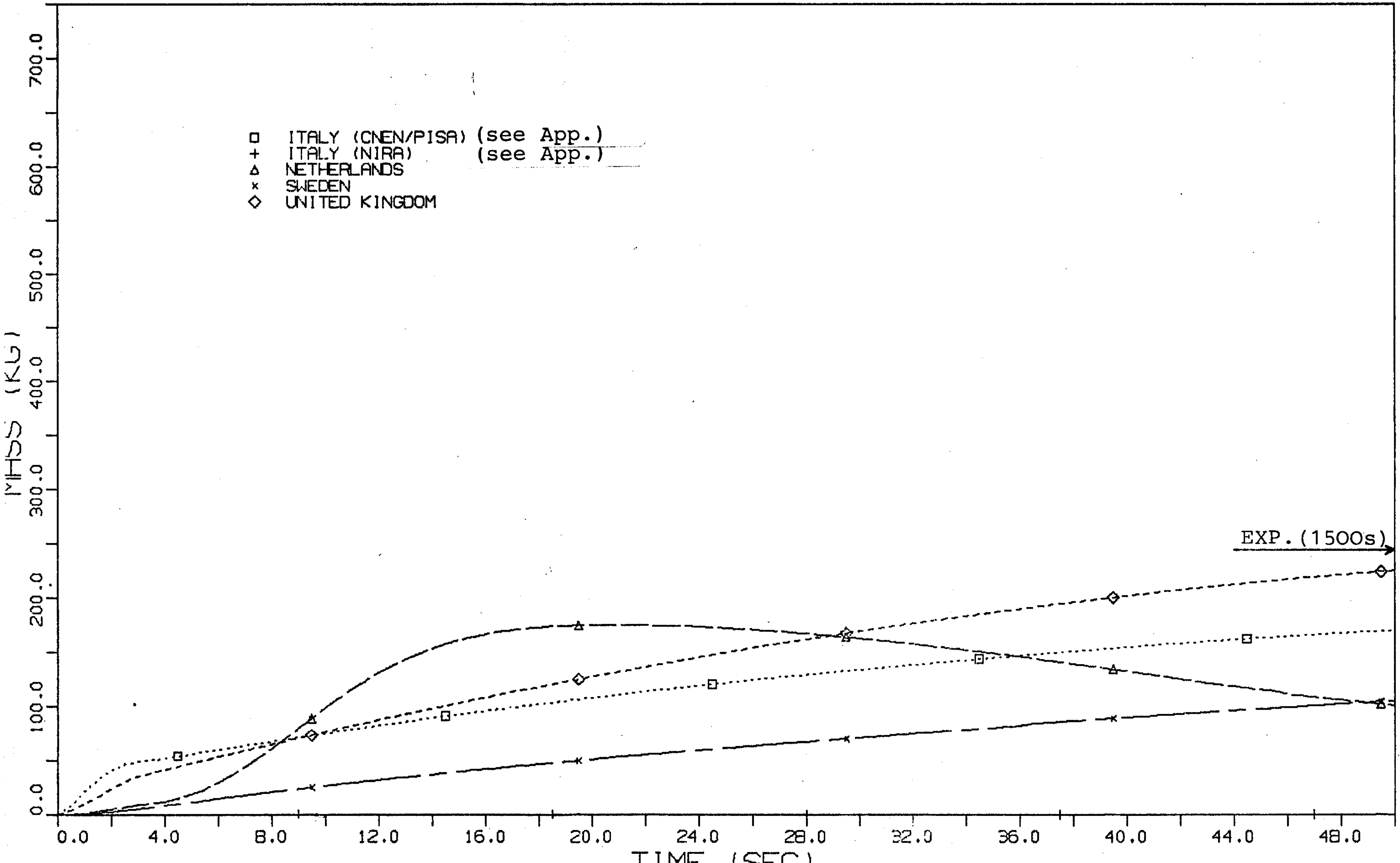

FIG. **42 B** HISTORY OF WATER MASS IN COMPARTMENT R8

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

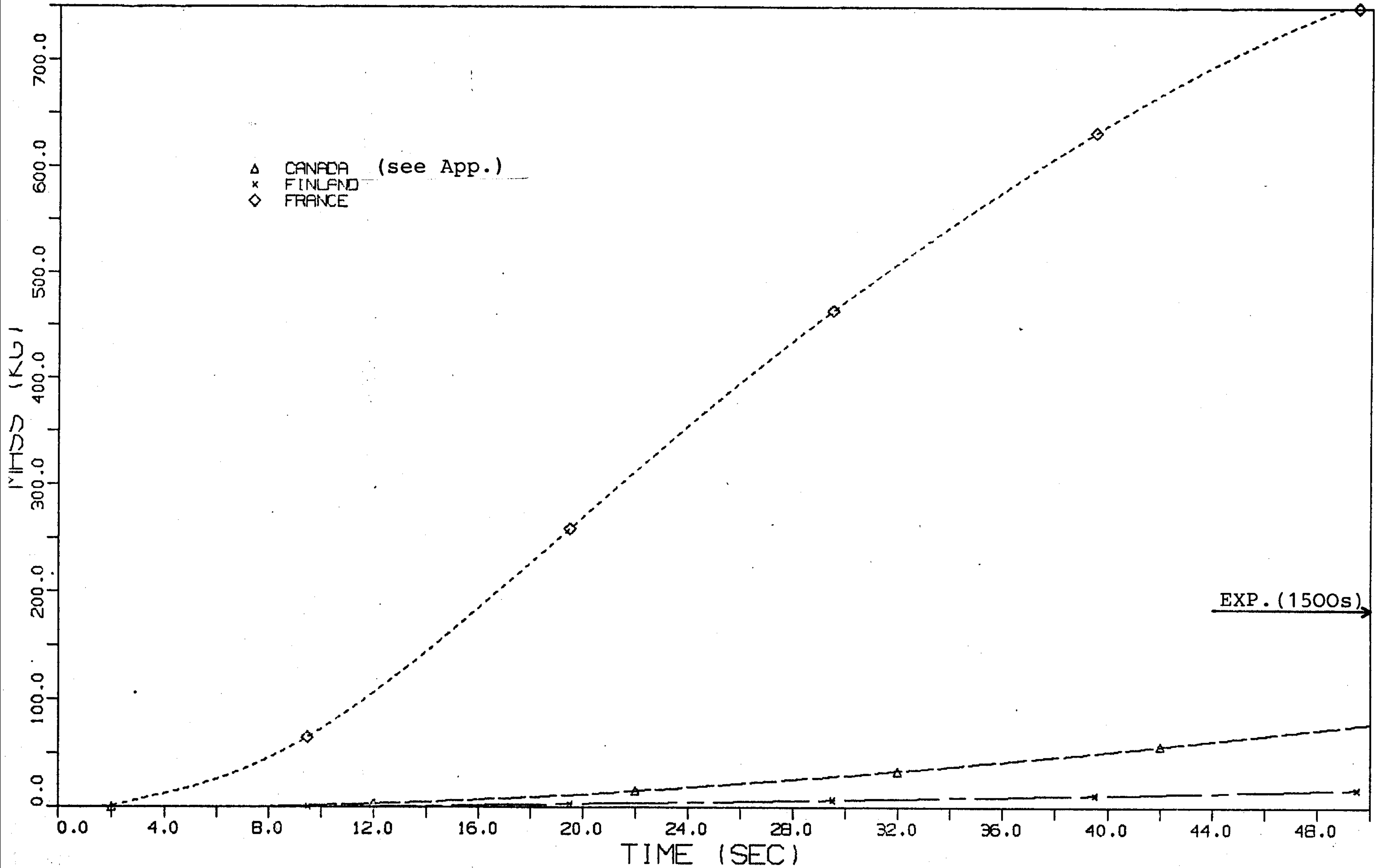

FIG. 43A HISTORY OF WATER MASS IN COMPARTMENT R9

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

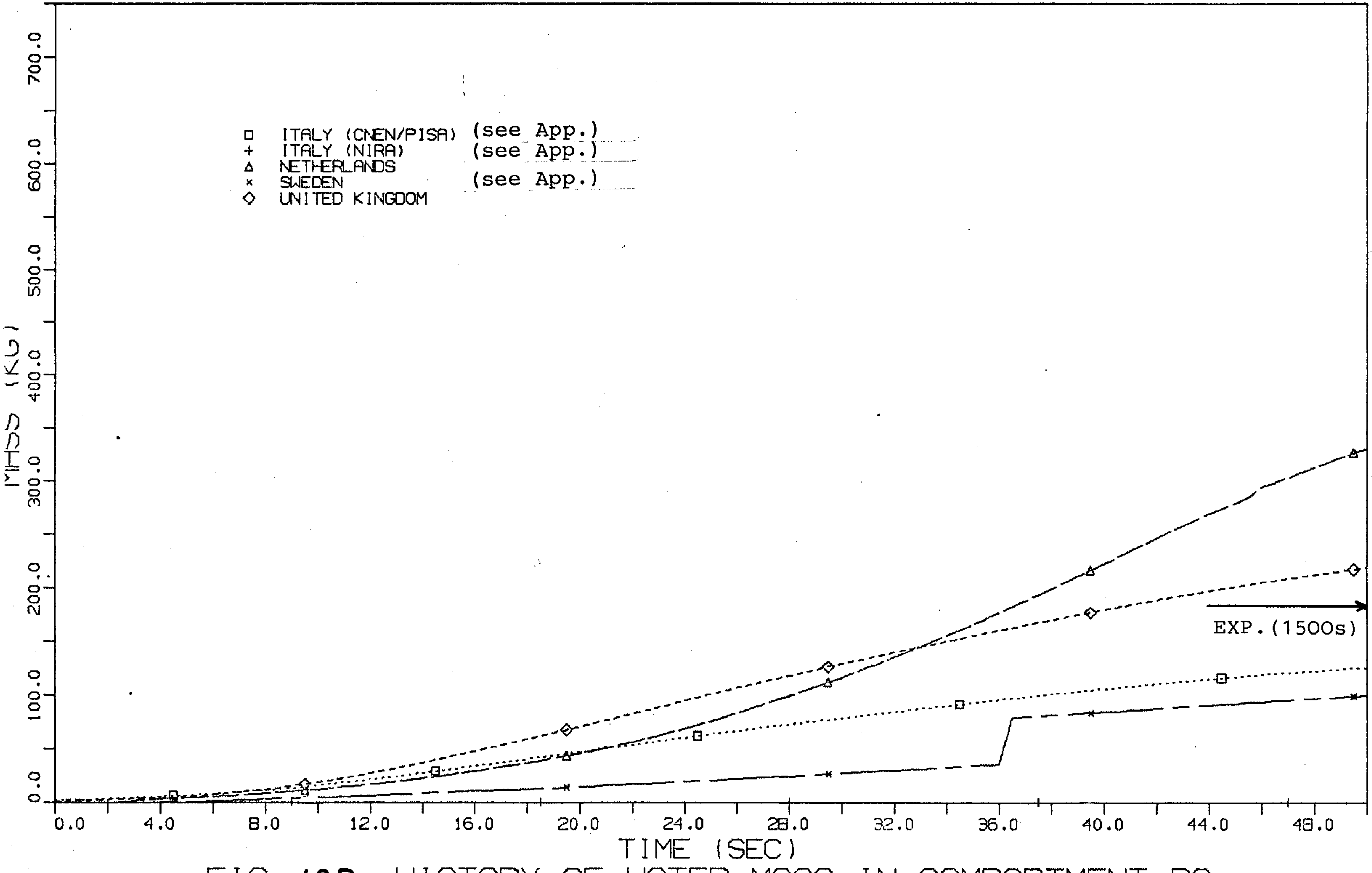

FIG. **43B** HISTORY OF WATER MASS IN COMPARTMENT R9

3.4.3 Time interval 0 to 1500 s

- Pressure history in containment (figs. 44A, 44B):

  While few participants overpredict peak pressure to a higher amount, some participants underpredict the pressure decrease of the earlier stages of the cooling-down process. At the end of the time interval all participants more or less overpredict the pressure history thus indicating that the cooling-down process is in reality proceeding faster than calculated (higher heat absorption of the concrete walls and probably heat removal to the surroundings).

- Temperature history in containment (figs. 45A, 45B):

  It is difficult to attach integral calculational results to a measured value. Temperature maximum in compartment R9 occurring in this time interval is found nearly exactly (3 participants) or slightly overpredicted by most of the participants.

- History of water mass in containment (figs. 46A, 46B):

  For the whole time interval the experimental sum of water masses is considerably lower than the predicted results of most of the participants. This is mainly attributed to the fact that - even at the end of the time interval - a considerable portion of condensed water is still attached to the walls. Generally good agreement of the final value of the calculated results indicates that the time integral of the released mass flow rate at the rupture is calculated correctly. Three participants (Belgium+ with the assumption

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+ See App.

of the 10 % of released water and steam directly going to sump, Canada[+] assuming water flashing in source node with removal of unflashed liquid, Italy-CNEN/Pisa[++] and Italy-NIRA[+++]) considerably underpredict history of water mass.

[+] The data submitted was actually the mass of vapour (see App.)

[++] See App.

[+++] The submitted data represented the water mass instantly removed from the containment atmosphere instead of the total mass of condensed water (see App.).

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

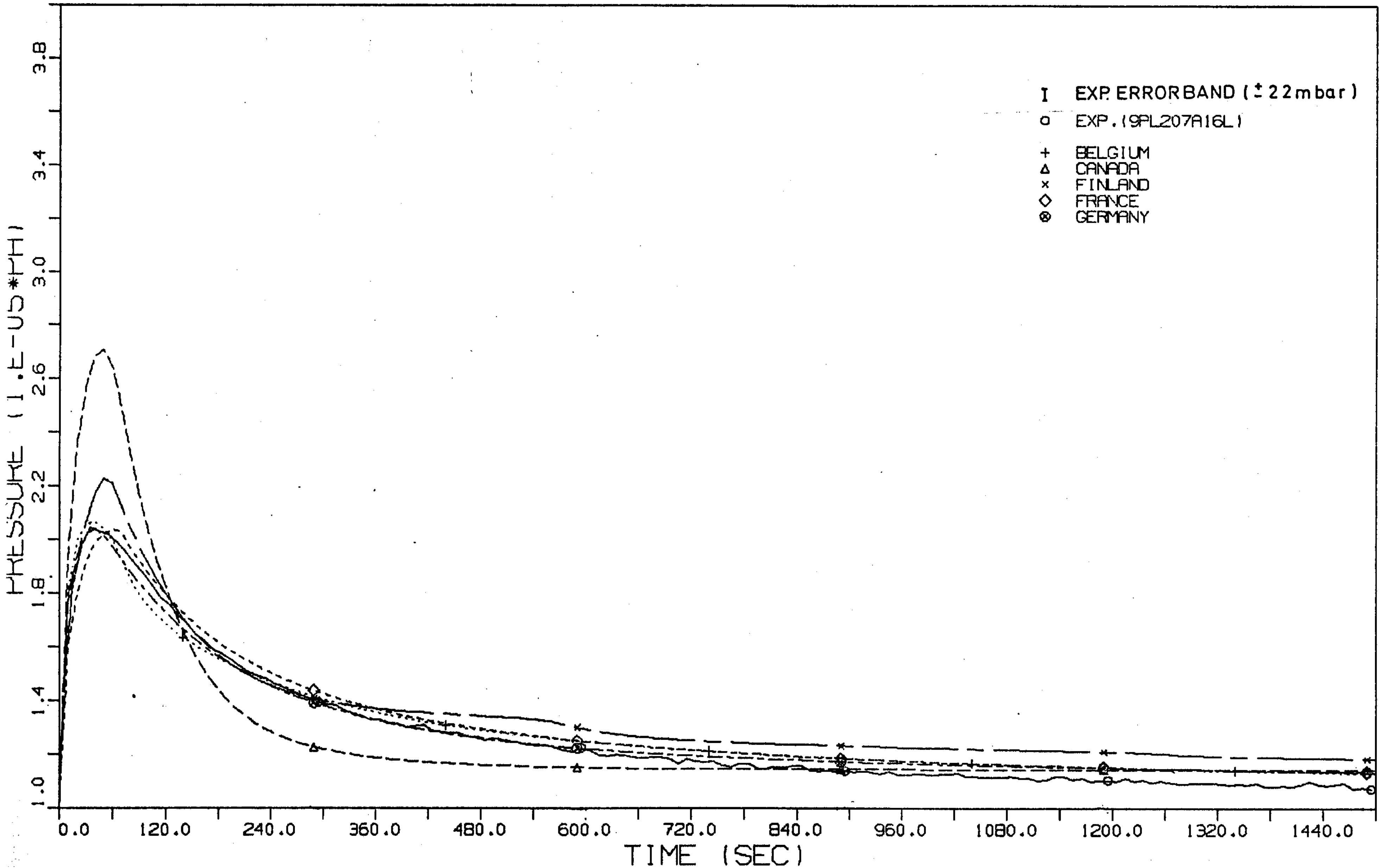


FIG. 44A PRESSURE HISTORY IN CONTAINMENT

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

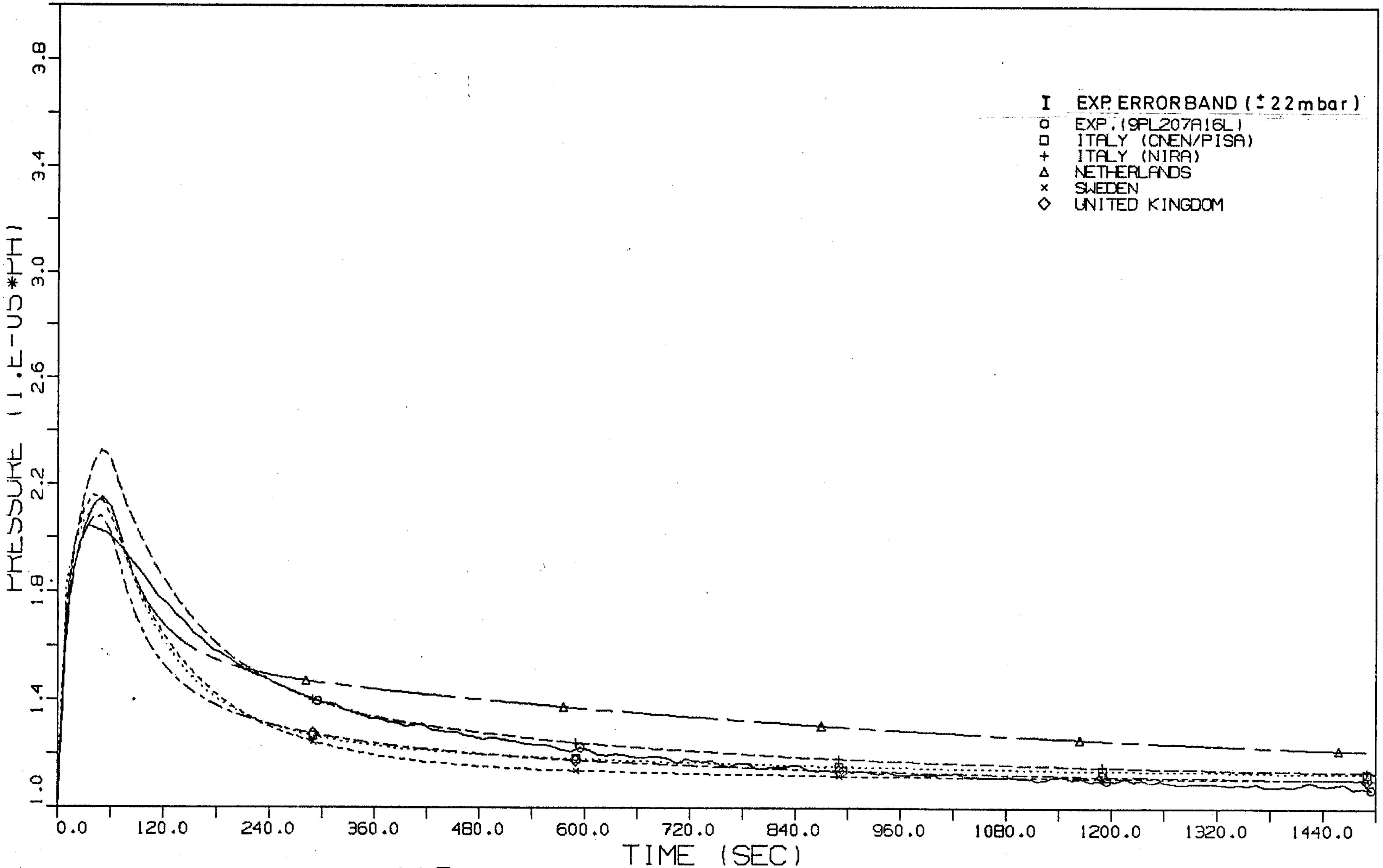


FIG. **44B** PRESSURE HISTORY IN CONTAINMENT

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

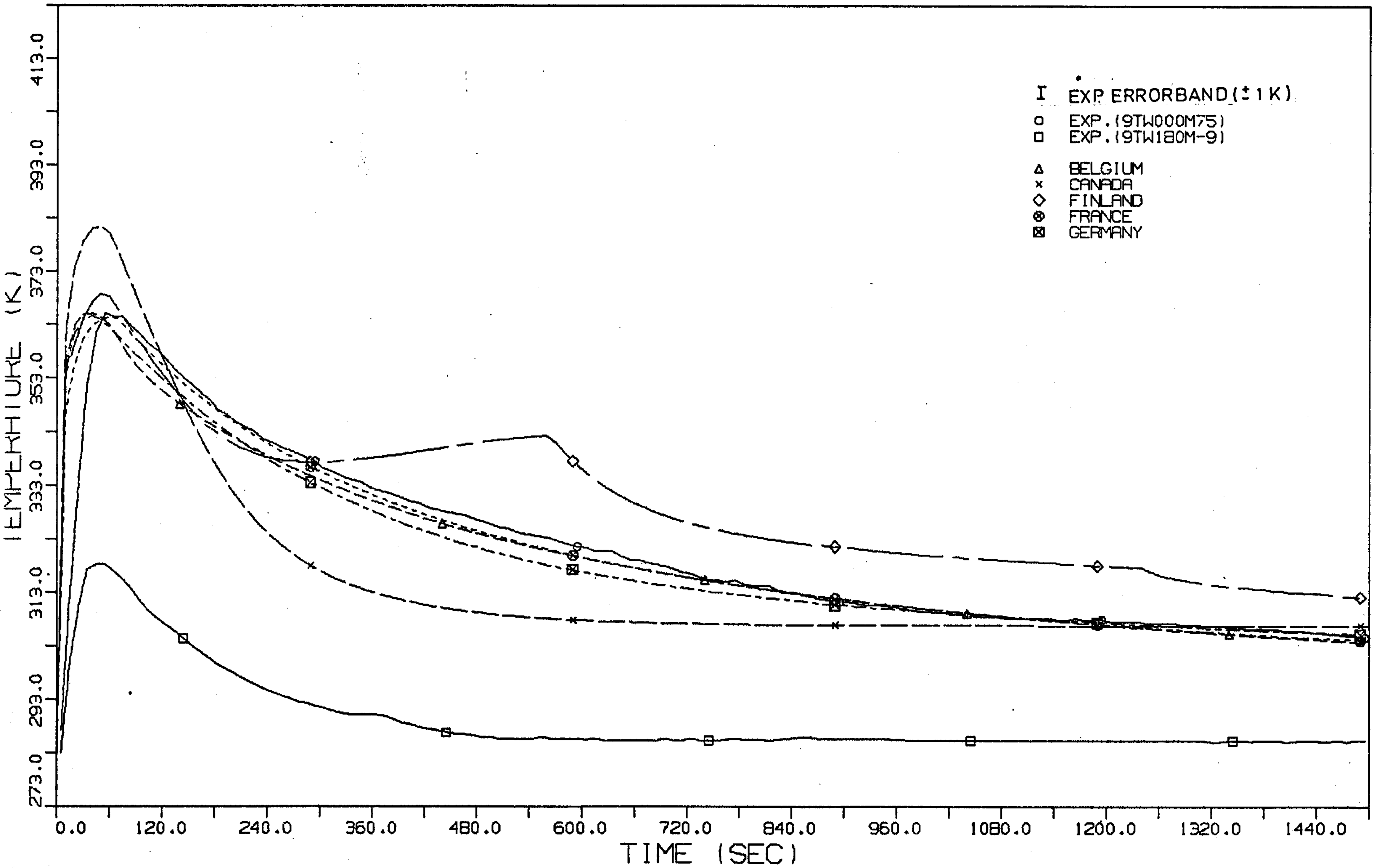


FIG. 45A TEMPERATURE HISTORY IN CONTAINMENT

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

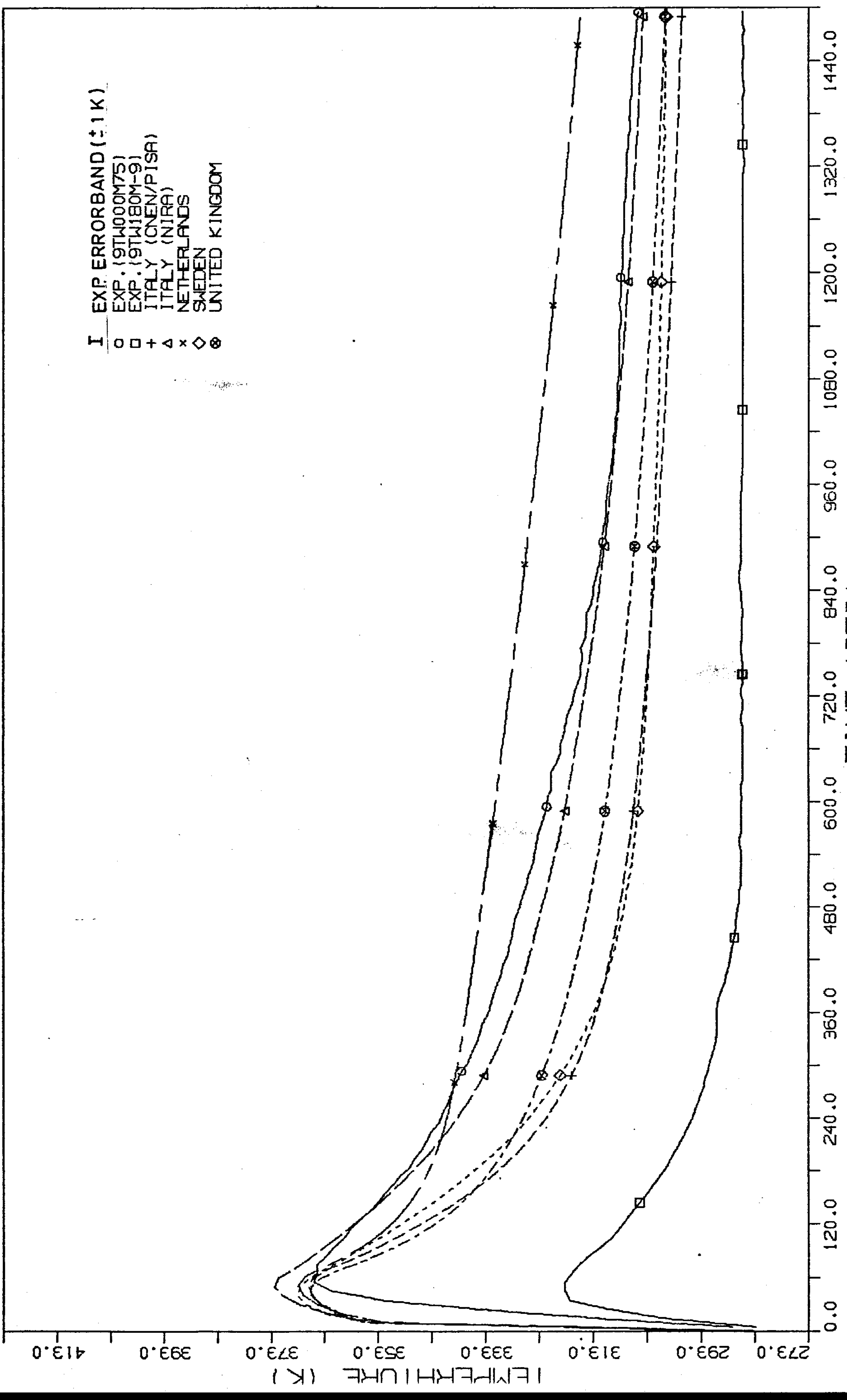


FIG. **45 B** TEMPERATURE HISTORY IN CONTAINMENT

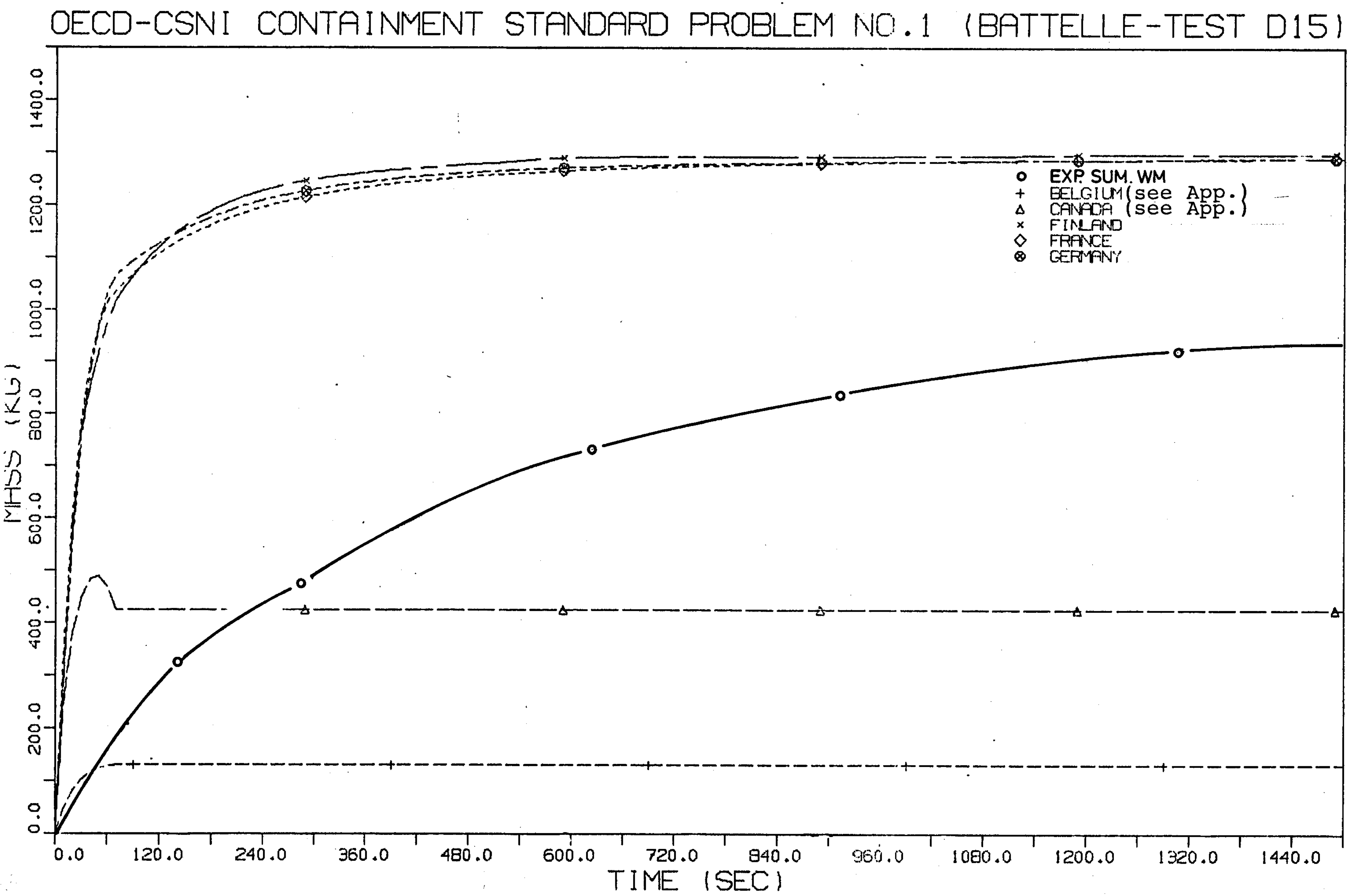


FIG. 46 A HISTORY OF WATER MASS IN CONTAINMENT

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)

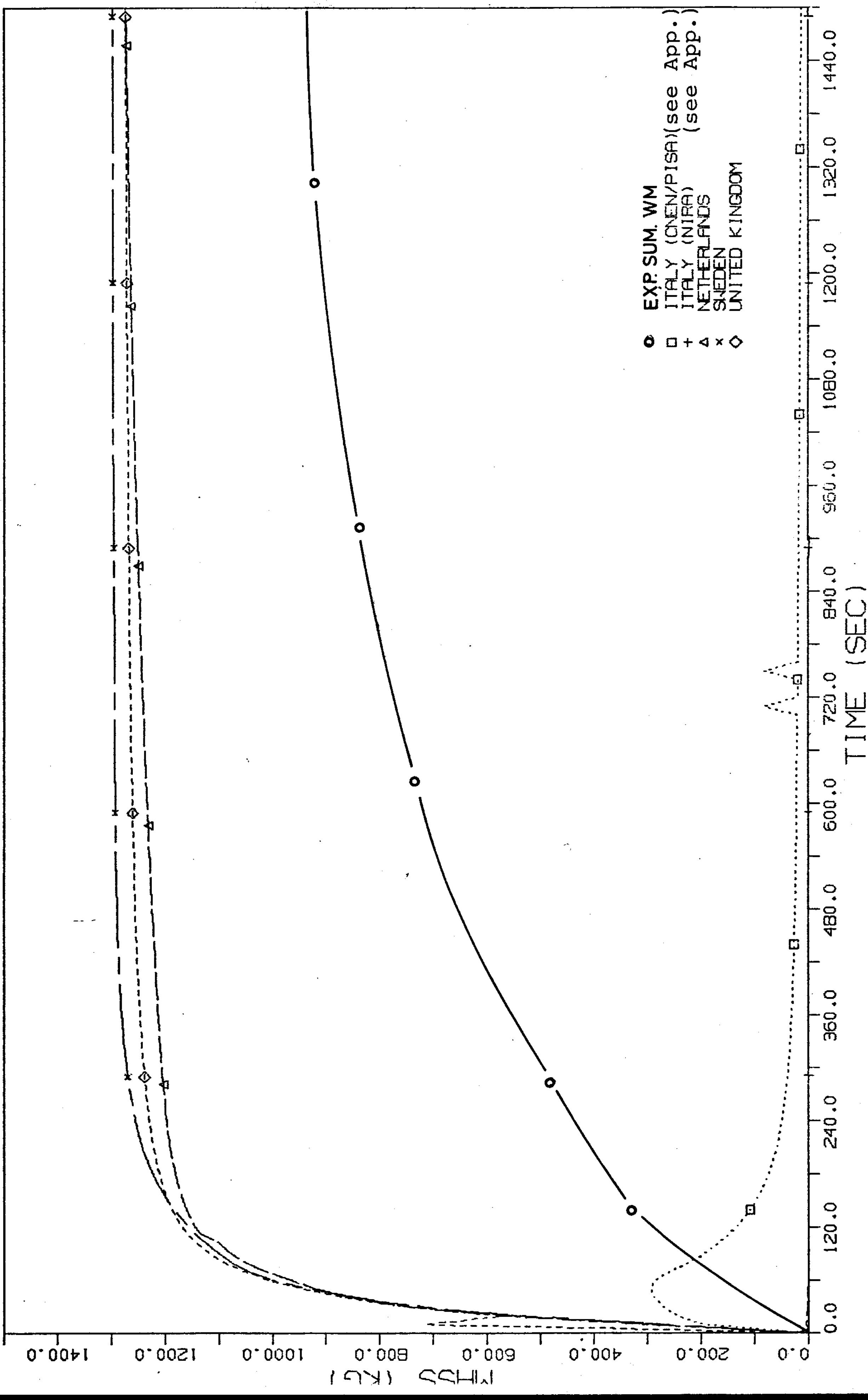


FIG. 46B HISTORY OF WATER MASS IN CONTAINMENT

3.4.4 Listing of most important characteristic variables

Supplementary to the comparative plots table 4 gives numerical values of some important characteristic variables from experiment and post-test calculations of Standard Problem participants.

Nomenclature is:

p_{maxR6} = maximum pressure in R6

$\Delta p_{maxR6-R9}$ = maximum pressure difference between R6 and R9

p_{max} = maximum pressure in containment

Country	Time interval 0 to 2.5 s				Time interval 0 to 50 s	
	p_{maxR6} (bar)	Time (s)	$\Delta p_{maxR6-R9}$ (bar)	Time (s)	p_{max} (bar)	Time (s)
Australia*	1.50	1.5	0.46	0.5	2.10	37
Belgium	1.61	2.5	0.48	0.4	2.07	39
Canada	1.72	2.5	0.62	0.5	2.55	50
Finland	1.57	1.7	0.50	0.6	2.57	50
France	1.53	1.7	0.44	0.5	1.99	45
F.R. Germany	1.57	1.4	0.51	0.6	2.04	40
Italy (CNEN/Pisa)	1.58	1.3	0.52	0.6	2.05	50
Italy (NIRA)	1.59	0.6	0.53	0.5	2.37	47
Netherlands	1.61	2.5	0.46	0.7	2.09	50
Sweden	1.54	0.6	0.48	0.5	2.03	46
United Kingdom	1.73	2.5	0.56	1.8	2.27	50
United States	1.62	2.5	0.50	0.5	-	-
Experiment	1.53 ± 0.03	0.5 to 2.5	0.49 ± 0.02	0.4	2.08 ± 0.02	40

* see footnote on page 5 and App.

TABLE 4: Numerical values of some characteristic variables

4. CONCLUSIONS AND RECOMMENDATIONS

The results of the participants in the first CSNI-Containment Standard Problem show that mainly lumped-parameter models were applied to analyse on best-estimate basis pressure differences as well as the total pressure built-up within the model containment. With these models most of the participants were able to post-calculate the simplified test (simple chain of 6 compartments, initial period of pure steam inlet flow to largely eliminate phase separation phenomena) with reasonable accuracy. However, the margins of analytical calculations were in general larger than the errorbands associated with the measurements of corresponding variables:

- Time interval 0 to 2.5 s:

  In general the results of the participants are within a "calculational errorband". Maximum deviations from experiment for pressure calculations range from - 45 % (big dome compartment) to + 41 % (rupture compartment) related to pressure increase (experimental errorband appr. ± 7 %). Calculated pressure differences between compartments important for safety-related design of thickness of inner walls show different margins (experimental errorband appr. ± 5 %): For the highest pressure difference deviations are within - 12 % and + 26 %, for other compartment combinations partly within the experimental errorband or within + 10 % and + 48 % (maximum of highest pressure difference but one).

- Time interval 0 to 50 s:

  The peak pressure important for structural design of the shell of a containment was calculated within the margins of - 8 % and + 49 % (corresponding experimental error ± 2 %).

It is a little bit surprising that on the average the bandwidth of these post-calculations is not lower than for "blind" German Containment Standard Problem No. 1 based on the same test.

A total of 11 different codes and in addition versions of them were applied. Especially for the long term range participants often used codes or versions of codes different from those in the short and medium time interval. At least at the moment results from conventional lumped-parameter models show in general about the same quality than those from the advanced 2D-concept.

Nodalization used by participants according to lumped-parameter approximation was chosen differently. Considering variables important for licensing one can say

- that for time interval 0 to 2.5 s a simulation of one node for one compartment seems to be sufficient with regard to pressure built-up and pressure differences,

- that for time interval 0 to 50 s the same nodalization is adequate also with regard to temperature equalization in all compartments but big dome compartment.

The greatest influence on the analytical results is found arising from the very different ways of handling energy exchange between fluid and structures:

- During the short term period with steam inlet flow (high heat transfer by highly turbulent condensation at the walls of the relatively long compartments) heat transfer coefficients up to 10000 $W/(m^2 K)$ for compartments near the break were calculated or taken as input parameter partly derived to match pressure histories. The higher heat transfer coefficients are the better seems the agreement between measured and experimental pressure histories.

  According to specification coating of concrete surfaces was relatively thin. Data revised after deadline of calculations (especially thicker coating) seem to have an influence on the calculational results the amount of it was partly discussed on the workshop based on additional analyses of the participants (see /11/ and App.).

Unfortunately, additional measurements for determination of heat transfer coefficients to the structures can hardly be evaluated in this time interval since especially coating thickness of "α-blocks" is not well known. Physical properties of the structures are known from literature only within a greater scatter.

- In the medium and the long term range empirical Tagami- and/or Uchida-correlation well known from licensing procedures was used in different ways by several participants. Partly heat transfer coefficient history was input parameter derived from the experiment. These and other assumptions mainly contribute to a high bandwidth of calculational results for peak pressure.

Handling of flow resistances between compartments was very different, too. Mainly two concepts were applied: one-dimensional quasisteady compressible flow and one-dimensional unsteady incompressible flow. Discharge coefficents ranged from 0.7 to 1.0 or pressure loss coefficients from 1.9 to 0.35. It is difficult to draw general conclusions on best concept or best coefficients for the individual overflow vents. Magnitude of discharge coefficients respectively pressure loss coefficients may be different for different direction of inlet and outlet flow.

Water carry-over to a higher amount was assumed by only few participants though in this case at least during steam inlet flow this phenomenon can only be of minor importance.

Another reason for deviations between calculated and measured values is thought to originate from relatively large errorbands of measured mass- and energy-release rates from the pressure vessel into the model containment (given input data) during certain periods of the experiment. It is difficult to quantify this influence on containment variables. Especially for this it seems highly desirable to improve instrumentation.

Regarding all these aspects it is to recommend to thouroughly study the reasons for the margins of the calculational results. This task being individual and beyond the scope of this report should be done by each participant for his own after exchange of experiences on the workshop (see App.). General conclusions from relating quality of calculations to important features and input parameters of the codes (e.g. nodalization, heat transfer, discharge or pressure loss coefficients, water carry-over) can hardly be drawn since the individual influence often cannot be separated (compensation). It seems desirable to replace the variety of free parameters by physical models (e.g. incorporation of heat transfer correlations depending on thermodynamic and flow properties of the fluid in most of the codes) and to base licensing procedure on best-estimate calculations with safety factors on the results.

It seems too early to draw quantitative conclusions from a single Standard Problem with respect to the achievable accuracy of predictions of thermo-fluiddynamic effects within a real full pressure containment. From this reason it is further to recommend to perform more Containment Standard Problems. From the practical point of view these should lead closer to conditions anticipated for containment design. Following this it is a good opportunity to "blind" participate in 2nd German Containment Standard Problem the basis being a test CASP2 in the same model containment. Test CASP2 is a pressurized water blowdown in a slightly changed arrangement of compartments compared to 1st Containment Standard Problem in order to obtain conditions as new ("virgin") as possible and as similar as possible to licensing conditions. In 1981 a Containment Standard Problem in the large-scale HDR-facility is planned.

REFERENCES

/1/ CSNI Standard Problems
CSNI Report No. 17,
August 1977

/2/ OECD-NEA Paris
Summary Record of the Conclusions and Decisions Reached at a Preparatory Meeting of Experts on a Comparative Analysis Standard Problem on Pressure and Temperature Loads on a Reactor Containment after a Loss-of-Coolant Accident held at the Battelle-Institut e.V. in Frankfurt am Main, Federal Republic of Germany, on 10th and 11th May 1978
SEN/SIN(78) 24, May 22, 1978

/3/ H. Karwat, G. Mansfeld, W. Winkler
Specification
OECD-CSNI-Containment-Standard-Problem No. 1
GRS, July 28, 1978

/4/ Battelle-Institut, Frankfurt
Standard Problem Experiment D15
Data of the Experimental Facility
Technischer Bericht BF-RS 50-42-8
August 1978

/5/ Battelle-Institut, Frankfurt
Quick Look Report Experiment D15 (English version)
Technischer Bericht BF-RS 50-30-D15-2
November 1978

/6/ A. Berning, W. Winkler
OECD-CSNI Containment Standard Problem No. 1
Experimental Data of Test D15
(Battelle-Model-Containment)
GRS-A-250, Dezember 1978

/7/ Project RS 50, Experiment D15
Supplementary Remarks on Water Level
Measurements

/8/ Battelle-Institut, Frankfurt, RS 50,
Coating of the Concrete Surface Areas Inside
the RS 50 Model Containment
May 1979

/9/ W. Winkler, G. Mansfeld
Containment-Standard-Problem:
Untersuchungen zu den Rand- und
Anfangsbedingungen des Standard-Problem-Versuchs D10
und des Wiederholungsversuchs D15 (Battelle-Modell-
Containment)
GRS-A-111, Februar 1978

/10/ OECD-NEA Paris
Summary Record of the Conclusions and Decisions
Reached at a Workshop on the Comparison of Calculations
for CSNI Comparative Analysis Standard Problem No. 1
on Pressure and Temperature Loads on a Reactor
Containment after a Loss-of-Coolant Accident held at
Gesellschaft für Reaktorsicherheit (GRS) mbH, Garching,
Federal Republic of Germany on the
17th and 18th September 1979
SEN/SIN (79)37, September 21, 1979

/11/ G. Hellings
Scientific Secretary's Report of the Workshop on the Comparison of Calculations for Comparative Analysis Standard Problem No. 1 on the Pressure and Temperature Loads in a Reactor Containment Following a LOCA held at Gesellschaft für Reaktorsicherheit (GRS) mbH, Garching, Federal Republic of Germany, 17th and 18th September 1979
SINDOC (79) 91
GRS, November 1979

/12/ W. Winkler
Draft Comparison Report on OECD-CSNI Containment Standard Problem No. 1: "Steamline Rupture within a Chain of Compartments"
GRS, September 1979
SINDOC (79)66

Appendix

Following a suggestion on the workshop and in a GRS-letter (Nov. 29, 1979) the participants Australia, Canada, Germany, Italy (CNEN/Pisa), Italy (NIRA), Sweden and United Kingdom sent comments on their submitted results (evaluated in the main part of the report) and partly results of parametrie or sensitivity studies. They are in above-mentioned order content of the appendix.

Jan. 14, 1980

REVISED ANALYSIS OF CASP 1 USING ZOCO V

J. Marshall and P.G. Holland, AAEC, Australia

The analysis of CASP 1 by the code ZOCO V was completely revised following receipt of the new data on surface coatings for the concrete walls. The original analysis had assumed no surface coatings and had a condensation heat transfer coefficient transient which had been derived to give fit to the measured pressure transient in the first compartment, R6. While incorporating the new data we found that the original modelling of the concrete walls as fed into the code was too simple and should be improved. The code permits walls to be divided into layers of prescribed thickness for the purpose of calculating the heat transfer and temperature distribution within them. After some trials it was found that if the surface 18 mm of the walls were divided into six layers of thicknesses graded from 1 to 10 mm then the calculated temperature gradient became reasonably continuous, and remained so over the whole period. Further subdivision had only minor effect on the calculated compartment pressure and temperature transients.

It was thought of interest to run the code, with the new surface data and wall description, using the inbuilt calculation of condensation heat transfer coefficient. This is based on the Henderson and Marchello correlation, which modifies the Nusselt falling film analysis by a function depending on the mole fraction of non-condensable gas at the wall surface. Use of ZOCO V in this way, i.e. as a predictive calculation with no tuned parameters, is described in the report SINDOC(79) 90 distributed at the Workshop at Garching in September 1979. Some of the results are reproduced here in a form compatible with the Comparison Report. Only the 50 second runs are shown; the 2.5 second calculations had the same parameters and so are contained within the longer runs.

Calculations of the pressure transients for compartments R6 and R8 are given in figures 1 and 2. In both cases the rise predicted in the first surge is about 20 kPa high at 2.5 seconds. The subsequent transient is then reasonably close to the measured values, except for a continuing rise which peaked at about 50 seconds rather than at 40 seconds as measured. The pressure transient calculated for compartment R9, figure 3, is quite close to the experimental results over the whole of the first 40 seconds.

The calculated temperature transient for compartment R6, figure 4, does not fit the measured transient chosen in the Comparison Report which first rose and then fell to a minimum at about 17 seconds. The other temperatures measured in this compartment do not exhibit this effect and would be much closer to the ZOCO prediction. The calculation for compartment 8, figure 5, is quite close to the measured transient over the whole period. For compartment 9, figure 6, the most notable discrepancy is that, in common with most other codes, ZOCO V did not calculate the time delay at the beginning of the transient, which is a feature in both measured temperatures.

There are difficulties in predicting the flow between compartments, particularly in the values of the three components, water, steam and air. ZOCO 5 permits arbitrary choice only in the proportion of water and in a discharge coefficient affecting the total flow (chosen as 1 in the present analysis). The proportions of steam and air are determined by the mean mass fractions calculated for the bulk fluid in each compartment. However, it is possible that the air is actually pushed ahead of the steam and that complete mixing does not begin until the later stages of the transient. Such an effect would perhaps explain the time delay in the measured temperatures for compartment R9, relative to the pressure rise. This is the last compartment in the chain and accumulates air from the whole system, so that the pressure would rise from this source without appreciable effect on the temperature.

The condensation heat transfer coefficient transients calculated are shown in figure 7. These arise from the inbuilt correlation in which the main arbitrary uncertainty is in the choice of length value for the Nusselt calculation. This is an obvious possibility for tuning, but for the present work we decided to use the height of each compartment in order to preserve fully the predictive feature of the calculations. The coefficient is, of course, very insensitive to the value of this length but as the correlation was originally derived from tests on small pipes it is of interest to determine its performance on a system with large plain surfaces. The heat transfer calculated appears to be too low over the first few seconds, resulting in high pressure values, but appears to be reasonable in the longer term. The low values perhaps occurred because the correlation is intended for low fluid velocities, and also because the fraction of non-condensable gas actually at the surfaces might have been much lower during this period than that calculated for the bulk fluid.

Results from calculations of the water mass transients are shown in figure 8 and predict that most of the water stays in compartment 6. This arises because the water carryover factor chosen was only 0.01. High values of this parameter tended to result in negative water mass values for some part of the transient and changes up to 0.5 gave only minor effect on the calculated pressure transients.

The code was also run with the specified surface coatings replaced by concrete layers having the same thickness. In this case the calculated transients were very similar in shape to those with the specified coatings but the pressure rise was lower over the whole transient, being about 30 kPa less at 50 seconds.

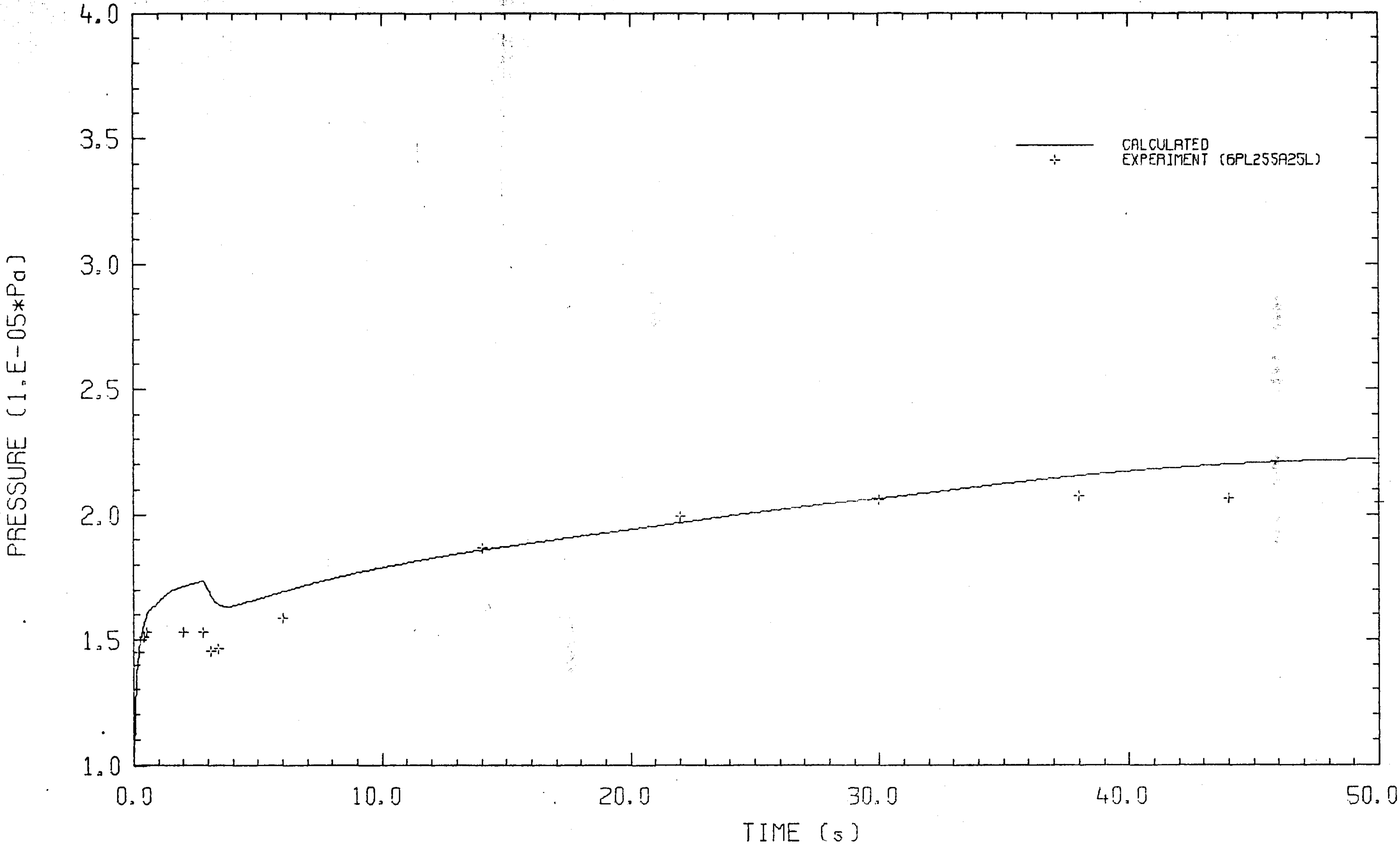


FIG. 1 PRESSURE HISTORY; COMPARTMENT A6

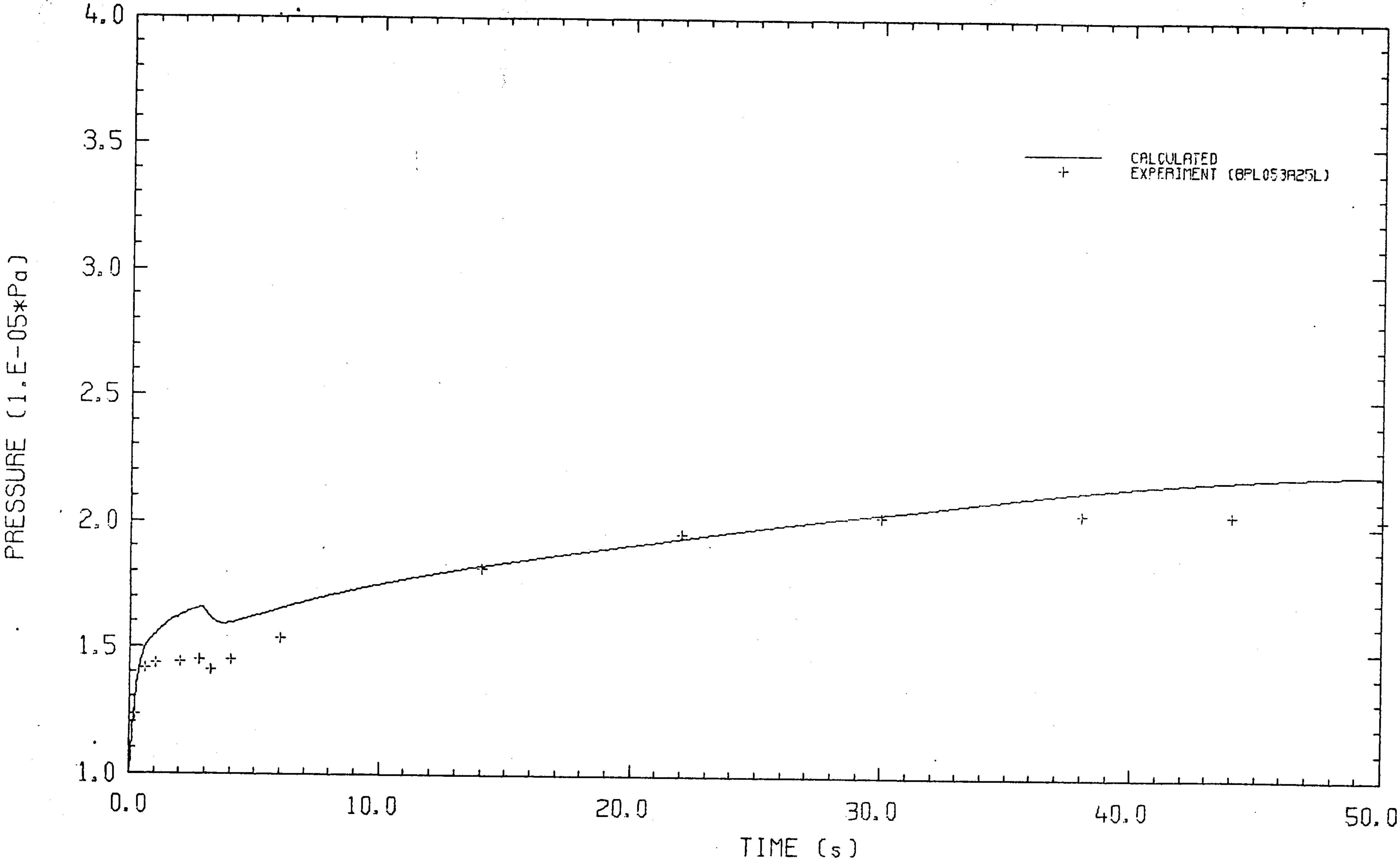


FIG. 2 PRESSURE HISTORY: COMPARTMENT R8

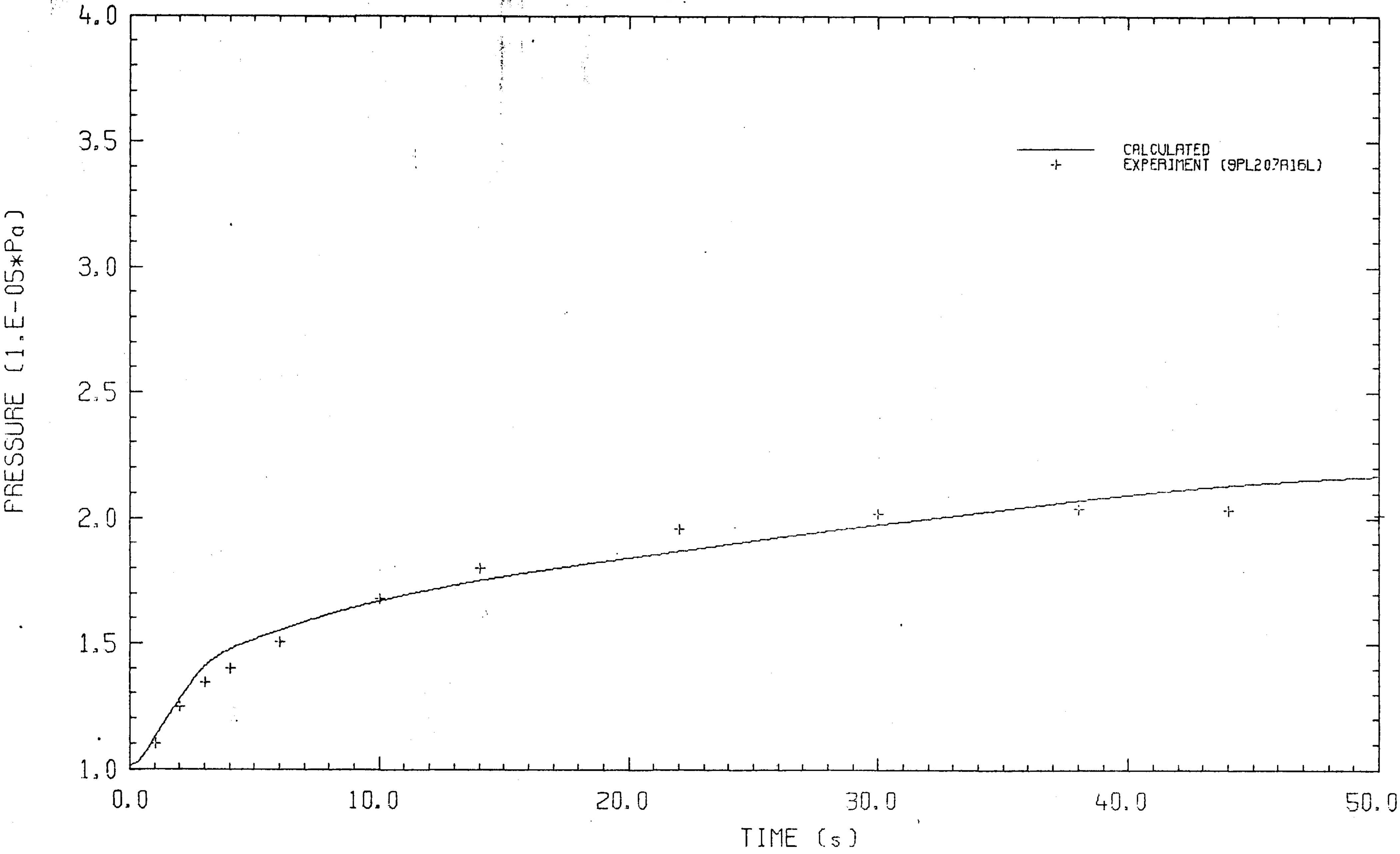


FIG. 3 PRESSURE HISTORY: COMPARTMENT R9

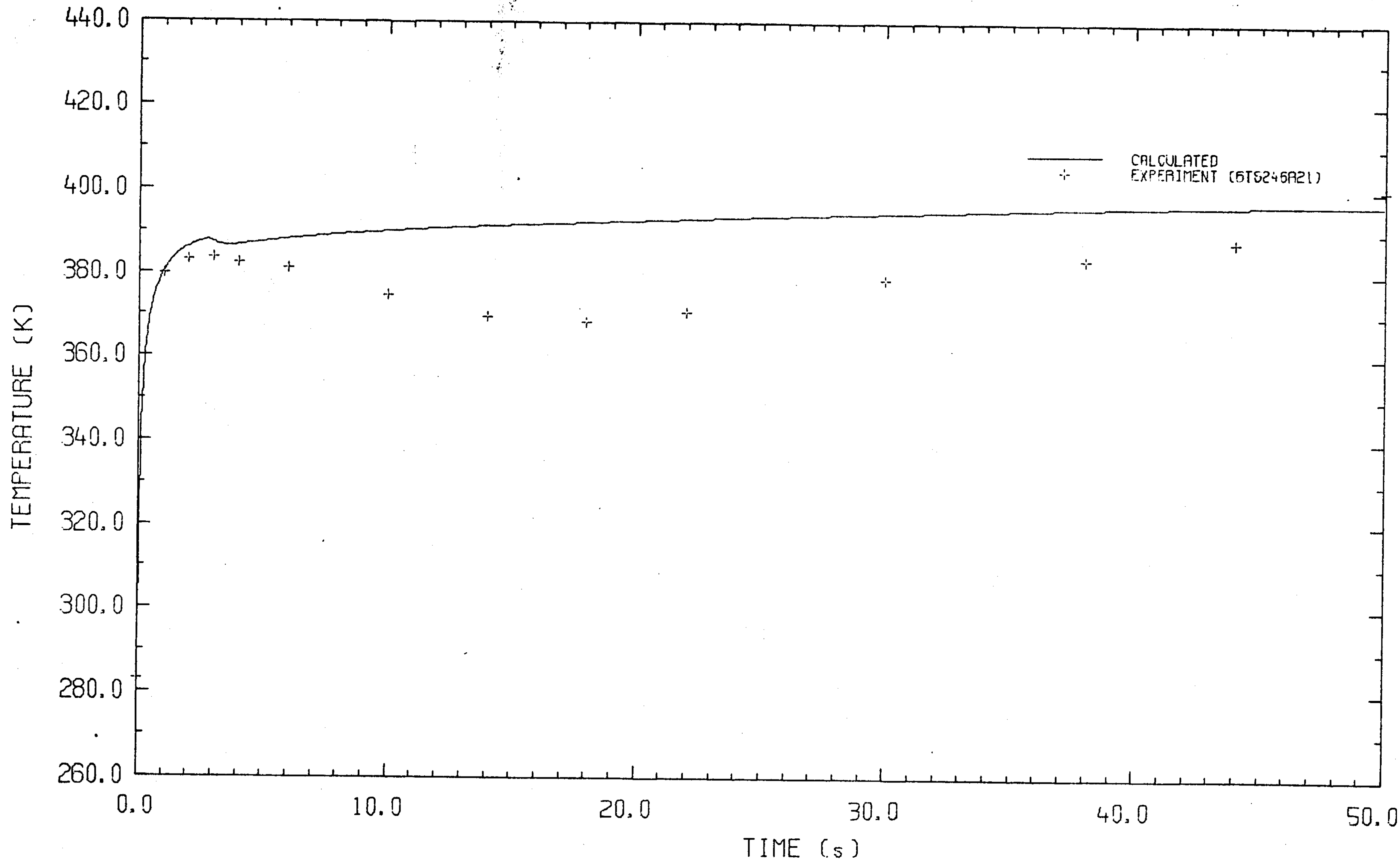


FIG. 4 TEMPERATURE HISTORY: COMPARTMENT A6

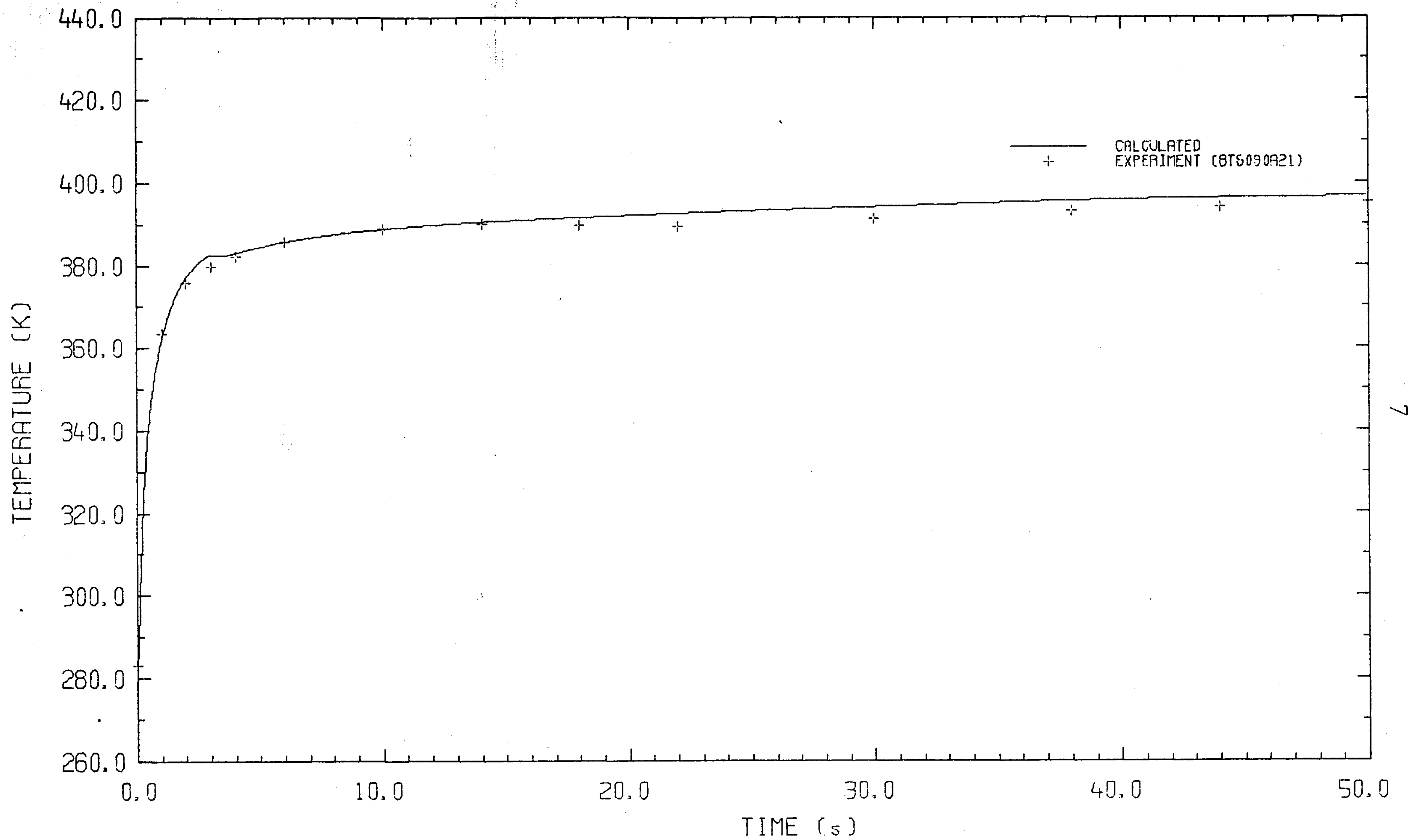


FIG. 5 TEMPERATURE HISTORY: COMPARTMENT A8

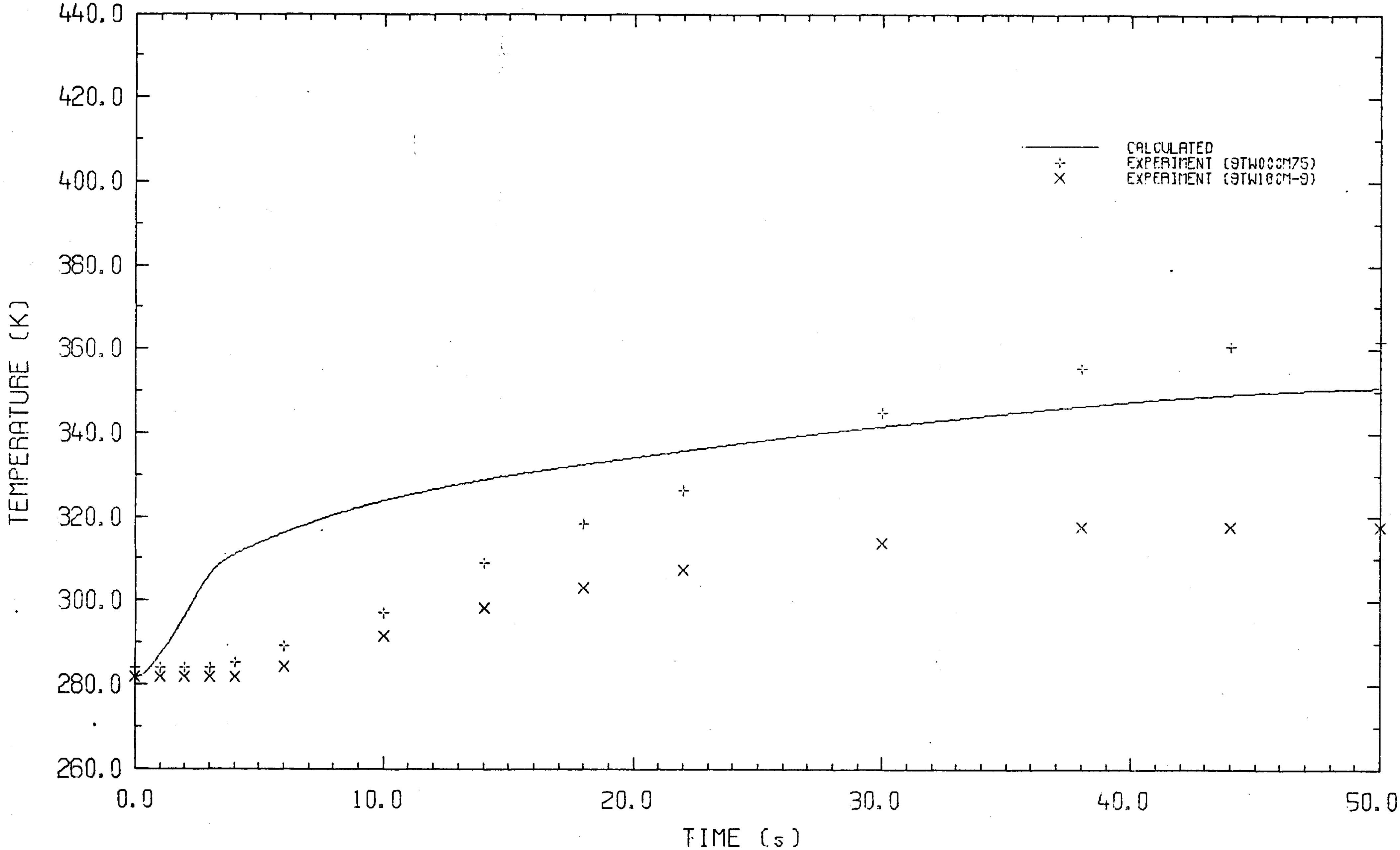


FIG. 6 TEMPERATURE HISTORY: COMPARTMENT A9

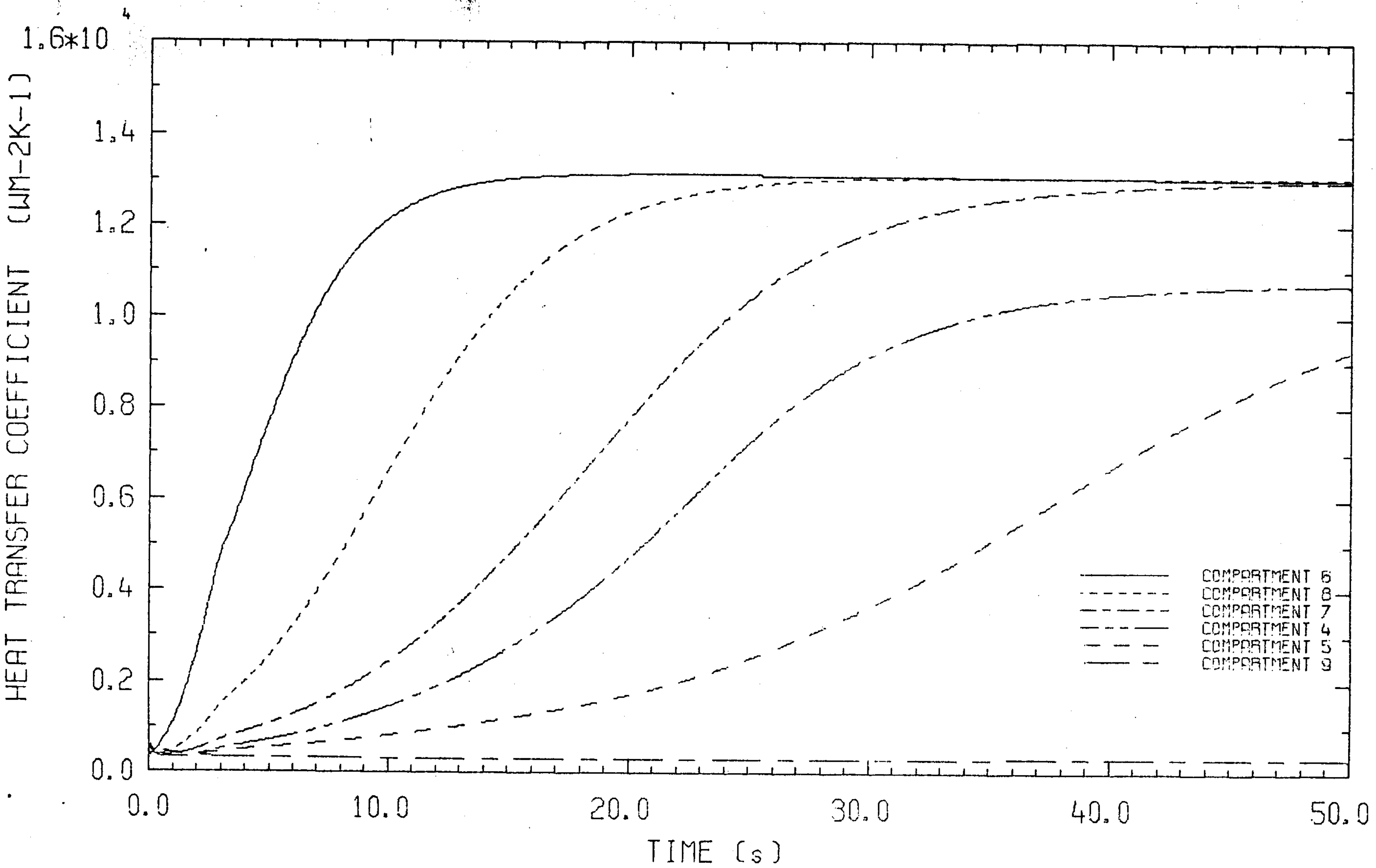


FIG. 7 CALCULATED HEAT TRANSFER COEFFICIENT TRANSIENTS

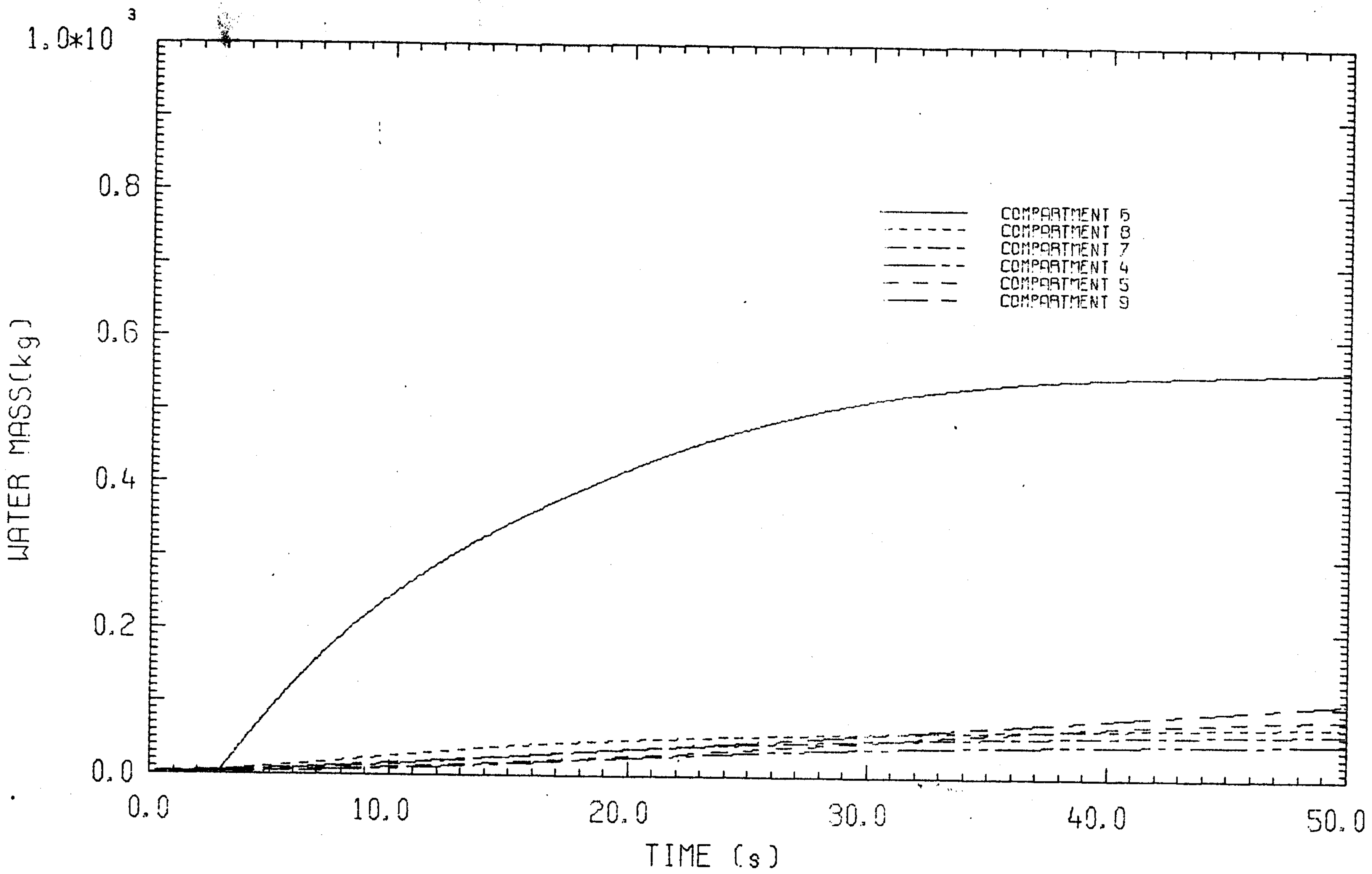


FIG. 8 CALCULATED WATER MASS TRANSIENTS

Belgium
(Tractionel)

Dr. E. J. Stubbe sent a post analysis report (Post analysis of the Battelle-Frankfurt test D15 using the codes TRAP, 27.9.79) to OECD-NEA. This report contains a correction for mass inventory (fig. 3), parametric studies on the influence of the paint and the results of an evaluation model analysis and was distributed along with SINDOC (79)164 of Oct. 22, 1979.

Canada
(AECL)

With letter of December 20, 1979 Mr. J. E. Dick communicated that AECL has revised its report of April 1979 distributed at the workshop (SINDOC (79)89 in /10/). "Changes consist primarily of scaling corrections to the predicted curves in Fig. 3-10 and two footnotes pointing out minor errors. One of the erros involved submission of the incorrect data of the mass of water in containment from 0-1500 seconds", which is plotted in Fig. 46A. The text of the corresponding footnote on page 12 of the revised report is:

> "As the result of an error, the data submitted for mass of liquid and plotted in Fig. 46A was actually the mass of vapour. The code logic which removes unflashed liquid from the source node is bypassed when the flow into containment ceases, in order to prevent removal of subsequently condensed liquid. Consequently the mass of vapour plus condensed liquid becomes essentially constant after flow stops."

The final report (revision of December 1979, 27 pages) was submitted along with above-mentioned letter and should be available from AECL.

Gesellschaft für Reaktorsicherheit (GRS) mbH
Germany

OECD-CSNI CONTAINMENT STANDARD PROBLEM NO. 1

Discussion of the Results Obtained with COFLOW for the Time Period 0 - 2.5 s

Submitted by
G. Hellings
Gesellschaft für Reaktorsicherheit (GRS)mbH
Dezember 1979

Forschungsgelände · 8046 Garching · Telefon (089) 32091 · Telex 5215110 grsm d

Calculations with the containment code COFLOW for the experiment D15 of the German research program RS50 have already been performed within the frame of the "blind" German Containment Standard Problem No.1. The correspondence between measured values and those predicted in the calculations was good. Therefore, for the short-term period, the same COFLOW calculation was presented in the OECD-CSNI Containment Standard Problem No.1.

The input data for this calculation as far as they were not given by the specification were chosen according to the results of the analysis of other experiments similar to experiment D15. Heat transfer coefficients during the short-term period were assumed to be large for compartments near the break due to condensation of steam. The consideration of flow velocities led to a good description of pressure in compartment R4 and pressure difference between compartments R4 and R5. Neglecting the flow velocities would lead to a higher pressure in compartment R4 (as can be seen in fig.1) but has no visible effect on the pressure in the other compartments.

The influence of the coating of the concrete walls during the short-term period was examined in a parametric study. Fig.2 shows the pressure in the break compartment R6 for different thicknesses of the coating when large heat transfer coefficients were assumed.

Some other parameter variations were performed which indicated that the correspondence between theoretical and experimental results can be improved a little by using larger discharge coefficients for the orifices Ü47 and Ü45. This assumption seems plausible because the flow through compartment R4 occured with a relatively high velocity like a "jet". The influence of these two discharge coefficients can be seen in fig.3 and 4 showing the pressures in the compartments R6 and R7 which were affected most by this variation. However, the larger discharge coefficients are specifically for the experiment D15 and have not yet been confirmed, so that no precipitate conclusions should be drawn from this parametric study. There might be a lot of other reasons for the small deviations between measured values and those calculated first because there are still some uncertainties on the analytical side as well as on the experimental side which have to be investigated in future. The main analytical problems are to get more information about heat transfer and flow resistances to confirm the coefficients used in the Standard Problem and about water transport between the compartment which could be neglected in the Standard Problem. The experimental efforts should be to improve measurement techniques and their accuracy especially for measuring mass flow rates and special effects (e.g. heat transfer coefficients).

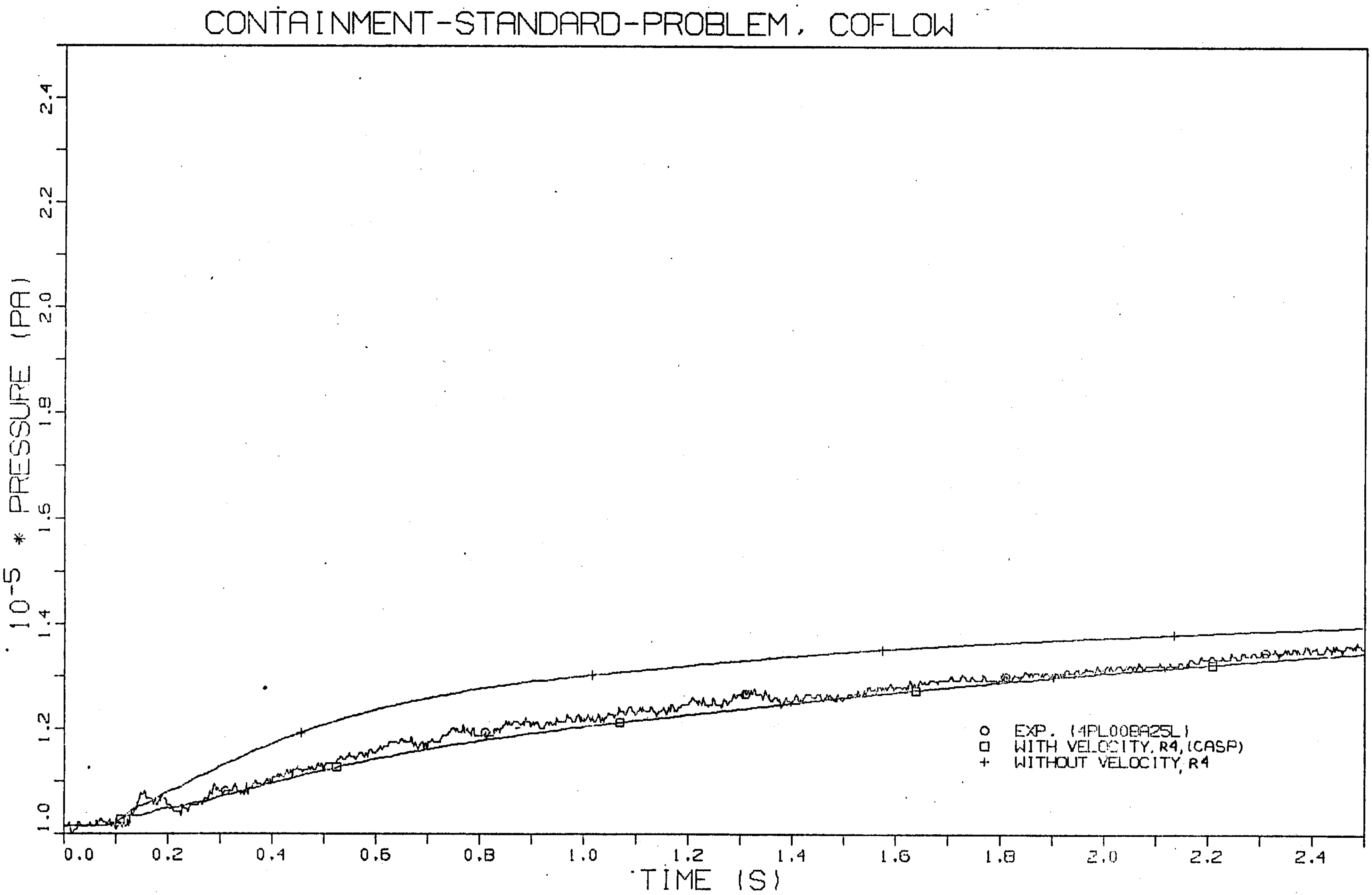


FIG.1: INFLUENCE OF THE FLOW VELOCITY

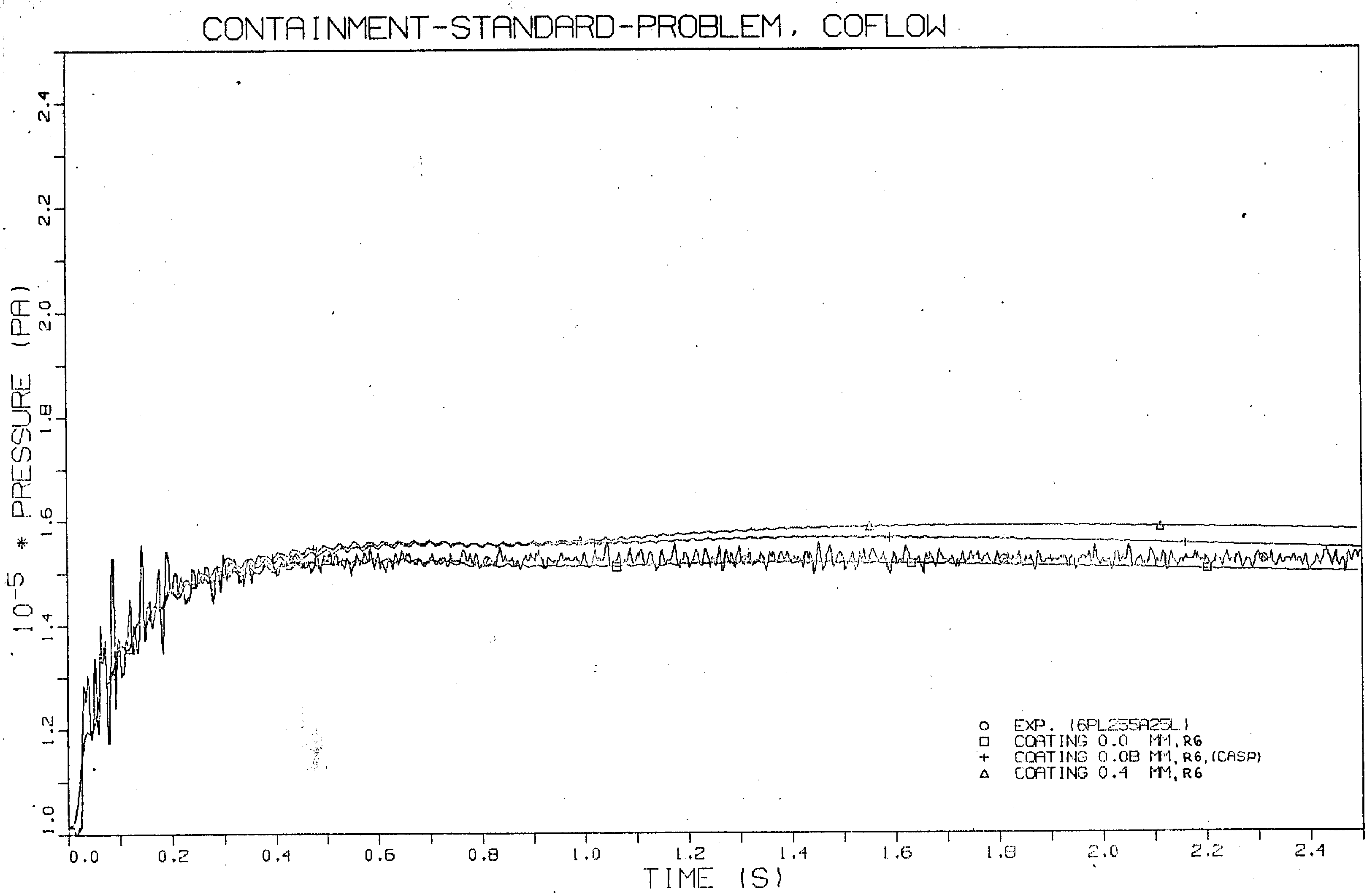


FIG. 2: INFLUENCE OF THE THICKNESS OF THE COATING

CONTAINMENT-STANDARD-PROBLEM, COFLOW-CALCULATION

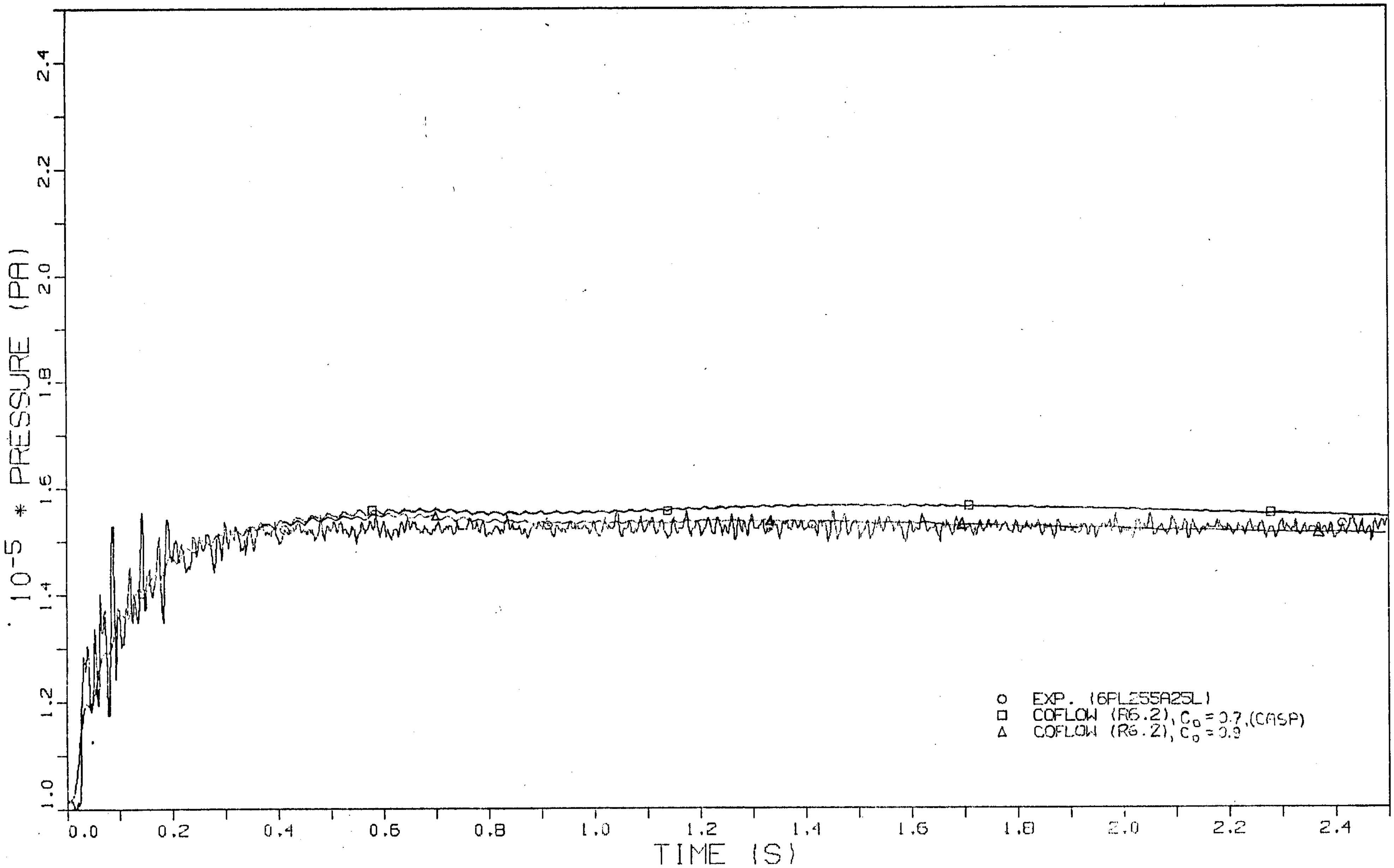


FIG. 3: TIME HISTORY OF PRESSURE, COMPARTMENT R6

CONTAINMENT-STANDARD-PROBLEM, COFLOW-CALCULATION

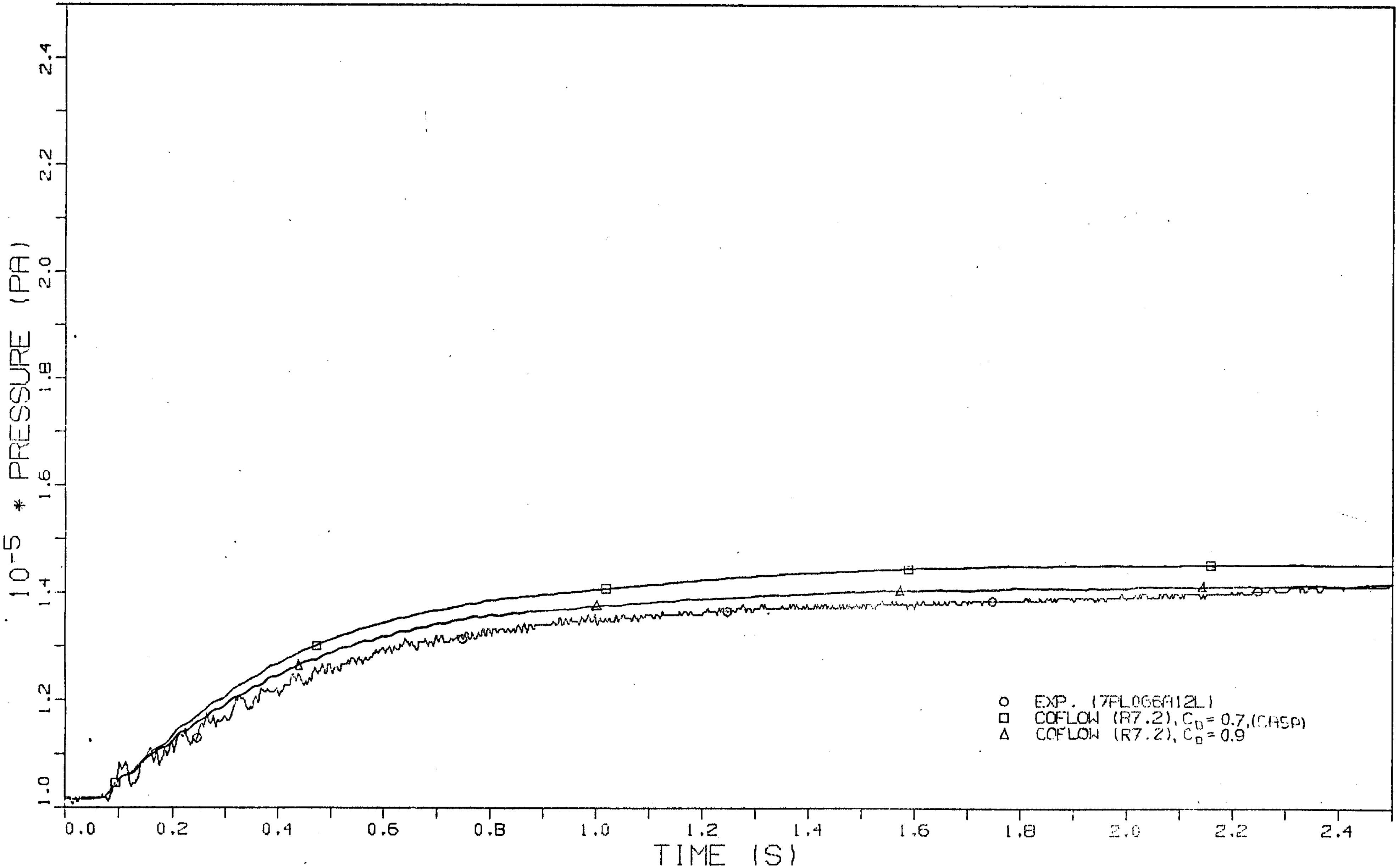


FIG.4: TIME HISTORY OF PRESSURE, COMPARTMENT R7

Italy

(CNEN/Pisa)

With letter of Sep. 27, 1979 Dr. M. Mazzini and Dr. F. Oriolo of Pisa University communicated that their submitted data in fig. 46B were related to vapor mass and not to water mass (see corrected graph below).

corrected version of fig. 46 B

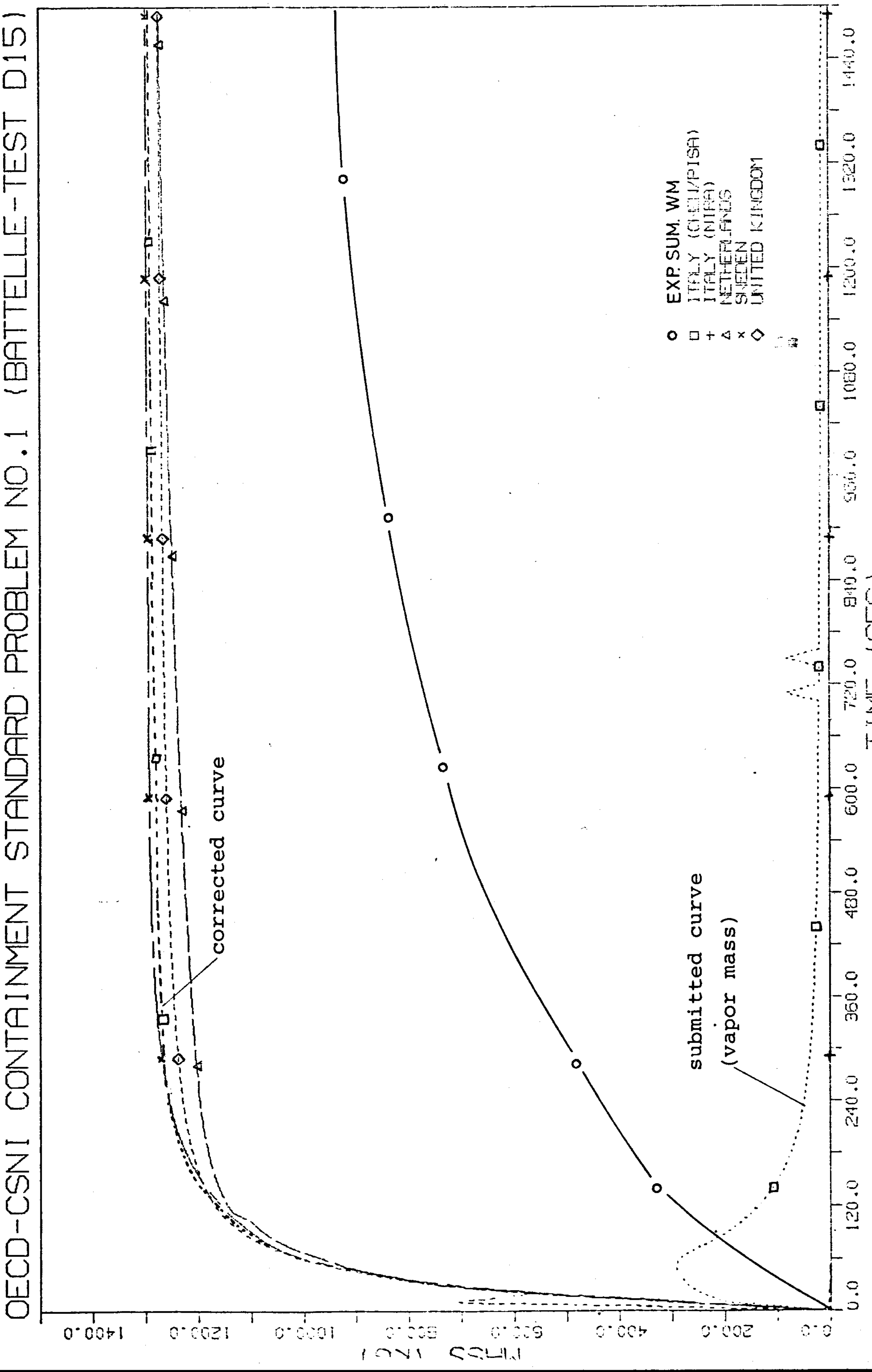


FIG. 46 B HISTORY OF WATER MASS IN CONTAINMENT

APPENDIX

1. GENERAL

The purpose of the participation to the standard problem was twofold : first, to verify the overall conservatism of the calculations performed for safety analysis purposes in the licensing procedure; second,to compare the PACO Code results aginst appropriate experimental data.

The first scope was easily achieved by performing the calculation with the well known assumptions for heat transfer coefficients and discharge coefficients at the junctions : the calculated pressures were larger than the experimental ones by more than 50%.

This so high conservatism is felt to be due also to the particular containment system lay-out and scale.

For the second scope, it was decided not to introduce any modification into the code itself, but to modify only input data, in order to check the code as it is, and to verify its overall ability to predict the pressure and temperature transients correctly, provided correct boundary conditions are assumed, in spite of the phisical complexity of the problem. The major assumptions refer to heat transfer coefficient, dicharge coefficient, nodalization and are reportes in table 3 of the text.

2. DISCUSSION OF RESULTS

The main remarks on the comparison of the experimental and calculated transients are reported in the following.

a) A large HTC was required in order to obtain pressure and temperature transients similar to the experimental ones. However, considering the particular geometry of the system, in which the air-steam mixture flows in turbulent flow along the walls of fairly long compartments so that a drop-wise condensation can be expected, the coefficient seems reasonable.

b) The largest discrepancies between calculated and experimental transients in the short and medium term,are predicted in room n°9. It is evident from the experimental results that quite different temperature distributions exist in this compartment, thus indicating large stratification and non-homogeneity in the compartment itself. These effects cannot be accounted for by the code.

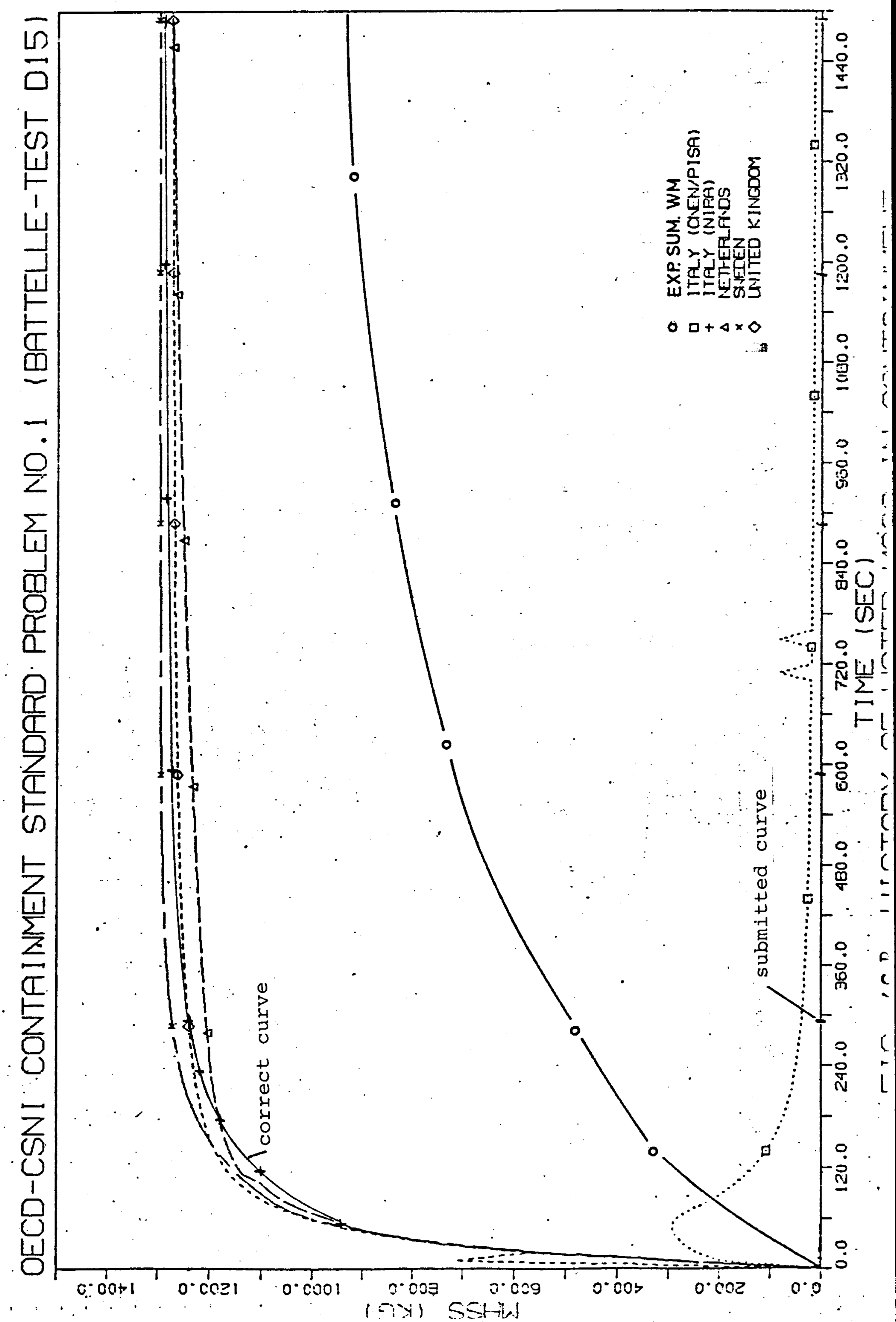
c) Effects of spatial non-equilibrium are evident in all rooms; they are probably enhanced by the particular geometry of the compartments and by their connection in series.
The code assumes equilibrium in the rooms. It also has the capability to model a flow in the connections having different characteristics with rispect to those of the fluid in the donor room(pistoning effect). However it was chosen not to use this option to avoid introducing additional arbitrarities and uncertainties in the calculation.

3. WATER MASS

In fig. 1, the calculated mass hold-up in the containment is reported for the long term transient the results are very close to the ones calculated by other partecipants.

Due to an error in the punched cards these data were not submitted with the other results of the calculation.

Figura 1


OECD-CSNI CONTAINMENT STANDARD PROBLEM NO.1 (BATTELLE-TEST D15)
EXP. SUM. WM
ITALY (CNEN/PISA)
ITALY (NIRA)
NETHERLANDS
SWEDEN
UNITED KINGDOM
correct curve
submitted curve
TIME (SEC)
0.0
120.0
240.0
360.0
480.0
600.0
720.0
840.0
960.0
1080.0
1200.0
1320.0
1440.0
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0

STUDSVIK ENERGITEKNIK AB, Sweden
J.E. Marklund

Oct. 10, 1979

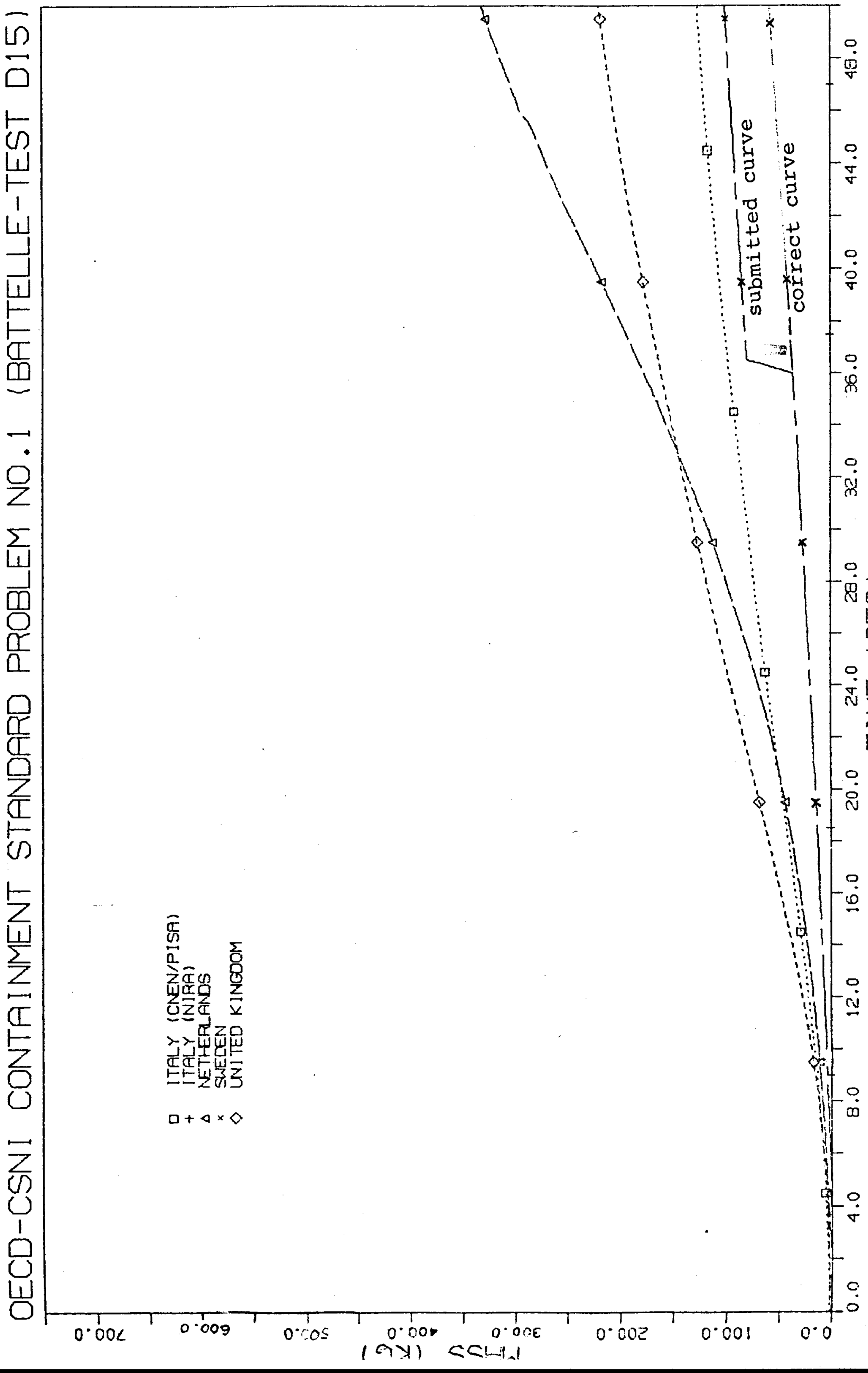
Comment on mass of water (0-50 s)

Due to an error in the interface routine producing the tables, the mass of water given in the submitted tables for the time interval 36.5 - 50 s in the 0-50 s case are too high with the following amounts:

Compartment	Error
R4	0.228 kg
R5	1.672 kg
R6	1.400 kg
R7	1.600 kg
R8	1.400 kg
R9	43.000 kg

The amounts are negligible except for the compartment R9 (see below revised fig. 43B).

corrected version of fig. 43 B



United Kingdom

(UKAEA, AEEW)

Comment of Mr. W. H. L. Porter (Dec. 10, 1979)

I have three conclusions from my work:

1) that over the first 2.5 seconds the enthalpy and the main outflow mass well have been overestimated,

2) that I surprisingly get a much better fit when using an orifice coefficient of unity in the vents between compartments,

3) that in the particular experiment the carry over and slip in the vents does not significantly alter the pressure and temperature results in the individual compartments.