OCT 7 1982

Docket Nos: 50-327/328
50-369/370
and 50-315/316

APPLICANT: Tennessee Valley Authority
Duke Power Company
American Electric & Power (Indiana & Mich. Elec. Co.)

FACILITY: Sequoyah Nuclear Power Station
McGuire Nuclear Power Station
D. C. Cook

SUBJECT: SUMMARY OF MEETING HELD ON AUGUST 4-5, 1982

A meeting was held on August 4-5, 1982, at the NRC office in Bethesda, Maryland, to discuss the results of the research program on hydrogen combustion and control. This program is sponsored by TVA, AEP, and Duke Power in support of their overall efforts to demonstrate the adequacy of the hydrogen control systems installed in their nuclear plants that utilize the ice condenser containment concept. The list of attendees for the meeting is provided as enclosure 1. A copy of the slides that were used during the meeting are provided in enclosure 2.

The importance of the research effort by the utilities was emphasized by the Project Manager in that Sequoyah and McGuire stations have license conditions that require a determination (prior to startup after the first refueling) that the installed system will perform its intended function in a manner that provides adequate safety margins. It was further noted that this is a mandate from the Commissioners themselves and this matter must receive their approval prior to restart of Sequoyah Unit 1. Sequoyah 1 completed its first core burn cycle, and startup is expected on or before January 1, 1983. For this reason the staff will have to issue its Safety Evaluation Report in mid-November to be consistent with the Sequoyah 1 plant schedule.

Quarterly progress reports have been issued on the licensee's efforts and a number of topical reports will be issued in the near future. Also, each licensee has been requested to submit an Executive Summary Report whose purpose is to set forth their position and justification on the adequacy of their hydrogen control systems. The TVA Sequoyah report is expected in late September 1982.

The results of the laboratory tests on hydrogen control and combustion were discussed in considerable detail by each of the organizations that performed the tests for the utilities. This provided an opportunity for the staff and others to hear from the principal investigators the manner in which the experiments were carried out. The staff also solicited their opinions on whether or not the results of these experiments contributed to the resolution of the issues that are associated with their respective test program. The principal investigators appeared to be generally aware of the issues and need for the experiments to produce data that would contribute to the resolution of the issues. The discussions by the utility representatives and the investigators did not adequately cover, however, the staff's questions of how the experimental results supported the analysis on the hydrogen mitigation

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DATE ▶							

system. It is anticipated that each utility will provide this assessment in their respective Executive Summary Reports. During the presentations the staff noted in several instances that some of the data had not been previously presented in the quarterly reports. Also, TVA stated that the tests on their TAYCO ignitor were continuing. The results of such tests would be submitted at a later date. A few of the planned tests were not carried out as was anticipated in other documentation. One test of particular interest was a Whiteshell test that involved a 8.5% hydrogen/30% steam mixture with ignition taking place at the top of the test vessel. No explanation was provided, but the licensees were to investigate these deletions and report on this matter. Other comments on the adequacy of the experiments were provided by the staff during the meeting; however, the staff noted that it would respond, formally, to its adequacy after further analysis of the data. On September 17, 1982, a NRR letter was issued to each licensee requesting additional information which was based on the available data and discussions during the August 4-5, 1982, meeting.

With respect to safety related equipment surviving a successive number of deliberate ignition hydrogen burns in containment, the licensees reanalyzed the exposed equipment for a different flame speed and radiative heat. The results show that the temperatures were within the qualification temperatures. On this basis, the licensees stated that the designated safety related equipment will survive deliberate hydrogen burns. Staff comments on this matter have now been prepared and they were forwarded to the utilities for response.

No further work on local detonations was performed by the licensees, since they consider that all possible areas were discussed in previous correspondence and reports. Nevertheless, the staff has requested further information in this area in the letter of September 17, 1982.

Carl Stahle, Project Manager
Licensing Branch No. 4
Division of Licensing

Enclosures:
As stated

cc: See next page

OFFICE	DL:LB #4	DL:LB #4	ORB #1	LA:DL:LB #4	DL:LB #4		
SURNAME	CStahle/hmc	RBirkel	RCilimberg	MDuncan	EAdensam		
DATE	10/6/82	10/7/82	10/ /82	10/7/82	10/ /82		

Enclosure 1

List of Attendees

For H_2 Meeting
On August 4-5, 1982

NAME	ORGANIZATION
V. Srinivas	Westinghouse
K. J. Vehstedt	American Electric Power
D. A. Medek	American Electric Power
J. L. Milhoan	NRC - Office of Policy Evaluation
R. A. Strehlow	Univ. of Illinois at Urbana
C. G. Tinkler	NRC/CSB
R. L. Palla	NRC/CSB
Jerry S. Wills	TVA - SQN Licensing Engineer
R. C. Torok	Acurex Corp.
Bob Zalosh	Factory Mutual
A. L. Sudduth	Duke Power Company
A. J. Ignatonis	NRC/I&E, RII
Don L. Williams	TVA
Wang Lau	TVA
Bob Bryan	TVA
David Renfro	TVA
Gregory Hudson	Duke Power Company
Harold Polk	NRC/SEB
Morton Fleishman	NRC/RES/DRA
W. R. Butler	NRC/CSB
K. I. Parczewski	NRC/CMEB/DE
Heiki Tamm	AECL/WNRE
Gary Quittschreiber	NRC/HCRS
John Long	NRC/NRR/RSB
John T. Larkins	NRC/RES/SAAB
Matt. A. Lechowicz	Bechtel
Al Nofufrancesco	NRC/CSB
Clifford Anderson	NRC/DST/GIB
T. Su	NRC/GIB
D. Houston	NRC/DL/LB #2
K. Steyer	NRC/RES
Bal Raj Sehgal	EPRI
Pat Worthington	NRC/RES/CEB
John Hosler	EPRI
John Carey	EPRI
Tom Auble	EPRI
R. A. Birkel	NRC/NRR/DL/LB #4
G. A. Copp	Duke Power Company
Loren Thompson	EPRI
Lewis Muhlestein	Westinghouse Hanford/HEDL
Jerry Bloom	Westinghouse Hanford/HEDL
R. K. Mattu	NUS Corp.
G. M. Fuls	Westinghouse/OPS
Fred Peters	Westinghouse/ARD
C. Stahle	NRC/NRR/DL/LB #4
Ken Perry	Westinghouse/OPS
Bob Shepard	MP&L

Enclosure 2

Information Presented at

H_2 Meeting on August 4-5, 1982

OFFICE ▶							
SURNAME ▶							
DATE ▶							

MEETING SUMMARY DISTRIBUTION

Docket No(s): 50-327/328 50-369/370 50-315/316

OCT 7 1982

NRC/PDR
Local PDR
TIC/NSIC/TERA
LB #4 r/f
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Project Manager C. Stahle, R. Birkel & R. Cilimberg
Licensing Assistant M. Duncan

NRC Participants:

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C. G. Tinkler
R. L. Palla
A. J. Ignatonis
H. Polk
M. Fleishman
W. R. Butler
K. I. Parczewski
G. Quittschreiber
J. Long
J. T. Larkins
A. Notufrancesco
C. Anderson
T. Su
D. Houston
K. Steyer
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R. Birkel
C. Stahle

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Enclosure 1

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For H_2 Meeting
On August 4-5, 1982

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G. M. Fuls	Westinghouse/OPS
Fred Peters	Westinghouse/ARD
C. Stanle	NRC/NRR/DL/LB #4
Ken Perry	Westinghouse/OPS
Bob Shepard	MP&L

Enclosure 2

Information Presented at

H_2 Meeting on August 4-5, 1982

WATER FOG INERTING EXPERIMENTS

EPRI RP 1932-1 (Task 5)

Factory Mutual Research Corporation
Norwood, Massachusetts

OBJECTIVE: Determine Hydrogen Flammability Limit Variation With Applied Fog Density, Drop Size, and Temperature.

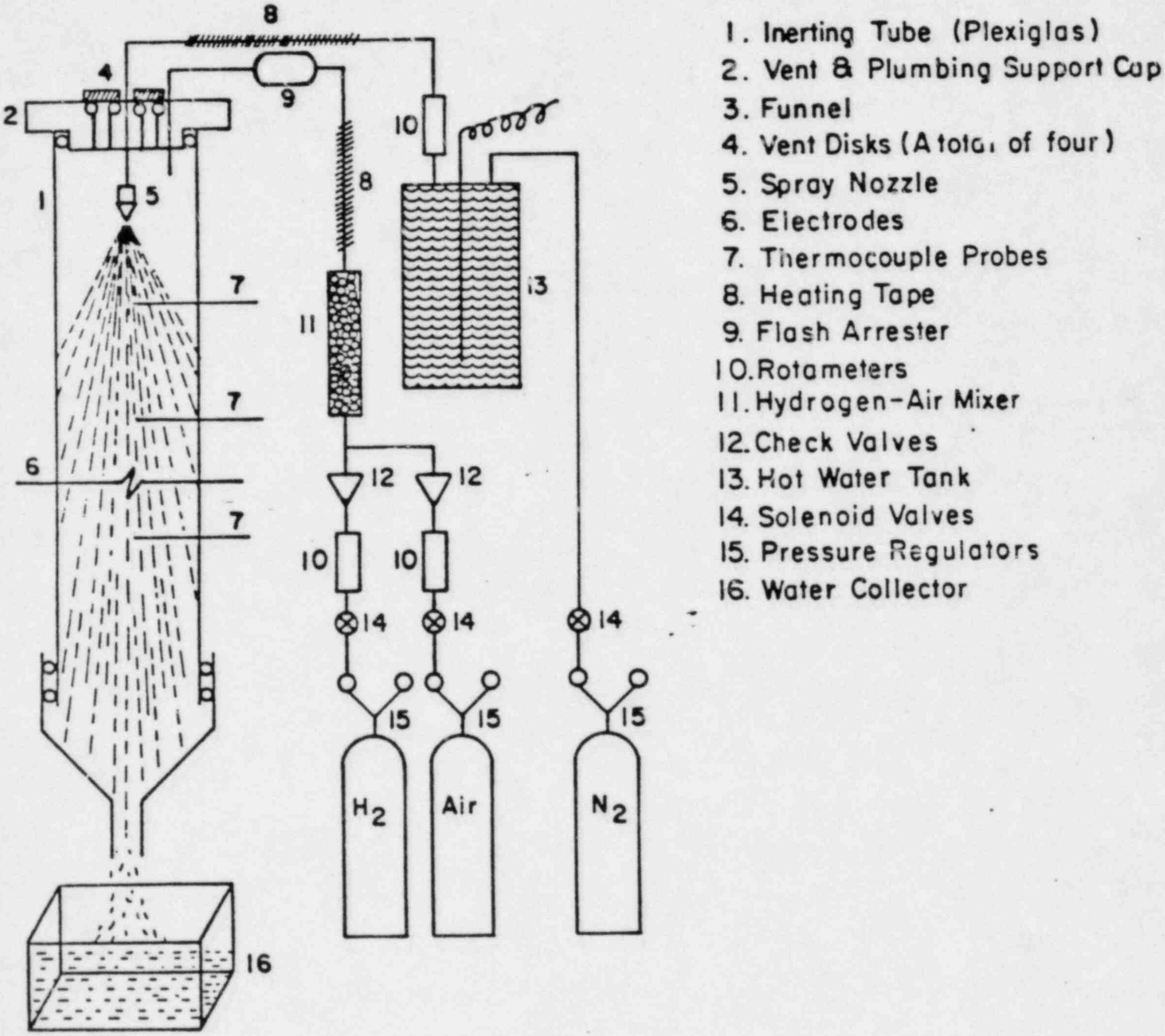


Figure 2-1. Hydrogen-Water Fog Inerting Experimental Setup

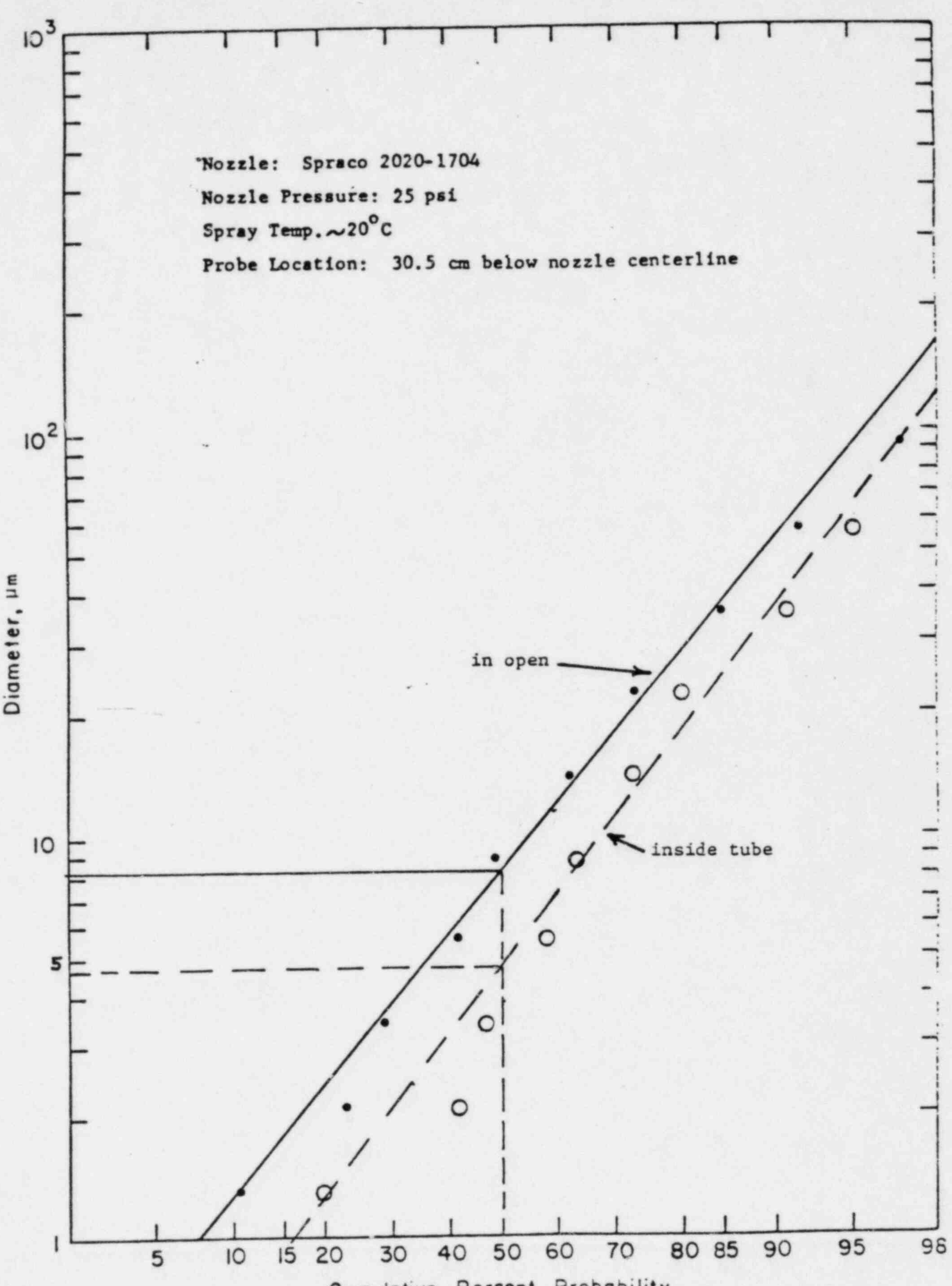
Nozzle	Vol Mean Drop Size (microns)	Flow Rate (cc/min)	Spray Angle
Sonicore 35H	22	170	
Spraco 2163	35	470	65°
Spraco 1806	43	60	40°
Spraco 2020	50	460	61°
Spraco 1405	92	550	20°

DROP SIZE AND CONCENTRATION MEASUREMENTS

INSTRUMENT: HOT WIRE ANEMOMETER
(KLD ASSOCIATES MODEL DC-2)
COUNTS AND SIZES DROPS BASED
ON DROP COOLING

ADVANTAGE: CONVENIENT FOR DROP SIZE
DISTRIBUTIONS IN TUBE AND
IN OPEN AREA

LIMITATION: CONCENTRATION CALCULATION
REQUIRES DROP VELOCITIES



Nozzle: Spraco 2020-1704
Nozzle Pressure: 25 psi
Spray Temp. ~20°C
Probe Location: 30.5 cm below nozzle centerline
in open
inside tube
Diameter, μm
10³
10²
10
5
1
5
10
15
20
30
40
50
60
70
80
85
90
95
98
Cumulative Percent Probability

FOG INERTING DATA

FOR H_2 - AIR - H_2O MIXTURES

TEMP	HYDROGEN LFL (DRY VOL %)	
(OC)	NO FOG DRY-SAT	DENSE FOG*
20	4.0-4.1	4.6-7.2**
50	4.0-4.7	5.4-7.9**
70	4 -7.7	5.4-8.5

* FOG DENSITY - 10^{-4} - 10^{-2} GM/CC

**HIGHEST VALUE IS FOR SONICORE NOZZLE

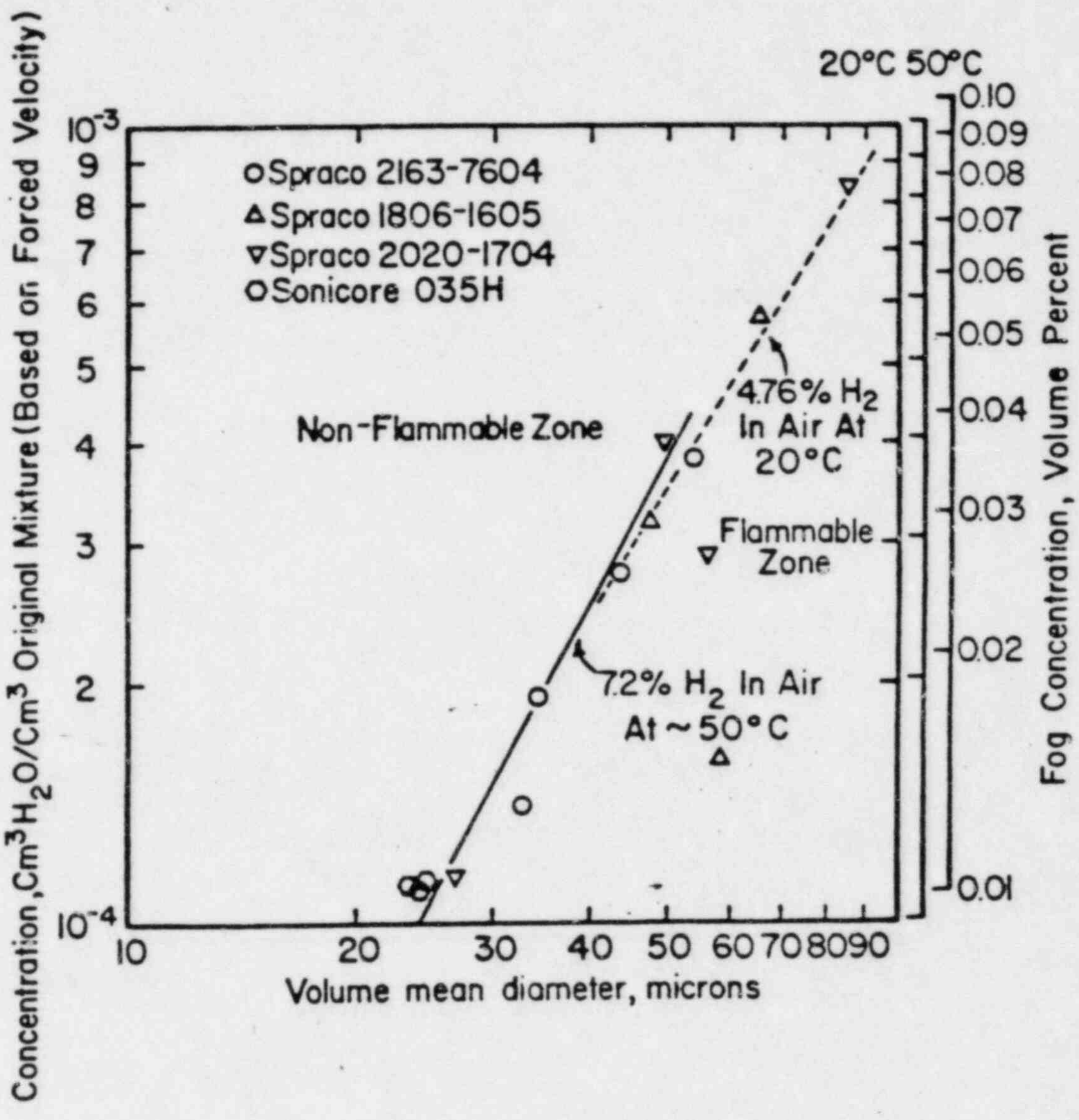


Figure 4-3. Fog Concentration as a Function of Drop Size to Achieve indicated Inerting Levels

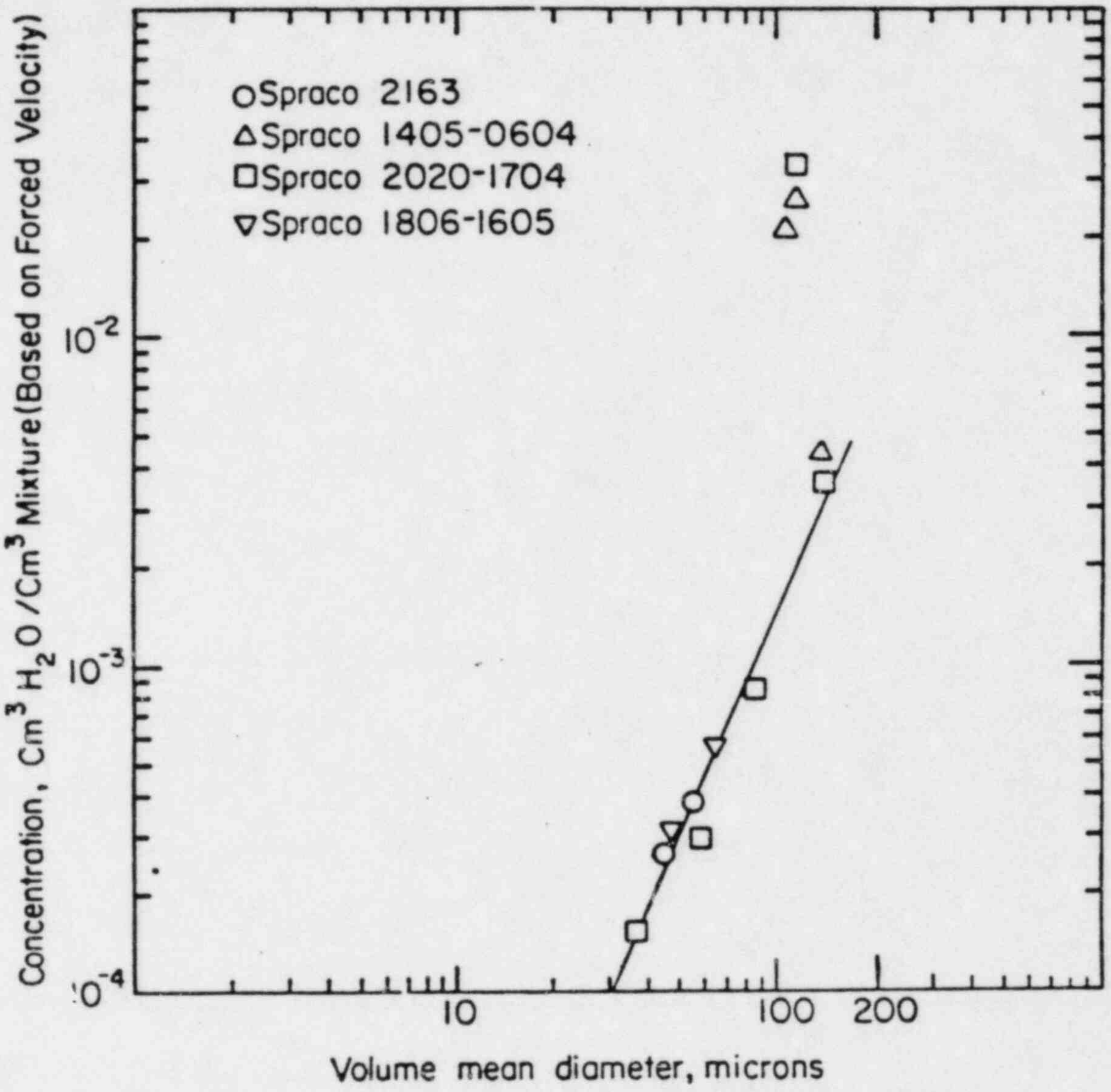


Figure 4-4. Fog Concentration versus Drop Size Requirements for Inerting to 4.76 Hydrogen at 20°C

CONCLUSIONS

1. DENSE WATER FOGS CAUSE ONLY A SLIGHT INCREASE IN HYDROGEN LFL (FROM 4.0 TO 4.6- 7.2%) AT ROOM TEMPERATURE.

2. FOG INERTING EFFECT IS MORE PRONOUNCED AT HIGHER TEMPERATURES (5.4-7.9% LFL AT 50^{o}C).

3. FOG DENSITIES REQUIRED TO ACHIEVE A GIVEN LFL INCREASE APPROXIMATELY AS SECOND POWER OF CHARACTERISTIC FOG DROP SIZE. PREDICTABLE FROM QUENCHING THEORY AND DROPLET HEAT TRANSFER EQUATIONS.

FACTORY MUTUAL MICRO-FOG

PROJECT OBJECTIVE

Select nominal micro-fog conditions for hydrogen combustion pressure suppression tests in the Acurex test vessel.

FACTORY MUTUAL MICRO-FOG

PROJECT METHODOLOGY

Conduct hydrogen flammability tests with micro-fogs of varying densities, droplet sizes, and temperatures.

FACTORY MUTUAL MICRO-FOG

PROJECT TEST PARAMETERS

Droplet size:

2-15 microns (number mean diameter)

Concentration:

2E-5 - 3E-2 cm^3 H_2O/cm^3 Mixture

Temperature:

20-70 °C

FACTORY MUTUAL MICRO-FOG
PROJECT CONCLUSION

- Dense micro-fogs cause only a marginal increase in the hydrogen lower flammability limit (LFL) at room temperature.

- Increasing the micro-fog temperature results in large increases in the hydrogen LFL.

- Micro-fog densities required to achieve hydrogen inerting are strongly dependent on the micro-fog characteristic drop size.

ACUREX MICRO-FOG PROJECT OBJECTIVE

Investigate the hydrogen combustion pressure suppression characteristics of a water micro-fog.

ACUREX MICRO-FOG PROJECT

QUIESCENT TEST MATRIX

HYDROGEN CONCENTRATION V/O	FOG NOZZLE PRESSURE (psi)	
	20	30
5.0	—	—
7.5	—	—
10.7	—	—
10.7	—	X
10.7	X	—
7.5	—	X
7.5	X	—

ACUREX MICRO-FOG PROJECT

TRANSIENT TEST MATRIX

HYDROGEN FLOW (lb/min)		STEAM FLOW (lb/min)	FOG NOZZLE PRESSURE (psi)	
0.035	0.105	2.1	20	30
X	—	—	X	—
X	—	X	X	—
X*	—	—	—	X
—	X	—	—	X
X	—	—	—	X
X	—	X	—	X

*vessel mixing fan on

ACUREX MICRO-FOG

PROJECT CONCLUSIONS

- Fogs apparently generated sufficient turbulence in the quiescent tests for hydrogen deflagrations to behave more adiabatically then in tests without fog.

- Fogs apparently generated sufficient turbulence in the transient tests that the increased mixing allowed ignition to occur earlier, resulting in lower pressure rises.

ACUREX IGNITOR LOCATION

PROJECT OBJECTIVE

Investigate the effect of ignitor location on hydrogen combustion during transient conditions.

ACUREX IGNITOR LOCATION

PROJECT METHODOLOGY

Conduct transient hydrogen combustion tests with the ignition source at three different locations. Conduct tests with and without steam and water spray.

ACUREX IGNITOR LOCATION PROJECT TEST MATRIX

IGNITOR LOCATION	HYDROGEN FLOW (lb/min)		STEAM FLOW (gpm)	SPRAY FLOW (lb/min)
	0.035	0.105	2.1	15
TOP	X	–	X	–
TOP	X	–	–	–
BOTTOM	X	–	X	X
BOTTOM	X	–	X	–
BOTTOM	X	–	–	–
BOTTOM	–	X	X	–
BOTTOM	–	X	–	–
CENTER	X	–	X	X
CENTER	X	–	X	–
CENTER	X	–	–	–

ACUREX IGNITOR LOCATION

PROJECT CONCLUSIONS

- Ignitor location does affect combustion characteristics in a transient environment.

- For this test configuration, lowering the ignitor location generally produced a milder pressure rise.

NRC / UTILITY

REVIEW OF
EPRI HYDROGEN RESEARCH PROGRAM

AUGUST 4, 1982

HYDROGEN MIXING AND DISTRIBUTION

IN

CONTAINMENT ATMOSPHERES

G.R. BLOOM

L.D. MUHLESTEIN

A.K. POSTMA

HANFORD ENGINEERING DEVELOPMENT LABORATORY

WESTINGHOUSE HANFORD COMPANY

RICHLAND, WASHINGTON 99352

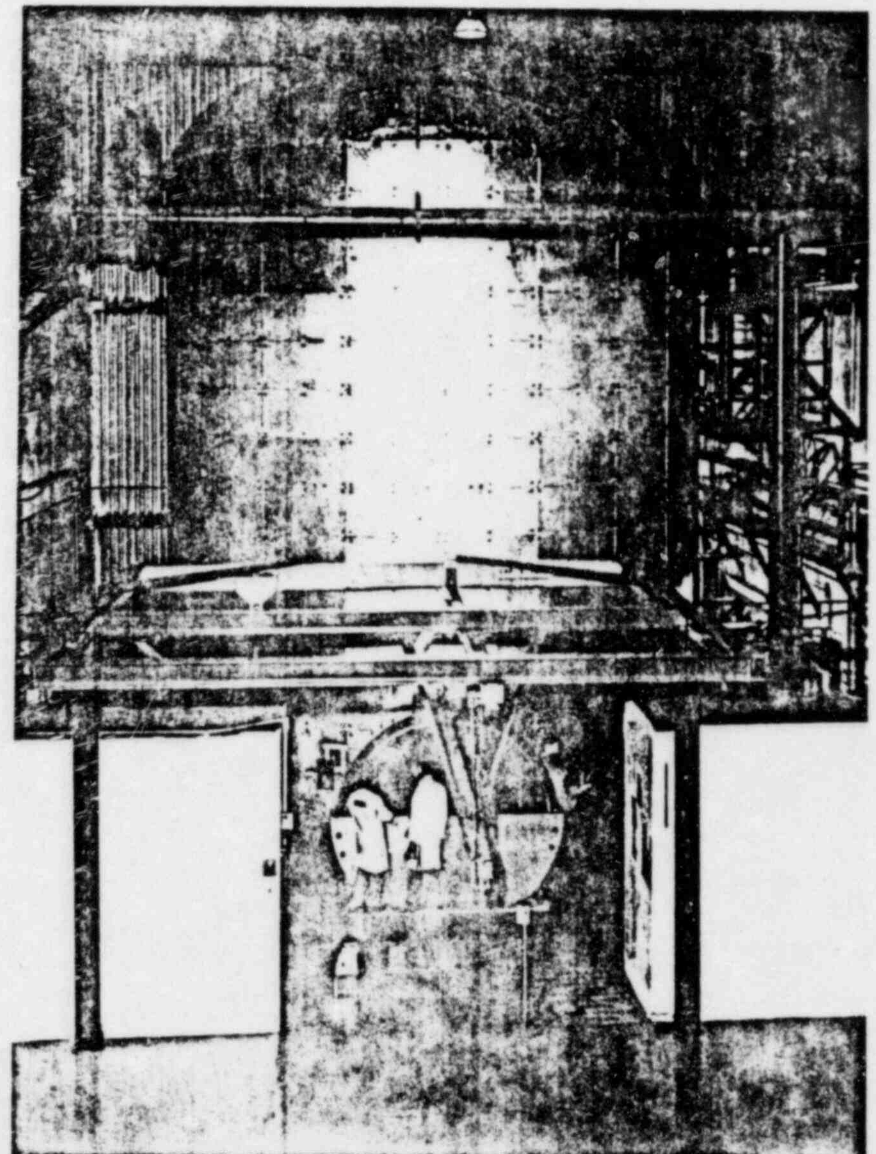
HYDROGEN MIXING IN CONTAINMENT ATMOSPHERES

OBJECTIVE:

- MEASURE HYDROGEN MIXING AND DISTRIBUTION IN SIMULATED LWR ACCIDENT ENVIRONMENT
- PROVIDE EXPERIMENTAL BASIS FOR EVALUATION OF ANALYSIS METHODS.

PROGRAM:

- SCALED COMPARTMENT FABRICATED IN 30,000 ft^3 CSTF VESSEL
- HYDROGEN DISTRIBUTION AND MIXING DETERMINED FOR CONDITIONS SIMULATING LOSS OF COOLANT ACCIDENT



HEDL 8100-221.1

CONTENTS

PROGRAM EMPHASIS

DETERMINE HYDROGEN MIXING AND DISTRIBUTION IN LOWER COMPARTMENT AREA OF LWR ICE CONDENSER PLANT AFTER TWO POSTULATED HYDROGEN RELEASE SCENARIOS.

HYDROGEN RELEASE SCENARIOS

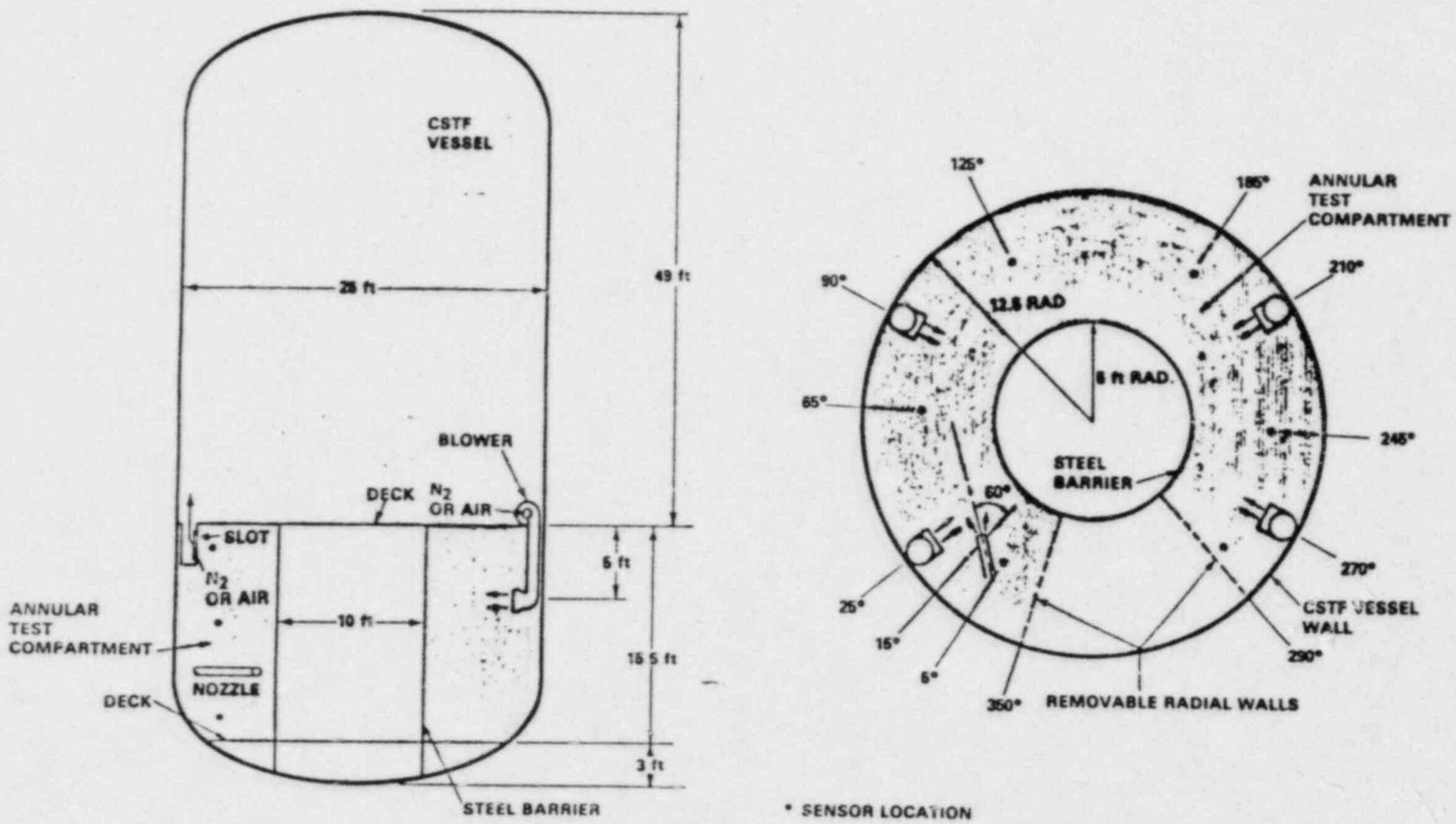
1. POSTULATED PIPE BREAK

   * 2-INCH PIPE
   * SONIC VELOCITY JET (2080 FT / SEC)
   * CHOKED FLOW CONDITIONS
   * HOT HYDROGEN / STEAM (600 DEG F - 1220 LBS / MIN)
   * HORIZONTAL RELEASE CONFIGURATION

2. POSTULATED RELEASE FROM PRESSURIZER RELIEF TANK

   * 10-INCH RUPTURE DISK
   * HIGH VELOCITY VERTICAL JET (1200 FT / SEC)
   * HOT HYDROGEN / STEAM (600 DEG F - 1220 LBS / MIN)
   * VERTICAL RELEASE CONFIGURATION

TEST COMPARTMENT SCHEMATIC



• SENSOR LOCATION

SIMILARITY MODELING

SIMILARITY THEORY

SCALE MODEL TEST RESULTS CAN BE APPLIED TO FULL-SCALE SYSTEMS PROVIDED ALL RELEVANT SIMILARITY PARAMETERS (DIMENSIONLESS GROUPS) FOR MODEL AND SYSTEM HAVE SAME NUMERICAL VALUE.

NON-IDEAL MODELING

* DOMINANT SIMILIARITY PARAMETERS IDENTIFIED
* TEST CONDITIONS SELECTED TO YIELD SIMILARITY FOR ESSENTIAL DIMENSIONLESS GROUPS
* NON-ESSENTIAL PARAMETERS DISTORTED

GEOMETRICAL SIMILARITY

* ALL IMPORTANT LENGTH RATIOS TO BE THE SAME FOR MODEL AND PROTOTYPE
* VESSEL SIZE LED TO A 0.3 LINEAR SCALE FACTOR

DOMINANT MIXING PROCESSES

* HIGH SPEED JET MIXING
  - DOMINATED IN NEAR AND FAR FIELD BY MOMENTUM FORCES.
  - BOUYANCY FORCES CONTRIBUTE IN FAR FIELD

* FAN-INDUCED RECIRCULATING AIR FLOW
  - INITIAL MOMENTUM EFFECTS FOLLOWED BY EFFECTS OF BOUYANT FORCES

* NATURAL CONVECTION FLOWS
  - MOMENTUM FORCES GENERATED BY BOUYANT FORCES

MODELING CRITERIA

SUMMARY

- PRESERVE GEOMETRIC SIMILARITY
- PRESERVE DENSIMETRIC FROUDE NUMBER
- PRESERVE SCALED RELATIVE TIMES
  (REQUIRED BECAUSE OF COMPETING MIXING PROCESSES)
- PRESERVE DENSITY RATIOS OF JET TO
  AMBIENT ATMOSPHERE

DENSIMETRIC FROUDE NUMBER:

RATIO OF MOMENTUM TO BUOYANCE FORCES

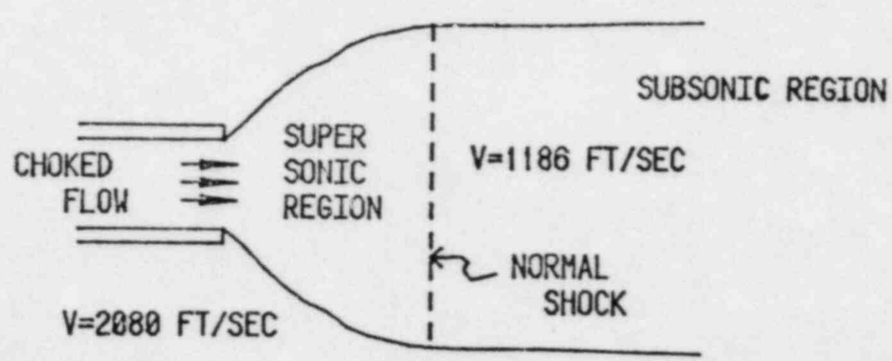
$$\overline{F_R} = \frac{U}{\left(gL\frac{\Delta\rho}{\rho_j}\right)^{1/2}}$$

SAMPLE MODELING CALCULATIONS

PLANT CONDITIONS FOR 2-INCH PIPE BREAK

PARAMETER		VALUE
STEAM FLOW RATE	GIVEN	1200 LB/MIN
HYDROGEN FLOW RATE	GIVEN	20 LB/MIN
GAS TEMPERATURE	GIVEN	600 °F
MASS FLUX		870 LB/SEC FT^2
SONIC VELOCITY		2080 FT/SEC
DENSITY OF GAS EXITING PIPE		0.42 LB/FT^3
GAS PRESSURE		300 PSIA
VELOCITY OF EXPANDED JET		1186 FT/SEC
DENSITY OF EXPANDED JET		0.030 LB/FT^3

CONCEPT



SAMPLE MODELING CALCULATIONS

PARAMETER	VALUE	
PLANT		
GAS VELOCITY	1186 FT/SEC	
GAS TEMPERATURE	600 °F	
GAS DENSITY	0.030 LB/FT^3	
AIR DENSITY	0.068 LB/FT^3	
DENSITY RATIO	0.44	MODELING CRITERIA
$\bar{F}_R$	201.6	MODELING CRITERIA
VOLUME TURNOVER TIME	1.9 MIN	
TEST		
GAS TEMPERATURE	300 °F	
GAS DENSITY	0.028 LB/FT^3	
AIR DENSITY	0.063 LB/FT^3	
DENSITY RATIO	0.45	
GAS VELOCITY	640 FT/SEC	
MASS FLOW RATE	55.7 LB/MIN (STEAM 54 LB/MIN; HYDROGEN 1.8 LB/MIN)	
RECIRCULATION FLOW RATE	3733 FT^3/MIN	
VOLUME TURNOVER TIME	1.1 MIN	

PRELIMINARY TESTS, (HM-P1 THROUGH HM-P4)

DETERMINE SEPARATE AND COMBINED EFFECTS
ON GAS DISTRIBUTION FROM
NATURAL AND FORCED AIR RECIRCULATION.

TEST NUMBER	RECIRCULATION FLOW (CFM)	INITIAL LOWER CONTAINMENT GAS TEMP (F)	
HM-P1	0	85	- NATURAL CONVECTION, AMBIENT GAS TEMPERATURE
HM-P2	3700	85	- FORCED CONVECTION, AMBIENT GAS TEMPERATURE
HM-P3	0	150	- NATURAL CONVECTION, ELEVATED GAS TEMPERATURE
HM-P4	3700	150	- FORCED CONVECTION, ELEVATED GAS TEMPERATURE

HIGH VELOCITY MIXING TESTS, (HM-1 THROUGH HM-5)

DETERMINE SEPARATE AND COMBINED EFFECTS ON GAS DISTRIBUTION FROM FORCED AIR RECIRCULATION AND MOMENTUM OF HIGH VELOCITY JET

TEST NUMBER	RECIRCULATION FLOW (CFM)	SOURCE	He / H_2 FLOW RATE (LB/MIN)	STEAM FLOW RATE (LB/MIN)	
HM-1	0	He-STEAM	0.9	27	NATURAL CONVECTION HIGH/LOW JET FLOW
HM-2	0	He-STEAM	1.8	54	
HM-3	3700	He-STEAM	0.9	27	FORCED CONVECTION HIGH/LOW JET FLOW
HM-4	3700	He-STEAM	1.8	54	
HM-5	3700	H_2-STEAM	0.9	54	CONFIRMATORY TEST

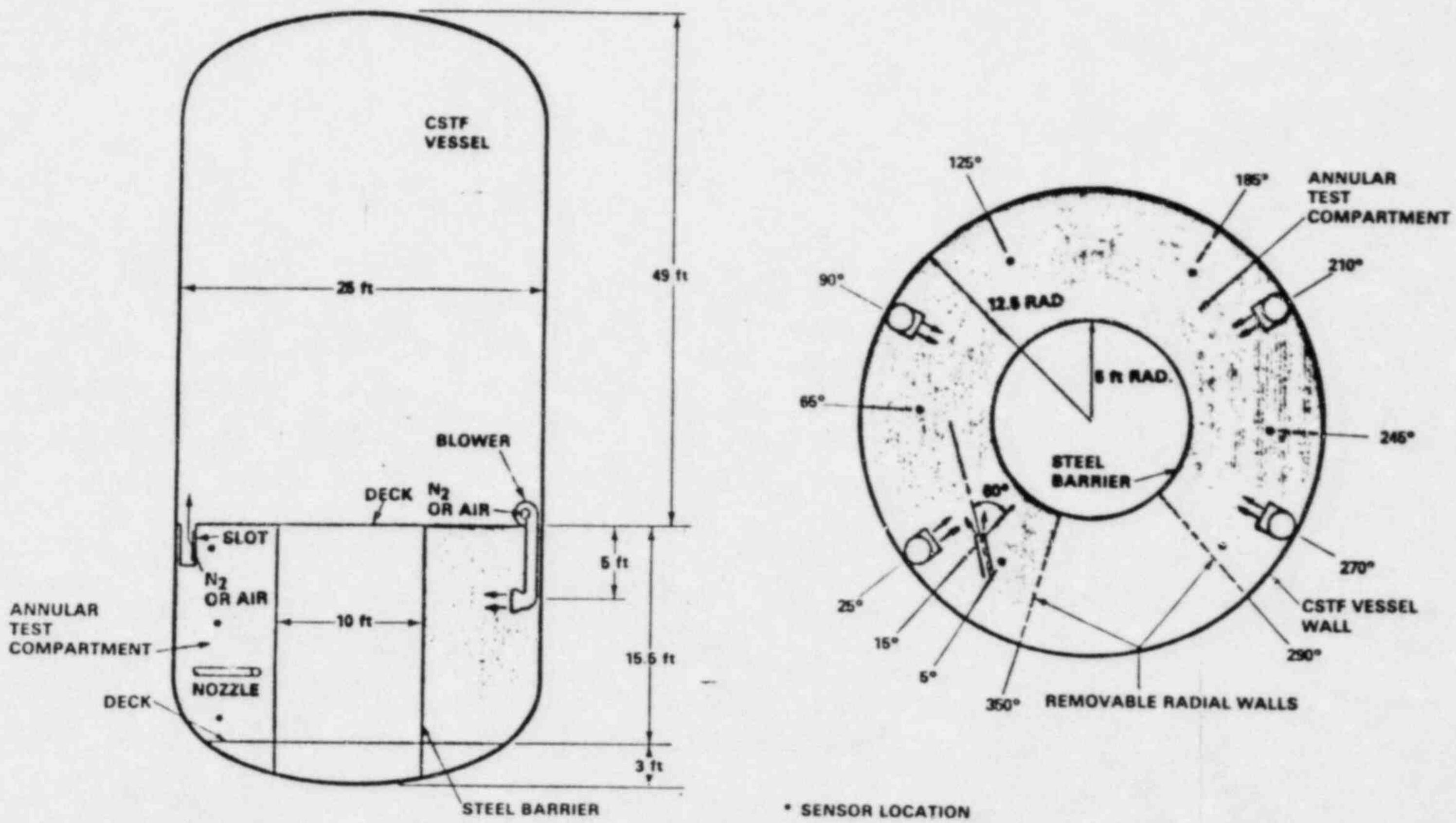
HIGH VELOCITY VERTICAL MIXING TESTS (HM-6, HM-7)

DETERMINE GAS DISTRIBUTION RESULTING FROM HYDROGEN/STEAM RELEASE FROM PRESSURE R[illegible]F TANK OR VERTICAL ORIENTED HIGH VELOCITY JET

TEST NUMBER	RECIRCULATION FLOW (CFM)	SOURCE	He FLOW RATE (LB/MIN)	STEAM FLOW RATE (LB/MIN)
HM-6	3700	He-STEAM	0.9	27
HM-7	3700	He-STEAM	1.8	54

} FORCED CONVECTION HIGH/LOW JET FLOW

TEST COMPARTMENT SCHEMATIC



INSTRUMENTATION

* HYDROGEN / HELIUM CONCENTRATION	- TWELVE THERMAL CONDUCTIVITY AND TWO COMBUSTIBLE TYPE ANALYZERS
* OXYGEN CONCENTRATION	- FIVE MONITORS
* GAS TEMPERATURES	- OVER 25 TYPE K THERMOCOUPLES
* COMPARTMENT GAS VELOCITIES	- TEN HOT FILM ANEMOMETERS
* RECIRCULATION AIR FLOW	- TWO HOT FILM ANEMOMETERS

ALL DATA COLLECTED BY DATA ACQUISITION SYSTEM
AND DISPLAYED ON STRIP CHART RECORDERS

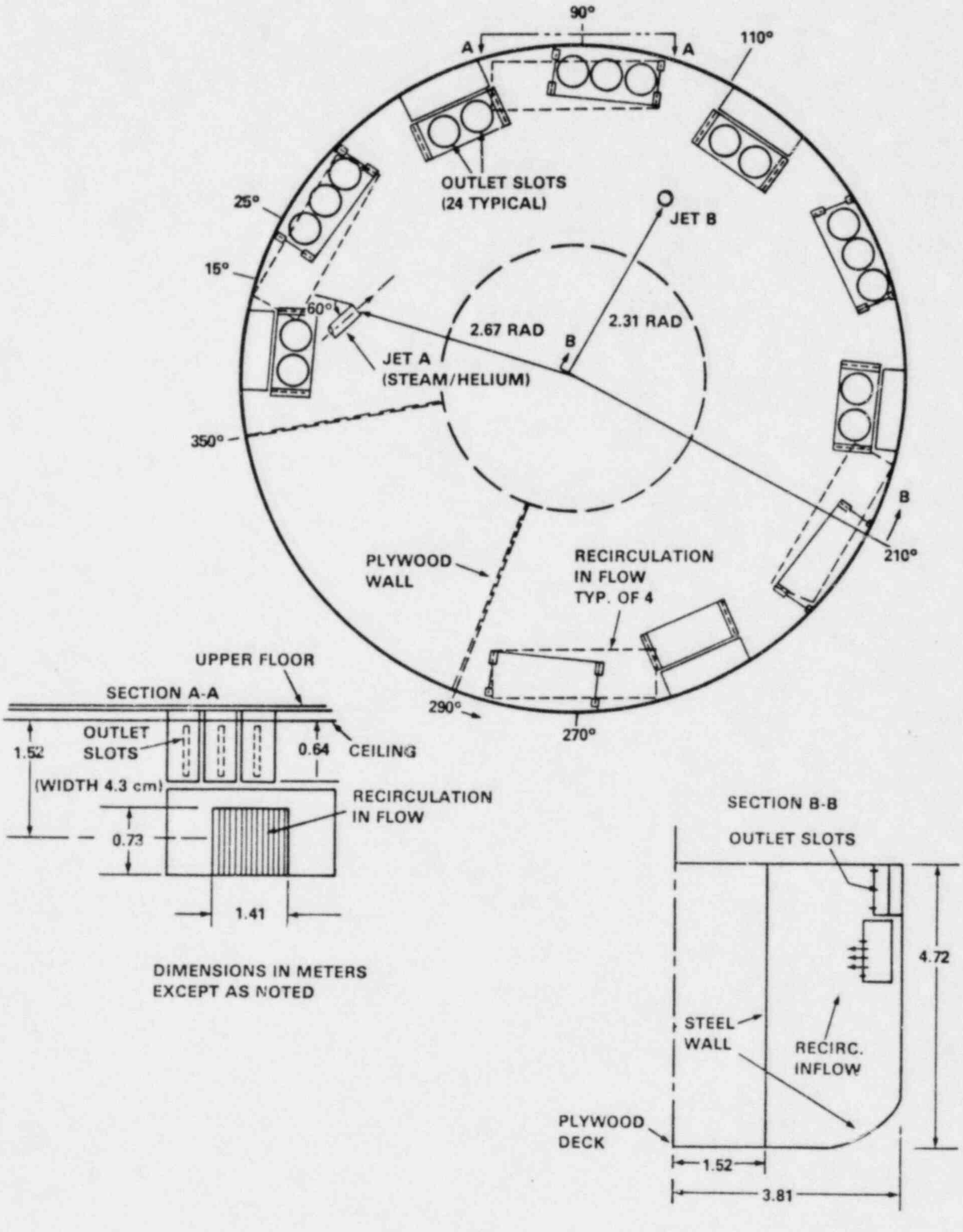
INSTRUMENTATION LOCATION

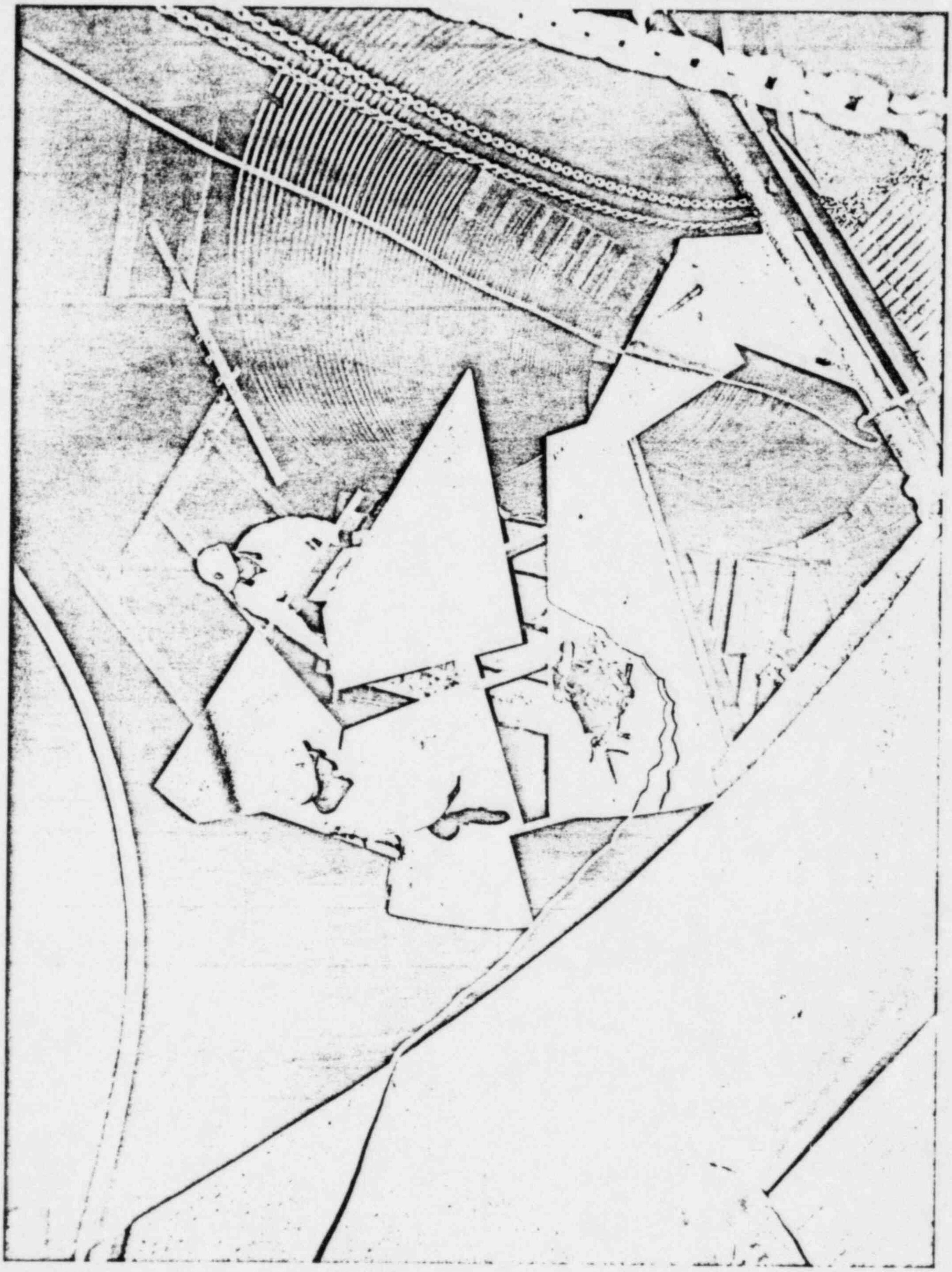
DESIGNATION	LOCATION
TOP	9 INCHES BELOW UPPER DECK
MIDPLANE	7.75 FT UP FROM LOWER DECK
BOTTOM	1.0 FT UP FROM LOWER DECK

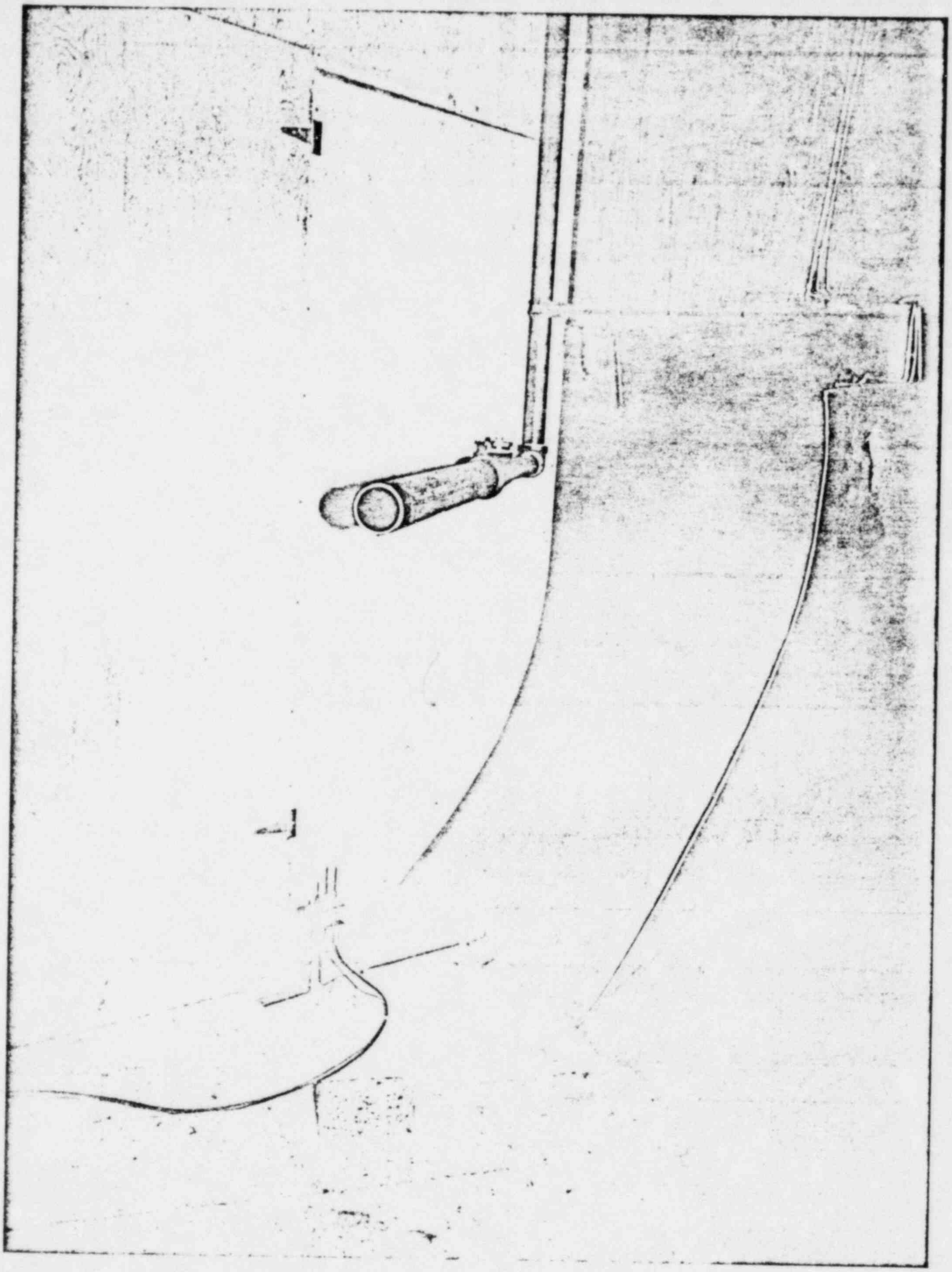
SENSOR LOCATION	GAS VELOCITY PROBE	GAS SAMPLE	THERMOCOUPLE
5^o, TOP	X	X	X
65^o, TOP	X	X	X
125^o, TOP	X	X	X
185^o, TOP	X	X	X
245^o, TOP	X	X	X
5^o, MIDPLANE			X
65^o, MIDPLANE			X
125^o, MIDPLANE	X	X	X
185^o, MIDPLANE			X
245^o, MIDPLANE			X
5^o, BOTTOM	X	X	X
65^o, BOTTOM			X
125^o, BOTTOM	X	X	X
185^o, BOTTOM	X	X	X
245^o, BOTTOM	X	X	X

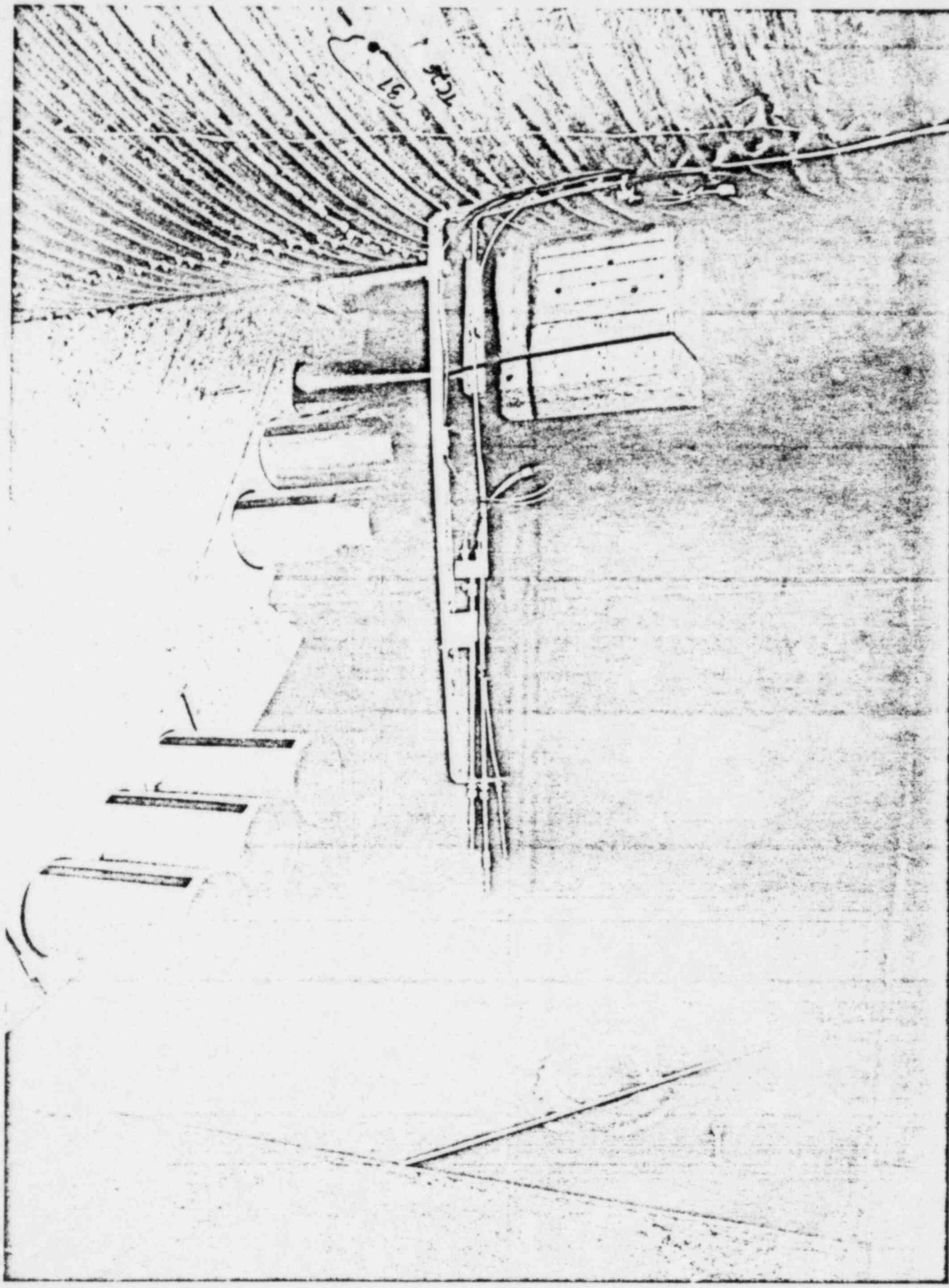
INSTRUMENTATION SENSITIVITY

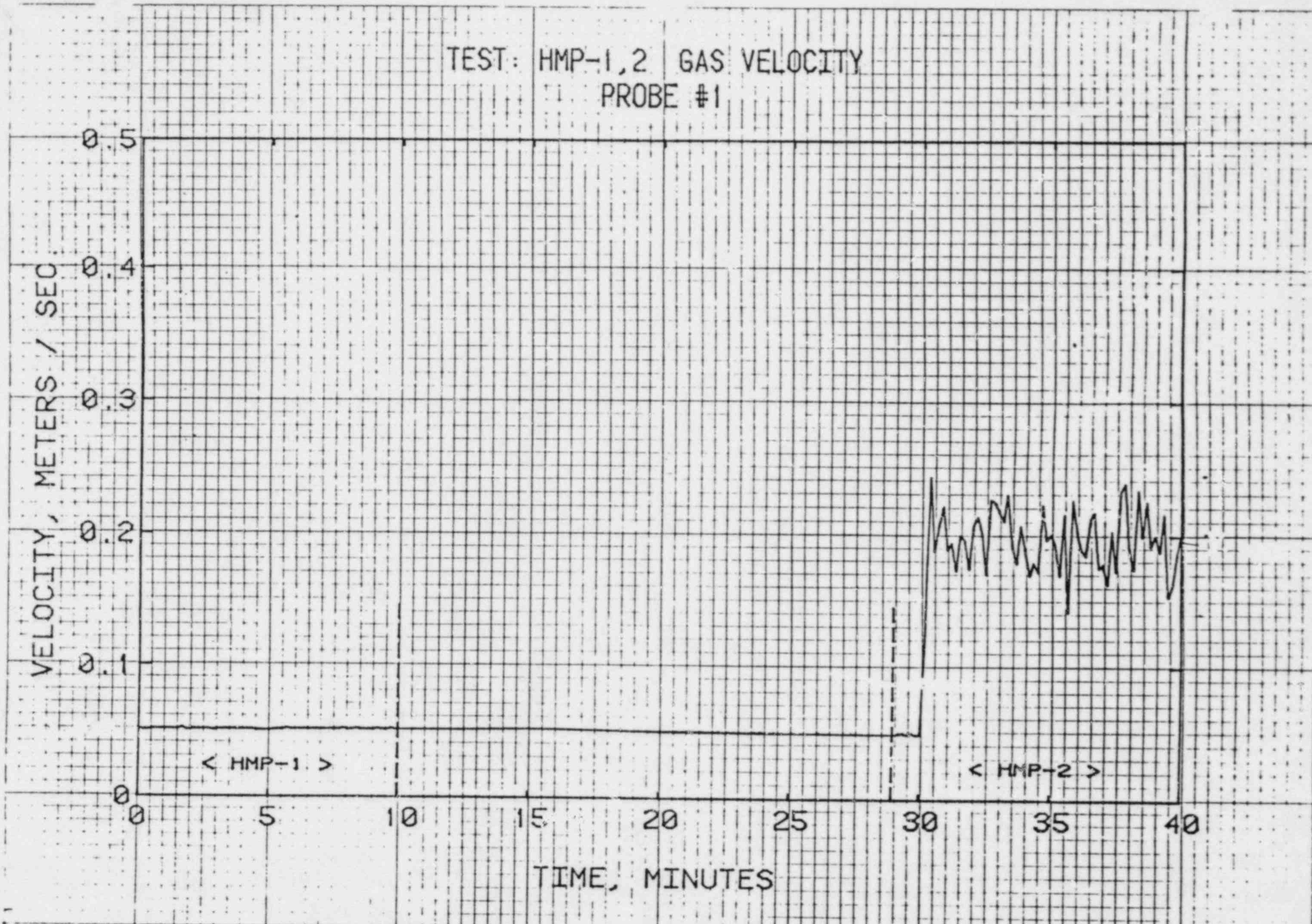
<u>GAS CONCENTRATIONS</u>	
° DRY BASIS CONCENTRATION	
- RESOLUTION	± 0.25 VOLUME %
- ACCURACY	± 0.7 VOLUME %
° RESPONSE TIME	
- SAMPLE LINE	10 - 20 SEC
- SENSOR	~ 50 SEC
- DATA SYSTEM	~ 26 SEC
<u>TEMPERATURE</u>	
° TEMPERATURE	± 4°F
° RESPONSE TIME	
- SENSOR	~ 20 SEC
- DATA SYSTEM	0 - 30 SEC
<u>GAS VELOCITIES</u>	
° LOCAL VELOCITY	
- CALIBRATION	± 0.2 SFPS
- DIRECTION UNKNOWN	+ 50% - 0%
- WATER VAPOR CONCENTRATION NOT ACCOUNTED FOR	+ 50% - 0%
° RESPONSE TIME	
- SENSOR	~ 1 M SEC
- DATA SYSTEM	~ 2 SEC


90°
A
A
110°
OUTLET SLOTS
(24 TYPICAL)
25°
JET B
15°
60°
2.67 RAD
2.31 RAD
B
JET A
(STEAM/HELIUM)
350°
B
210°
PLYWOOD
WALL
RECIRCULATION
IN FLOW
TYP. OF 4
290°
270°
UPPER FLOOR
SECTION A-A
OUTLET
SLOTS
1.52
0.64
CEILING
(WIDTH 4.3 cm)
RECIRCULATION
IN FLOW
0.73
1.41
DIMENSIONS IN METERS
EXCEPT AS NOTED
SECTION B-B
OUTLET SLOTS
4.72
STEEL
WALL
RECIRC.
INFLOW
PLYWOOD
DECK
1.52
3.81






37



TEST: HMP-1,2 GAS VELOCITY
PROBE #1
VELOCITY, METERS / SEC
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
< HMP-1 >
< HMP-2 >
TIME, MINUTES

SUMMARY RESULTS OF PRELIMINARY TESTS
(HM-P1 - HM-P4)

	*LOCAL AVERAGE AIR VELOCITIES M/MIN (FT/MIN)		
	NEAR FLOOR	MIDDLE	NEAR TOP
NATURAL CONVECTION ONLY AMBIENT TEMP HM-P1	5 (16)	3 (9)	4 (12)
NATURAL CONVECTION ONLY ELEVATED TEMP HM-P3	17 (57)	---	20 (67)
NATURAL CONVECTION + FORCED CONVECTION AMBIENT TEMP HM-P2	5 (16)	7 (24)	13 (43)
NATURAL CONVECTION + FORCED CONVECTION ELEVATED TEMP HM-P4	27 (87)	---	26 (85)

* + 50% / - 0% FLOW VELOCITY MAGNITUDE UNCERTAINTY DUE TO UNKNOWN FLOW DIRECTION.

TEST FROUDE NUMBER SUMMARY

	JET $F_{\bar{R}}$ NO.			RECIRCULATION $F_{\bar{R}}$ NO.		
		ACTUAL			ACTUAL	
TEST #	TARGET	START	END	TARGET	START	END
HM-1	100	113	137	N/A	N/A	N/A
HM-2	200	234	352	N/A	N/A	N/A
HM-3	100	103	110	0.5	0.54	0.52
HM-4	200	221	265	0.5	0.51	0.42
HM-5	200	185	226	0.5	0.52	0.61
HM-6	100	100	106	0.5	0.64	0.61
HM-7	200	160	205	0.5	0.52	0.46

JET $F_{\bar{R}}$ = 200 FOR PLANT

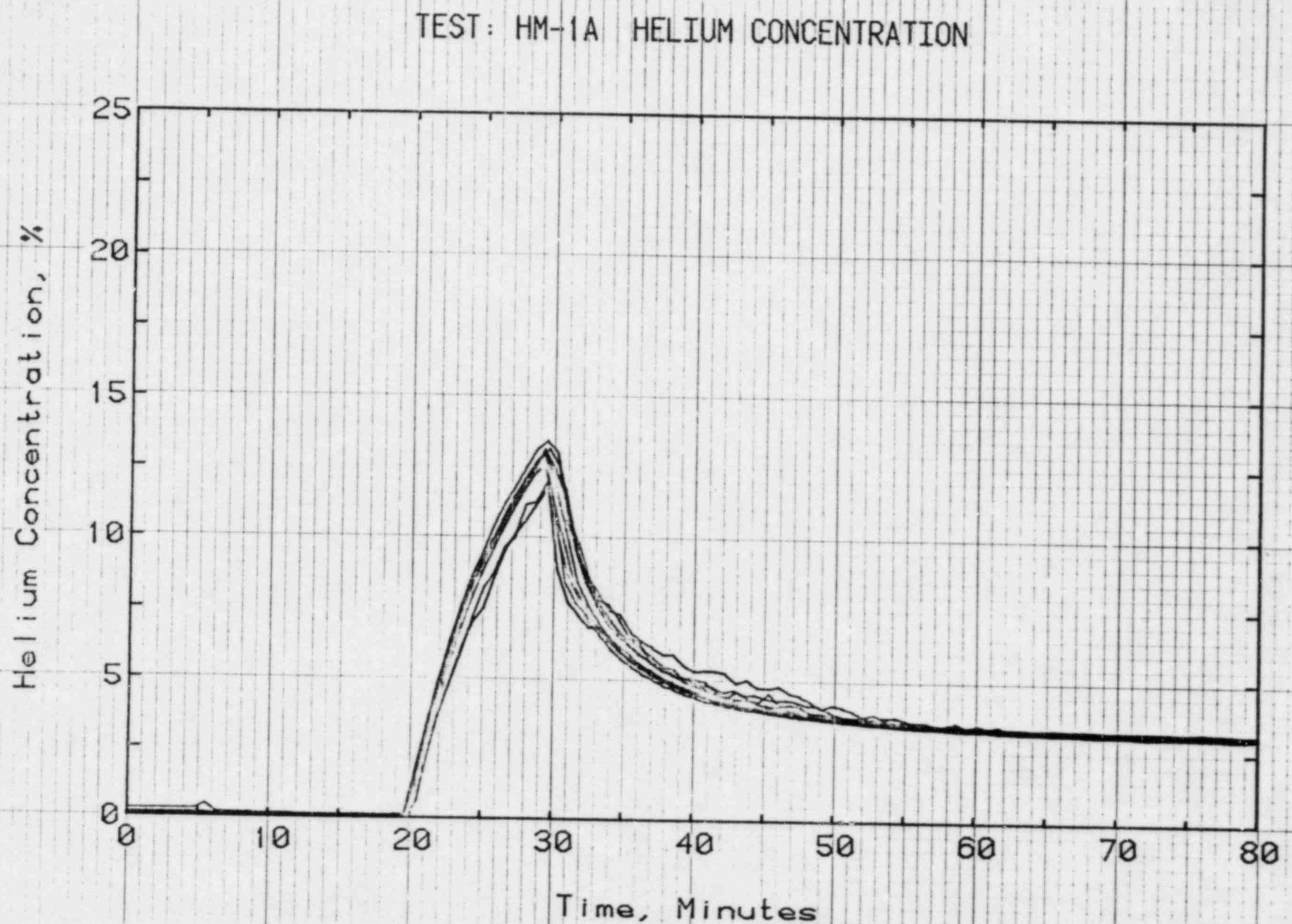
RECIRCULATION $F_{\bar{R}}$ = 0.5 FOR PLANT

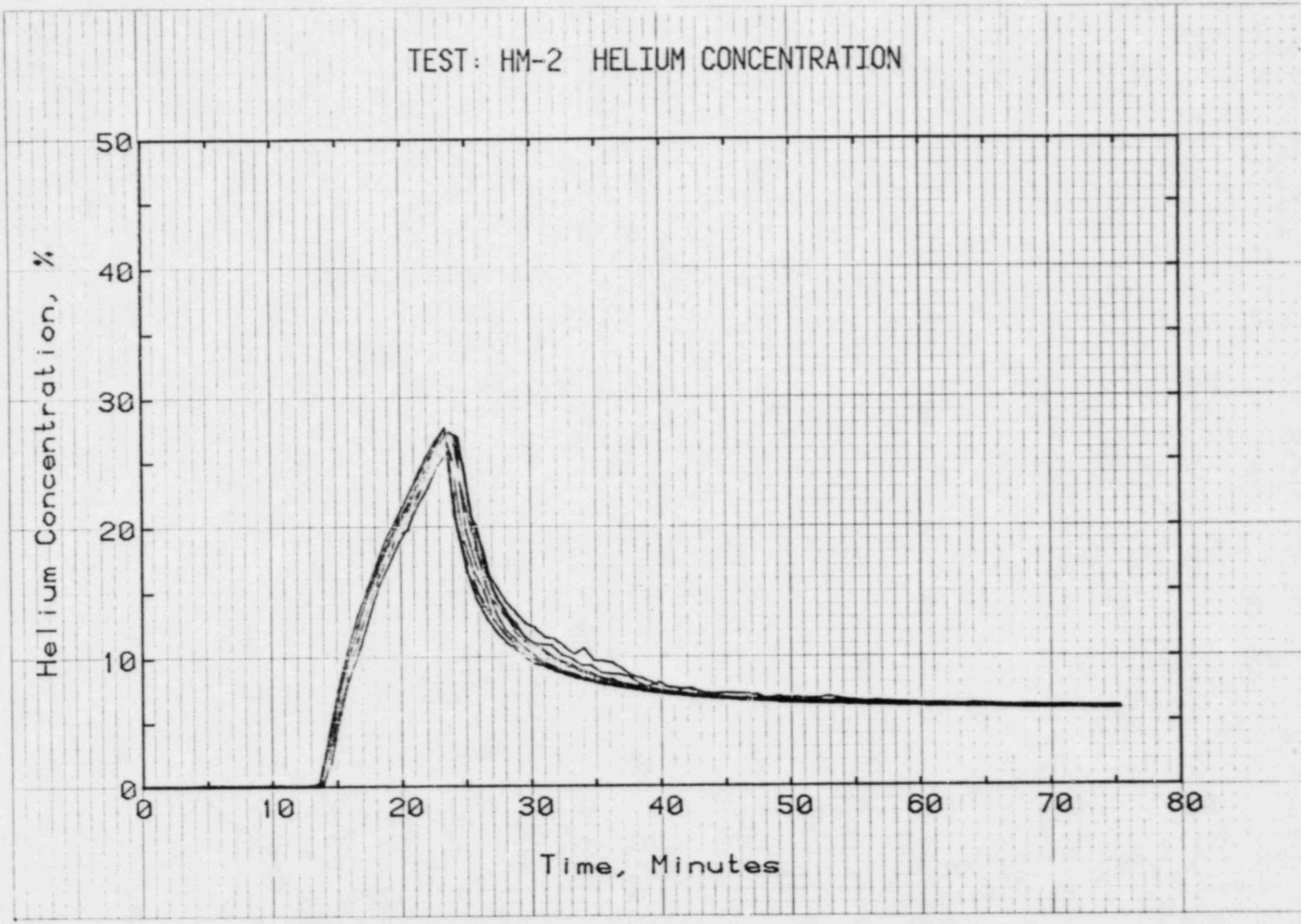
TEST DENSITY RATIOS SUMMARY

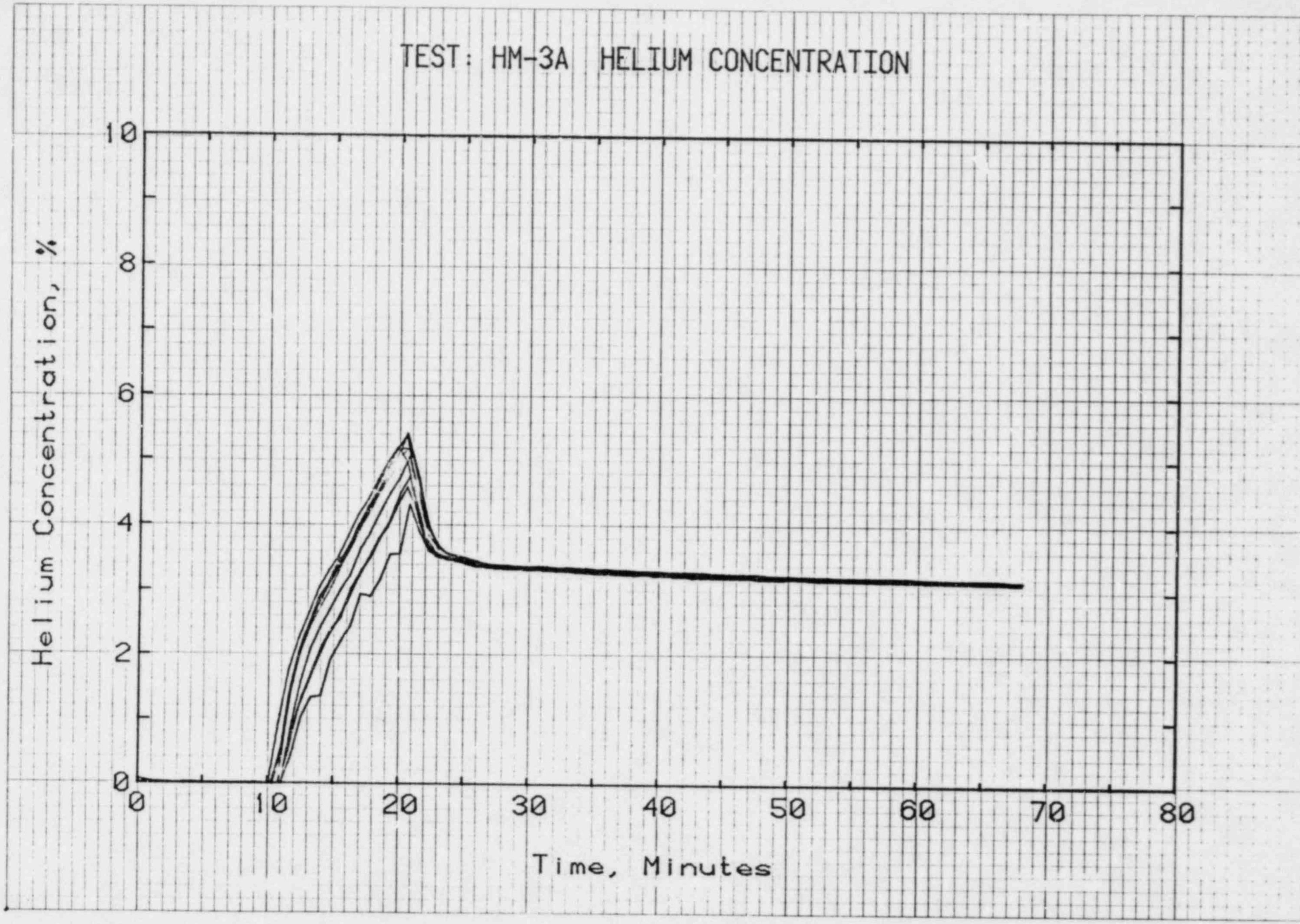
	JET		RECIRCULATION	
	$^*\rho_J/\rho_A$		$^{**}\rho_R/\rho_A$	
	TARGET = 0.45		TARGET = 1.11	
TEST NO.	START	END	START	END
HM-1	0.59	0.63	---	---
HM-2	0.62	0.74	---	---
HM-3	0.51	0.53	1.11	1.12
HM-4	0.56	0.60	1.12	1.18
HM-5	0.53	0.54	1.12	1.08
HM-6	0.53	0.55	1.07	1.08
HM-7	0.53	0.59	1.11	1.15

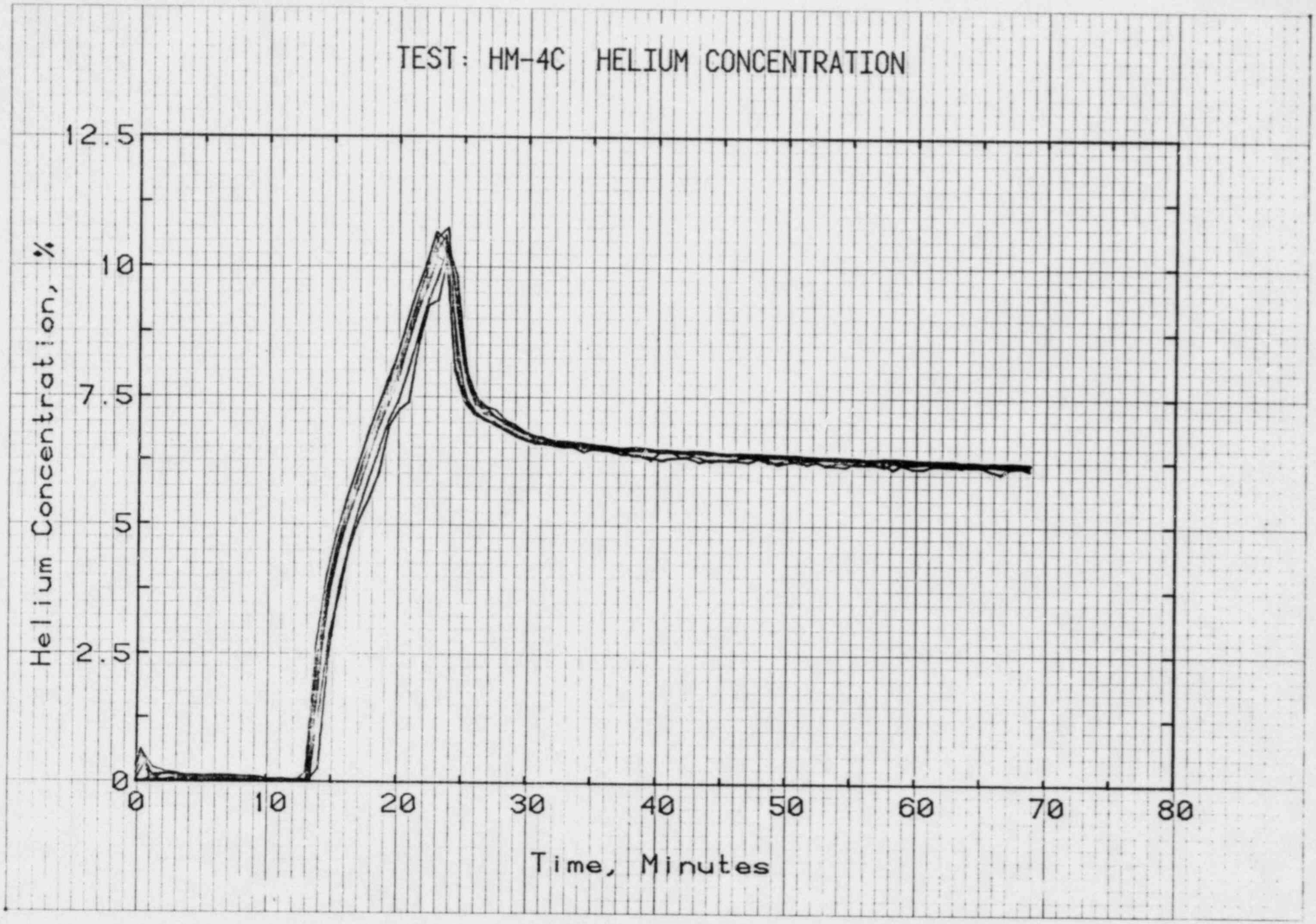
* JET ρ_J/ρ_A = 0.44 FOR PLANT

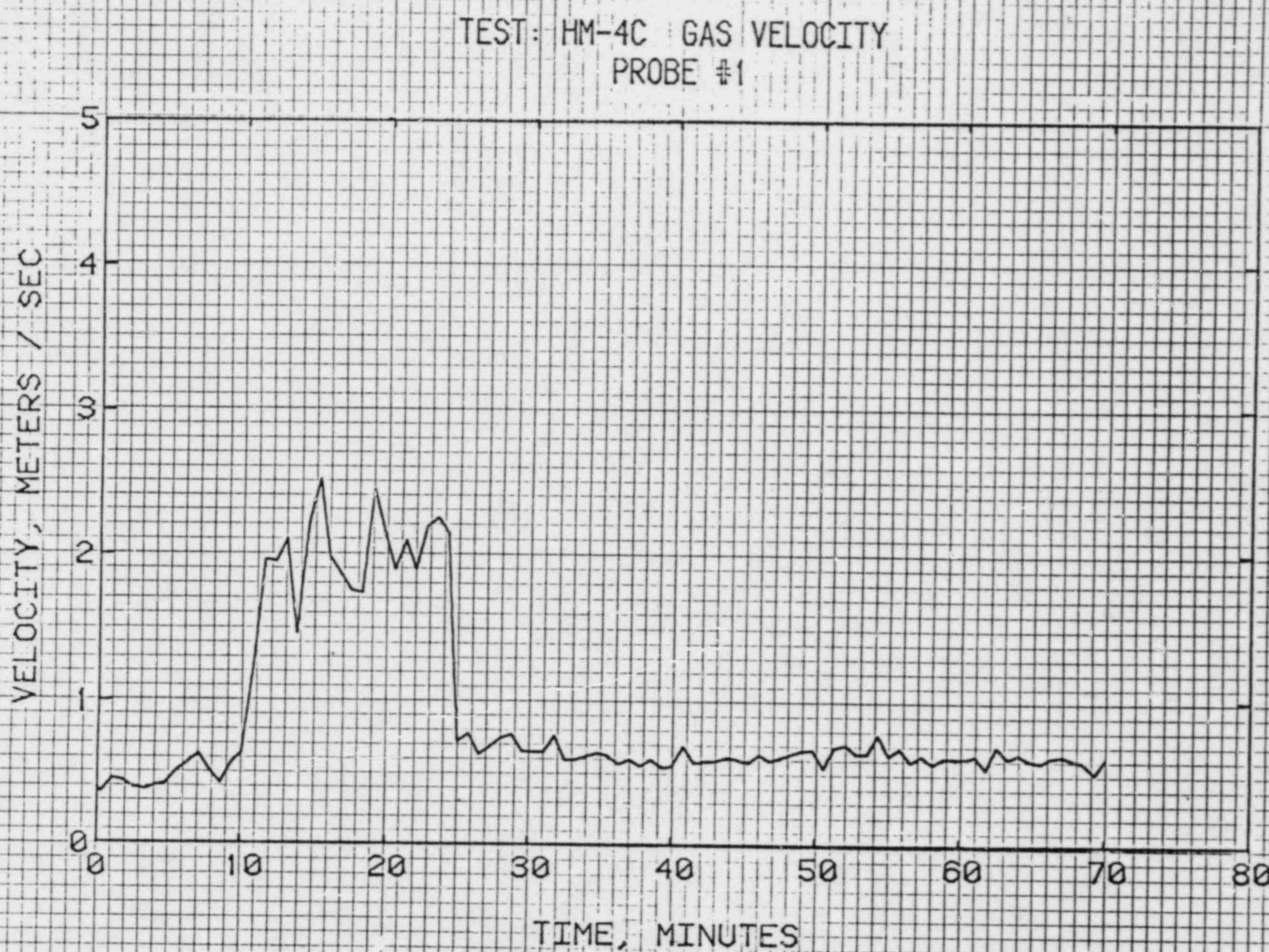
** RECIRCULATION ρ_R/ρ_A = 1.50 FOR PLANT

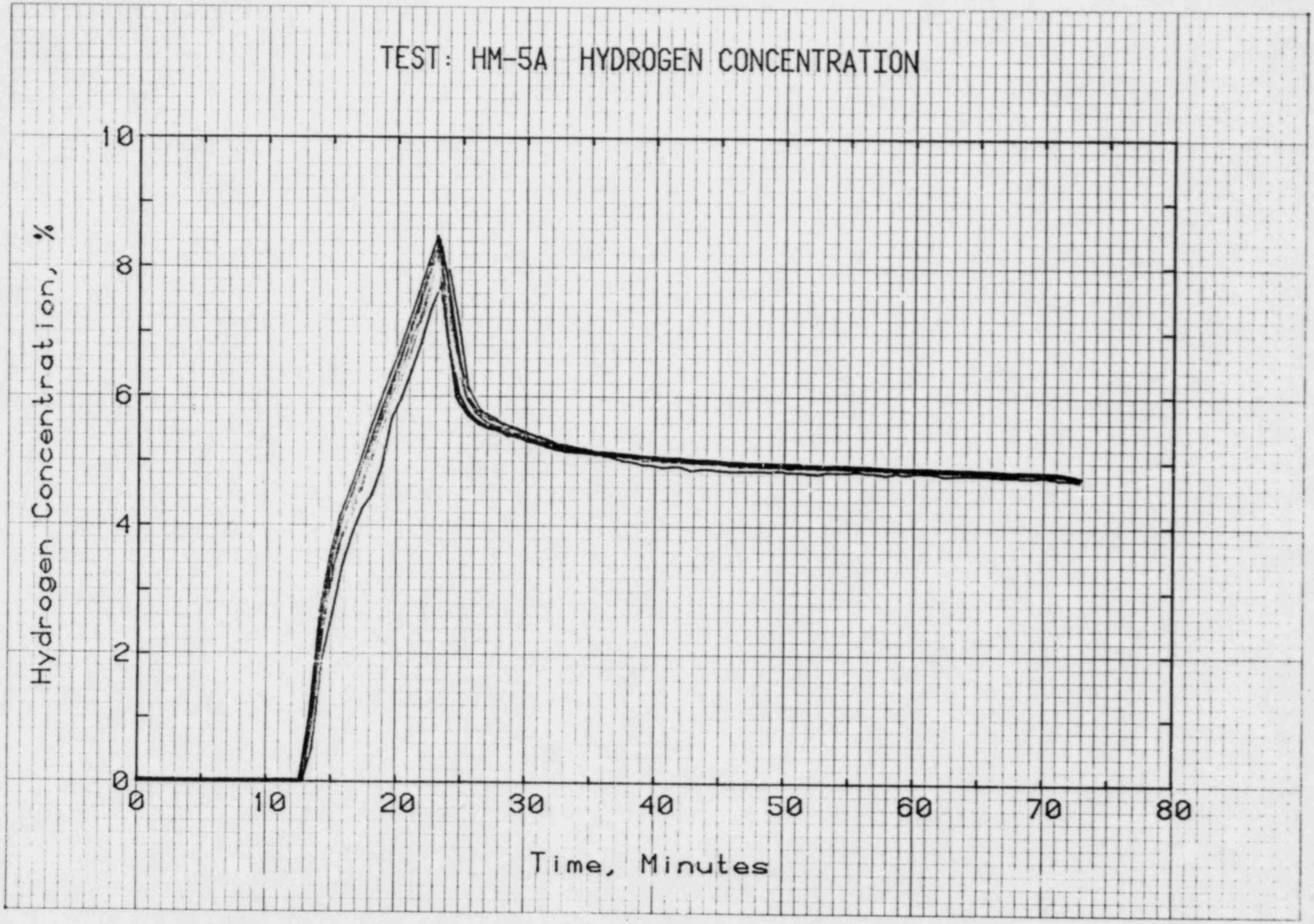

TEST: HM-1A HELIUM CONCENTRATION
Helium Concentration, %
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
Time, Minutes

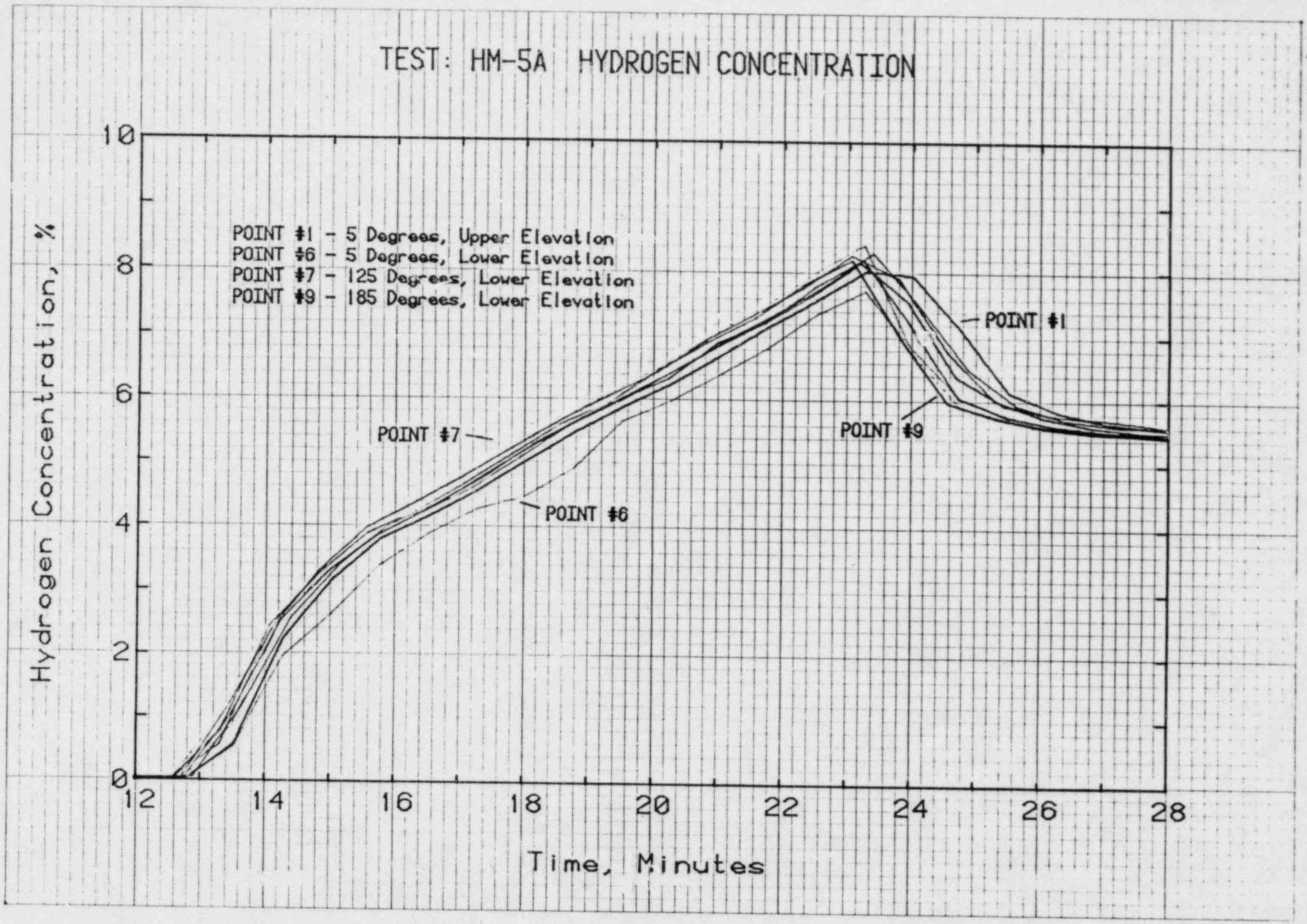

TEST: HM-2 HELIUM CONCENTRATION
Helium Concentration, %
0
10
20
30
40
50
0
10
20
30
40
50
60
70
80
Time, Minutes

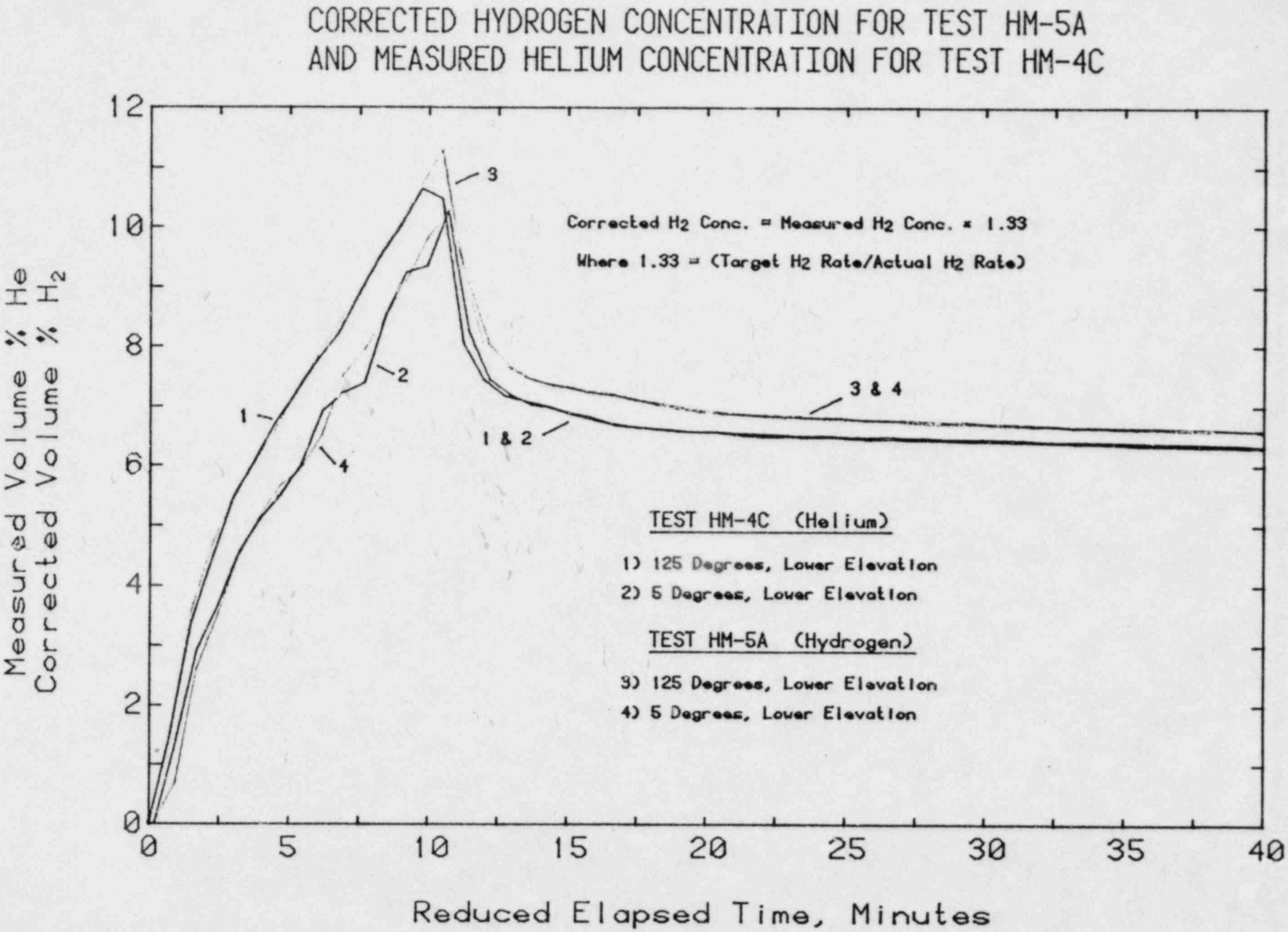

TEST: HM-3A HELIUM CONCENTRATION
Helium Concentration, %
0
2
4
6
8
10
0
10
20
30
40
50
60
70
80
Time, Minutes

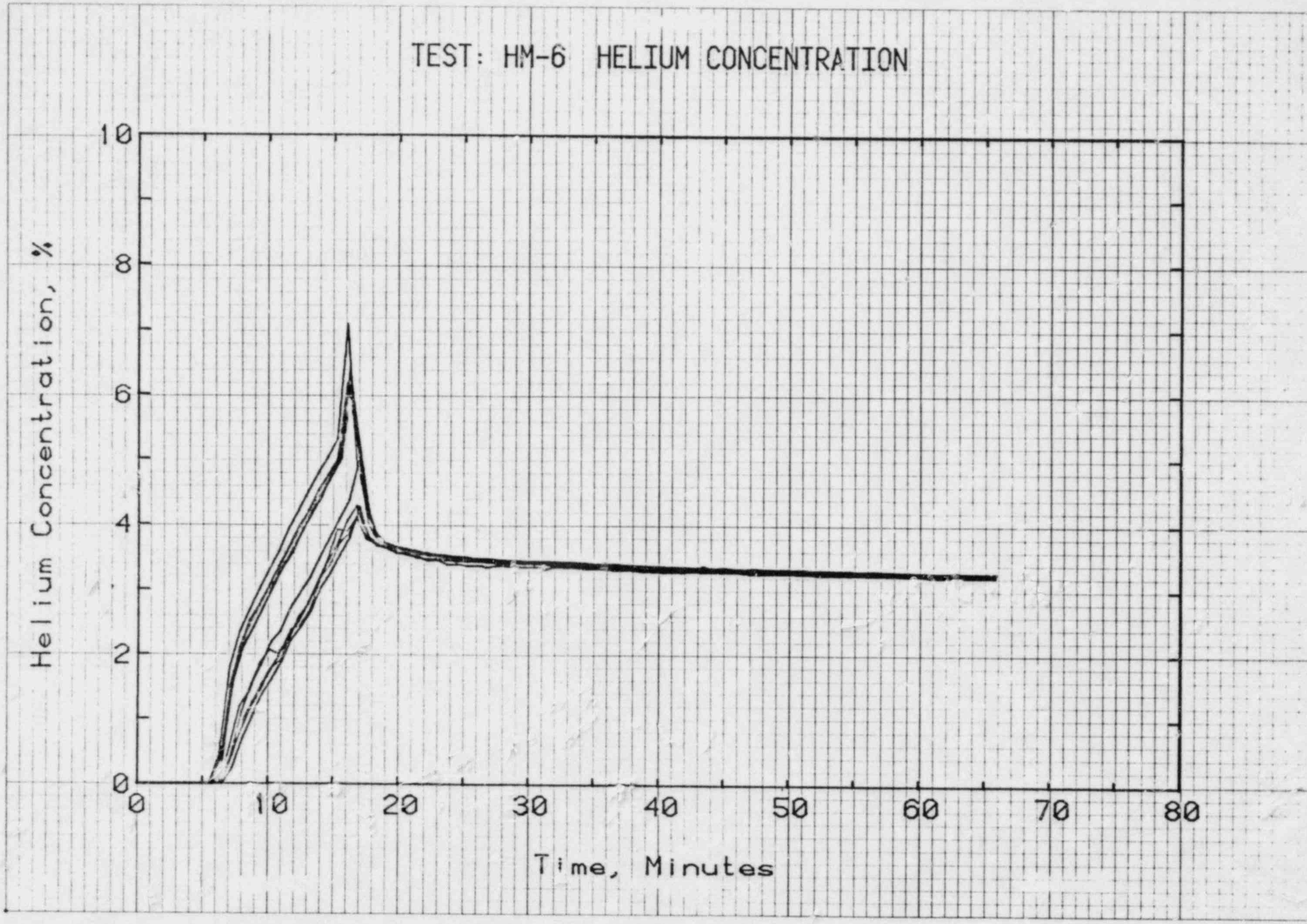

TEST: HM-4C HELIUM CONCENTRATION
Helium Concentration, %
12.5
10
7.5
5
2.5
0
0
10
20
30
40
50
60
70
80
Time, Minutes


TEST: HM-4C GAS VELOCITY
PROBE #1
VELOCITY, METERS / SEC
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
TIME, MINUTES

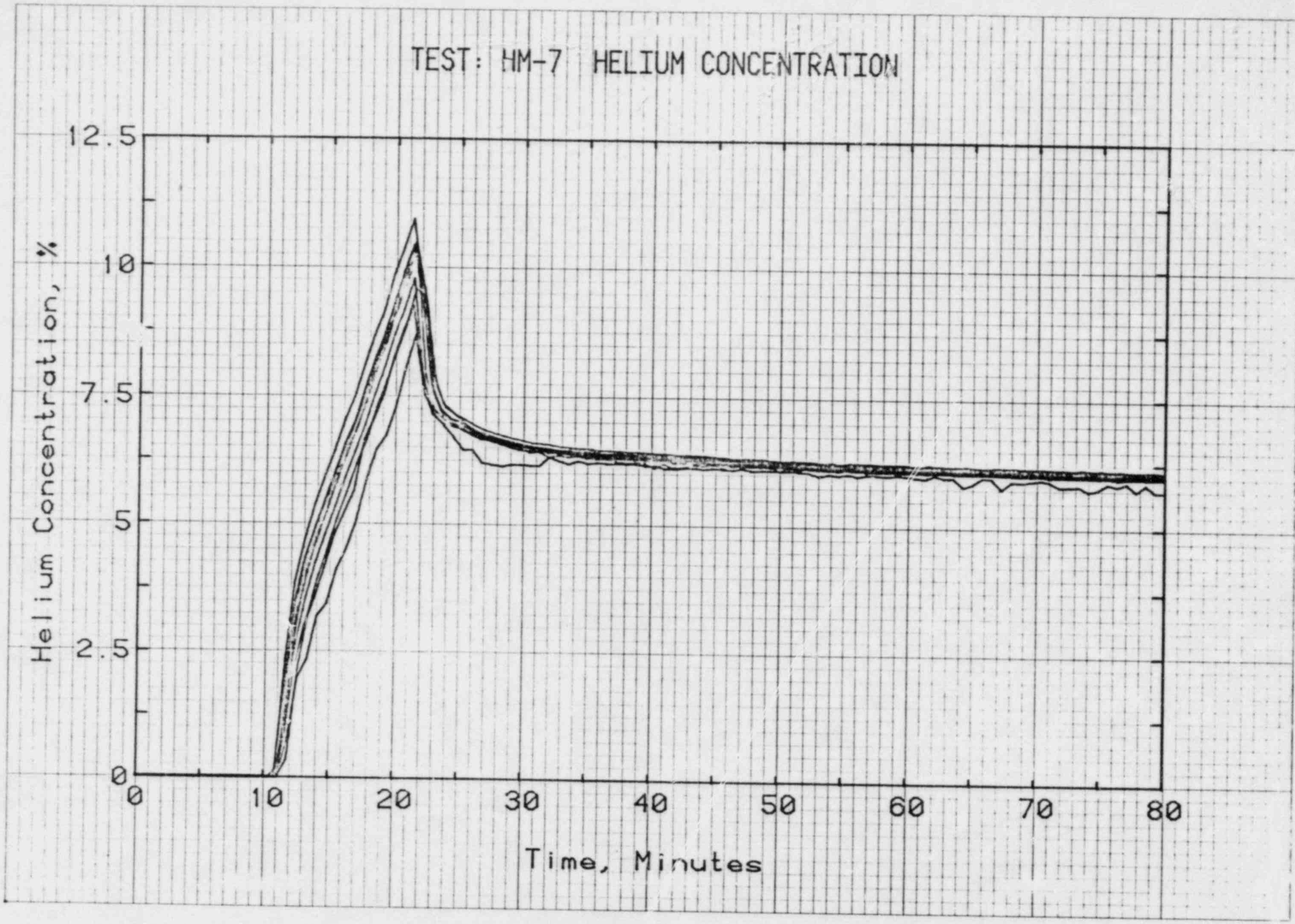

TEST: HM-5A HYDROGEN CONCENTRATION
Hydrogen Concentration, %
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
Time, Minutes


TEST: HM-5A HYDROGEN CONCENTRATION
POINT #1 - 5 Degrees, Upper Elevation
POINT #6 - 5 Degrees, Lower Elevation
POINT #7 - 125 Degrees, Lower Elevation
POINT #9 - 185 Degrees, Lower Elevation
POINT #1
POINT #7
POINT #9
POINT #6
Hydrogen Concentration, %
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Time, Minutes


CORRECTED HYDROGEN CONCENTRATION FOR TEST HM-5A
AND MEASURED HELIUM CONCENTRATION FOR TEST HM-4C
Corrected H2 Conc. = Measured H2 Conc. * 1.33
Where 1.33 = (Target H2 Rate/Actual H2 Rate)
Measured Volume % He
Corrected Volume % H2
Reduced Elapsed Time, Minutes
1
2
3
4
1 & 2
3 & 4
TEST HM-4C (Helium)
1) 125 Degrees, Lower Elevation
2) 5 Degrees, Lower Elevation
TEST HM-5A (Hydrogen)
3) 125 Degrees, Lower Elevation
4) 5 Degrees, Lower Elevation
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
40

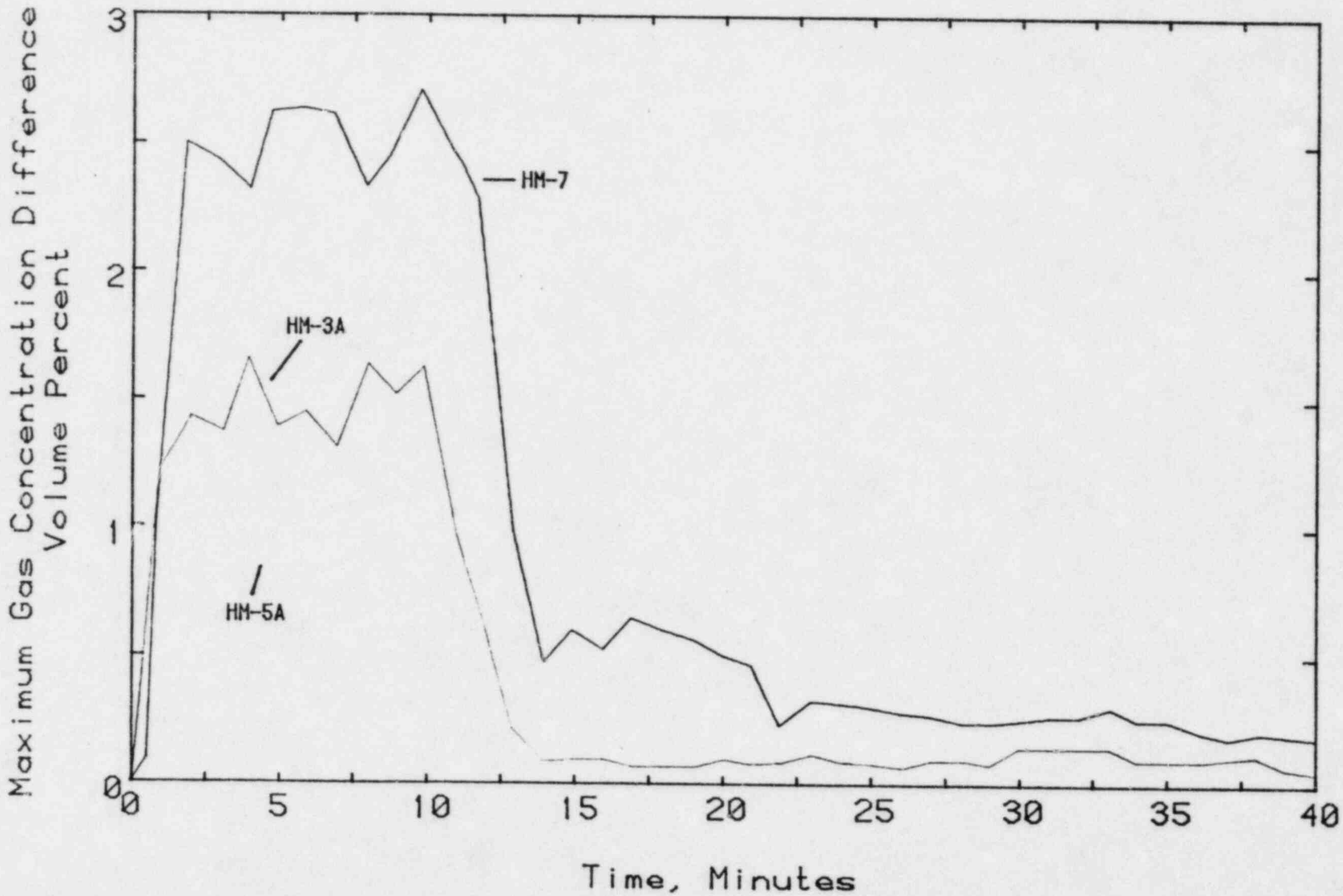


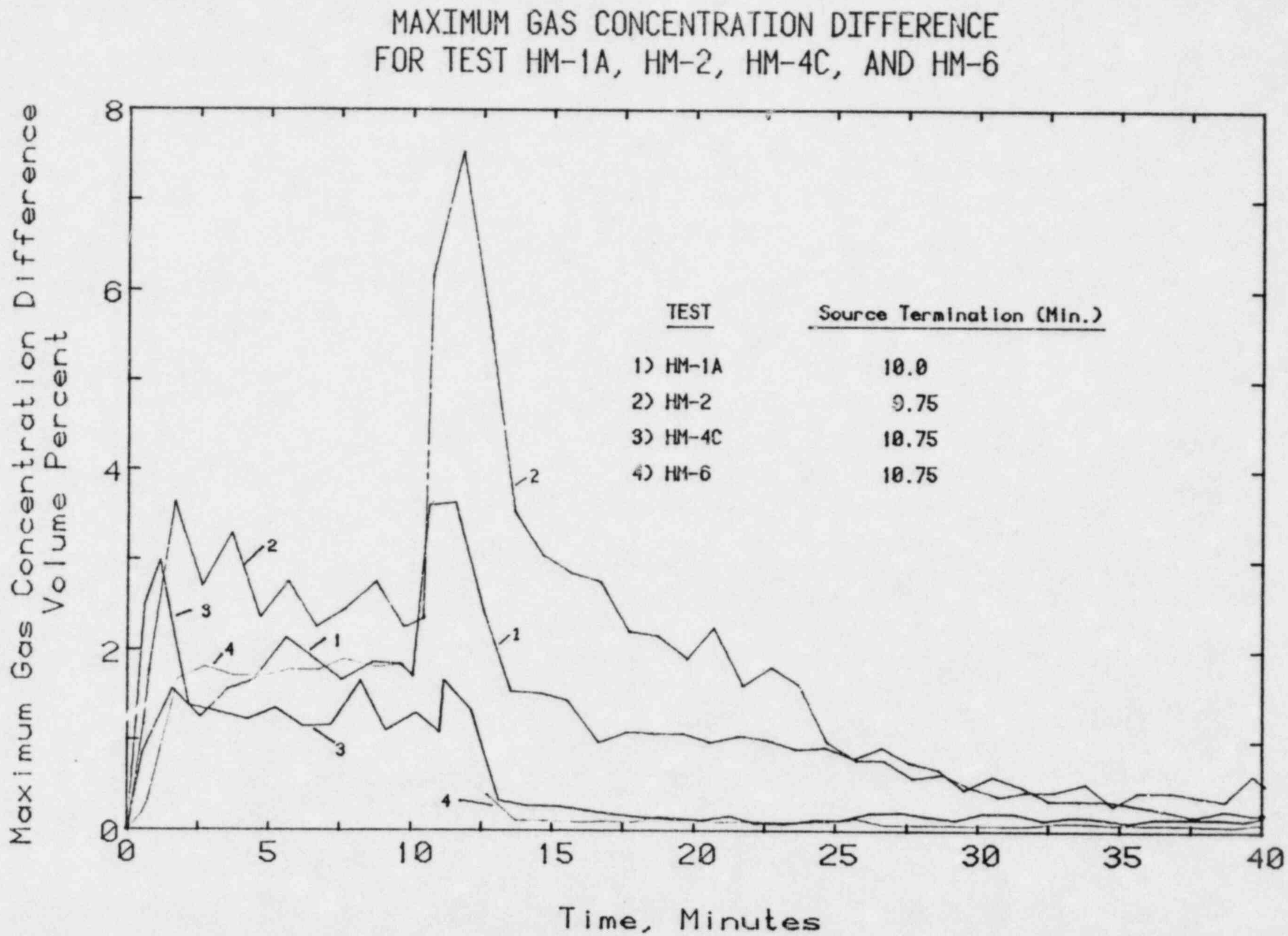
TEST: HM-6 HELIUM CONCENTRATION
Helium Concentration, %
0
2
4
6
8
10
0
10
20
30
40
50
60
70
80
Time, Minutes



TEST: HM-7 HELIUM CONCENTRATION
Helium Concentration, %
12.5
10
7.5
5
2.5
0
0
10
20
30
40
50
60
70
80
Time, Minutes

MAXIMUM GAS CONCENTRATION DIFFERENCE
FOR TEST HM-3A, HM-5A, AND HM-7




MAXIMUM GAS CONCENTRATION DIFFERENCE
FOR TEST HM-1A, HM-2, HM-4C, AND HM-6
Maximum Gas Concentration Difference
Volume Percent
Time, Minutes
TEST
Source Termination (Min.)
1) HM-1A 10.0
2) HM-2 9.75
3) HM-4C 10.75
4) HM-6 10.75
0
2
4
6
8
0
5
10
15
20
25
30
35
40
1
2
3
4

HE/H_2 CONCENTRATIONS CORRECTED FOR WATER VAPOR

TEST NO.	RELEASE GAS	PEAK TEMP. (^{o}F)	MAXIMUM PEAK CONC. DRY BASIS (VOL. %)	MAX. Δ CONC. DRY BASIS (VOL. %)	MAXIMUM PEAK CONC. WET BASIS** (VOL. %)	MAX. Δ CONC. WET BASIS** (VOL. %)
HM-1	HE	176	13.5	1.5	7.0	0.3
HM-2	HE	198	27.7	2.0	6.3	-0.6
HM-3	HE	152	5.4	1.1	3.9	0.6
HM-4	HE	174	10.7	0.7	5.8	0.2
HM-5	H_2	165	8.5	0.4	5.4	0.3
HM-6	HE	152	*5.5	1.8	4.0	1.0
HM-7	HE	178	11.0	2.3	6.0	-0.5

* ESTIMATE BASED ON EXTROPOLATED DATA SINCE THERE WAS INADVERTANT HIGH HE RELEASE RATE FOR LAST ONE MINUTE TEST.

** WET BASIS ESTIMATED ASSUMING ATMOSPHERE IS SATURATED WITH WATER VAPOR AT TEMPERATURE OF GAS.

SUMMARY AND CONCLUSIONS

* MAXIMUM OBSERVED CONCENTRATION DIFFERENCE WAS 2.5 % DURING THE RELEASE PERIOD FOR THE CONFIGURATION TESTED.

* GOOD MIXING OCCURS IN THE LOWER COMPARTMENT REGION WITH HIGH VELOCITY JET, FORCED AIR RECIRCULATION AND NATURAL CONVECTION GAS MIXING PROCESSES.

* STRONG INFLUENCE OBSERVED ON LOCAL AIR VELOCITY FROM NATURAL CONVECTION HEAT TRANSFER AND NATURAL CONVECTION PROVIDES WELL MIXED AIR VOLUME.

* FORCED AIR RECIRCULATION INCREASES GAS MIXING, DECREASES MAXIMUM HELIUM CONCENTRATION, AND DECREASES MIXING TIME.

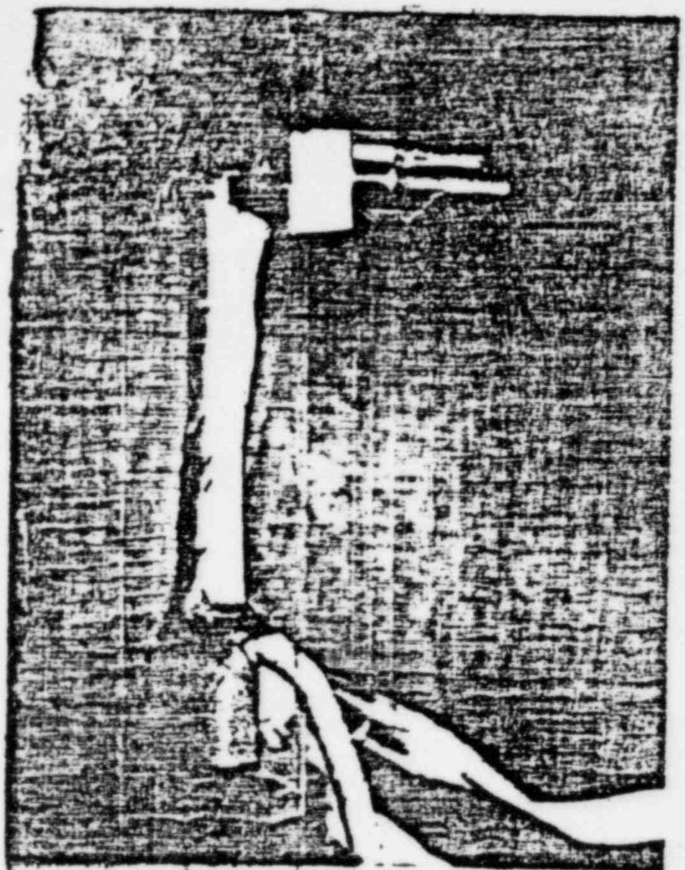
* HIGH VELOCITY HELIUM/STEAM JET RELEASE IS DOMINANT MIXING PROCESS, AND SUBSTANTIALLY INCREASES LOCAL AIR VELOCITIES.

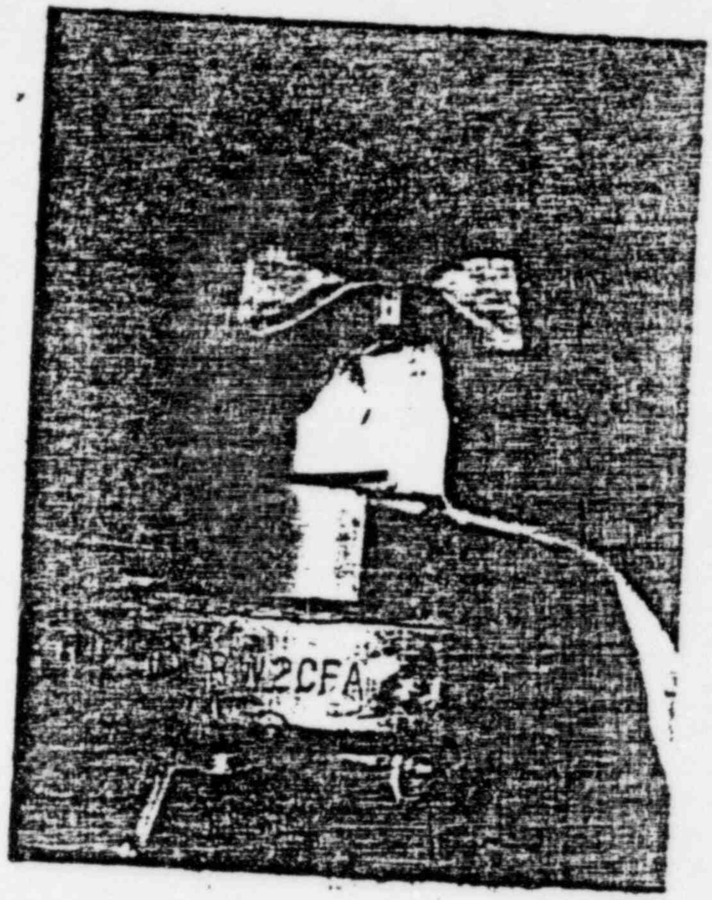
IGNITER EFFECTIVENESS STUDIES

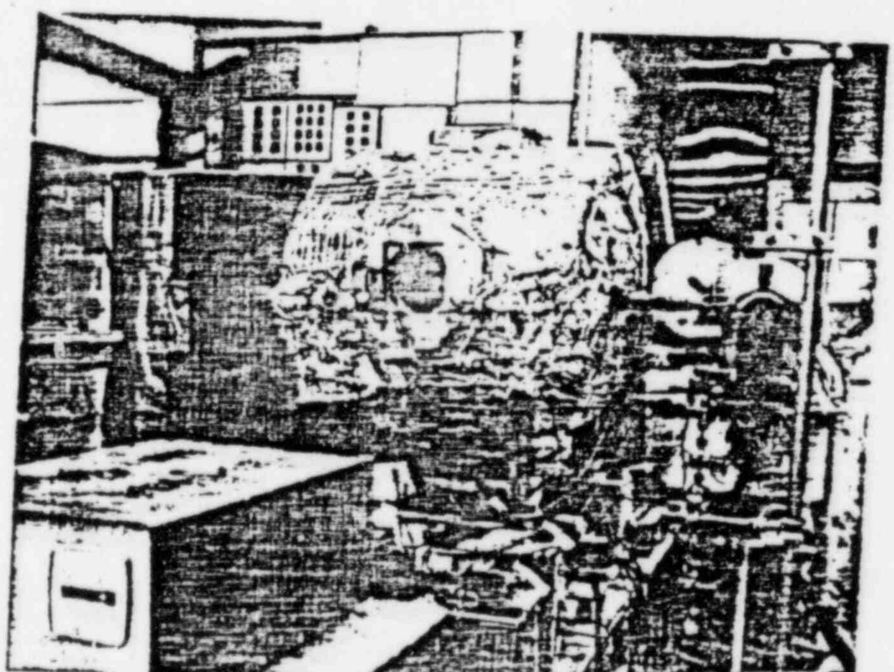
AECL - WNRE.

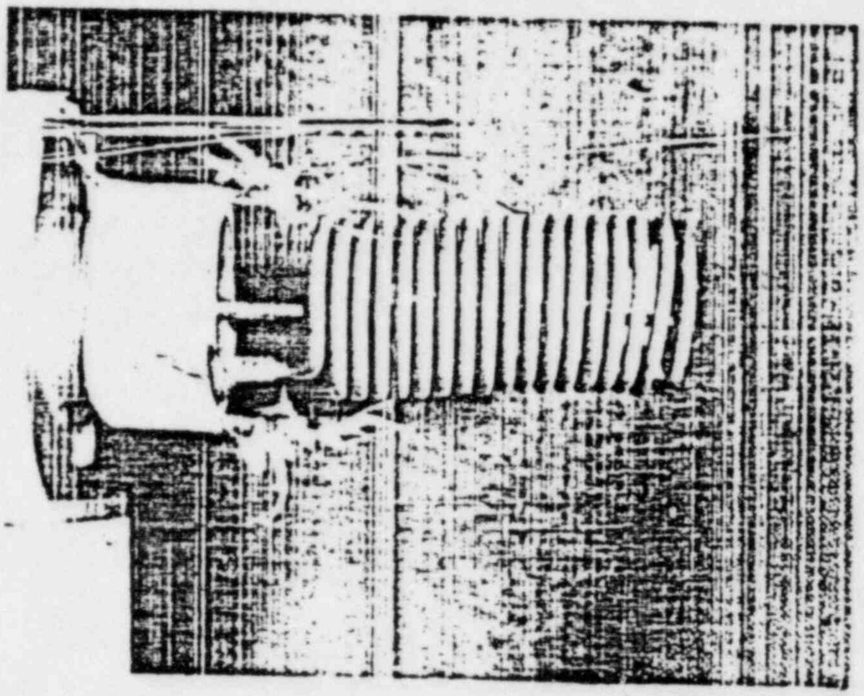
Objective:

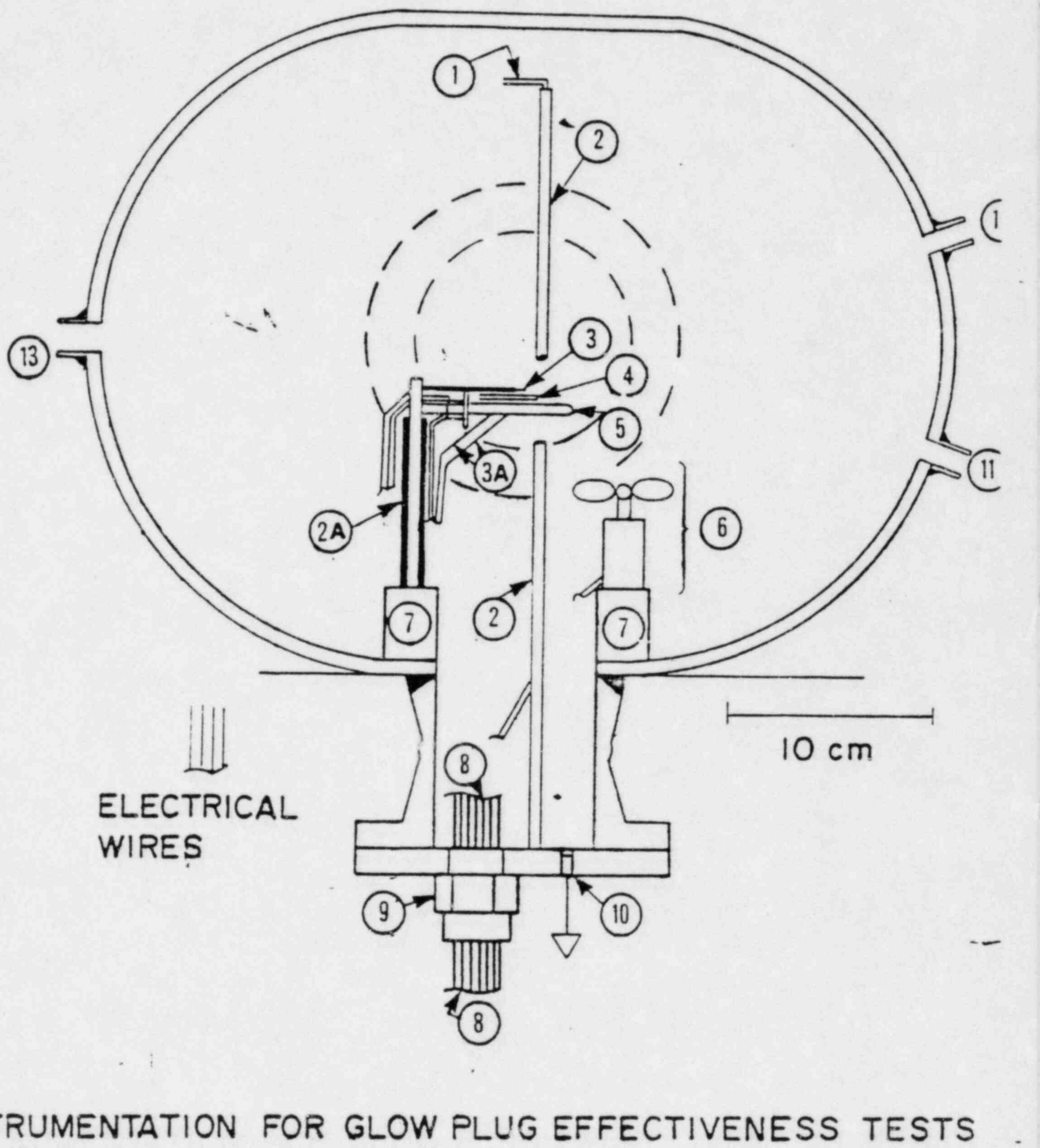
to investigate the effectiveness of hydrogen-air-steam ignition systems particularly near the LFL, in both quiescent & turbulent conditions.




RW2CFA







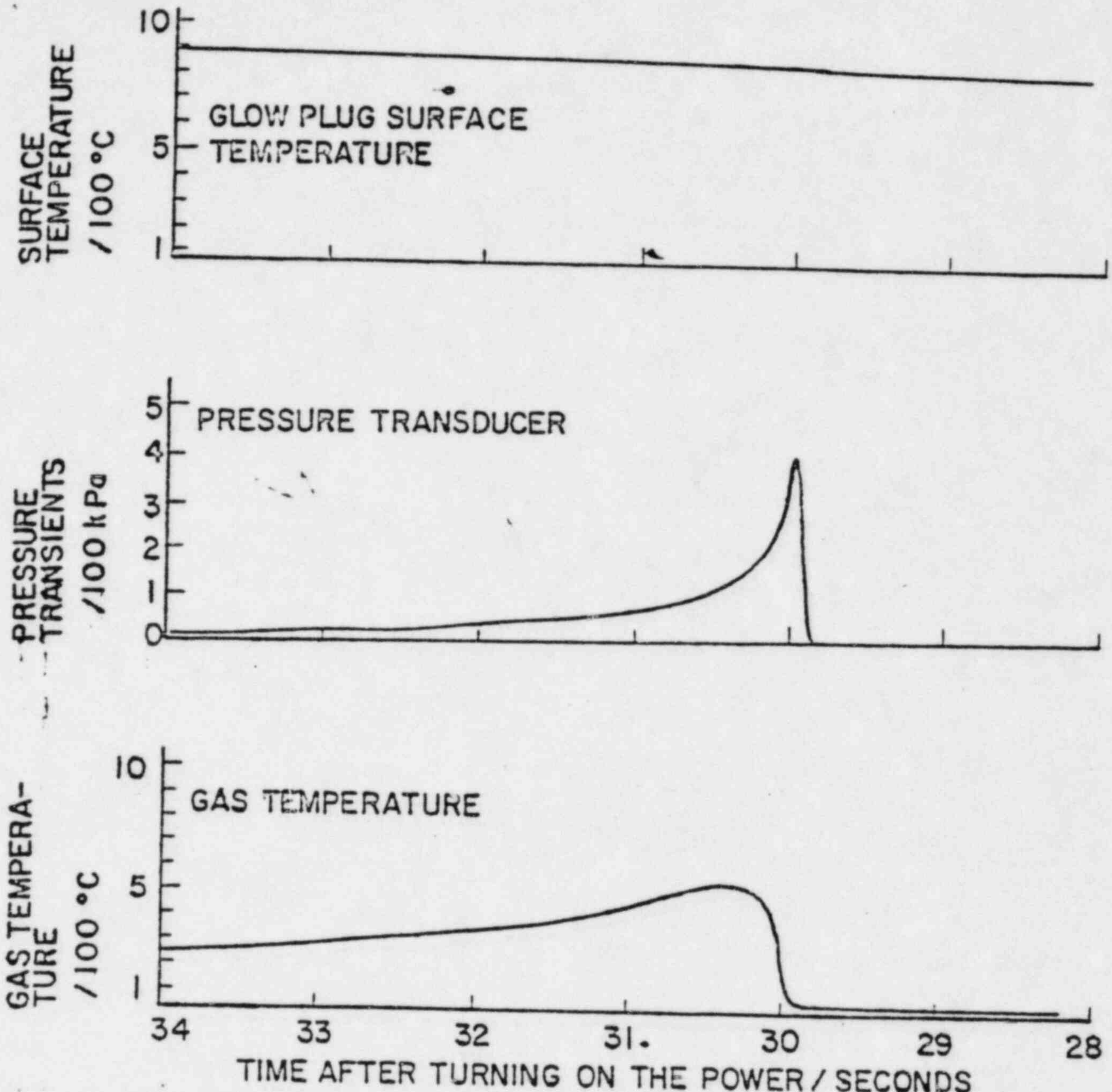
INSTRUMENTATION FOR GLOW PLUG EFFECTIVENESS TESTS
(17 - LITRE VESSEL)

MEASUREMENTS

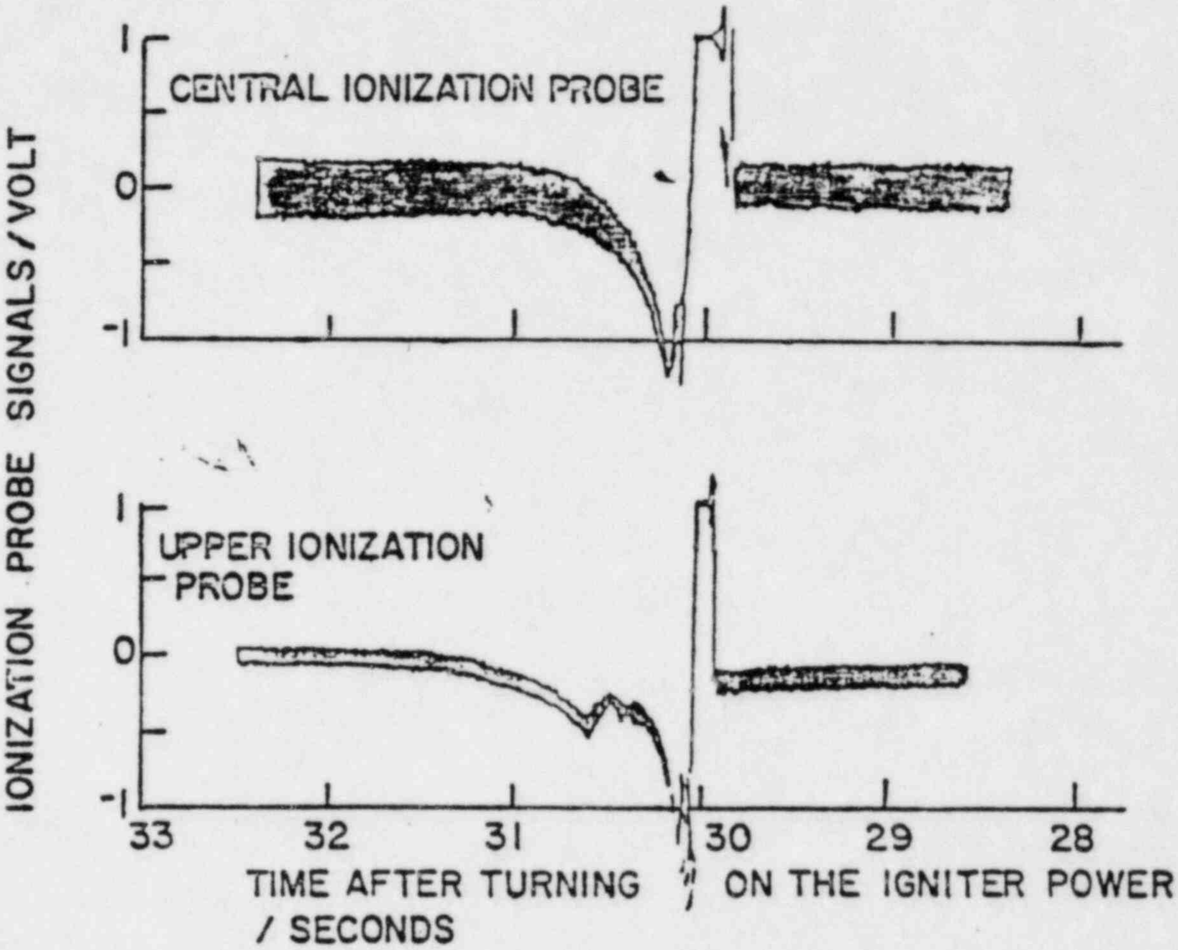
Initial Conditions:
- temperature
- pressure
- concentration
  - partial press.
  - mass spec.

Transient Conditions:
- ionization ⇒ combustion
- pressure ⇒ peak
- temperature of gas ⇒ peak
- glow plug temp. ⇒ ignition temp.

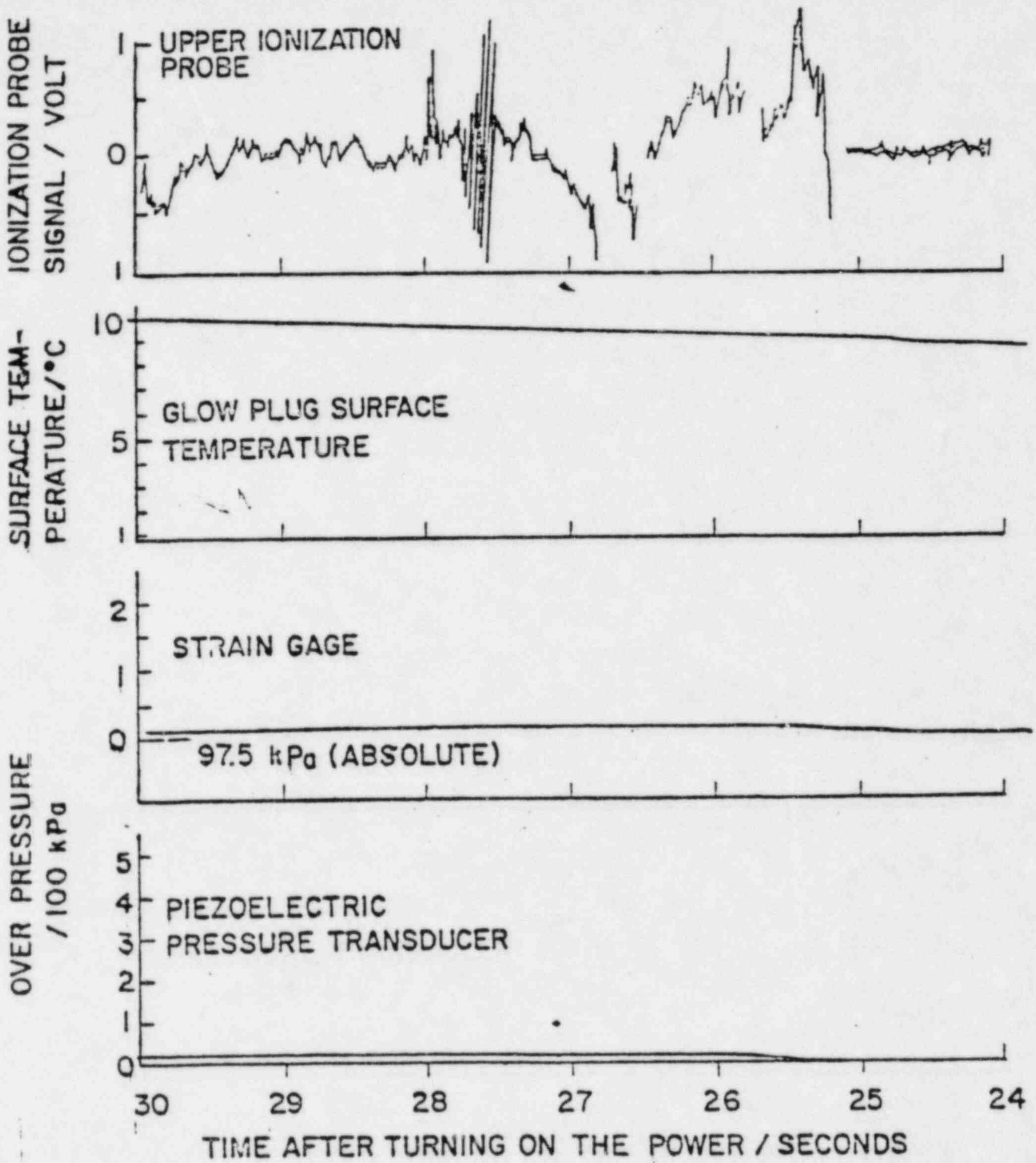
Final Conditions:
- pressure
- concentration (mass spec)



OBSERVED TRANSIENTS IN THE IGNITER EFFICIENCY TEST. A GM AC NO.7 GLOW PLUG OPERATED AT 12 VAC IN A 12.9%-HYDROGEN / 17.4%-STEAM / 69.7%-AIR MIXTURE IN A 17-LITRE VESSEL.



12 OBSERVED TRANSIENTS IN THE IGNITER EFFICIENCY TEST. A GM AC NO. 7 GLOW PLUG OPERATED AT 12 VAC IN A 12.9% - HYDROGEN / 17.4% - STEAM / 69.7% - AIR MIXTURE IN A 17-LITRE VESSEL.



22. OBSERVED TRANSIENTS IN THE IGNITER EFFICIENCY TEST. A GM AC NO. 7 GLOW PLUG OPERATED AT 14 VAC IN A 10%-HYDROGEN / 37.2%-STEAM / 48.8%-AIR MIXTURE IN A 17-LITRE VESSEL.

12

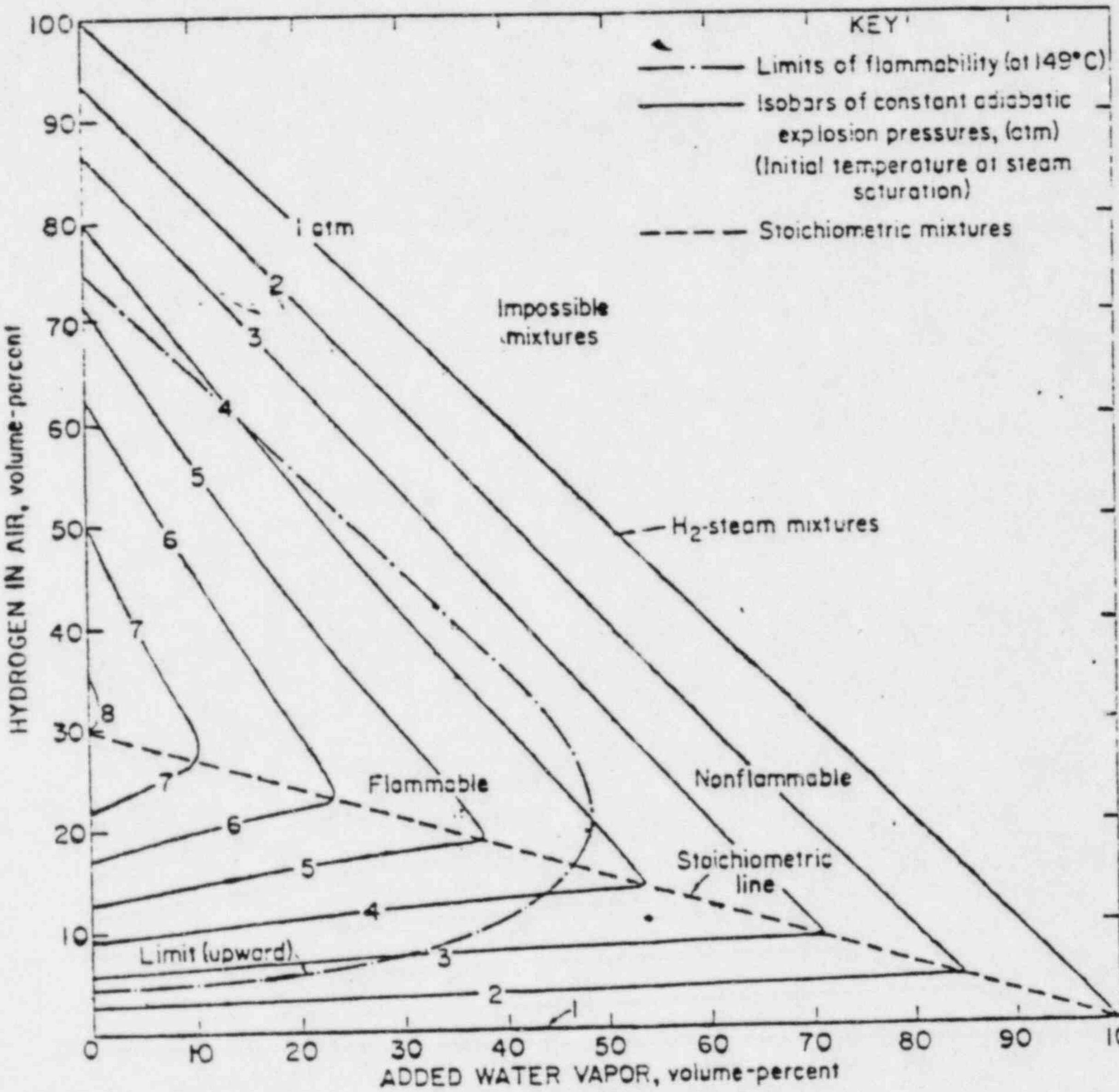
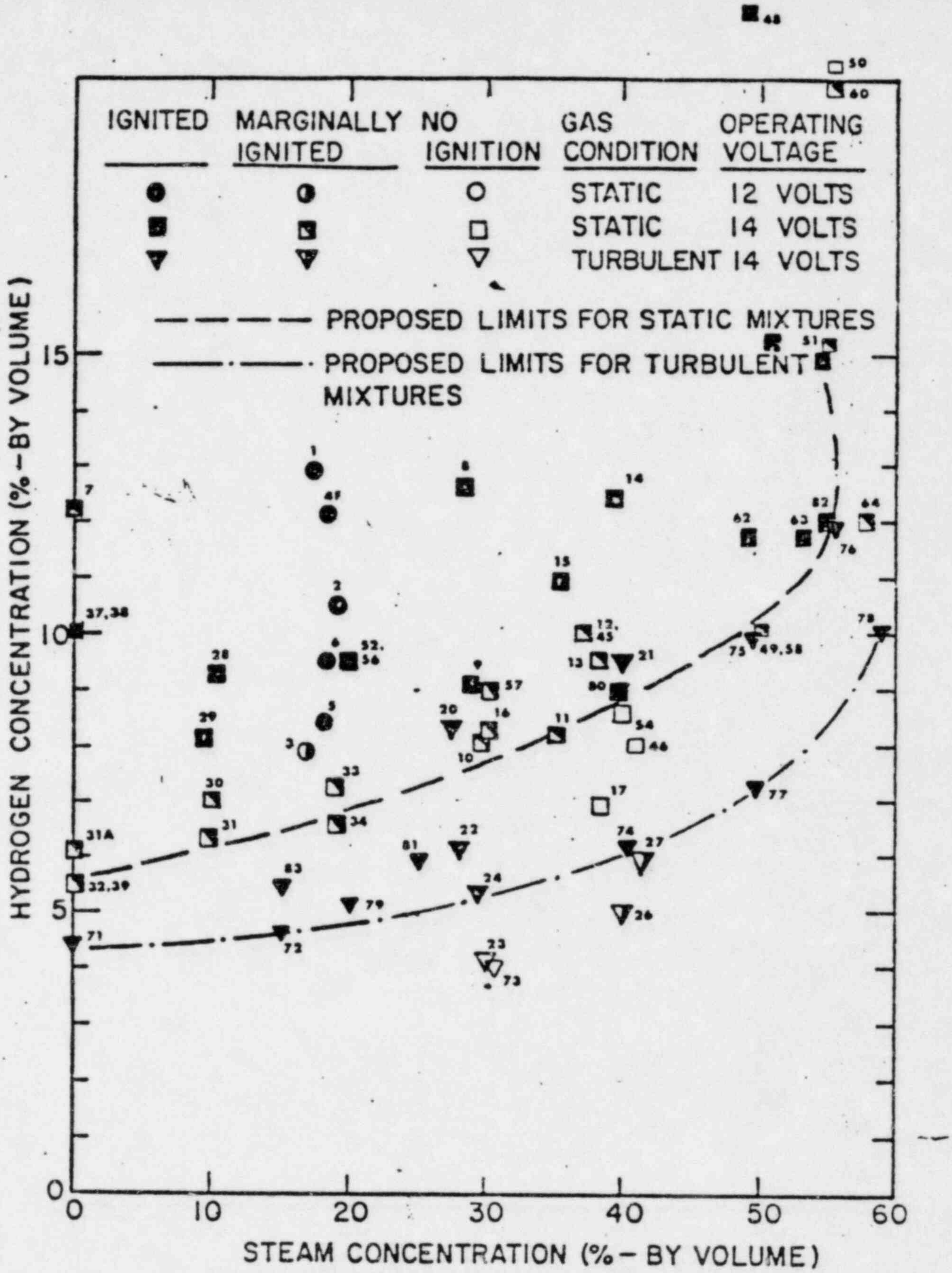
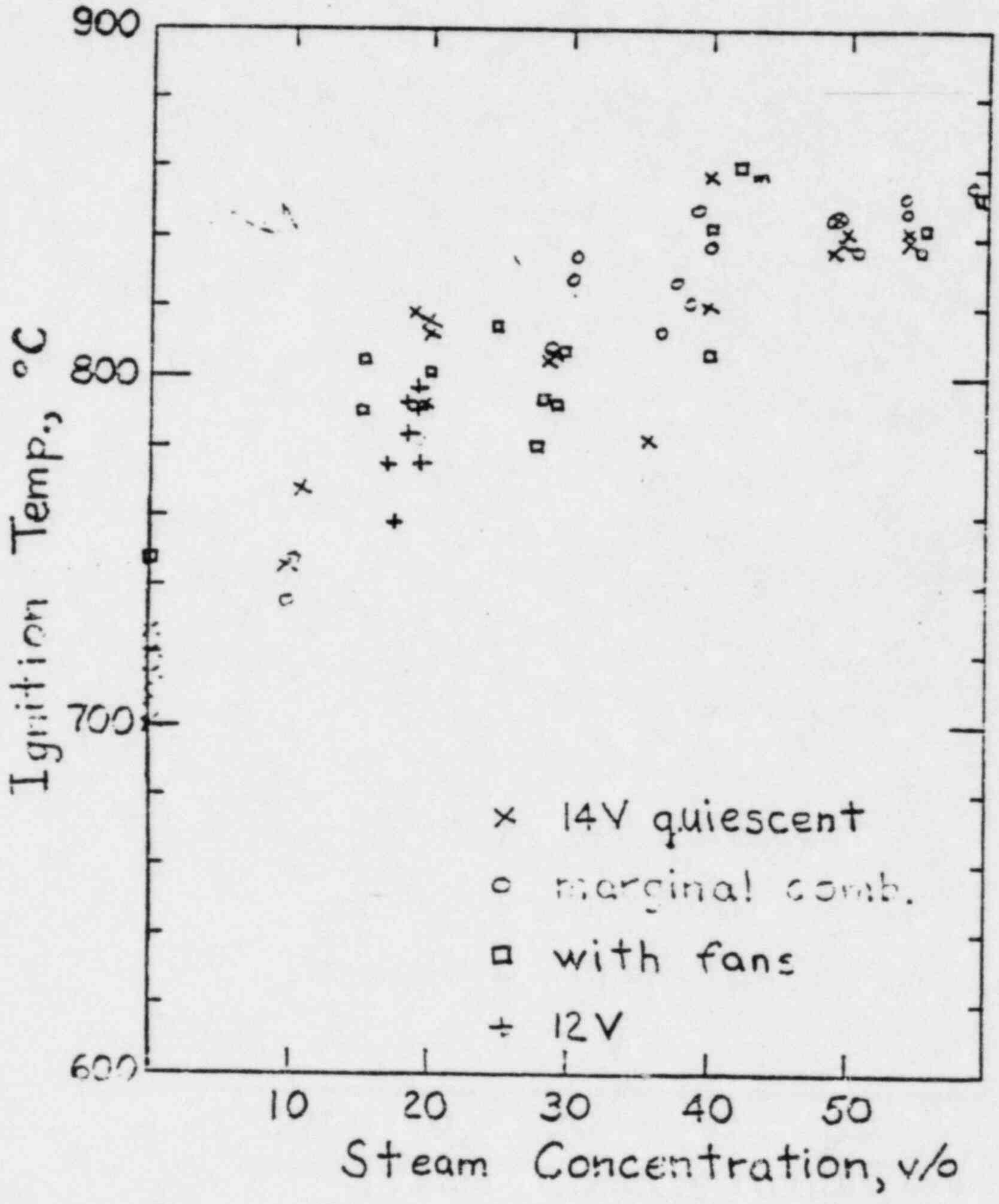


FIGURE 11. - The flammability domain for upward flame propagation for H_2-Air-H_2O(vapor) mixtures. The flammability limit curve is superimposed on the isobaric contours of calculated, adiabatic explosion pressures.



THE IGNITION LIMITS OF HYDROGEN/AIR/STEAM MIXTURES USING A GM AC MODEL NO. 7 THERMAL GLOW PLUG LOCATED AT THE CENTRE OF A 17-LITRE QUASI-SPHERICAL VESSEL.



GLOW PLUG TEMP. @ IGNITION
VS.
STEAM CONCENTRATION

CTF Experiments

1. Extent of reaction of lean mixtures

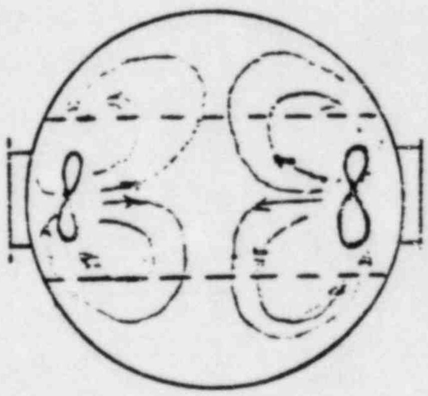
$4\% < H_2 < 10\%$
$0\% \leq H_2O \leq 30\%$

2. Laminar Spherical Deflagrations

$10\% \leq H_2 \leq 42\%$
$0\% \leq H_2O \leq 30\%$

3. Effect of Turbulence Induced by Fans & Obstacles

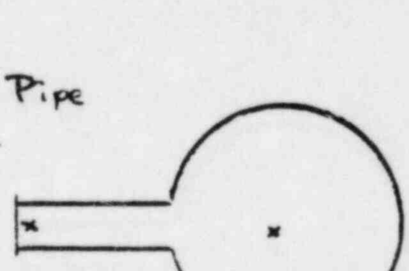
2 fans w/ air deflectors
& continuously variable speed
(7 air changes/min/fan)



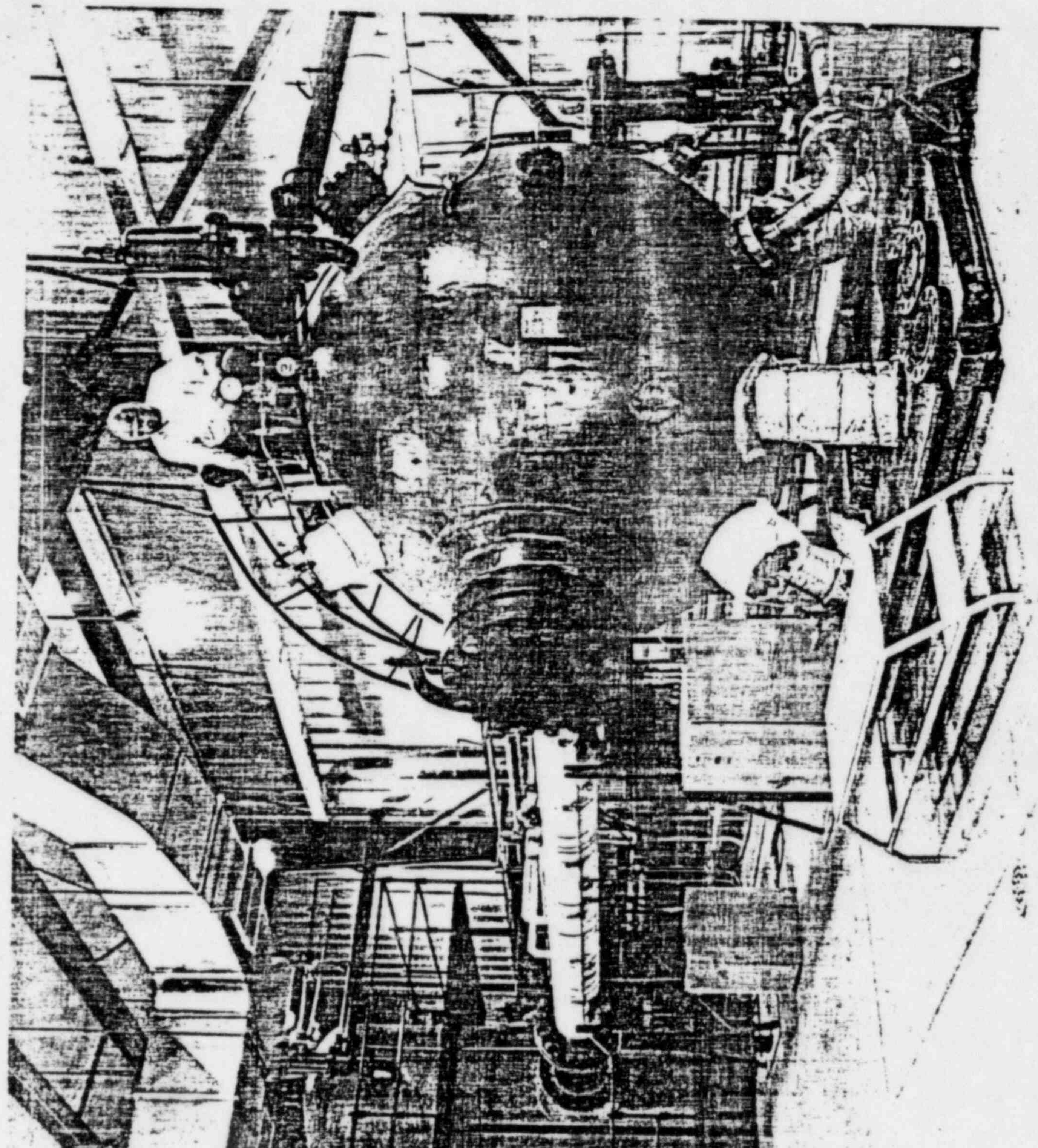
horizontal gratings
@ 1/3 points
1" holes in 1/4" plate.
50% blocked area

lean mixtures & richer (10-20%) mixtur

4. Sphere & Protruding Pipe



× ignition points



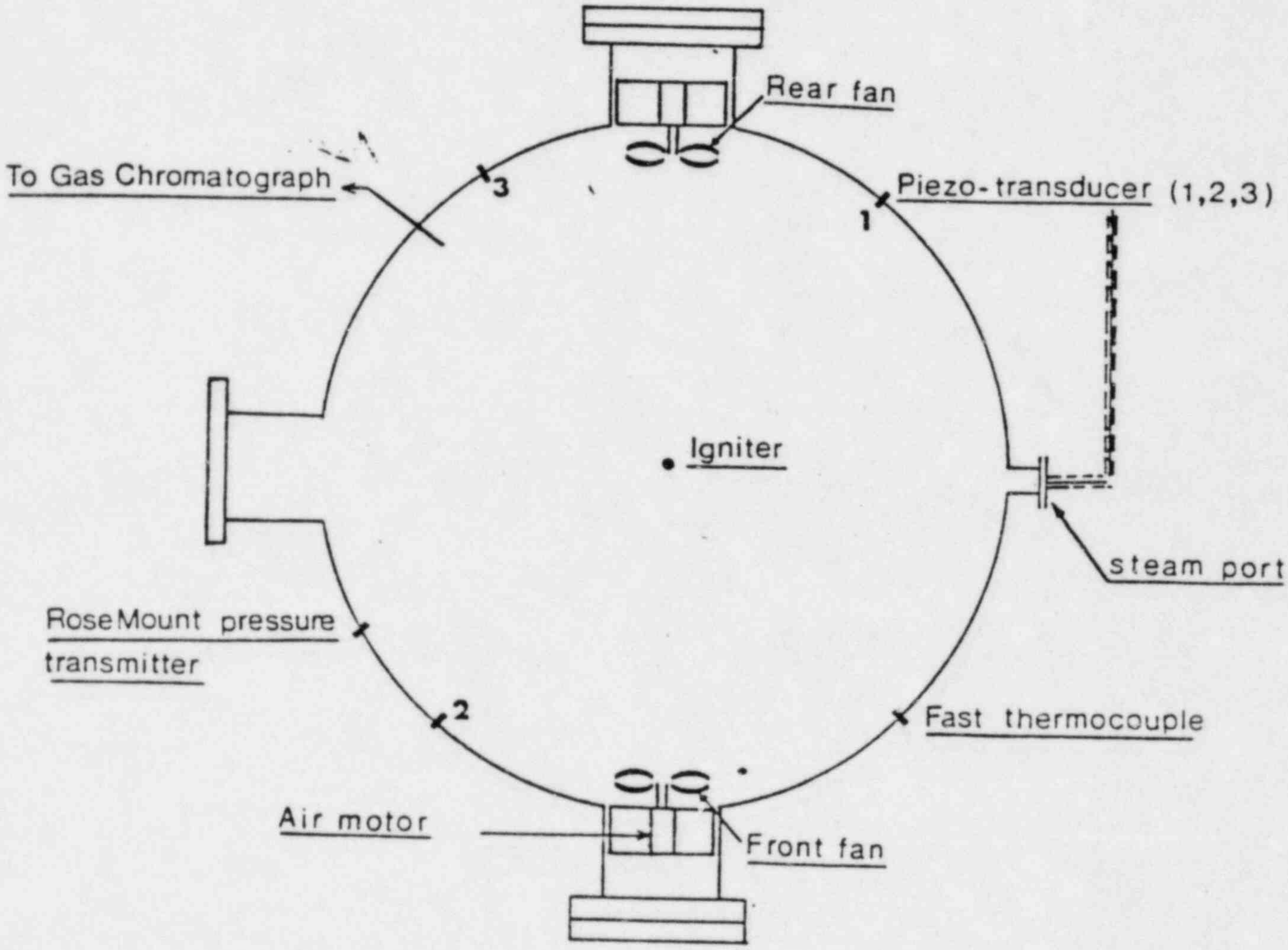
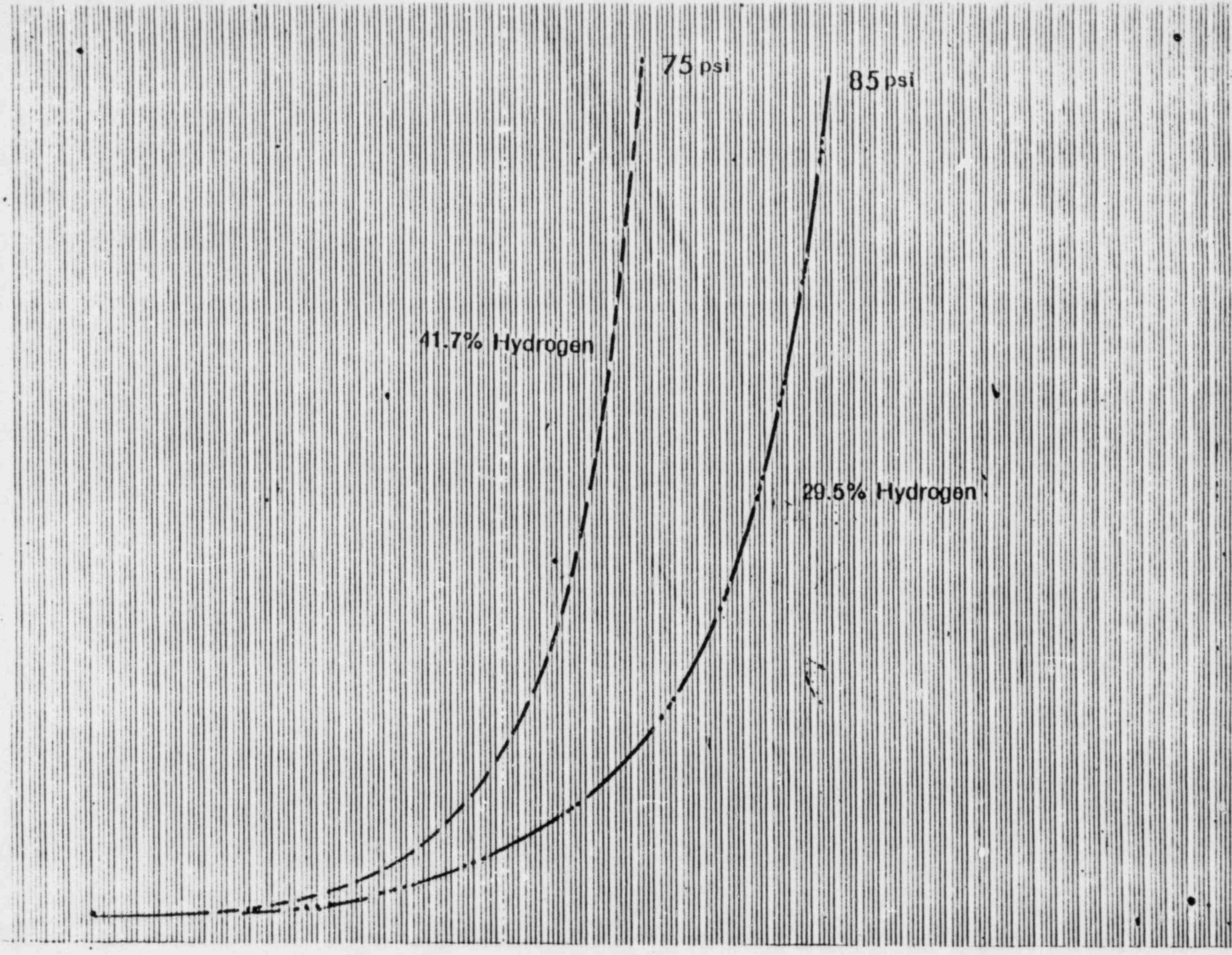
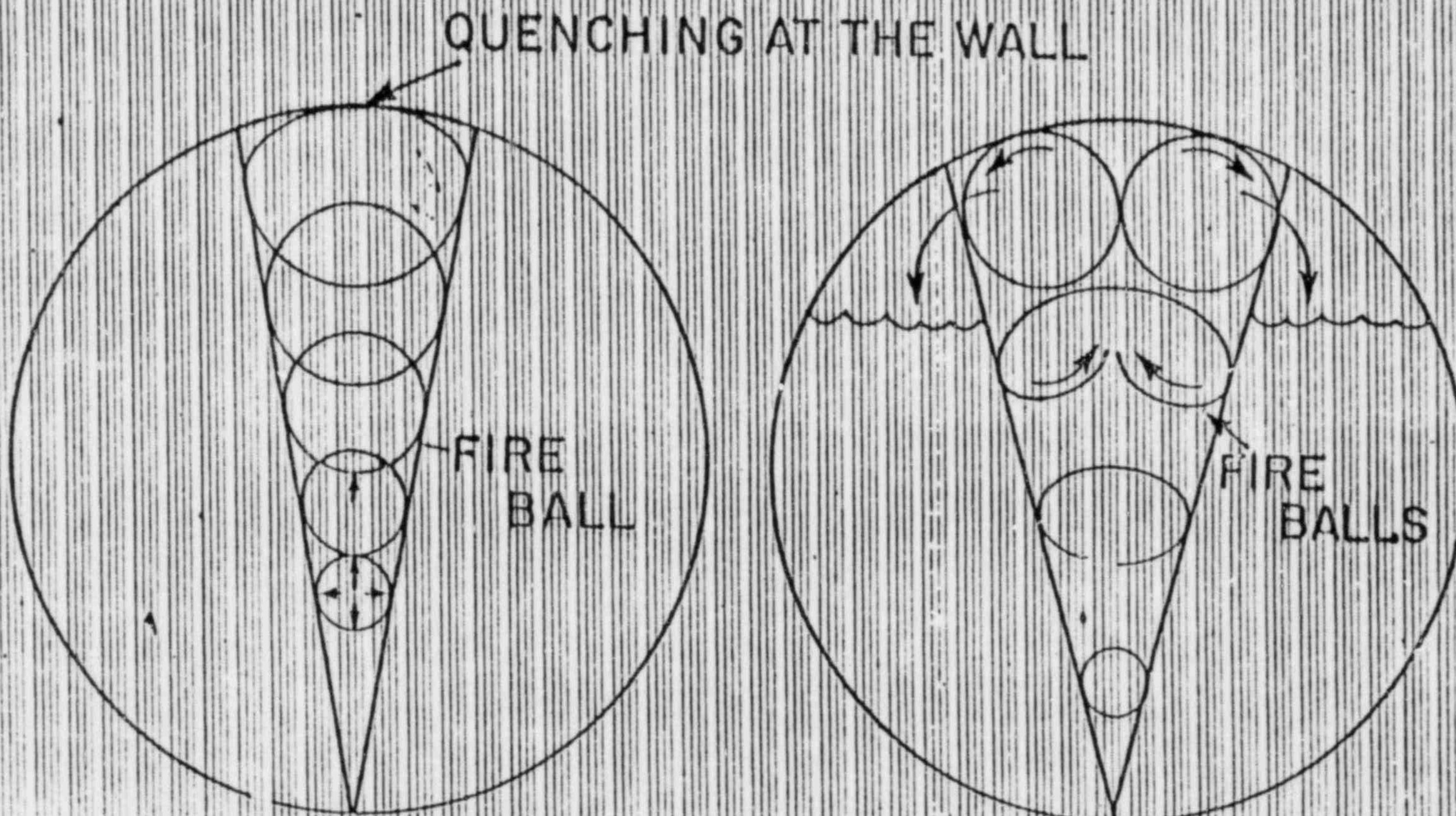


Figure 1: ARRANGEMENT OF FANS IN THE SPHERE AND INSTRUMENTATION

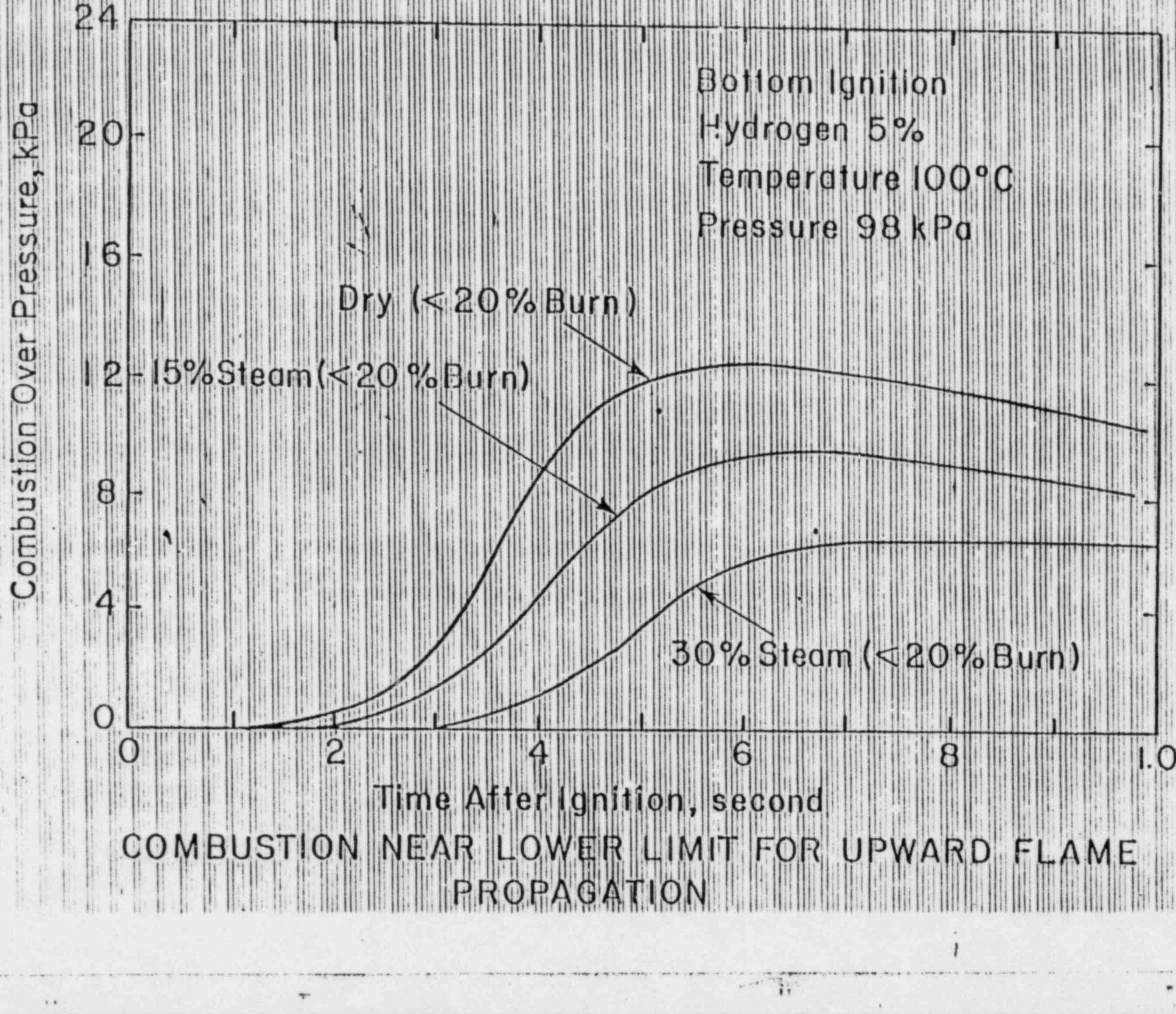

75 psi
85 psi
41.7% Hydrogen
29.5% Hydrogen



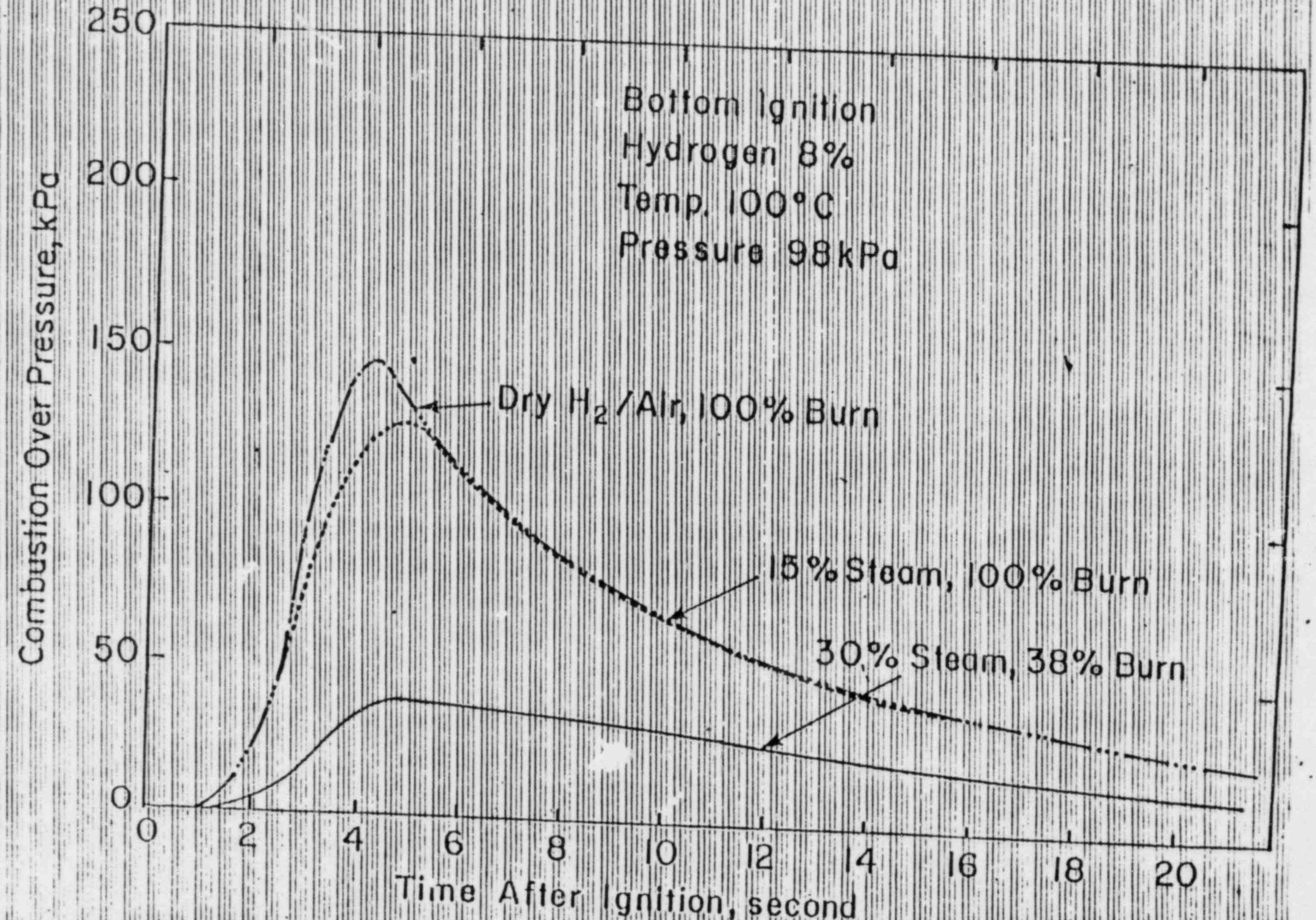
UPWARD PROPAGATION ONLY

UPWARD FOLLOWED BY
DOWNWARD PROPAGATION

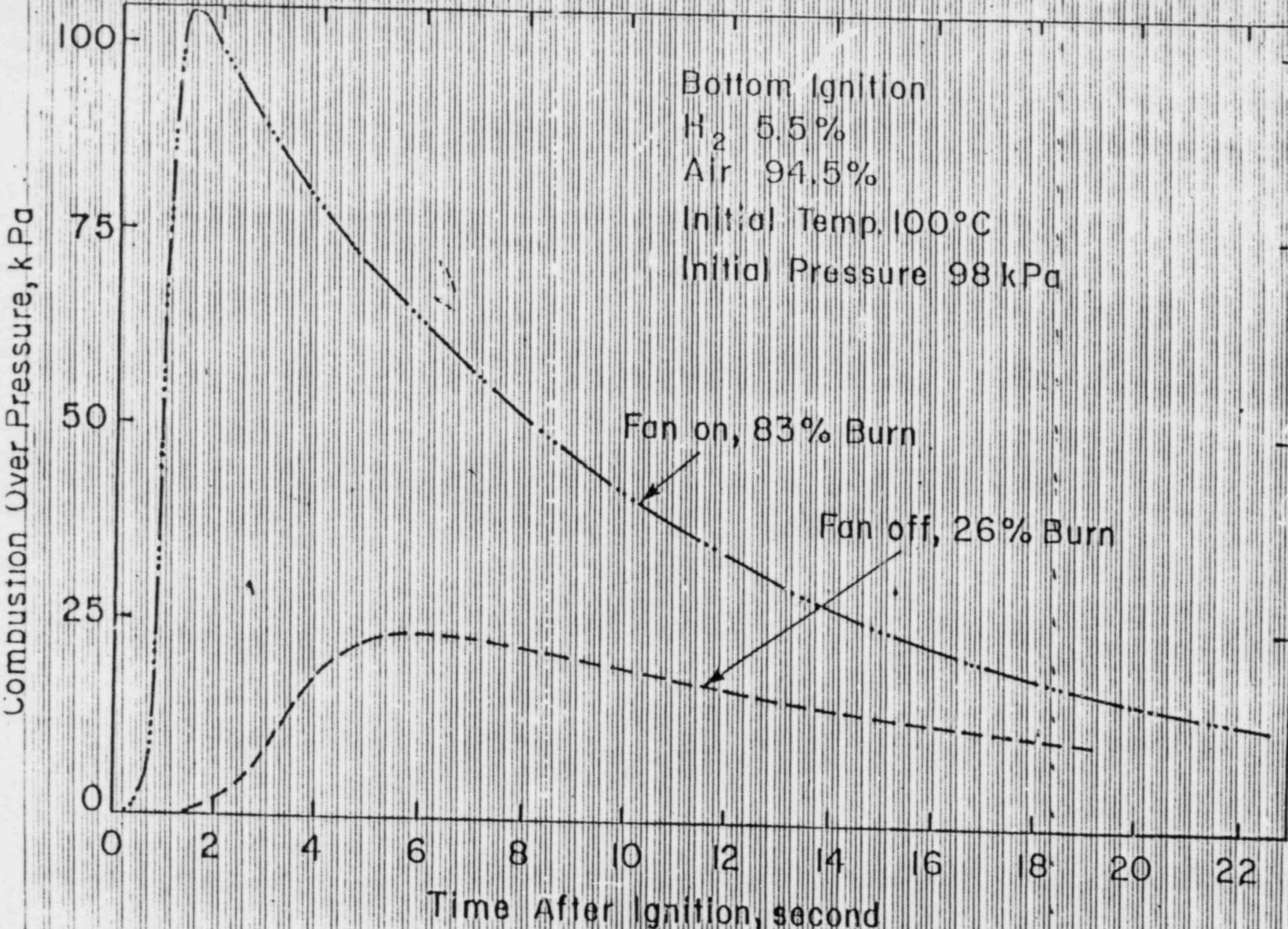
SCHEMATIC OF FLAME PROPAGATION



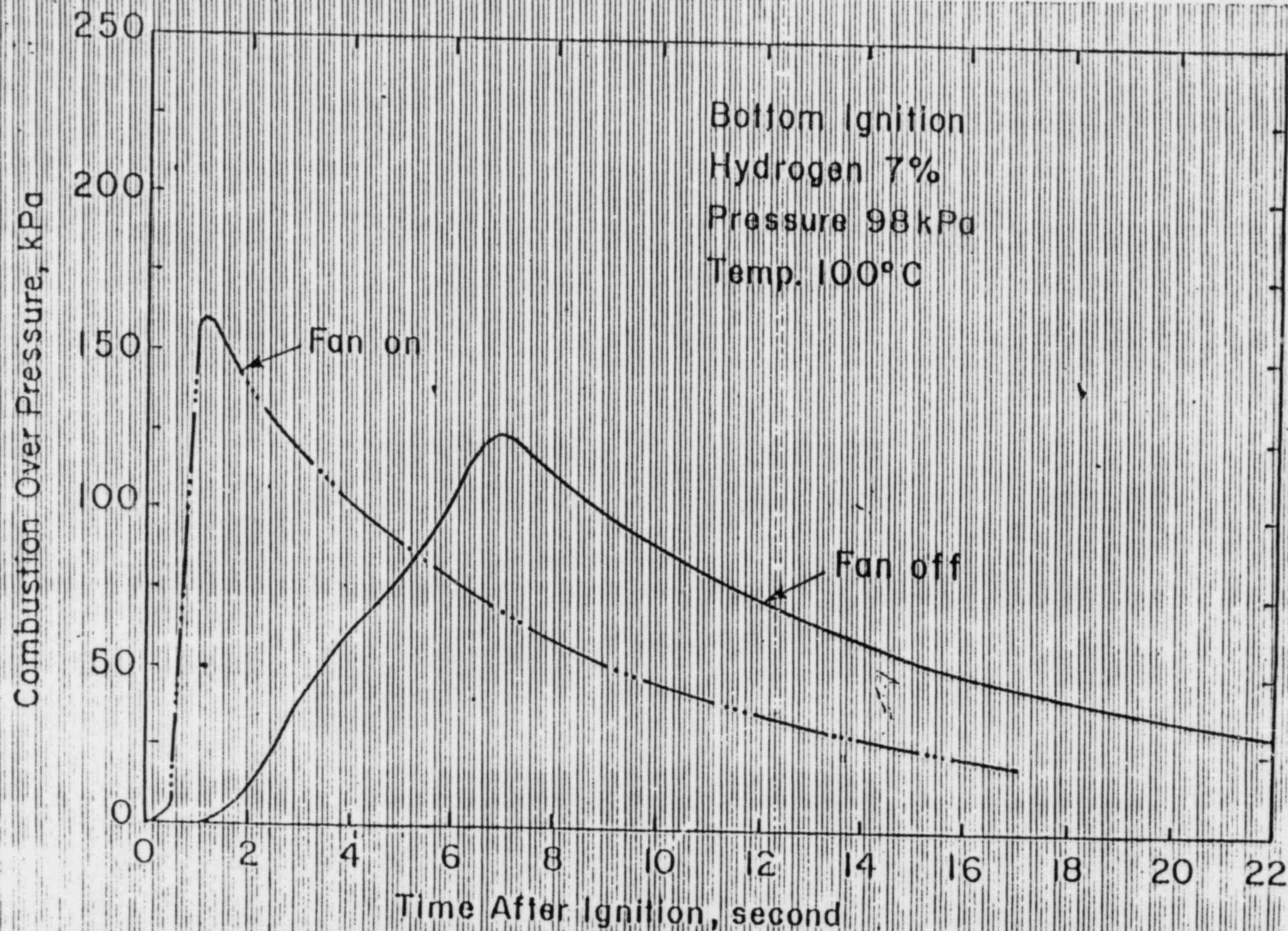
COMBUSTION NEAR LOWER LIMIT FOR UPWARD FLAME PROPAGATION



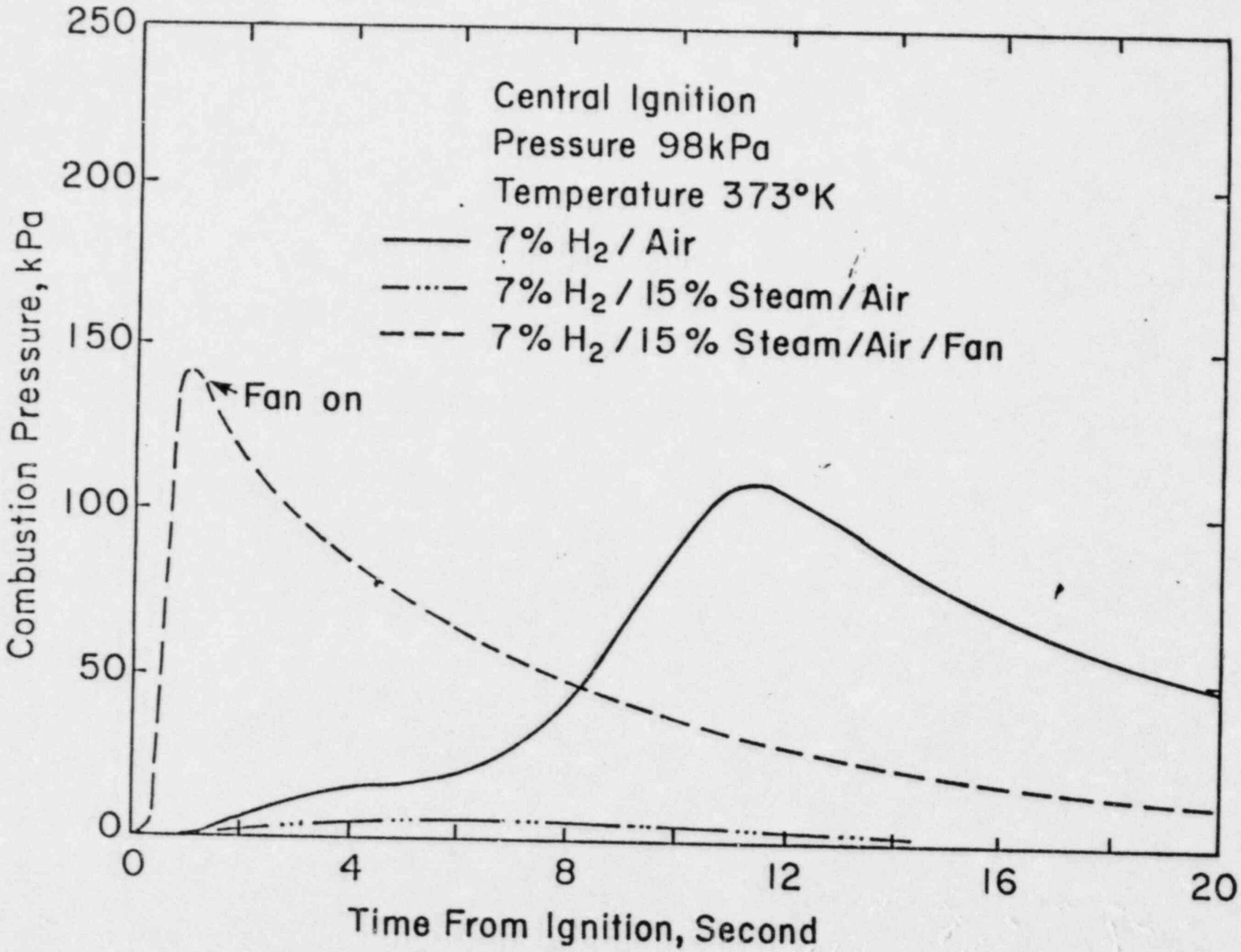
EFFECT OF STEAM ADDITION



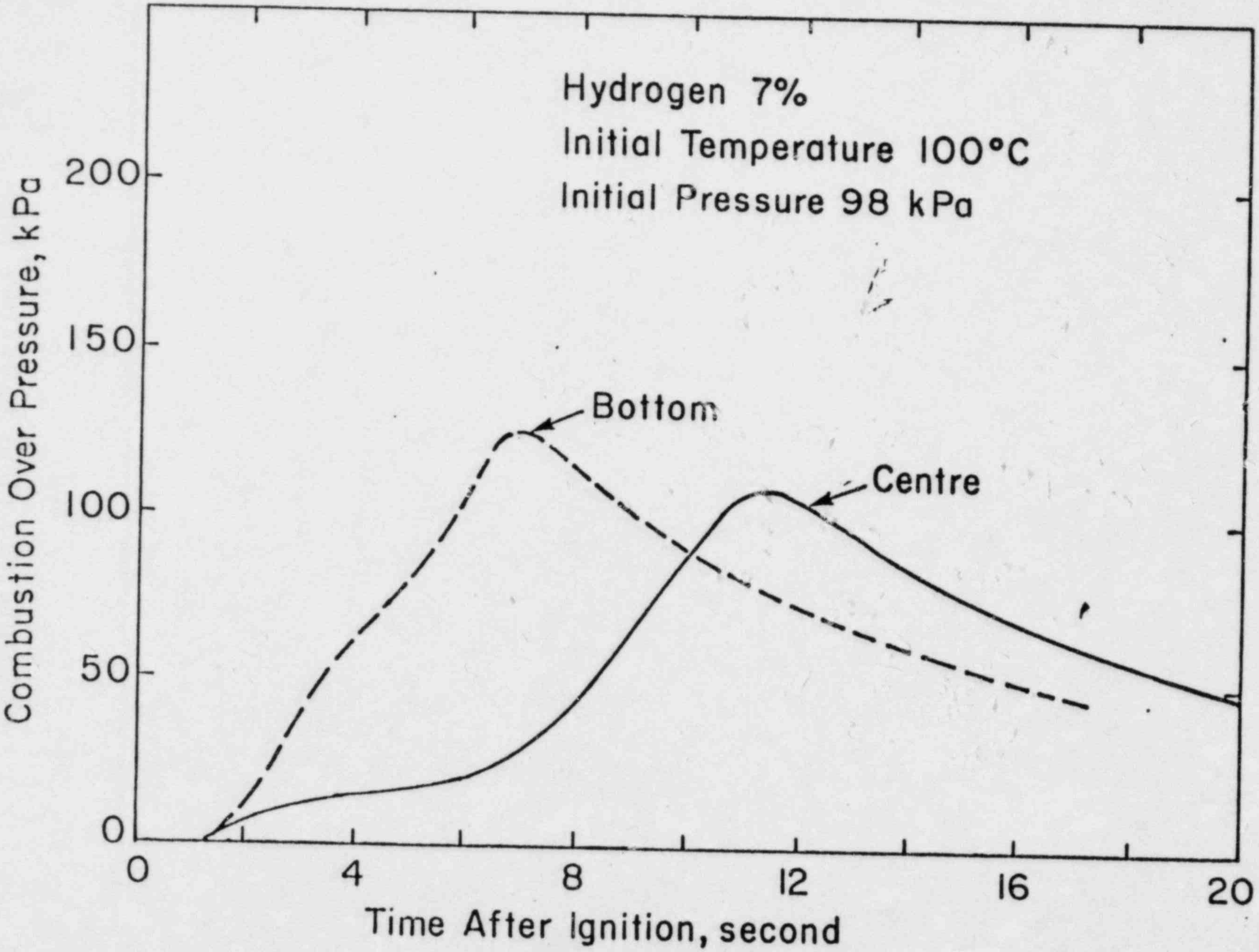
EFFECT OF INITIAL TURBULENCE ON H_2 BURN



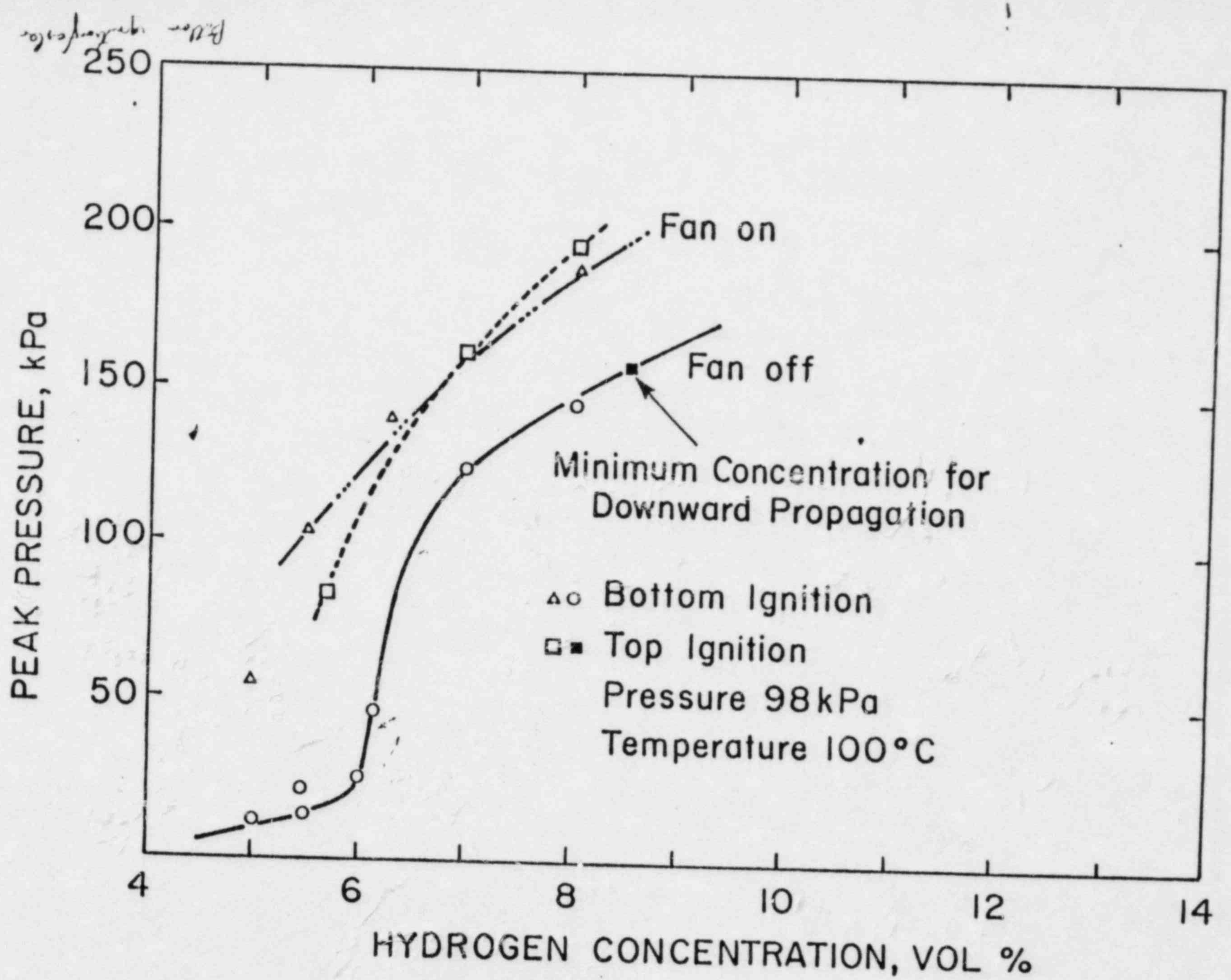
EFFECT OF INITIAL TURBULENCE ON COMBUSTION



RELATIVE EFFECTS OF STEAM AND TURBULENCE



EFFECT OF IGNITOR LOCATION



PEAK PRESSURE, kPa
250
200
150
100
50
4
6
8
10
12
14
HYDROGEN CONCENTRATION, VOL %
Fan on
Fan off
Minimum Concentration for Downward Propagation
Bottom Ignition
Top Ignition
Pressure 98 kPa
Temperature 100°C

Series 1 - Near LFL

- small amounts of steam do not markedly affect nature & extent of combustion
- bottom ignition is faster & more complete
- fan-induced turbulence increases rate & extent of combustion
- steam inhibition is more evident with central than with bottom ignition.

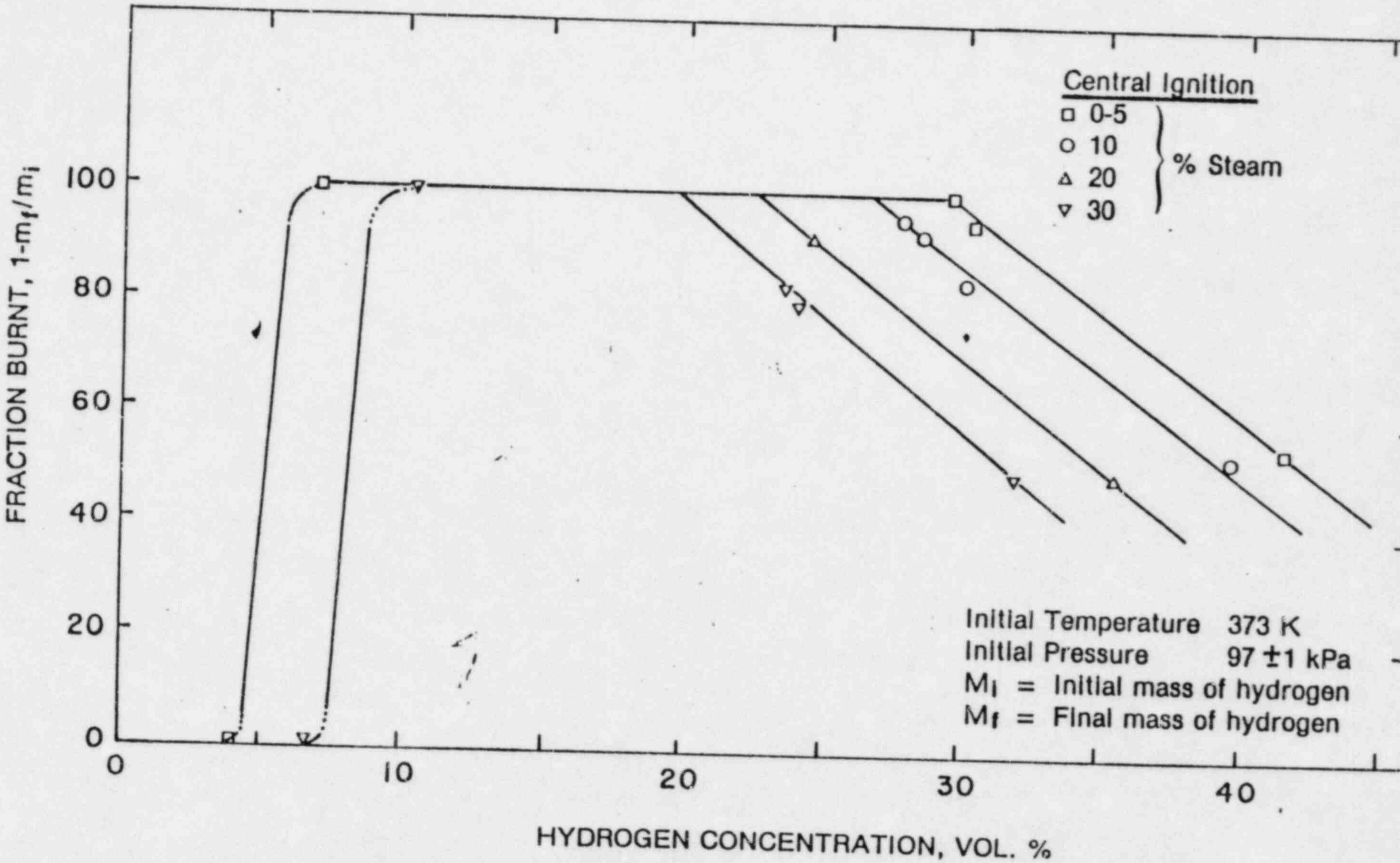


Figure 4: EFFECT OF STEAM ON THE EXTENT OF BURN

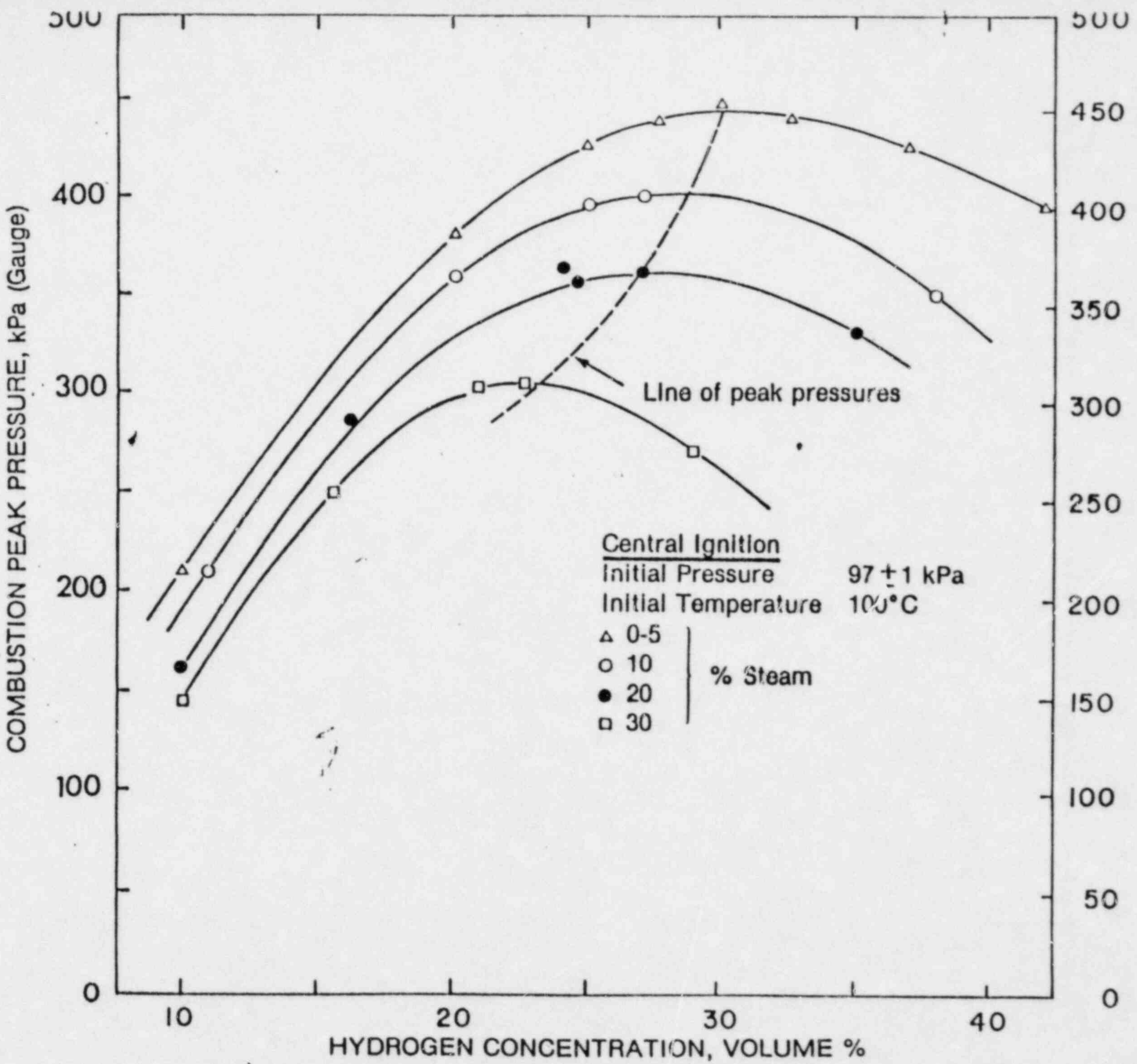


Figure 3: EFFECT OF STEAM AT HIGH CONCENTRATIONS

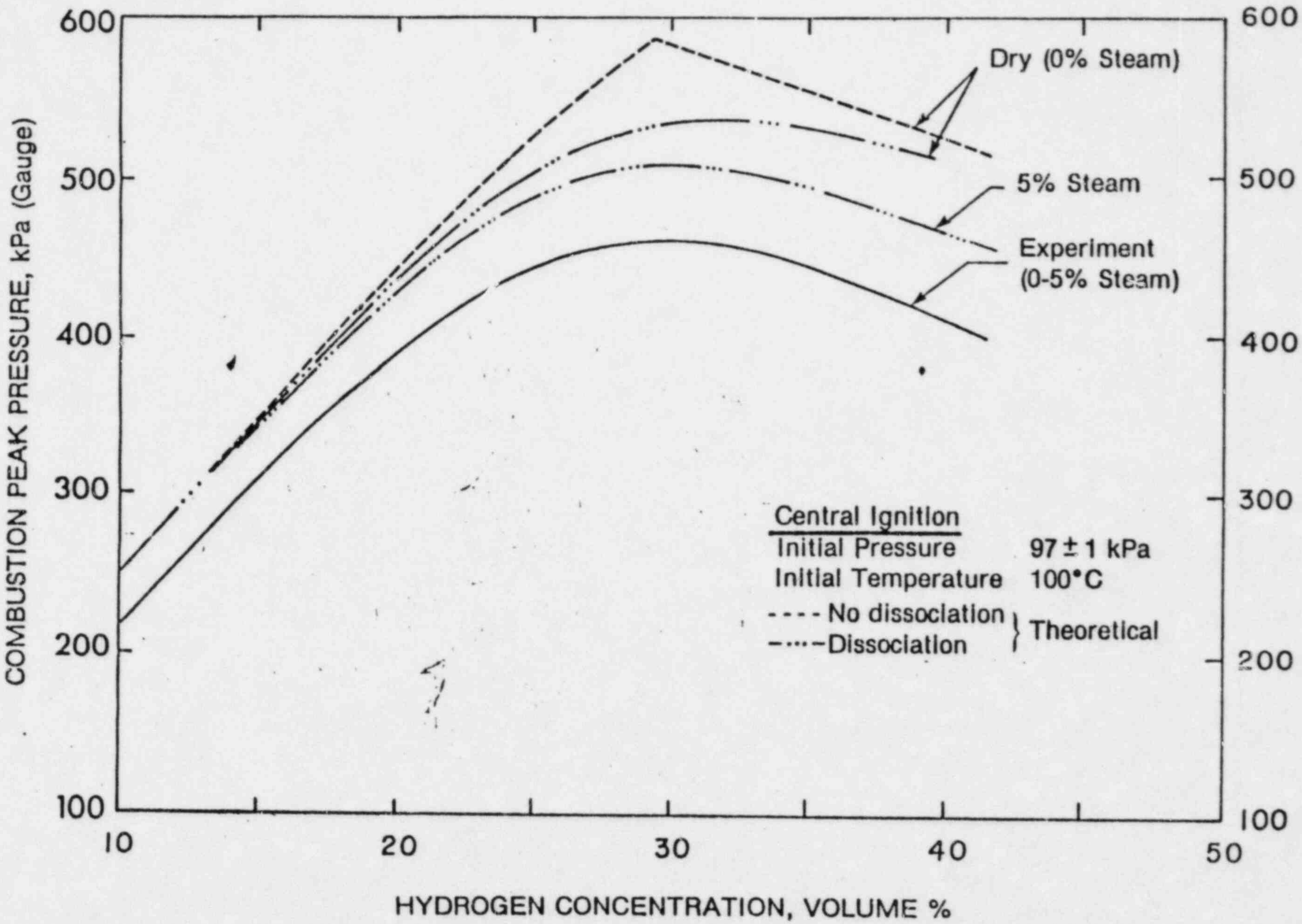


Figure 5: COMPARISON BETWEEN PREDICTED AND OBSERVED PRESSURE RISE

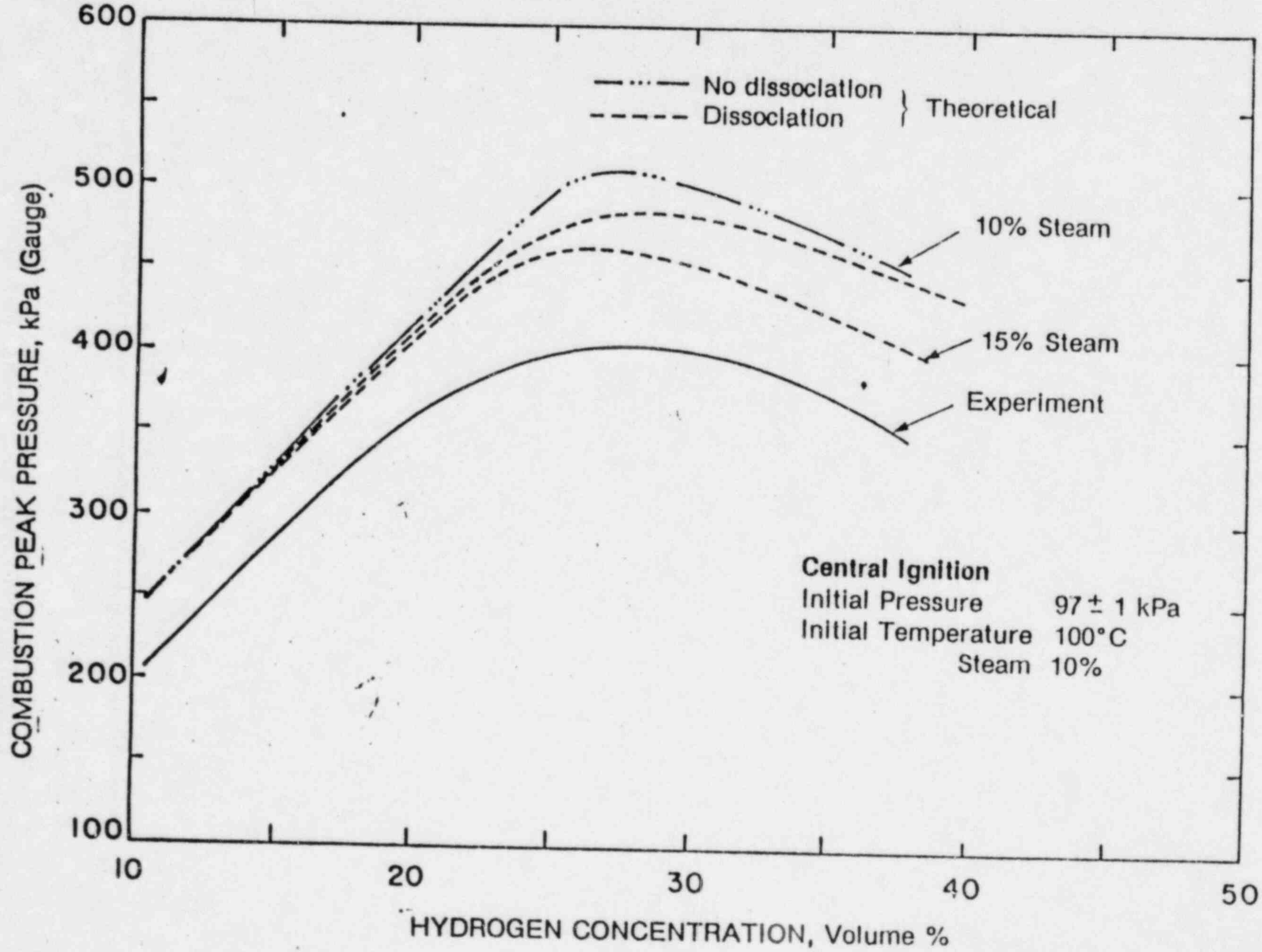


Figure: **Comparison Between the Predicted and Observed Pressure Rise**

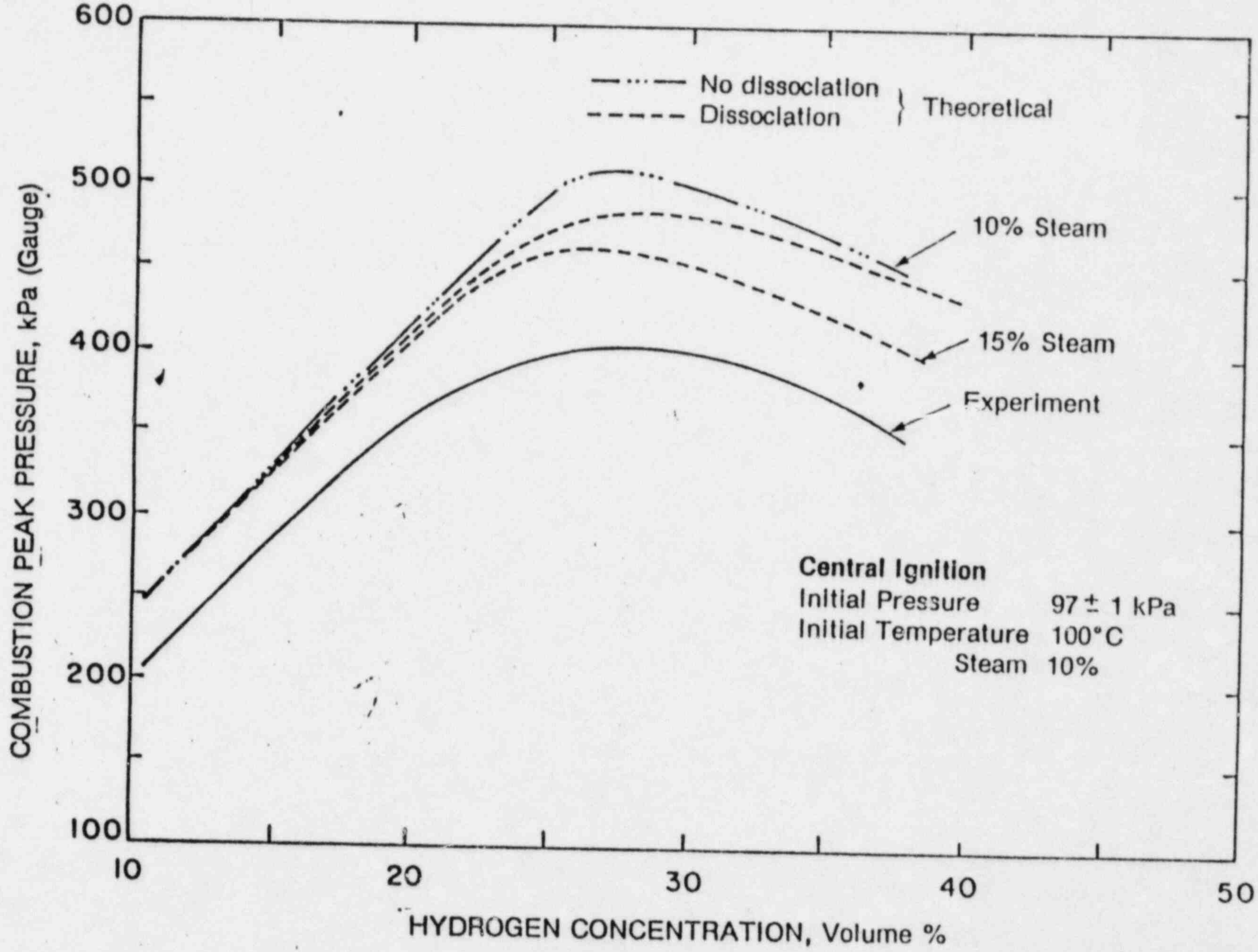


Figure: Comparison Between the Predicted and Observed Pressure Rise

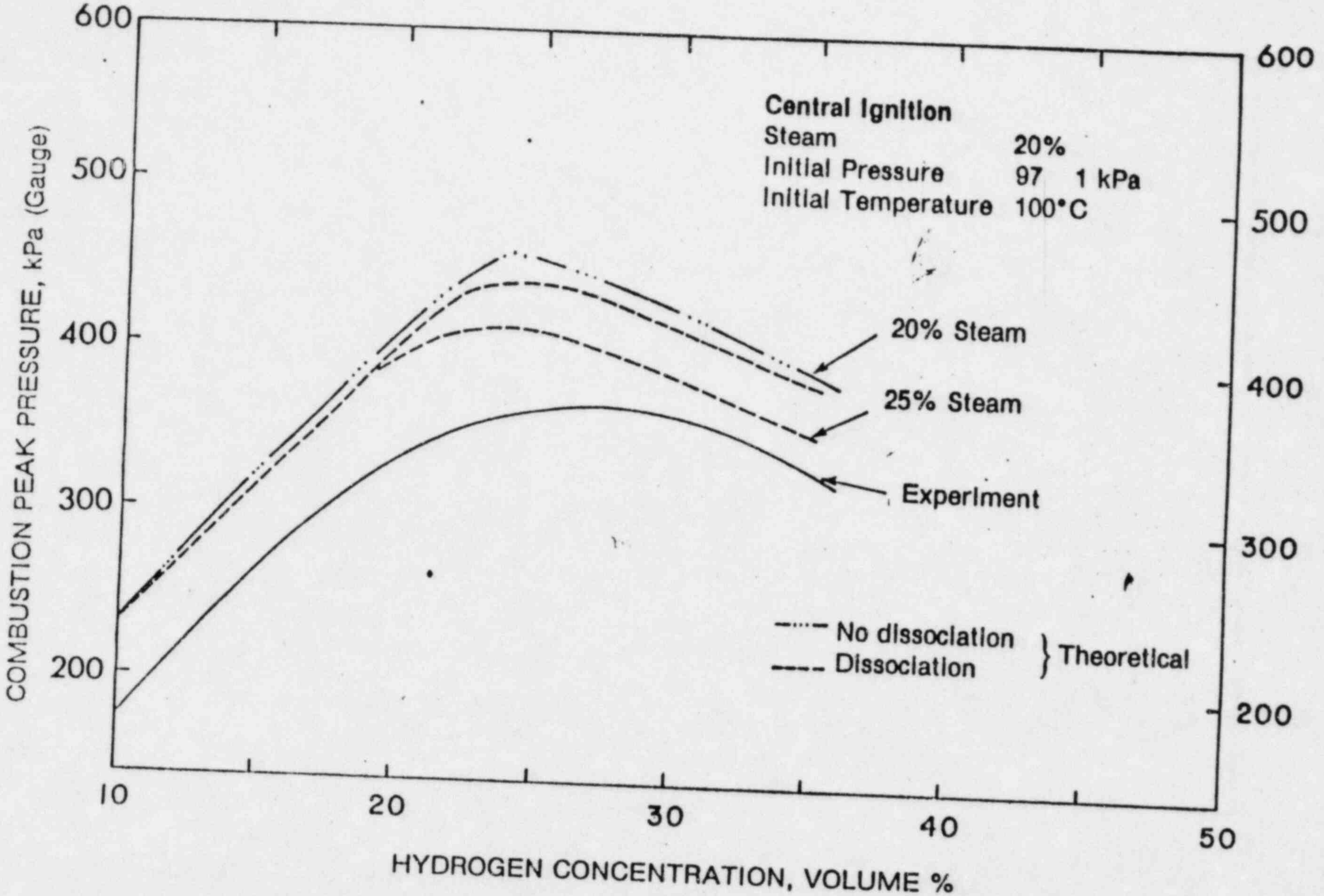


Figure: Comparison Between Predicted and Observed Pressure Rise

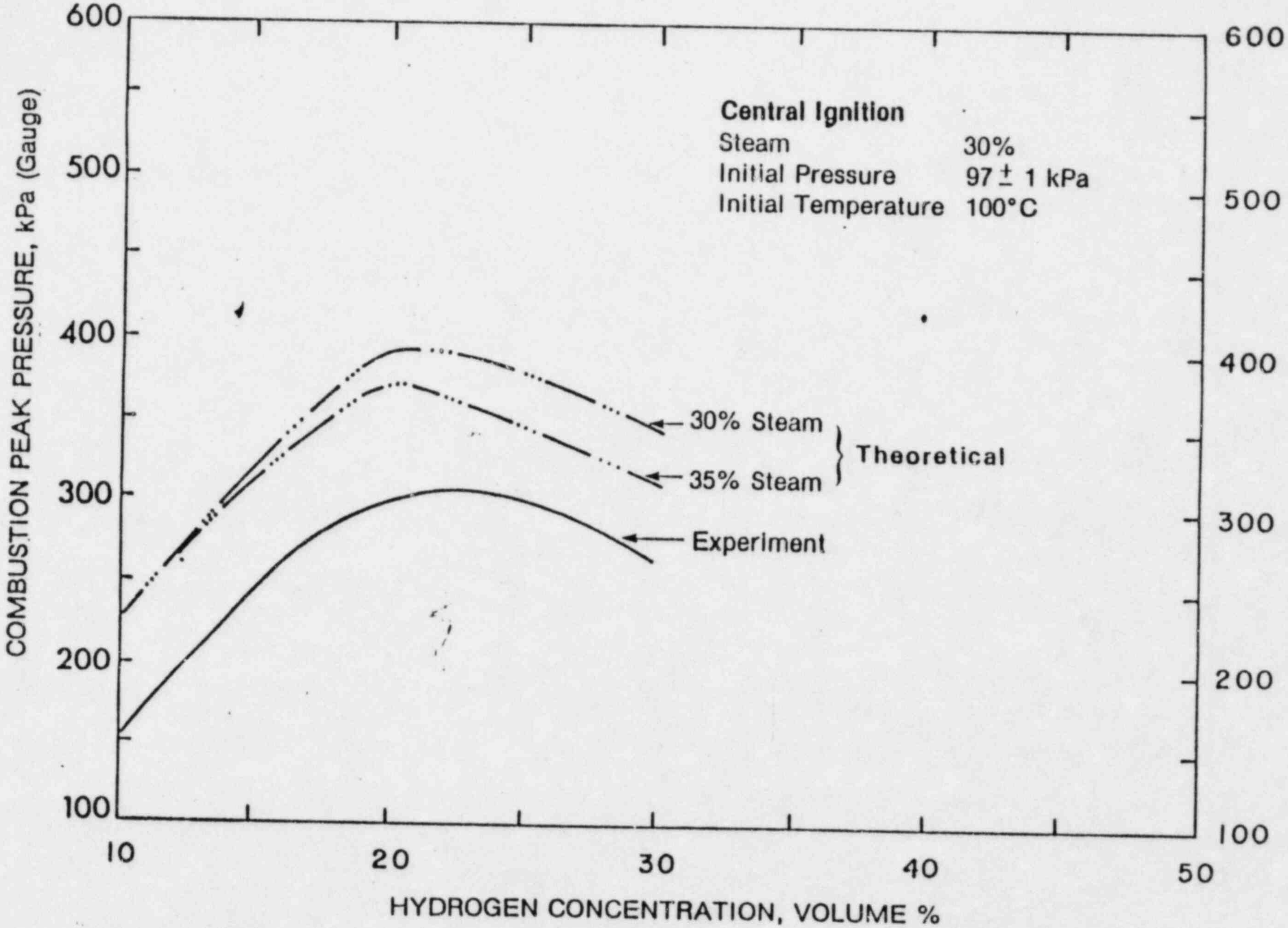


Figure: Comparison Between Predicted and Observed Pressure Rise

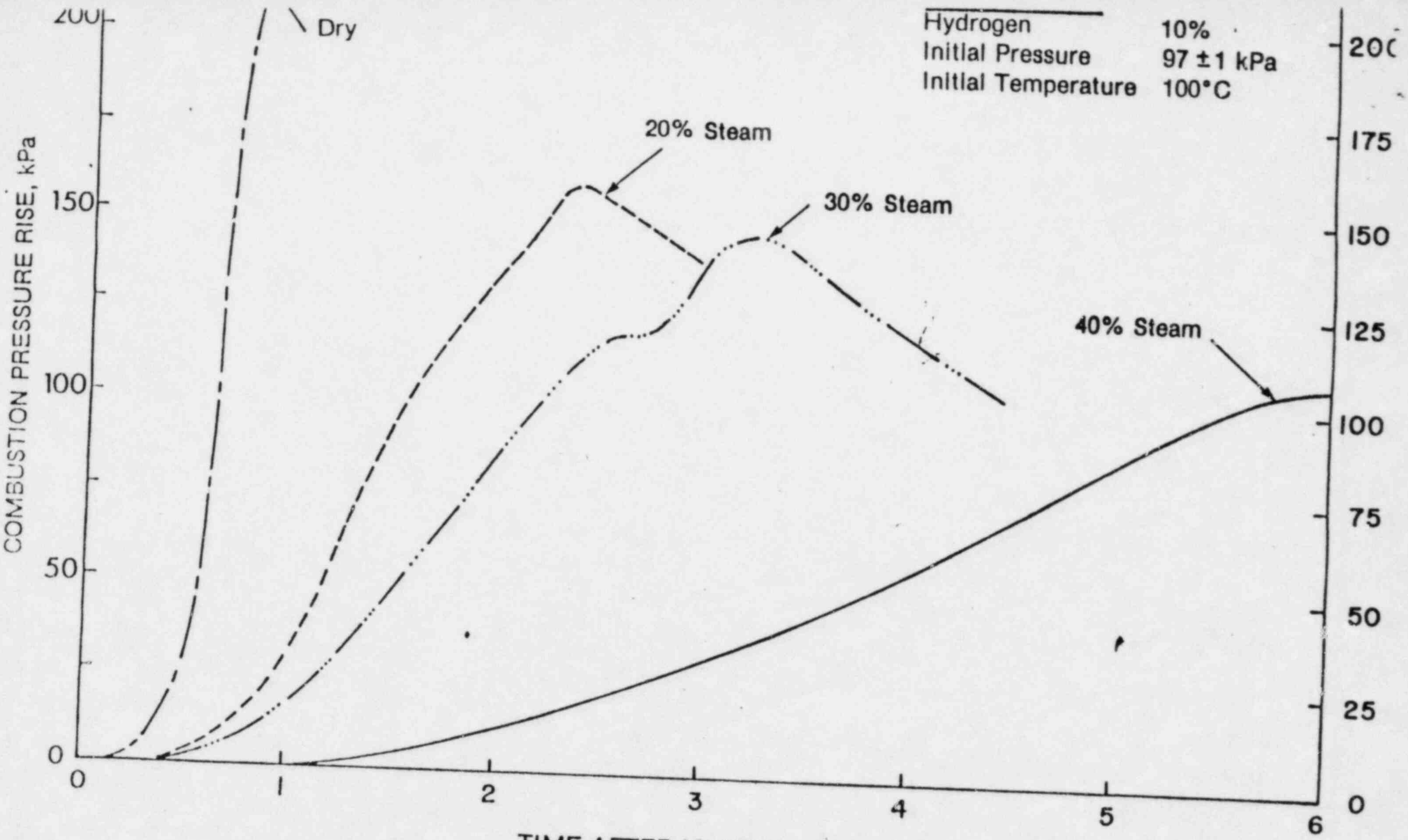


Figure 2: EFFECT OF STEAM ON COMBUSTION UNDER QUIESCENT CONDITIONS

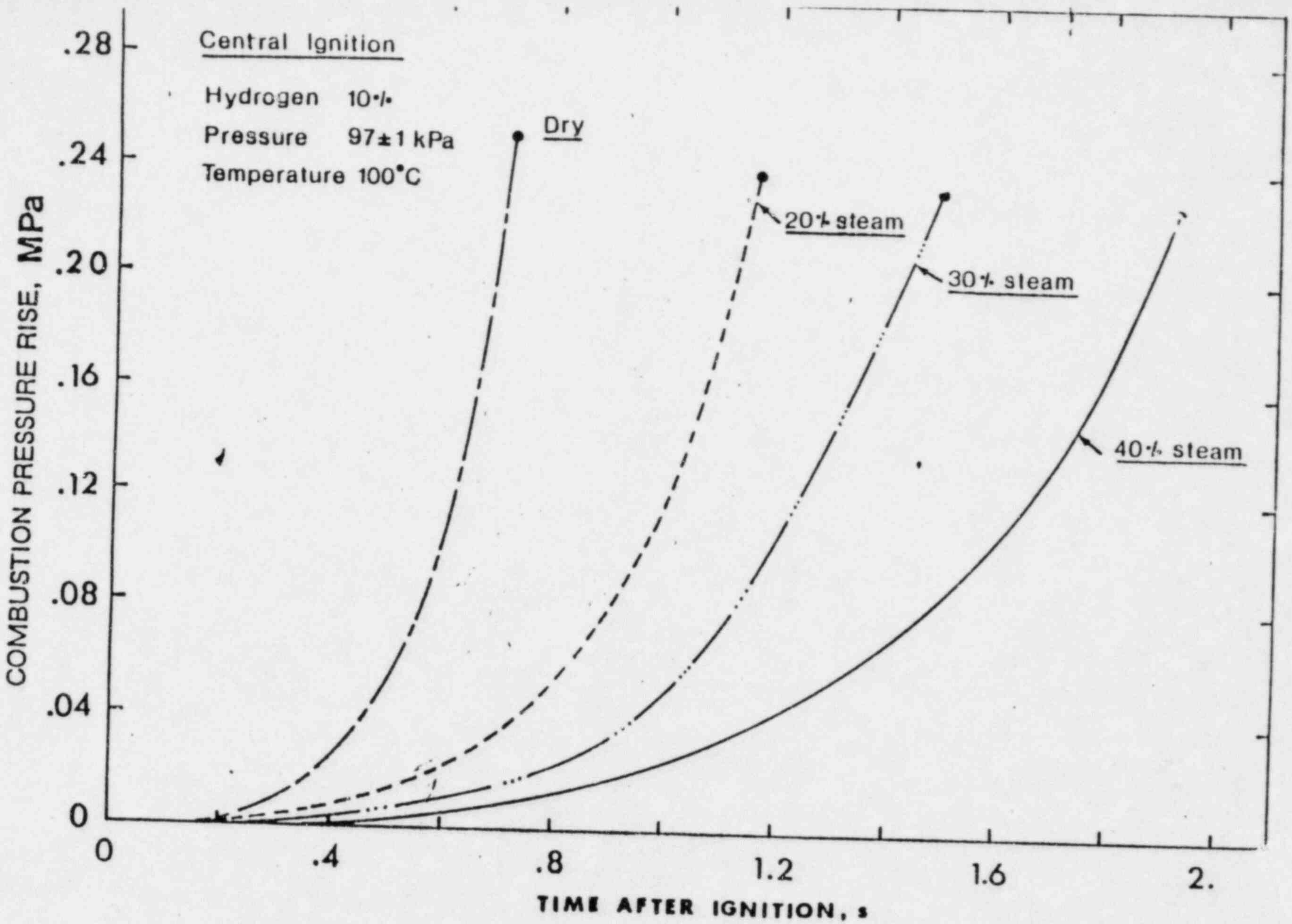


Figure 5(b): THEORETICAL PRESSURE RISE AT 10% HYDROGEN

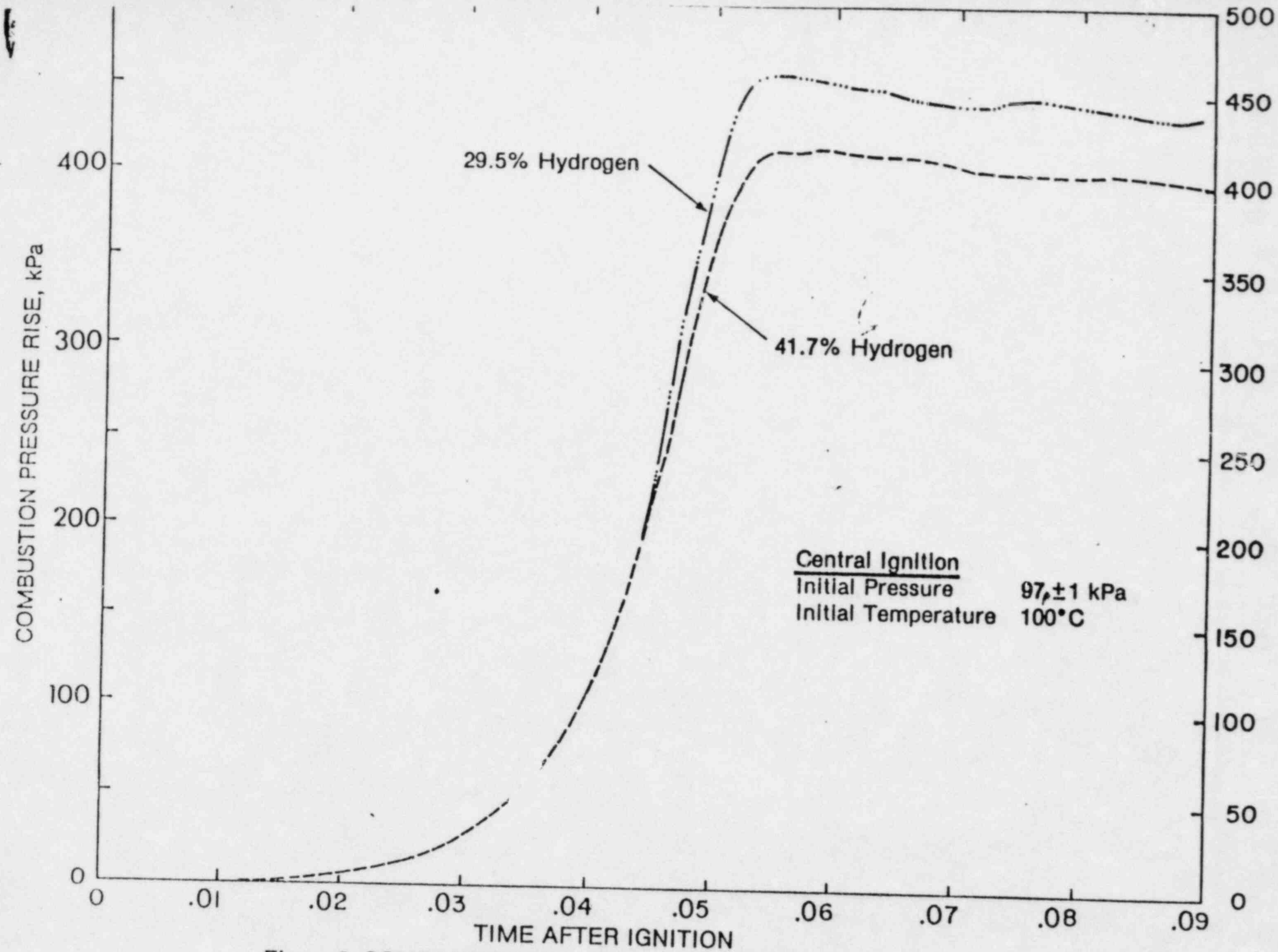


Figure 6: COMPARISON OF PRESSURE-TIME HISTORY OF
MAXIMUM BURNING VELOCITY AND STOICHIOMETR[illegible]

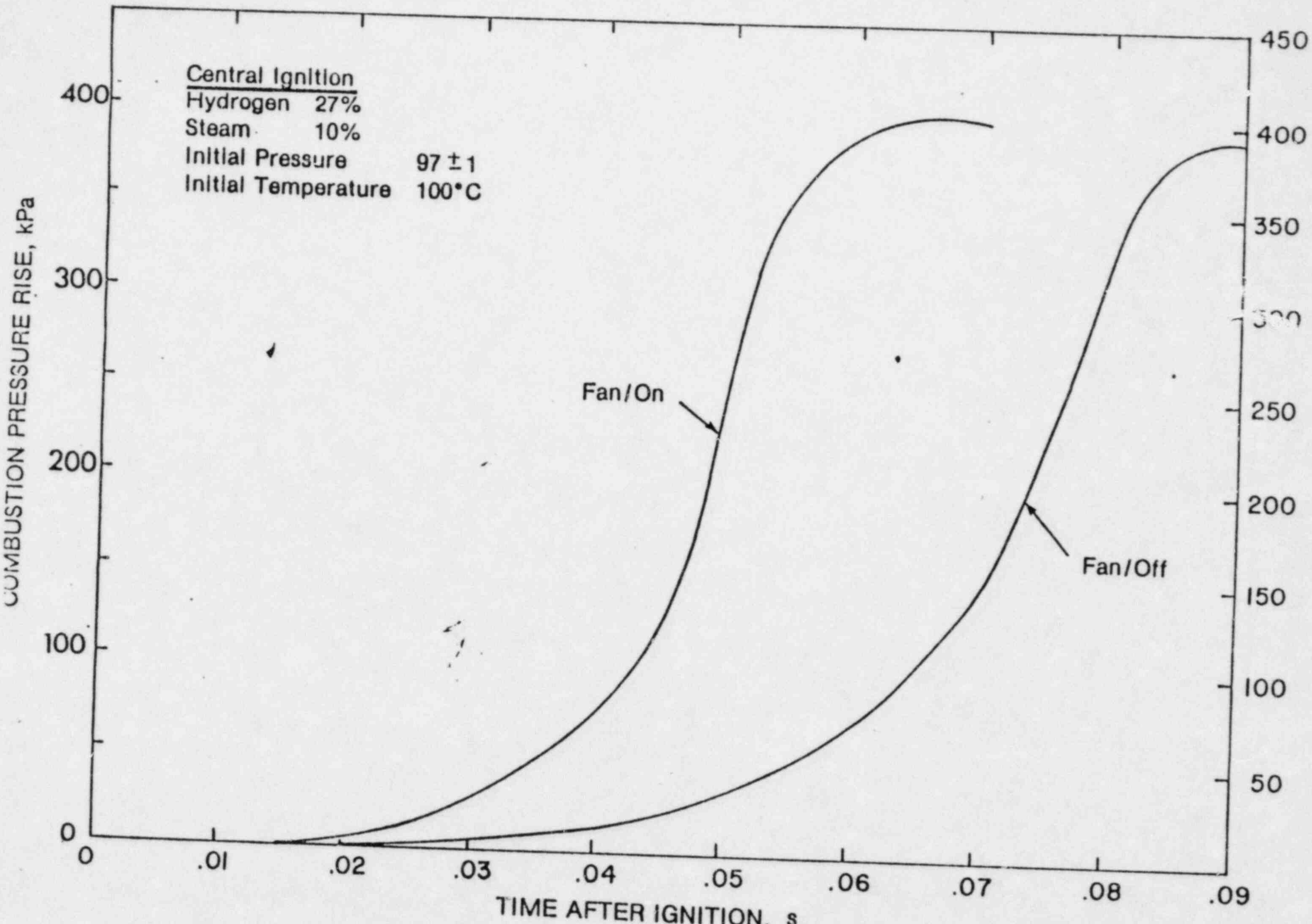


Figure 7: EFFECT OF TURBULENCE ON COMBUSTION

Series 2

- measured peak pressures < adiabatic, particularly with steam

- fan-induced turbulence effect less pronounced than for Series 1

- combustion time is shortest for a dry stoichiometric mixture

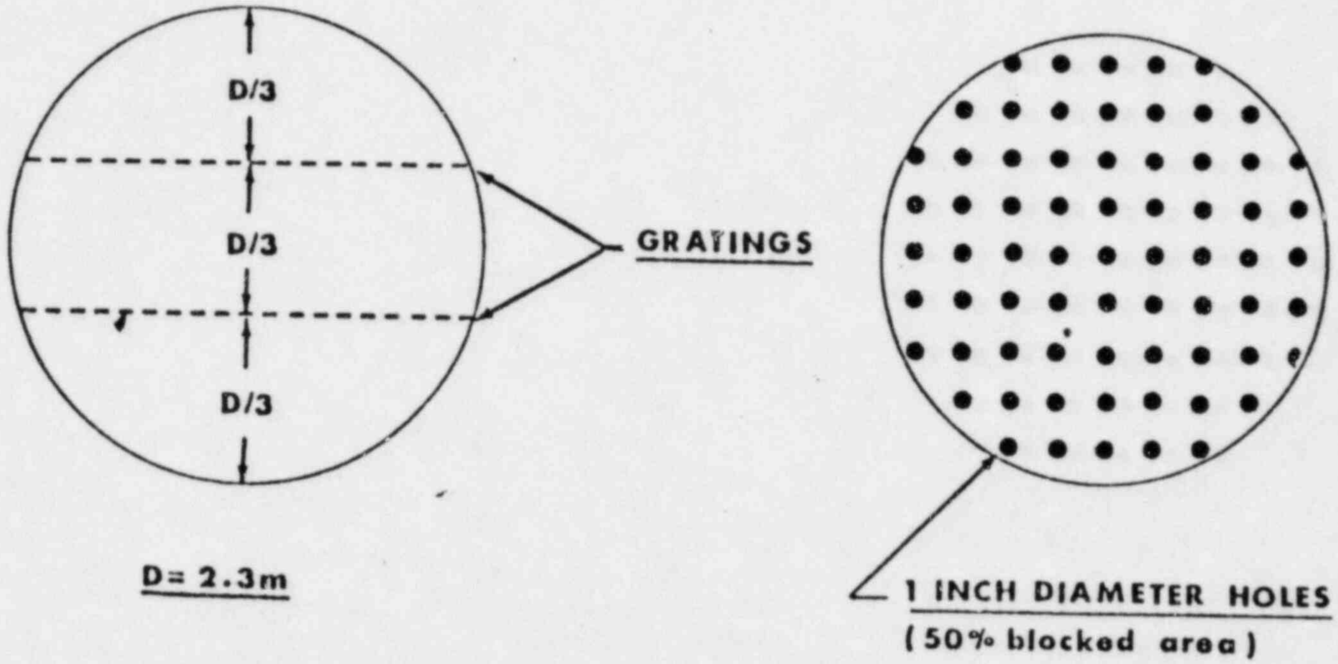


Figure 8: SCHEMATIC OF THE ARRANGEMENT OF GRATINGS IN THE SPHERE

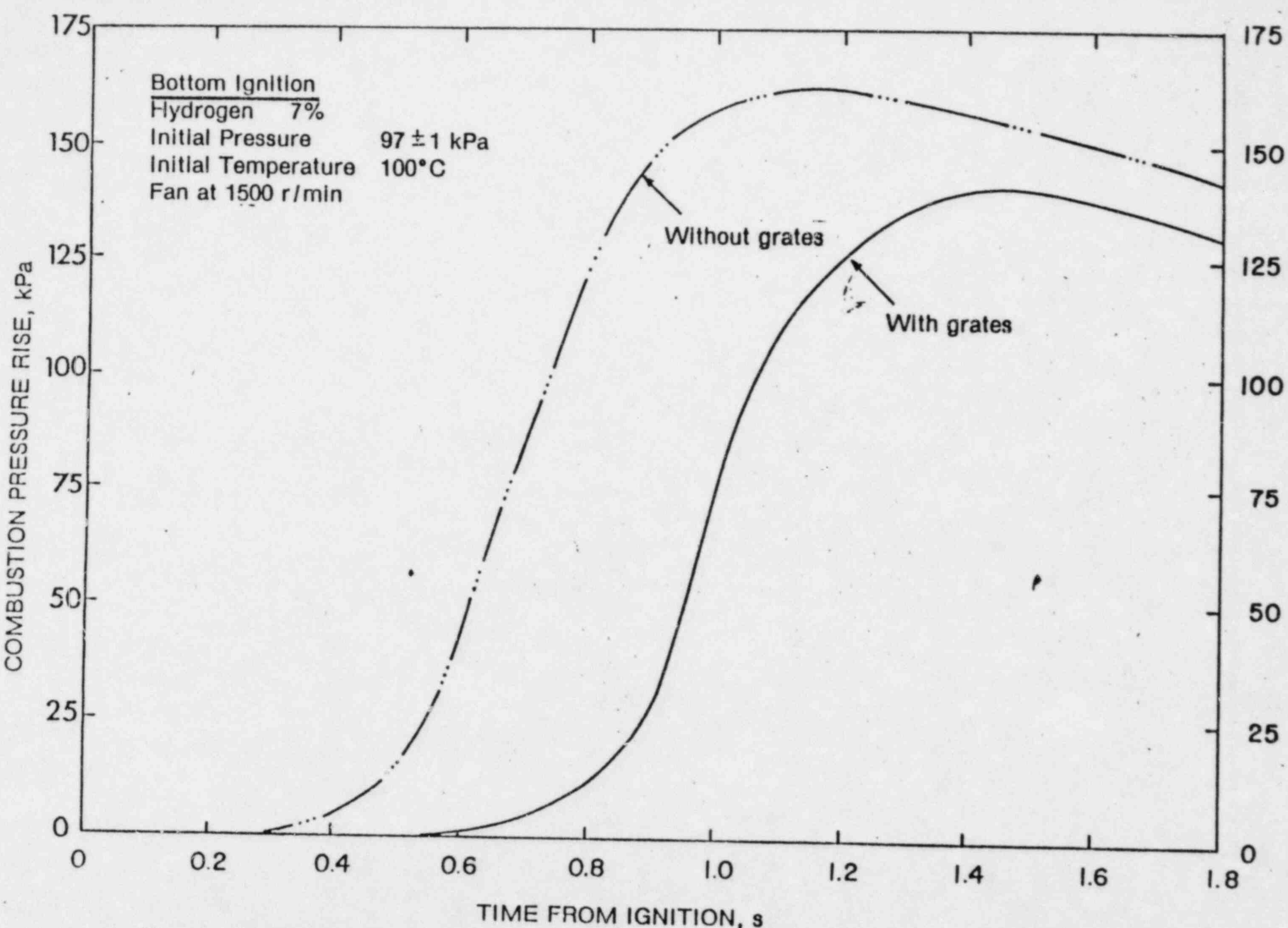


Figure 11: EFFECT OF GRATINGS ON COMBUSTION IN THE PRESENCE OF TURBULENCE

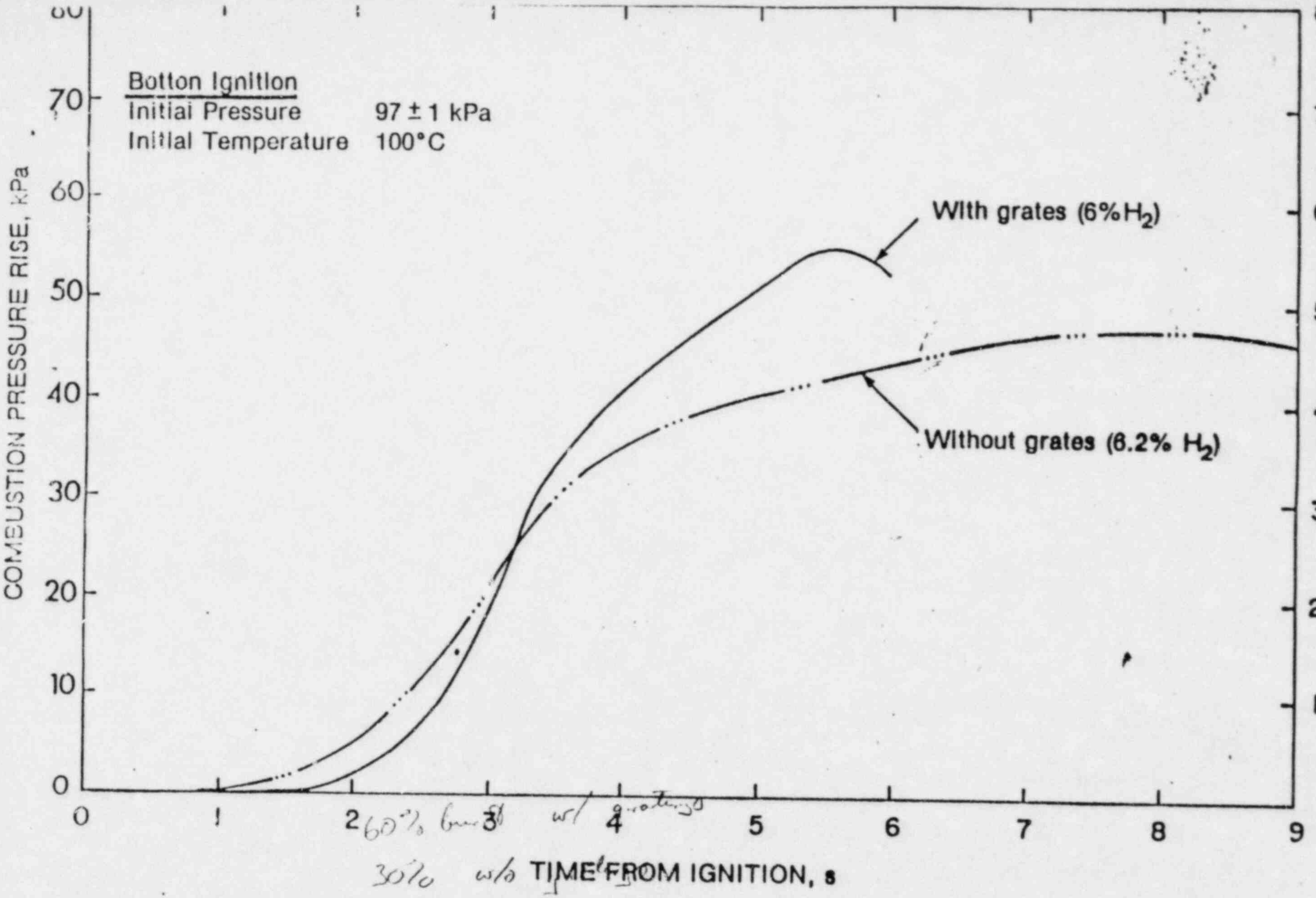


Figure 9: EFFECT OF GRATINGS ON COMBUSTION AT LOW HYDROGEN CONCENTRATIONS

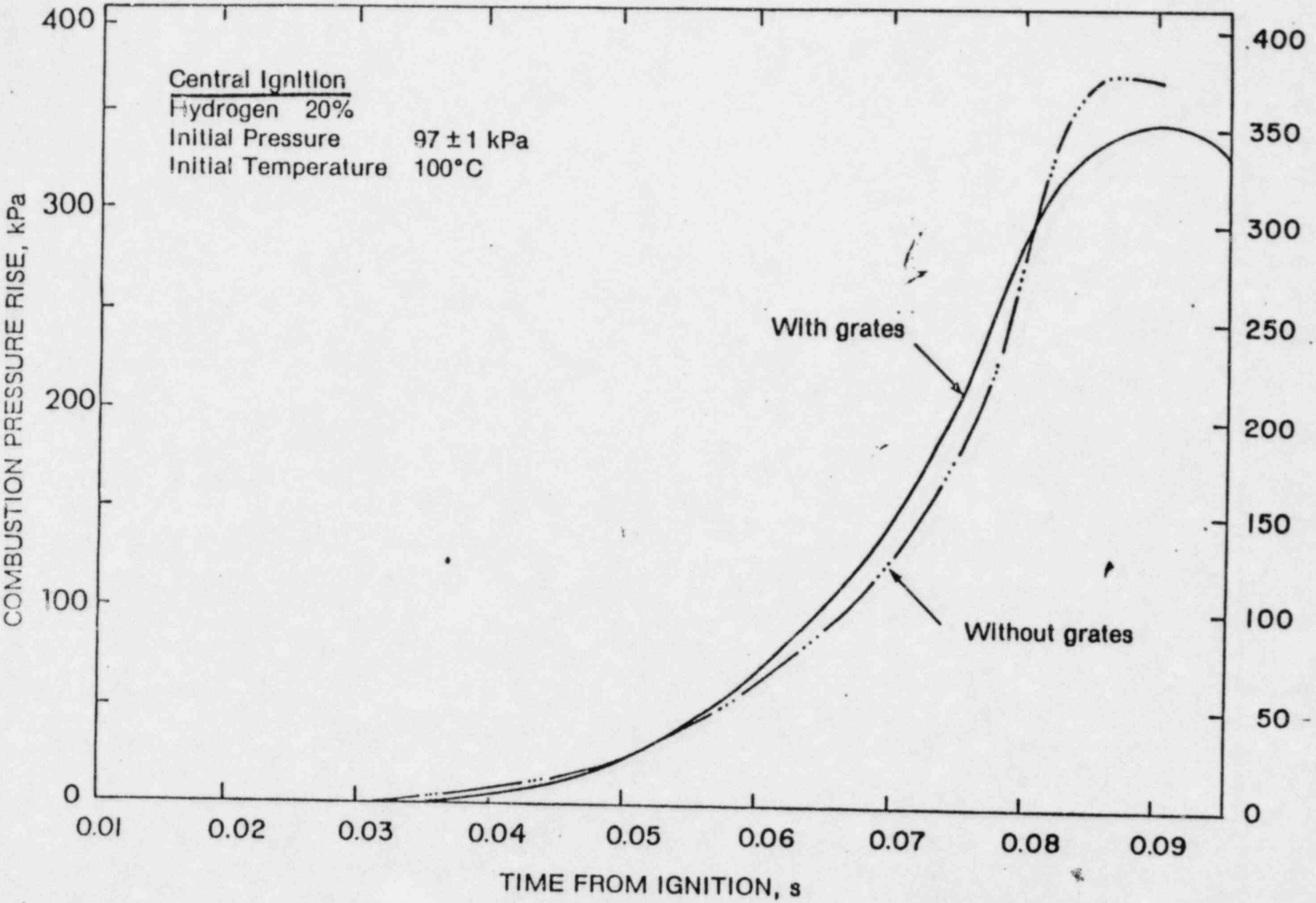
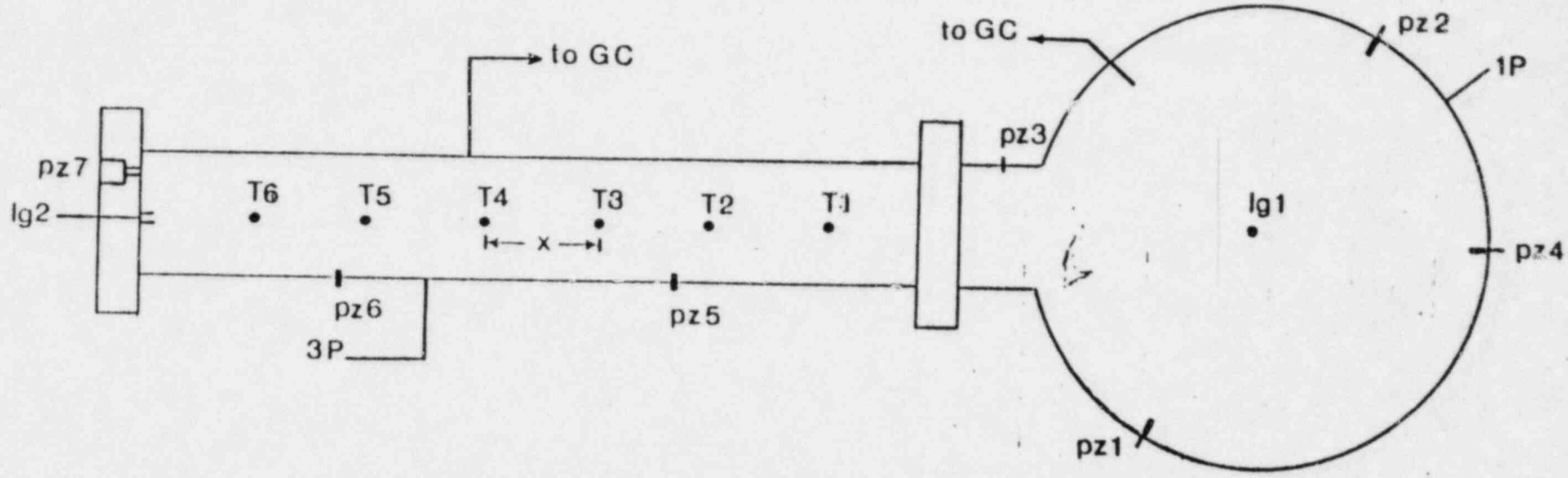


Figure 10: EFFECT OF GRATINGS ON COMBUSTION AT HIGH HYDROGEN CONCENTRATIONS

Gratings

- increase the extent of combustion and (to a lesser extent) the rate, @ low (ca 6%) concentrations

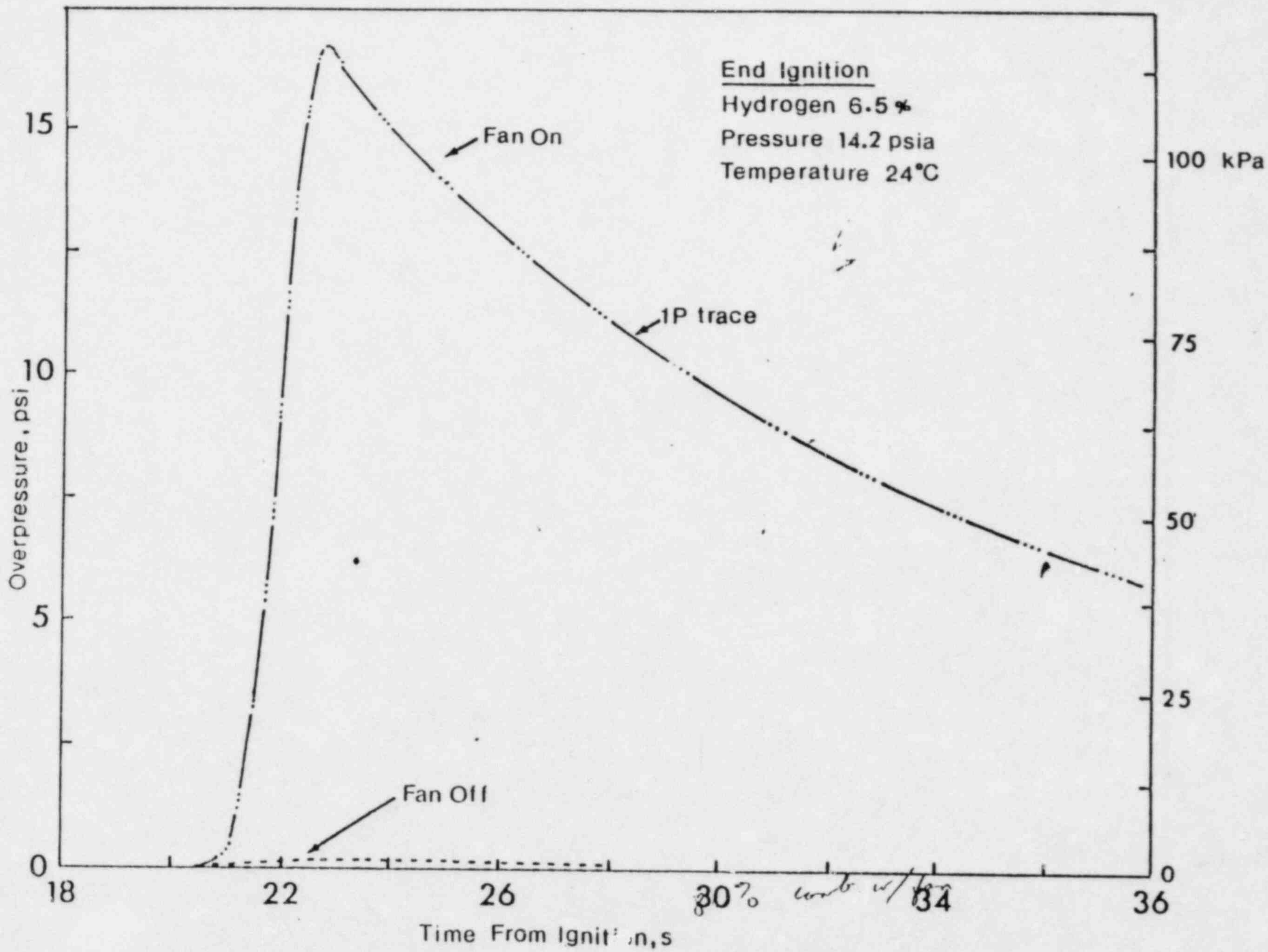
- @ high H_2 conc. (>10%) gratings act as heat sinks, reducing the peak pressure
- with fan turbulence, gratings reduced combustion rate & peak pressure.



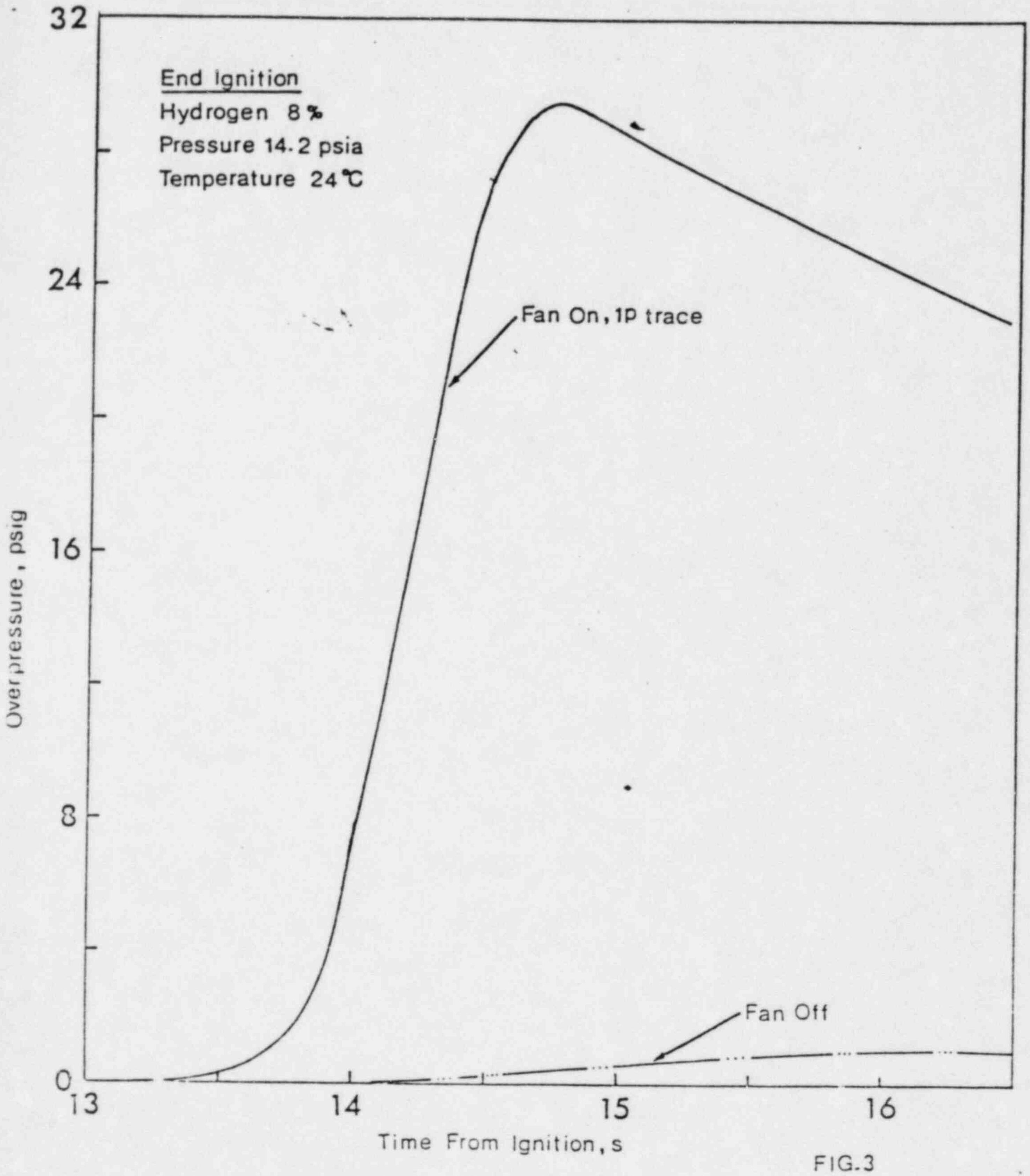
pz1 to 7	pressure transducers
T1 to T6	thermocouples
1P, 3P	Rosemount transmitters
Ig1, Ig2	igniters
x	33.75 inches spacing

SCHEMATIC OF THE INSTRUMENTED PIPE & SPHERE

FIG. 1



End Ignition
Hydrogen 6.5%
Pressure 14.2 psia
Temperature 24°C
Fan On
1P trace
Fan Off
Overpressure, psi
Time From Ignit' ,n, s
0
5
10
15
18
22
26
30
34
36
0
25
50
75
100 kPa



32
24
16
8
0
Overpressure , psig
End Ignition
Hydrogen 8 %
Pressure 14.2 psia
Temperature 24 °C
Fan On, 1P trace
Fan Off
13
14
15
16
Time From Ignition, s

FIG.3

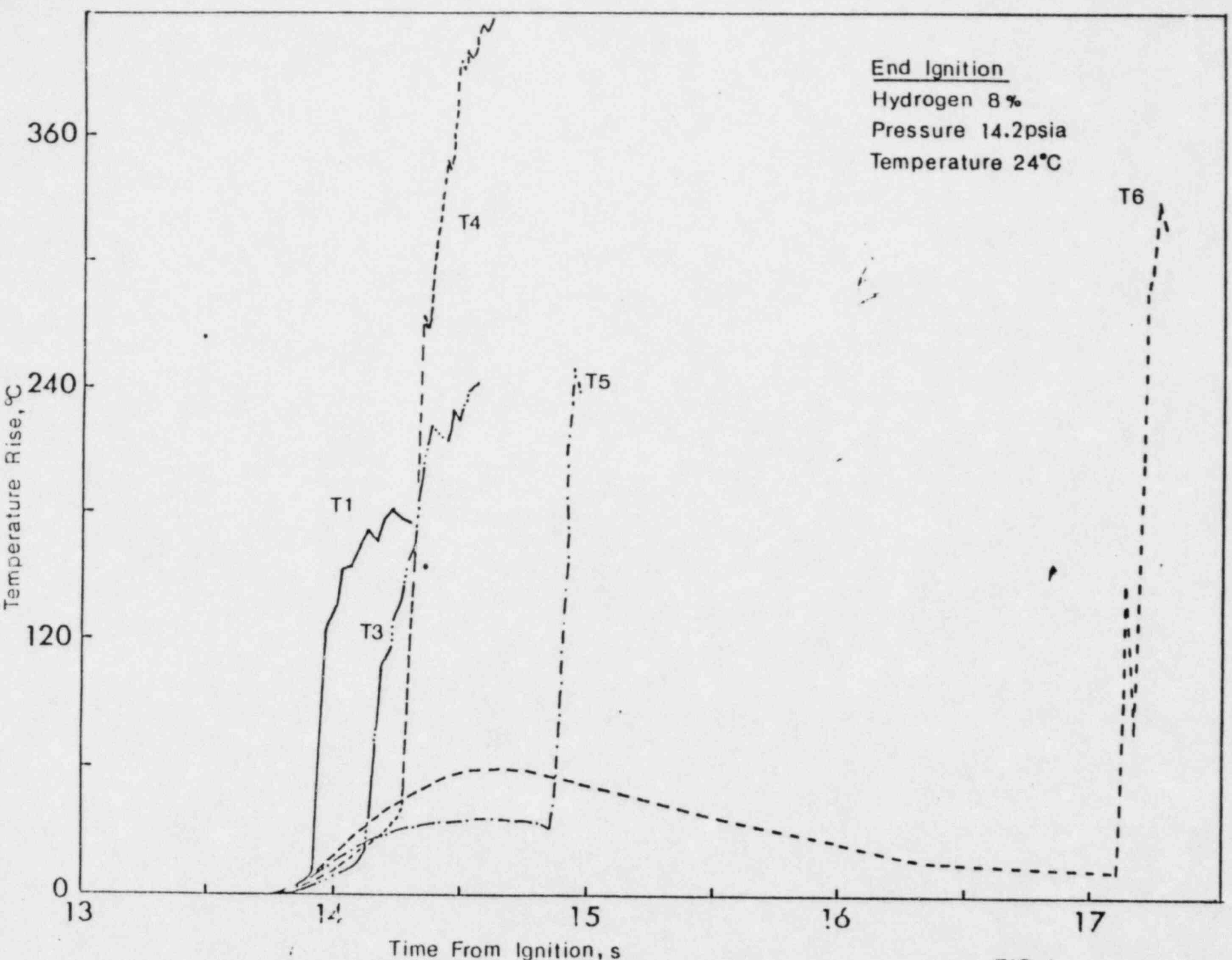
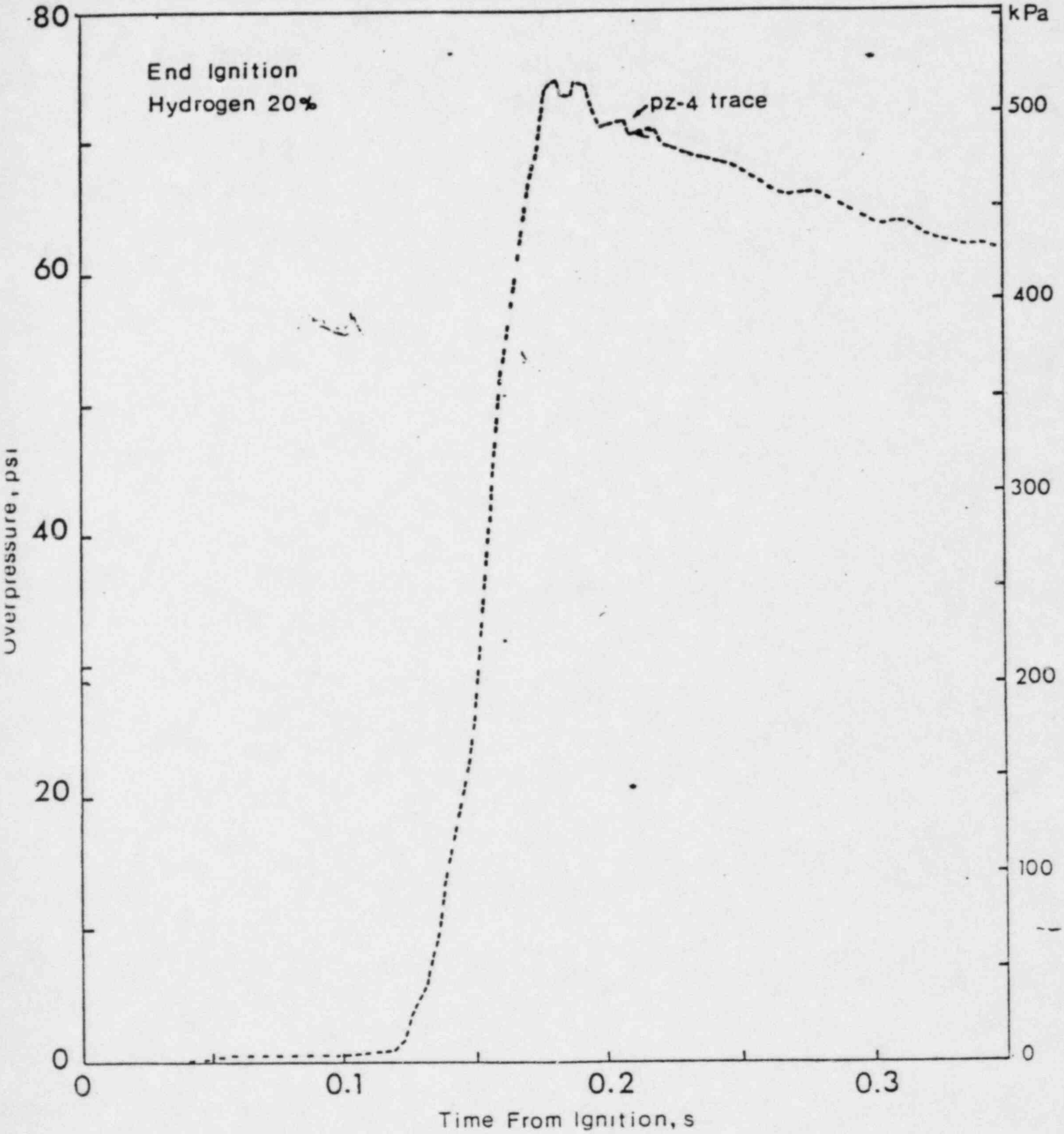
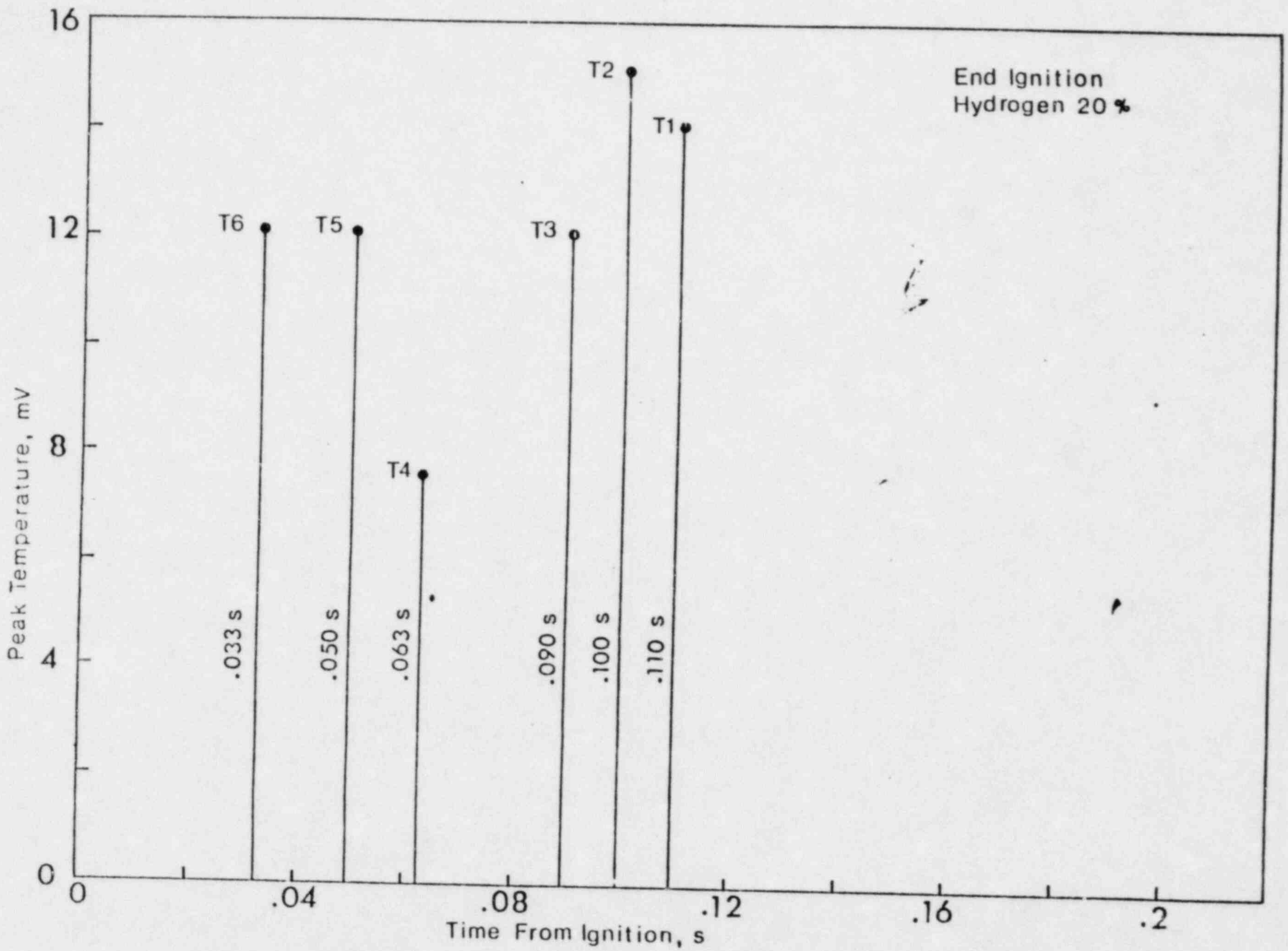

End Ignition
Hydrogen 8 %
Pressure 14.2psia
Temperature 24°C
T1
T3
T4
T5
T6
360
240
120
0
Temperature Rise, °C
13
14
15
16
17
Time From Ignition, s

FIG. 4



End Ignition
Hydrogen 20%
pz-4 trace
Overpressure, psi
kPa
80
60
40
20
0
500
400
300
200
100
0
0
0.1
0.2
0.3
Time From Ignition, s



End Ignition
Hydrogen 20 %
Peak Temperature, mV
Time From Ignition, s
16
12
8
4
0
0
.04
.08
.12
.16
.2
T1
T2
T3
T4
T5
T6
.033 s
.050 s
.063 s
.090 s
.100 s
.110 s

FIG. 6

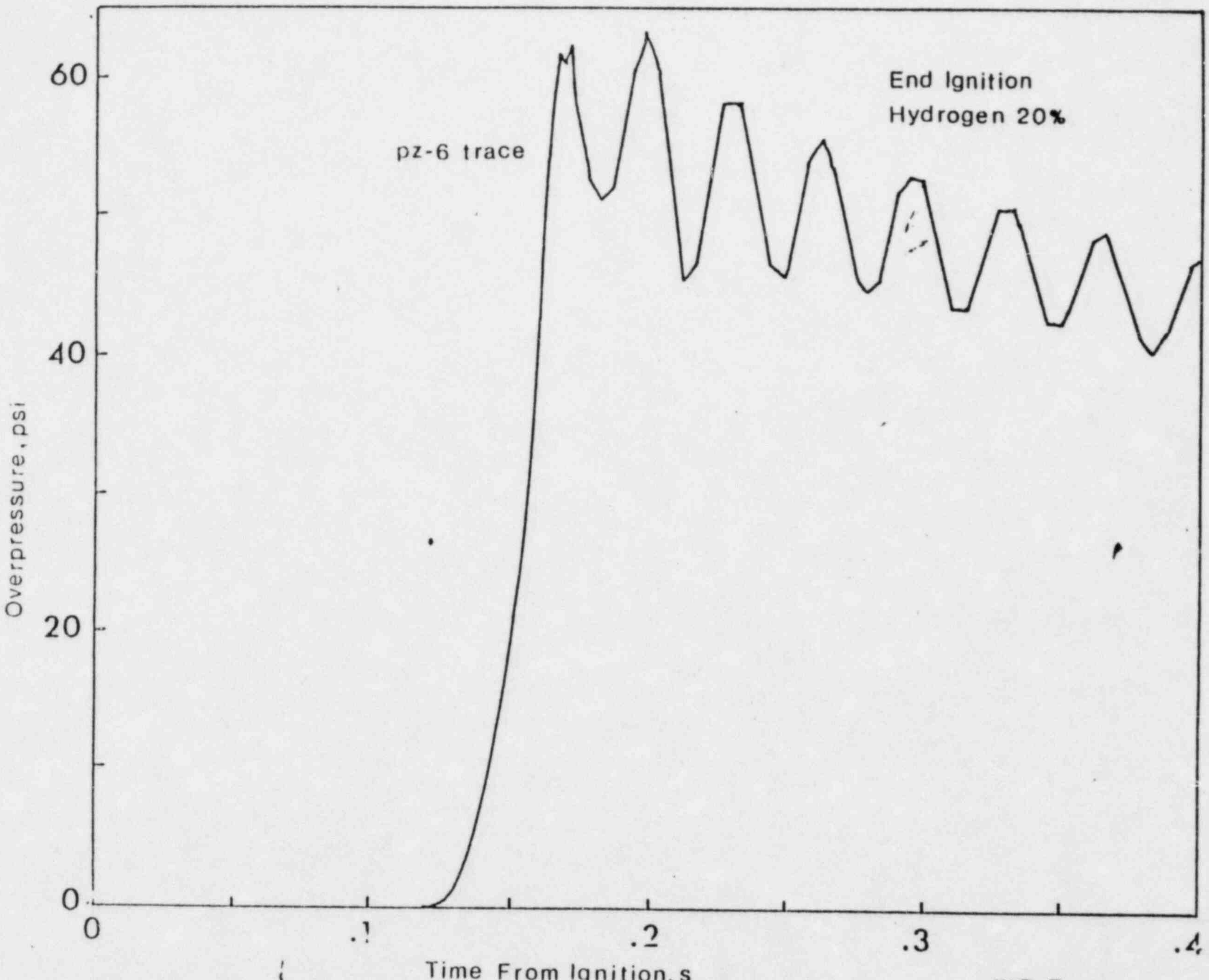
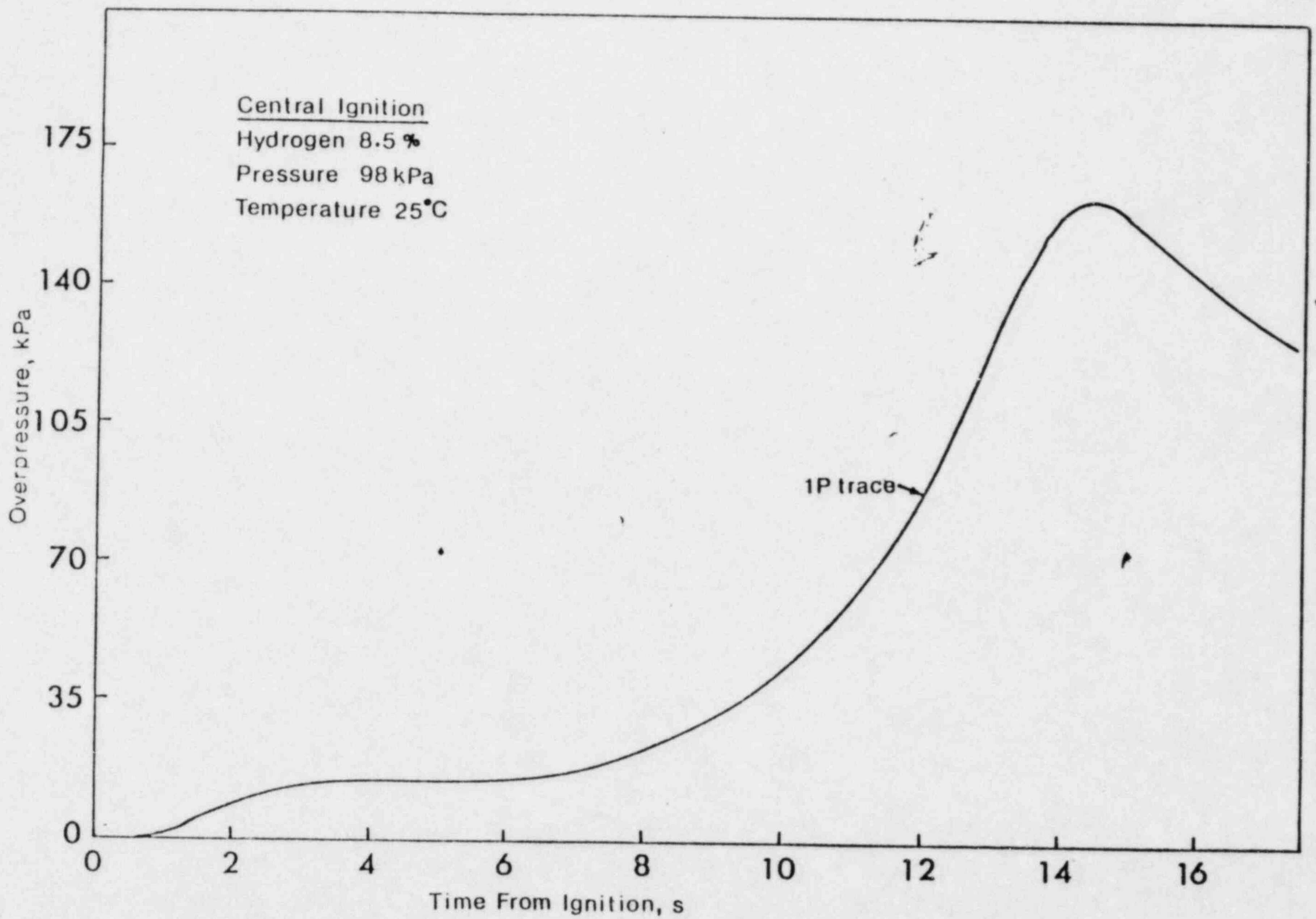
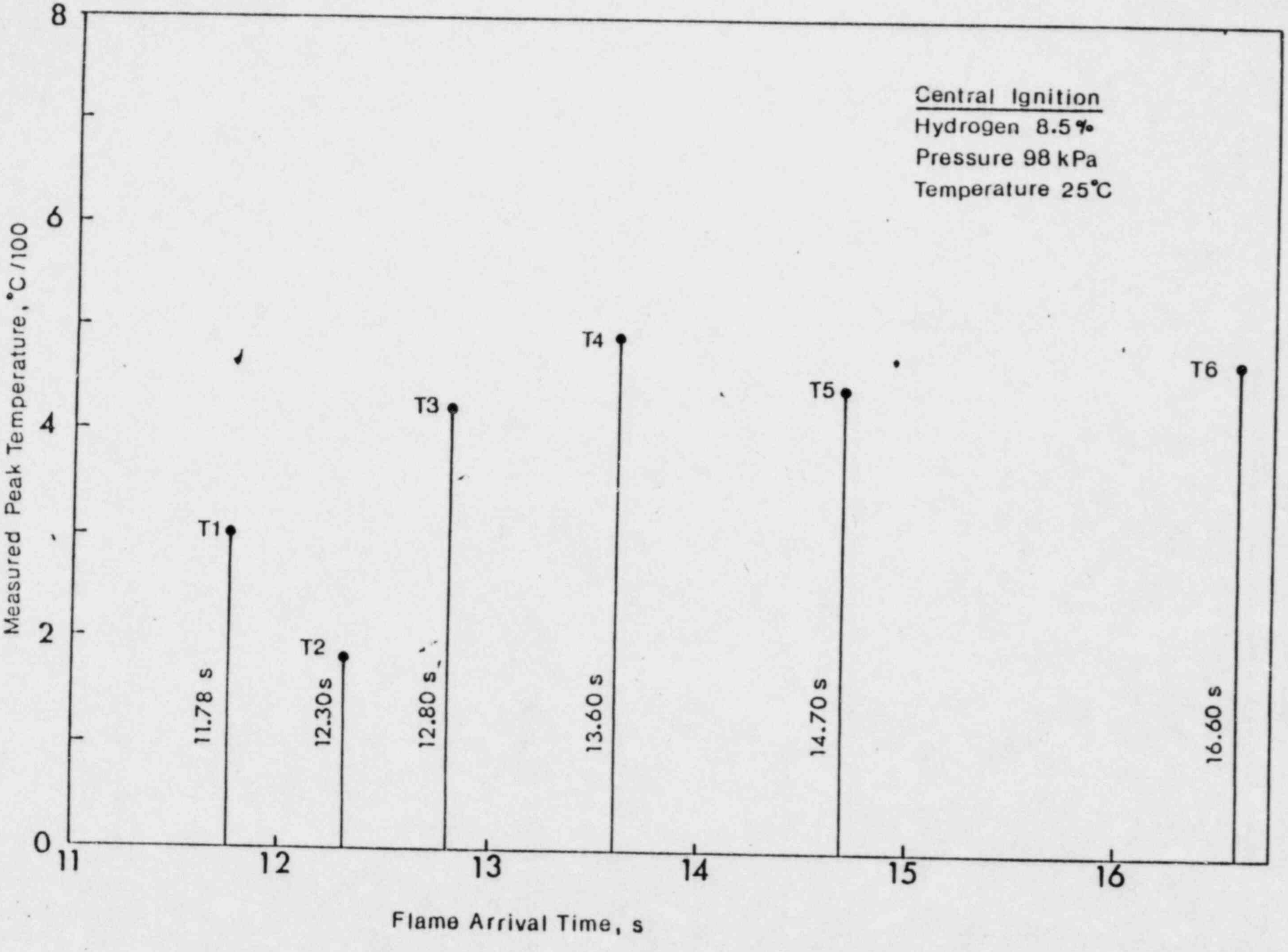

60
40
20
0
Overpressure, psi
pz-6 trace
End Ignition
Hydrogen 20%
0
.1
.2
.3
.4
Time From Ignition, s

FIG 7


Central Ignition
Hydrogen 8.5 %
Pressure 98 kPa
Temperature 25°C
1P trace
Overpressure, kPa
0
35
70
105
140
175
0
2
4
6
8
10
12
14
16
Time From Ignition, s



Central Ignition
Hydrogen 8.5%
Pressure 98 kPa
Temperature 25°C
Measured Peak Temperature, °C/100
Flame Arrival Time, s
T1
T2
T3
T4
T5
T6
11.78 s
12.30 s
12.80 s
13.60 s
14.70 s
16.60 s
0
2
4
6
8
11
12
13
14
15
16

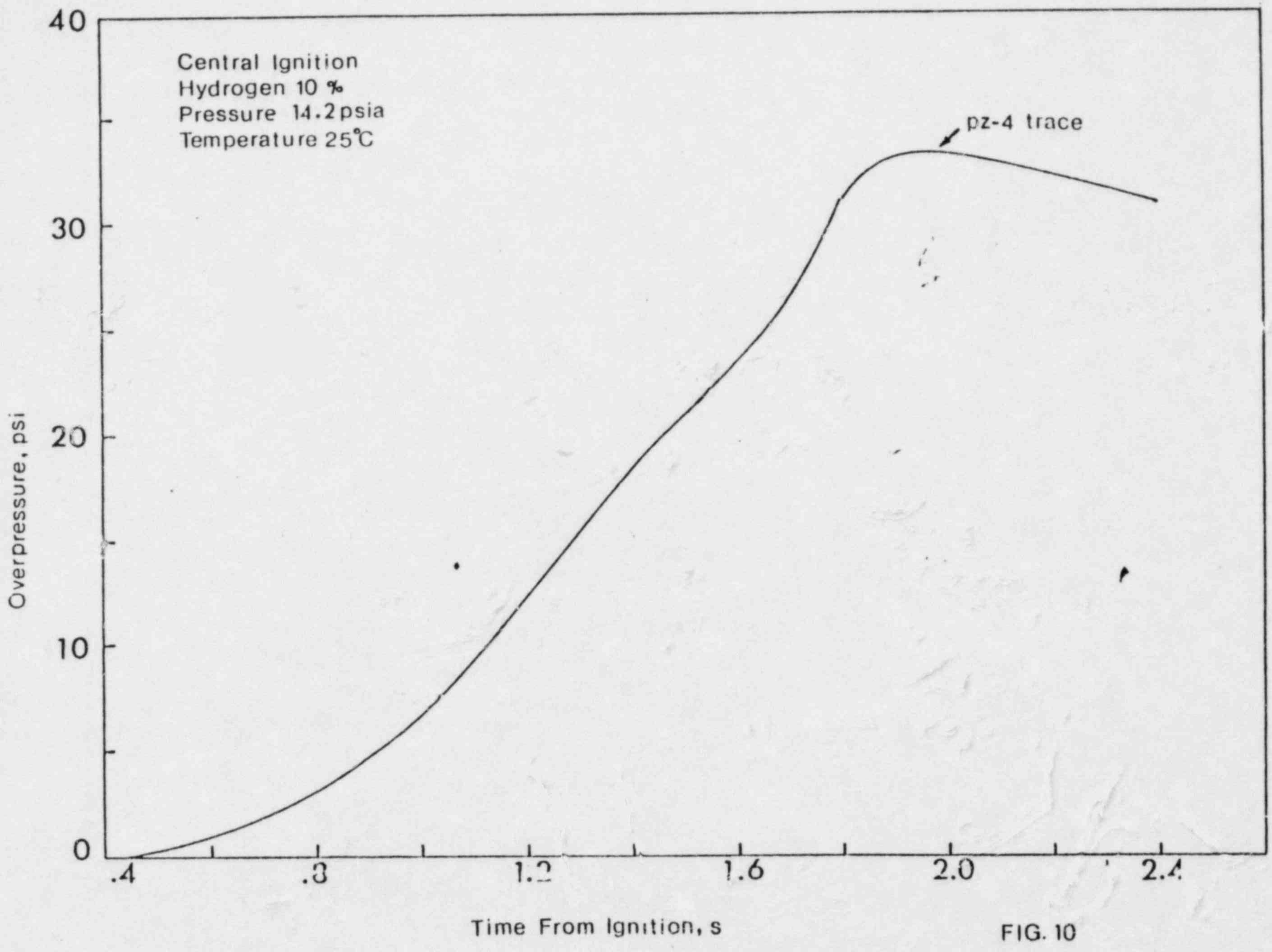
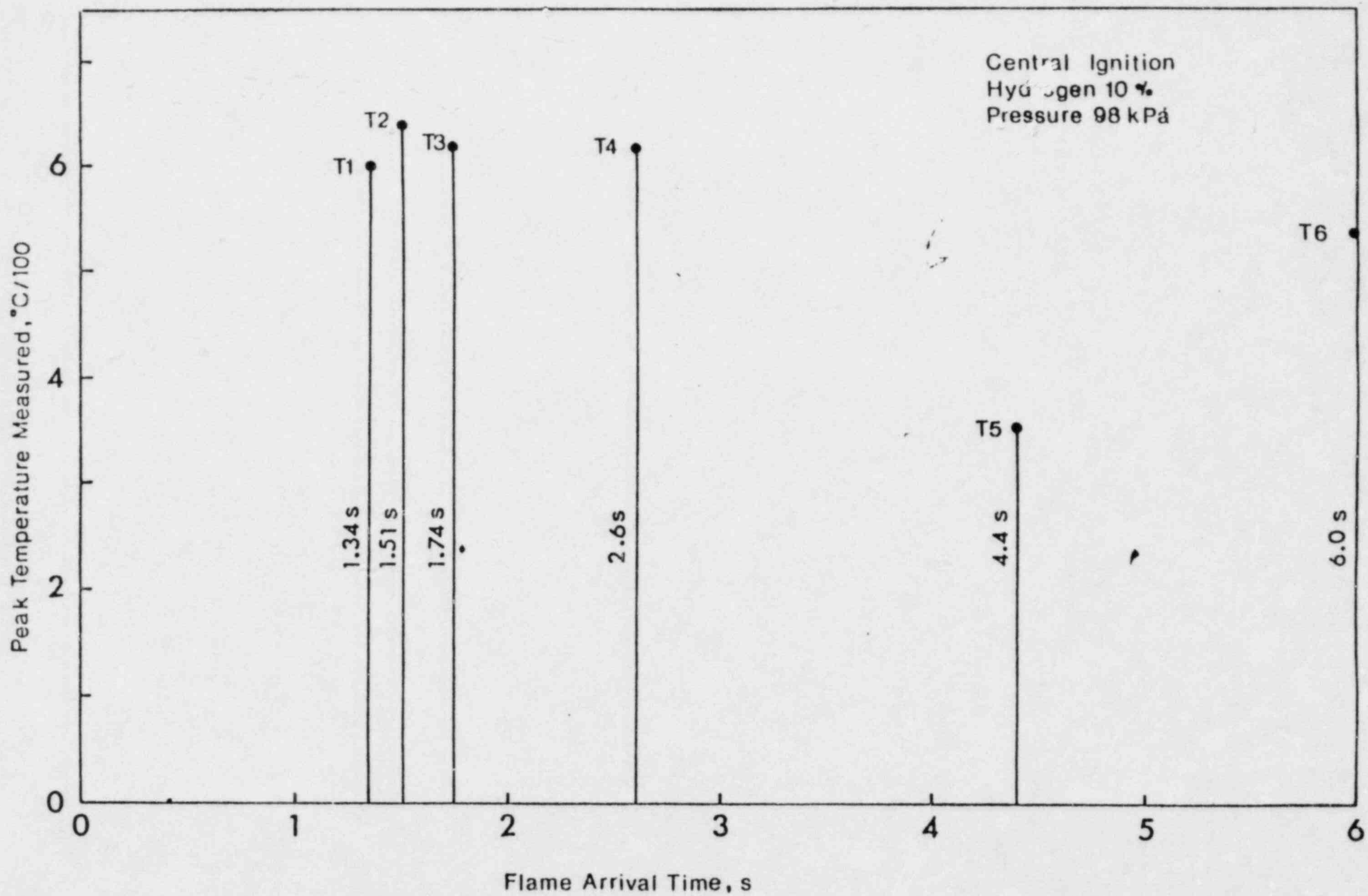

Central Ignition
Hydrogen 10 %
Pressure 14.2 psia
Temperature 25°C
pz-4 trace
Overpressure, psi
0
10
20
30
40
.4
.8
1.2
1.6
2.0
2.4
Time From Ignition, s

FIG. 10



Central Ignition
Hydrogen 10 %
Pressure 98 kPa
T1
T2
T3
T4
T5
T6
1.34 s
1.51 s
1.74 s
2.6s
4.4 s
6.0 s
Peak Temperature Measured, °C/100
0
2
4
6
0
1
2
3
4
5
6
Flame Arrival Time, s

FIG. 11

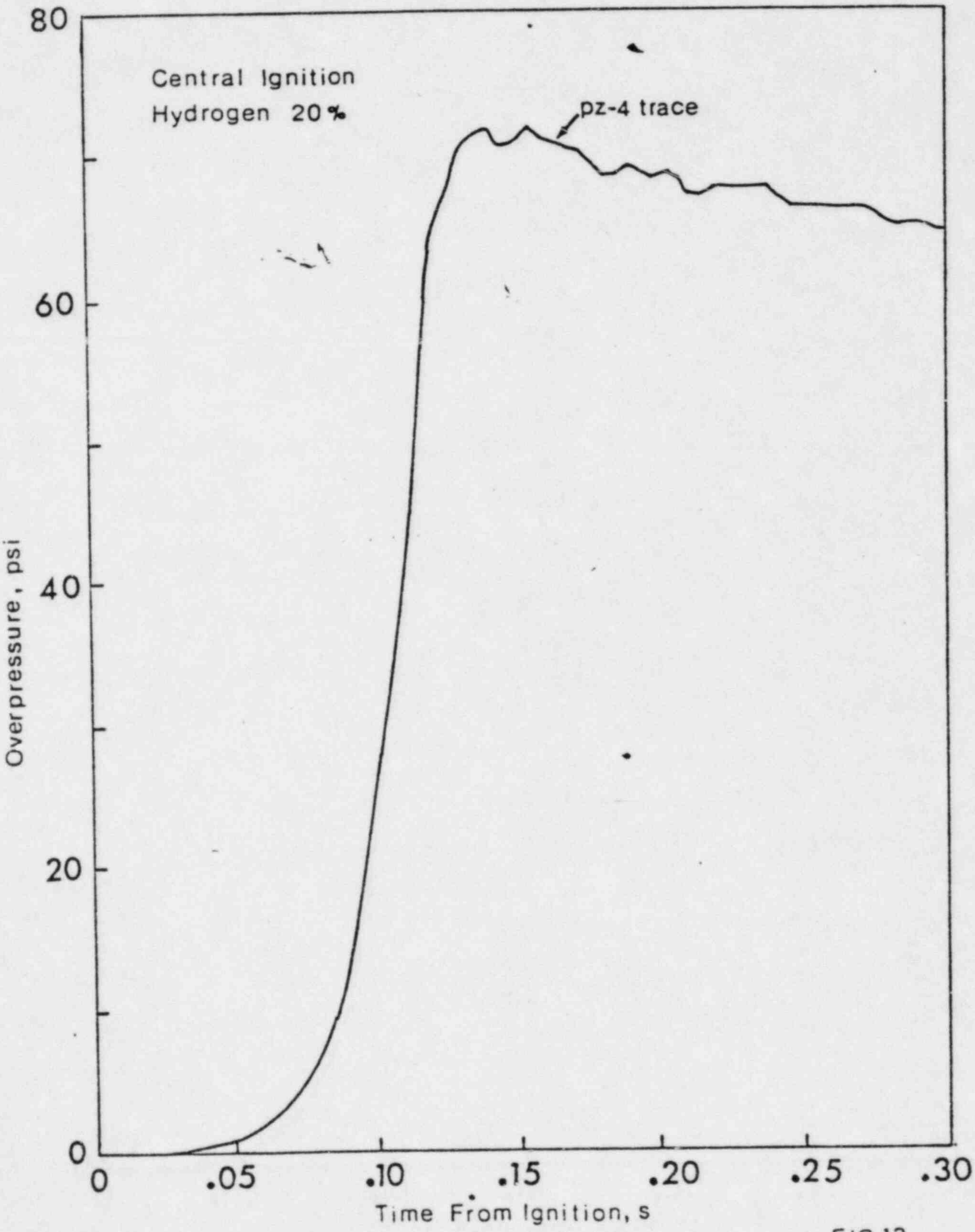
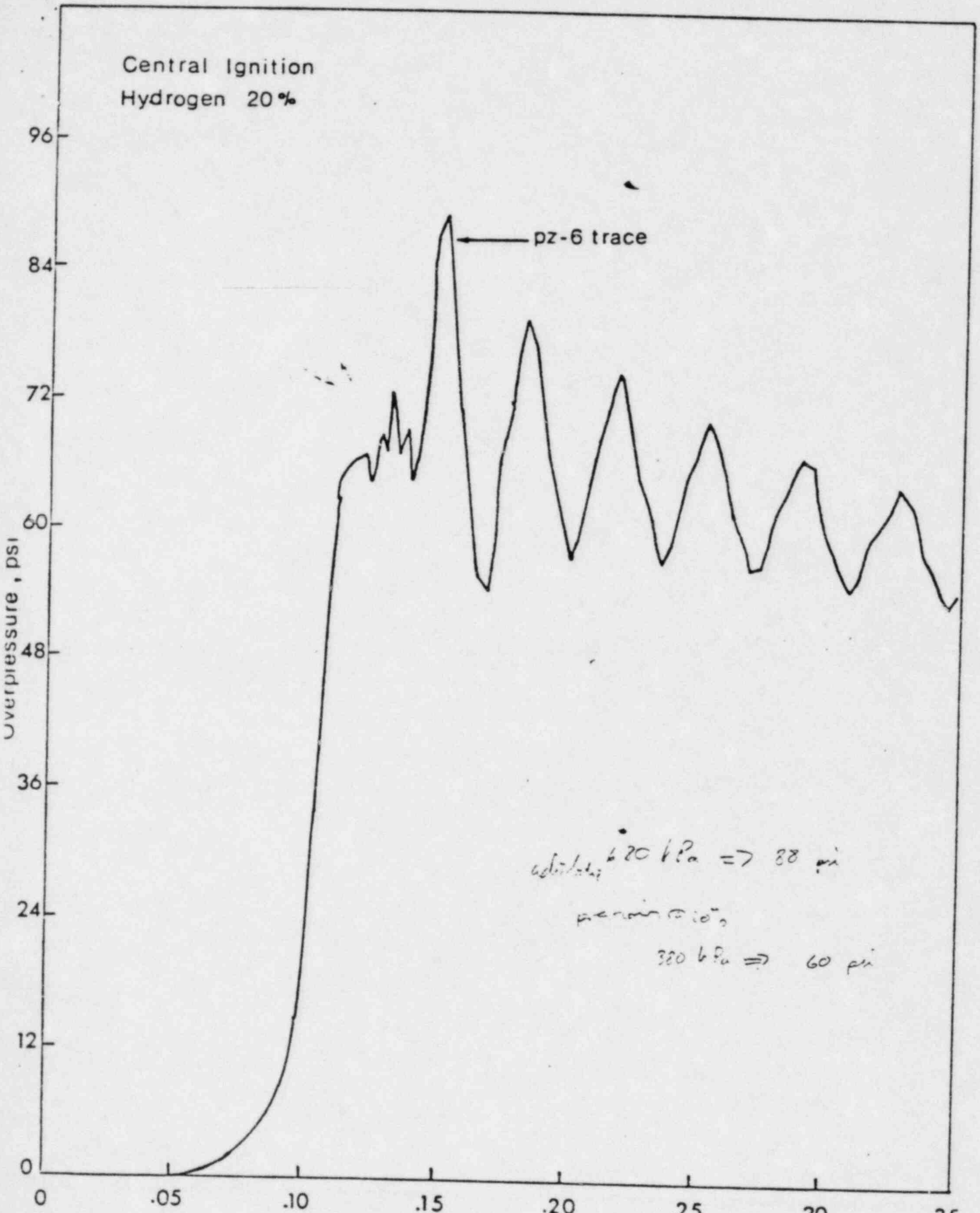

80
60
40
20
0
Central Ignition
Hydrogen 20%
pz-4 trace
Overpressure, psi
0
.05
.10
.15
.20
.25
.30
Time From Ignition, s

FIG.12



Central Ignition
Hydrogen 20%
pz-6 trace
96
84
72
60
48
36
24
12
0
Overpressure, psi
0
.05
.10
.15
.20
.25
.30
.35
Time From Ignition, s
620 kPa => 88 psi
380 kPa => 60 psi

FIG. 14

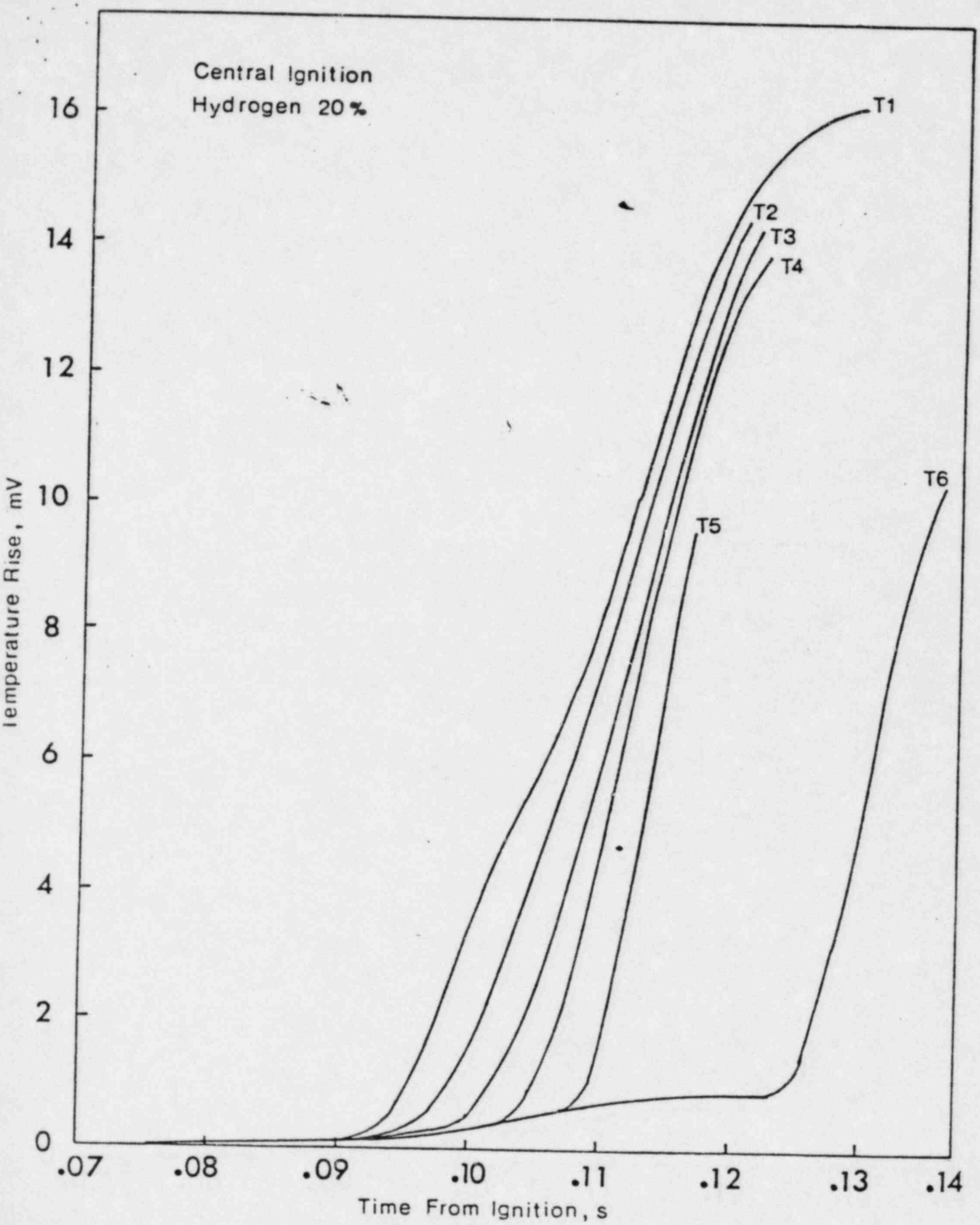
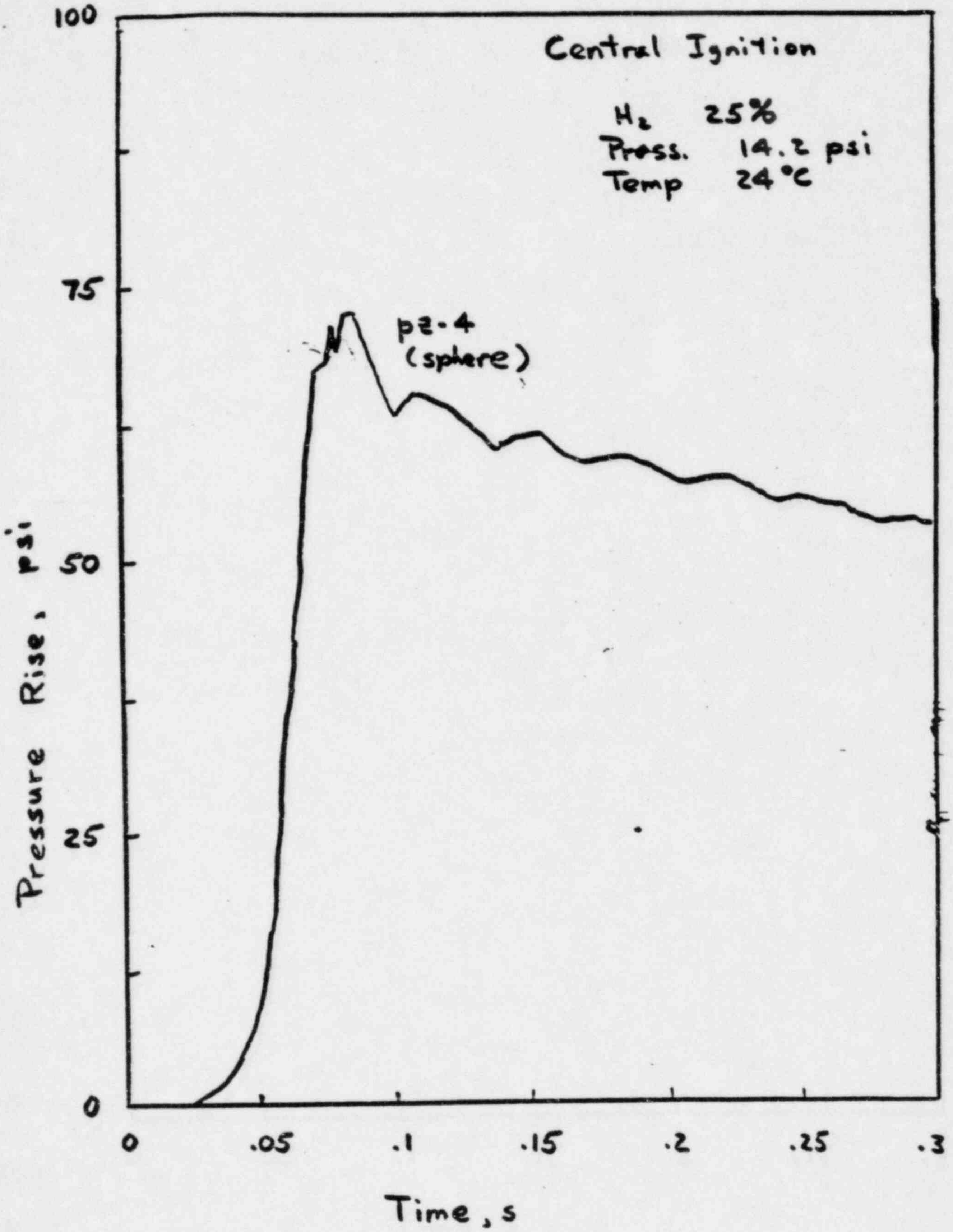
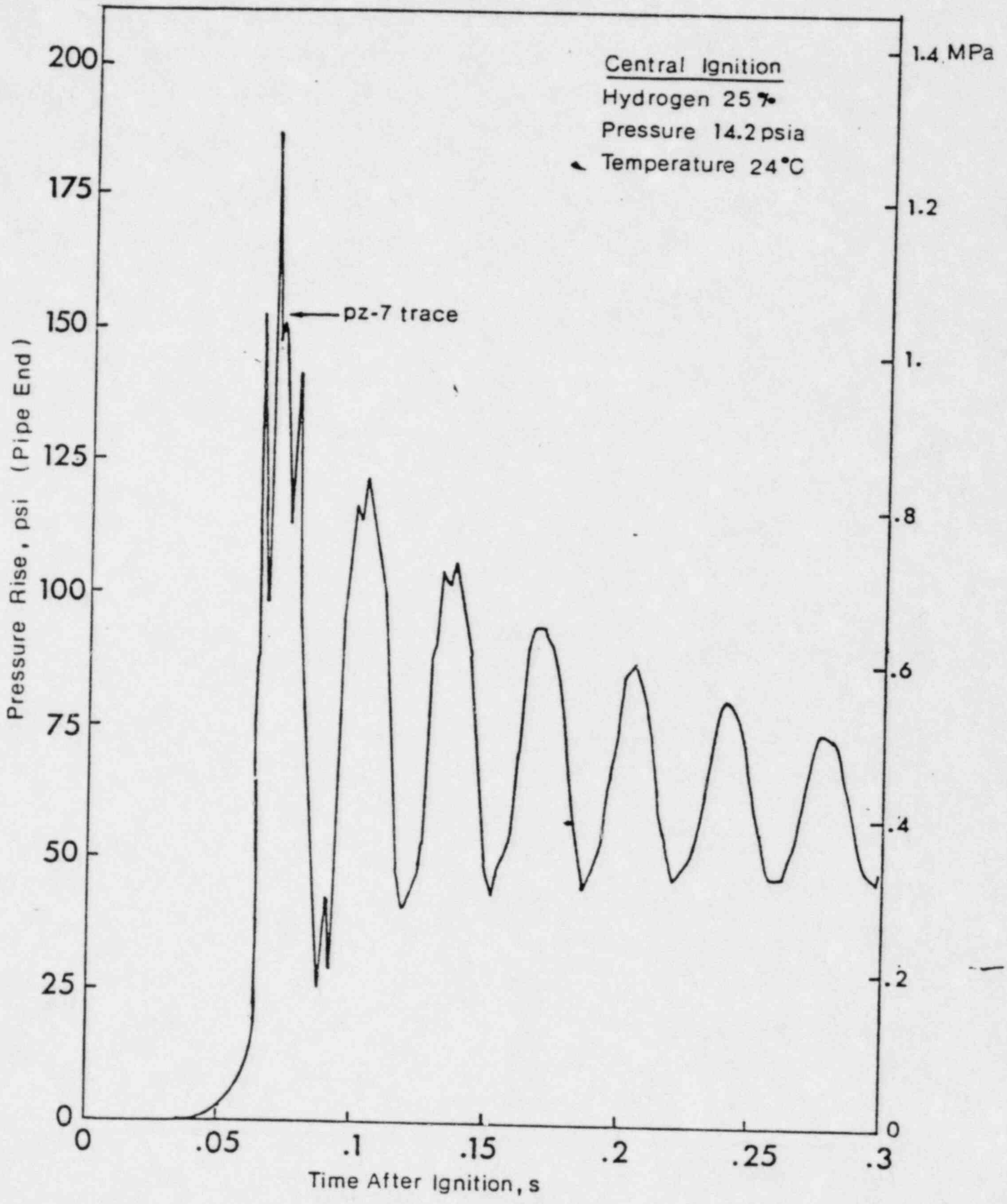
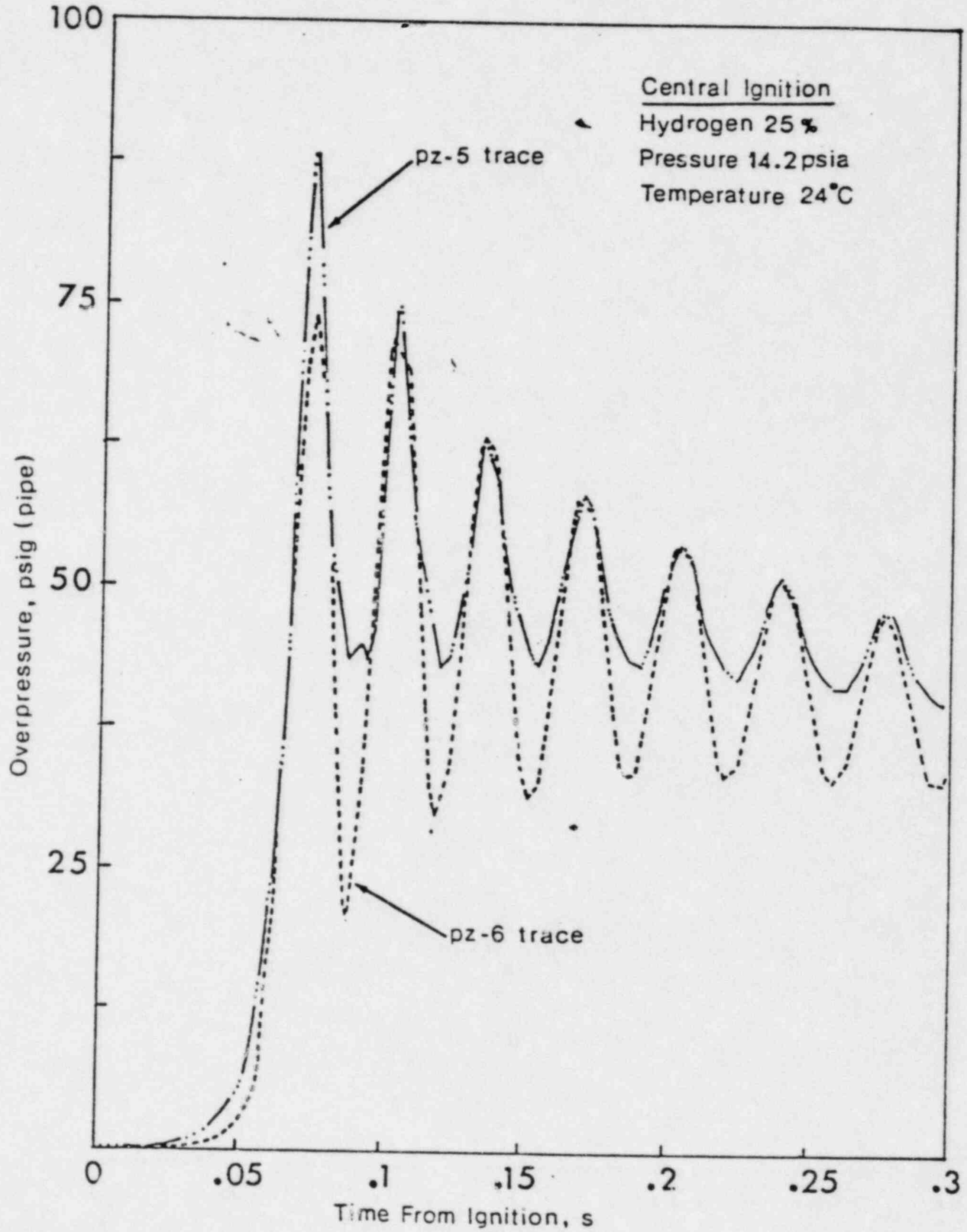

Central Ignition
Hydrogen 20%
T1
T2
T3
T4
T5
T6
16
14
12
10
8
6
4
2
0
Temperature Rise, mV
.07
.08
.09
.10
.11
.12
.13
.14
Time From Ignition, s

FIG.13



Central Ignition
H_2 25%
Press. 14.2 psi
Temp 24 °C
pz-4
(sphere)
100
75
50
25
0
Pressure Rise, psi
0
.05
.1
.15
.2
.25
.3
Time, s


Central Ignition
Hydrogen 25 %
Pressure 14.2 psia
Temperature 24°C
pz-7 trace
Pressure Rise, psi (Pipe End)
Time After Ignition, s
0
25
50
75
100
125
150
175
200
.05
.1
.15
.2
.25
.3
.2
.4
.6
.8
1.
1.2
1.4 MPa



Central Ignition
Hydrogen 25 %
Pressure 14.2 psia
Temperature 24°C
pz-5 trace
pz-6 trace
100
75
50
25
Overpressure, psig (pipe)
0
.05
.1
.15
.2
.25
.3
Time From Ignition, s

FIG. 17

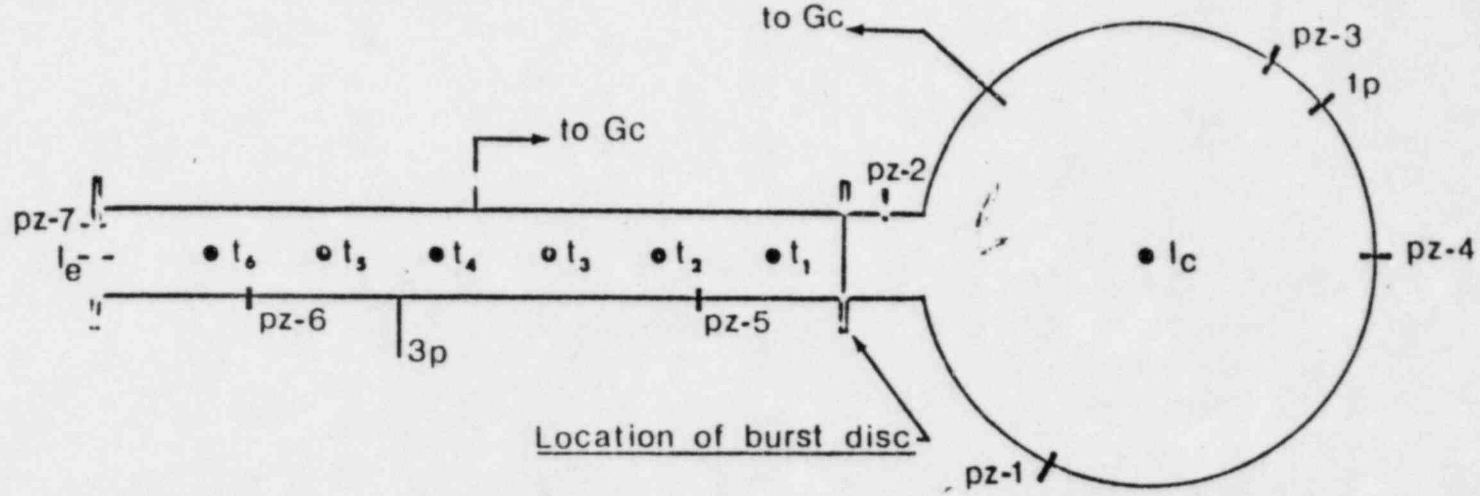
Series 4a

Pipe-end ignition

- for H_2 conc $<$ upward-downward limits, the flame propagates only along top of pipe & virtually no combustion results in sphere
- with fan-induced turbulence, a fully developed flame returns to the pipe

Sphere-centre ignition

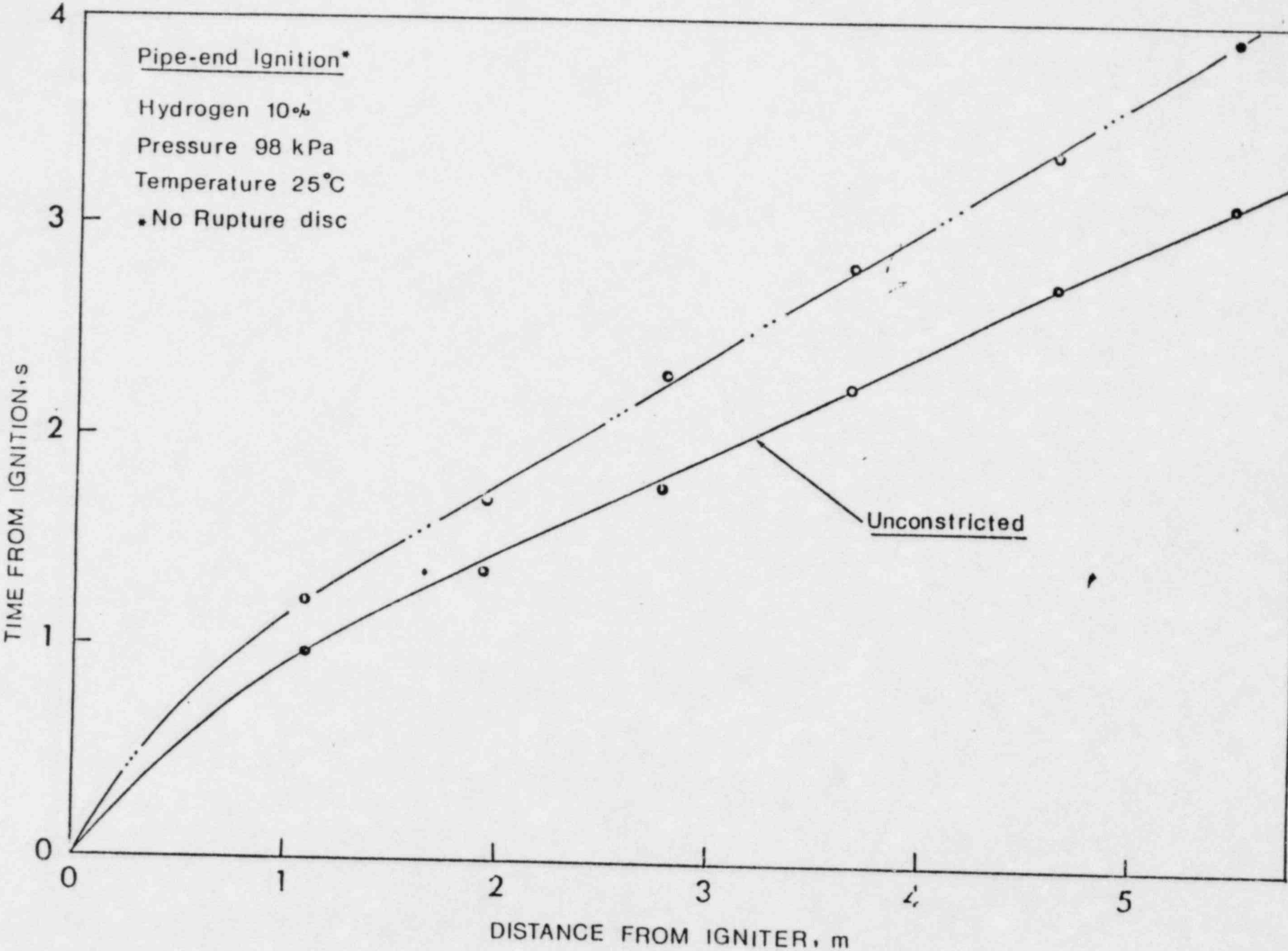
- higher flame speeds are observed with sphere-central ignition
- large acoustic oscillations are seen in the pipe for $H_2 \geq 20\%$
- peak pressures > adiabatic are seen for very high H_2 concentrations.

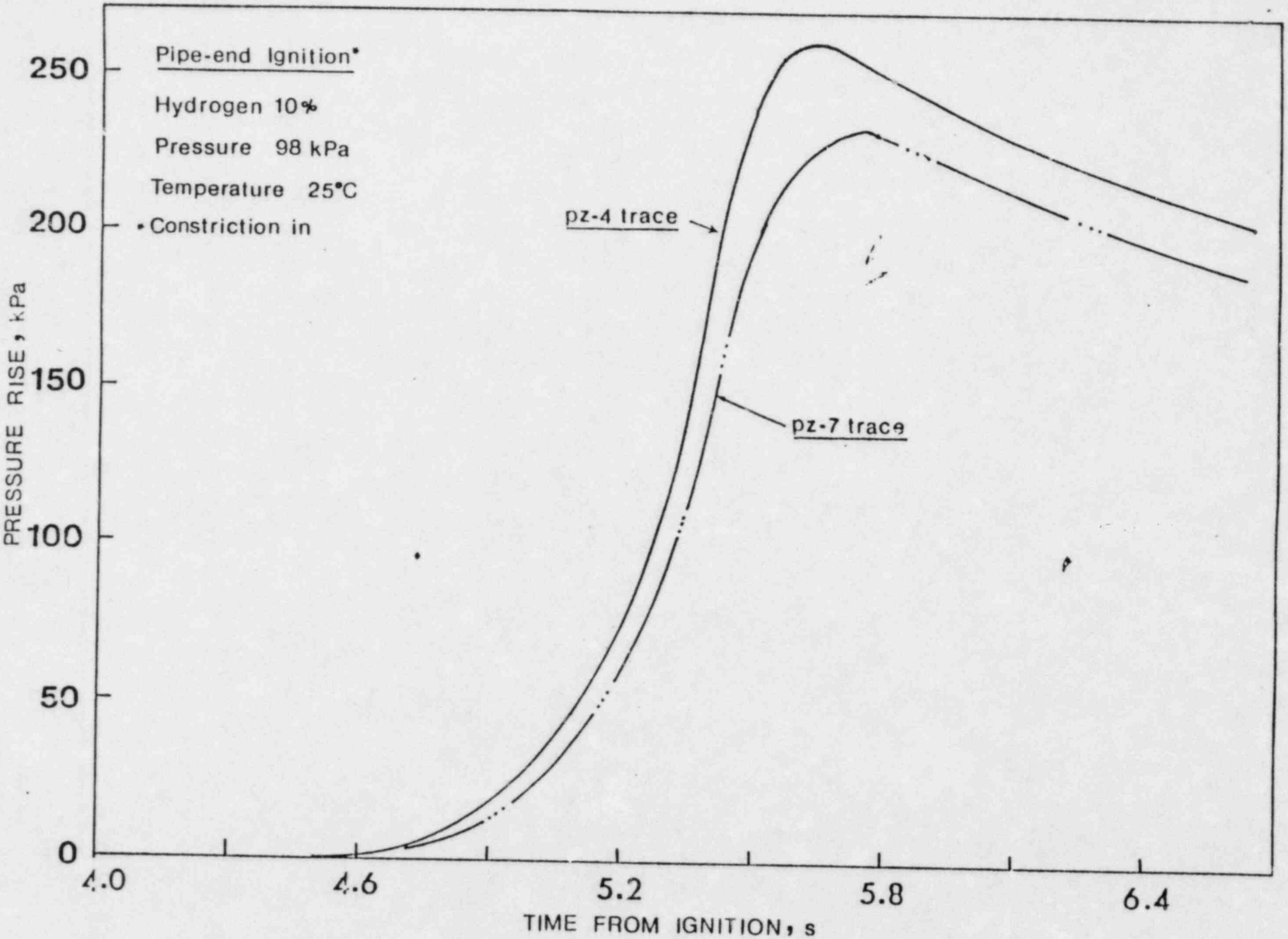


pz-1 to pz-7	Pressure Transducers
t_1 to t_6	Thermocouples
1p, 3p	Rosemount Transmitters
I_C, I_e	Igniters

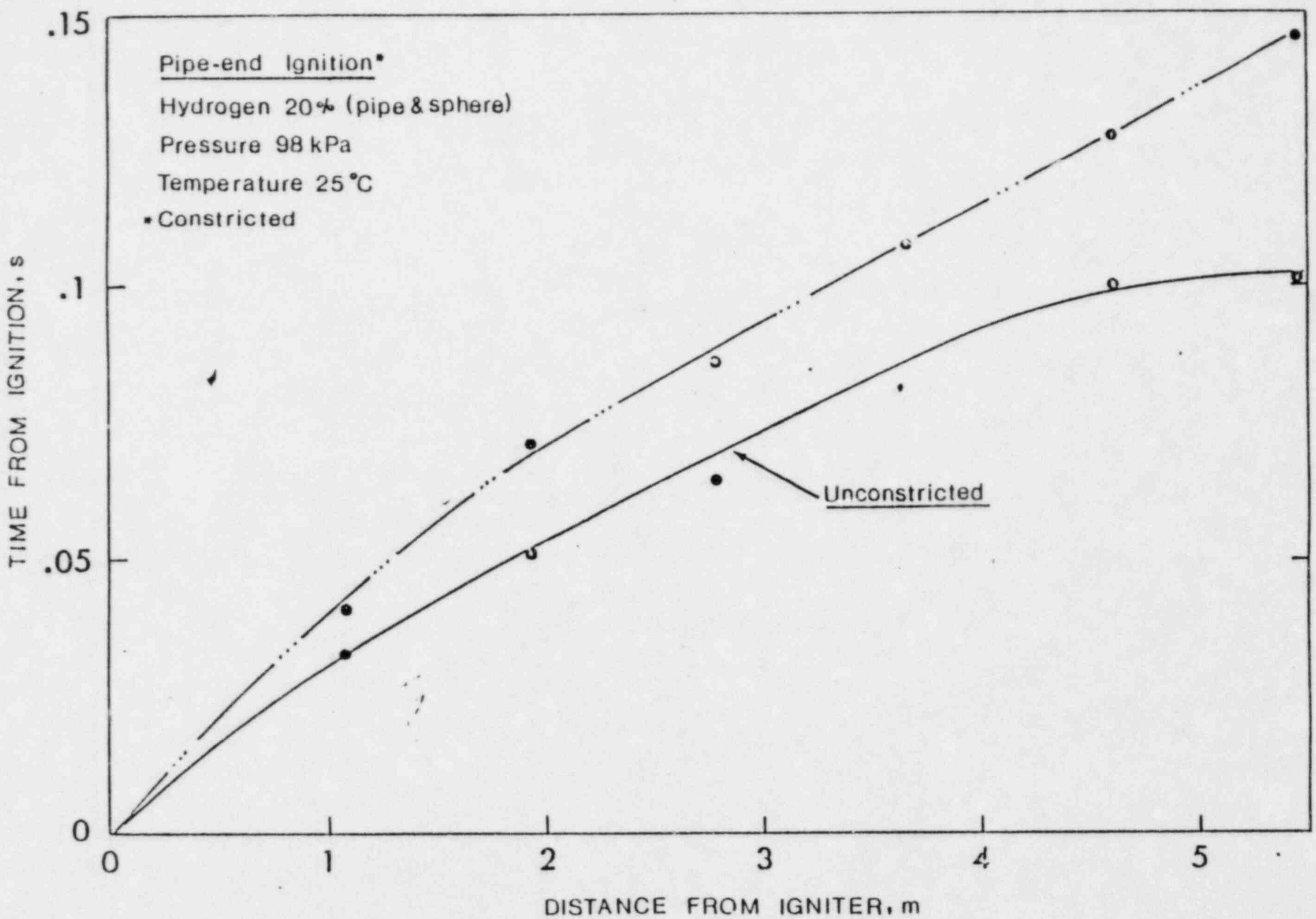
Thermocouple spacing 857 mm

SCHEMATIC OF THE INSTRUMENTED PIPE & SPHERE

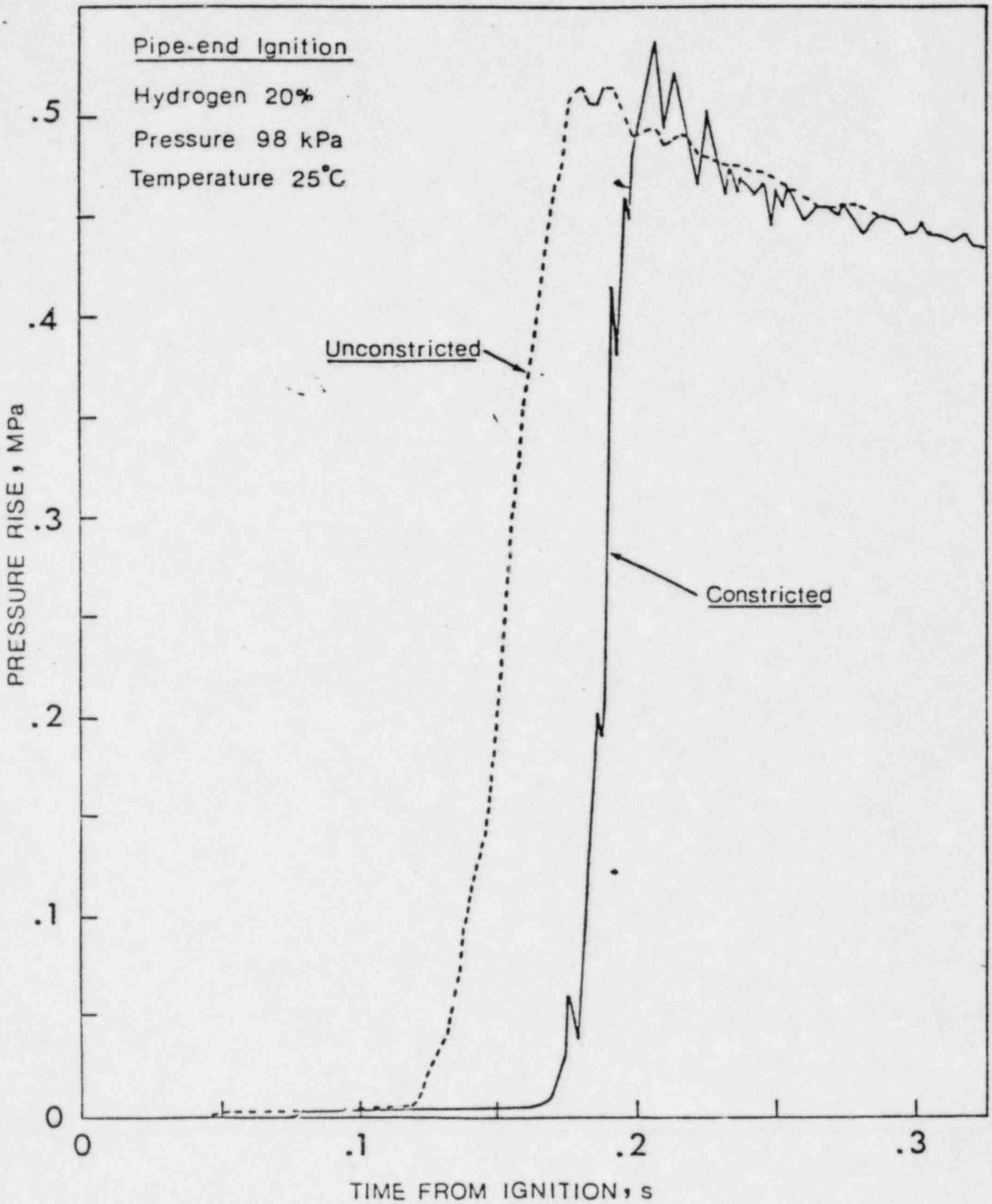

Pipe-end Ignition*
Hydrogen 10%
Pressure 98 kPa
Temperature 25°C
*No Rupture disc
Unconstricted
TIME FROM IGNITION, s
DISTANCE FROM IGNITER, m
0
1
2
3
4
5



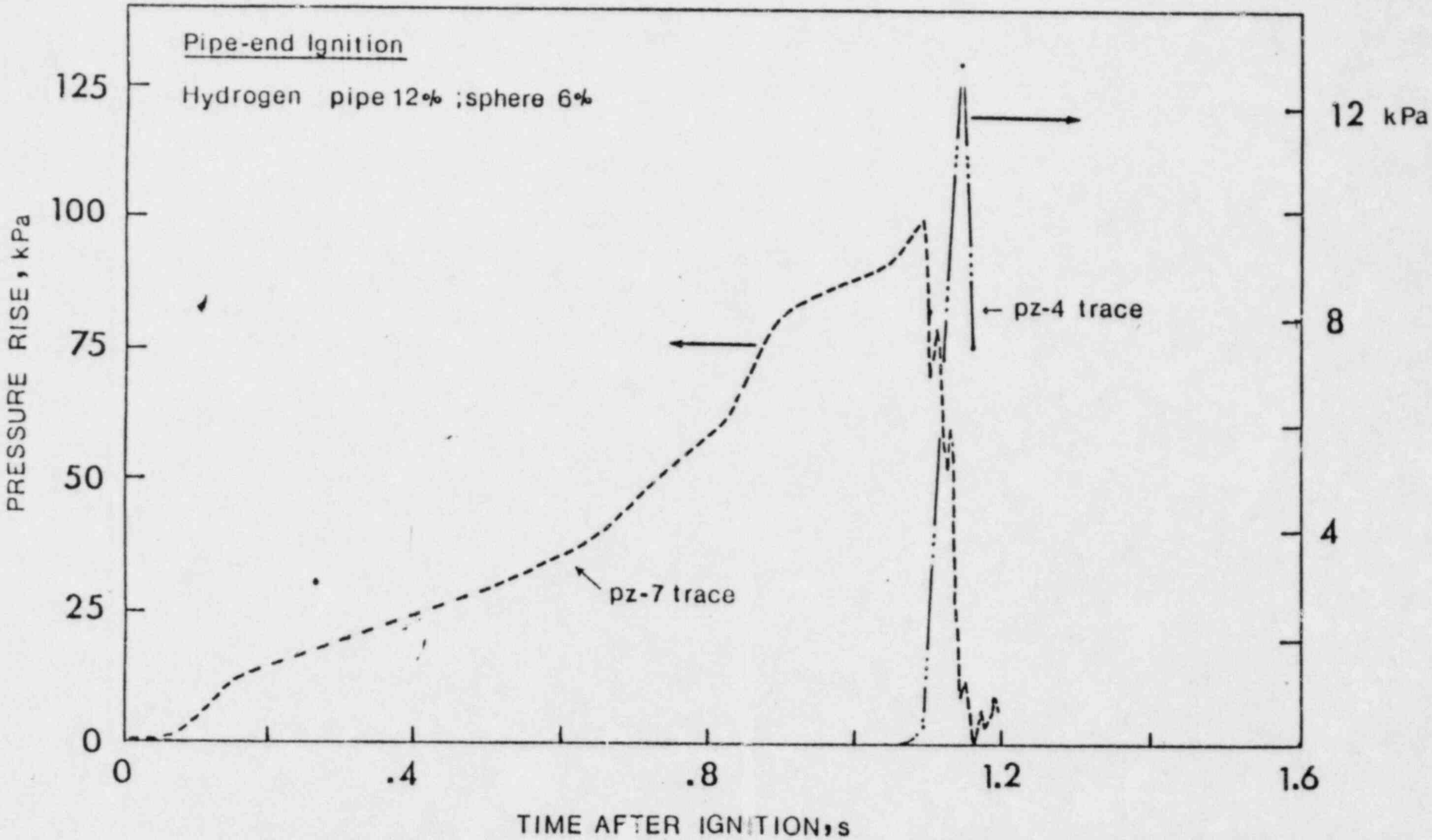
Pipe-end Ignition*
Hydrogen 10%
Pressure 98 kPa
Temperature 25°C
*Constriction in
pz-4 trace
pz-7 trace
PRESSURE RISE, kPa
0
50
100
150
200
250
4.0
4.6
5.2
5.8
6.4
TIME FROM IGNITION, s



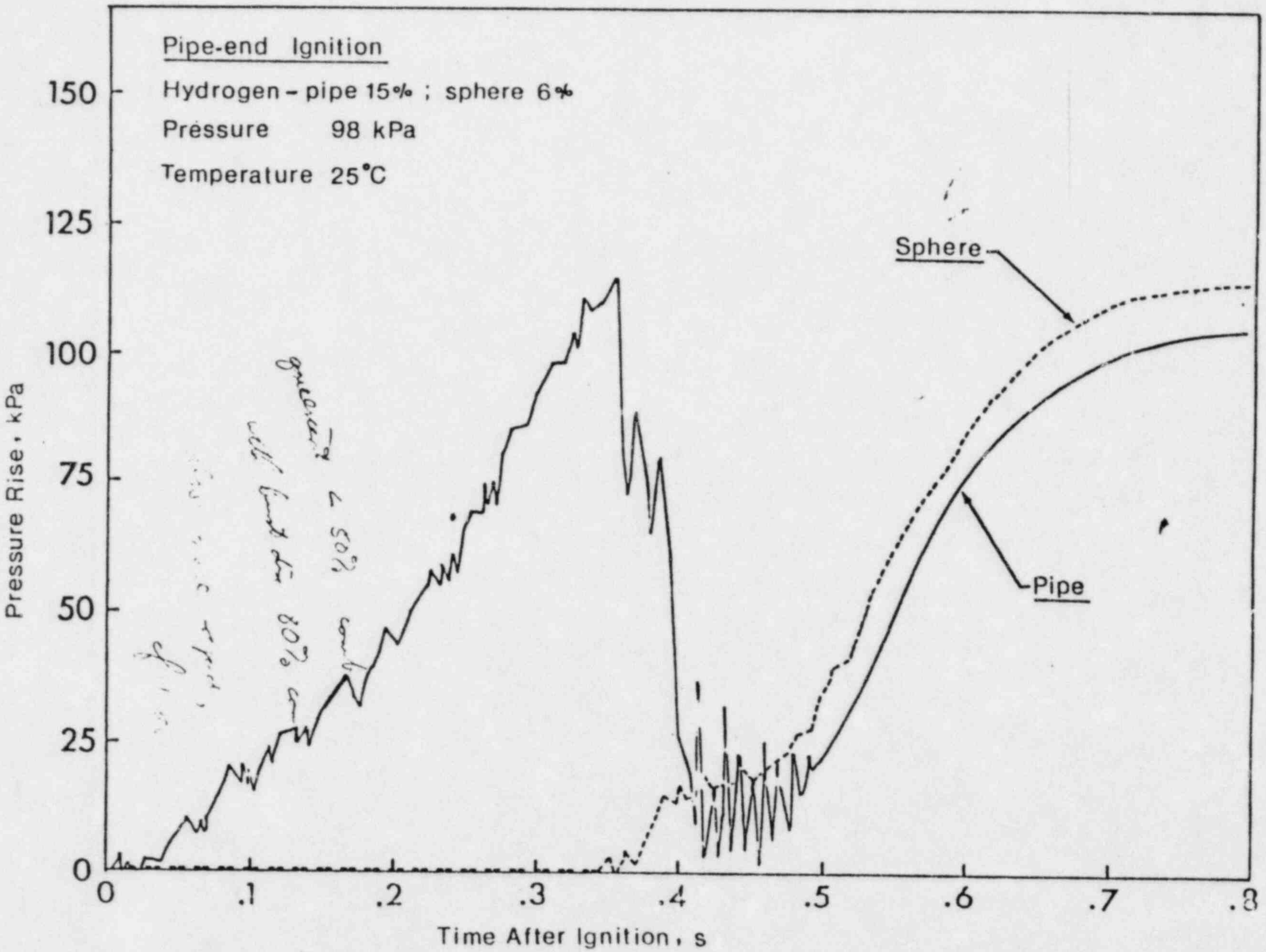
.15
.1
.05
0
TIME FROM IGNITION, s
Pipe-end Ignition*
Hydrogen 20% (pipe & sphere)
Pressure 98 kPa
Temperature 25°C
* Constricted
Unconstricted
0
1
2
3
4
5
DISTANCE FROM IGNITER, m

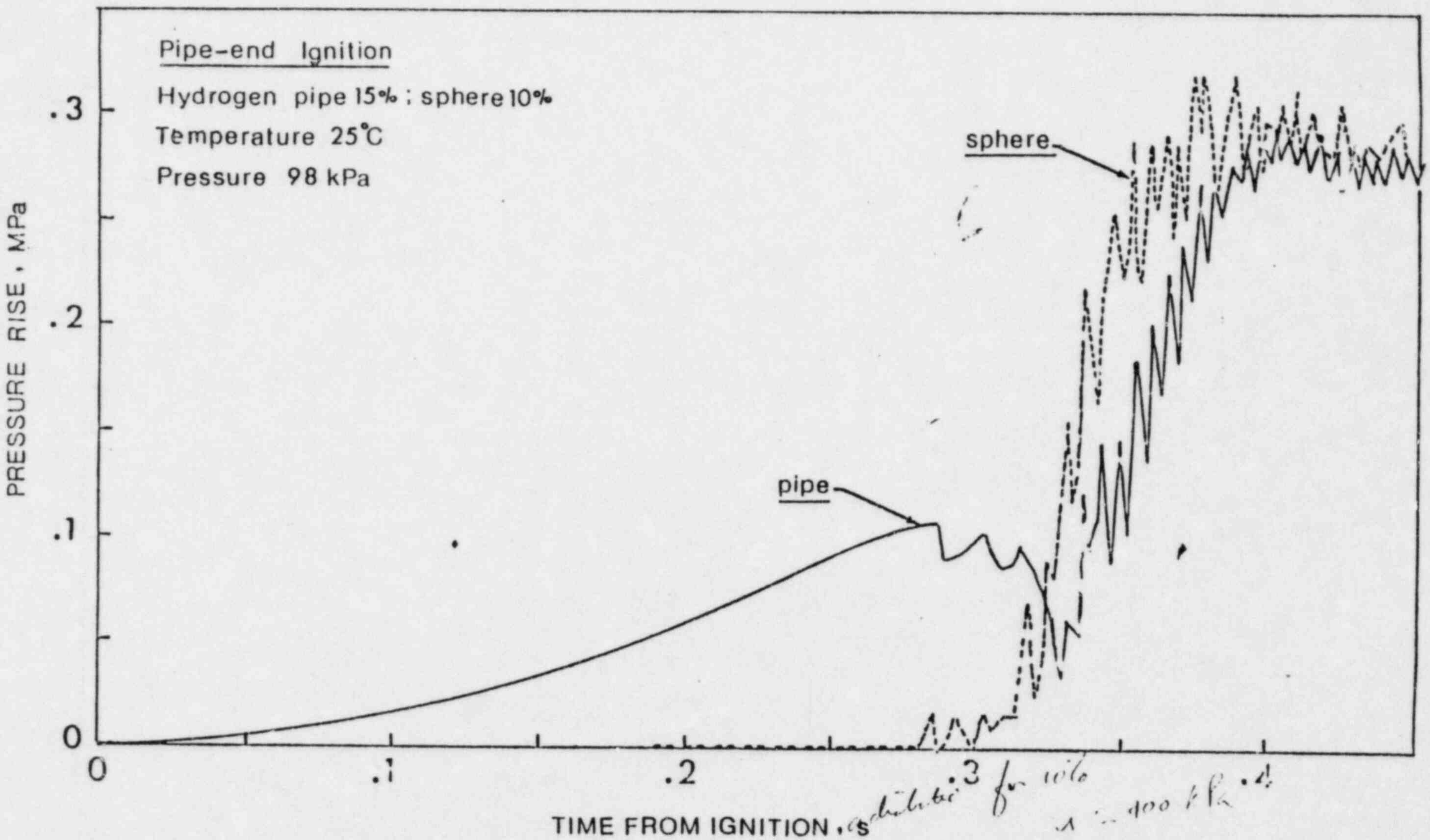


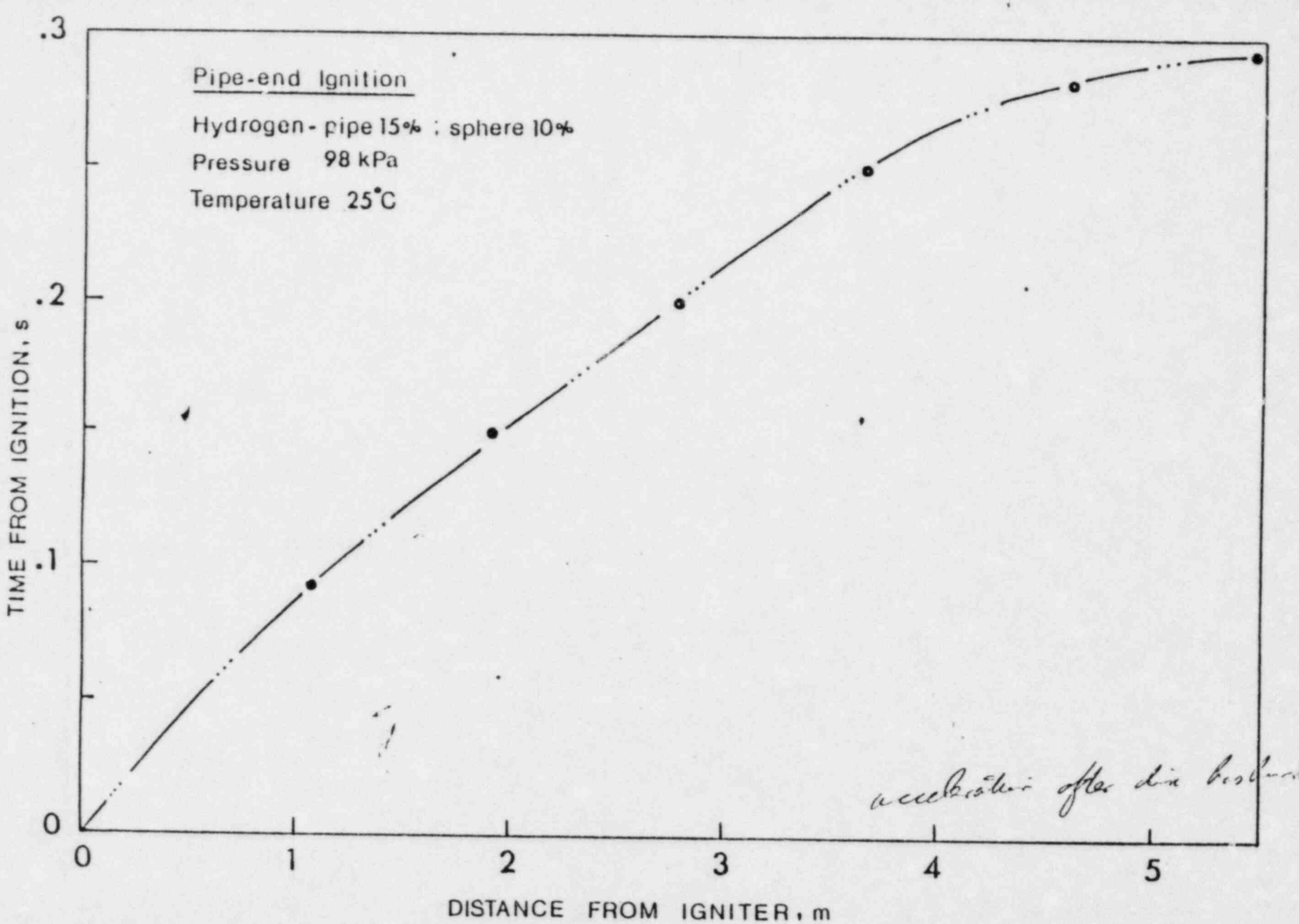
Pipe-end Ignition
Hydrogen 20%
Pressure 98 kPa
Temperature 25°C
Unconstricted
Constricted
PRESSURE RISE, MPa
TIME FROM IGNITION, s
0
.1
.2
.3
.4
.5

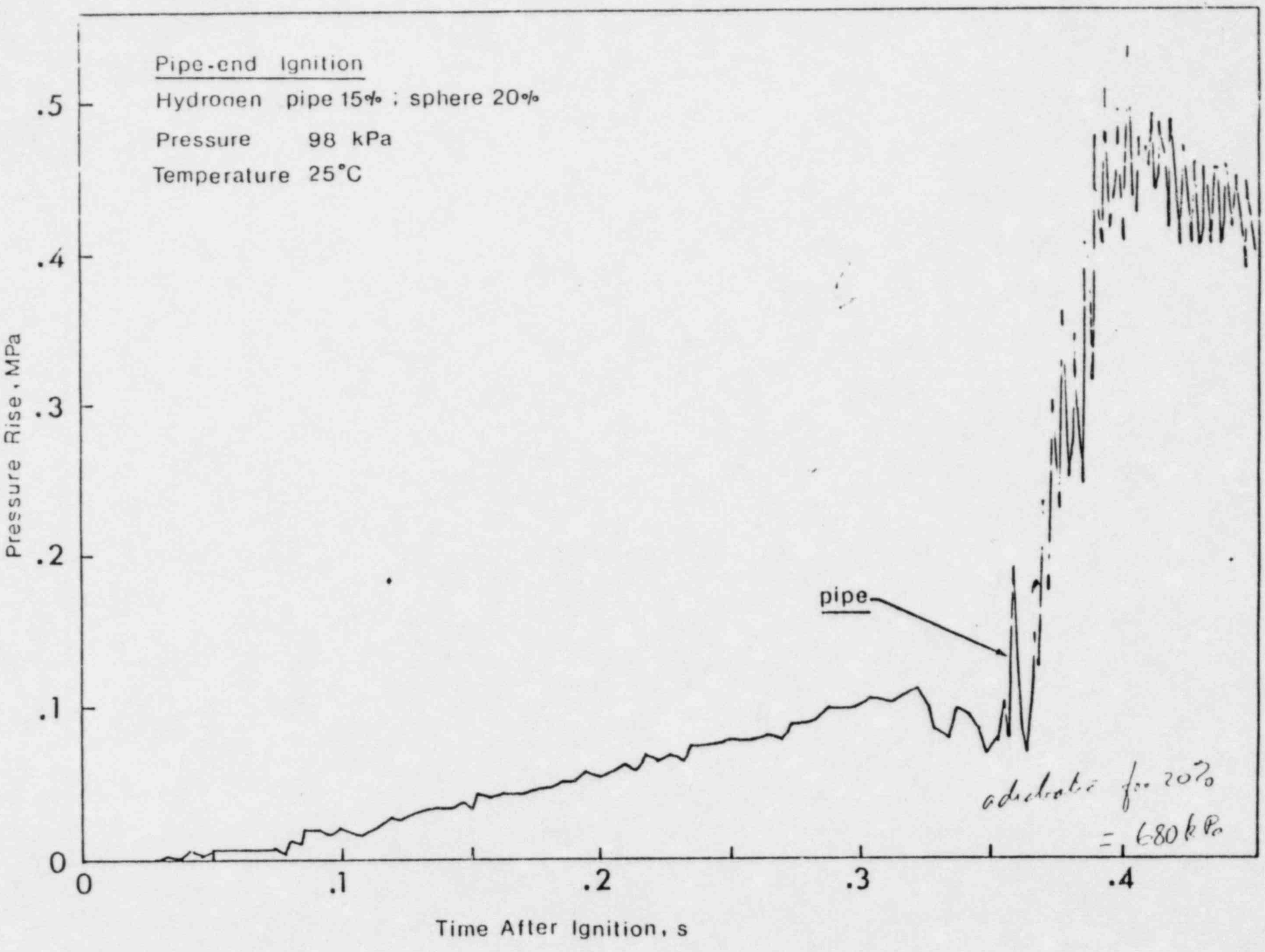


Pipe-end Ignition
Hydrogen pipe 12% ;sphere 6%
PRESSURE RISE, kPa
125
100
75
50
25
0
12 kPa
8
4
pz-4 trace
pz-7 trace
0
.4
.8
1.2
1.6
TIME AFTER IGNITION, s


Pipe-end Ignition
Hydrogen - pipe 15% ; sphere 6%
Pressure 98 kPa
Temperature 25°C
Sphere
Pipe
Pressure Rise, kPa
Time After Ignition, s
0
25
50
75
100
125
150
.1
.2
.3
.4
.5
.6
.7
.8


Pipe-end Ignition
Hydrogen pipe 15% ; sphere 10%
Temperature 25°C
Pressure 98 kPa
sphere
pipe
PRESSURE RISE , MPa
.3
.2
.1
0
0
.1
.2
.3
.4
TIME FROM IGNITION , s


Pipe-end Ignition
Hydrogen - pipe 15% ; sphere 10%
Pressure 98 kPa
Temperature 25°C
TIME FROM IGNITION, s
.3
.2
.1
0
DISTANCE FROM IGNITER, m
0
1
2
3
4
5


Pipe-end Ignition
Hydrogen pipe 15% ; sphere 20%
Pressure 98 kPa
Temperature 25°C
Pressure Rise, MPa
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
pipe
Time After Ignition, s
adiabatic for 20%
= 680 kPa

Series 4b

- presence of constriction inhibits flame acceleration

- turbulence produced by constriction, increases combustion rate in sphere.

With rupture disc:

- @ high H_2 in pipe, turbulence produced by sudden rupture increases the extent & rate of combustion in sphere
- disc rupture sets up pressure oscillations during combustion in sphere.

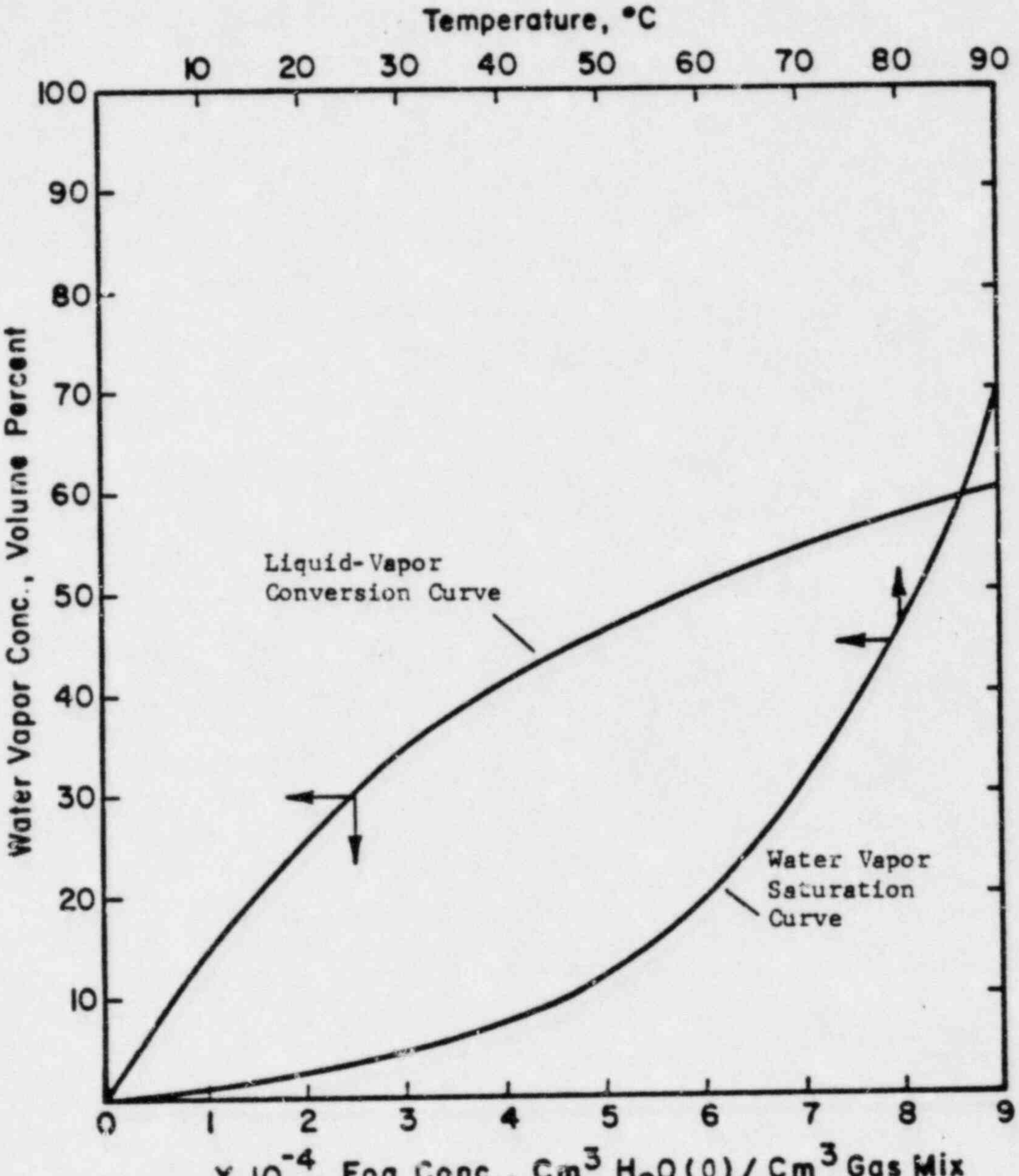


Figure 4-1 . Liquid-Vapor Conversion and Water Vapor Saturation Relationships

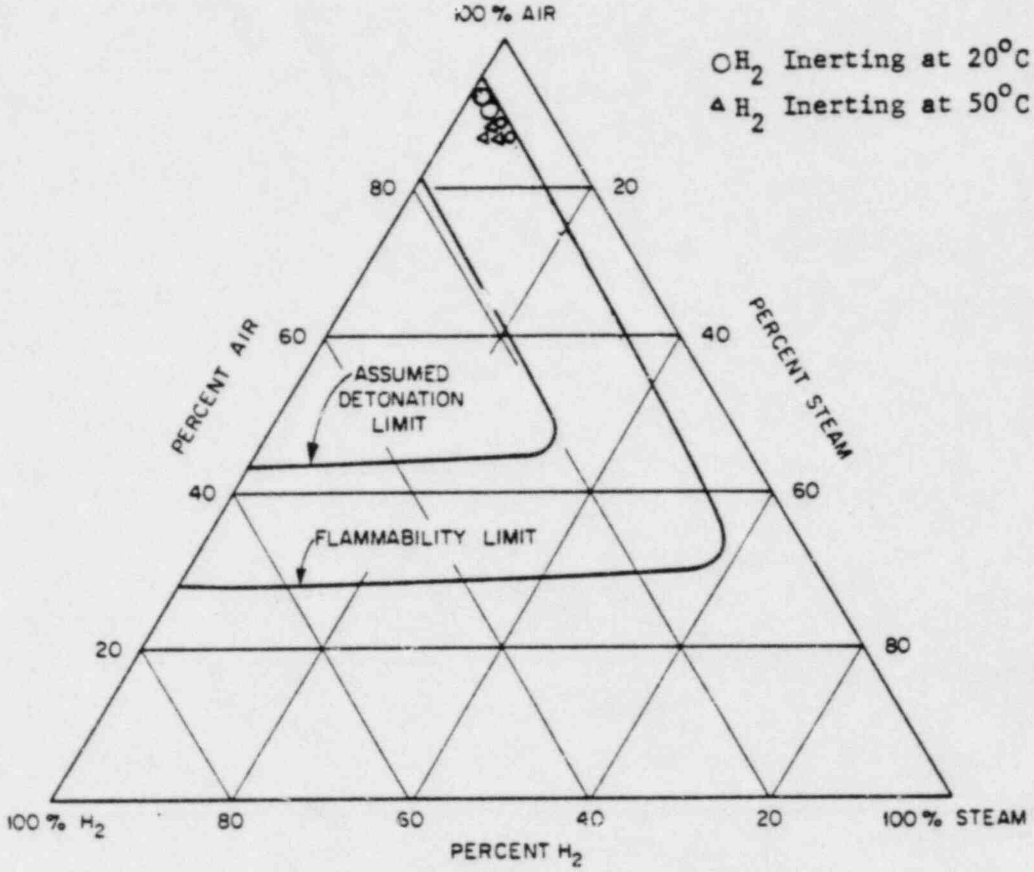
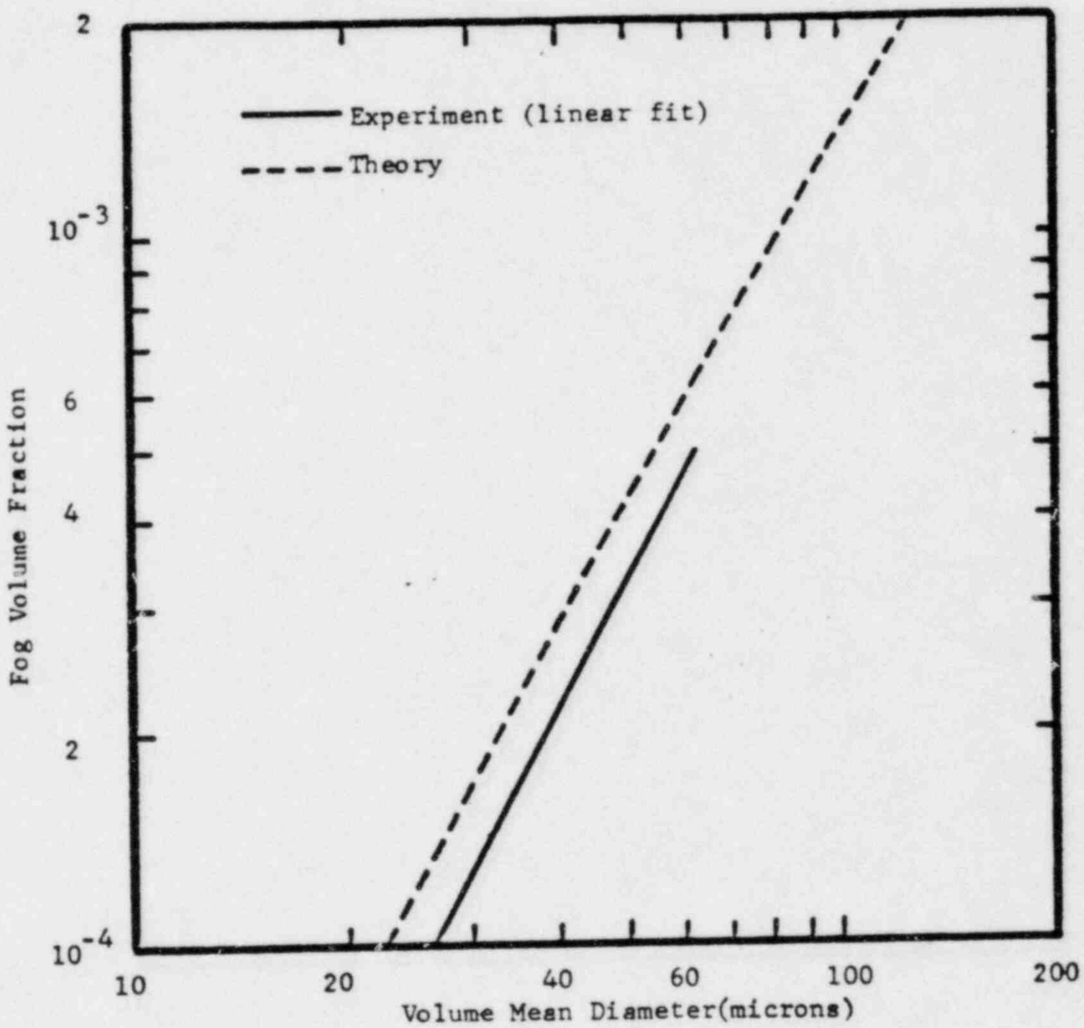


Figure 4-2. Detonation and flammability limits for air-hydrogen-steam mixtures Data Points represent water fog inerting data obtained in this study for nozzles and include water vapor saturation concentrations (Curves are from ref. 6)

Table 4-3

HYDROGEN-WATER FOG INERTING DATA AT ~70°C

Nozzle	Press. (psi)	Vol. Mean Dia. Micron	No. Median Micron	Conc. $\frac{cm^3 H_2O}{cm^3 Mix}$	H_2O Flux $cm^3/cm^2 min$	H_2O Inerting Conc. (%)
Spraco	10	-	-	-	-	6.76
2163-7604	20	-	-	-	-	7.18
	30	-	-	-	-	7.62
	40	-	-	-	-	8.46
Spraco	10	-	-	-	-	5.88
1405-0604	20	-	-	-	-	6.32
	30	-	-	-	-	7.62
	40	-	-	-	-	7.67
Spraco	10	-	-	-	-	4.98
1806-1605	20	-	-	-	-	5.43
	30	-	-	-	-	5.43
	40	-	-	-	-	5.43



COMPARISON OF EXPERIMENT AND THEORY FOR 7.2% HYDROGEN IN AIR AT 50oC

HYDROGEN CONTROL STUDIES

BY

RAYMOND C. TOROK

FEBRUARY 3, 1982

ACUREX Corporation

TEST SPECIFICATION

- ACCIDENT SCENARIOS

  -- PREHEAT
  -- QUIESCENT BURNS
  -- TRANSIENT BURNS
  -- STEAM INJECTION
  -- SPRAY

- TEST PARAMETERS

  -- HYDROGEN CONCENTRATION
  -- HYDROGEN INJECTION RATE
  -- INITIAL TEMPERATURE
  -- STEAM INJECTION
  -- WATER CONCENTRATION/DROP SIZE
  -- IGNITOR LOCATION

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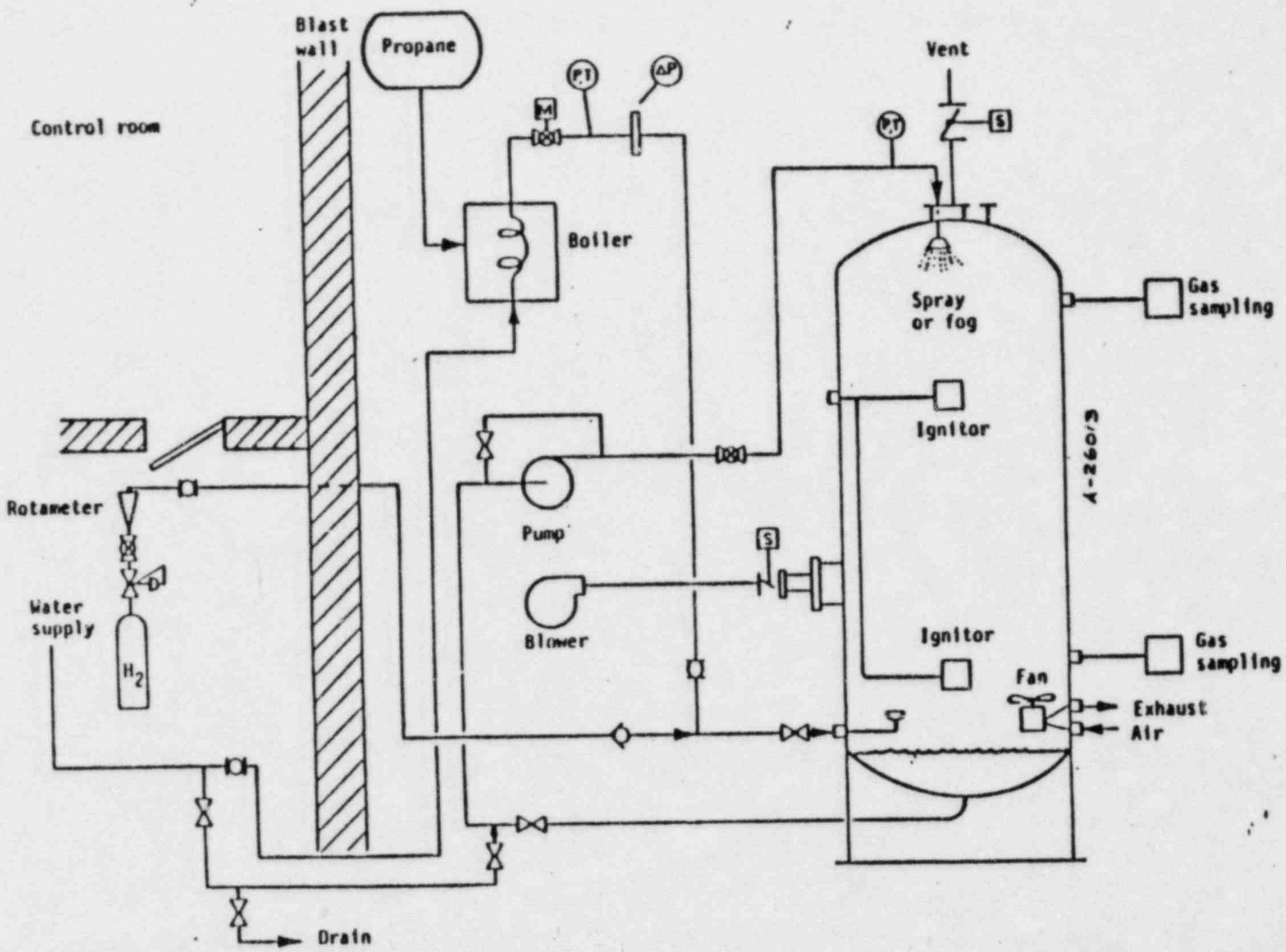
HYDROGEN CONTROL STUDIES
MECHANICAL SCHEMATIC



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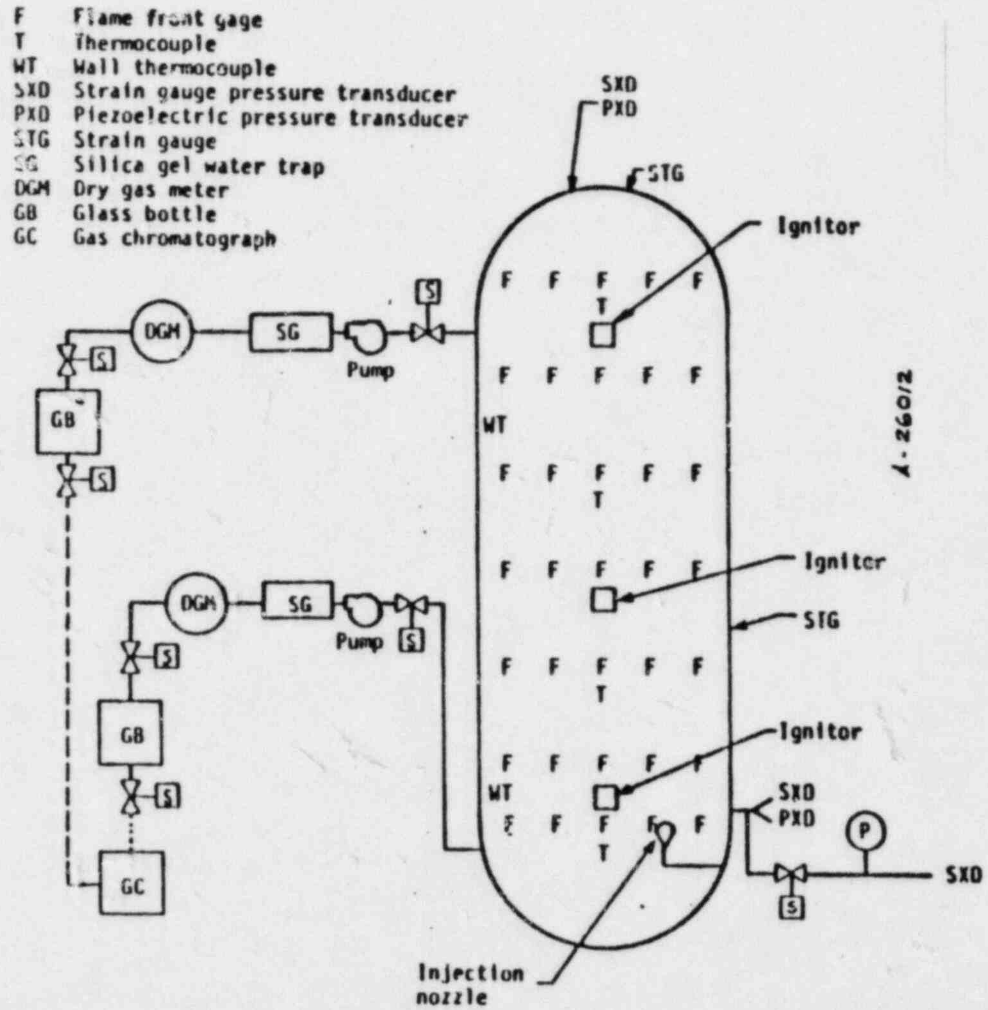
HYDROGEN CONTROL STUDIES
INSTRUMENTATION LOCATIONS



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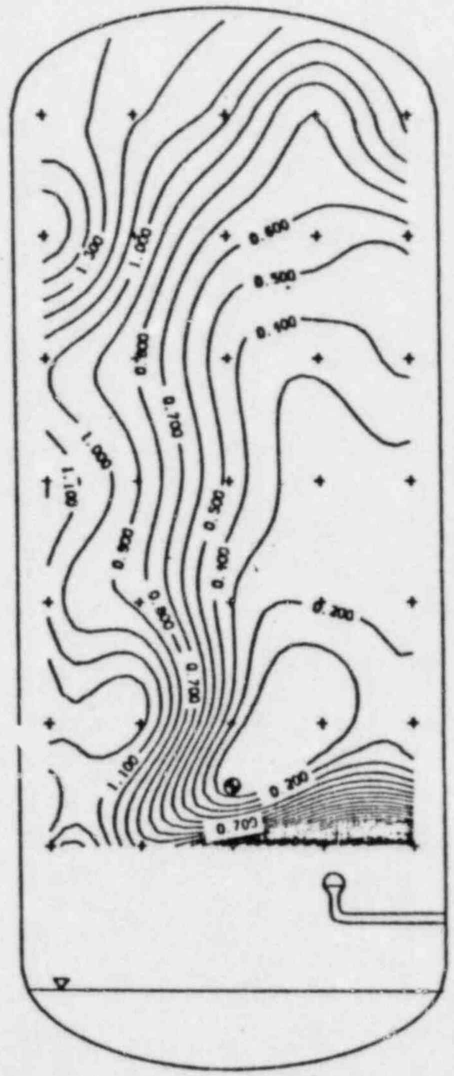
TEST PROCEDURES

- QUIESCENT
  - SEAL VESSEL
  - PREHEAT
  - INJECT H_2
  - SAMPLE GAS
  - IGNITOR ON
  - BURN
  - SAMPLE GAS
  - PURGE + COOL

- DYNAMIC
  - SEAL VESSEL
  - PREHEAT
  - IGNITOR ON
  - START H_2 FLOW, STEAM FLOW
  - BURN
  - STOP H_2, STEAM
  - SAMPLE GAS
  - PURGE + COOL

FLAME FRONT PROPAGATION -- TEST 2.8

T_0 = 127 SEC



0.105 LBM/MIN HYDROGEN
BOTTOM IGNITOR
NO STEAM FLOW
NO SPRAY

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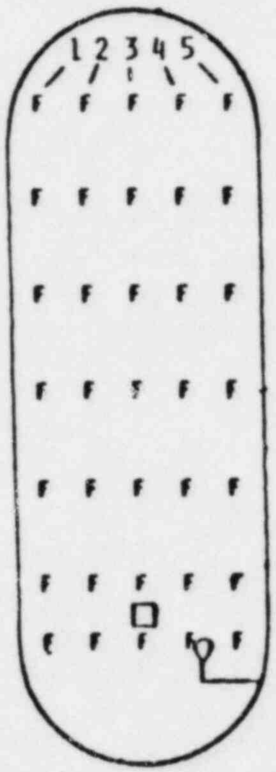
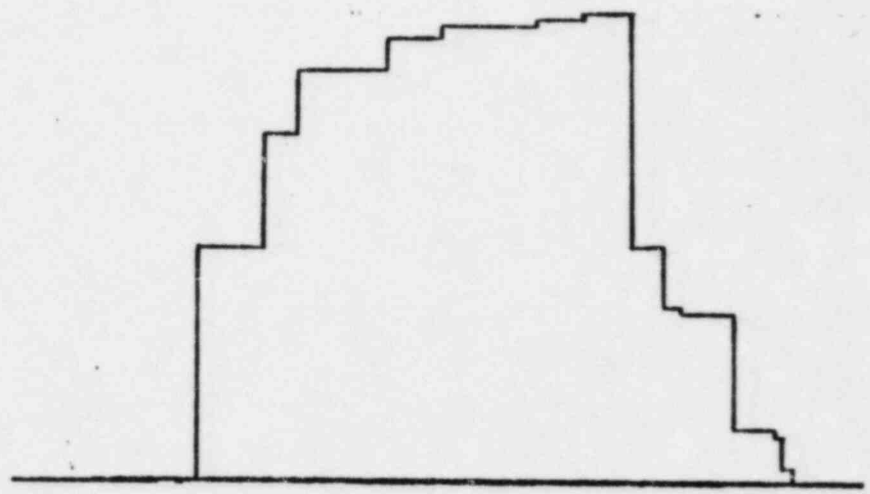
FLAME FRONT DETECTORS



5 CHANNELS
7 FFD'S PER CHANNEL



1 CHANNEL OUTPUT

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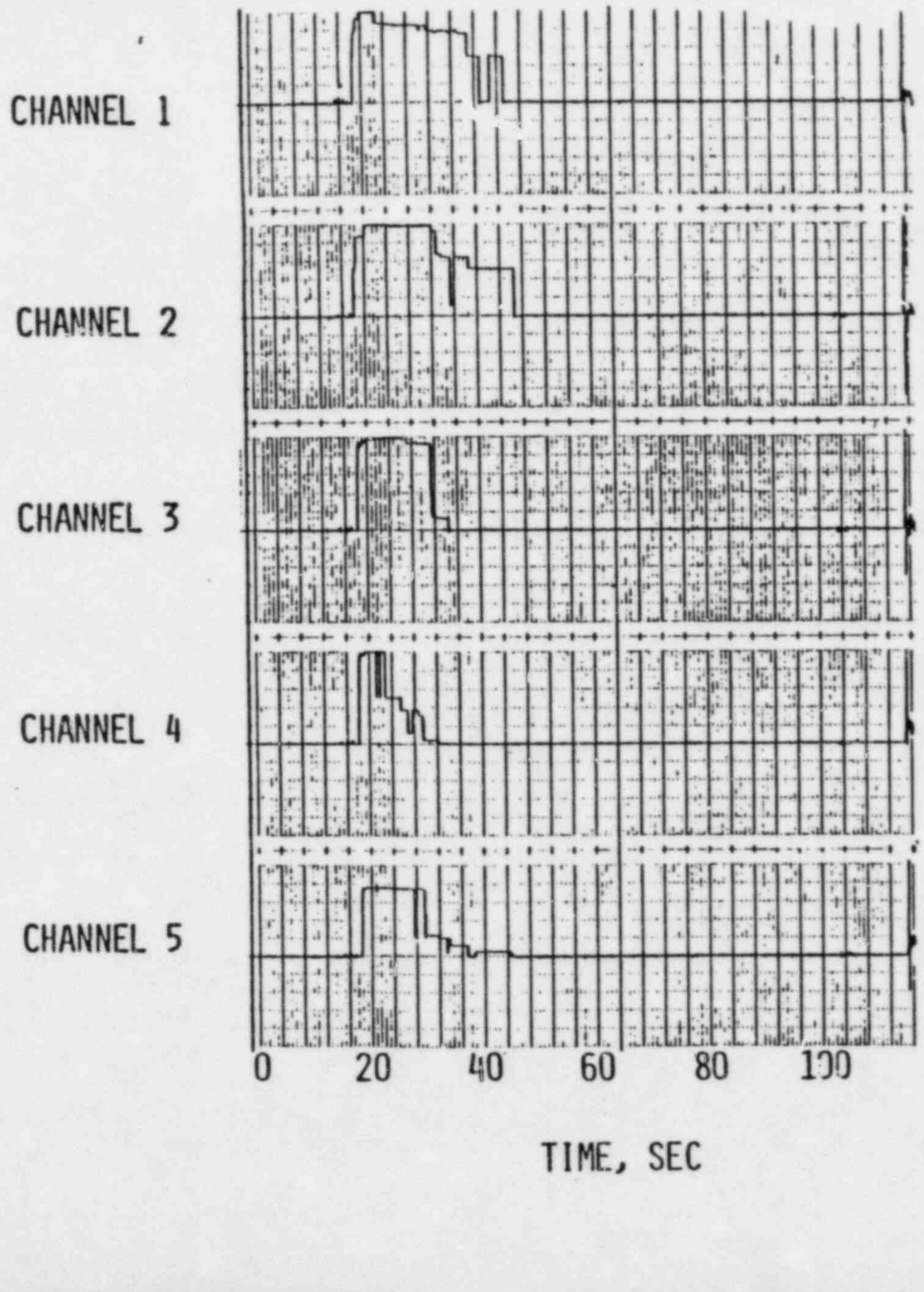
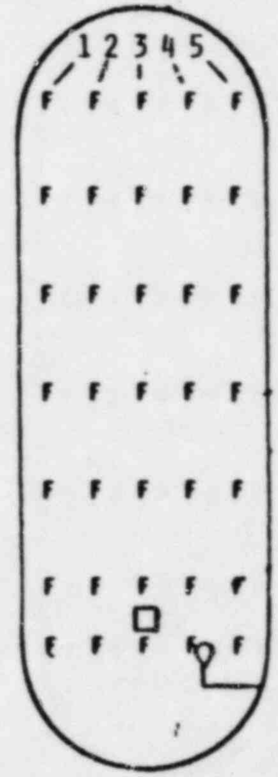
GLOBAL
DISCRETE

FLAME FRONT ACTIVITY -- TEST 3.1



QUIESCENT
10.7% HYDROGEN
MICROFOG



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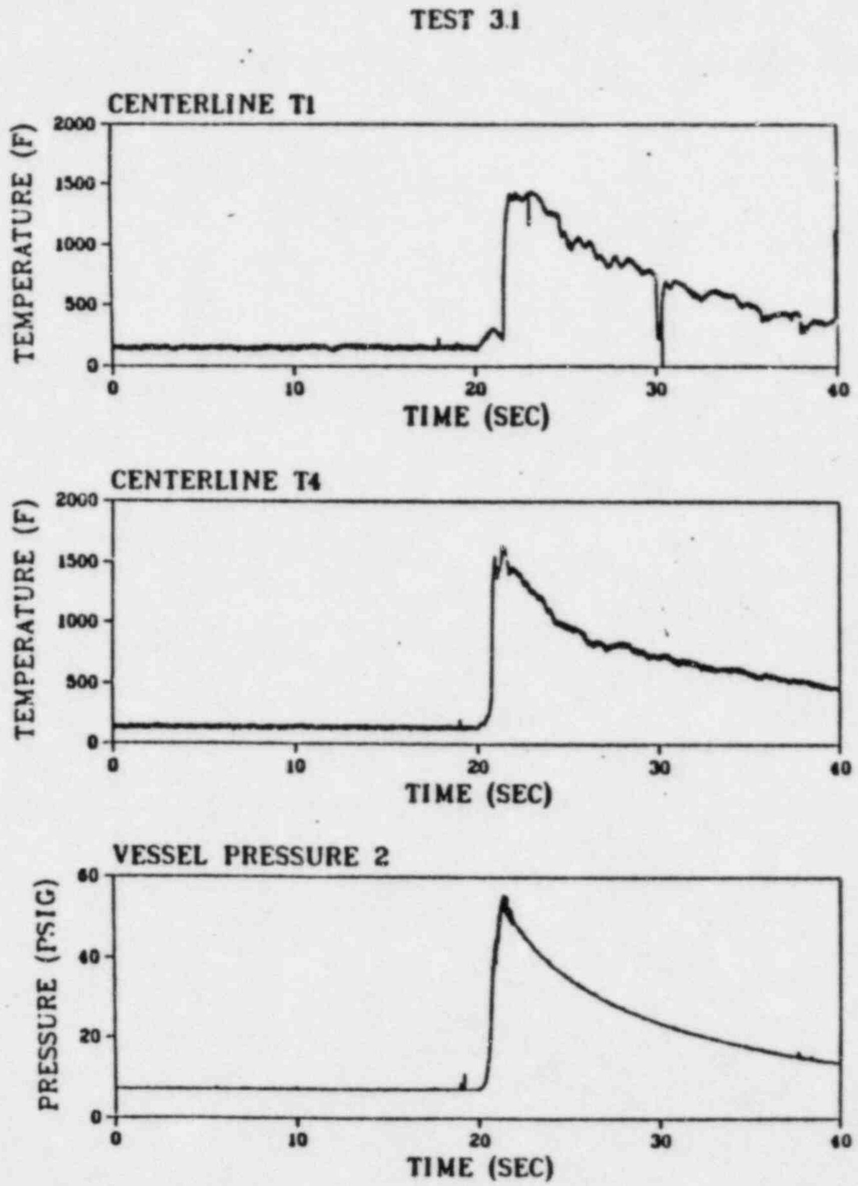
QUIESCENT BURN -- TEST 3.1



10.7 V/O HYDROGEN

MICROFOG

BOTTOM IGNITOR

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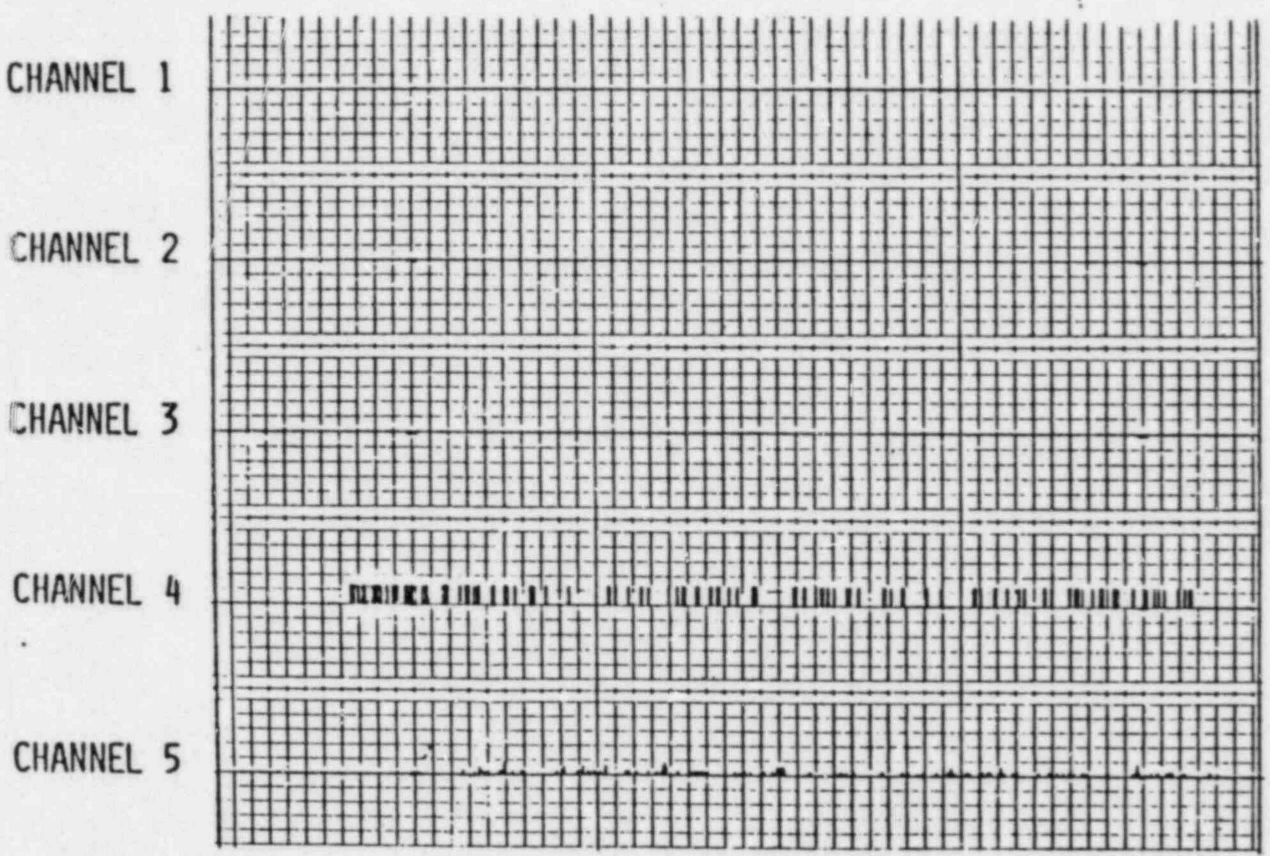
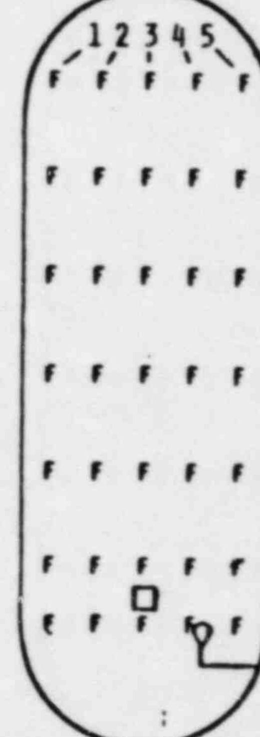
FLAME FRONT ACTIVITY -- TEST 3.5

(LOCAL / INTERMITTENT)



DYNAMIC
0.035 LBM/MIN HYDROGEN
MICROFOG



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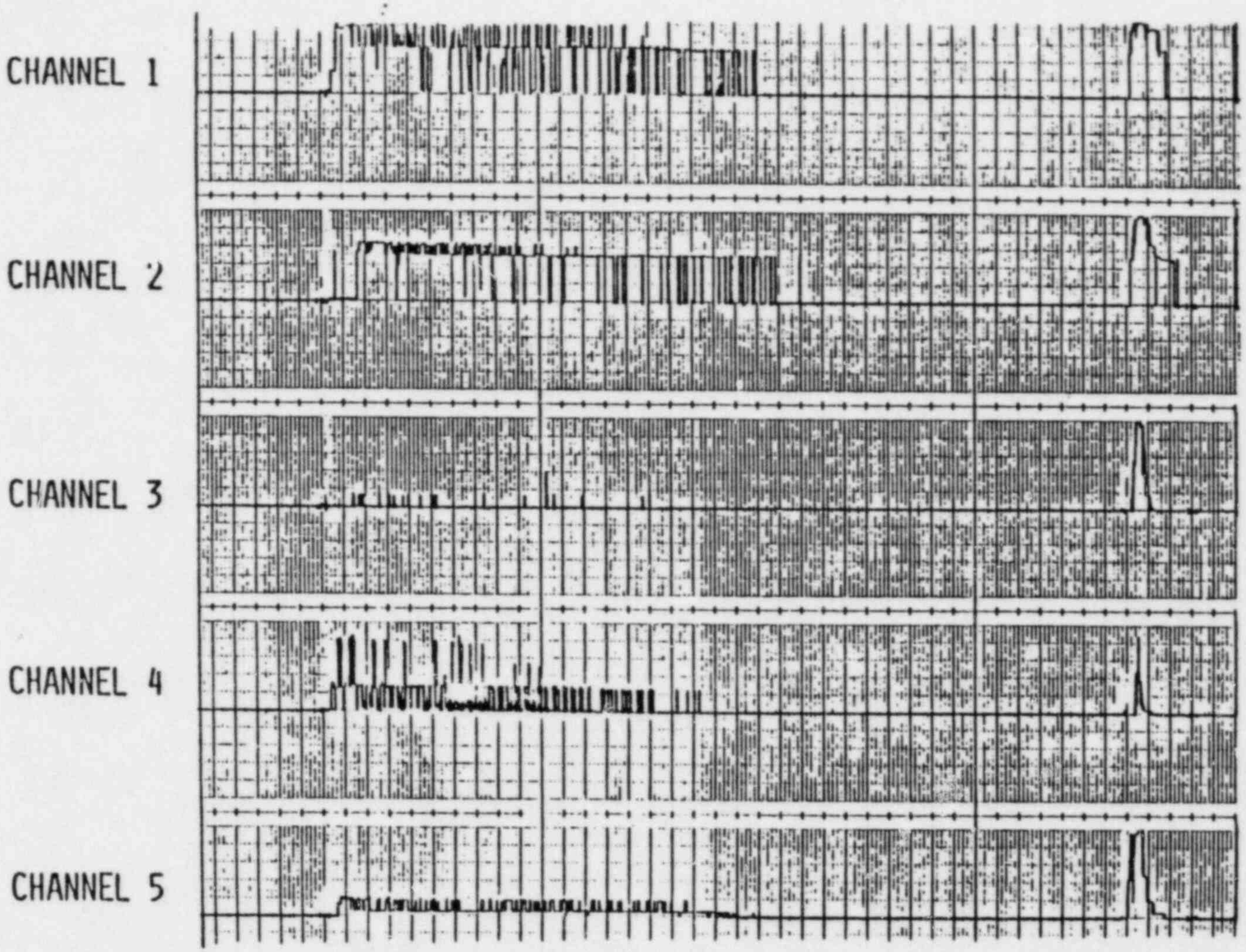
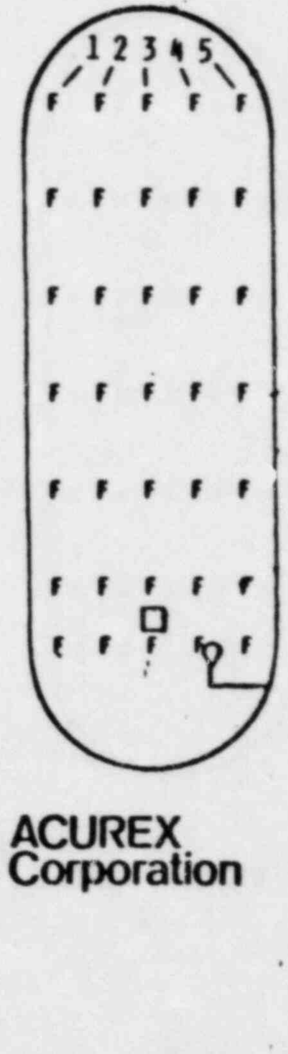
Global intermittent
Global discrete

FLAME FRONT ACTIVITY -- TEST 2.7



DYNAMIC
0.105 LBM/MIN HYDROGEN
2.1 LBM/MIN STEAM



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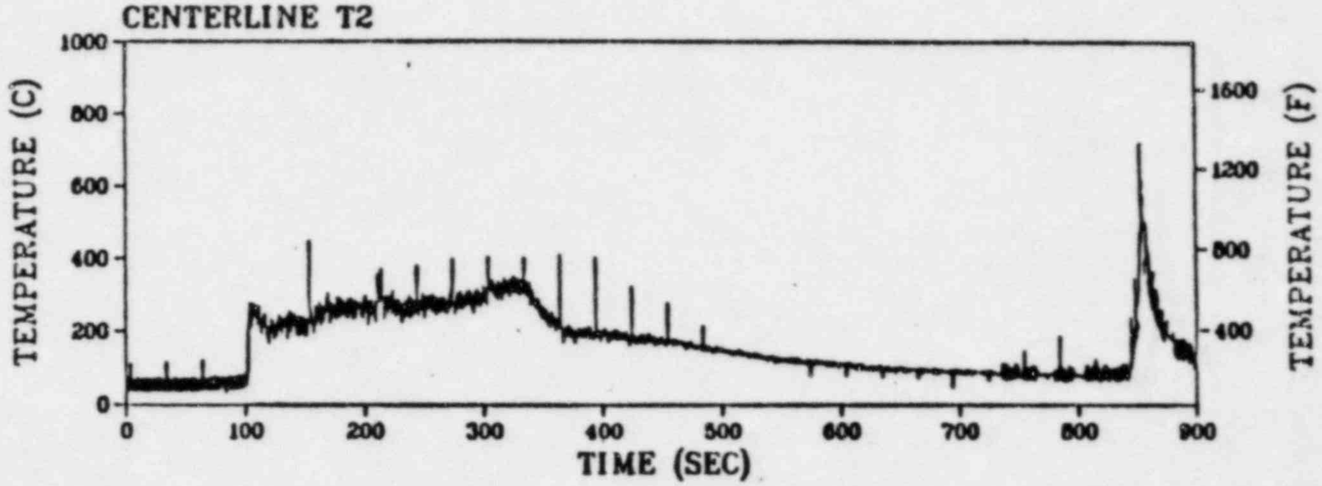
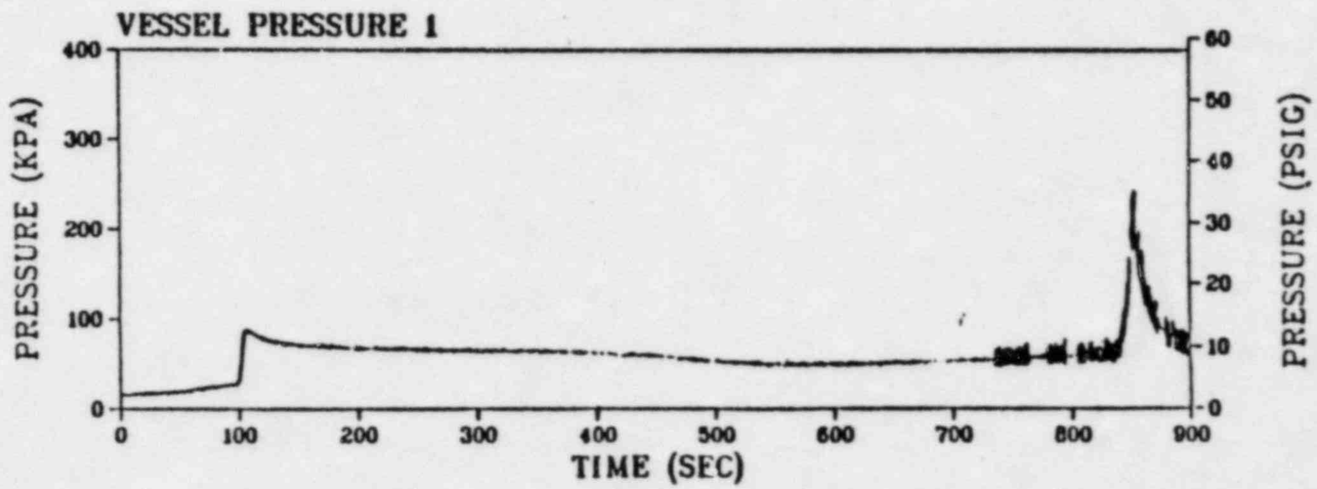
PRESSURE AND TEMPERATURE -- TEST 2.7





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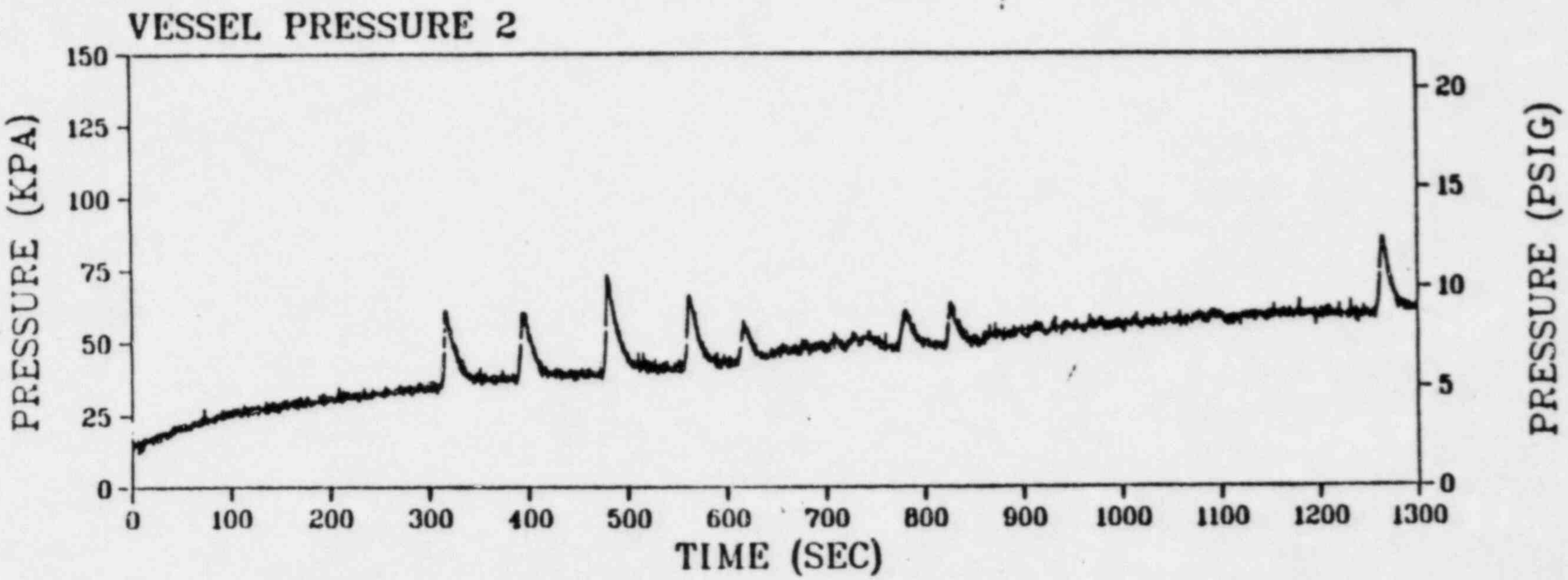
PRESSURE -- TEST 3.6

LOCAL DISCRETE



DYNAMIC

.035 lbm/min H_2

2.1 lbm/min steam

20 PSI fog

ACUREX Corporation

SPRAY EFFECTS -- DYNAMIC INJECTION TESTS

0.035 LBM/MIN H_2, BOTTOM IGNITOR

	TEST	SPRAY	MAX ΔP, PSI	GAS ANALYSIS		
				BURN[A]	H_2	O_2
W/O STEAM	2.6	--	28	GD, LI	2.1	12
	3.5	20 PSI FOG	2.0	LI	3.3	6.8
	3.9	30 PSI FOG	1	LI	0.1	9.2
W/STEAM	2.5	--	4.5	LI, LD	7.9	5.7
	2.4	SPRAYCO 1713	1	LI	5.5	5.1
	3.6	20 PSI FOG	5.0	LD	6.2	5.1
	3.10	30 PSI FOG	1.6	LD	3.7	3.7

[A]L -- LOCAL I -- INTERMITTENT
G -- GLOBAL D -- DISCRETE

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HYDROGEN CONTROL TESTS -- SUMMARY

QUIESCENT

IGNITION IN ALL TESTS
BURN COMPLETE WITH H_2 7.5 V/O
MAX ΔP 50 PSI

DYNAMIC

IGNITION IN ALL TESTS

	MAX ΔP
0.035 LBM/MIN H_2 W/O STEAM	28
0.035 LBM/MIN H_2 W STEAM	13
0.105 LBM/MIN H_2 W/O STEAM	23.5
0.105 LBM/MIN H_2 W STEAM	24
ALL FOG AND SPRAY CASES	5

ACUREX Corporation

EQUIPMENT SURVIVABILITY

I. BASED ON NRC QUESTIONS SEPTEMBER 1981 TVA REANALYZED EQUIPMENT ASSUMMING:

A. 1ft/sec flame speed

B. A seperate radiative heat transfer term

II. MODEL VERIFICATION

A. Showed the model with same heat transfer coefficients melted teflon on thermocouple wire

B. Excellent reproduction of Westinghouse results for a transmitter thermal response to a MSLB

III. CONCLUSIONS

*A. Temperatures very reasonable—
all equipment will survive*

*B. Adresses all outstanding NRC
concerns discussed with TVA or ACRS*