HYDROGEN BEHAVIOR AND CONTROL

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TECHNOLOGY EXCHANGE MEETING 3
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8006270 050

HYDROGEN PROGRAM TASKS

GENERIC:

1. BASED ON PRESENT KNOWLEDGE, PREPARE A COMPENDIUM OF INFORMATION ON HYDROGEN BEHAVIOR DURING ACCIDENTS.

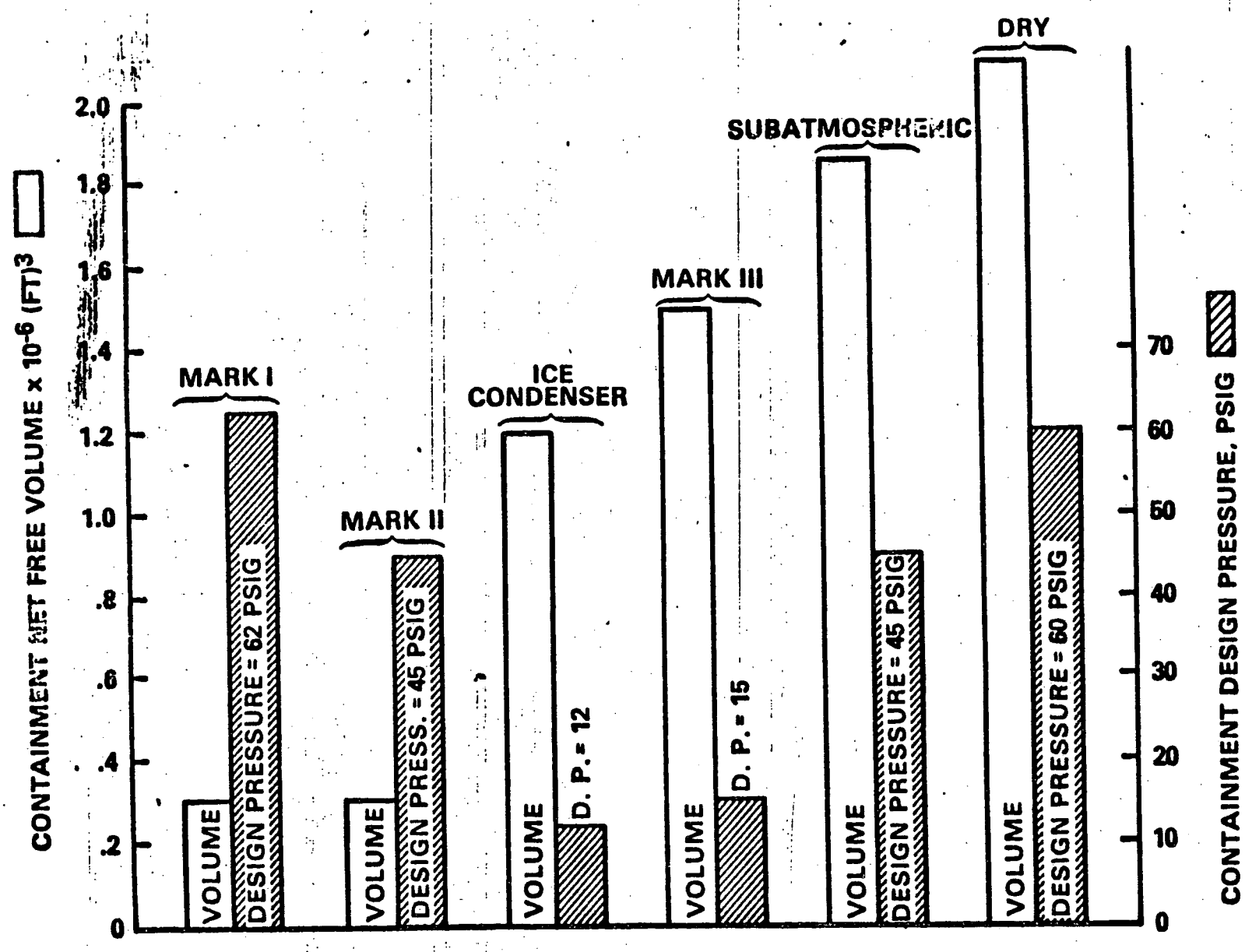
2. IDENTIFY RESEARCH NEEDED TO IMPROVE UNDERSTANDING AND TO INVESTIGATE TECHNIQUES FOR THE PREVENTION OR MITIGATION OF DETRIMENTAL EFFECTS.

ZIP SPECIFIC:

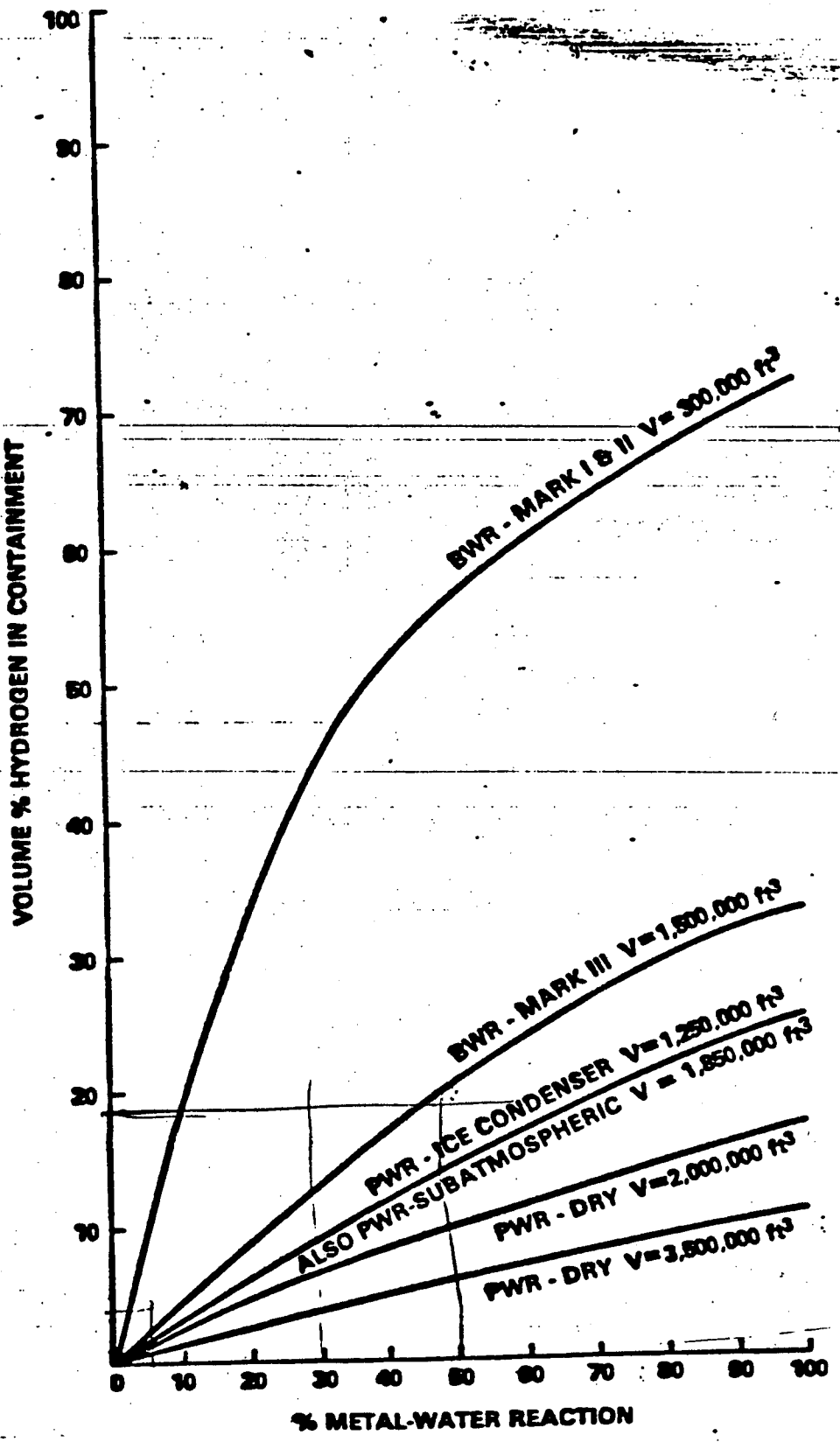
3. ESTIMATE THE LOADS ON CONTAINMENT RESULTING FROM THE COMBUSTION OF HYDROGEN.

FIGURE 3

COMPARISON OF CONTAINMENT VOLUMES AND DESIGN PRESSURES (TYPICAL 1200 MWe PLANT)



VOLUME % HYDROGEN IN CONTAINMENT VS % METAL-WATER REACTION



SANDIA HYDROGEN SAFETY PROGRAM

COMPENDIUM - PERFORM LITERATURE SEARCH TO DETERMINE RESEARCH NEEDS, BOTH ANALYTICAL AND EXPERIMENTAL, TIED TO PWR AND BWR ACCIDENTS.

1. H_2 AND O_2 SOURCES
2. H_2 DETECTION
3. COMBUSTION
4. MITIGATION SCHEMES

H_2 AND O_2 SOURCES - QUANTITY, RATES AND TRANSPORT

A. METAL-WATER REACTIONS, ZR, FE, OTHER

B. RADIOLYSIS

C. CORE-CONCRETE INTERACTIONS

D. GALVANIZED AND PAINTED MATERIALS

E. SOLUBILITY-KINETICS, IMPURITIES

F. TRANSPORT AND LOCAL CONCENTRATIONS

G. OTHER COMBUSTIBLES WHICH COULD AFFECT SAFETY

KEY ELEMENTS OF GAS GENERATION DURING MELT/ CONCRETE INTERACTIONS

1) DECOMPOSITION OF CONCRETE TO YIELD CO_2 AND H_2O

2) REACTION OF CO_2 AND H_2O WITH THE MELT TO YIELD CO AND H_2

3) BURNING OF CO AND H_2

OR

4) REACTION OF CO AND H_2 TO FORM CH_4

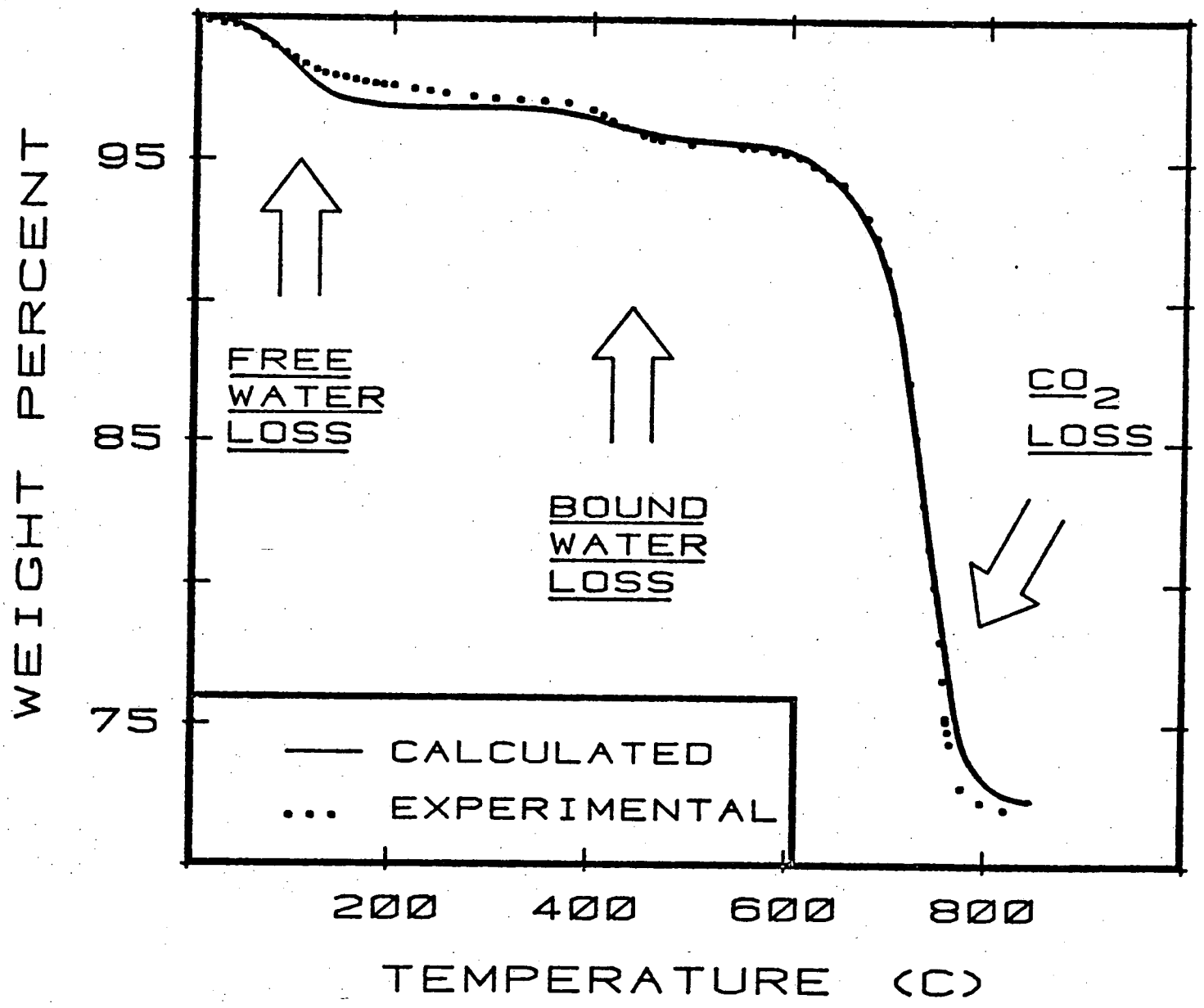
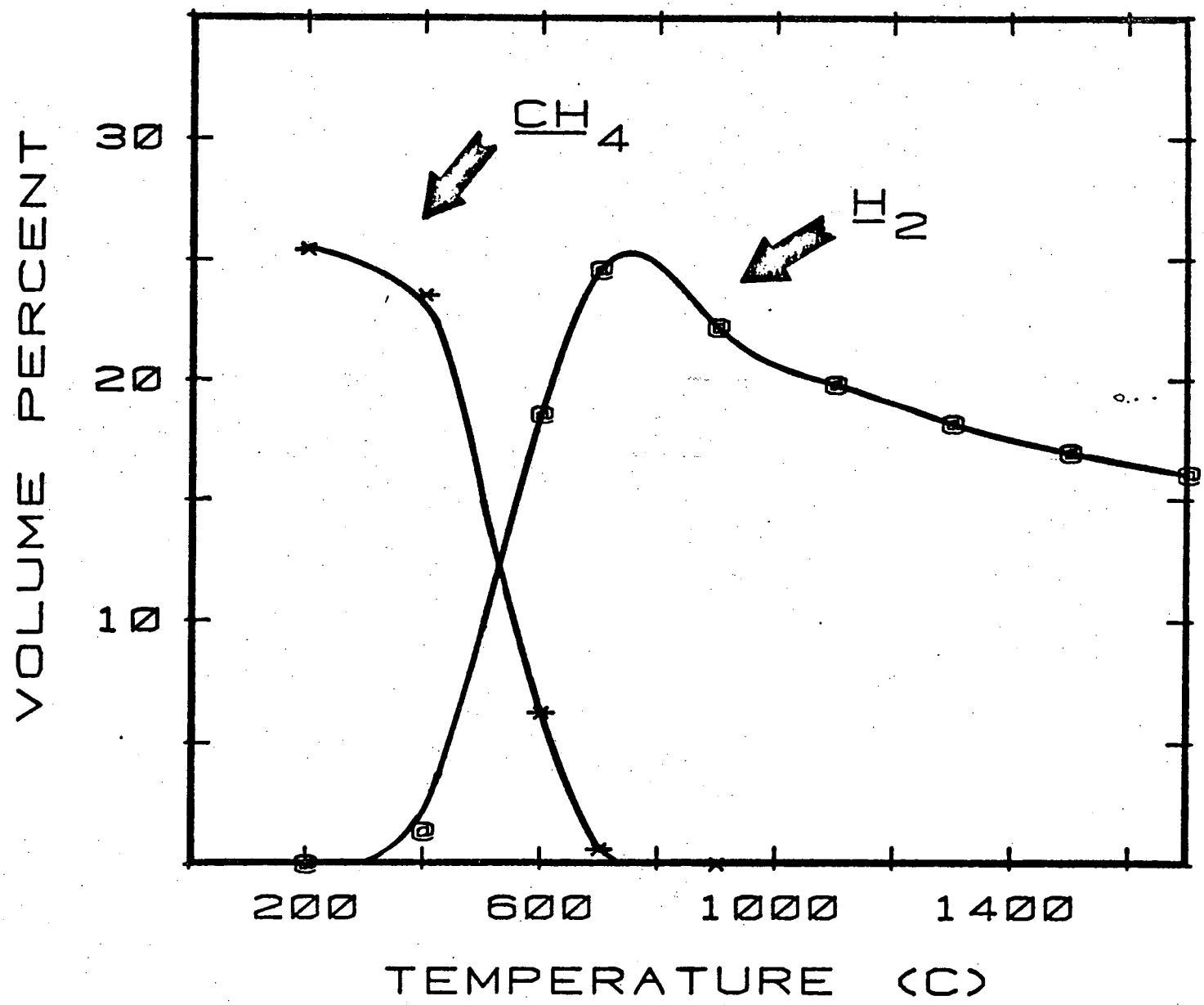

WEIGHT PERCENT
95
85
75
FREE WATER LOSS
BOUND WATER LOSS
CO_2 LOSS
CALCULATED
EXPERIMENTAL
200
400
600
800
TEMPERATURE (C)

FIGURE 6. METHANE AND HYDROGEN CONTENTS VERSUS GAS TEMPERATURE



CODES FOR GAS RELEASE FROM CONCRETE

COWAR-2	GEN'L ELECTRIC
WATRE	HEDL
USINT	SANDIA

CODES ARE NOW GOING THROUGH CODE COMPARISON STUDIES AT GE SPONSORED BY TMC (DOE)

GENERATION OF COMBUSTIBLES FROM CORE-CONCRETE INTERACTIONS

STATE OF KNOWLEDGE

1. ESTIMATES OF THE GENERATION OF HYDROGEN AND OTHER COMBUSTIBLES ARE EXTREMELY UNCERTAIN.

2. CONTAINMENT OVERPRESSURIZATION COULD RANGE FROM 10 TO 100 PSI WITHOUT COMBUSTION.

3. THERMODYNAMIC MODELS OF GAS CHEMISTRY ARE ADEQUATE AT PRESENT IN VIEW OF THE STATE OF EXPERIMENTAL STUDIES.

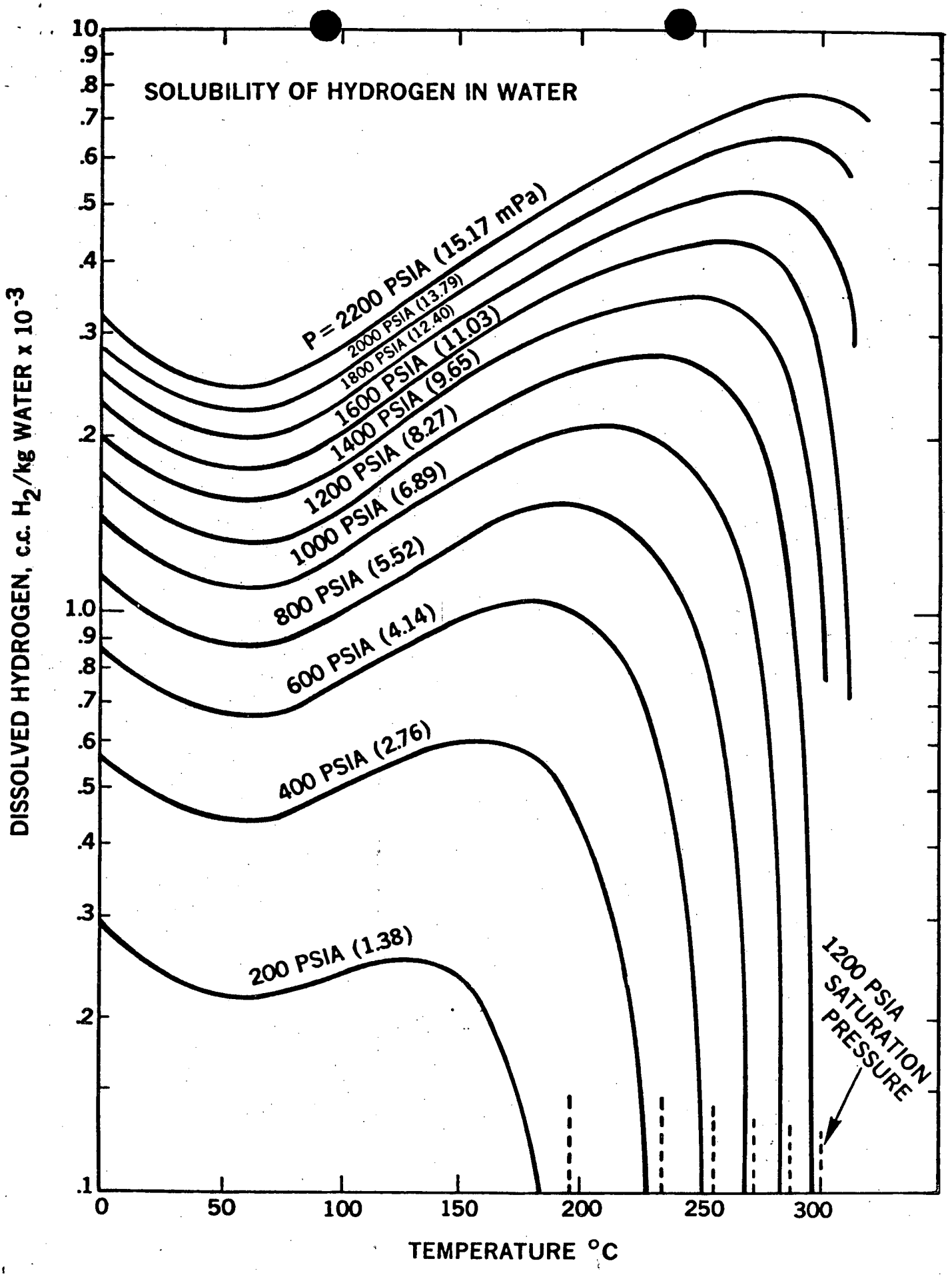
4. CHEMICAL REACTIONS IN GAS ABOVE MELT ARE VERY IMPORTANT FOR ANALYSIS OF DETONATION OR PRESSURIZATION HAZARDS.

TABLE 6: SAMPLE CALCULATION OF ZINC-CORROSION YIELD AND RATE FOR PAINTS AND GALVANIZING

TEMPERATURE °K	ZINC-BASED PAINT 150,000 FT^2		ZINC GALVANIZING 30,000 FT^2	
	H_2 PRODUCTION RATE (KG/HR)	TIME TO ATTAIN TOTAL YIELD[A] (HRS)	H_2 PRODUCTION RATE (KG/HR)	TIME TO ATTAIN TOTAL YIELD[B] (HRS)
422 (300°F)	5.2	20	1.1	50 (2 DAYS)
413 (285°F)	3.6	30	0.72	73 (3 DAYS)
380 (225°F)	0.77	138 (6 DAYS)	0.15	338 (14 DAYS)
339 (150°F)	0.07	1420 (59 DAYS)	0.02	3480 (145 DAYS)

A) TOTAL YIELD FROM PAINTED SURFACES IS 106 KG H_2

B) TOTAL YIELD FROM GALVANIZED SURFACES IS 52 KG H_2


SOLUBILITY OF HYDROGEN IN WATER
P = 2200 PSIA (15.17 mPa)
2000 PSIA (13.79)
1800 PSIA (12.40)
1600 PSIA (11.03)
1400 PSIA (9.65)
1200 PSIA (8.27)
1000 PSIA (6.89)
800 PSIA (5.52)
600 PSIA (4.14)
400 PSIA (2.76)
200 PSIA (1.38)
1200 PSIA SATURATION PRESSURE
DISSOLVED HYDROGEN, c.c. H2/kg WATER x 10-3
TEMPERATURE °C
10
.9
.8
.7
.6
.5
.4
.3
.2
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
50
100
150
200
250
300

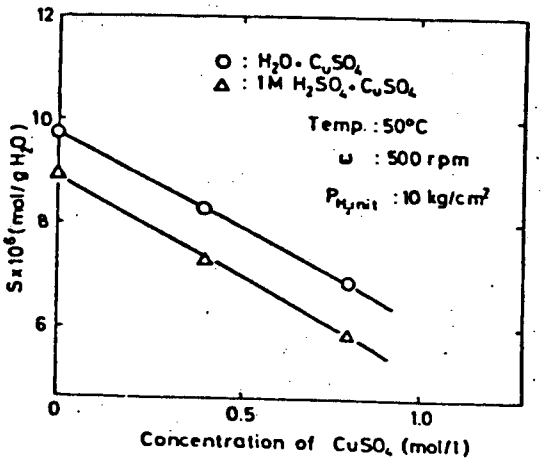


Fig. 2 Observed additivity for the solubility of hydrogen gas in $H_2SO_4-CuSO_4$ solutions

FIG 8

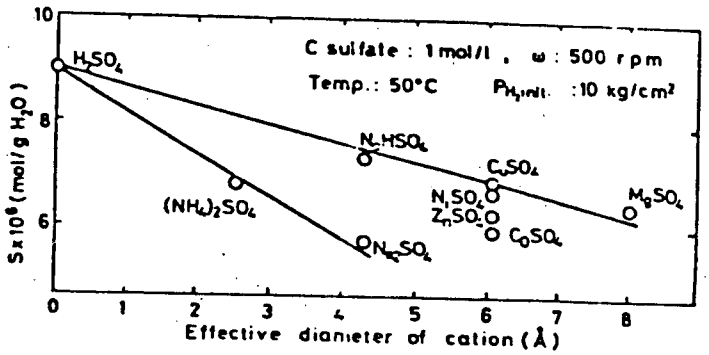


Fig. 3 Solubility of hydrogen gas in sulfate solution.

FIG 7

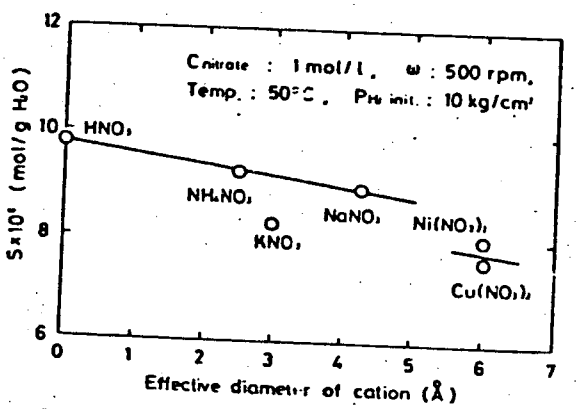


FIG 8

Fig. 5 Solubility of hydrogen gas in nitrate solutions.

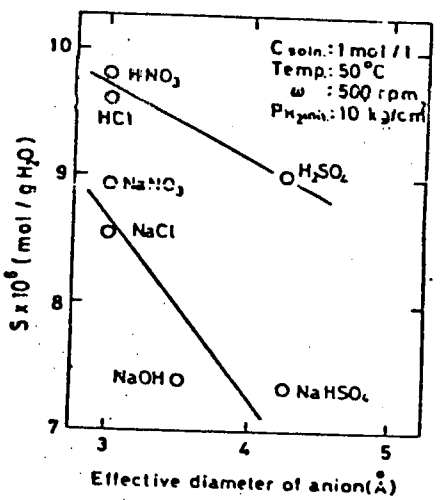


FIG 9

Fig. 6 Dependence of effective anion diameter upon the solubility of hydrogen gas.

REF 1

HYDROGEN DETECTION

NEEDED FOR:

- PRIMARY WATER SAMPLING
- CONTAINMENT GAS ANALYSIS
- EXPERIMENTAL MEASUREMENTS

CHARACTERISTICS:

- SPATIAL RESOLUTION
- REAL TIME RESPONSE
- ACCURACY
- RELIABILITY
- HARDNESS UNDER NORMAL AND ACCIDENT CONDITIONS

HYDROGEN COMBUSTION

PRIMARY CONCERN:

- THE HIGH PRESSURES GENERATED MAY BE SUFFICIENT TO FAIL CONTAINMENT.

OTHER CONCERNS:

- HIGH TEMPERATURES AND PRESSURES MAY LEAD TO FAILURE OF SAFETY-RELATED EQUIPMENT.
- DETONATIONS MAY PRODUCE MISSILES WHICH COULD JEOPARDIZE EQUIPMENT OR BREACH CONTAINMENT.

H_2 COMBUSTION

A. DEFLAGRATION, DETONATION AND TRANSITION

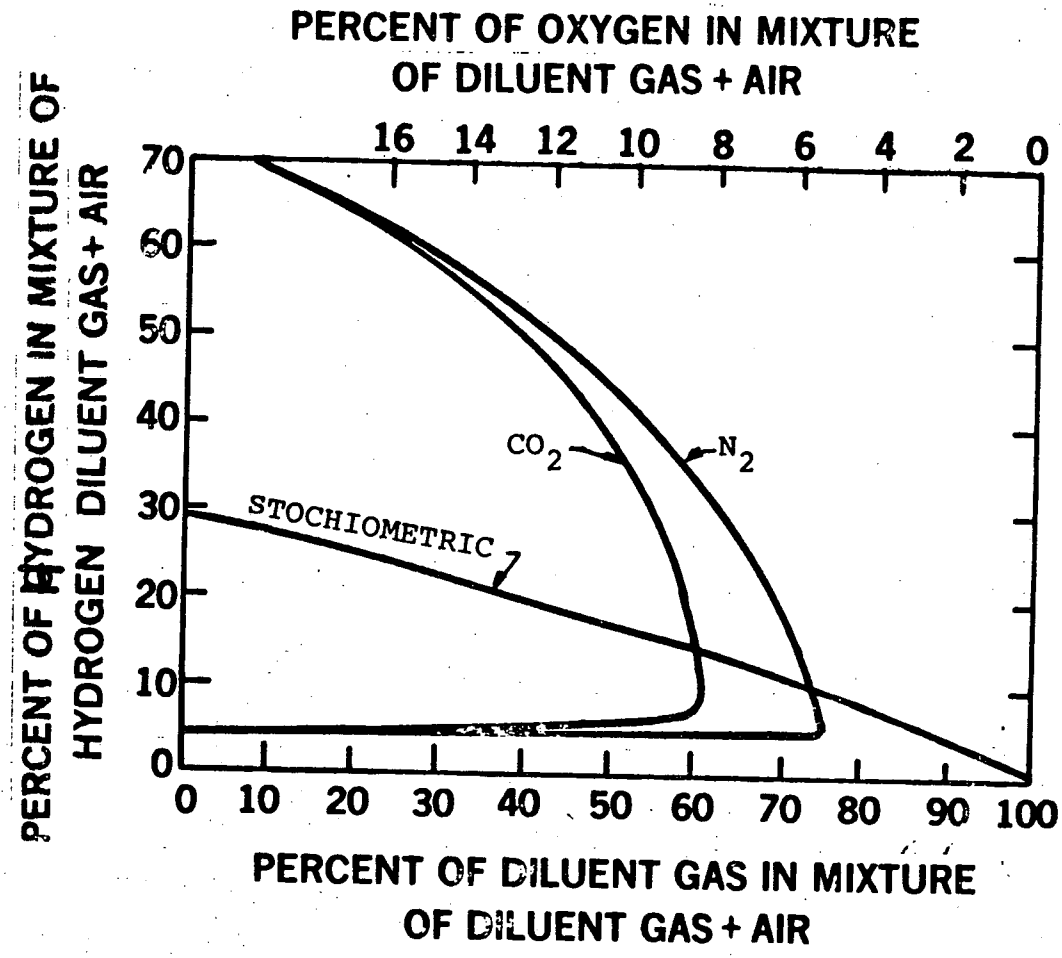
B. STRUCTURAL LOADS AND DAMAGE CRITERIA

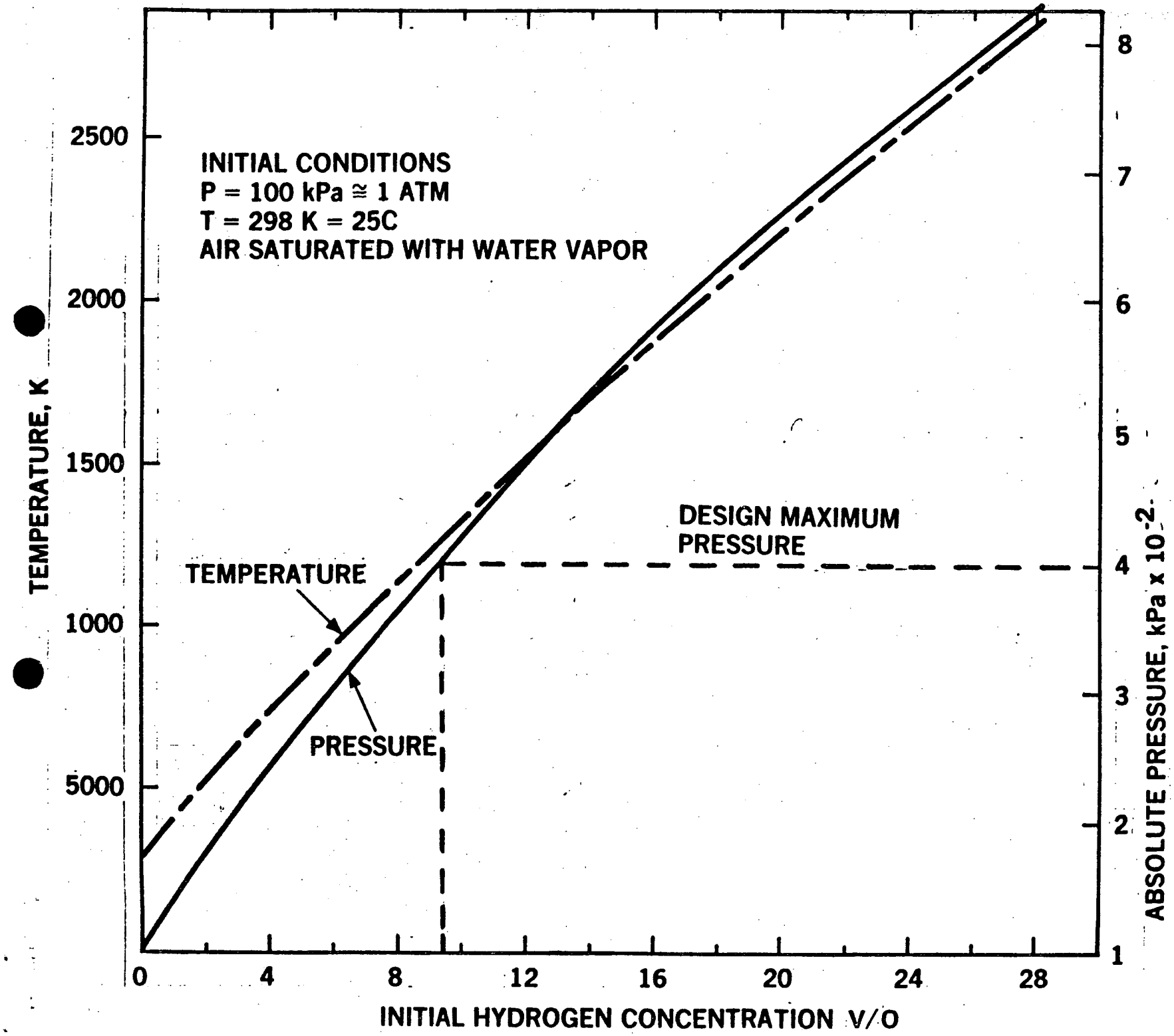
C. SCALE AND GEOMETRY EFFECTS

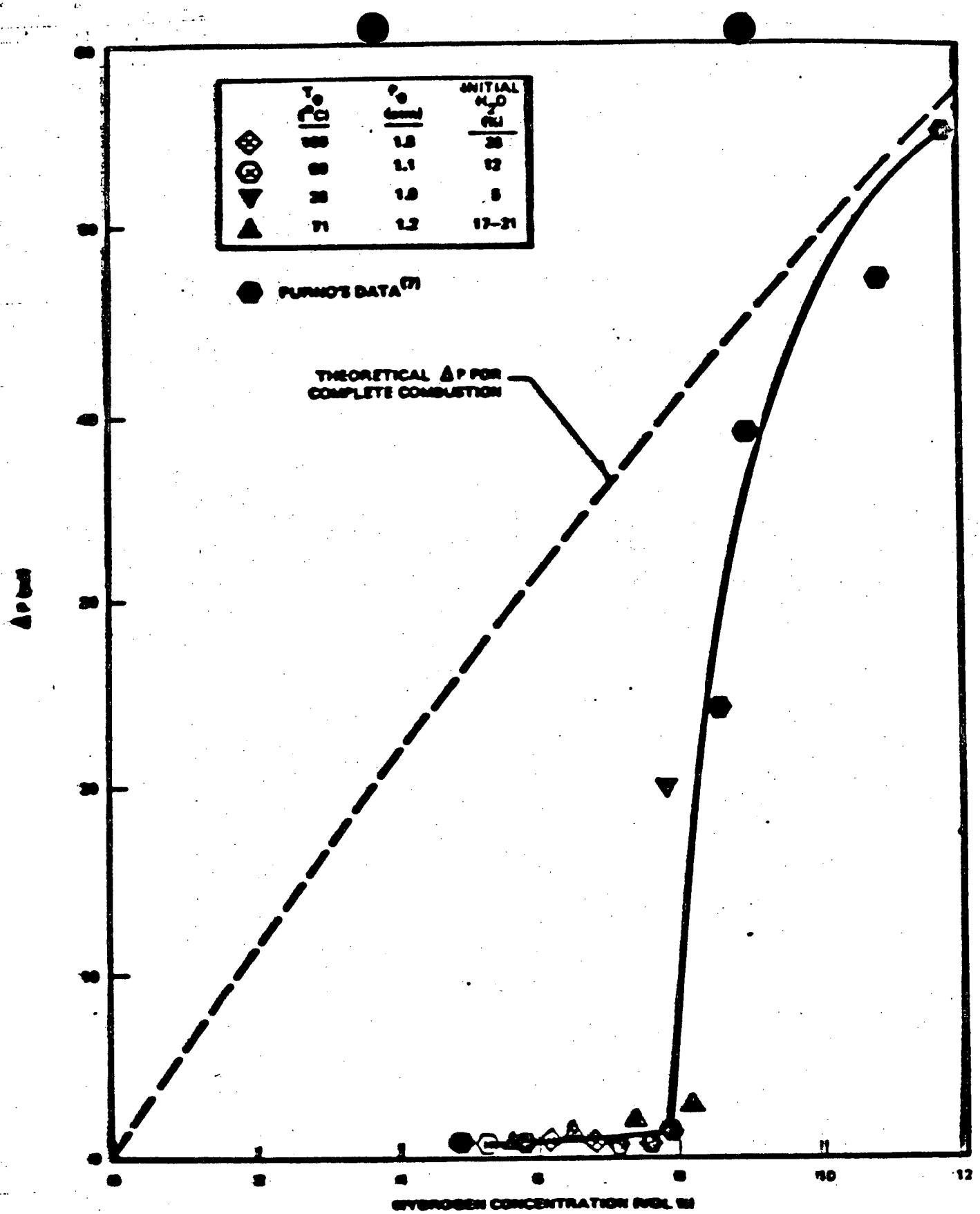
D. HOMOGENEOUS VS. NONUNIFORM CONCENTRATIONS

HYDROGEN BURNING CHARACTERISTICS

CHARACTERISTICS	HYDROGEN CONCENTRATION VOL. % IN AIR	IN O_2
NON-FLAMMABLE	0-4	0-4
FLAME PROPAGATES UPWARDS ONLY; COMBUSTION INCOMPLETE	4-6	4-
HORIZONTAL PROPAGATION; INCOMPLETE COMBUSTION	6-9	-8
DOWNWARD PROPAGATION; COMBUSTION NEARLY COMPLETE	9-18	8-16
DETONATION POSSIBLE BUT NOT ALWAYS OBSERVED	18-59	16-90
DETONATION IMPOSSIBLE	59-74	90-95
NON-FLAMMABLE	74-100	95-100


PERCENT OF OXYGEN IN MIXTURE
OF DILUENT GAS + AIR
16 14 12 10 8 6 4 2 0
PERCENT OF HYDROGEN IN MIXTURE OF
HYDROGEN DILUENT GAS + AIR
70 60 50 40 30 20 10 0
CO_2
N_2
STOCHIOMETRIC
0 10 20 30 40 50 60 70 80 90 100
PERCENT OF DILUENT GAS IN MIXTURE
OF DILUENT GAS + AIR


INITIAL CONDITIONS
P = 100 kPa ≅ 1 ATM
T = 298 K = 25C
AIR SATURATED WITH WATER VAPOR
DESIGN MAXIMUM PRESSURE
TEMPERATURE
PRESSURE
TEMPERATURE, K
2500
2000
1500
1000
5000
ABSOLUTE PRESSURE, kPa x 10^-2
8
7
6
5
4
3
2
1
0
4
8
12
16
20
24
28
INITIAL HYDROGEN CONCENTRATION V/O



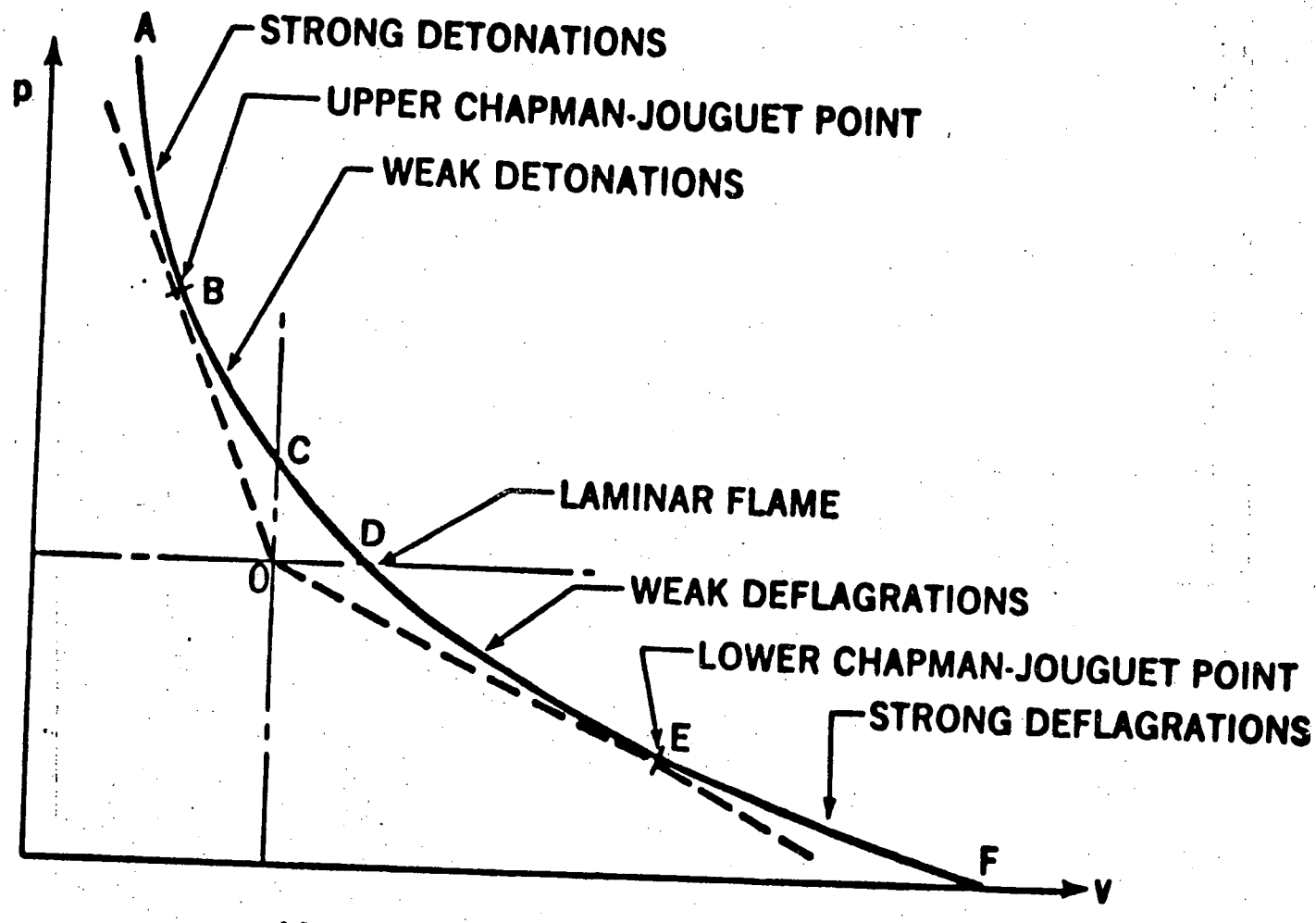
T_0 (°C)
P_0 (atm)
INITIAL H_2O (%)
1.1
12
1.2
17–21
PURNO'S DATA[7]
THEORETICAL ΔP FOR COMPLETE COMBUSTION
ΔP (psi)
0
10
20
30
40
50
60
2
4
6
8
10
12
HYDROGEN CONCENTRATION (VOL %)

DEFLAGRATIONS

- LAMINAR
  1. FLAME SPEEDS $\sim$1-3 M/S IN AIR
  2. QUASI-STATIC LOADING
- TURBULENT (NORMAL)
  1. MOST PREVALENT DUE TO OBSTRUCTIONS INSTABILITIES
  2. FLAME SPEEDS $\sim$10 X LAMINAR
  3. LOADING MOSTLY QUASI-STATIC
- PSEUDO-DETONATIONS (EXTREME TURBULENCE)
  1. FLAME SPEEDS $\gtrsim$ MACH 0.1
  2. CAUSED BY MANY OBSTRUCTIONS
  3. DYNAMIC COMPONENT IN LOADS

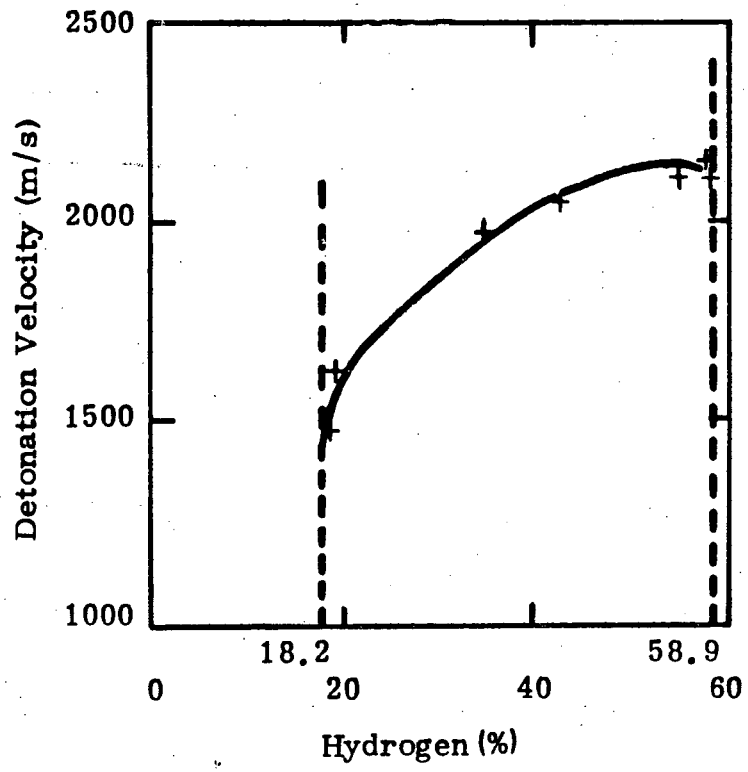
DETONATIONS

- VELOCITIES ARE SUPERSONIC IN UNBURNED GAS (~1400-2000 M/S IN AIR).
- PRESSURE AND TEMPERATURES RISES CAN BE COMPUTED FROM CHAPMAN-JOUGUET CONDITIONS.
- LOADS STRONGLY IMPULSIVE, ENHANCED BY REFLECTED SHOCK WAVES, ULTIMATELY APPROACHING STATIC VALUES.
- DEFLAGRATION TO DETONATION TRANSITION VERY UNCERTAIN; CAUSED BY REFLECTED SHOCK WAVES, OBSTACLES, STRONG IGNITION SOURCES.

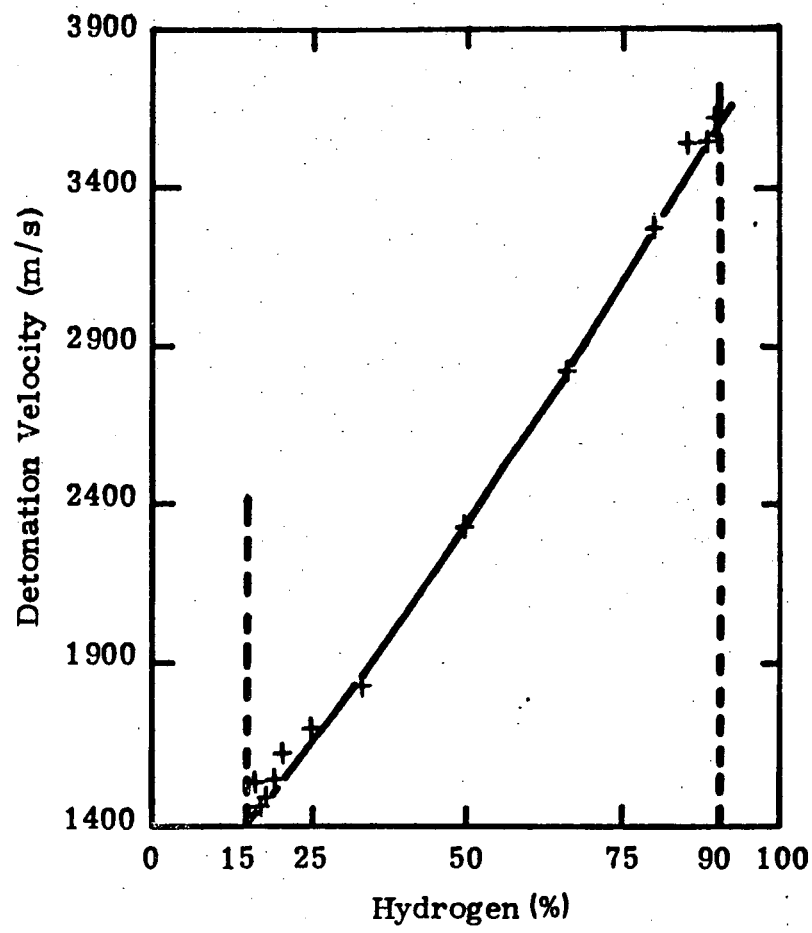


HUGONIOT DIAGRAM

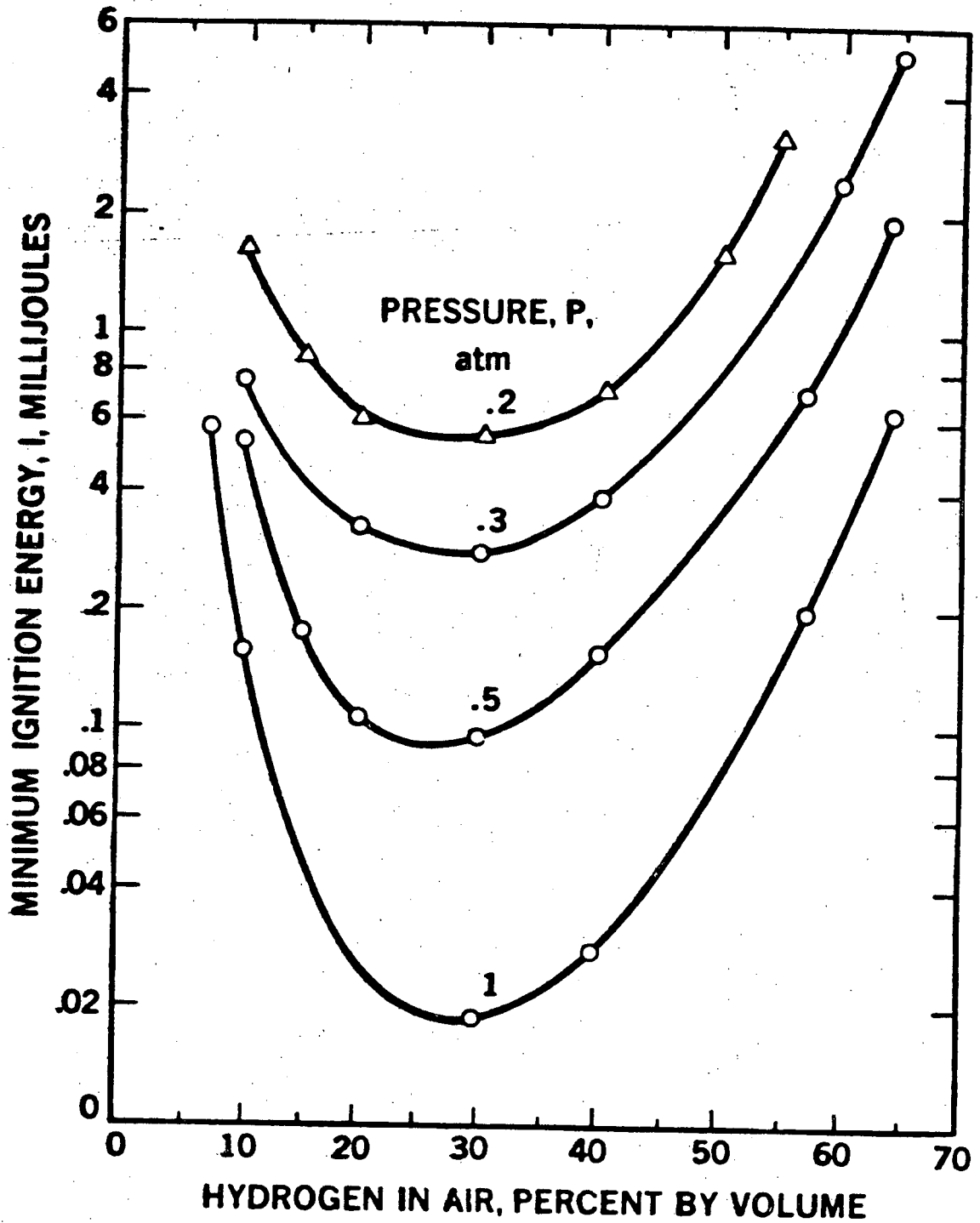
not shown

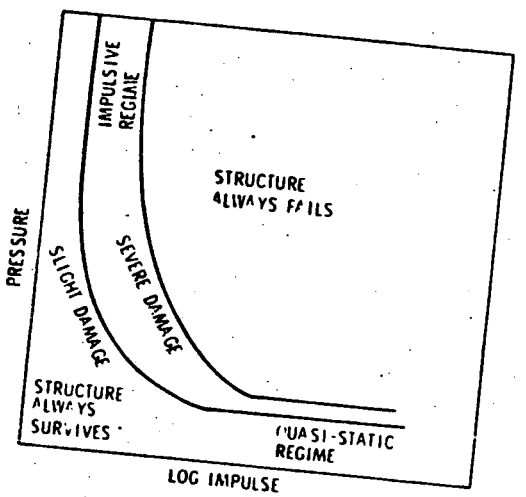


HYDROGEN-AIR DETONATION VELOCITY

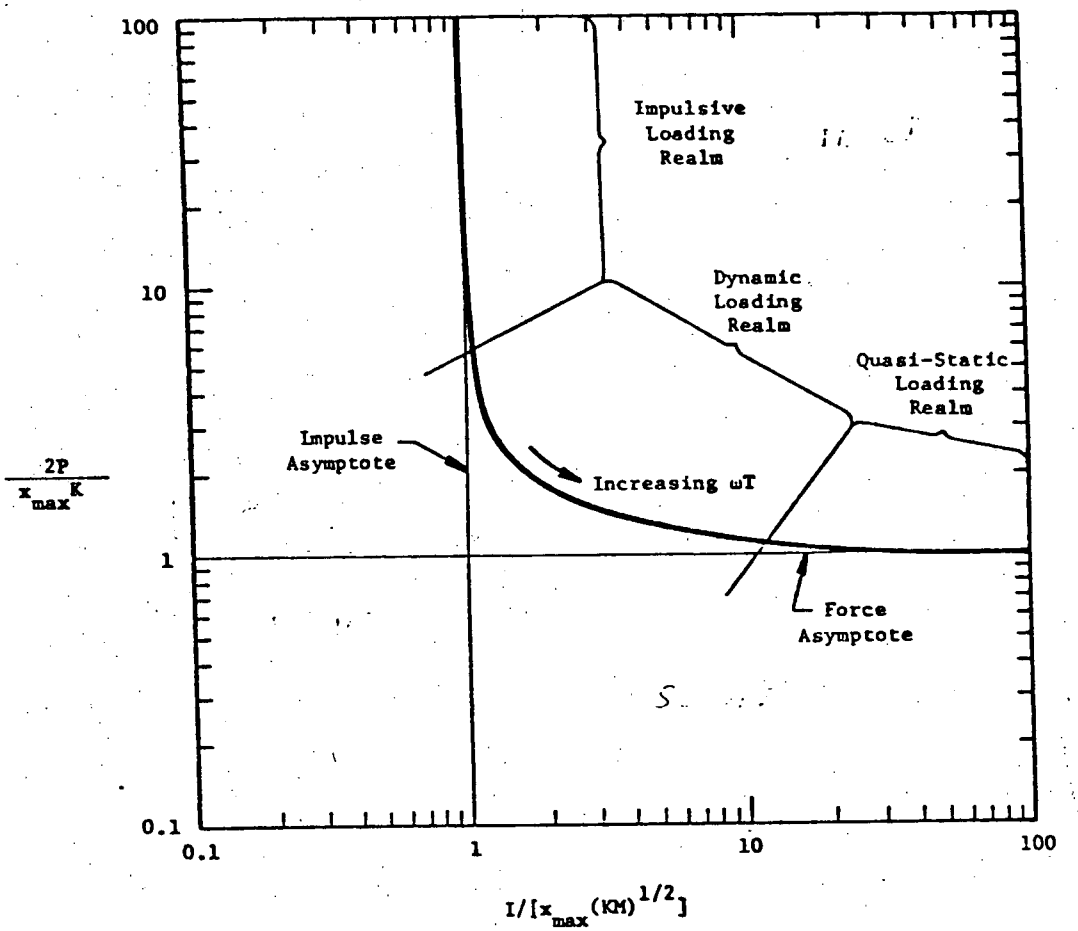


HYDROGEN-OXYGEN DETONATION VELOCITY


MINIMUM IGNITION ENERGY, I, MILLIJOULES
6
4
2
1
8
6
4
.2
.1
.08
.06
.04
.02
0
PRESSURE, P,
atm
.2
.3
.5
1
0
10
20
30
40
50
60
70
HYDROGEN IN AIR, PERCENT BY VOLUME



Idealized isodamage contours on a P-I diagram.



P-I DIAGRAM FOR BLAST LOADED ELASTIC OSCILLATOR

Table II

GAS MIXTURES FOR CSQ H_2 BURNING CALCULATIONS (INITIAL TEMPERATURE 375K)

MIXTURE	1	2	3	4
Mass H_2 (kg)	500	300	300	500
Mole Fraction H_2	0.073	0.045	0.044	0.051
Mass H_2O (kg)	0.	0.	1440	26280
Mole Fraction H_2O	0.	0.	0.024	0.3[illegible]
Mole Fraction O_2	0.195	0.200	0.196	0.136

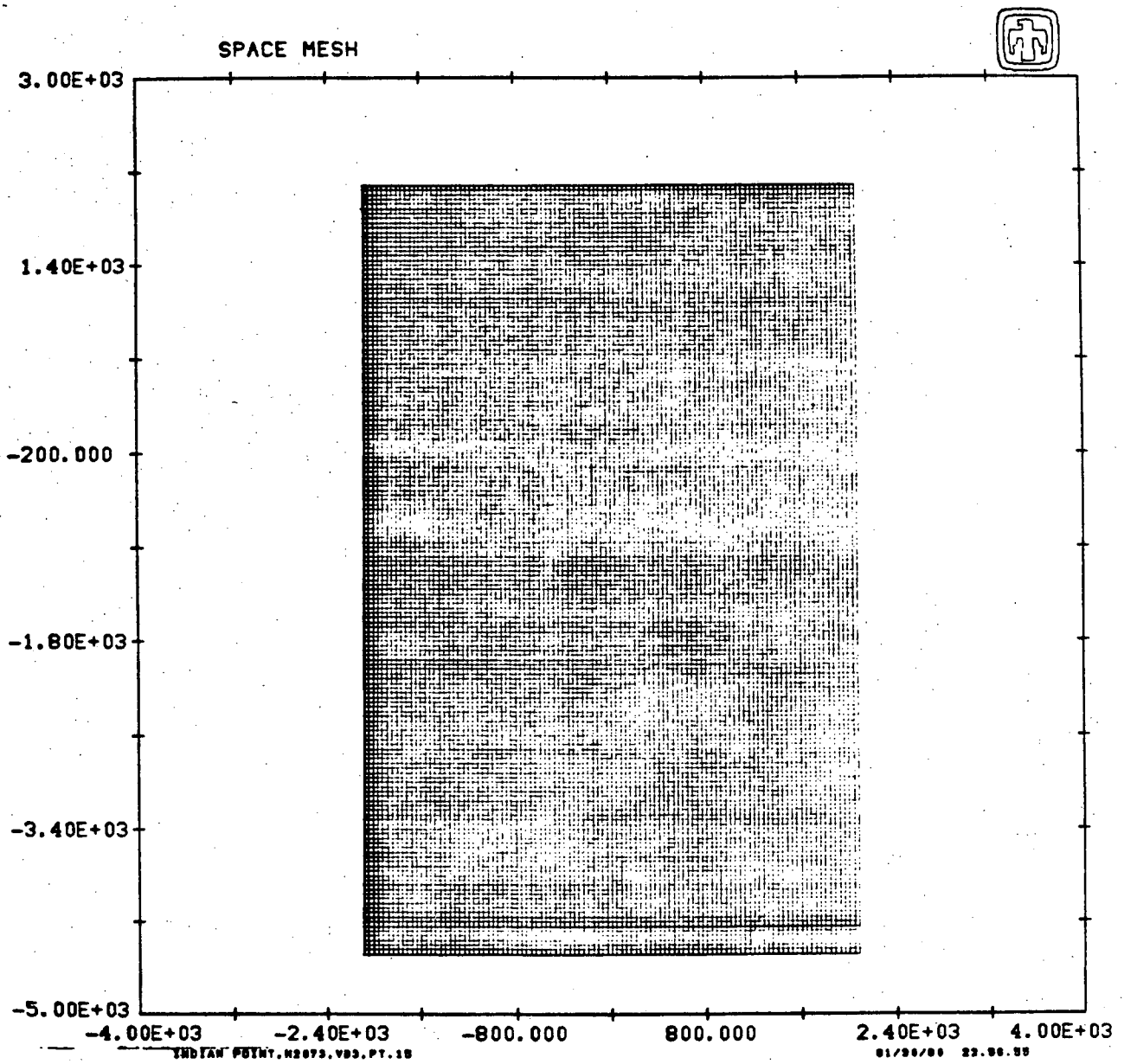
(O_2 and N_2 masses are 21179 and 69718 kg, respectively;
Total Volume 7.39×10^4 m^3)

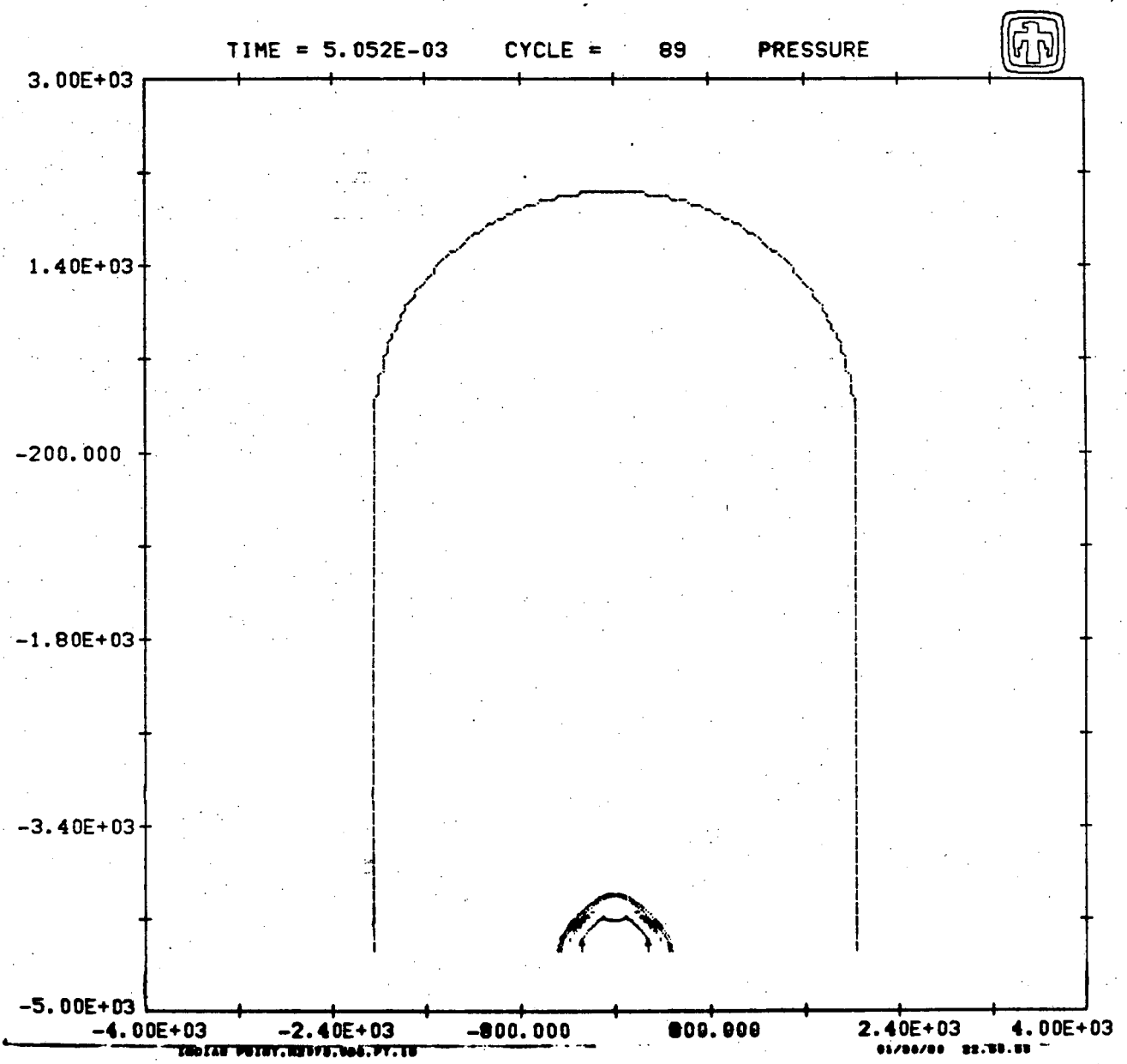
MIXTURE	INITIAL CONDITIONS		ISOCHORIC BURN		CHAPMAN-JOUGUET DETONATION		
	Density(kg/m^3)	Pressure (MPa)	Pressure	Temperature (K)	Density	Pressure	Temperatu
1	1.237	0.144	0.454	1231	1.976	0.852	1446
2	1.234	0.139	0.328	904	1.911	0.592	1053
3	1.254	0.143	0.330	888	1.938	0.594	1032
4	1.592	0.205	0.493	924	2.493	0.890	1067

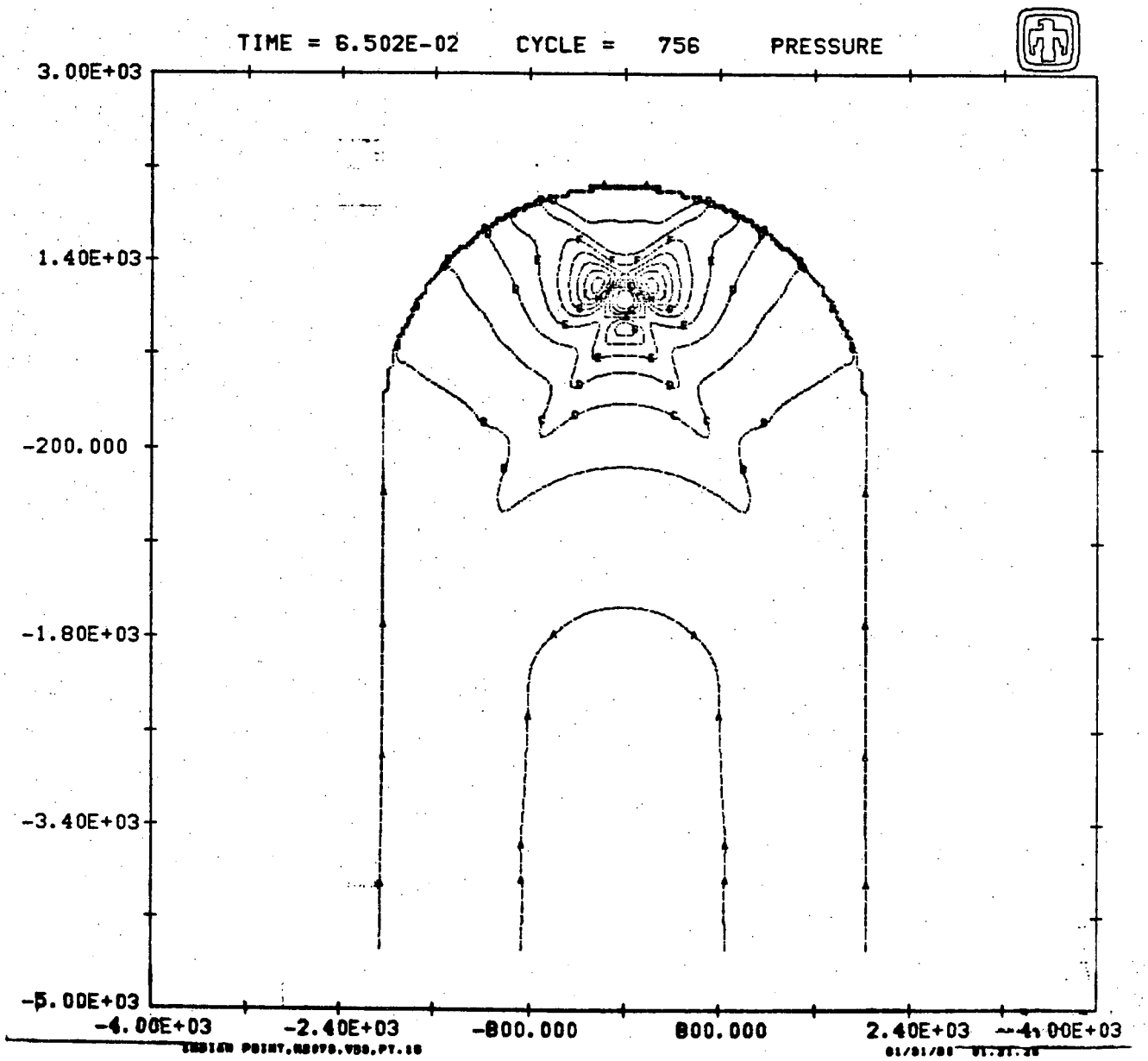
CONTOURS

A	3.00000E+06
B	5.00000E+06
C	7.00000E+06
D	9.00000E+06
E	1.10000E+07
F	1.30000E+07
G	1.50000E+07
H	1.70000E+07
I	1.90000E+07
J	2.10000E+07

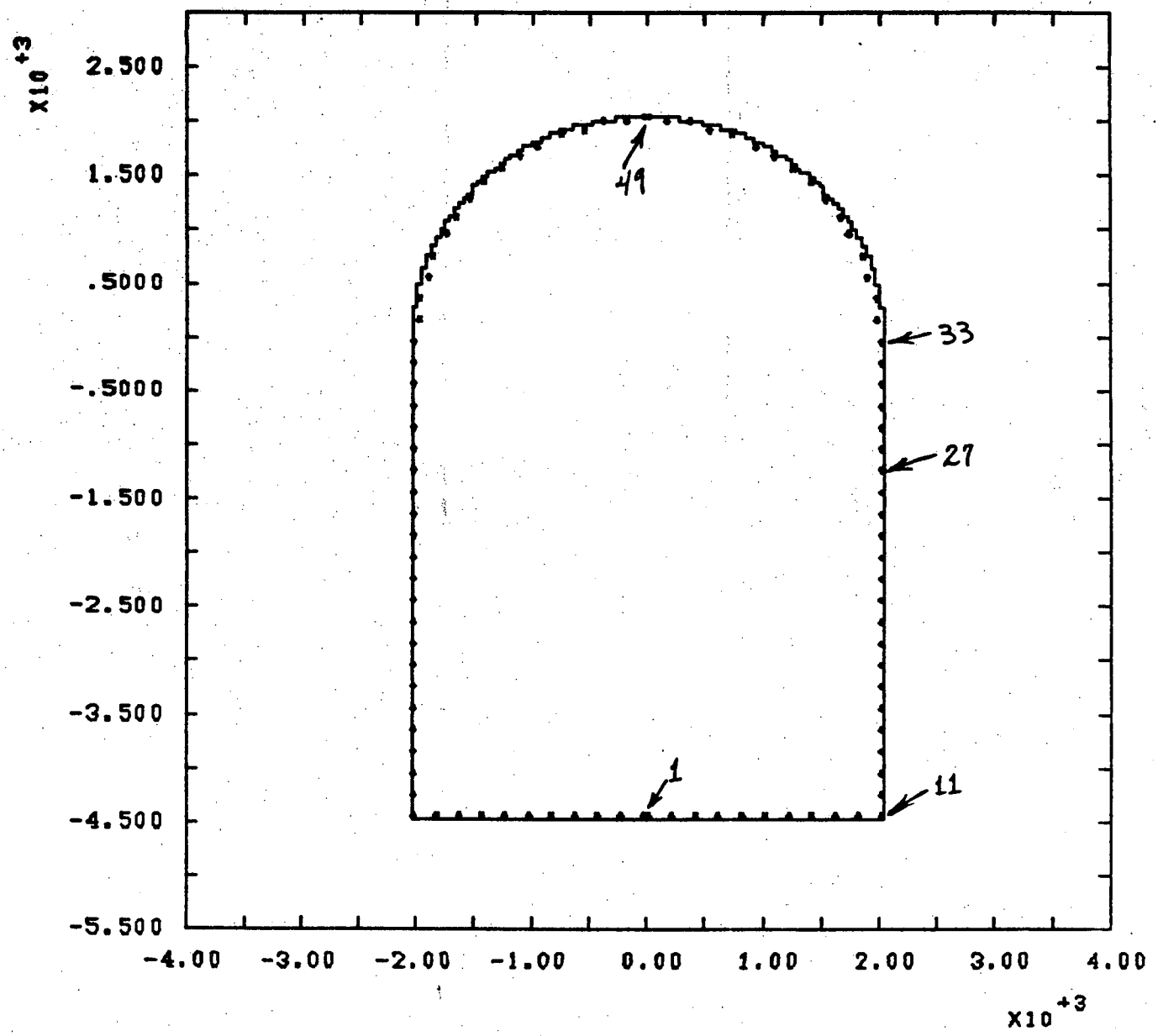
10^6 dynes/cm^2 = 1 bar

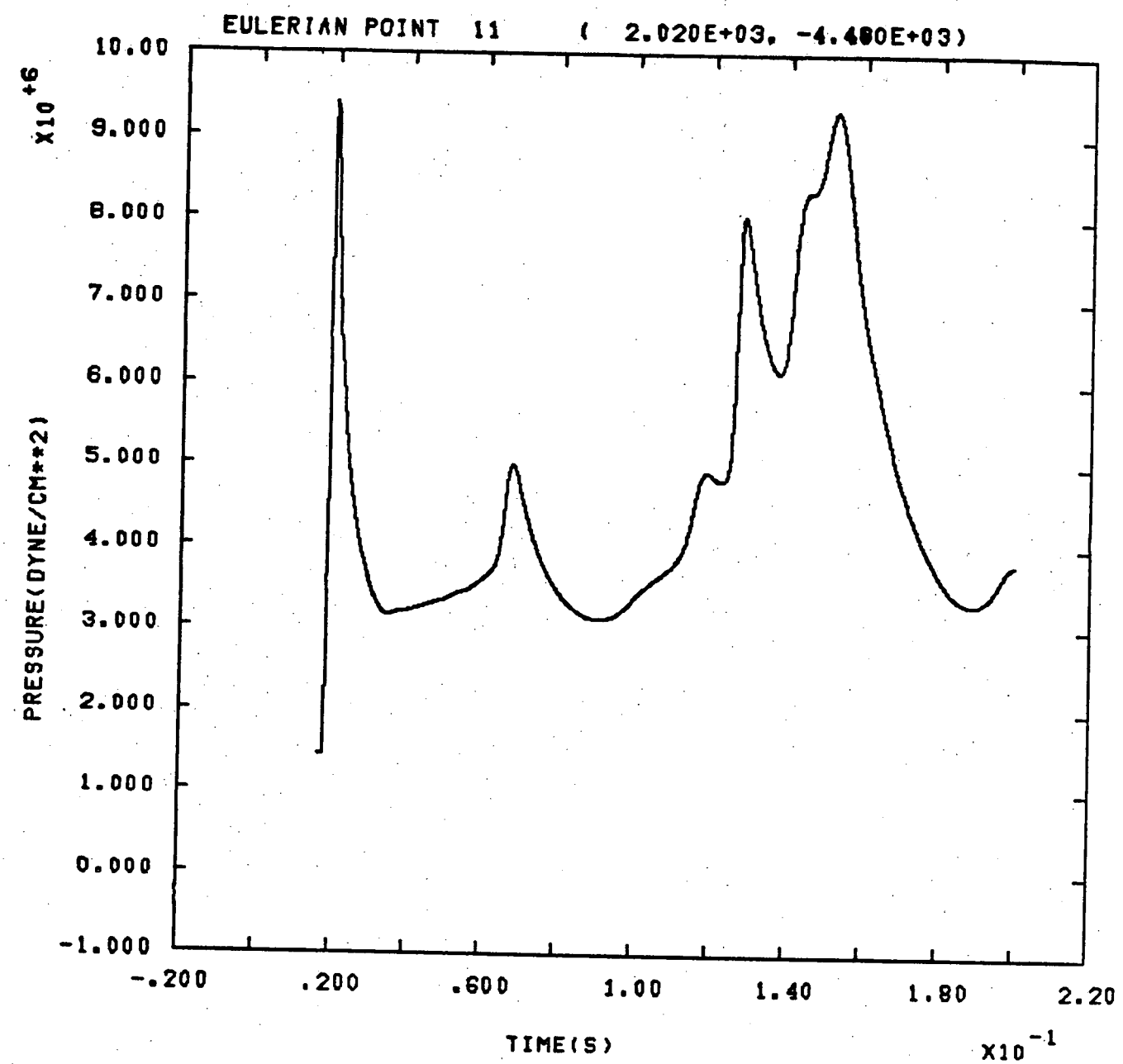

SPACE MESH
3.00E+03
1.40E+03
-200.000
-1.80E+03
-3.40E+03
-5.00E+03
-4.00E+03
-2.40E+03
-800.000
800.000
2.40E+03
4.00E+03


TIME = 5.052E-03 CYCLE = 89 PRESSURE
3.00E+03
1.40E+03
-200.000
-1.80E+03
-3.40E+03
-5.00E+03
-4.00E+03
-2.40E+03
-800.000
800.000
2.40E+03
4.00E+03

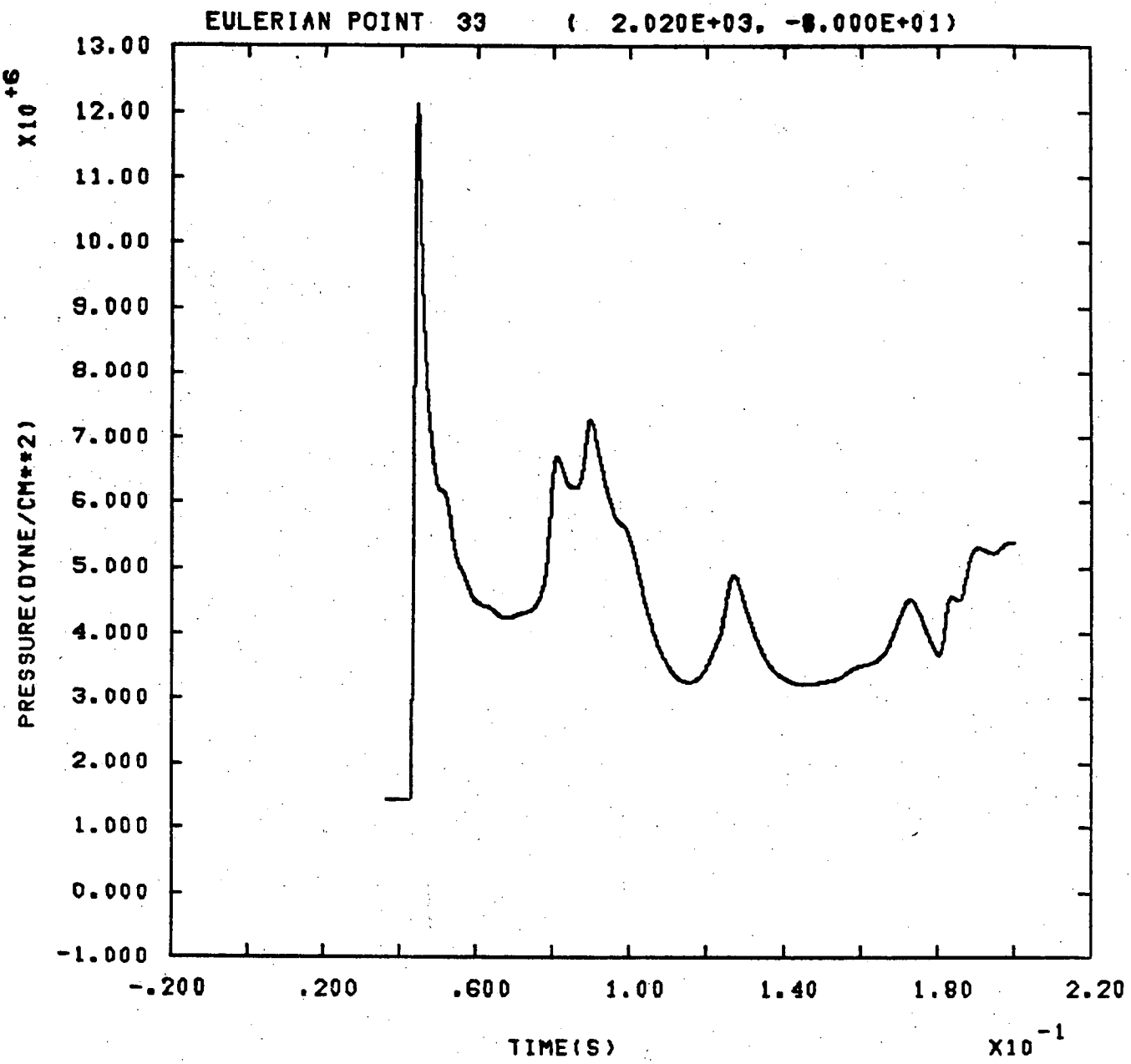

TIME = 6.502E-02 CYCLE = 756 PRESSURE
3.00E+03
1.40E+03
-200.000
-1.80E+03
-3.40E+03
-5.00E+03
-4.00E+03
-2.40E+03
-800.000
800.000
2.40E+03
4.00E+03

INDIAN POINT FIXED MESH LINES AND HISTORY POINTS





INDIAN POINT,H2073,VB3,PT.15
01/30/80 22.56.55



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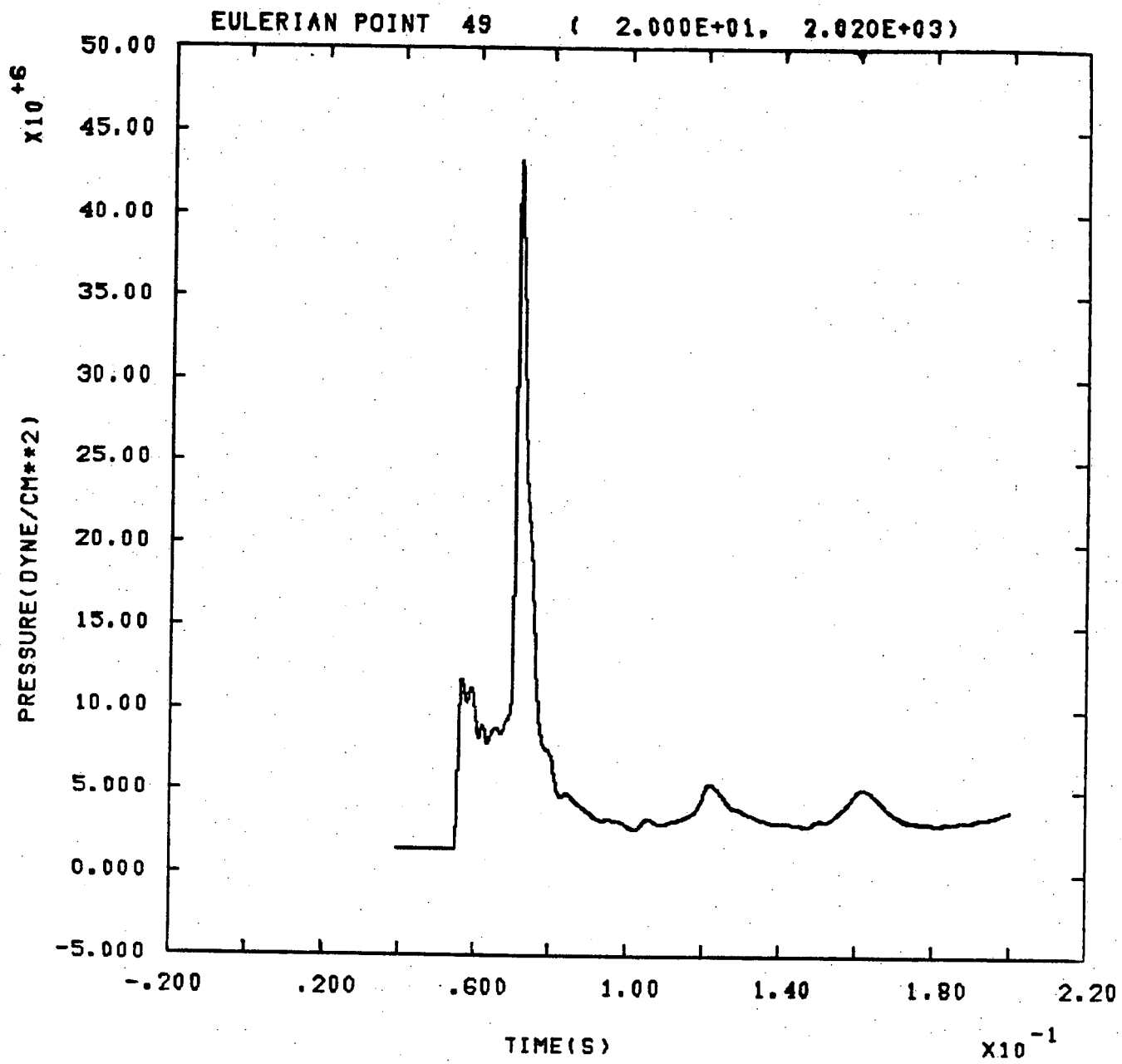
01/30/80 22.56.55



INDIAN POINT,H2073,VB3,PT.15
01/30/80 22.56.55

Mitigation Schemes

A. Ignition sources

B. Diluent - water droplets

C. Suppression - chemical (Halon) or mechanical

D. Inerting or oxygen control - hydrazine, engines

E. Dispersion - fans

F. Primary system strategies - gettering

G. Recombiners, others

DELIBERATE IGNITION

ADVANTAGES:

- INEXPENSIVE, EASY TO RETROFIT
- SMALL TEMPERATURE, PRESSURE RISES
- ABETTED BY DIFFERENCES IN UPWARD AND DOWNWARD PROPAGATION LIMITS
- IF IGNITION IS INEVITABLE, CONTROL IS BENEFICIAL

QUESTIONS:

- CAN UNCONTROLLED IGNITION BE PREVENTED?
- RELIABILITY, STRENGTH, NUMBER, TYPE AND PLACEMENT OF SOURCES?
- HOW ACCURATELY CAN CONCENTRATIONS BE MEASURED?
- IS HYDROGEN UNIFORMLY MIXED?
- AUTOMATIC, MANUAL OR COMBINED SYSTEMS?
- INTERACTION WITH OTHER MITIGATION WITH OTHER MITIGATION SCHEMES SUCH AS FOGS?

EFFECTS OF WATER SPRAYS ON HYDROGEN COMBUSTION

1. THE TEMPERATURE AND PRESSURE RISE ARE GREATLY REDUCED.
2. DETONATIONS ARE INHIBITED.
3. TURBULENT DEFLAGRATIONS PROMOTED. FLAME SPEED INCREASED.
4. LOWER FLAMMABILITY LIMITS INCREASED.

REF. CARLSON, KNIGHT & HENRIE, AI-73-29
USED 500 MICRON DROPS, .05% DROPS BY VOLUME.

USE OF FOGS

INJECT FINE WATER DROPS THROUGHOUT CONTAINMENT VOLUME BEFORE COMBUSTION.

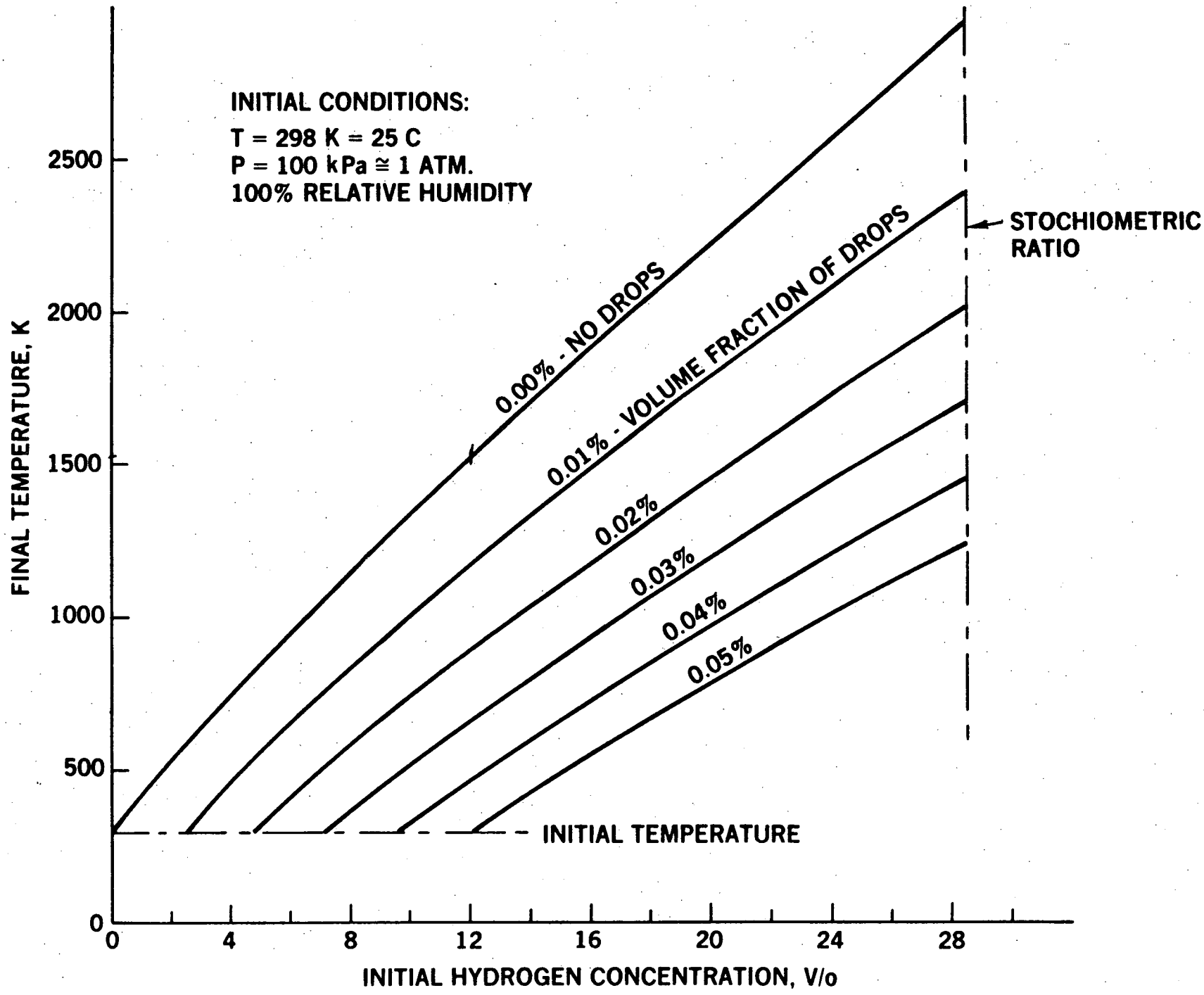
FOR A TWO MILLION CUBIC FOOT CONTAINMENT, .05% DROPS BY VOLUME IS 1000 CUBIC FEET, A REASONABLE VOLUME.

POSSIBLE ADVANTAGES OF FOGS

1. THE SYSTEM REDUCES CONTAINMENT PRESSURE NOT ONLY FOR HYDROGEN COMBUSTION, BUT ALSO FOR STEAM RELEASE. IT IS A THERMAL CAPACITANCE.

2. NO NEW PENETRATIONS OF CONTAINMENT ARE REQUIRED. WATER MIGHT BE INTERNALLY STORED, OR THE SYSTEM MIGHT BE CONNECTED TO THE EXISTING SPRAY SYSTEMS.

3. IF THE DROPS ARE FINE ENOUGH, BELOW 10 MICRONS DIAMETER, THE SETTLING TIME WILL BE LONG (PERHAPS A FEW HOURS). FAILURE OF POWER TO INJECT FOG FOR SHORT TIMES CAN BE TOLERATED, ONCE THE FOG IS IN PLACE.


INITIAL CONDITIONS:
T = 298 K = 25 C
P = 100 kPa ≅ 1 ATM.
100% RELATIVE HUMIDITY
0.00% - NO DROPS
0.01% - VOLUME FRACTION OF DROPS
0.02%
0.03%
0.04%
0.05%
STOCHIOMETRIC RATIO
INITIAL TEMPERATURE
FINAL TEMPERATURE, K
2500
2000
1500
1000
500
0
0
4
8
12
16
20
24
28
INITIAL HYDROGEN CONCENTRATION, V/o

HYDROGEN BEHAVIOR

STATE OF KNOWLEDGE

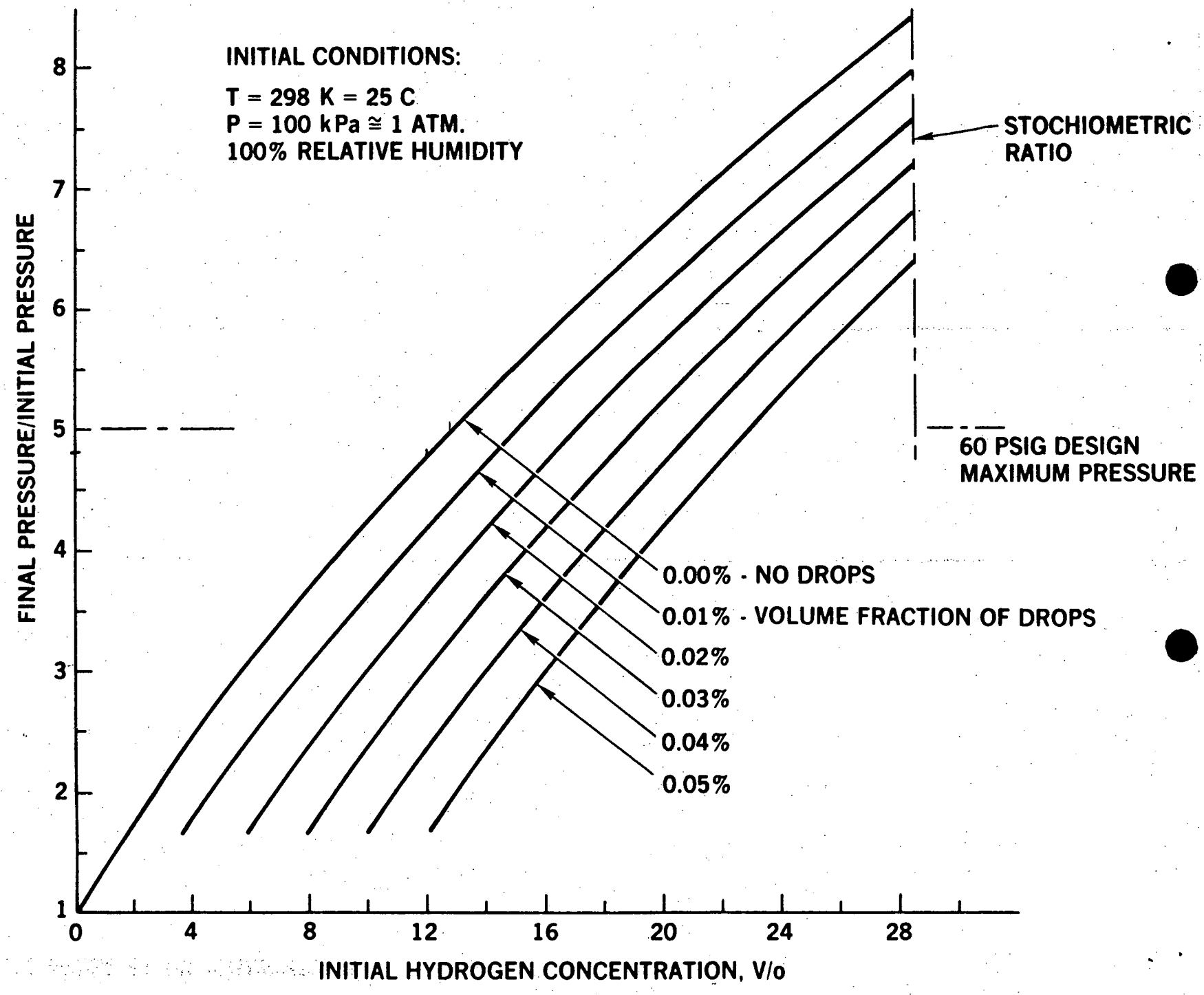
- GIVEN A SERIOUS ACCIDENT IN A LWR, COPIOUS QUANTITIES OF HYDROGEN MAY BE PRODUCED FROM SEVERAL SOURCES.

- THE COMBUSTION OF THIS HYDROGEN POSES A THREAT TO CONTAINMENT INTEGRITY AND EQUIPMENT SURVIVABILITY.

- THE LARGE PWR CONTAINMENTS ARE THE LEAST VULNERABLE TO THESE THREATS.

- THERE ARE SEVERAL PROMISING MITIGATION SCHEMES WHICH COULD IMPROVE SAFETY IN ALL LWRs, BUT MORE RESEARCH IS NEEDED ON

  1. THE QUANTIFICATION OF THE THREAT,
  2. THE FEASIBILITY AND DESIGN OF MITIGATION SCHEMES, AND
  3. THE INTERACTION OF MITIGATION SCHEMES AND INTEGRATED SYSTEM BEHAVIOR.


INITIAL CONDITIONS:
T = 298 K = 25 C
P = 100 kPa ≅ 1 ATM.
100% RELATIVE HUMIDITY
STOCHIOMETRIC RATIO
60 PSIG DESIGN MAXIMUM PRESSURE
0.00% - NO DROPS
0.01% - VOLUME FRACTION OF DROPS
0.02%
0.03%
0.04%
0.05%
FINAL PRESSURE/INITIAL PRESSURE
1
2
3
4
5
6
7
8
0
4
8
12
16
20
24
28
INITIAL HYDROGEN CONCENTRATION, V/o

IN-VESSEL SOURCES OF HYDROGEN PRODUCTION

M. L. PICKLESIMER, FBRB/RES/NRC

PRESENTATION TO THE TECHNOLOGY EXCHANGE MEETING ON HYDROGEN

MAY 20, 1980

SOURCES OF HYDROGEN IN THE REACTOR VESSEL

RADIOLYSIS OF WATER

OXIDATION OF STAINLESS STEEL IN STEAM

OXIDATION OF ZIRCALOY IN STEAM

OXIDATION OF UO_2 BY STEAM TO UO_{2+X}

REACTION EQUATIONS:

$ZR + 2H_2O \rightarrow ZRO_2 + 2H_2$ $\Delta H = -224{,}000$ CAL/GMOL OXIDE (1)

LBS H_2/LB ZR OXIDIZED = 4/91.22 = 0.04385

LBS H_2/LB STEAM CONSUMED = 4/36 = 0.1111

304 S. STEEL + $H_2O \rightarrow FE_2O_3 + CR_2O_3 + H_2$ $\Delta H_{FE} = -24{,}500$ CAL/GMOL OXIDE

(304 S. STEEL = 18% CR, 8% NI, 74% FE) $\Delta H_{CR} = -99{,}000$ CAL/GMOL OXIDE

LBS H_2/LBS 304.S.S. OXIDIZED = 5.52/100 = 0.0552

LBS H_2/LB STEAM CONSUMED = 6/54 = 0.1111

RATE EQUATION:

$W = \delta(T)^{1/2}$

WHERE - W = WEIGHT OF OXYGEN CONSUMED (WEIGHT GRAIN OF METAL, GRAMS)

T = TIME, SECONDS

δ = RATE CONSTANT

$\delta^2/2$ = 0.1811 EXP (-39,900/RT) FOR ZR

R = GAS CONSTANT

T = TEMPERATURE IN DEGREES K

METAL PRESENT IN CORE SUBJECT TO STEAM OXIDATION (TMI-2)

ZIRCALOY - FUEL RODS = 36,816 RODS $\cong$ 42,200 LBS (ACTIVE ZONE)
TOTAL IN CORE $\cong$ 54,000 LBS (INCLUDING GUIDE TUBES, PLENUM REGIONS, BURNABLE POISON RODS)

304 S.S. - CONTROL RODS = 16 RODS IN EACH OF 69 ASSEMBLIES $\cong$ 1200 LBS
UPPER END FITTINGS = 17 LBS/FITTING, 177 FITTINGS $\cong$ 3000 LBS

TOTAL 304 S.S. = 4200 LBS

ESTIMATES OF HYDROGEN PRODUCED IN TMI-2

CALCULATIONS FROM CORE DAMAGE ESTIMATE

OXIDATION OF ZIRCALOY	= 750 - 850 LBS H_2
OXIDATION OF STAINLESS STEEL	$\leq$ 40 LBS H_2
RADIOLYSIS OF WATER	= 0 LBS H_2 (SUPPRESSED BY OXIDATION PRODUCED H_2)
OXIDATION OF UO_2	= ? LBS H_2
TOTAL H_2 PRODUCED	= 790 - 890 LBS

CALCULATIONS FROM CONTAINMENT BURN AND GAS ANALYSES

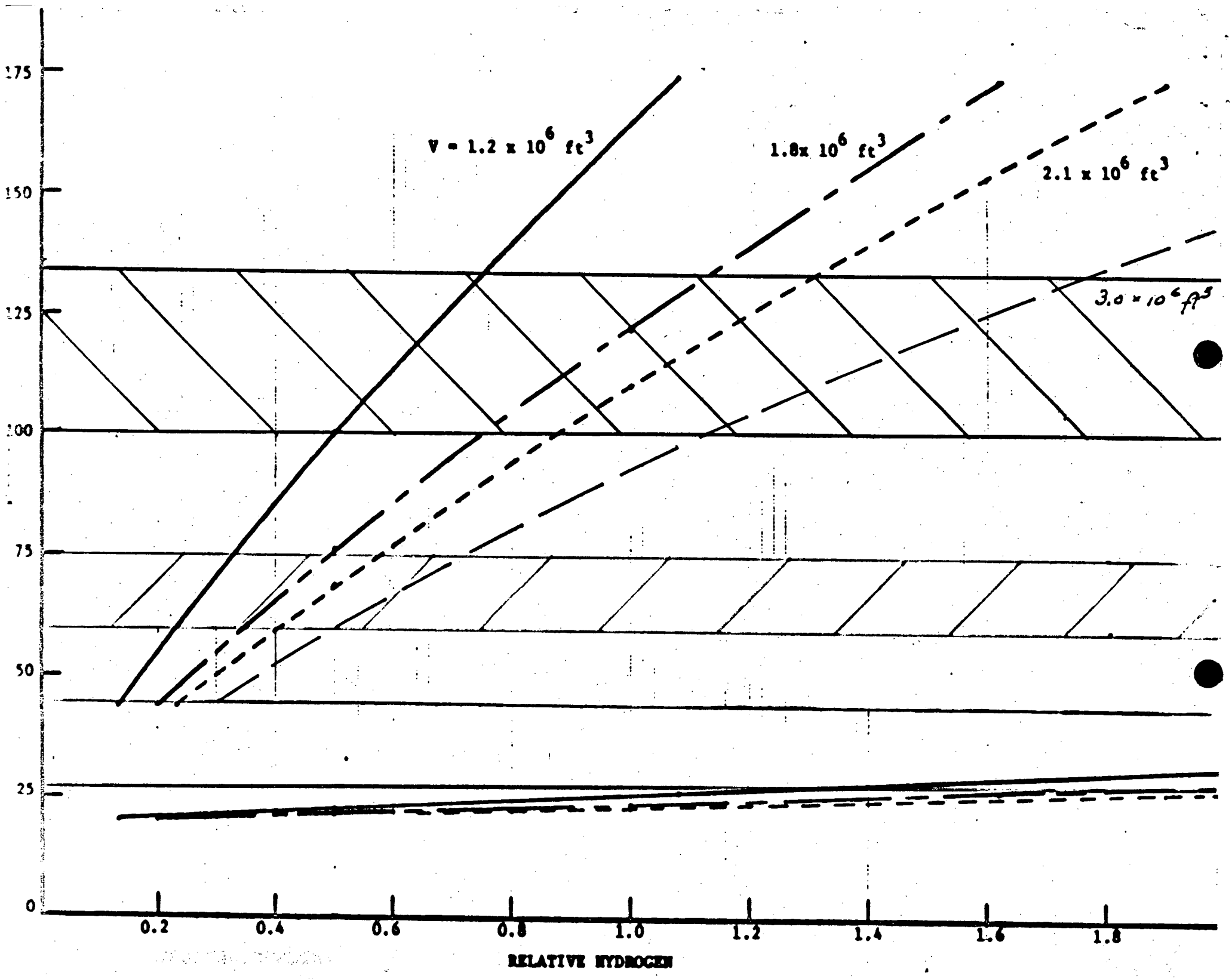
RELEASED TO CONTAINMENT	= 775 LBS	
BURNED	=	600 LBS
REMAINING IN CONTAINMENT	=	175 LBS
REMAINING IN RCS AT 16 HOURS	=	220 LBS
IN SOLUTION IN COOLANT AT 16 HOURS	= 60 LBS	
IN BUBBLE AT 16 HOURS	= 160 LBS	
TOTALS	= 995 LBS H_2	995 LBS H_2

P. Cybulskis

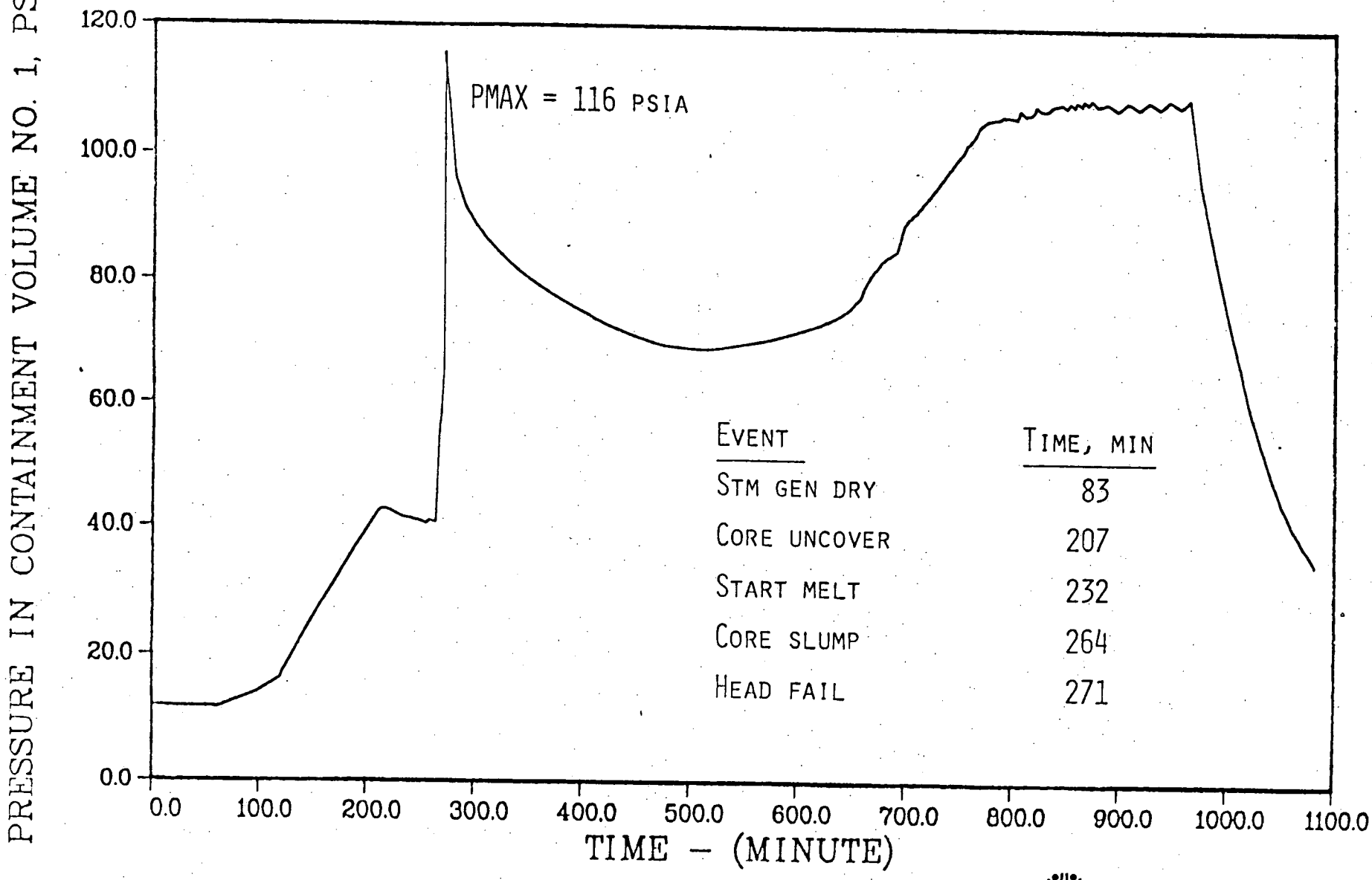
Case	Meltdown Model	Melting Temperature	Reaction In Melted Nodes	Melt Fraction For Slumping	Accident Sequence	Fraction Cladding Reacted	
1	A	High	Yes	Small	AB	0.96	
2	A	Base	Yes	Small	AB	0.94	
3	A	Low	Yes	Small	AB	0.68	
4	A	High	No	Small	AB	0.60	
5	A	Base	No	Small	AB	0.50	
6	A	Low	No	Small	AB	0.29	
7	A	Base	No	Small	AB	0.52	*
8	A	Base	No	Large	AB	0.48	
9	A	Base	No	Large	TML	0.38	
10	A	Base	Yes	Large	TML	0.39	
11	B	Base	Yes	Large	TML	0.40	**
12	A	Base	Yes	Small	TML	0.88	
13	A	Base	Yes	Small	TML	0.70	
14	A	Base	No	Small	TML	0.48	
15	C	Base	No	Small	TML	0.20	
16	A	Base	No	Large	TML	0.58	***
17	A	Base	No	Large	TML	0.95	***

CASE	FCR	MHP	END OF BOIL			AFTER HEAD FAILURE		
			MHB	POLD	PNEW	MHB	POLD	PNEW
1	0.96	1860	1860	50	137			
2	0.94	1836	1836	46	132			
3	0.68	1317	1317	49	110			
4	0.60	1177	1177	50	105			
5	0.50	974	974	45	91			
6	0.29	559		NF				
7	0.52	1017	1017	48	96			
8	0.48	932	932	45	88			
9	0.38	733					NF	
10	0.39	752					NF	
11	0.40	771					NF	
12	0.88	1697	986	46	93	1309	49	110
13	0.70	1362	741	35	71	1362	57	120
14	0.48	923		NF		923	48	91
15	0.20	386		NF			NF	
16	0.58	1114		NF		1114	48	100
17	0.95	1826	934	27	74	1826	50	135

FCR = 1.00 = 1928 lb H_2


175
150
125
100
75
50
25
0
V = 1.2 x 10^6 ft^3
1.8x 10^6 ft^3
2.1 x 10^6 ft^3
3.0 x 10^6 ft^3
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
RELATIVE HYDROGEN

INDIAN PT 3, TMLB – BASE CASE



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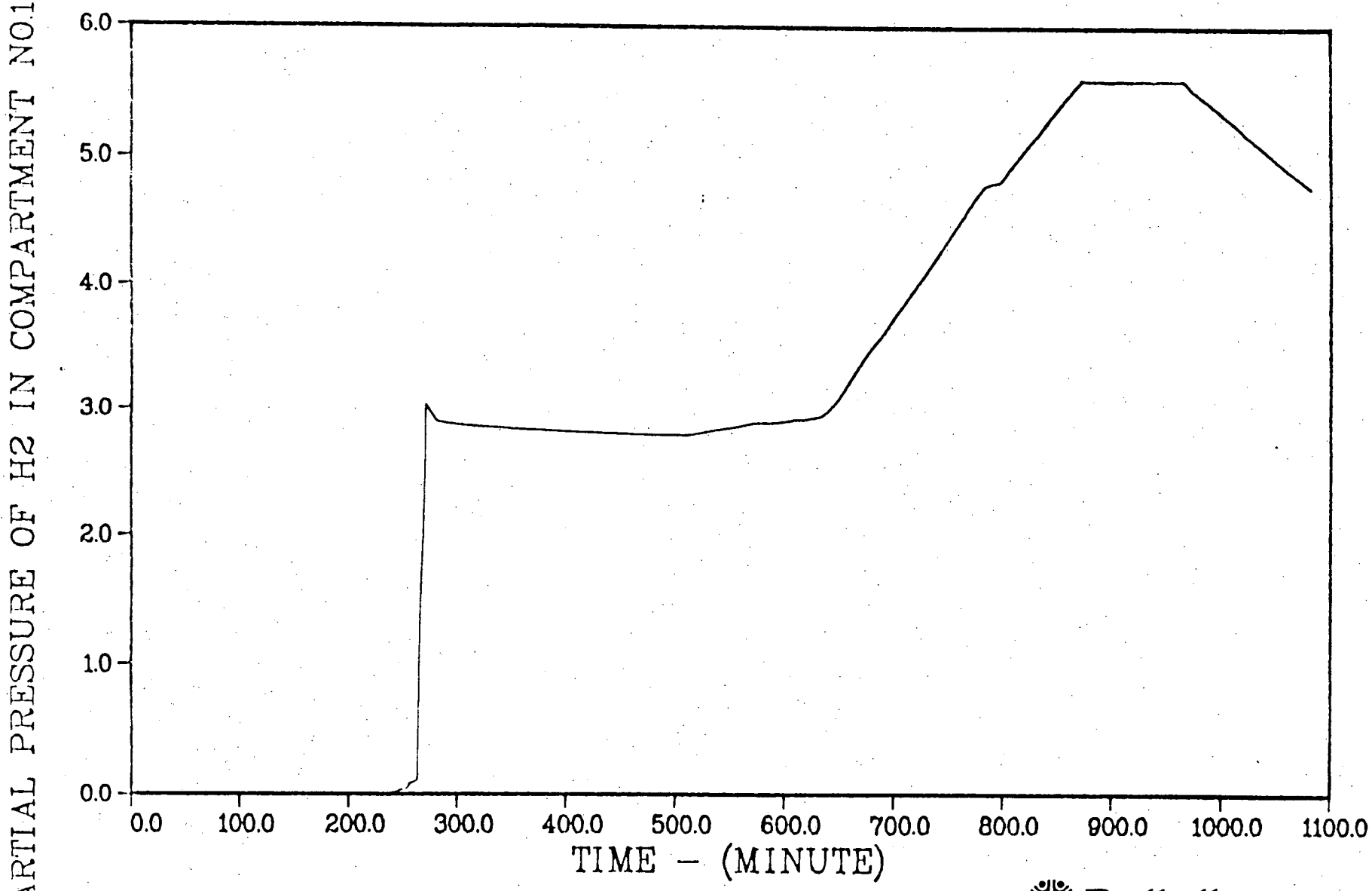
Columbus Laboratories

IP3TMLB BASE CASE



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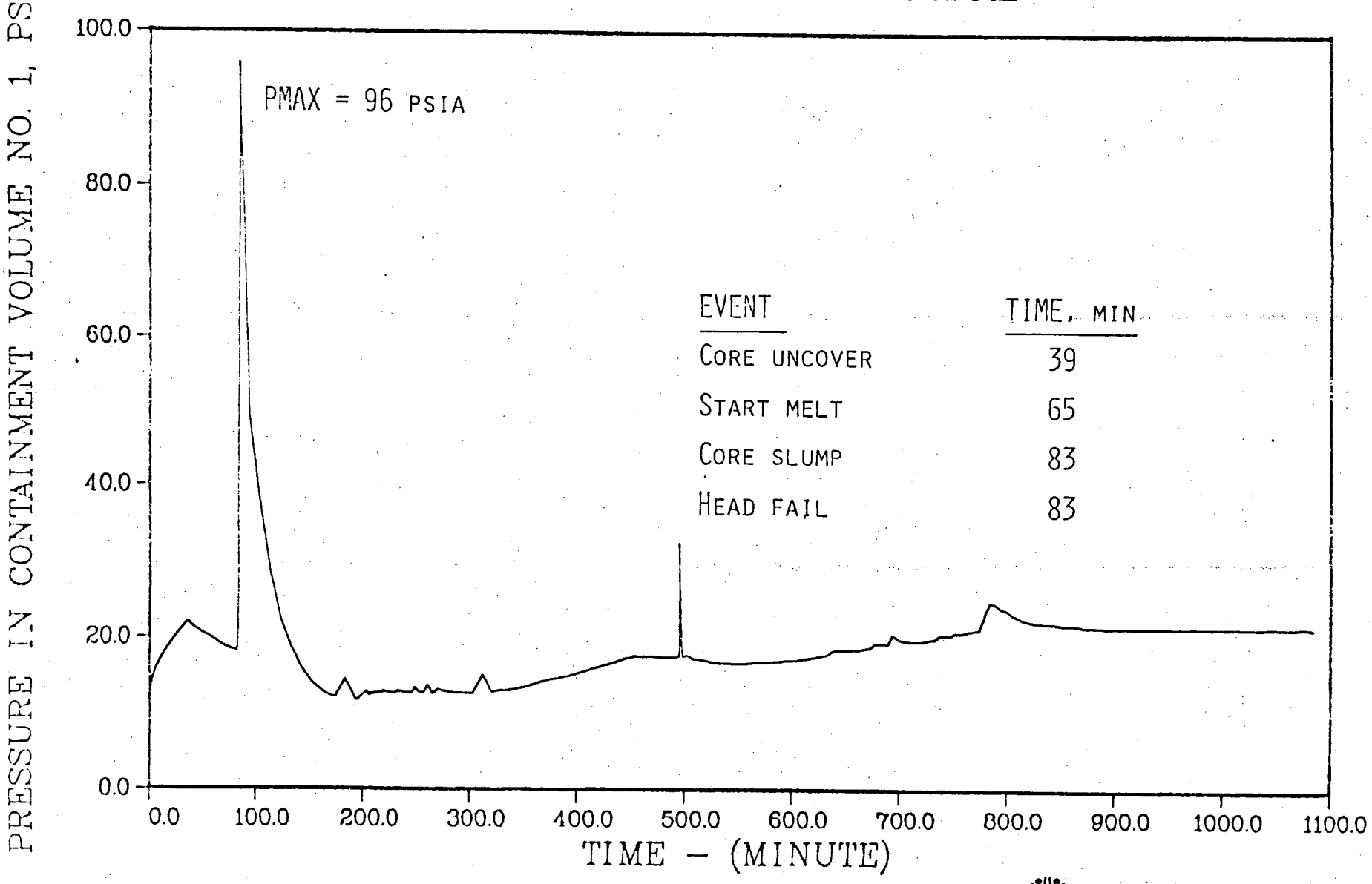
IP3 S2D BASE CASE



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BNL HYDROGEN STUDY - PRELIMINARY FINDINGS

ACCIDENT ANALYSIS WITH MARCH CODE

- TMLB', AB, S_2B
- EFFECT OF CONTAINMENT COOLERS

METHODS OF HYDROGEN CONTROL

- REVIEW OF PREVIOUSLY PROPOSED METHODS
- ALTERNATIVE PROPOSALS

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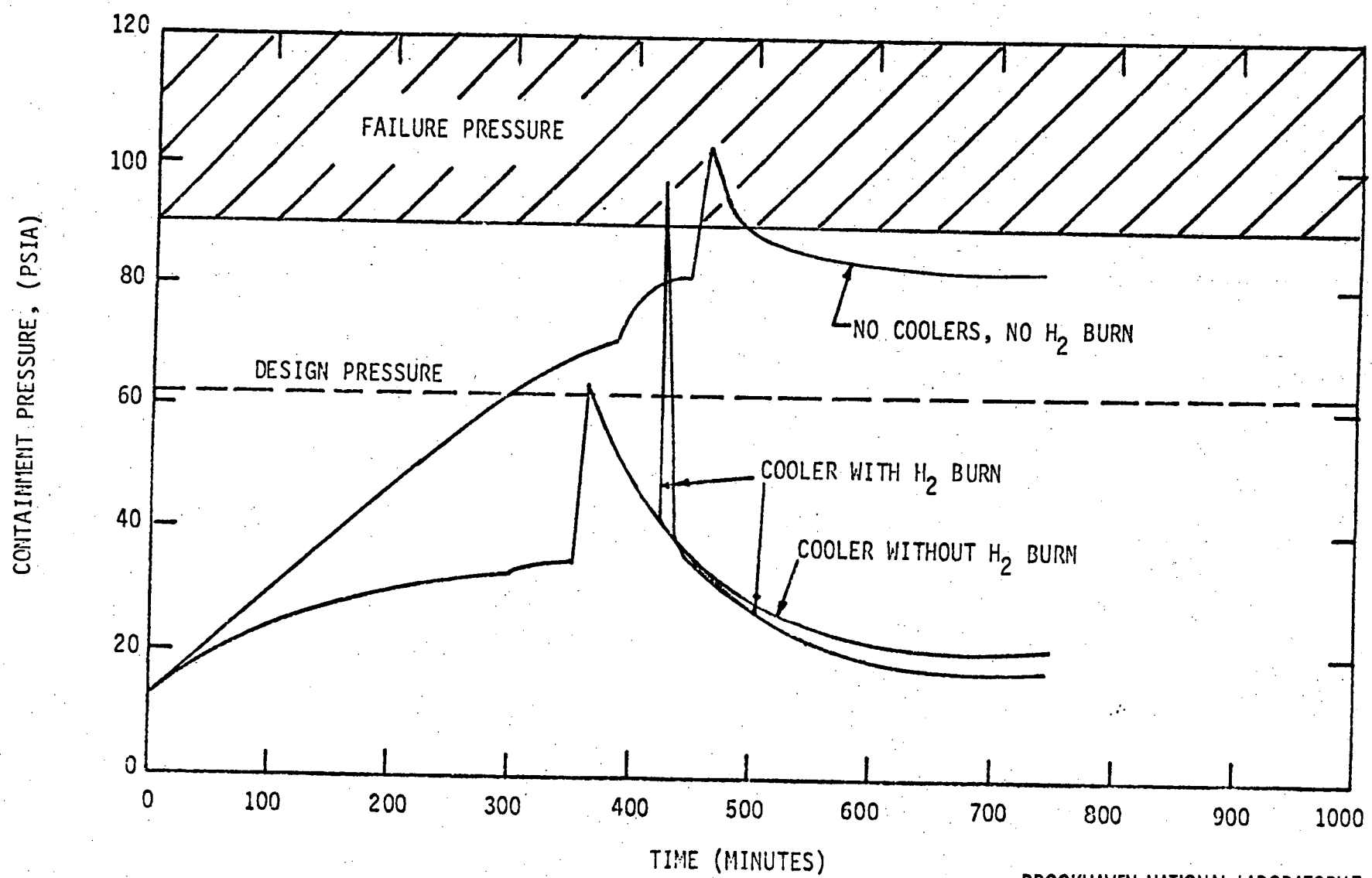
S_2B INDIAN POINT 3

(EFFECTS OF 1 COOLER AND HYDROGEN BURN)



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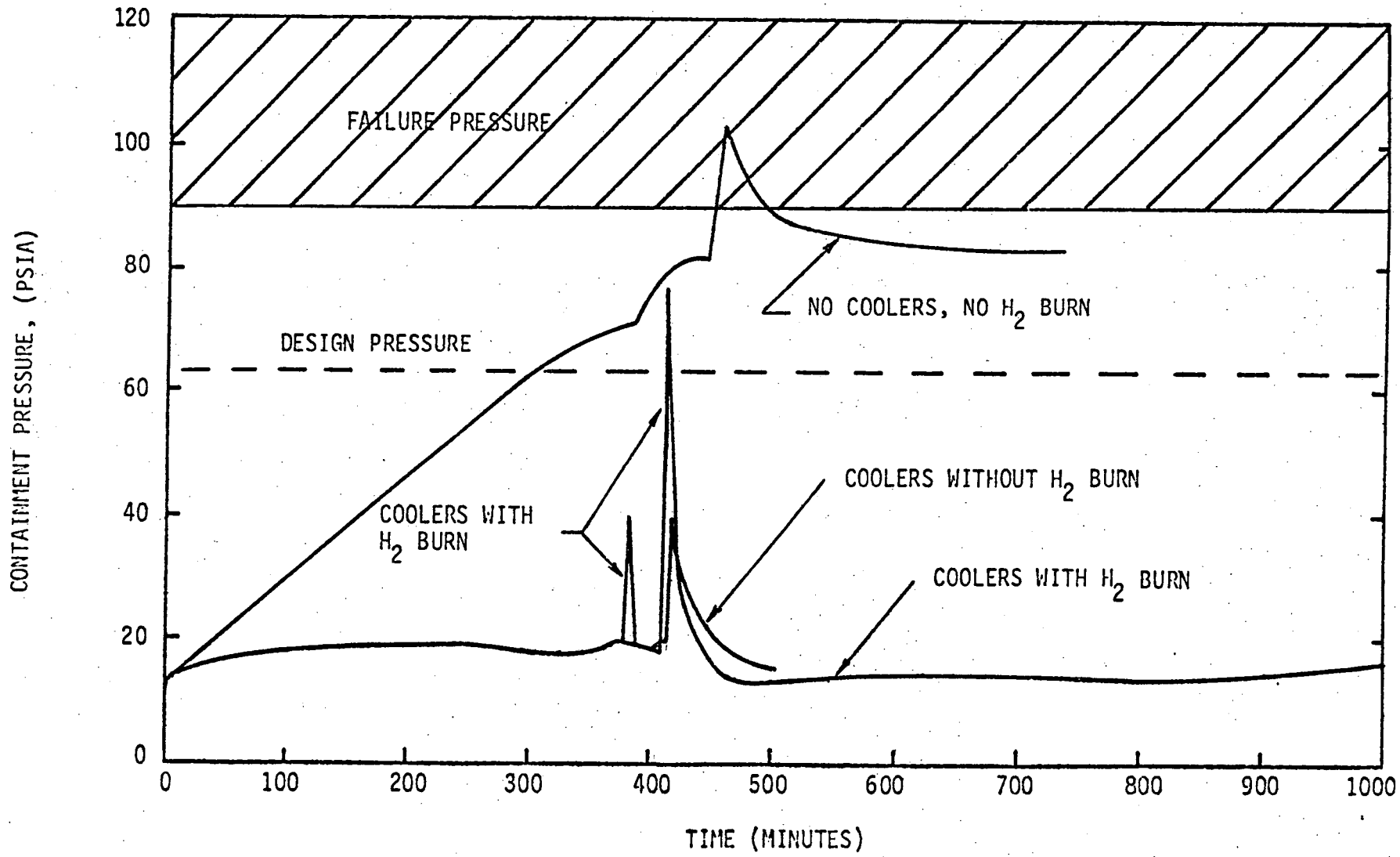
S_2B INDIAN POINT 3

(EFFECTS OF 3 COOLERS AND HYDROGEN BURN)



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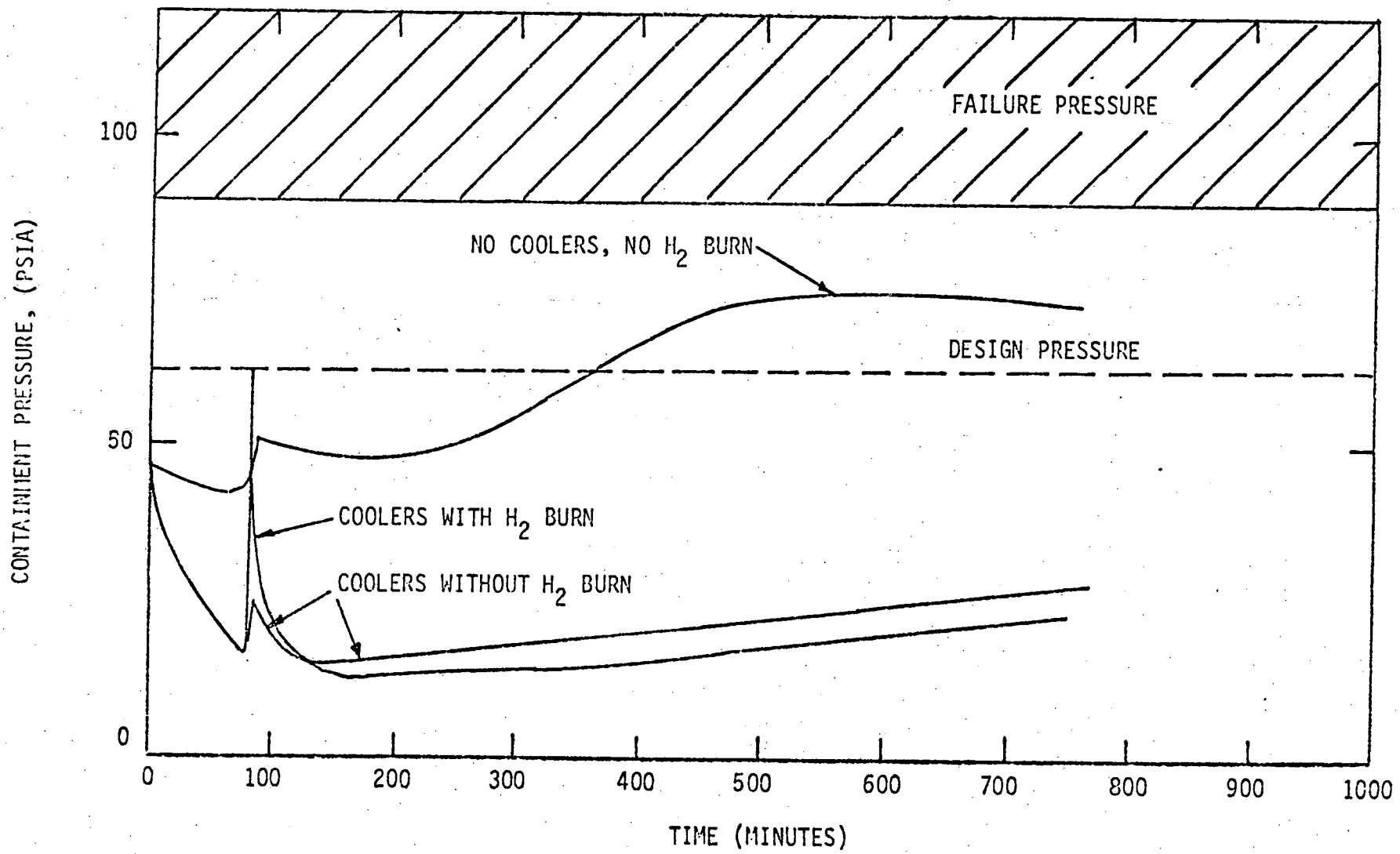
AB INDIAN POINT 3

(EFFECTS OF 3 COOLERS AND H_2 BURN)



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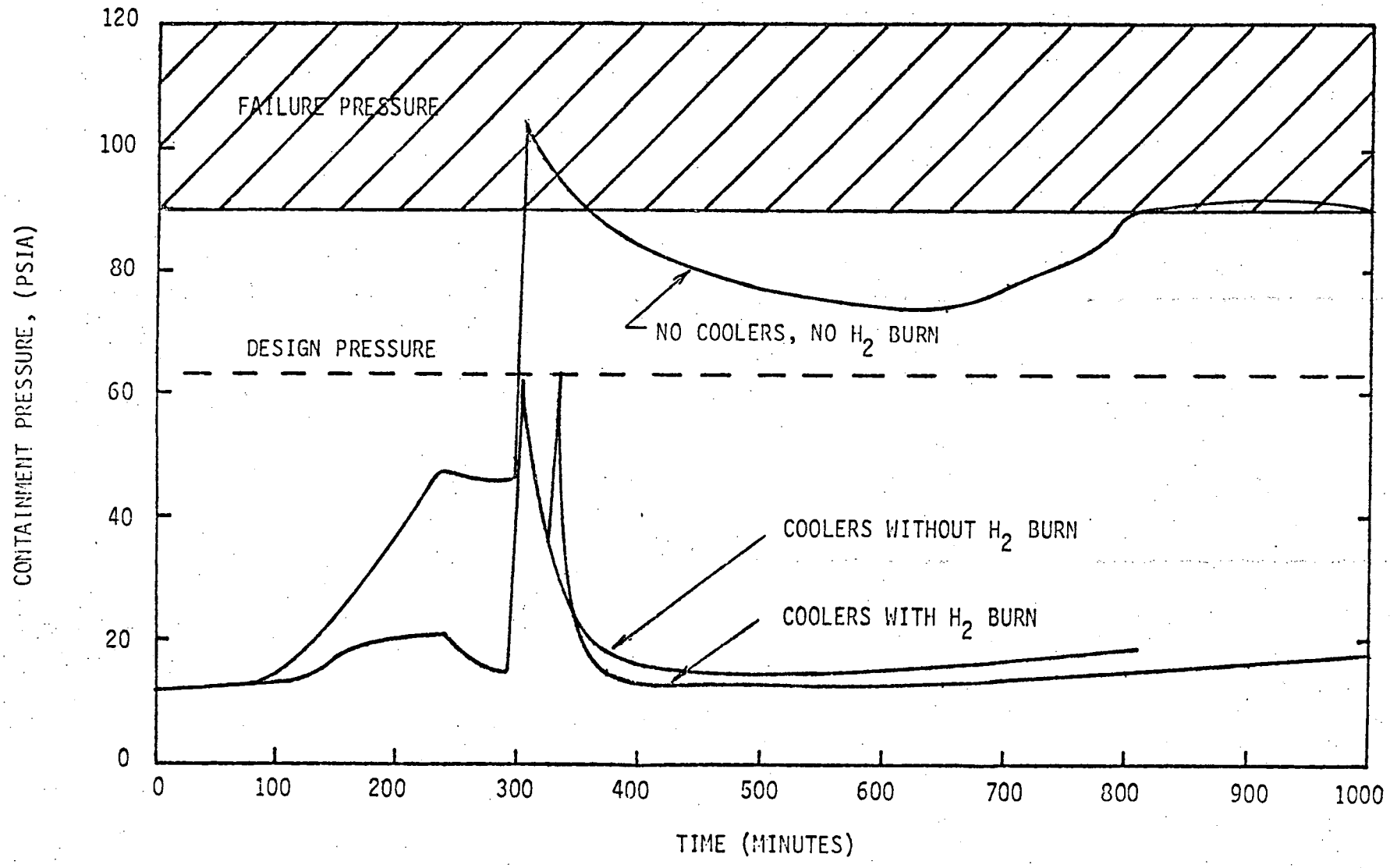
TMLB' INDIAN POINT 3

(EFFECTS OF 3 COOLERS AND HYDROGEN BURN)



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