TRAC CODE INDEPENDENT ASSESSMENT

PART B

by

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Summary

The primary objective of the TRAC code independent assessment work at Brookhaven National Laboratory (BNL) is to evaluate the basic thermal hydraulic models in TRAC. In view of this, several separate-effects tests have been chosen for evaluation by using the TRAC-P1A code, as released on March, 1979. These tests, mostly suggested by the NRC staff, can be grouped in the following categories:

1) One-dimensional steady-state experiments, namely (a) Moby-Dick Nitrogen-Water tests[1], (b) BNL Flashing Flow tests[2], and (c) KFK-IRE Nozzle Flow Tests[3].

2) One-dimensional transient experiments, namely (a) Shock-tube test with air, (b) CANON experiments[4], and (c) Marviken critical flow tests[5,6].

3) Multi-dimensional steady-state experiments, namely (a) RPI two-dimensional phase separation tests[7], and (b) FRIGG loop tests[8].

We shall now briefly discuss the results obtained so far at BNL.

1. One-Dimensional Steady-State Experiments

(a) The Moby-Dick nitrogen-water low pressure tests[1] in a vertical channel were chosen to examine the TRAC models for relative velocity and to check the code's capability for calculating two-component two-phase choked flow. It is found that the code can calculate choked flow, at least from the numerical viewpoint, and the mass flow rate remains unaffected by the back pressure. However, the code with homogeneous two-phase friction factor overpredicts the experimental values of the mass flow rate by approximately 20%. For the case of high nitrogen flow rate (Run 3141), the code did not even reach a steady-state. LASL has been informed of the difficulty and further sensitivity studies are in progress at BNL.

(b) The BNL low pressure flashing flow tests[2] of initially subcooled water in a converging - diverging vertical channel provide a comparison of the nonequilibrium vapor generation models in TRAC. It was found in the experiment that significant liquid superheating exist at the inception point of flashing. This phenomenon is not modeled in TRAC. Consequently, vapor generation begins earlier in the code and the predicted mass flow rates are usually smaller than the experimental values.

(c) Only one test of the KFK-IRE high pressure horizontal nozzle flow experiment has been computed with TRAC so far. The annular two-phase flow friction factor was used. Good agreement has been found with the measured flow rate.

2. <u>One-Dimensional Transient Experiments</u>

(a) An idealized thought experiment has been conducted in a shock-tube filled with air to separate the numerics of TRAC from its modeling. The TRAC-predicted results are compared with the simple analytical solutions[9]. It is found that the code does exhibit some numerical diffusion at both the shock and the rarefaction wave fronts. Some numerical "noise" has also been observed at higher initial pressure ratios (50 or more).

(b) The CANON experiments[4] provide the pressure and void fraction measurements during a pipe blowdown of initially subcooled high pressure water. Four of these tests with two different opening sizes and two different initial subcooling were compared with TRAC prediction. In general, the agreement was good. However, the TRAC calculations tend to empty the pipe somewhat earlier than the experiment.

(c) The Marviken tests[5,6] are full scale vessel blowdown tests and are conducted to study critical flow in large diameter pipes. The test 22 (L/D=1.5) and the test 24 (L/D=0.33) mainly differ in nozzle lengths. TRAC-P1A under-predicts the mass flux in the nozzle and the pressure in the vessel for the test 22. However, it predicts the pressure in the vessel well in the test 24 for the early part of the transient, but the mass flux prediction is lower by a maximum of 25% from the experimental value. This could be due to many factors such as wall friction, interfacial mass transfer and vessel internals, etc. These are being looked into.

3. <u>Multi-Dimensional Steady-State Experiments</u>

(a) Two-dimensional phase separation tests[7] were conducted at RPI to see how phases (air/water) separate in a thin vessel (0.914m x 0.3m x 0.0126 m). A mixture of air-water flows into the test section through the bottom and flows out at the two exit pipes attached near the top. There is also a provision to insert vertical rods in it. These tests should assess the effects of the interfacial momentum transfer. So far test 3 has been tried and TRAC-P1A did not converge after 4200 steps. However, the mixture flows out at both the top pipes and void fraction increases with the height in the test section. Further simulation will be done with one outlet closed and/or with rods inserted.

(b) The FRIGG loop tests[8] provide detail void fraction and pressure drop data in a 36-rod electrically heated bundle. The TRAC-P1A code is being applied to simulate some of these tests. However, no result has yet been obtained.

In addition to assessing the TRAC code with the above experiments, an informal document[10] has been prepared in order to described the basic thermal hydraulic models and correlations employed in the TRAC-P1A code.

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References

1. Jeandey, C., and Barriere, G., "Partie I: Etude Experimentale d'Ecoulements Eau-Air a Grande Vitesse," DTCE/STT/SETRE Note T.T. no. 599, Janvier 1979.

2. Zimmer, G. A., et al., "Pressure and Void Distributions in a Converging-Diverging Nozzle with Nonequilibrium Water Vapor Generation," BNL-NUREG-26003, April 1979.

3. Kedziur, F., "Investigation of Strongly Accelerated Two-Phase Flow," Paper presented at the ICHMT Conference, Dubrovnik, September 1978.

4. Riegel, B., and Marachal, A., "Experience CANON Depressurisation d'une Capasite en Double Phase Eau-Vapeur," CEA-CENG Note T.T. no. 547, April 1977.

5. Ericson, L., et al., "MXC-222, Interim Report Results from Test 22," Joint reactor safety experiments in Marviken Power Station, Sweden, MX3-87, March 1979.

6. Ericson, L., Et al., "MXC-224, Interim Report Results from Test 24," Joint reactor safety experiments in Marviken Power, Sweden, MX3-91, May 1979.

7. Lahey, R. T., "Two-Phase Flow Phenomena in Nuclear Reactor Technology," Quarterly Progress Report 8, NUREG-CR-0418, March-May, 1978.

8. Nylund, O., et al., "FRIGG Loop Project; Hydrodynamic and Heat Transfer Measurements on a Full-Scale Simulated 36-rod Marviken Fuel Element with Uniform Heat Flux Distribution," FRIGG-2, AB Atomenergi, Stockholm, 1968.

9. Liepmann, H. W., and Roshko, A., "Elements of Gasdynamics," Chapter 3, John Wiley & Sons, Inc., N.Y., 1967.

10. Rohatgi, U. S., and Saha, P., "Constitutive Relations in TRAC-P1A," August, 1979.

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TRAC-P1A ASSESSMENT AT BNL
(APRIL, 1979 - SEPTEMBER, 1979)

- 1-D STEADY-STATE EXPERIMENTS
  - MOBY-DICK NITROGEN-WATER TESTS (BLIND)
  - BNL FLASHING FLOW TESTS
  - KFK-IRE NOZZLE FLOW TESTS (BLIND)
- 1-D TRANSIENT EXPERIMENTS
  - SHOCK TUBE TESTS WITH AIR
  - CANON BLOWDOWN TESTS
  - MARVIKEN CRITICAL FLOW TESTS (BLIND)
- MULTI-DIMENSIONAL EXPERIMENTS
  - RPI 2-D PHASE SEPARATION TESTS
  - FRIGG LOOP TESTS (BLIND)

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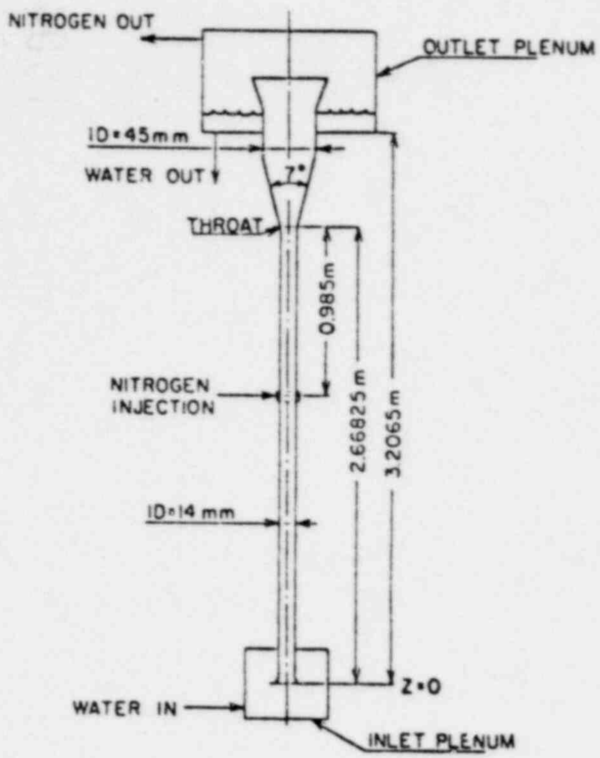
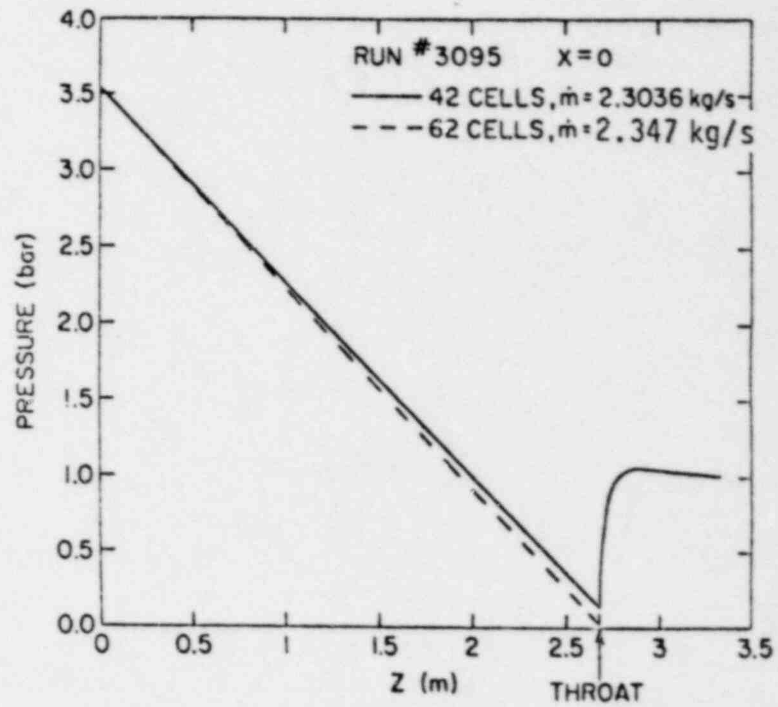
MOBY-DICK N_2-WATER TESTS



Schematic of Moby-Dick Nitrogen/ Water Test Section (BNL Neg. No. 7-1181-79)



TRAC prediction of Run 3095 (BNL Neg. No. 7-1177-79)

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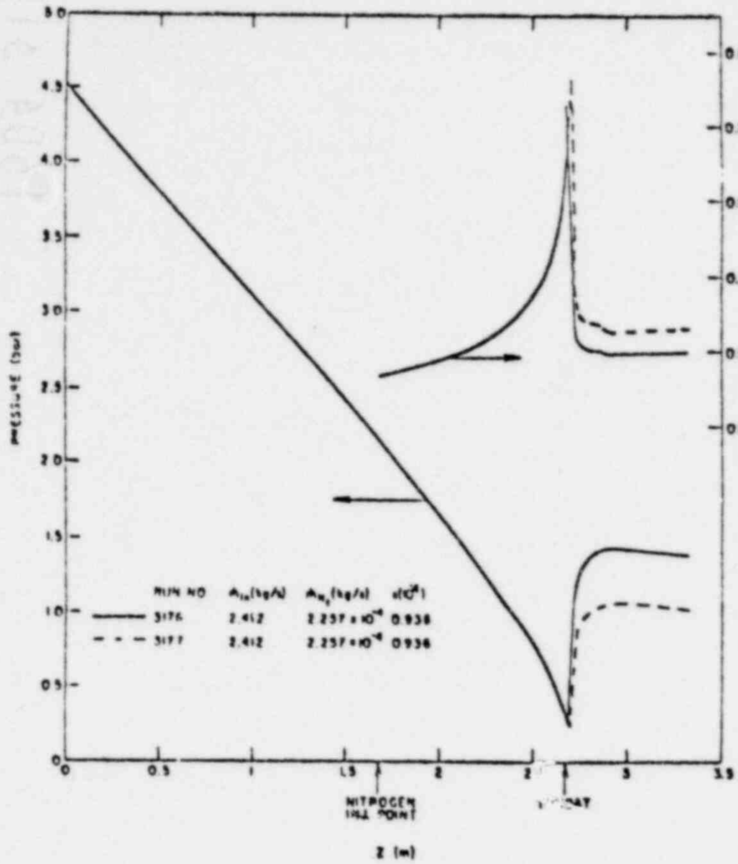
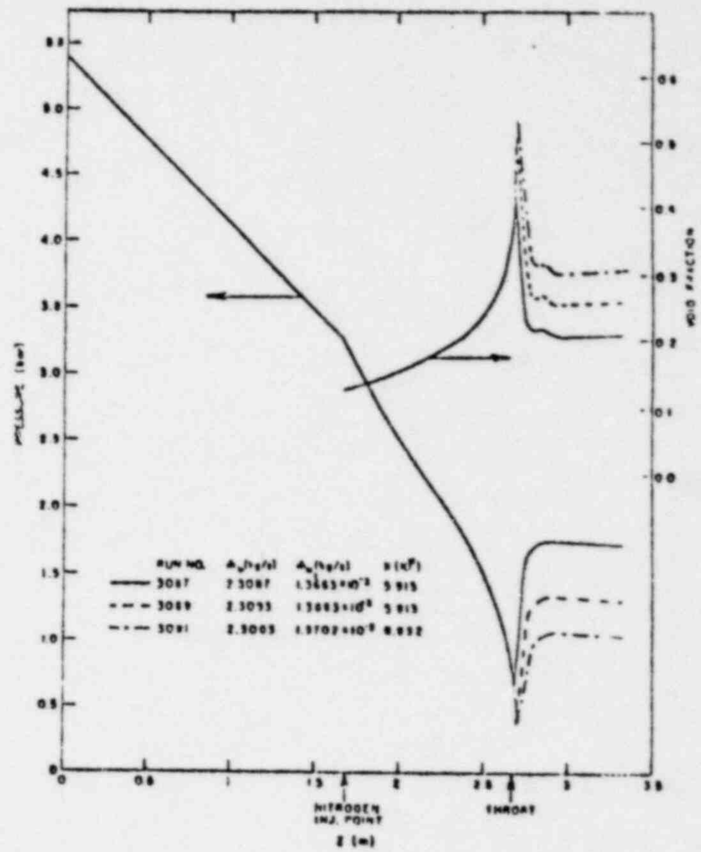


TRAC prediction of Runs 3176 and 3177 (BNL Neg. No. 7-1168-79)



TRAC prediction of Runs 3087, 3089 and 3091 (BNL Neg, No. 7-1169-79)

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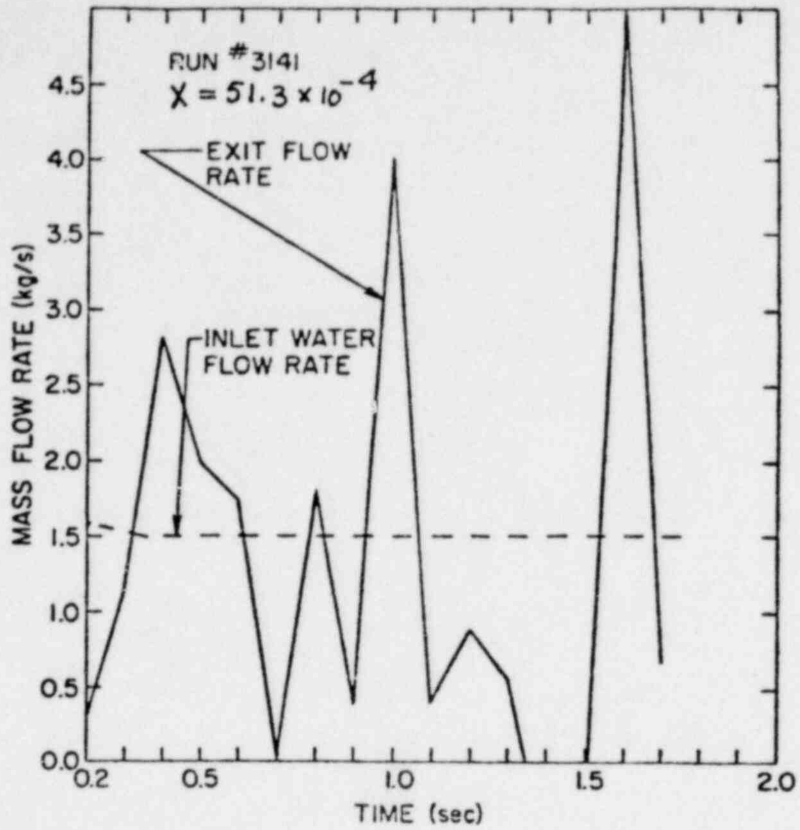
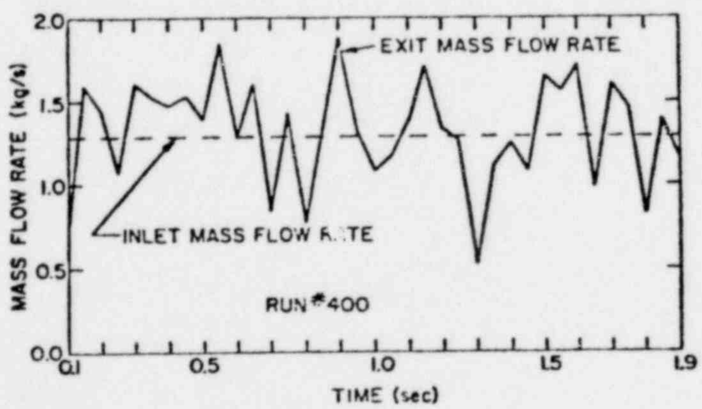


Exit and Inlet Mass Flow Rates for Run 3141 (BNL Neg. No. 7-1170-79)
(Nitrogen-Water Test)



Exit and Inlet Mass Flow Rates for Run 400 (Steam-Water test)
(BNL Neg. No. 7-1179-79)

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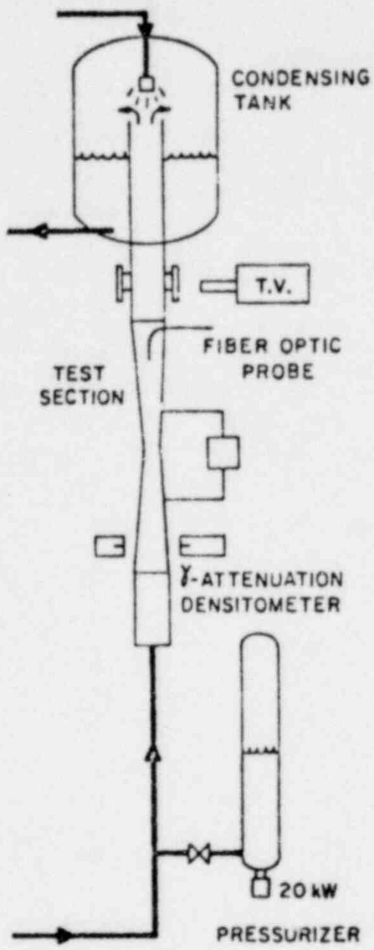
MOBY-DICK NITROGEN-WATER TEST RESULTS

RUN NO.	QUALITY	INLET MASS FLOW (KG/S)		ERROR+ (%)
		EXPT	TRAC CALC.*	
3095	0	1.912	2.3036	20.5
3176, 3177	0.936×10^{-4}	2.0566	2.4125	17.3
3087, 3089, 3091	5.9×10^{-4}	1.915	2.309	20.5
3141	51.3×10^{-4}	1.2223	DID NOT REACH A STEADY-STATE	-

* CALCULATIONS BASED ON 42 CELLS AND INLET BREAK CELL LENGTH OF 0.5 M

+ ERROR $\equiv \left[\frac{\text{CALC.} - \text{EXPT.}}{\text{EXPT.}}\right] \times 100$

BNL FLASHING FLOW EXPERIMENTS IN A CONVERGING-DIVERGING NOZZLE



THROAT DIA. = 25 MM

TEST SECTION LENGTH = 600 MM

INLET &
EXIT DIA. = 50 MM

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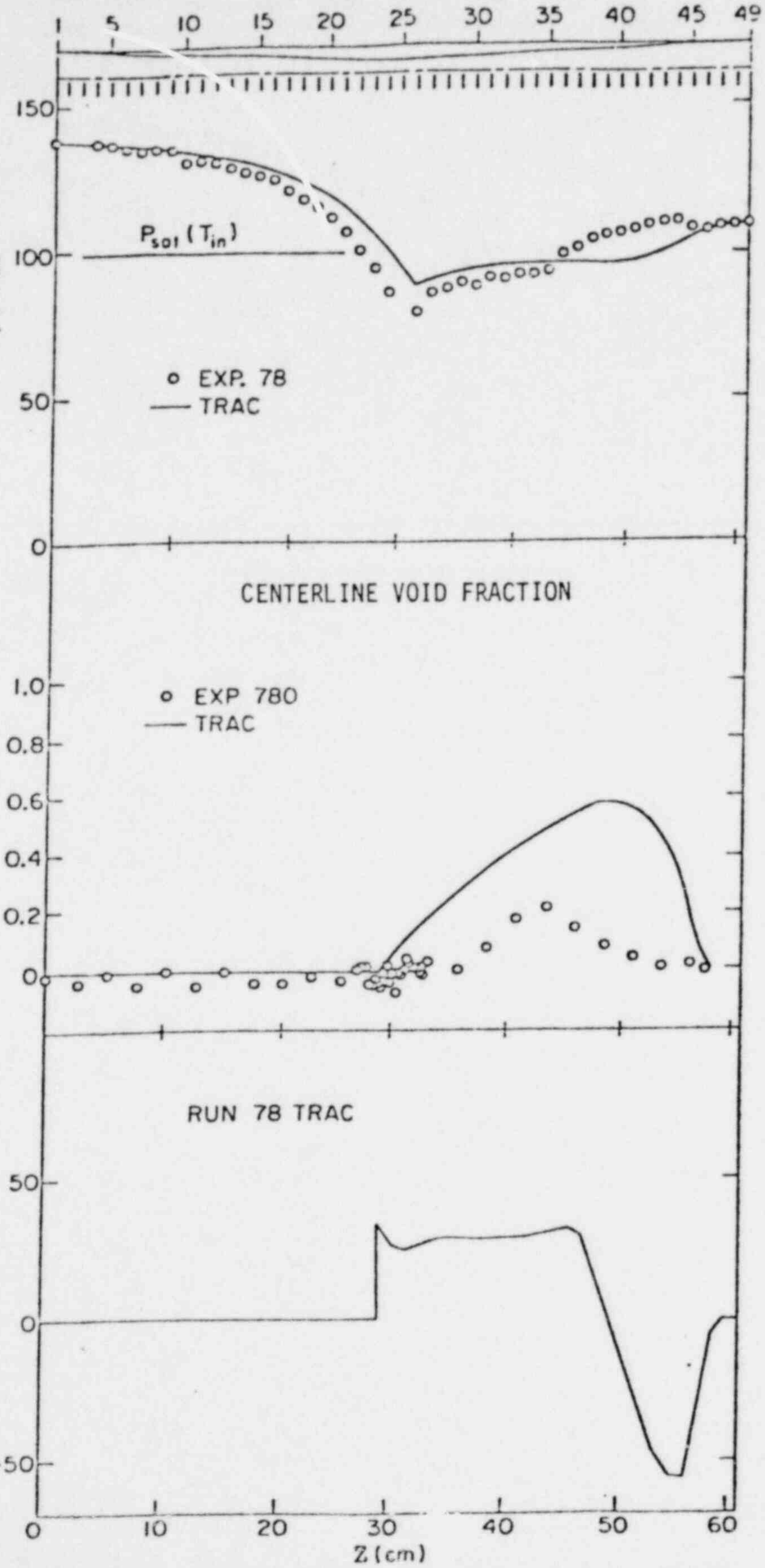

Comparison of TRAC Predictions With BNL Experimental Results.

Run No. 78-780, G_{in} = 2610 kg/m^2 s, p_{in} = 138 kPa, T_{in} = 99.3 ^oC.

(BNL Neg. No. 7-652-79).

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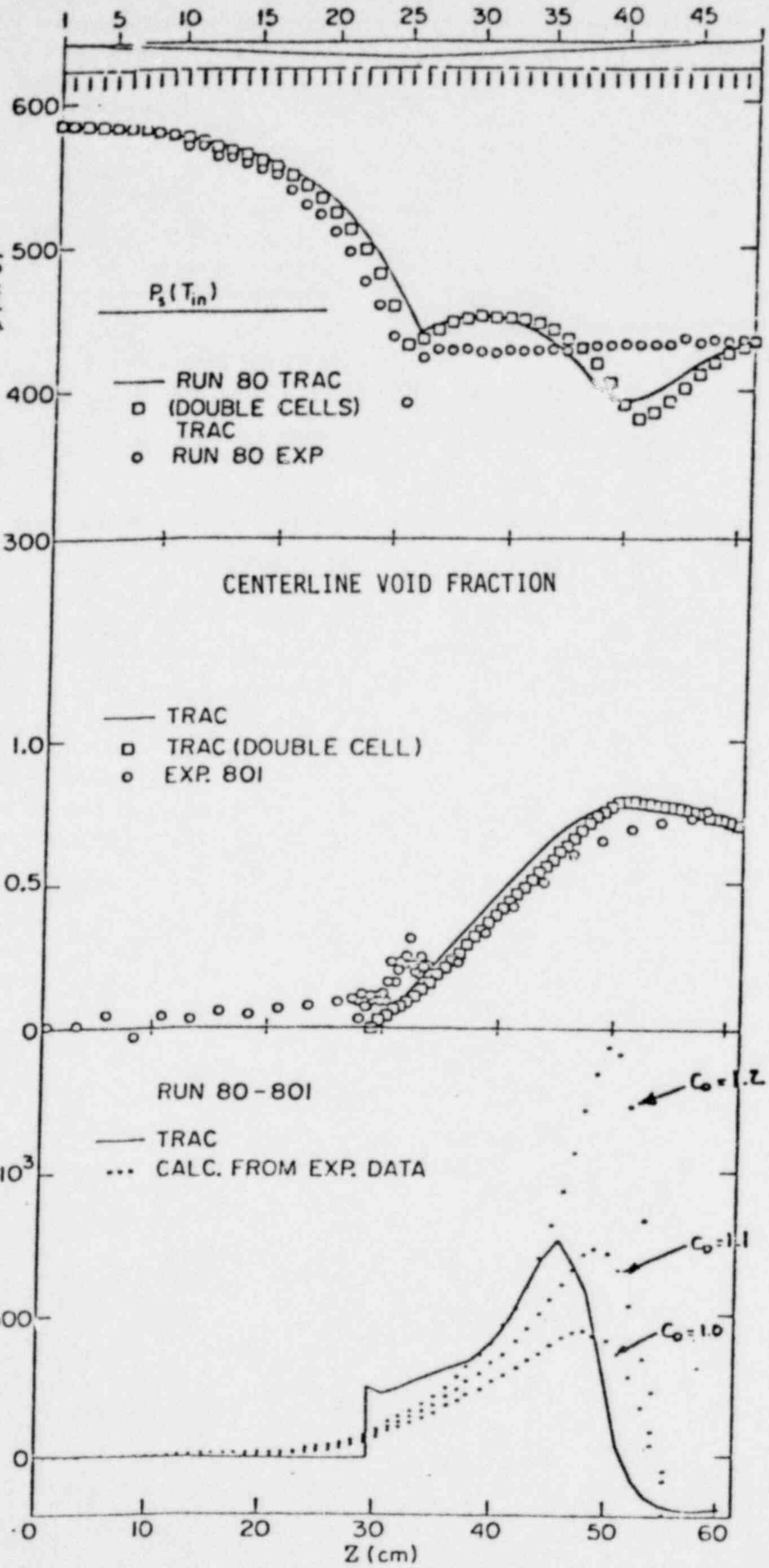

Comparison of TRAC Predictions With BNL Experimental Results.

Run No. 80-801. G_{in} = 4360 kg/m^2 s, p_{in} = 585 kPa, T_{in} = 148.3 °C.
(BNL Neg. No. 7-654-79).

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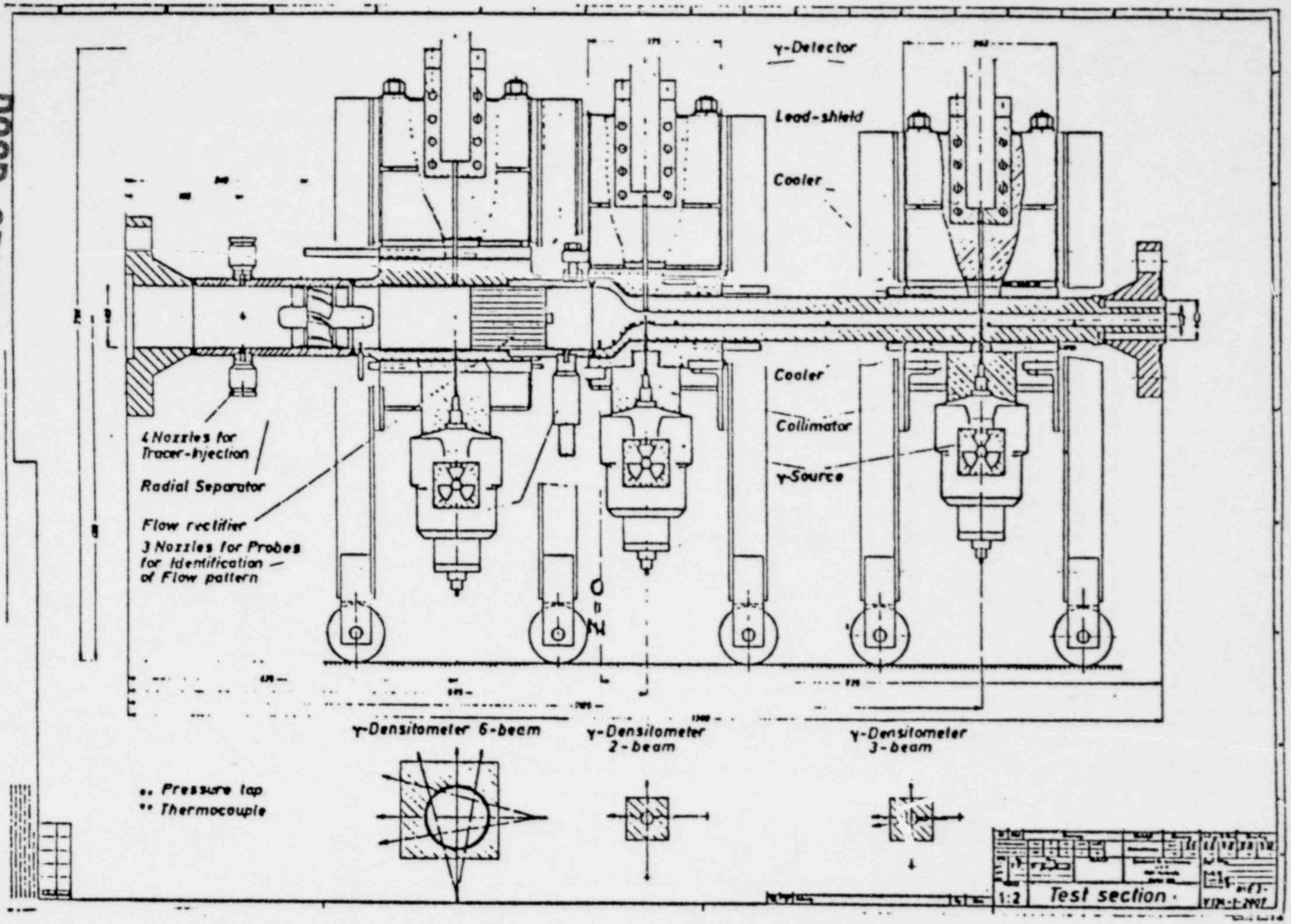
BNL FLASHING TEST RESULTS

TEST SERIES	P_{IN} (BAR)	T_{IN} (°C)	P_{EXIT} (BAR)	INLET MASS FLUX (KG/M^2-S)		ERROR (%)
				EXPT.	TRAC. CALC.	
79	1.24	99.4	1.14	2270	1854	- 18.3
78	1.38	99.3	1.10	2610	2288	- 12.3
77	1.57	99.4	0.92	3060	2667	- 12.8
76	3.95	99.3	0.85	6040	6283	+ 4.0
80	5.85	148.3	4.36	4360	3930	- 9.9



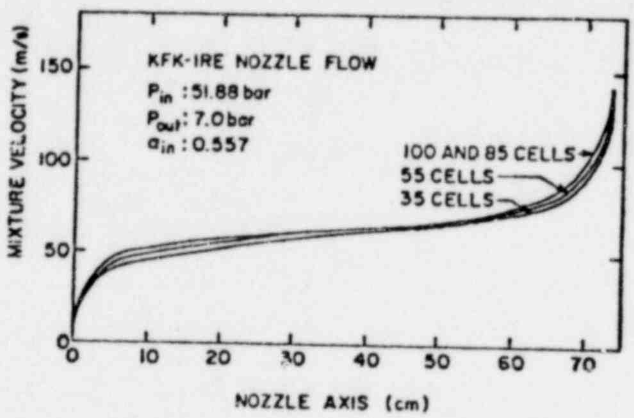
The IRB Test Section

KFK - IRE NOZZLE FLOW TEST

TEST NO. V 15.09.78/11.11

$X_{INLET} = 0.038$

$P_{IN} = 51.88$ BAR $\quad P_{EXIT} = 7.0$ BAR

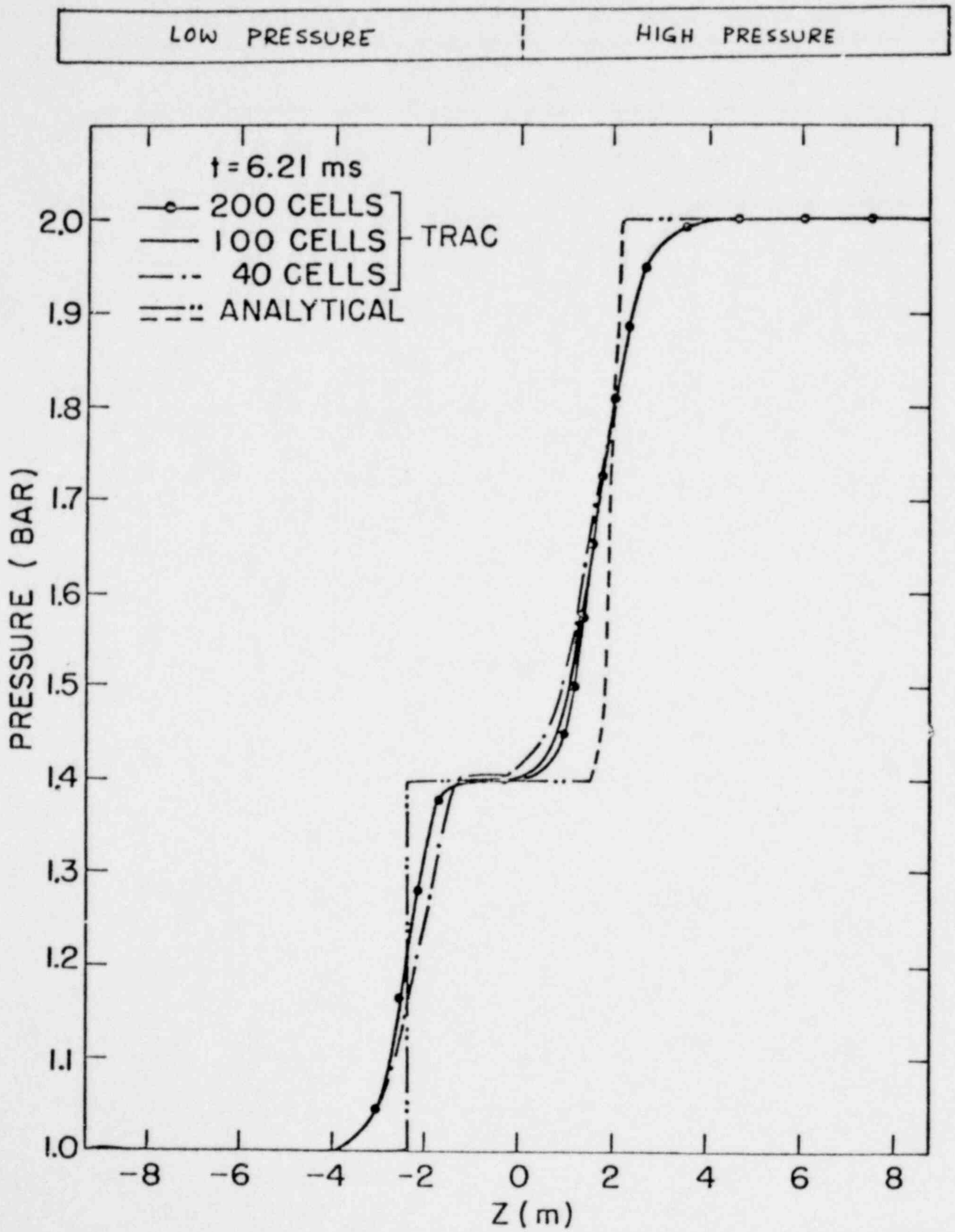


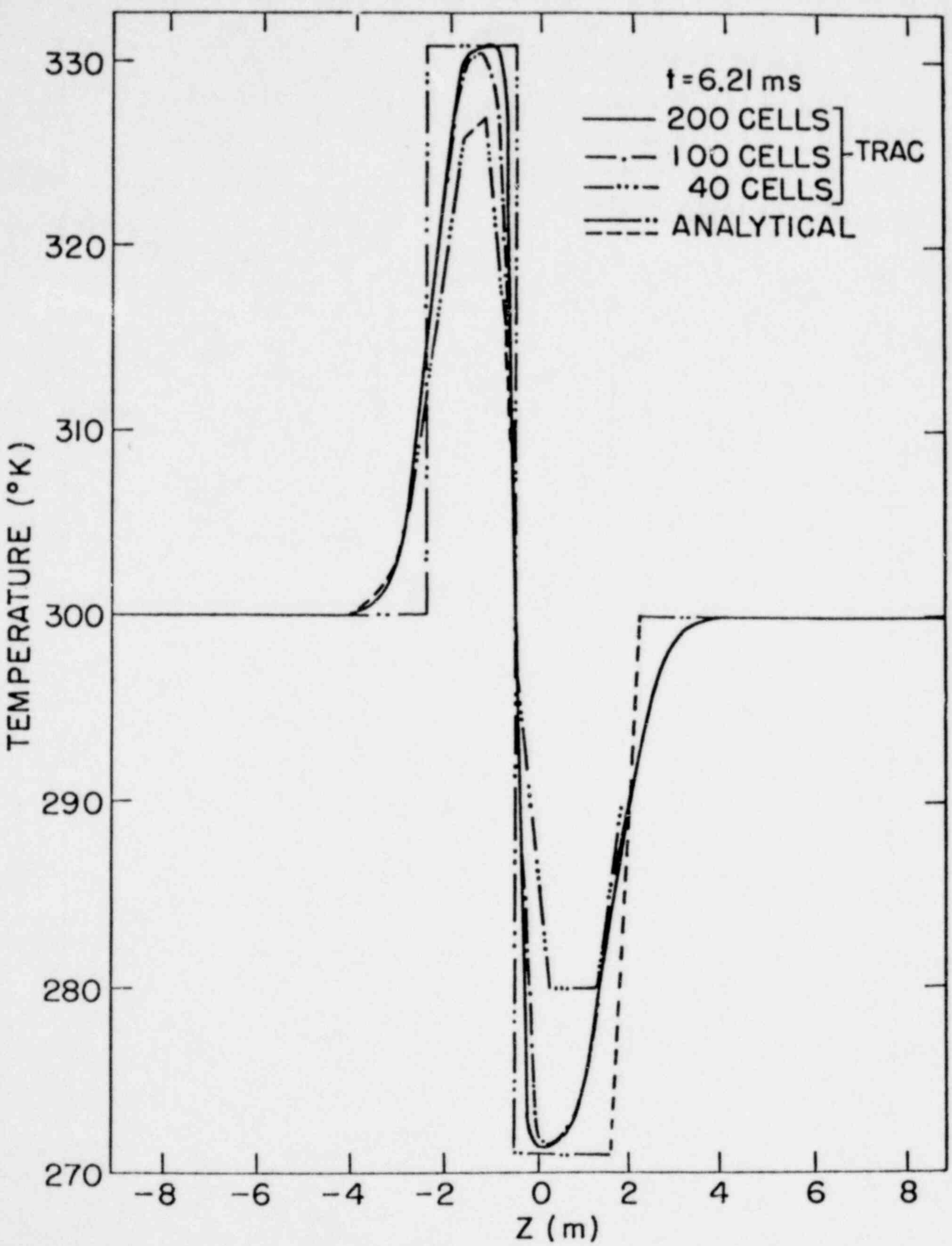
$\dot{M}_{CALC.} = 3.1474$ KG/S $\quad \dot{M}_{EXPT} = 3.065$ KG/S

(85 CELLS)

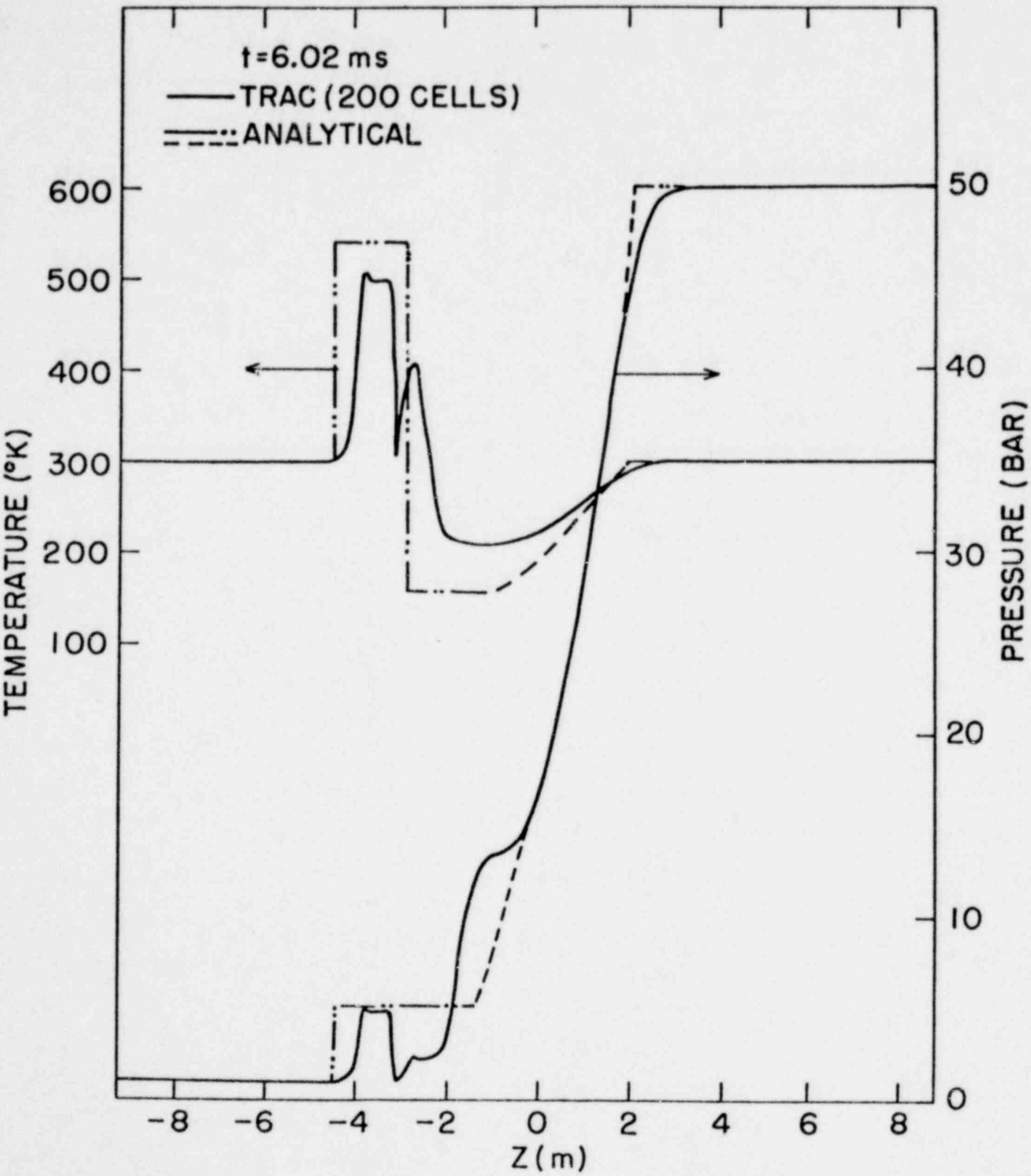
ERROR = 2.7%

SHOCK - TUBE TEST





t=6.21 ms
200 CELLS
100 CELLS
40 CELLS
TRAC
ANALYTICAL
330
320
310
300
290
280
270
TEMPERATURE (°K)
-8
-6
-4
-2
0
2
4
6
8
Z (m)


t=6.02 ms
TRAC (200 CELLS)
ANALYTICAL
TEMPERATURE (°K)
600
500
400
300
200
100
PRESSURE (BAR)
50
40
30
20
10
0
-8
-6
-4
-2
0
2
4
6
8
Z (m)

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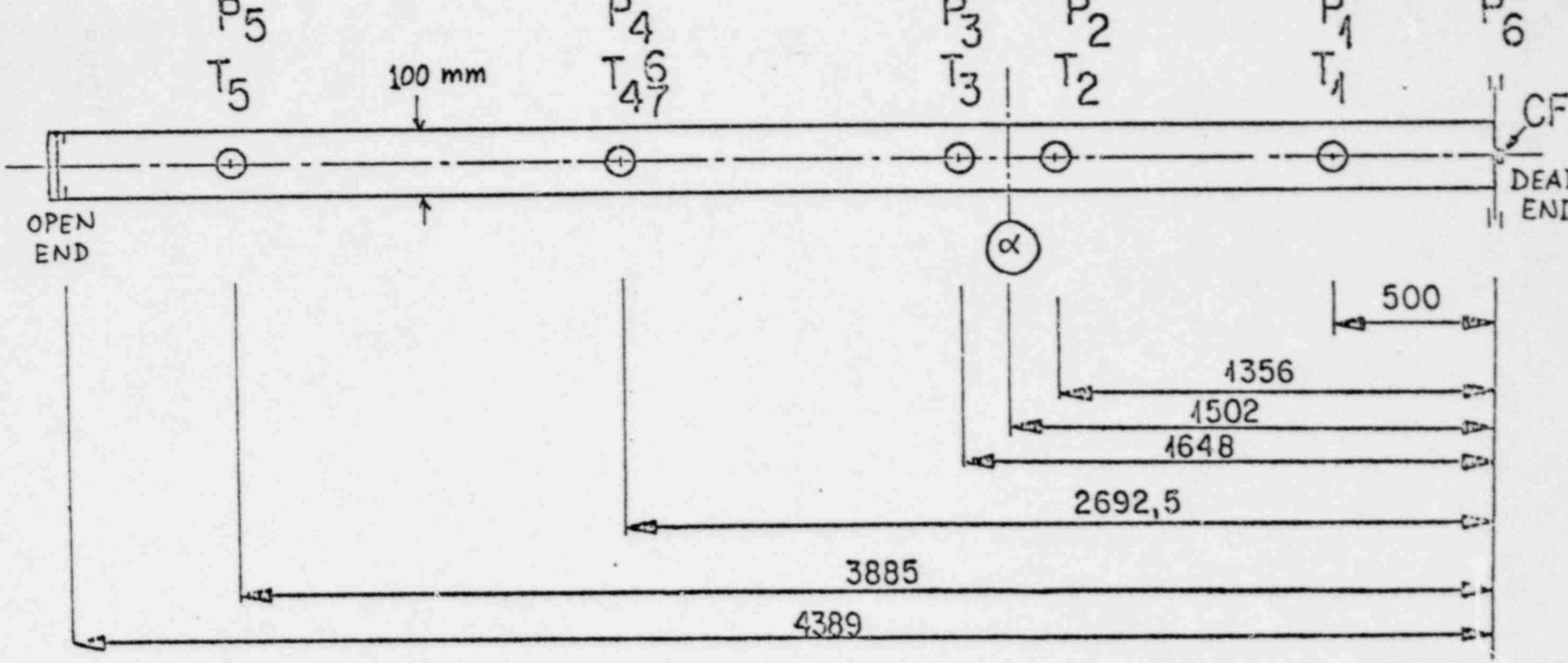

CANON Schéma des points de mesure

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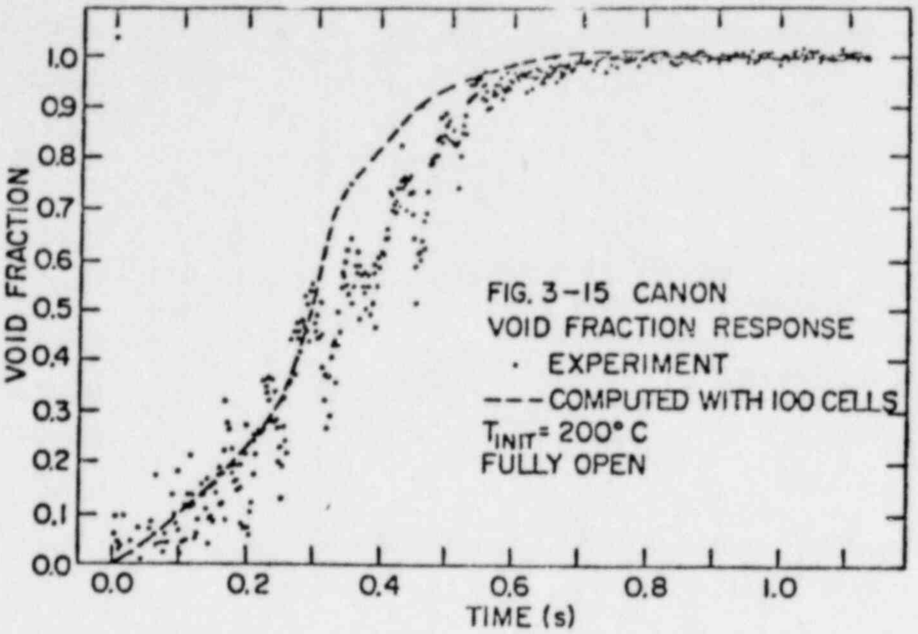
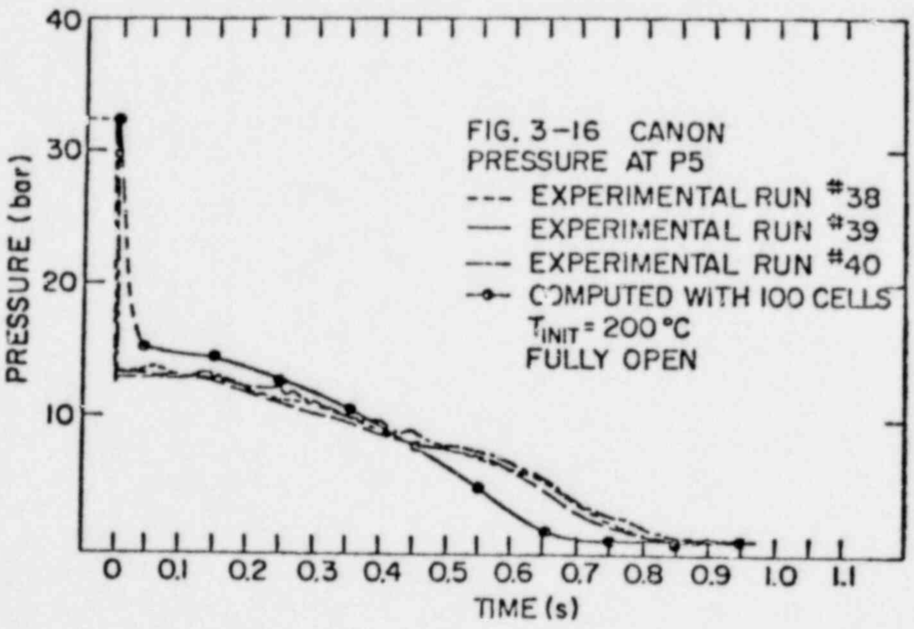


(BNL Neg. No. 8-132-79)



(BNL Neg. No. 8-131-79)

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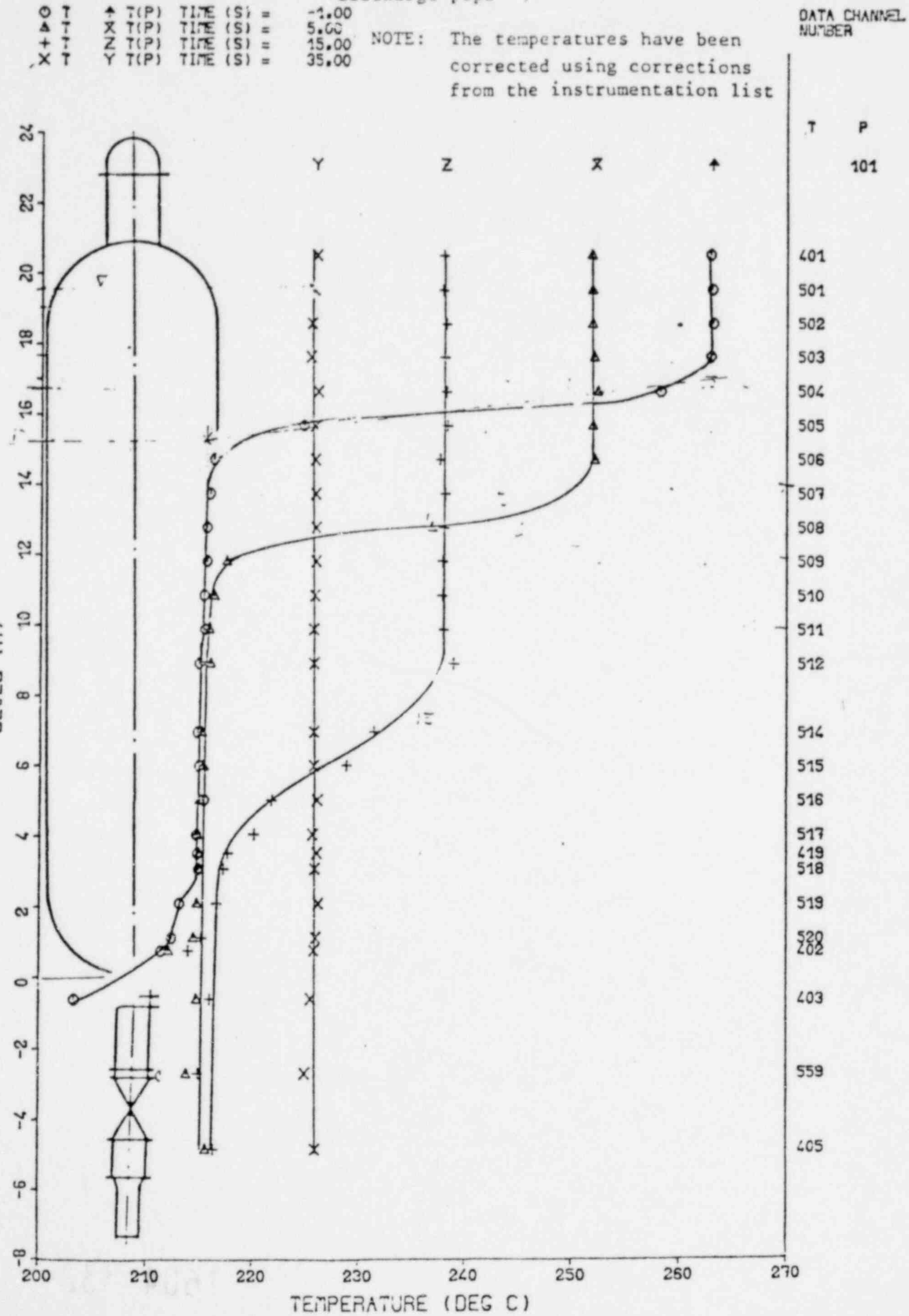
TEST 22 Fig 6:1 Temperature profiles in the vessel and the discharge pipe



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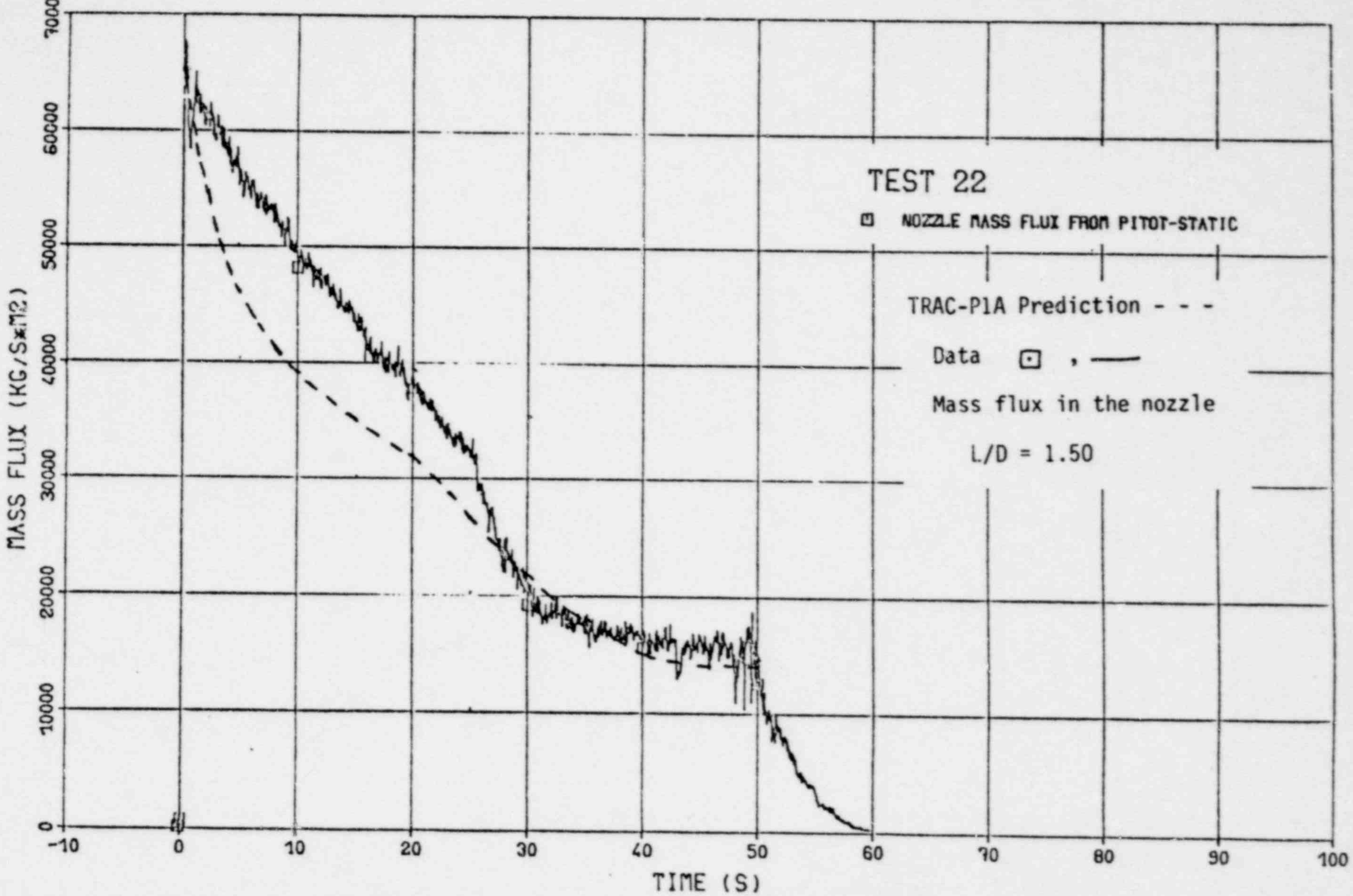
TEST 22
NOZZLE MASS FLUX FROM PITOT-STATIC
TRAC-P1A Prediction - - -
Data ⊡ , ——
Mass flux in the nozzle
L/D = 1.50
MASS FLUX (KG/S*M2)
TIME (S)
0
10000
20000
30000
40000
50000
60000
70000
-10
0
10
20
30
40
50
60
70
80
90
100

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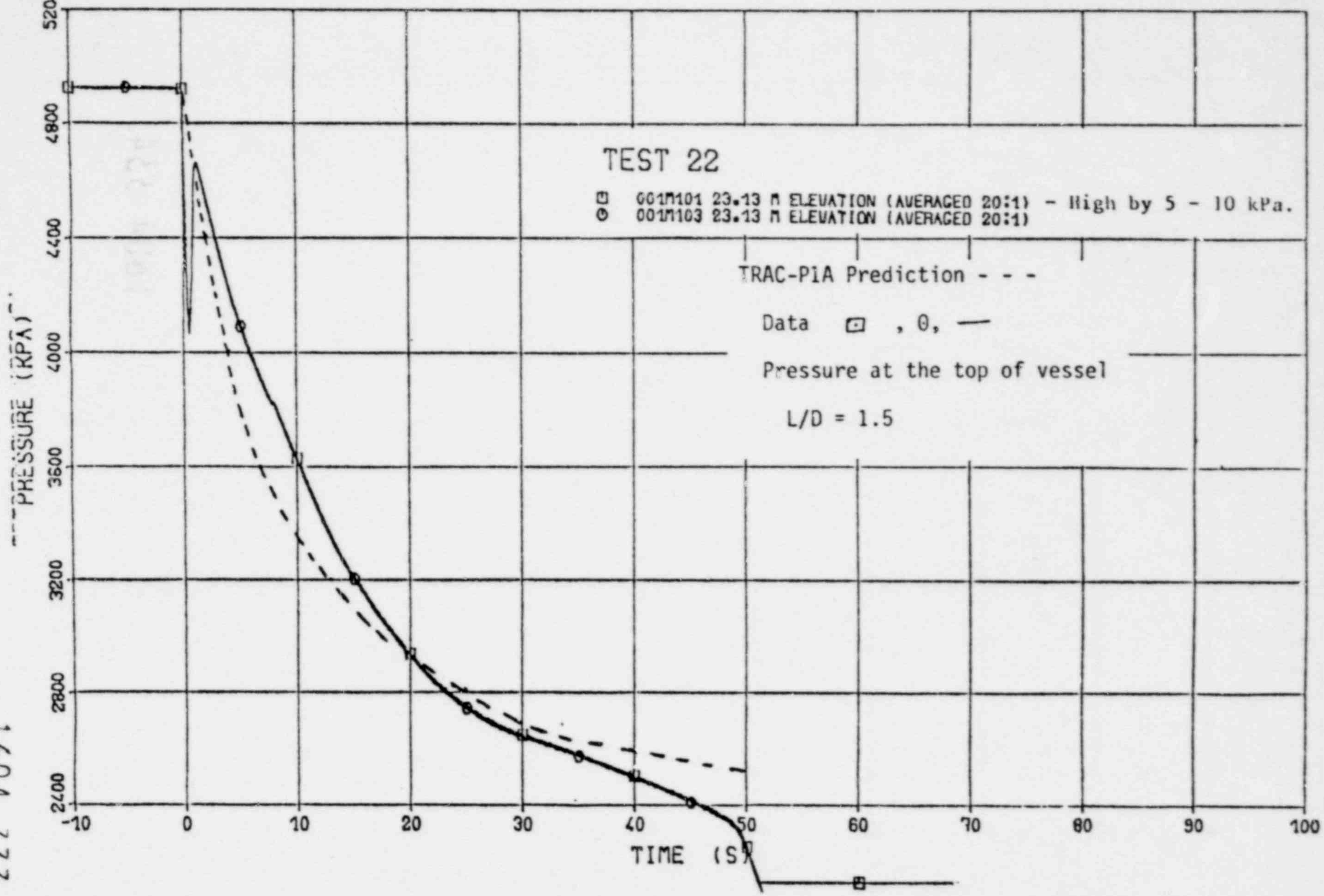

TEST 22
001M101 23.13 M ELEVATION (AVERAGED 20:1) - High by 5 - 10 kPa.
001M103 23.13 M ELEVATION (AVERAGED 20:1)
TRAC-P1A Prediction - - -
Data ⊡ , 0, —
Pressure at the top of vessel
L/D = 1.5
PRESSURE (KPA)
TIME (S)
5200
4800
4400
4000
3600
3200
2800
2400
-10
0
10
20
30
40
50
60
70
80
90
100

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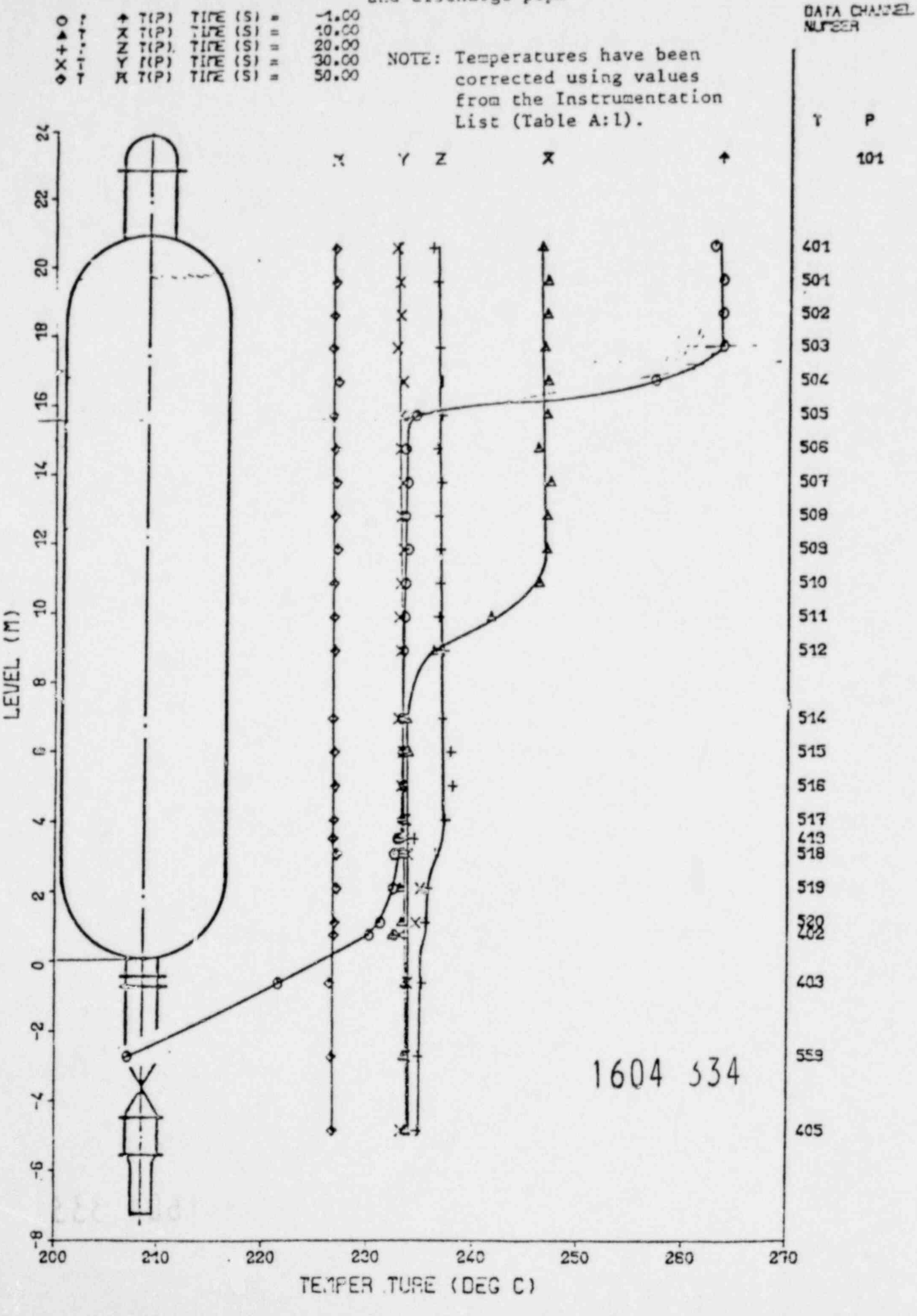
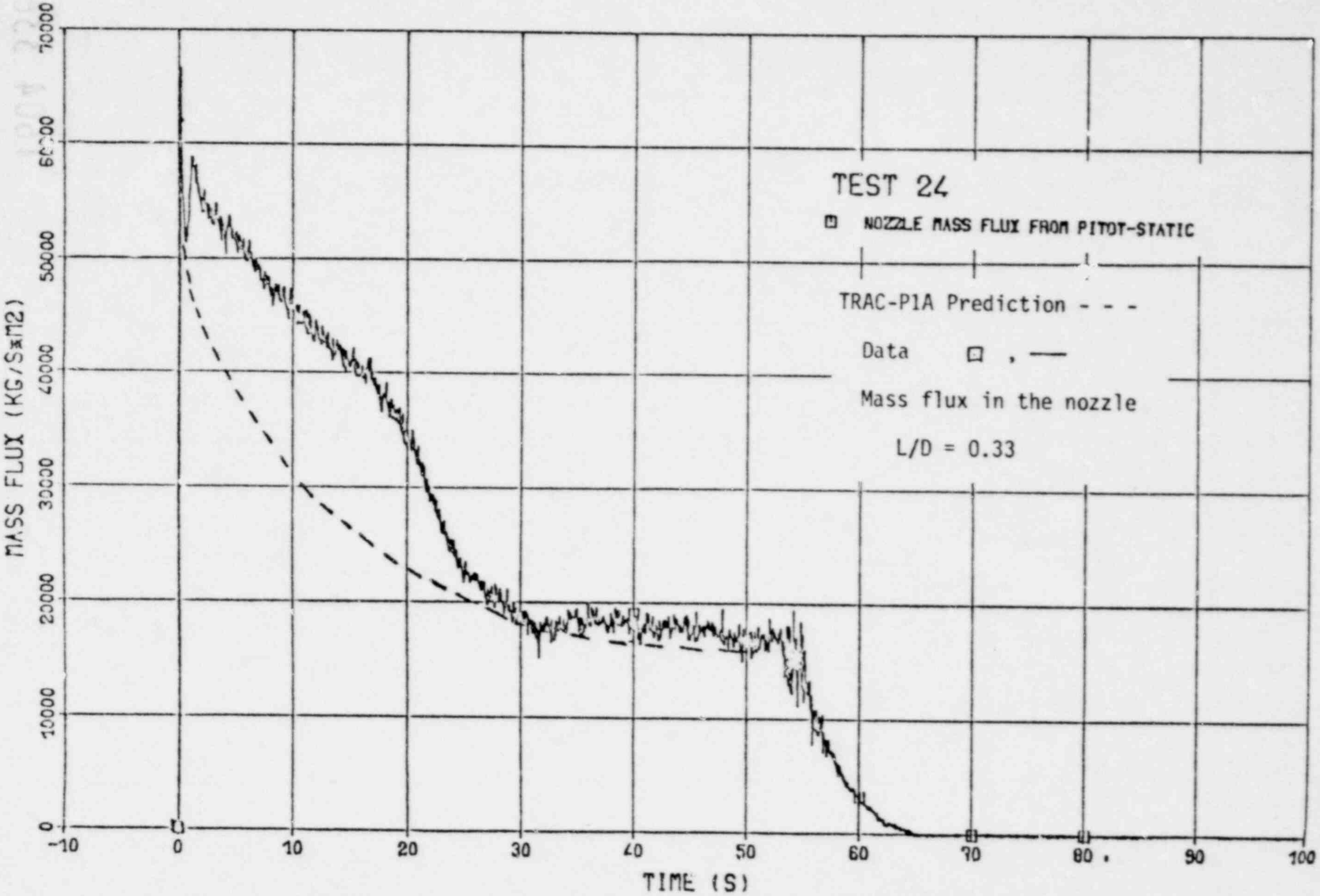
TEST 24 Fig 6:1 Temperature profiles in the vessel and discharge pipe




TEST 24
NOZZLE MASS FLUX FROM PITOT-STATIC
TRAC-P1A Prediction - - -
Data □ , ——
Mass flux in the nozzle
L/D = 0.33
MASS FLUX (KG/S*M2)
TIME (S)
0
10000
20000
30000
40000
50000
60000
70000
-10
0
10
20
30
40
50
60
70
80
90
100

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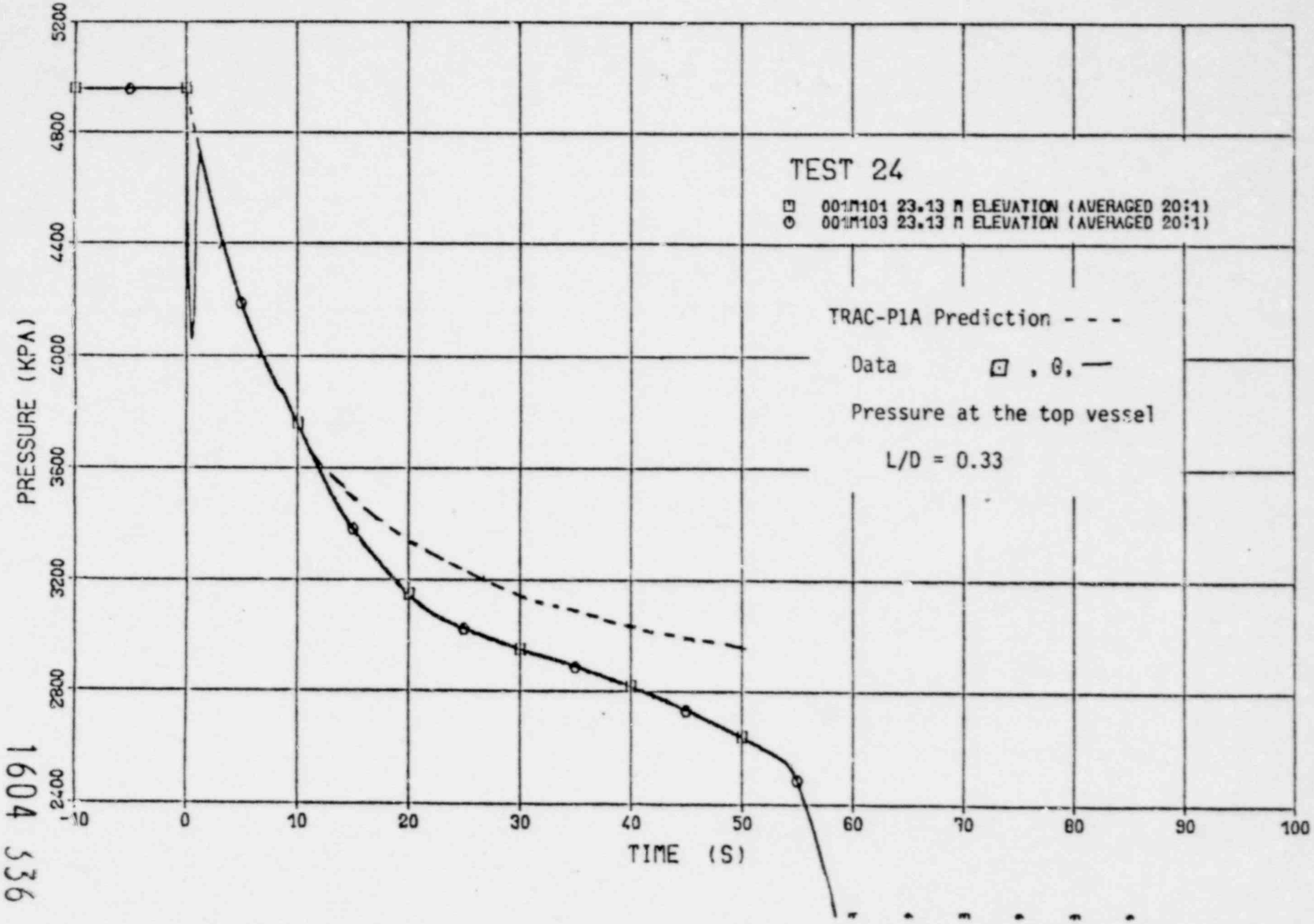

TEST 24
001M101 23.13 M ELEVATION (AVERAGED 20:1)
001M103 23.13 M ELEVATION (AVERAGED 20:1)
TRAC-P1A Prediction - - -
Data ⊡ , ʘ, —
Pressure at the top vessel
L/D = 0.33
PRESSURE (KPA)
TIME (S)

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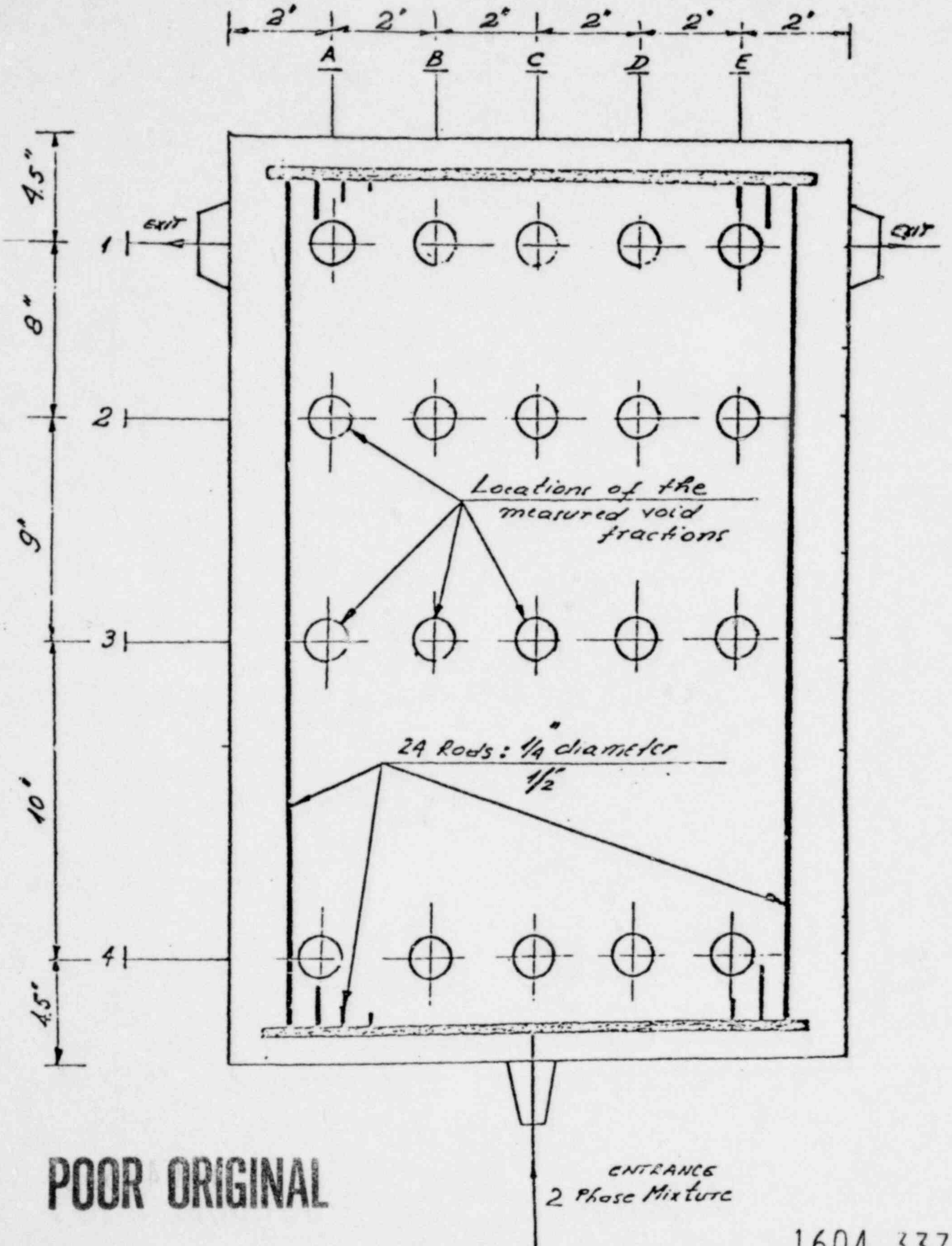
RPI Two-dimensional Test Section - Void Fraction Measurement-



POOR ORIGINAL

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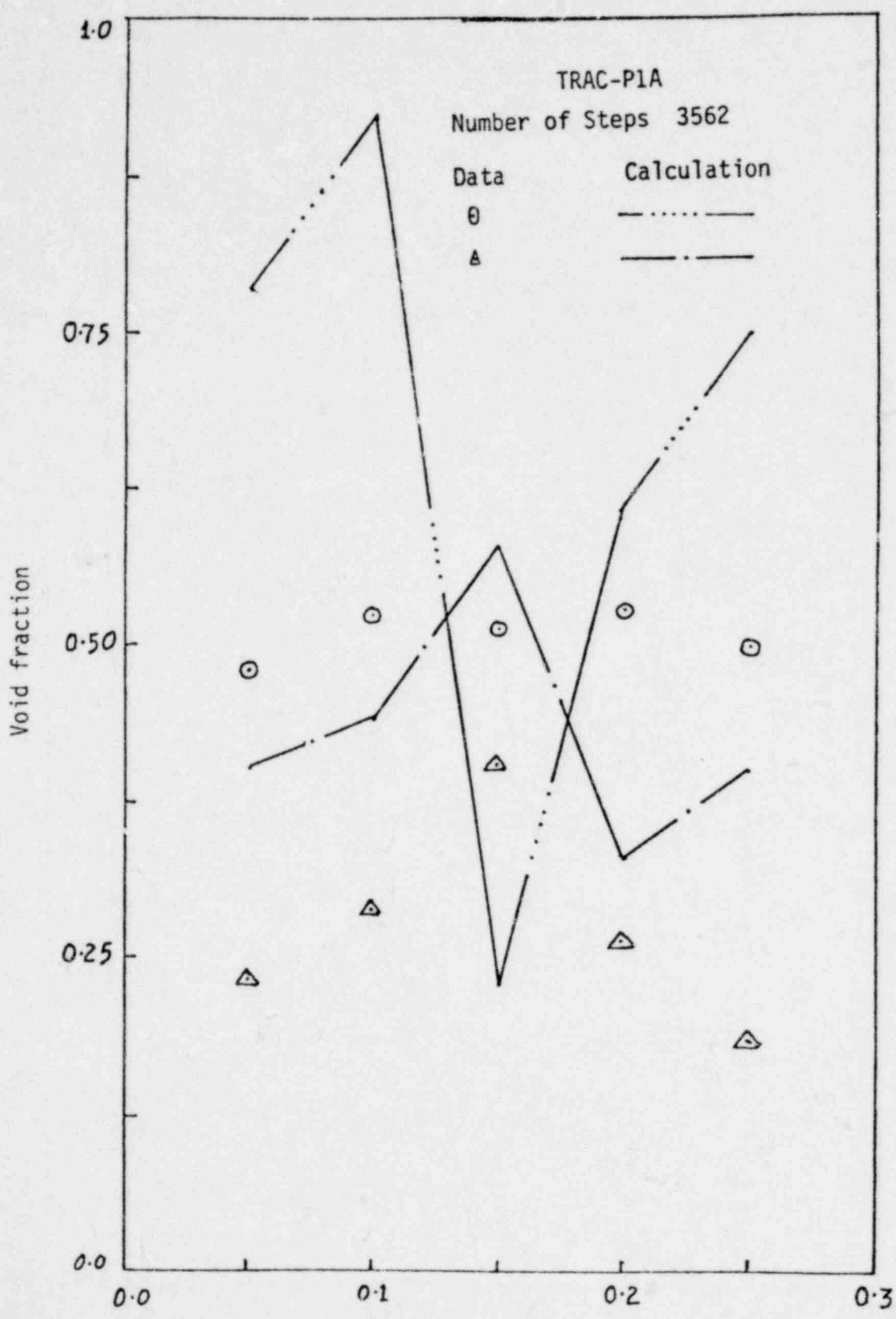
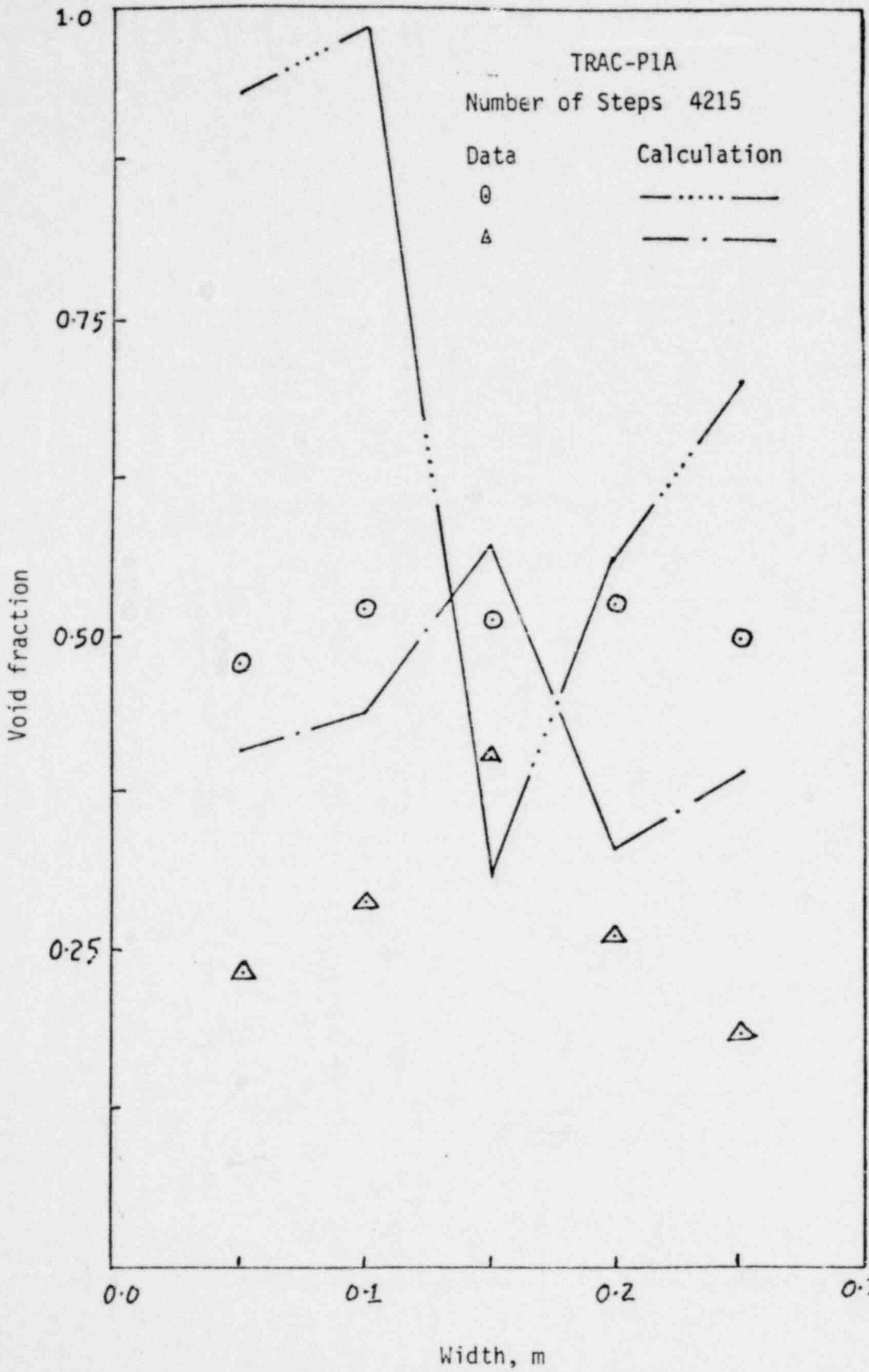

TRAC-P1A
Number of Steps 3562
Data
Calculation
1·0
0·75
0·50
0·25
0·0
0·0
0·1
0·2
0·3
Void fraction
Width, m



1.0
0.75
0.50
0.25
0.0
0.1
0.2
0.3
TRAC-P1A
Number of Steps 4215
Data
Calculation
Void fraction
Width, m

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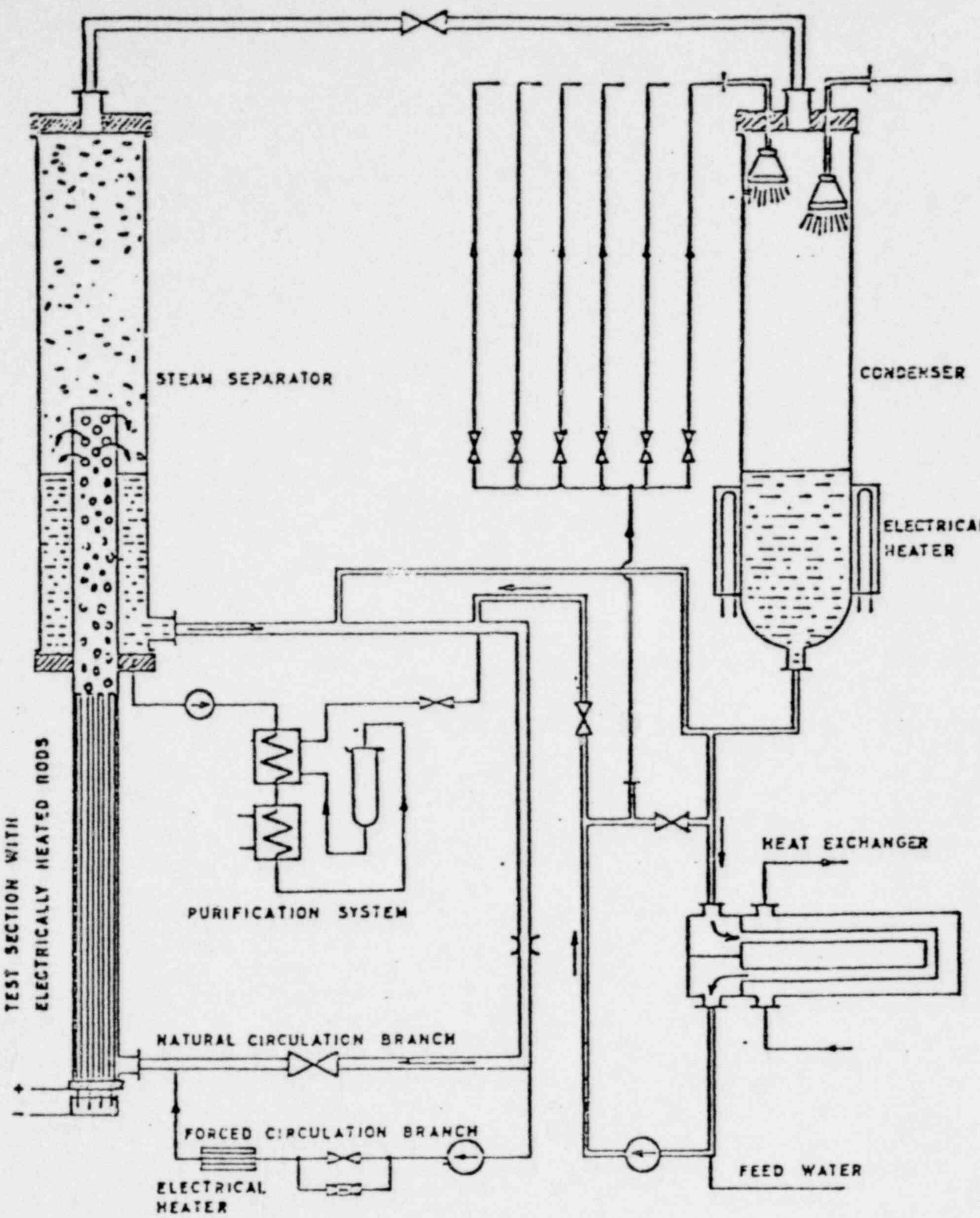

CONSTRUCTION MATERIAL : CARBON STEEL

COOLING CAPACITY : 8 MW

MAX. PRESSURE : 100 bars

SIMPLIFIED FLOW DIAGRAM FOR THE FRIGG LOOP.

POOR ORIGINAL

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SUMMARY AND CONCLUSIONS

- 1-D STEADY-STATE EXPERIMENTS
  - TRAC-P1A CAN CALCULATE CHOKED FLOW IN PIPES
  - THE CODE OVERPREDICTS THE MASS FLOW RATES FOR MOBY-DICK NITROGEN-WATER TESTS
  - HOWEVER, IT UNDERPREDICTS THE MASS FLOW RATES FOR BNL STEAM-WATER FLASHING FLOW TESTS. THIS IS PROBABLY DUE TO LACK OF NUCLEATION DELAY IN THE CODE.
  - IT PREDICTS THE KFK-IRE MASS FLOW RATE (FOR ONE TEST) WELL
  - SOMETIMES THE CODE DOES NOT CONVERGE TO A STEADY-STATE
  - FURTHER SENSITIVITY STUDY IS IN PROGRESS AT BNL

- 1-D TRANSIENT EXPERIMENTS

  - IN GENERAL, THE CODE DOES NOT HAVE ANY PARTICULAR DIFFICULTY IN FOLLOWING A TRANSIENT (AT LEAST, FOR THE CASES STUDIED AT BNL).

  - THE CODE DOES EXHIBIT SOME NUMERICAL DIFFUSION AS EXPECTED (SEE THE SHOCK-TUBE TESTS). ALSO, SOME NUMERICAL "NOISE" AT HIGHER PRESSURE RATIOS.

  - REASONABLE AGREEMENT WITH THE CANON EXPERIMENTS. (FURTHER COMPARISON IS IN PROGRESS).

  - CODE PREDICTIONS ARE NOT IN GOOD AGREEMENT WITH THE MARVIKEN TESTS 22 AND 24.

- MULTI-DIMENSIONAL EXPERIMENTS

  - THE CODE DID NOT PRODUCE A STEADY-STATE FOR RPI 2-D PHASE SEPARATION TESTS.

  - FOR THE FRIGG LOOP EXPERIMENTS, ONLY THE TEST SECTION IS BEING SIMULATED AT THIS TIME.