KAISER MARQUARDT

FAILURE MALFUNCTION REPORT

RED FLAG TWX (FINAL REPORT)

DATE OF FAILURE/MALFUNCTION: 05/23/97

REPORT NO.: 5285-001 REV. A

SYMPTOMATIC REPORT

ITEM	NAME	PART OR MODEL NUMBER	MANUFACTURER	SERIAL NUMBER	OPERATING TIME/CYCLE
FAILED ITEM	INJECTOR ASSY.	X42881	KAISER MARQUARDT	N/A	UNKNOWN
NEXT ASSY					UNKNOWN
END ITEM	CALORIMETER CHAMBER ASSY.	X42880	KAISER MARQUARDT	N/A	UNKNOWN

WHAT OPERATION FAILURE DISCOVERED ? HOT-FIRE TEST

REPLACEMENT PART NO.: NONE

REPLACEMENT SERIAL NO.: N/A

RELATED IRR, FMR, ETC.: N/A

WHAT WERE INDICATIONS & SUSPECTED CAUSE OF TROUBLE ?

During Run No. 1038 a 1 second test, the test article was damaged by fire. Post test inspection revealed that the Hydrogen inlet fitting to the injector was consumed, and the hydrogen line was separated from the test article.

ITEM	ELAPSED TIME (MAN HOURS)
TROUBLESHOOTING	Hrs
REPAIR	Hrs
FUNCTIONAL TEST	Hrs
INSPECTION	Hrs
DOCUMENTATION	Hrs

REPORTED BY: Bob Humphrey DATE: 7-14-97

CONT'D ON PAGE:

DEPT. NO.: 7870

SUPERVISOR:

FAILURE ANALYSIS REPORT

WHAT WAS THE CAUSE OF THE FAILURE ?

The cause of the hot fire failure was LOX and GH_2 mixing and burning internally at the Hydrogen feedline prior to injector interface. The root cause for the fire has been traced to the GN_2 purge check valve on the LOX feed system. The internal components of the check valve were installed incorrectly allowing Oxygen flow into the Hydrogen feed system then into the injector.

CONT'D ON PAGE 2

RELATED IRR, FMR, EO, ETC.:

ANALYZED BY: Bob Humphrey R.T.H. Jeff Mays JAM DATE: 7-14-97

DEPT. NO.: 7870

EVALUATION

EVALUATION & CORRECTIVE ACTION

SEE PAGE 4 FOR EVALUATION & CORRECTIVE ACTION.

CONTINUED ON PAGE 4

RELATED CORRECTIVE ACTION DOCUMENTS (EOs, ETC.):

RELEASE DATES:

EFFECTIVITY:

PROGRAM MANAGER CONCURRENCE: Dave W. Escher DATE: 7/14/97

CORRECTIVE ACTION RESPONSIBILITY:

RELIABILITY CONCURRENCE: Robert T. Humphrey 07-08-97

TD FMR (KM 182)

WHAT WAS THE CAUSE OF FAILURE? (continued from cover page):

THE INVESTIGATION

The hot fire test was conducted for a 1 second duration with inlet pressures set at 1210 psia Hydrogen, and 1071 psia LOX. Shut down occurred at the end of the one second pulse. Post test inspection revealed that the Hydrogen inlet fitting to the injector was consumed, and the Hydrogen line was separated from the test article. The Calorimeter injector; GH_2 flex line; and connection fitting were removed from the test cell and brought up to Engineering for evaluation. The initial post test observations of the hardware and cell connections indicated a violent, high temperature combustion event had occurred. These observations were based on the fact that the hydrogen inlet tube, flex hose fitting, and connector fitting were melted and damaged. There was metallic slag on the injector face, as well as in the chamber. Black deposits were also observed on the injector face. The interior portion of the injector was melted. The Teflon coating in the Hydrogen flex line was in very good condition. There was a build-up of slag in the Calorimeter chamber. Flake particles were dispersed around the test item, on the supporting bracket and on the test cell floor. The test cell was sealed off until photographs and collection of failure evidence was performed.

Figures 1 through 15 photo document the conditions of the hardware as described above, immediately after the failure. Figures 1 through 4 show the injector face and injector inlets. On the face of the injector, a black `sooty' deposit was observed. In Figure 3, the GH_2 inlet damage is shown. Figures 5 through 8 show the interior condition of the injector as first viewed through the inlets using a borescope. Figure 9 shows the fitting connecting the GH_2 flex line to the injector. Figures 10 & 11 show the interior condition of the flex line. The white material observed in these figures is Teflon. The next set of photographs were taken in the test cell. Figures 12 & 13 are the Calorimeter Chamber, downstream from the injector. Note the `slag' build-up in the chamber. Figure 14 shows a `flake' particle which came to rest behind the injector/chamber assembly. Figure 15 shows a collection of `flake' particles observed below the injector/chamber assembly on the test cell floor.

A Failure Investigation Committee (F.I.C.) was formed to follow-up on the investigation. The F.I.C. was chaired by Reliability, and members were brought in from Project, Manufacturing, Materials, and Data Engineering. A "Fish-Bone" diagram was assembled with input from all members of the F.I.C., SEE Figure 16. The different legs of the fish-bone were evaluated by both the responsible member of the F.I.C. and the chairman.

The first leg reviewed was the Procedures. In this section there were three sub-categories. They were the "set-up" list, the "check-off" list, and the test procedure. All three items were covered in a Test Readiness Review (TRR), performed on May 19, 1997 SEE ATTACHMENT I. At that time, a system schematic of the piping and instrumentation was included, See Figure 17. The initial system schematic differs from the actual set-up which was physically verified after the failure, See Figure 18.

The difference between the two schematics are as follows. The initial system schematic introduced during the TRR, indicated separate GN2 supply systems to the propellant lines. In the actual set-up schematic, the GN2 purge lines are common to both sides of the propellant system. The second difference is where the GN2 purge line enters the Hydrogen system. On the initial schematic, the purge is shown upstream of the Hydrogen check valve. In actuality, the purge enters the system downstream of the Hydrogen check valve. The "check-off" list and the actual Hot Fire Test procedure encompassed all necessary items to perform a successful test.

The Material compatibility was examined, as was the cryogenic properties. The Oxygen Free copper #C10200 employed in the design conforms to this application for both compatibility and cryogenically usage. The stainless steel plenum seal plates, and inlet fittings were also found to conform to this application, based on a literature search. The Material leg was eliminated as a contributing factor of the failure.

On the Manufacturing leg, all the operations listed were verified to have been performed per requirements. However, during proof pressure test, the injector was pressurized internally to 1,000 psid. The internal pressure was not the concern. The concern here was for the pressure which was downstream of the injector into the test fixture cavity. The pressure in the cavity caused the injector to flex and bend outward by 0.015in. The injector was straightened to within 0.001in. The injector was pressurized to 1,000 psid with a different configuration downstream.

However, the injector still flexed and bent 0.007in. Again the injector was straightened to within 0.001in. No damage was noted as a result of the distortions. No other anomalies were observed or discovered in the manufacturing or processing of the hardware.

On the Design leg, the `TEST SYSTEM' has been already addressed in this report. The wall thickness between the plenums and passages was reviewed with KM's stress expert. ATTACHMENT II of this report is the MEMO issued with the results. The conclusion of the report is that excessive stress was not a contributing factor in the failure of the injector.

The injector was sectioned parallel to the injector face through the GH_2 plenum. Figures 19, 20, and 21 show the sectioned halves of the injector. With these photographs, it is plain to see where the internal burning occurred. The plenum wall between the LOX and GH_2 has been burnt away. The sectioned halves were subjected to Scanning Electron Microscopy analysis. The first item examined was the injector half with the injector face. The black `sooty' deposit observed on the face was analyzed and found to be copper/Stainless Steel mixture with some Carbon, and Teflon, See Figures 22 & 23. The Carbon residue is most likely the result of using "shop-air" in the ignitor. Any oil in the "shop-air" would have been combusted leaving behind the black, `sooty' deposit. The Teflon found on the injector face appears to have come from the Teflon material lining the Hydrogen inlet flex line. The `slag' observed on the injector face was found to be copper/stainless steel mixture. A high amount of Oxygen was observed in both traces. No Teflon was observed, See Figures 24 & 25.

The interior edges were inspected at 12x and 18x magnification. The edges indicate molten melting of the material, rather than destruction from an explosion, See Figures 26 & 27.The Thermocouple removed from the LOX side of the system was analyzed. No copper slag was present, See Figure 28. This is significant in showing that there was no "blowback" up the LOX side of the system. Hence forward flow was constant throughout the test. The `flake' particle observed on the bracket behind the injector matches elementally to the injector, See Figure 29. Looking at the 10x mag. photograph in Figure 30, the pattern of the four internal holes is still visible.

The data from the `cold-flow' tests was compared to the hot-fire flow data. Several anomalies were observed. First anomaly observed is the slow rise in Chamber pressure during the hot-fire. The chamber pressure rose at a significantly faster rate during the cold-flow test. The second anomaly noted is a change in the flow of the Hydrogen at about 1 second into the test. It is after this point that there was internal burning in the injector taking place, See Figure 31. This anomaly was not observed in the GH2 cold-flow test run #1005, See Figure 32. No anomalies were observed in the LOX cold flow test, run #1004, Figure 33.

The final anomaly observed was a recorded temperature of +200° F at T_c `LTT' after ignition spike on the LOX side of the system, (approximately 4" from the injector head), See Figure 34. No other temperature anomalies were observed. Detail test data analysis indicated that the failure could have occurred at the GN2 check valve on the LOX system, resulting in LOX flow into the Hydrogen system. (SEE ATTACHMENT III ANALYSIS REPORT by RON COOK).

The GN2 check valve was removed from the test set-up and flow tested with GN2. The check valve flowed in both directions with inlet pressures of 2 to 2,000 psia. The internal components were removed, and examined. Physical verification of the GN2 purge check valve was performed. The internal components were verified to be installed incorrectly allowing for flow through the check valve in both directions See Figure 35.

EVALUATION & CORRECTIVE ACTION (continued from cover page.):

EVALUATION:

As a result of the incorrect assembly of the GN_2 check valve used in the purge system, both sides of the propellant feed systems were subjected to LOX during the flow tests. The LOX flowed through the common purge line and into the Hydrogen side. The detonation in the chamber forced high temperature combustion gasses into the LOX and GH_2 feed systems, which started the burning process at the GH_2 line to injector interface.

CORRECTIVE ACTION:

Remove the remaining check valves in the system, and verify proper installation of internal components and functionality.

The following is a list of recommendations which should be employed in the program as it progresses forward.

HARDWARE:

- During build-up of the replacement injector, if a processing anomaly occurs, bring together the entire RBCC team to discuss and evaluate.
- At critical processing points, employ test coupons...i.e. brazing, etc.

TEST SET-UP:

- Use separate purge sources, if possible, or use double check valves in purge lines to prevent backflow.
- Do not `cold-flow' propellants through the injector prior to the test.
- Do not `shop air' for igniter.
- Do not `pulse' igniter during start-up.
- Verify start-up ignition at lower pressure.
- Modify LOX and GH_2 plumbing to provide adequate purge and propellant flows.

- Move after-burner flare to within 3" of nozzle exit.
- SEE ATTACHMENT IV MEMO REGARDING CALORIMETER TEST PLUMBING & OPERATIONS MODIFICATIONS

DATA RECORDING:

- Employ high speed video (400 to 450 fps) for future tests, use time coding feature.
- Data recorders should be on at all times during test.
- Provide a graphical display of critical test parameters.

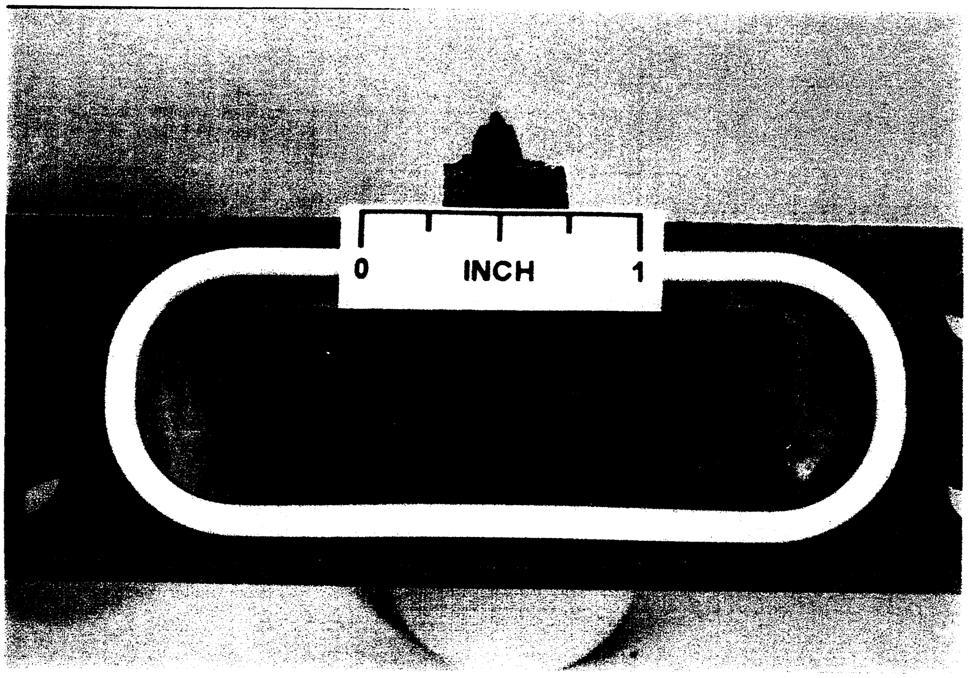


FIGURE 1- THE INJECTOR FACE

FIGURE 2- CLOSE-UP OF BLACK "SOOTY" DEPOSIT ON THE INJECTOR FACE.

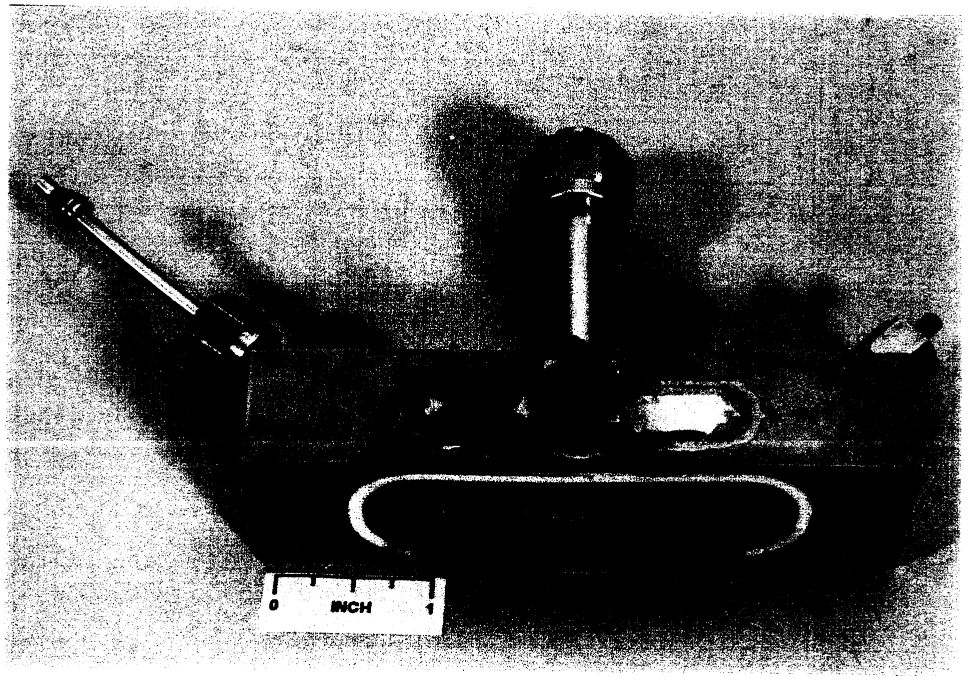


FIGURE 3 - OVERALL VIEW OF THE INJECTOR FROM THE HYDROGEN INLET SIDE.

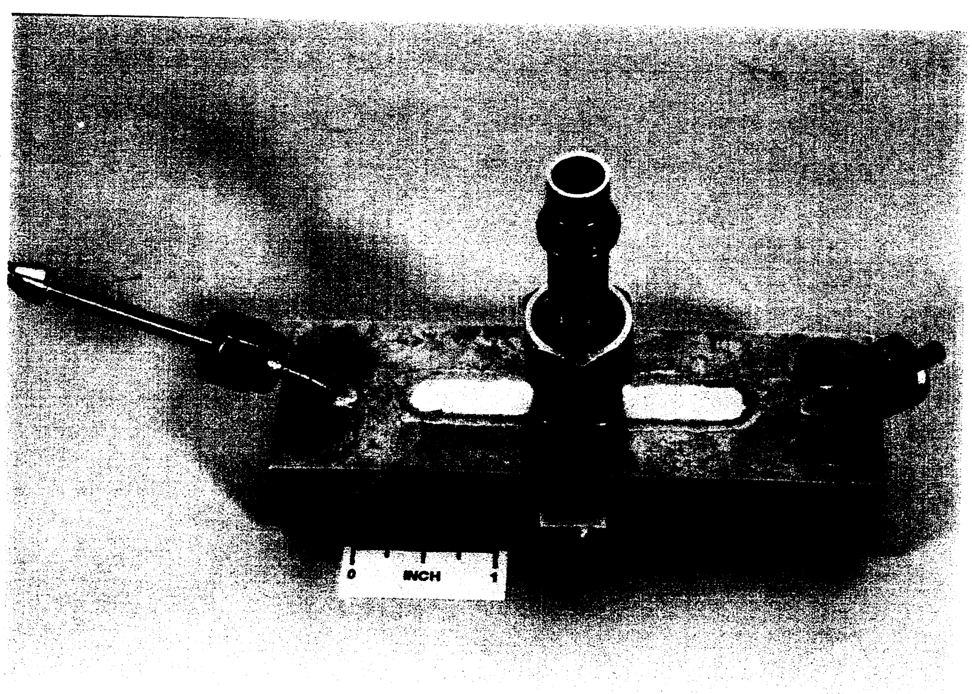


FIGURE 4 - OVERALL VIEW OF THE INJECTOR FROM THE LOX INLET SIDE.

FIGURE 5- VIEW OF THE INTERIOR PORTION OF THE INJECTOR FROM THE LOX INLET.

FIGURE 6- CLOSE-UP VIEW OF THE INJECTOR INTERIOR FROM THE LOX INLET.

FIGURE 7- VIEW OF THE INTERIOR PORTION OF THE INJECTOR FROM THE HYDROGEN INLET.

FIGURE 8- CLOSE-UP VIEW OF THE INJECTOR INTERIOR FROM THE HYDROGEN INLET.

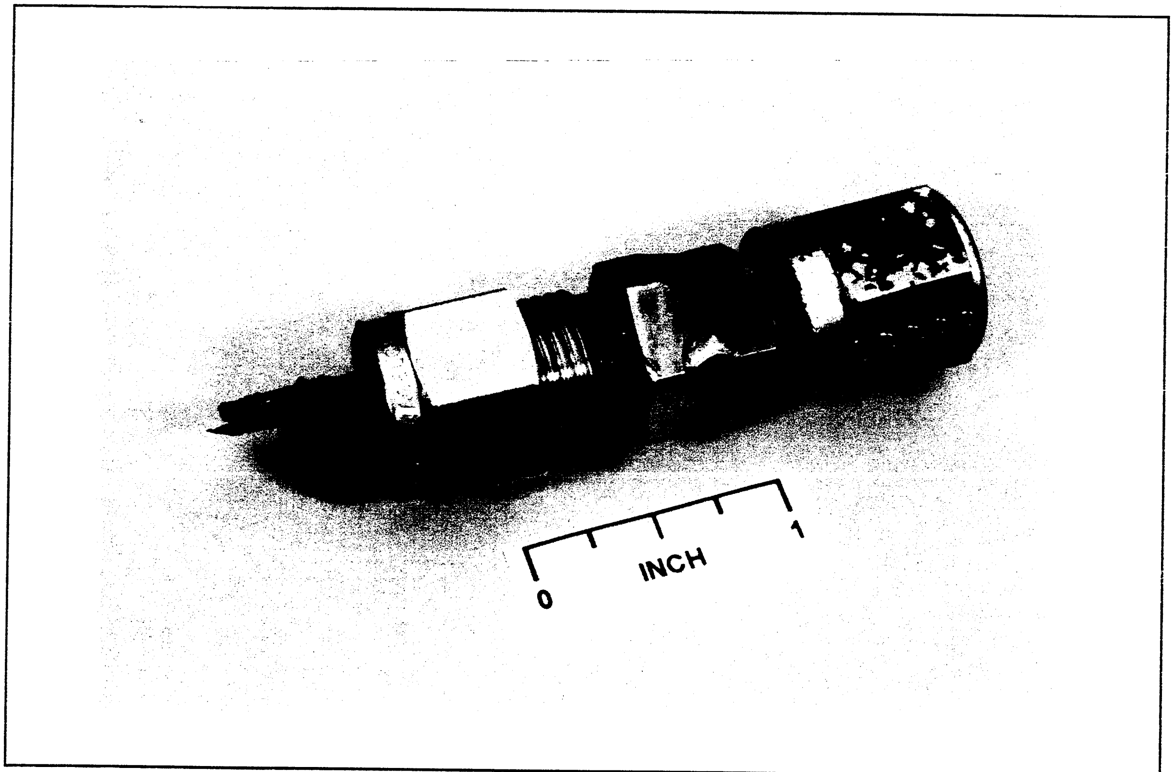


FIGURE 9- OVERALL VIEW OF THE CONNECTOR FITTING BETWEEN THE HYDROGEN FLEX LINE AND THE INJECTOR.

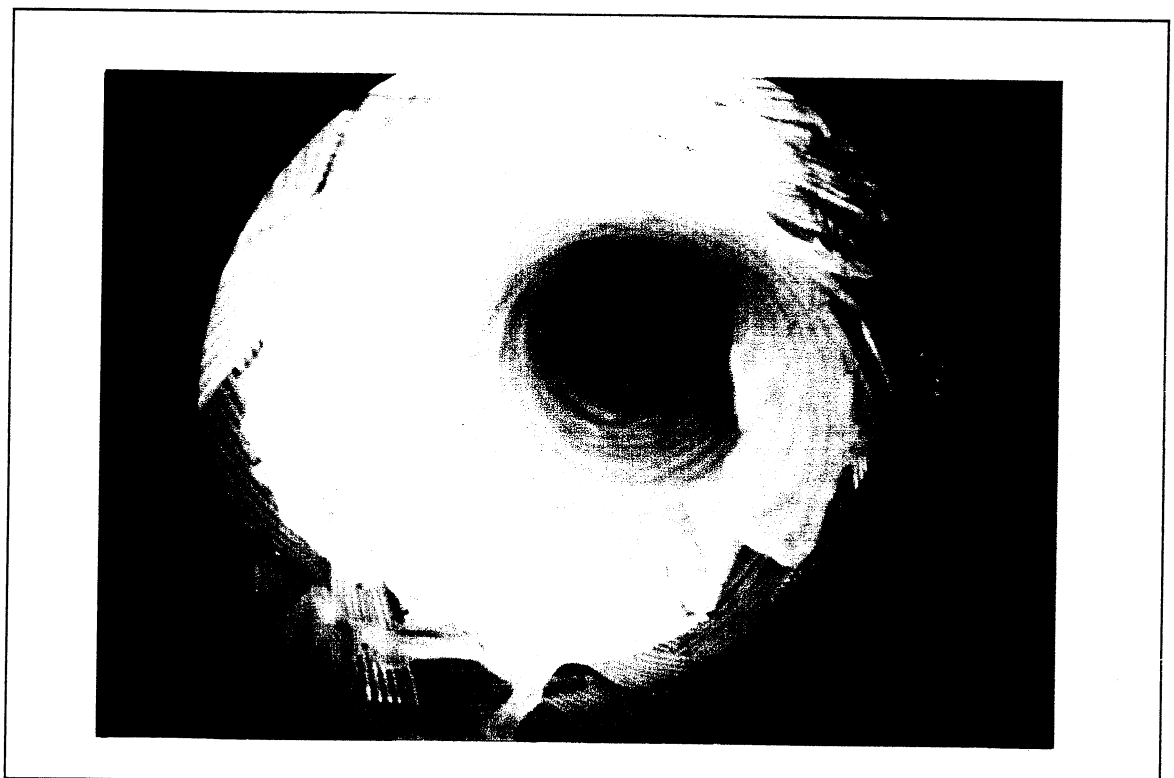


FIGURE 10- BORESCOPE VIEW OF THE INTERIOR PORTION OF THE FLEX TUBE NEAR THE BURNT OFF SECTION.

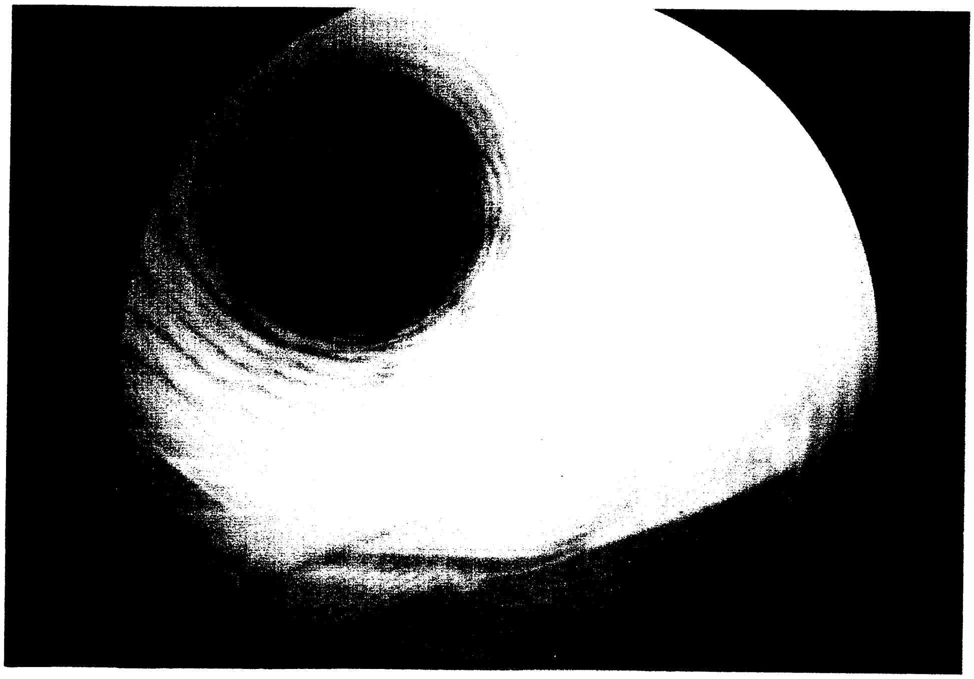


FIGURE 11- BORESCOPE VIEW OF THE INTERIOR PORTION OF THE FLEX TUBE FROM THE END OPPOSITE THE BURNT SECTION.

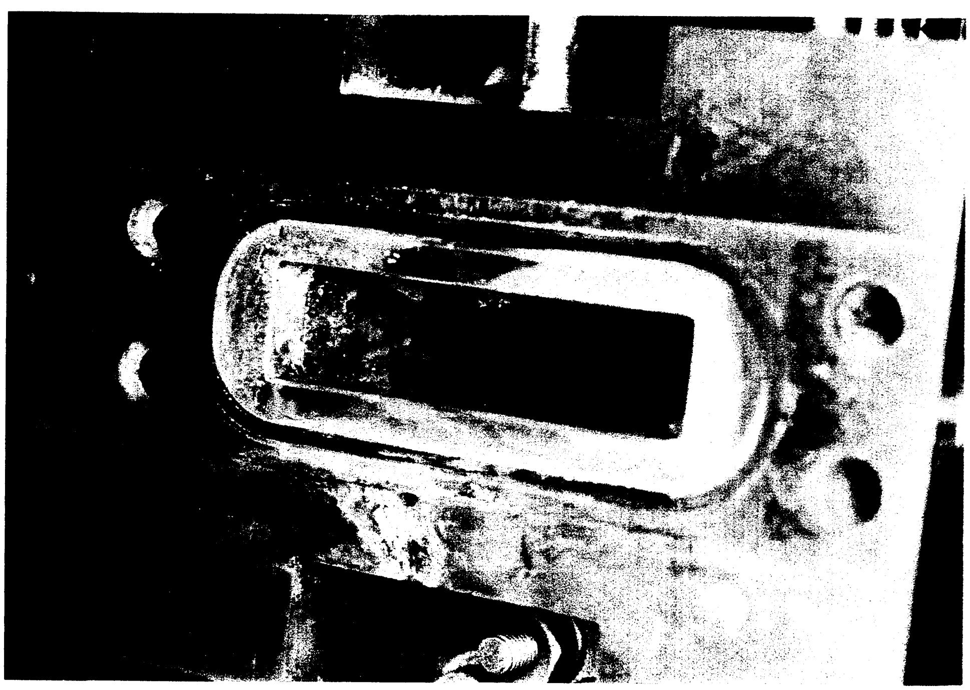


FIGURE 12- OVERALL VIEW OF THE CALORIMETER CHAMBER.

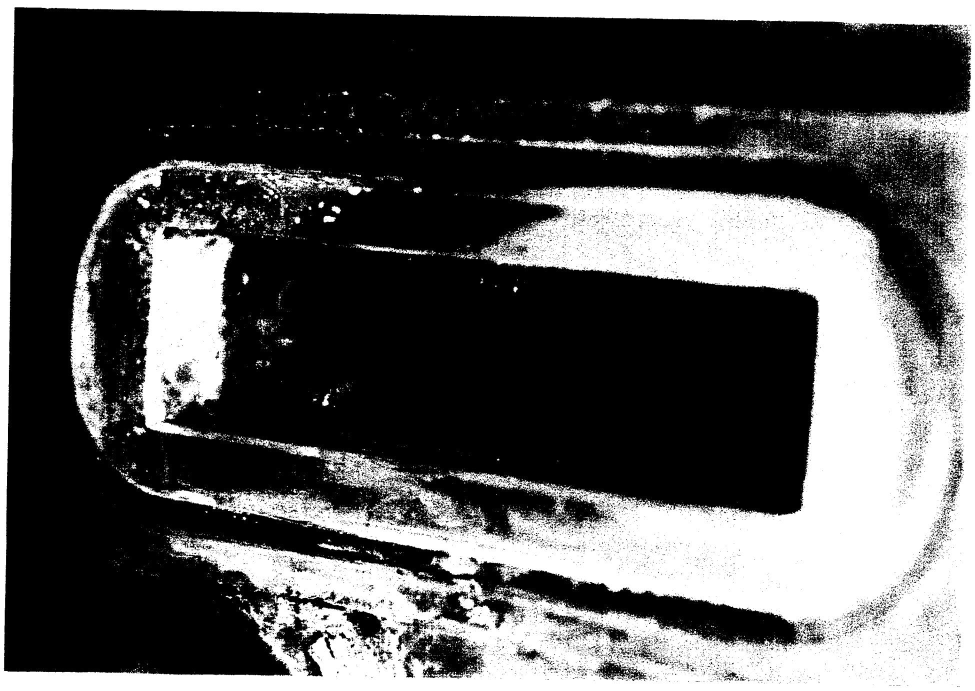
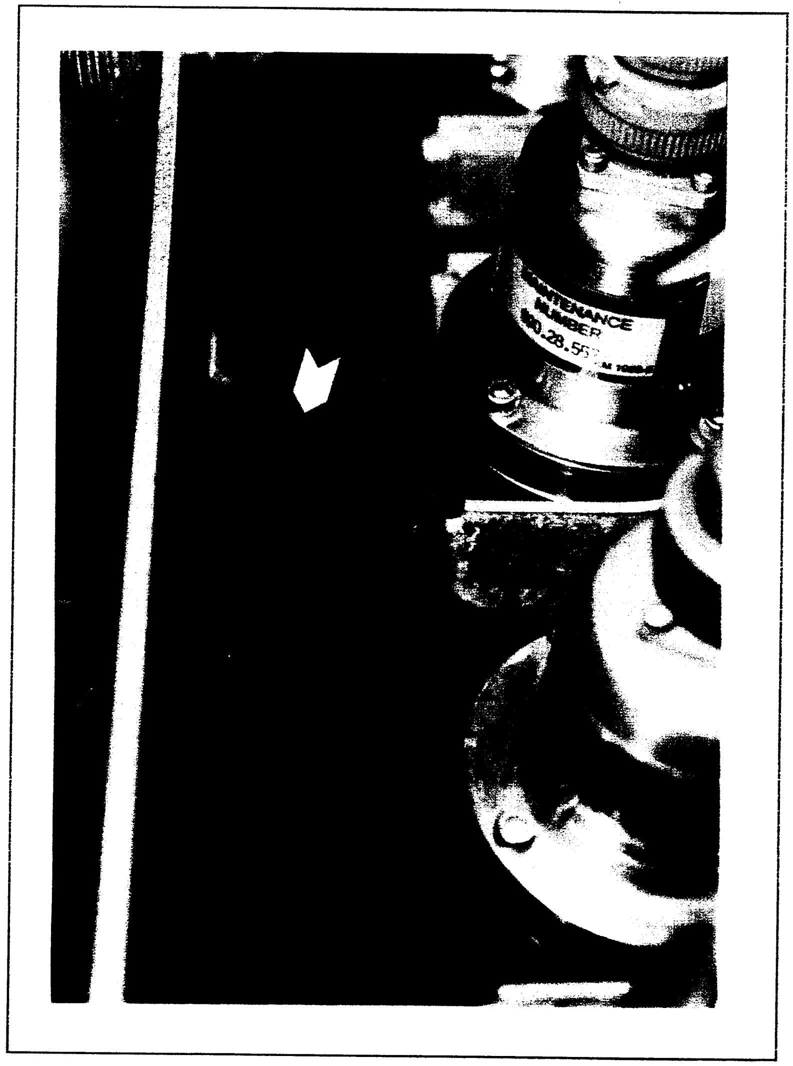


FIGURE 13-CLOSE-UP OF THE CALORIMETER CHAMBER SHOWING THE SLAG BUILD-UP.

FIGURE 14-"FLAKE" PARTICLE WHICH CAME TO REST BEHIND THE TEST ARTICLE ON A BRACKET.



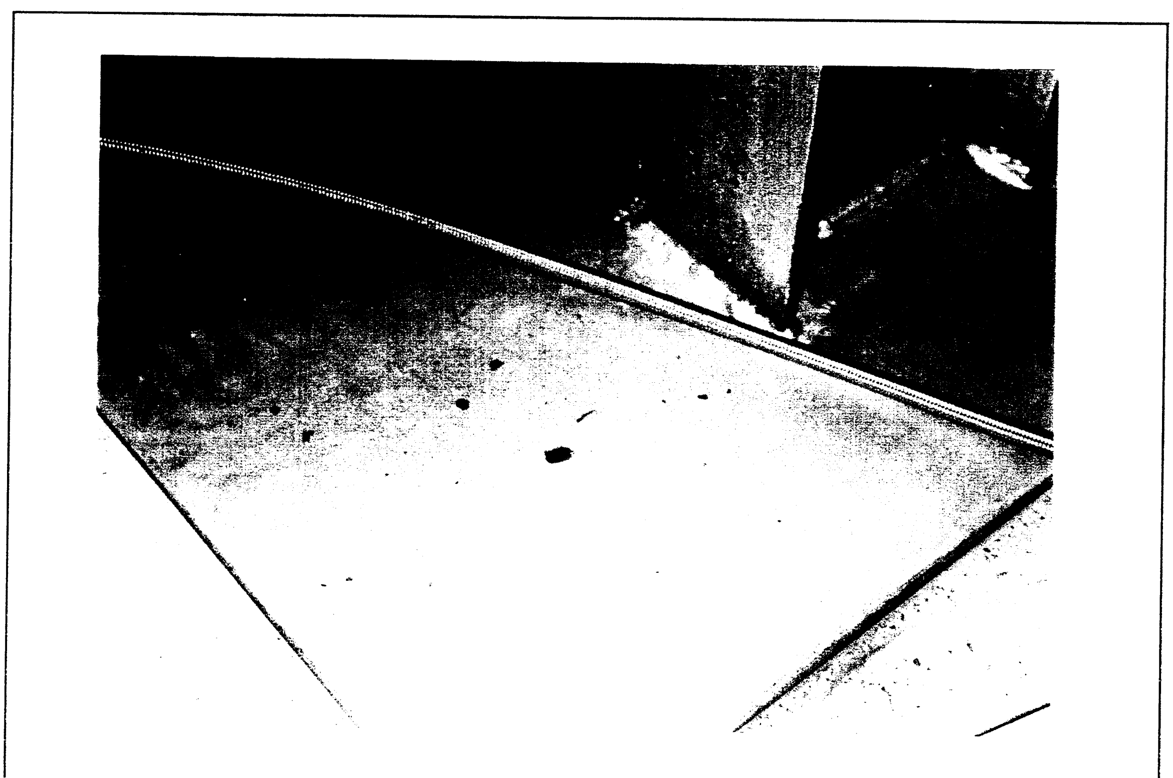


FIGURE 15-"FLAKE" PARTICLES WHICH WERE OBSERVED ON THE FLOOR OF THE TEST CELL BELOW THE TEST ARTICLE.

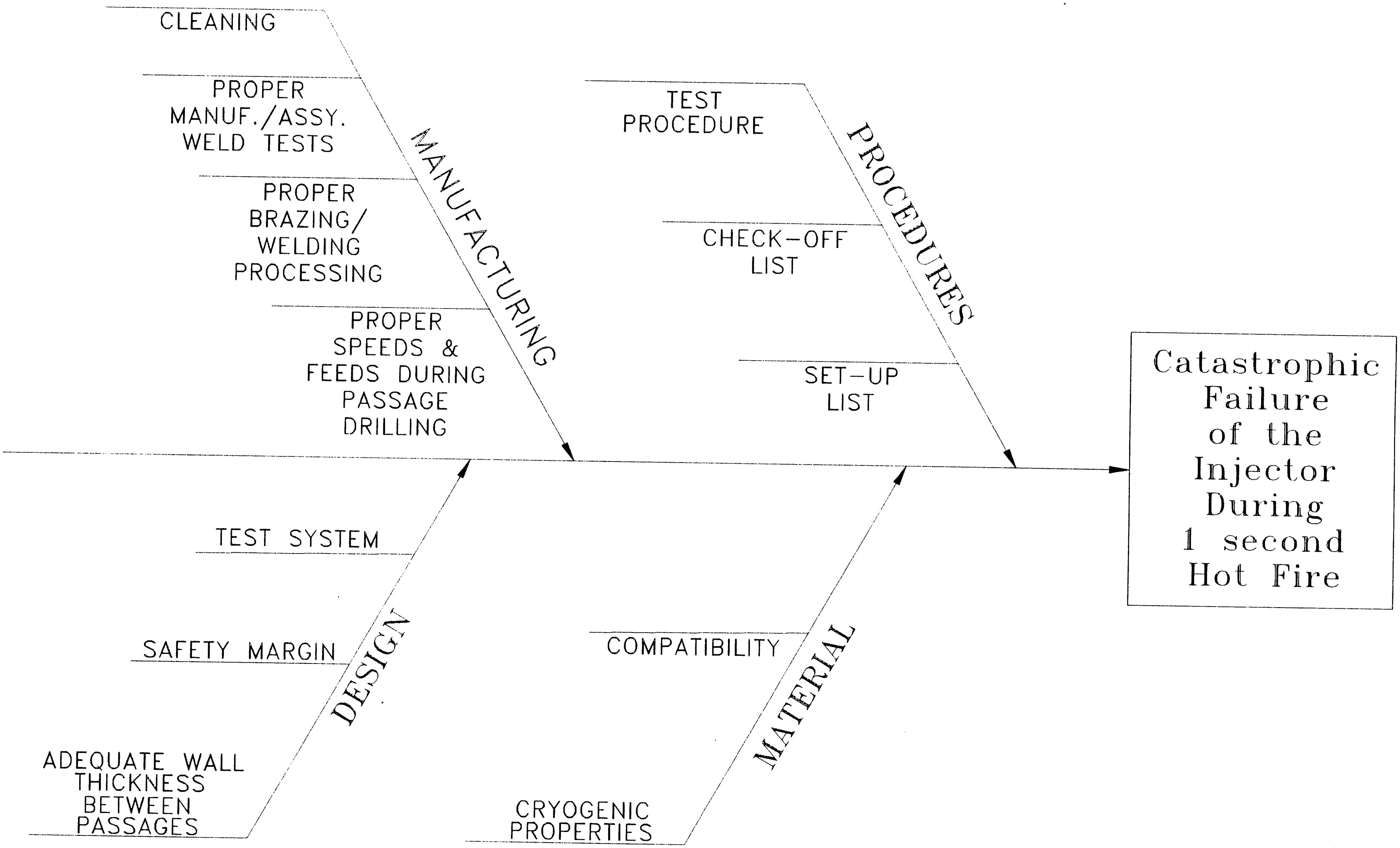


FIGURE-16

R.T. HUMPHREY
RBCC CALORIMETER
MAY 27,1997

PIPING AND INSTRUMENTATION DIAGRAM

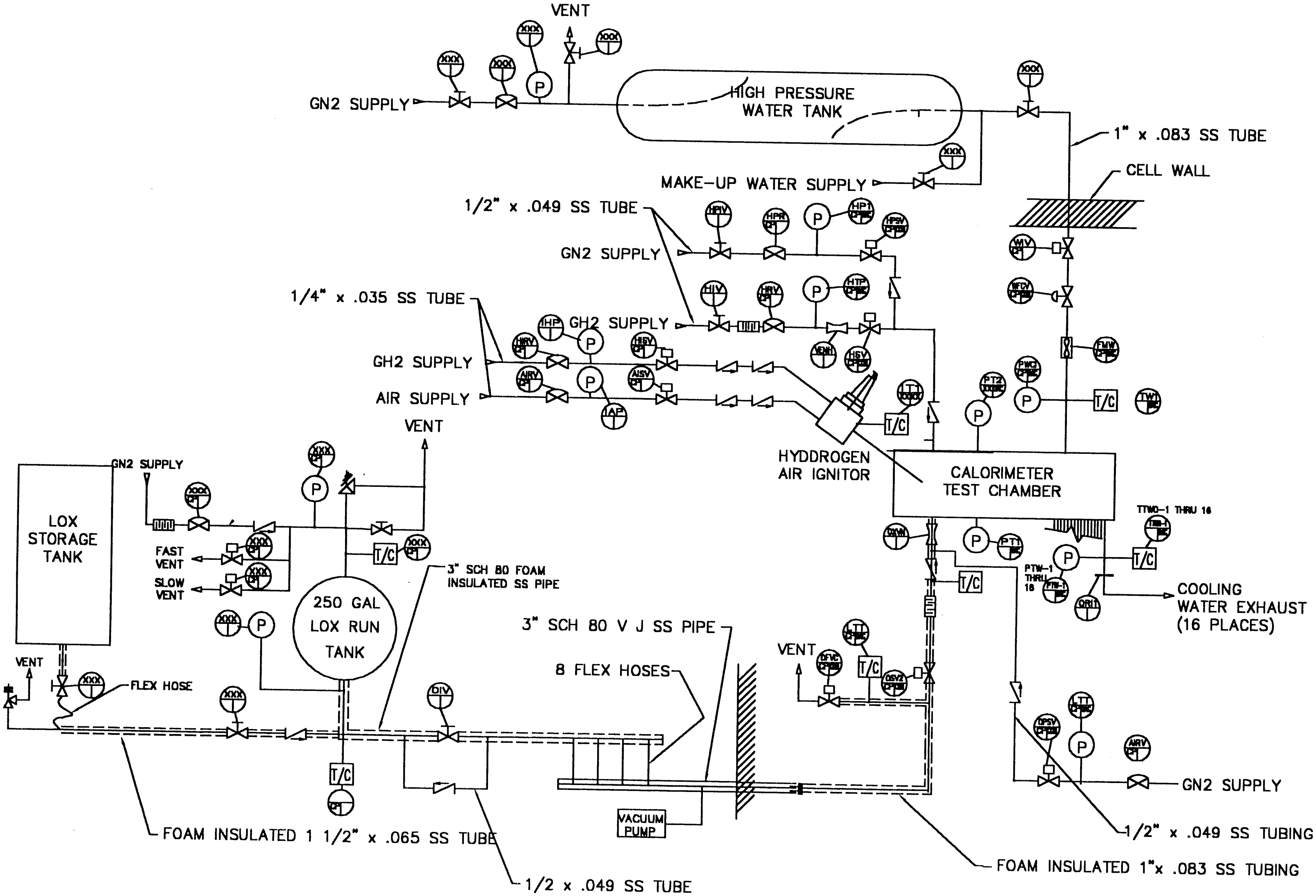


FIGURE 17

PIPING AND INSTRUMENTATION DIAGRAM

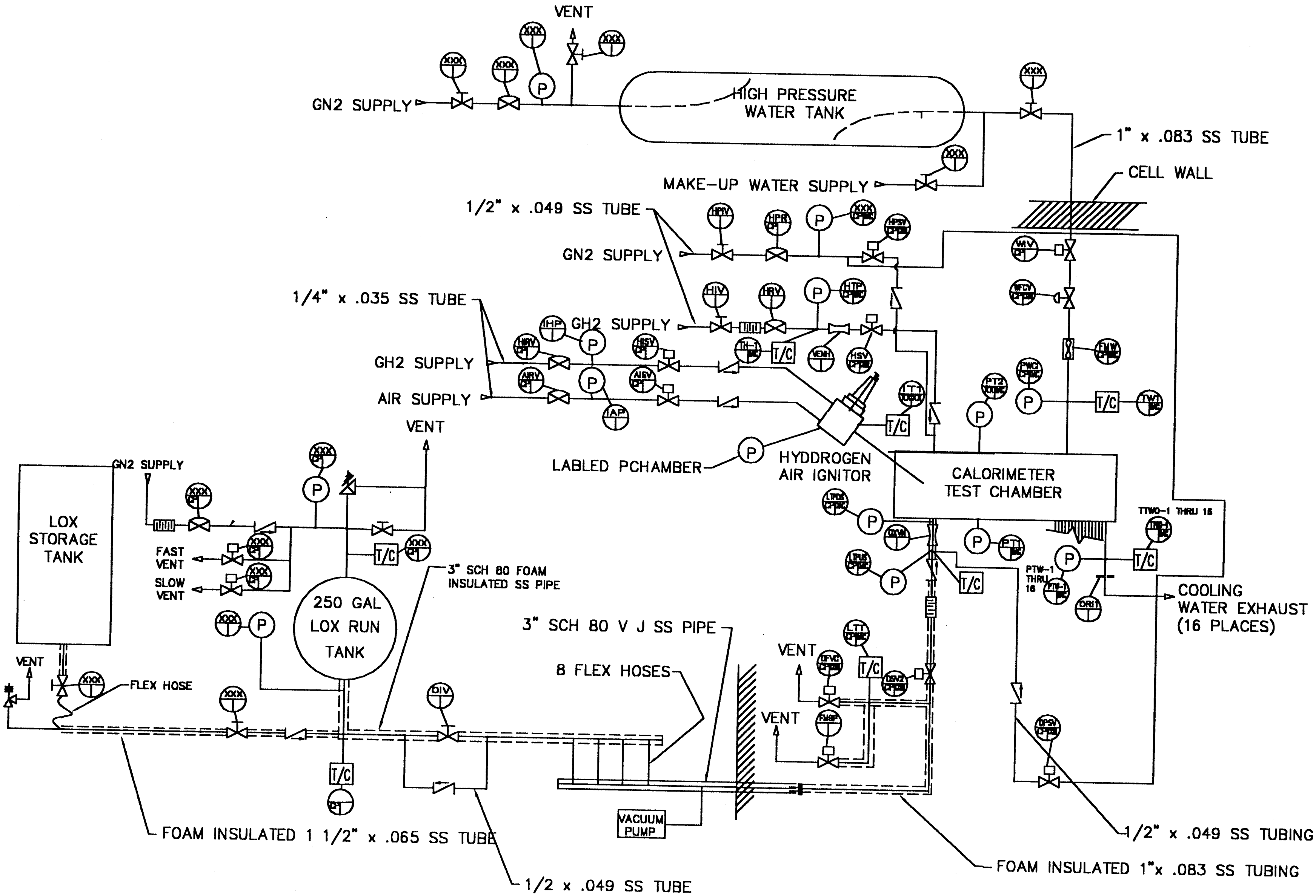


FIGURE 18

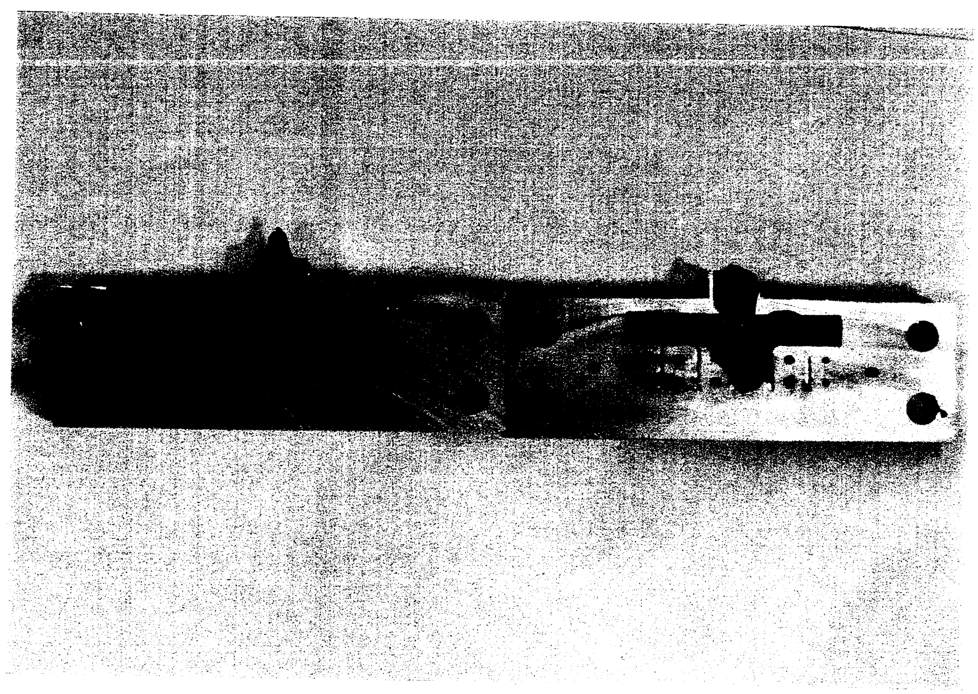


FIGURE 19-OVERALL VIEW OF THE INJECTOR INTERIOR AFTER SECTIONING.

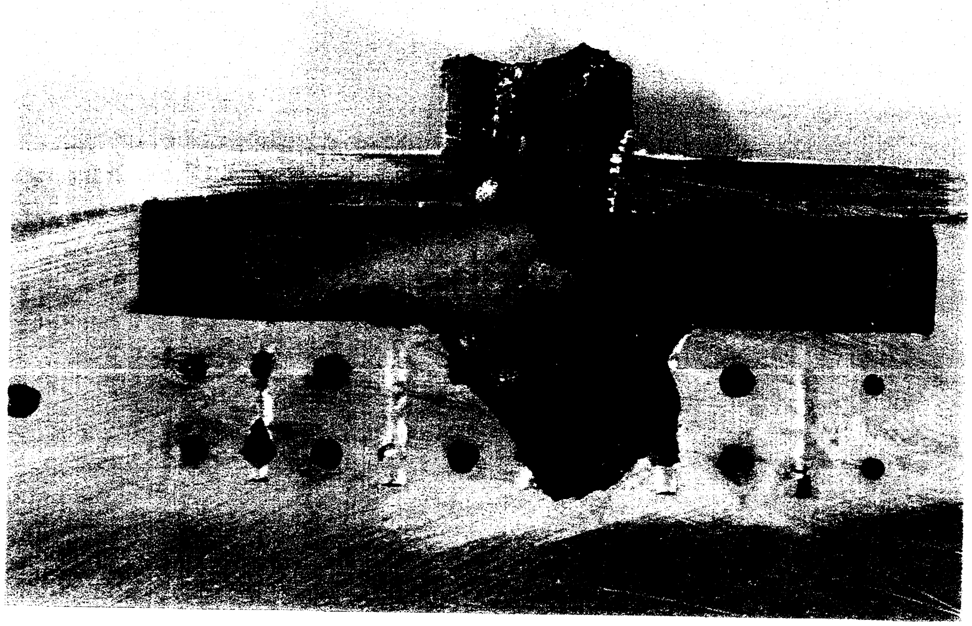


FIGURE 20- INTERIOR PORTION OF THE INJECTOR AFTER SECTIONING. THIS IS THE VIEW LOOKING OUT TOWARDS THE INJECTOR FACE.

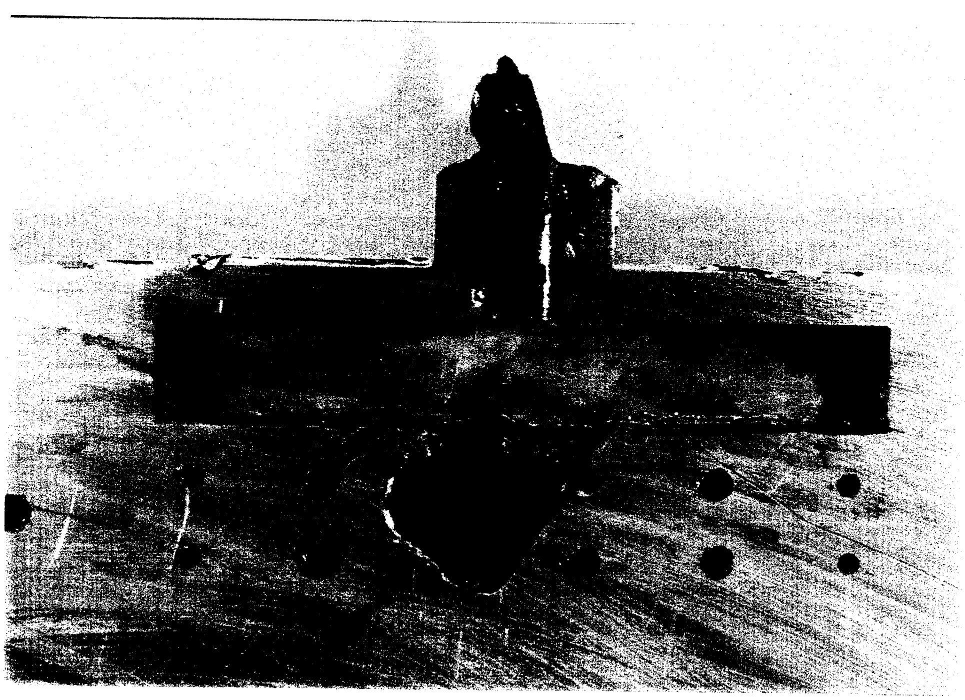


FIGURE 21- INTERIOR PORTION OF THE INJECTOR AFTER SECTIONING THROUGH THE HYDROGEN PLENUM. IN THIS VIEW WE ARE LOOKING OUT THROUGH THE LOX INLET.

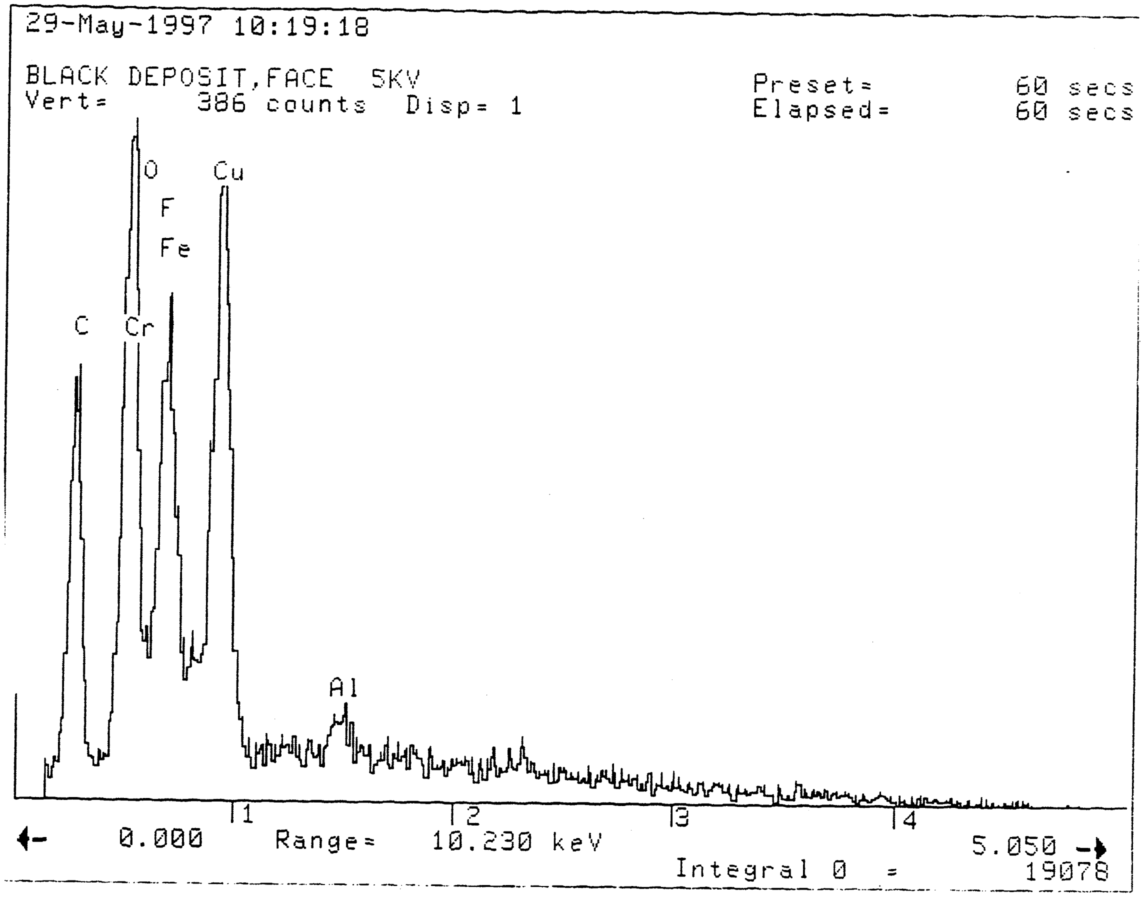


FIGURE 22 - SEM/EDAX ANALYSIS OF INJECTOR FACE AT 5KV

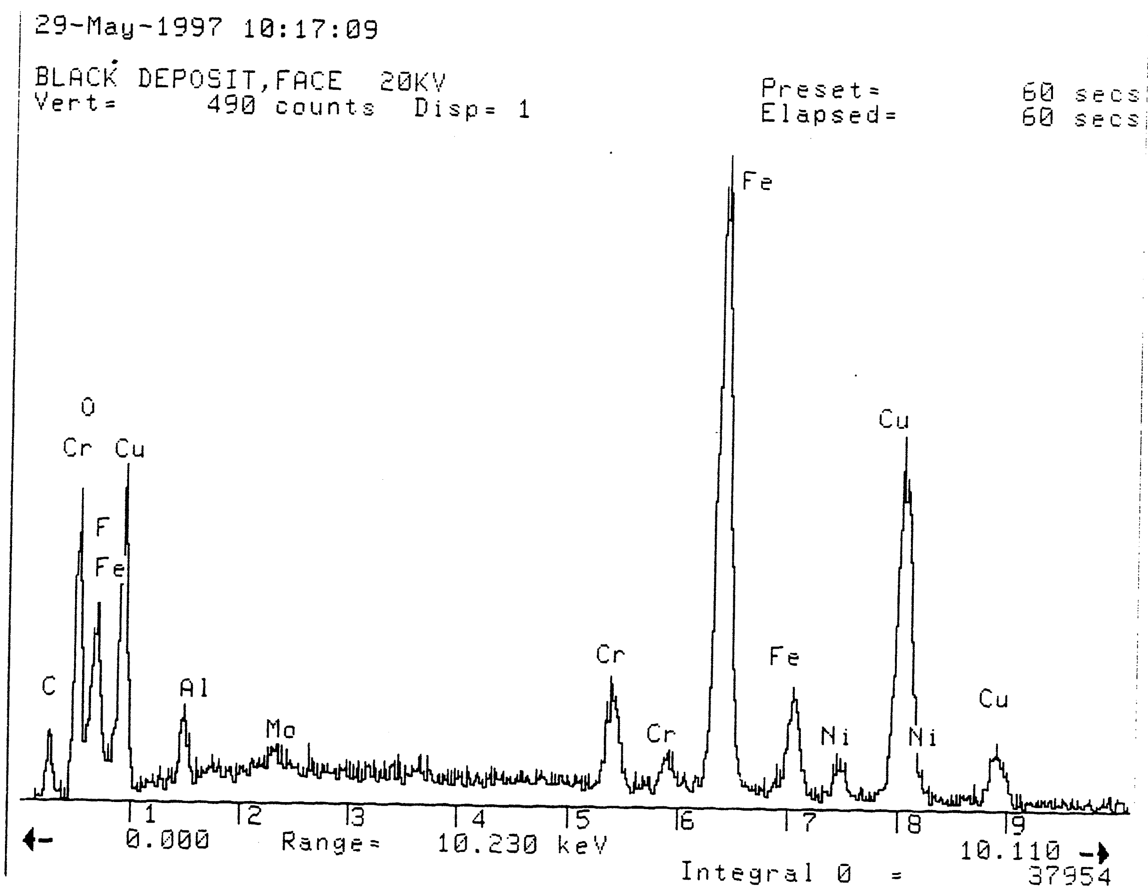


FIGURE 23 - SEM/EDAX ANALYSIS OF INJECTOR FACE AT 20KV

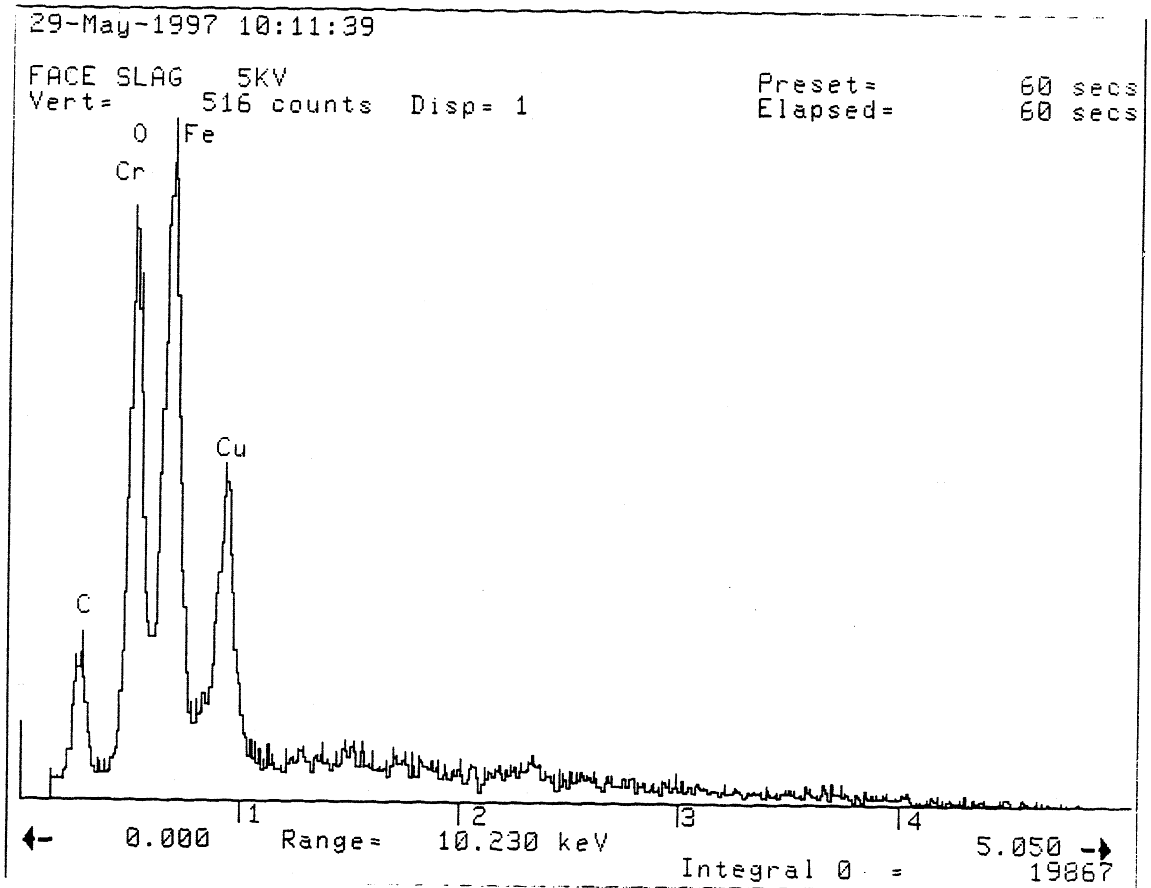


FIGURE 24 - SEM/EDAX ANALYSIS OF INJECTOR FACE AT 5KV

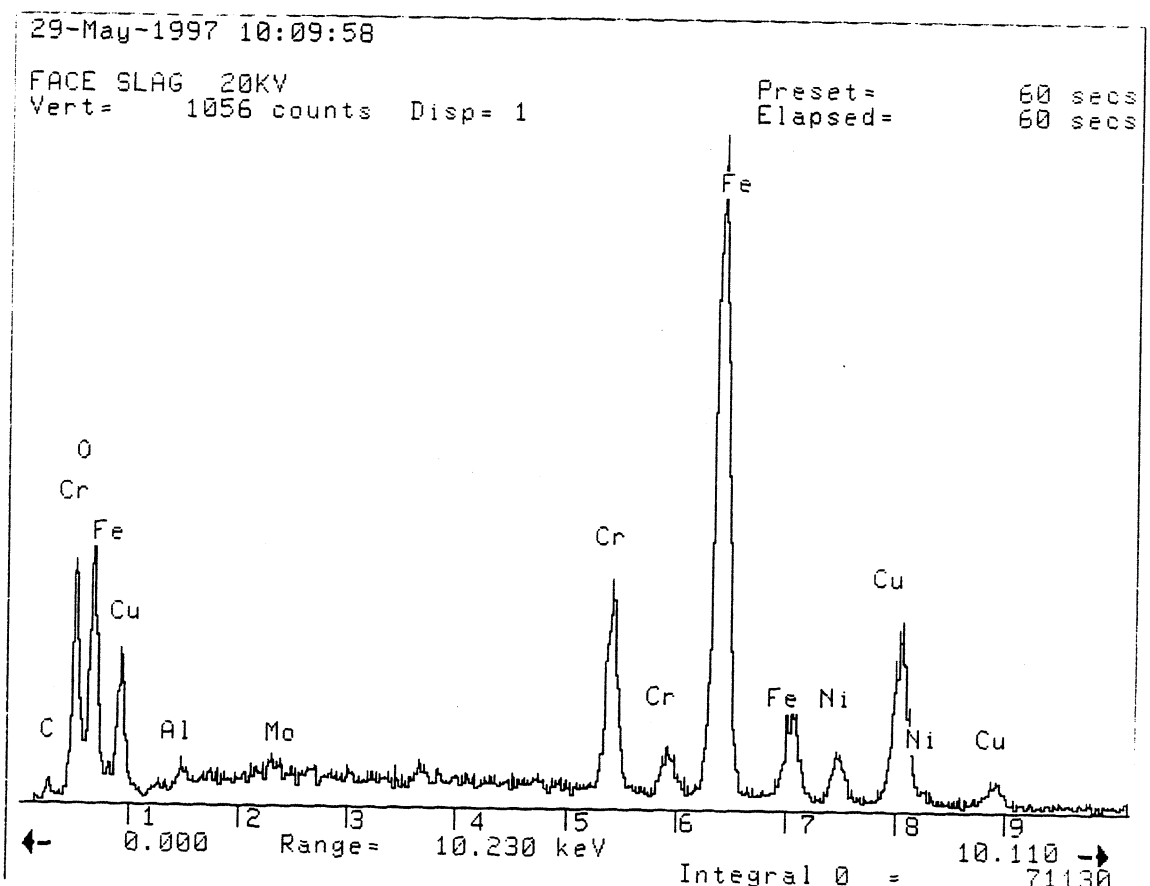


FIGURE 25 - SEM/EDAX ANALYSIS OF INJECTOR FACE AT 20KV

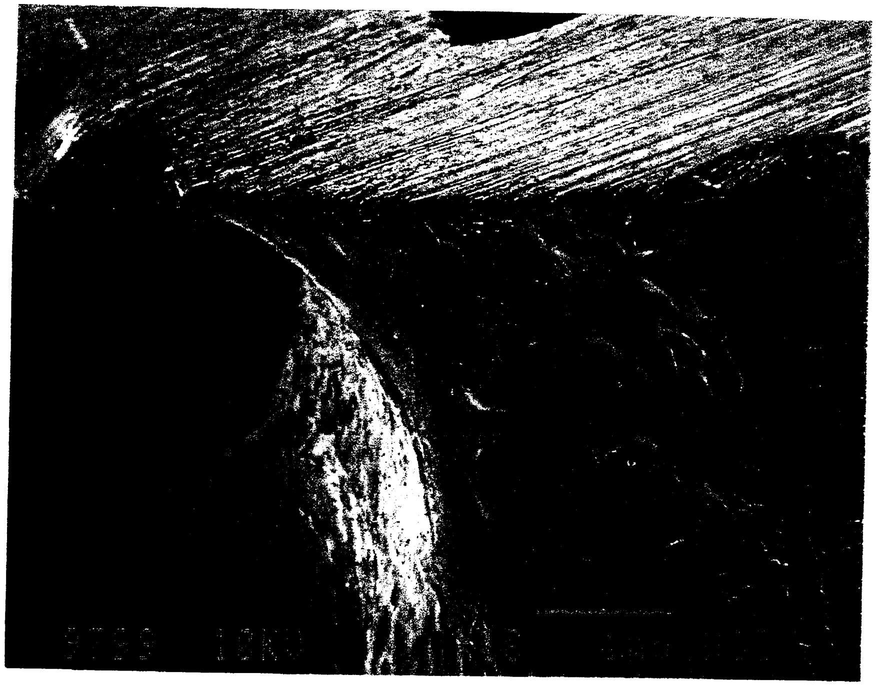


FIGURE 26- INTERIOR PORTION OF THE INJECTOR SURFACE AFTER SECTIONING. NOTE THE "MOLTEN FLOW" SURFACE CONTOURS.

FIGURE 27- INTERIOR PORTION OF THE INJECTOR SURFACES AFTER SECTIONING. NOTE THE "MOLTEN FLOW" SURFACE CONTOURS.

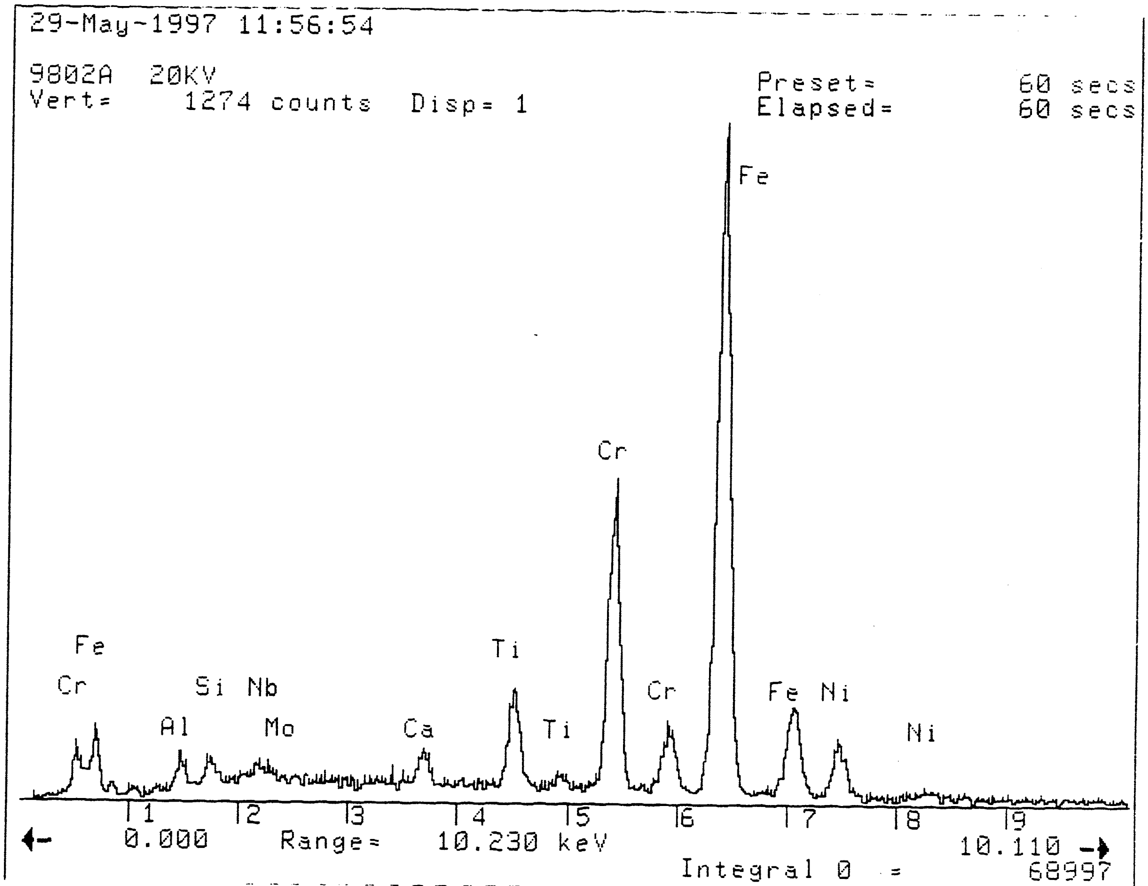


FIGURE 28 - SEM/EDAX ANALYSIS OF INJECTOR FACE AT 5KV

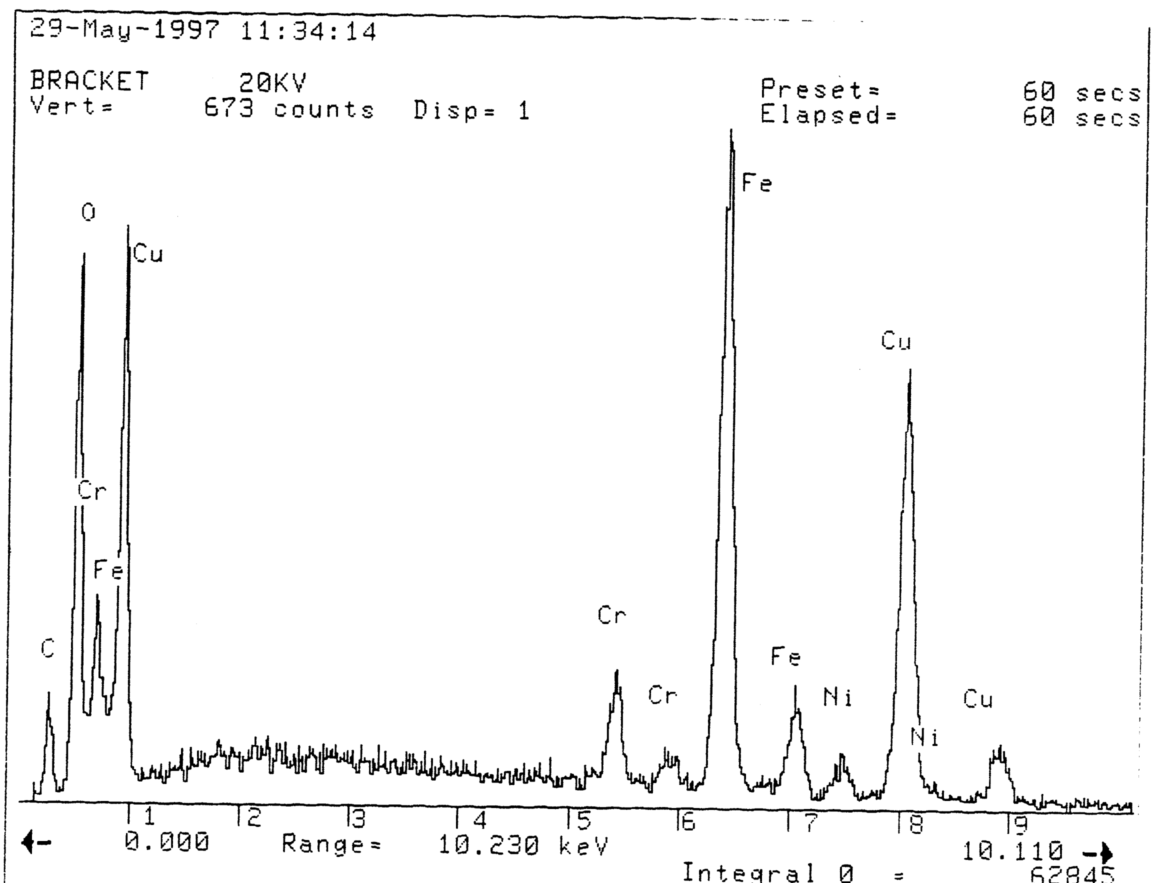


FIGURE 29 - SEM/EDAX ANALYSIS OF INJECTOR FACE AT 20KV

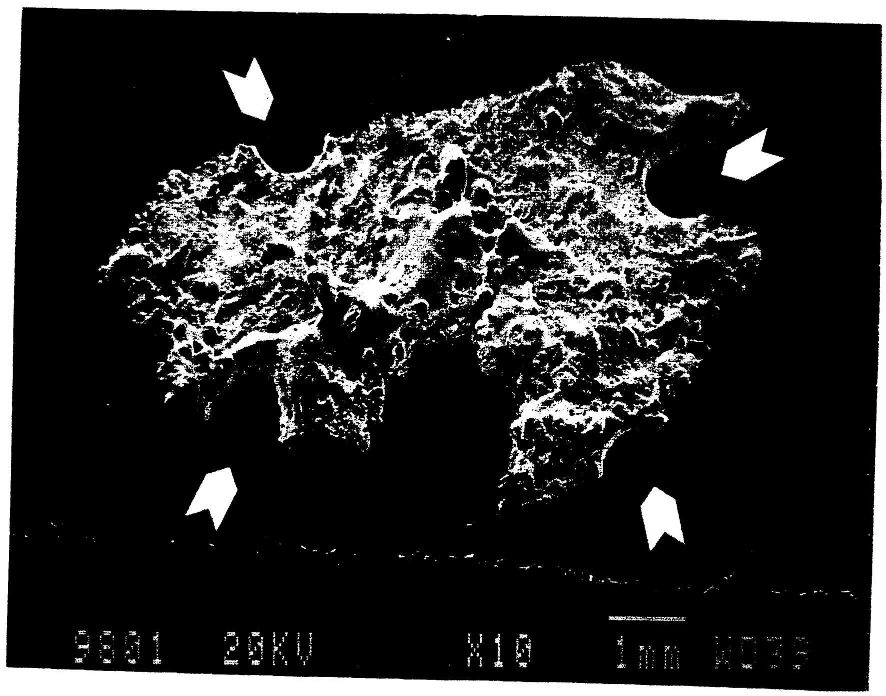


FIGURE 30- OVERALL VIEW OF THE "FLAKE" PARTICLE FOUND ON THE BACK MOUNTING BRACKET BEHIND THE ENGINE. THE YELLOW ARROWS HIGHLIGHT THE 4 HOLES.

HOTFIRE RESPONSE - R1038

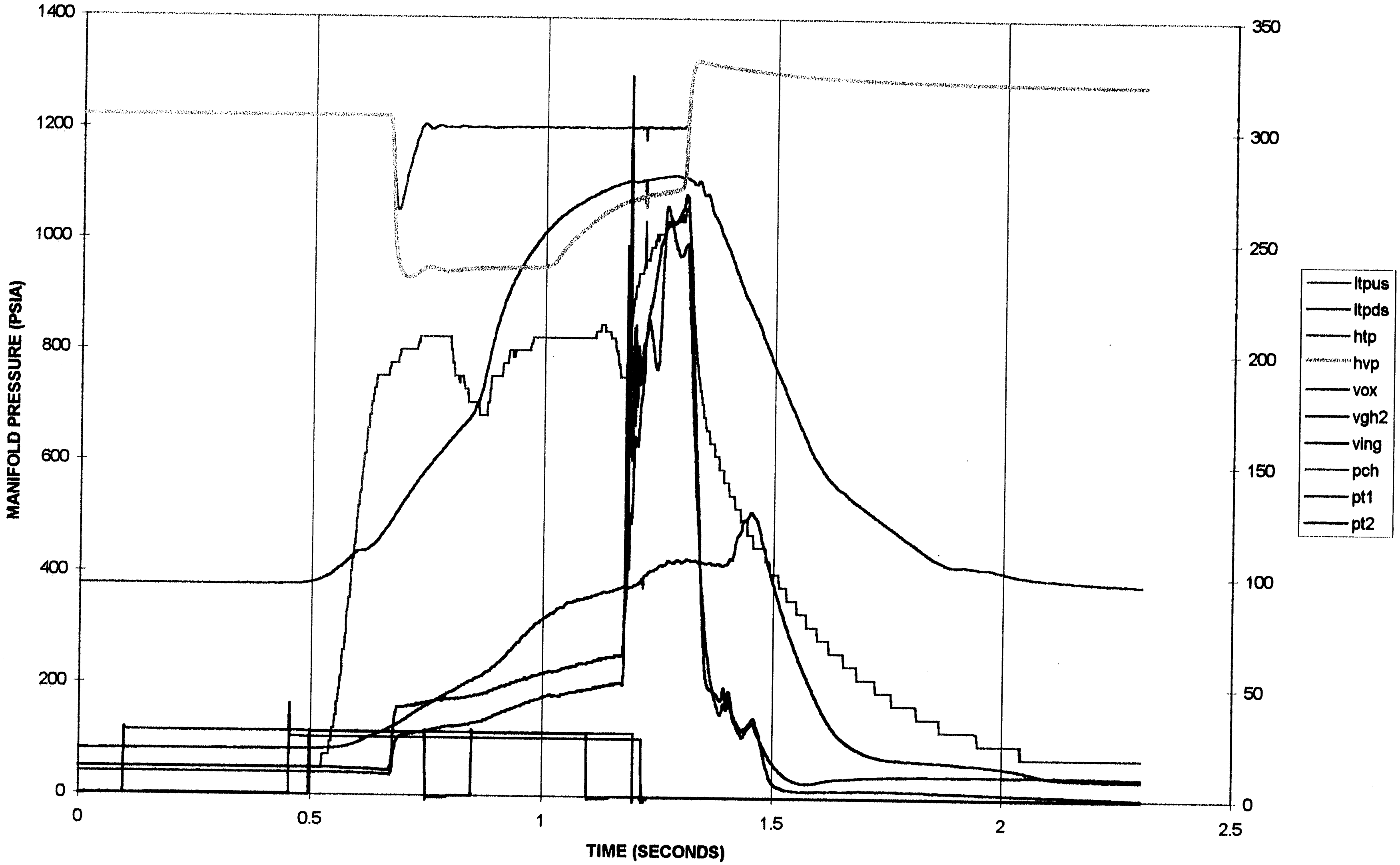


FIGURE 31

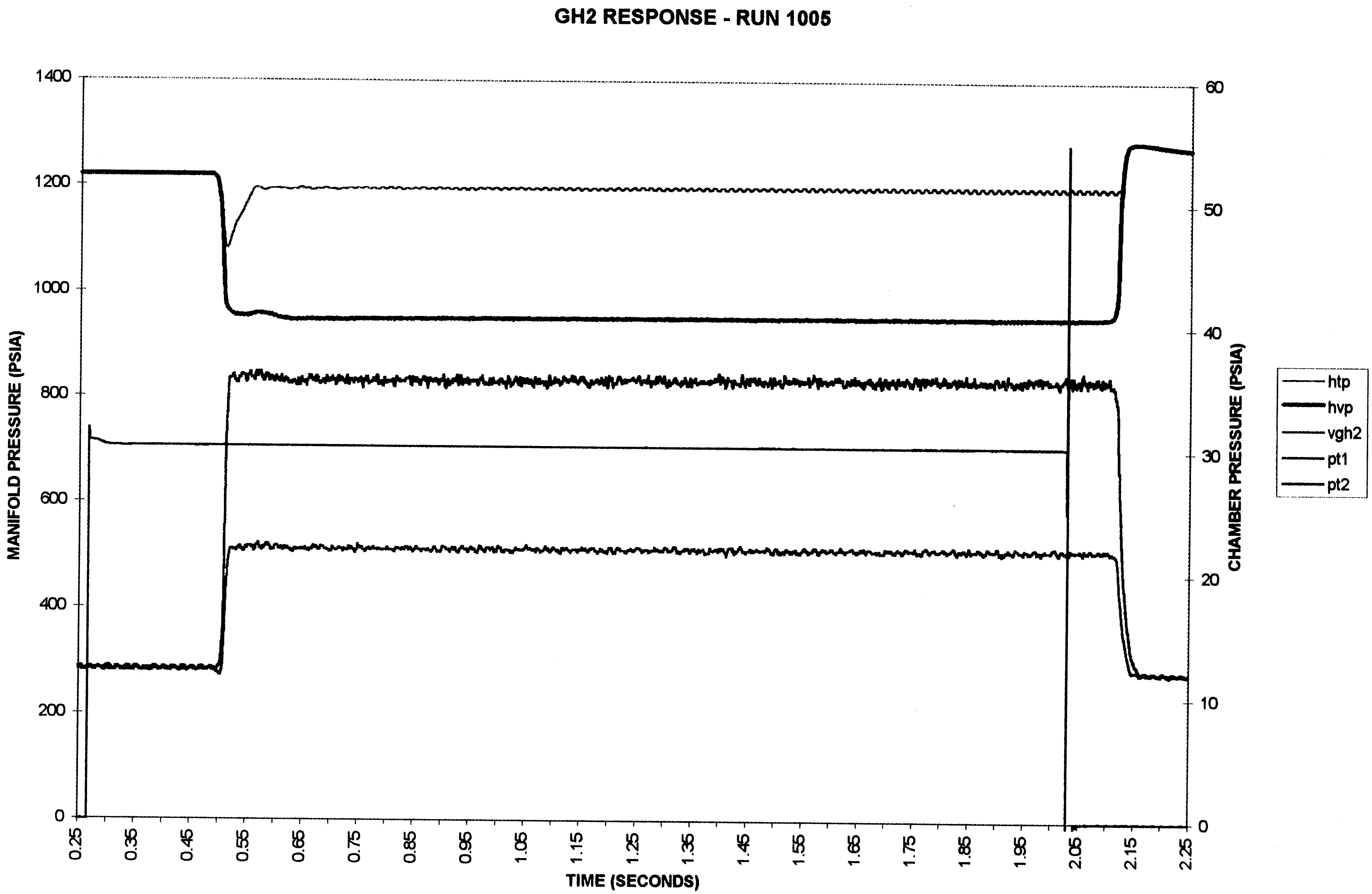

GH2 RESPONSE - RUN 1005
MANIFOLD PRESSURE (PSIA)
1400
1200
1000
800
600
400
200
0
CHAMBER PRESSURE (PSIA)
60
50
40
30
20
10
0
TIME (SECONDS)
0.25
0.35
0.45
0.55
0.65
0.75
0.85
0.95
1.05
1.15
1.25
1.35
1.45
1.55
1.65
1.75
1.85
1.95
2.05
2.15
2.25
htp
hvp
vgh2
pt1
pt2

FIGURE - 32

LOX SYSTEM RESPONSE

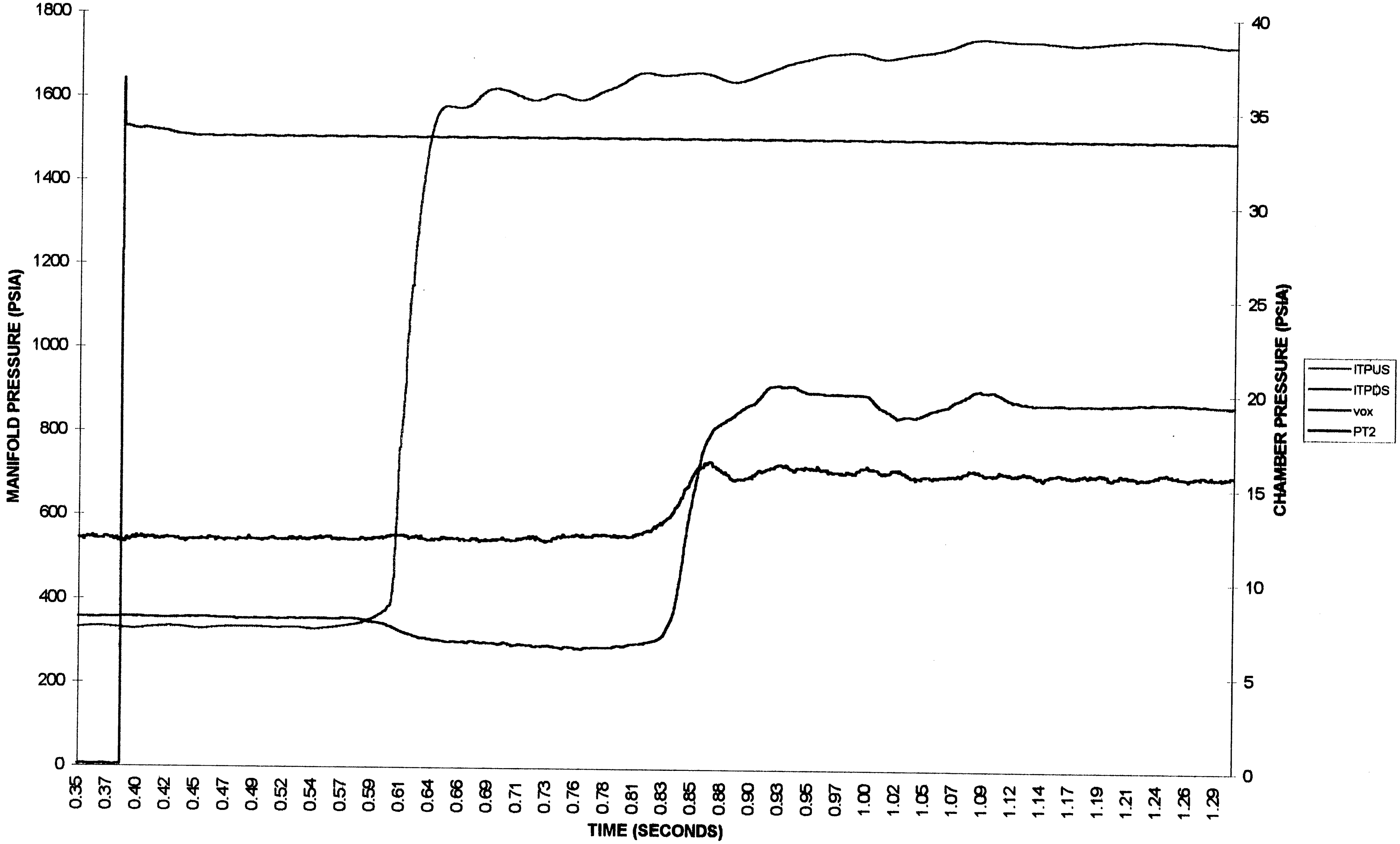


FIGURE - 33

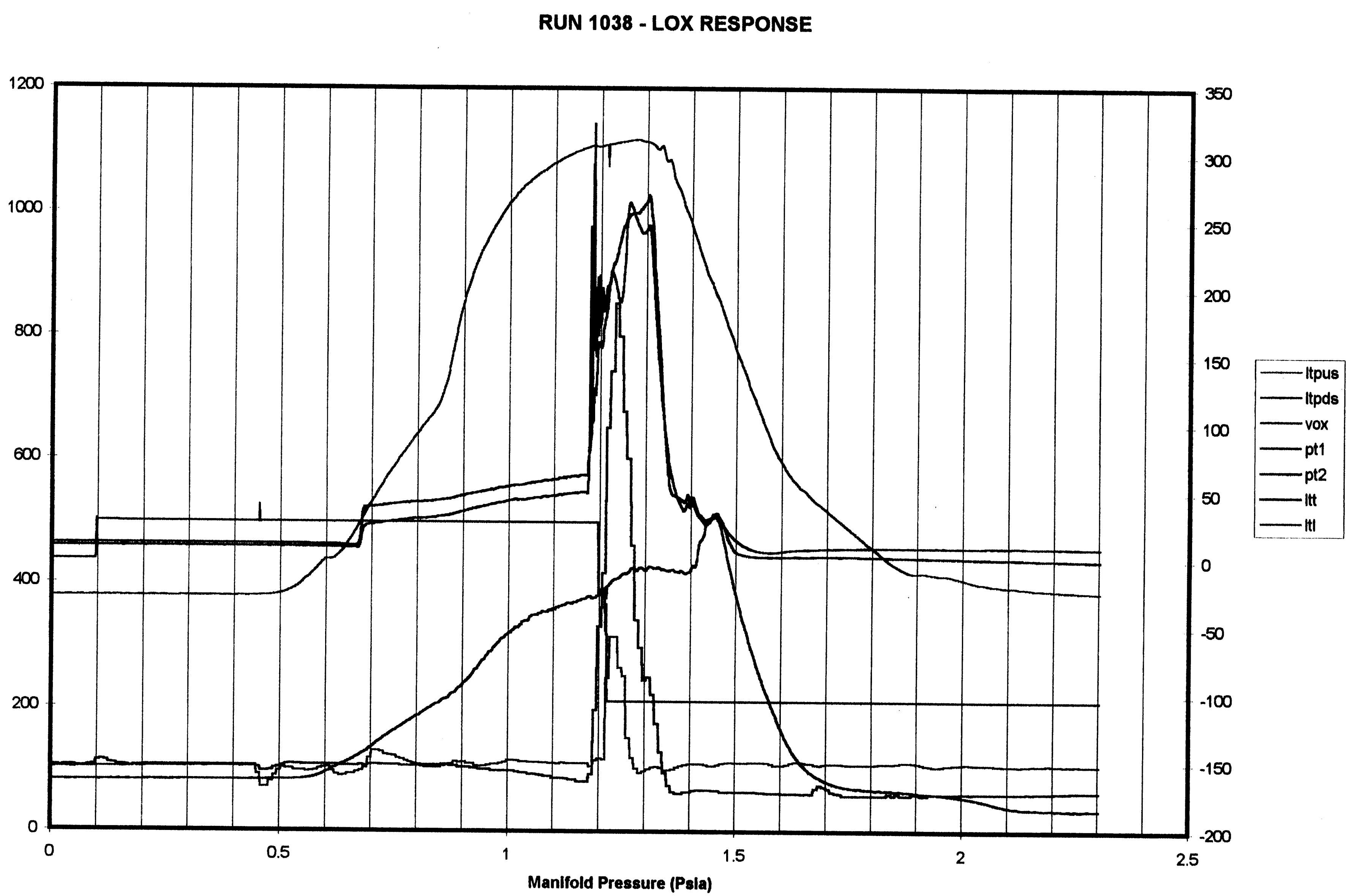
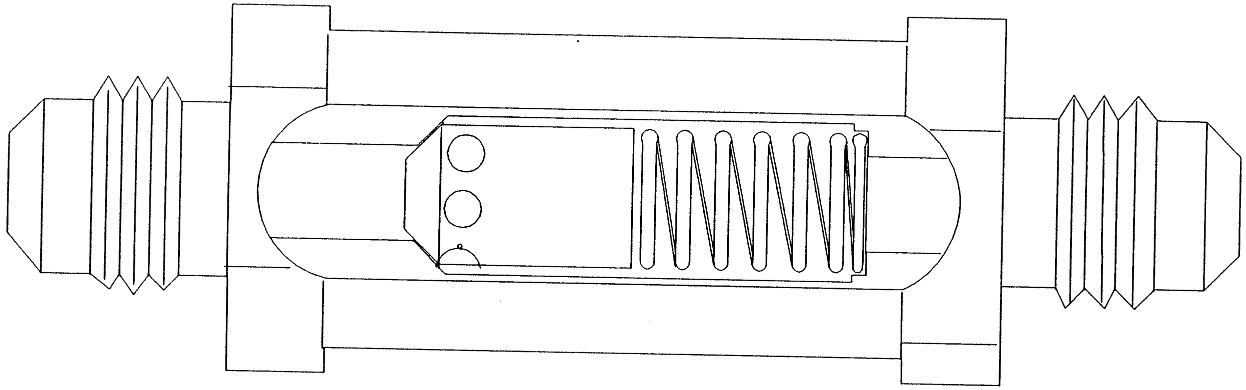

RUN 1038 - LOX RESPONSE
1200
1000
800
600
400
200
0
0
0.5
1
1.5
2
2.5
Manifold Pressure (Psia)
350
300
250
200
150
100
50
0
-50
-100
-150
-200
ltpus
ltpds
vox
pt1
pt2
ltt
ltl

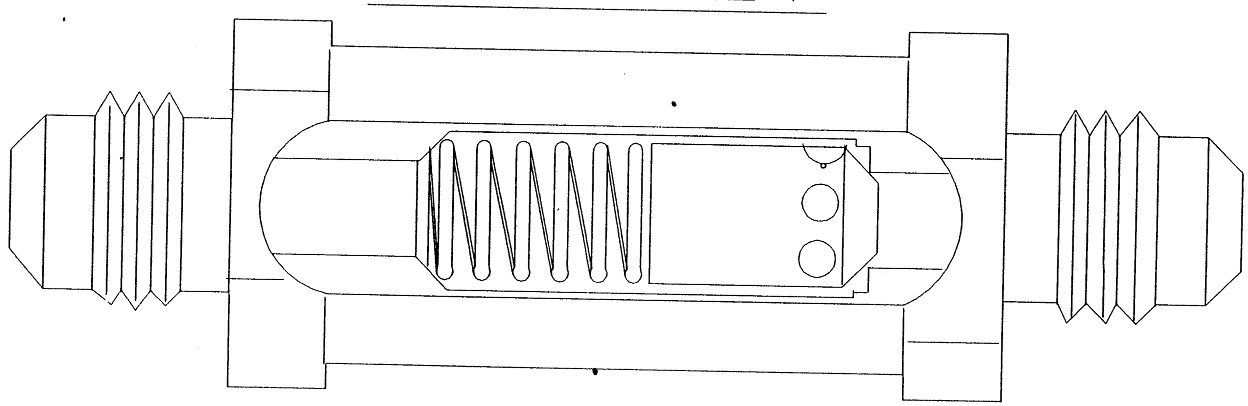
FIGURE- 34

SHOULD BE:



FLOW

"AS-BUILT"



FLOW

FIGURE 35

ATTACHMENT I

TEST READINESS REVIEW

RBCC CALORIMETER

TEST READINESS REVIEW

DATE: 05-19-97

TEST OBJECTIVES

- Experimentally Determine Heat Transfer Coefficients of the Combustion Chamber to Allow Greater Accuracy of Ejector Coolant Requirements
- Evaluate Ignition Characteristics to Establish Safe, Reliable Startup of Actual Hardware
- Validate Run Procedures - For Future Testing (Regen, Direct/Connect, Freejet)
- Demonstrate Injector Performance and Operation at Various Mixture Ratios (6,7,8,9)
- Verify Overall Performance and Minimum Required Chamber Length
- Demonstrate Reliable H_2/Air Ignitor System to Achieve Reliable Starts

TESTING METHODOLOGY

- √ Develop Test Plan, Test Matrix, and Facility Operating Requirements
- √ Develop Testing Procedures
- √ Develop Facility Operating Procedures
- √ Identify Critical System Characteristics
- √ Design, Layout, and Fabricate Test Setup
- √ Perform Hardware Functional Testing
- √ Perform System Checkout
- √ Experimentally Determine Critical System Characteristics (Waterflow, GH_2 Cold Flow, LOX Cold Flow)
- Perform Testing "Dry Runs" for Procedure/System Familiarity
- Perform Actual Testing

SEQUENCE OF TESTING

√ WATERFLOW CHECKOUT
  - Validate Coolant System Operation
  - Determine Data Reduction Program Acceptability

√ IGNITOR CHECKOUT
  -Verify Operability and Performance
  -Determine System Lags

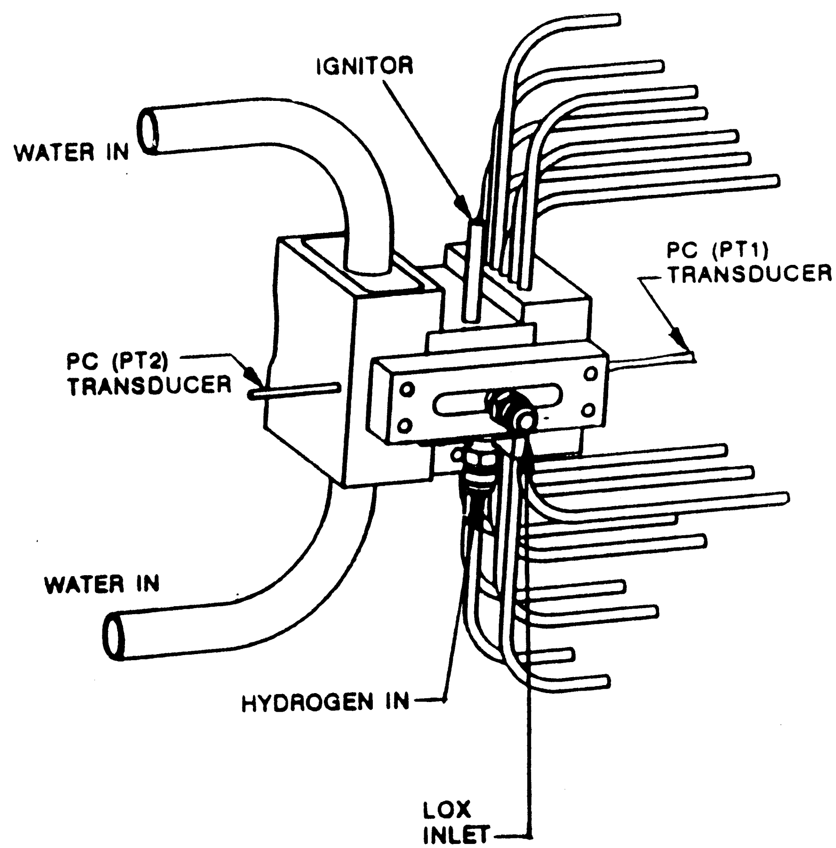
√ GH2 COLD FLOW RESPONSE CHECK
  - Validate Controls Operability and Final System Proof
  - Characterize System Response (Perform 3 Times for Repeatability)

√ LOX COLD FLOW RESPONSE CHECK

√ -Validate Controls Operability and Final System Proof
  -Characterize System Response & Fluid Quality (3 Times for Repeatability)

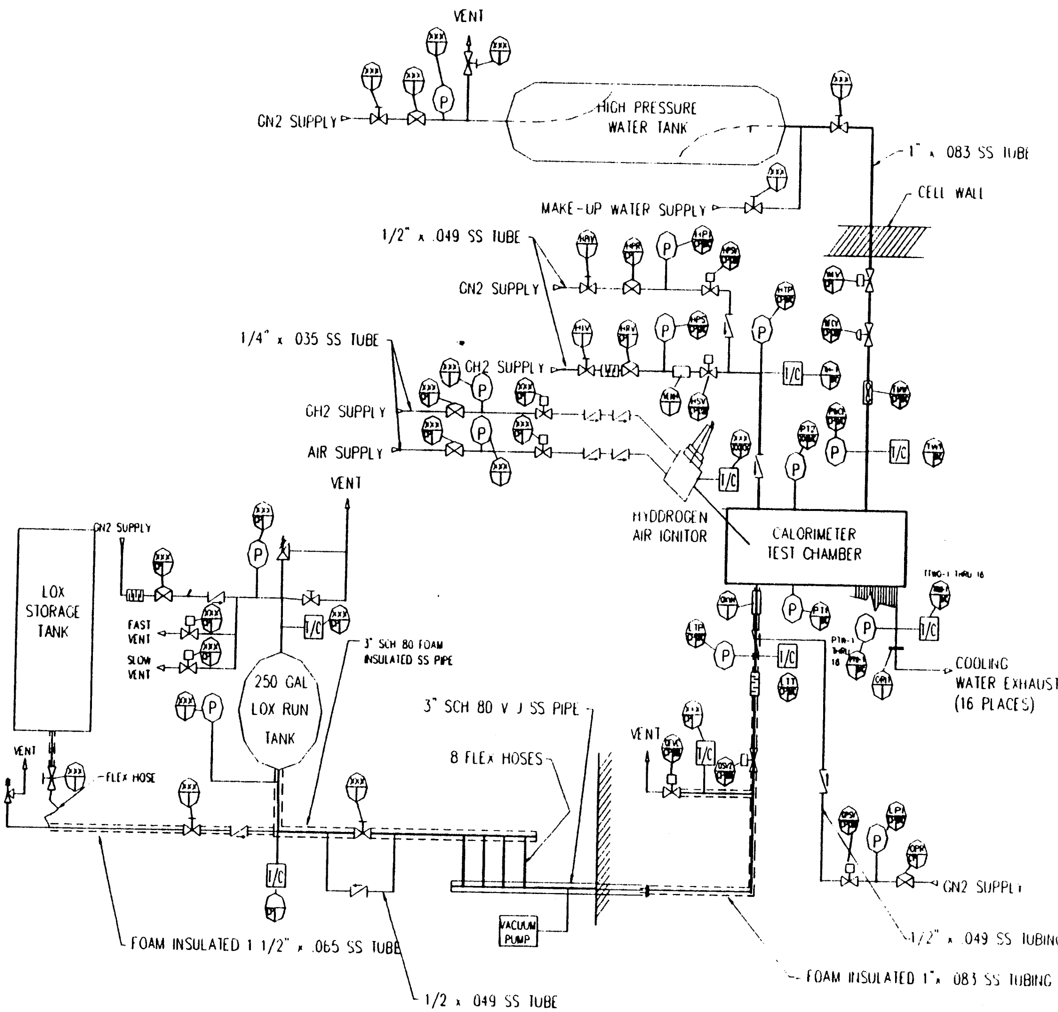
- DATA ANALYSIS & REVIEW, APPEND TEST PLAN FOR VALVE LEADTIMES & MODIFY TEST MATRIX AS REQUIRED
- PERFORM HOTFIRE TESTING

TEST HARDWARE



SYSTEM SCHEMATIC

PIPING AND INSTRUMENTATION DIAGRAM



TEST MATRIX
COLD FLOW

SYSTEM CHECK OUT	IGNITOR SYSTE		EJECTOR								COOLING WATER SYSTEM		GN2 PURGE SYSTEM	
	Air	GH2	GH2 SUPPLY			LOX SUPPL		CHAMBER PRESSURE		MIXTURE RATIO			LOX	GH2
	IAP	IHP	HPS	HTP	GH2 Flowrate	OPT	Flowrate	PT1	PT2		PWCI	FMW	LPI	HPI
	(Psia)	(Psia)	(Psia)	(Psia)	Lbm/sec	(Psia)	Lbm/sec	(Psia)	(Psia)		(Psia)	Lbm/sec	(Psia)	(Psia)
WATER FLOW CHECK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	TO BE DETER-MINED	>4.432	N/A	N/A
IGNITOR SYSTEM CHECK	100	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1500	>4.432	250	250
	200	200									1500	>4.432	250	250
	300	300									1500	>4.432	250	250
LOX COLD FLOW/ RESP.	N/A	N/A	N/A	N/A	N/A	1071	0.880	N/A	N/A	N/A	1500	>4.432	500	500
						1202	0.933				1500	>4.432	500	500
						1339	0.985				1500	>4.432	500	500
						1471	1.033				1500	>4.432	500	500
GH2 COLD FLOW/ RESP.	N/A	N/A	>1600	939	0.115	N/A	N/A	N/A	N/A	N/A	1500	>4.432	500	500
			>1600	1012	0.124						1500	>4.432	500	500
			>1600	1110	0.136						1500	>4.432	500	500
			>1600	1200	0.147						1500	>4.432	500	500

TEST MATRIX
HOT FIRE

Run Duration	IGNITOR SYSTEM		EJECTOR								COOLING WATER SYSTEM		GN2 PURGE SYSTE	
	Air	GH2	GH2 SUPPLY			LOX SUPPLY		CHAMBER PRESSUR		MIXTURE RATIO			LOX	GH2
	IAP	IHP	HPS	HTP	GH2 Flowrate	OPT	Flowrate	PT1	PT2		PWCI	FMW	LPI	HPI
(seconds)	(Psia)	(Psia)	(Psia)	(Psia)	(Ibm/sec)	(Psia)	(Ibm/sec)	(Psia)	(Psia)		(Psia)	(Ibm/sec	(Psia)	(Psia)
1	*	*	>1600	1200	0.147	1071	0.880	500	500	6	1500	>4.432	500	500
2	*	*	>1600	1200	0.147	1071	0.880	500	500	6	1500	>4.432	500	500
5	*	*	>1600	1200	0.147	1071	0.880	500	500	6	1500	>4.432	500	500
10	*	*	>1600	1200	0.147	1071	0.880	500	500	6	1500	>4.432	500	500
10	*	*	>1600	1200	0.147	1071	0.880	500	500	6	1500	>4.432	500	500
2	*	*	>1600	1110	0.130	1202	0.933	500	500	7	1500	>4.432	500	500
10	*	*	>1600	1110	0.130	1202	0.933	500	500	7	1500	>4.432	500	500
10	*	*	>1600	1110	0.130	1202	0.933	500	500	7	1500	>4.432	500	500
2	*	*	>1600	939	0.115	1471	1.033	500	500	9	1500	>4.432	500	500
10	*	*	>1600	939	0.115	1471	1.033	500	500	9	1500	>4.432	500	500
10	*	*	>1600	939	0.115	1471	1.033	500	500	9	1500	>4.432	500	500
2	*	*	>1600	1012	0.124	1339	0.985	500	500	8	1500	>4.432	500	500
10	*	*	>1600	1012	0.124	1339	0.985	500	500	8	1500	>4.432	500	500
10	*	*	>1600	1012	0.124	1339	0.985	500	500	8	1500	>4.432	500	500

SYSTEM SAFETY

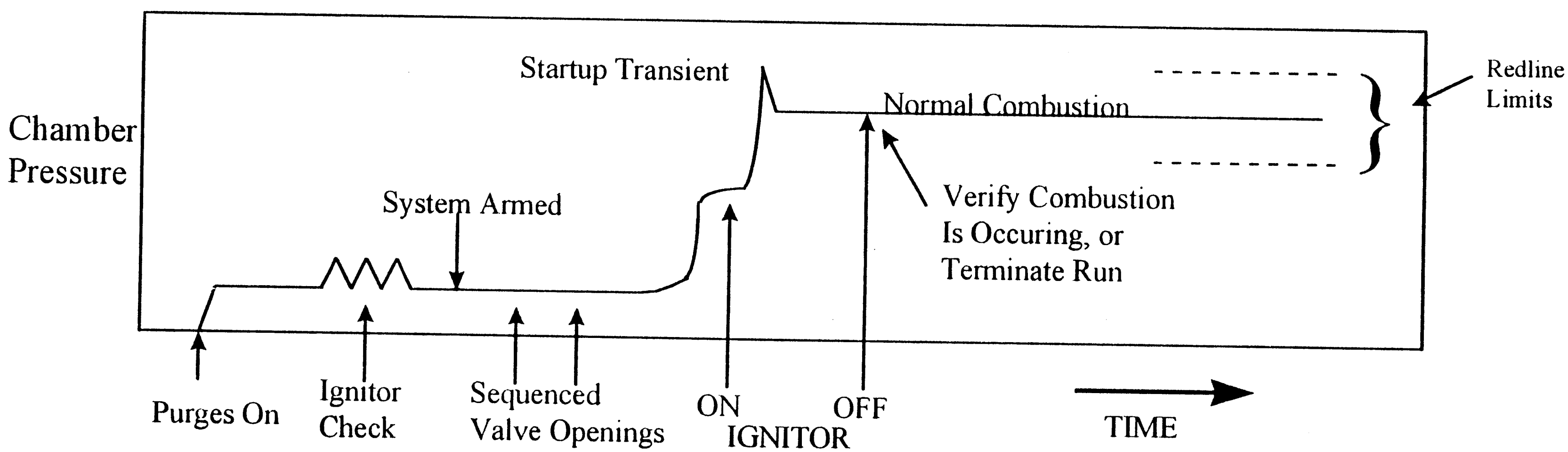
- Propellant Feed System GN_2 Purges are isolated by flow check valves, enabling instantaneous on-demand flow, thus reducing:
  - Eliminating Risk of Combustion in Manifolding
  - Controlled Startup and Shutdown Characteristics.
- Computer monitoring of critical parameters for red line limits, coupled with computer controlled propellant feed system to allow rapid shutdown of test.
- Exit flare to deflagrate any excess hydrogen to prevent accumulation in ducting.
- Large circulating airflow to ensure hydrogen levels are below the flammability limits.
- Visual Monitoring of Hardware During Testing

RUN PROCEDURE

- Chill Down Majority of LOX Feed System
- Load GH_2 System, and LOX Tank
- Verify Computer Controlled Valve Actuation Program is correct
- Set Required Cooling Water Flowrate
- Run LOX-side Flowcheck/System Chill-down
- Initiate LOX & GH_2 Purges
- Verify Ignitor Operation
- Initiate Flare
- Engage Data System, and Initiate Programmed Valve Actuation
- Once Test is completed, secure LOX system. Allow 10 minutes for cell purging, or secure facility if end of test day
- Inspect hardware and review data

STARTING SEQUENCE

- A final system checkout is performed with the valves controlled manually. Computer control is armed just prior to actual testing
- Experimentally determined feed system fill times are corrected by sequencing the valve actuations
- Engine firing must be within operating parameters once igniter is turned off, or run is automatically terminated



TEST PLANNING

- EACH RUN IS PERFORMED VIA A RUN DATA SHEET
- PROMOTES VISIBILITY OF TEST CONDITIONS
- ALLOWS EFFICIENT TRACKING OF TEST CONDITIONS
- PROVIDES QUICK REFERENCE FOR ALL PERSONNEL

TEST RUN DATA SHEET
RBCC CALORIMETER

RUN NO.________ RUN DATE:__________

RUN CONDITIONS:

LOX Venturi Pressure:__________psia LOX Tank Pressure:__________psia

H_2 Venturi Pressure: __________psia H_2 Supply Pressure:__________psia

Cooling Water Flow: __________lb/sec Water Tank Pressure:__________psia

N_2 Purge Pressure (LOX):__________psia N_2 Purge Pressure (H_2):__________psia

H_2/Air Ignitor Pressure
Air __________psig
H_2__________psig

Exhauster required? ____yes ____no

Exhaust Torch Pressure
Air __________psig
H_2__________psig

H2, LOX, Ignitor Timing (0 time is start of startup or shutdown)
Startup: LOX on ______sec
H2 on ______sec
Ignitor on ______sec
Ignitor off ______sec

Shutdown: LOX off ______sec
H2 off ______sec

Ignitor Operating Cycle: _____ms on, ______ms Off (repeating cycle)
Chamber Burn Duration:______sec

Operating Shut Down Limits:
Water out temp. (16 places) >___F Water flow <____ lb/sec
Water out press.(16 places) <___ psia
Chamber Press.(after ignitor off) ___<Pt1<___ psia

RUN DESCRIPTION:______________________________

APPROVALS:

Engineering	Operations	Project
J. Mays	B.R. Ellis	R. Wieveg

H:\MSWORD\Testsht.doc

R Wieveg

ATTACHMENT II

CALORIMETER INJECTOR PLATE - STRESS ANALYSIS

KAISER MARQUARDT
INTEROFFICE MEMORANDUM

June 16, 1997
file: inj3.1

TO: R. Wieveg

FROM: A. Runyon

SUBJECT: RBCC - CALORIMETER INJECTOR PLATE - STRESS ANALYSIS RECOMMENDED PROOF PRESSURE & STRESS IN LIGAMENT BETWEEN INLET AND OUTLET PLENUMS

COPIES: T. Chen, D. Lucci, S. Bartlett, R. Humphrey

REFERENCES :

1. IOM to R. Wieveg from A. Runyon, RBCC- CALORIMETER INJECTOR PLATE - STRESS ANALAYSIS., Jan. 14, 1997.

INTRODUCTION :

The stress analysis of Reference 1 was reviewed and modified in the light of certain problems with the copper Injector X42801A of the Calorimeter. The following tasks were addressed. The Injector is shown in Figure 1.

TASK 1. Considering that the Injector yielded excessively at a proof pressure of 1,000 psi, what should be the revised Proof pressure ?

TASK 2. Check the ligament between the inlet and outlet plenums. What magnitude stress causes failure across the section?

DISCUSSION AND RESULTS :

TASK 1 :

The stress model of the Injector from Ref. 1 was revised to conservatively account for the .082 inch diamete holes which were previously ignored. The reduced section properties are dated "6-13-97" in Figure 2: the dimensions are shown in Figure 3. Plots of the old and revised bending moments of inertia are shown in Figure 4. Figure 5 shows the stress vs. strain curve of OFHC copper at 70 degrees F.

The results for two pressures are shown below:

FIGURE 5	PRESSURE (PSI)	STRESS (PSI)	DEFLECTION (INCH)	STRAIN (IN/IN)
POINT A	1,000	9,875	.0015	PLASTIC RANGE
POINT B	700	6,913	.0011	.00038

It is seen from the stress versus strain curve that 1000 psi pressure will cause plastic straining up to .010 in/inch. This is excessive and should be reduced to 700 psi which will keep the stress in the elastic range of the copper material.

The recommended proof pressure is 700 psig.

TASK 2 :

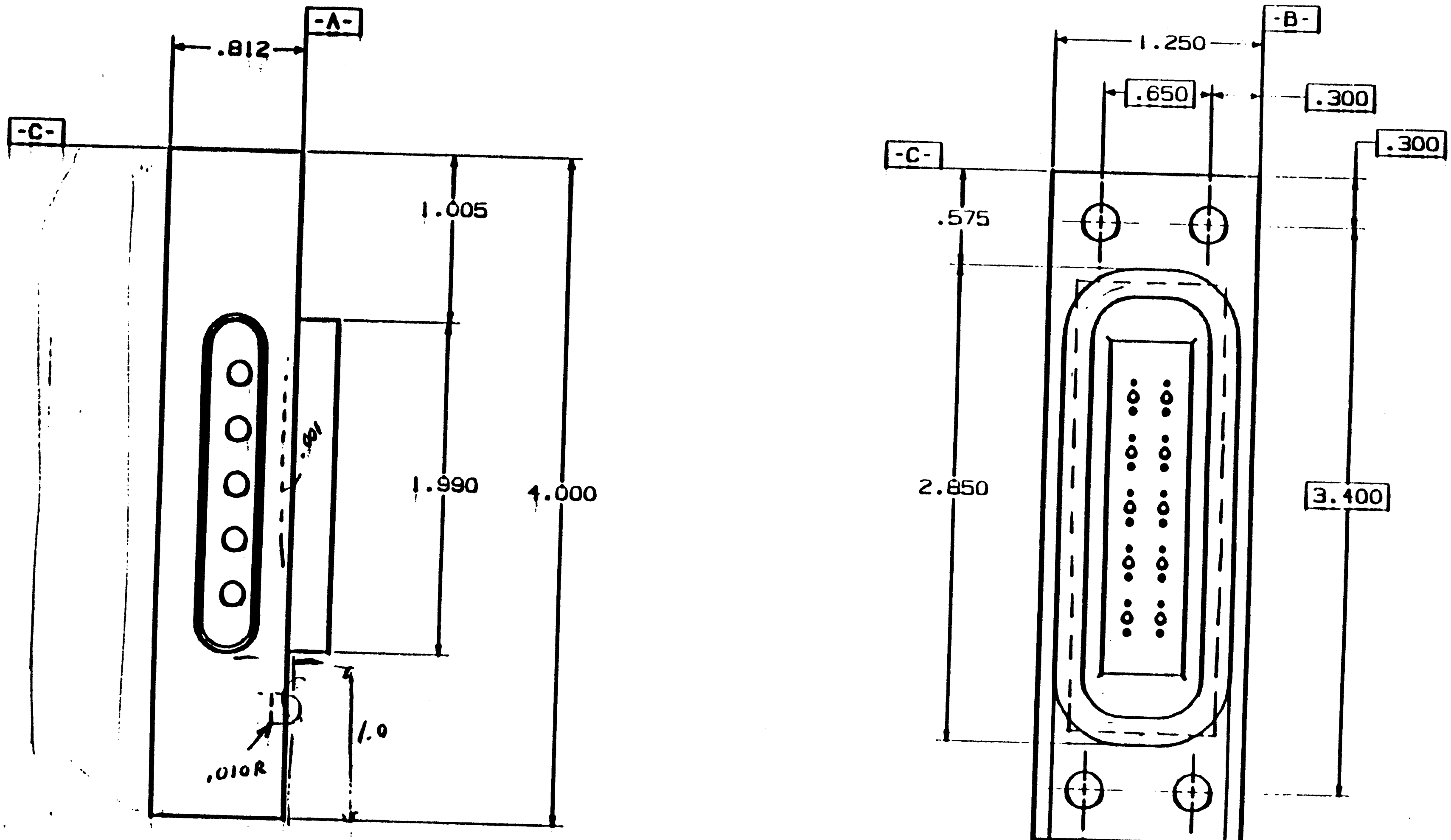
The finite element model shown in Figure 6 was used to assess the probability of a failure across the ligament caused by pressurization alone. The results for maximum stress in the ligament are as follows for three cases at 1000 psi pressure.

CASE	PRESSURIZED REGIONS	MAX STRESS (PSI)	ULTIMATE STRENGTH AT 70 DEGREES F (PSI)
A	PLENUMS 1, 2 AND HOLES	7,880	15,000
B	PLENUM 1 ONLY	6,845	15,000
C	PLENUM 2 ONLY	5,420	15,000

Reviewing the above numbers shows no reason to believe that excessive stress is the cause of failure.

The pressure to cause failure is estimated as

$$(15,000 / 7,880)*(1000) = 1900 \text{ psig}$$



1 x 2.85

FIGURE 1

copper
p = 500 psi operating
70-120°F

1/1 scale

p3 Ph

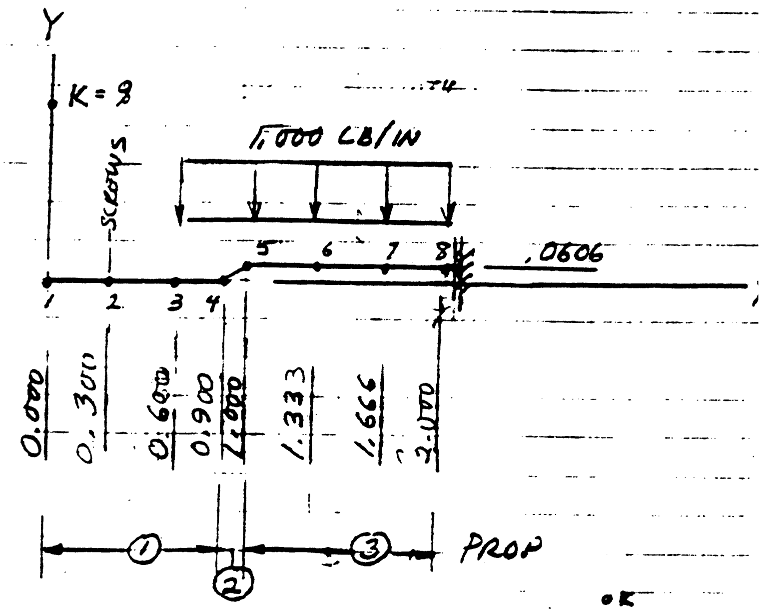
INJECTOR PLATE model. 2

COPPER

LOADING

$w = 1{,}000(1.0)$
$= 1{,}000$ LB/IN

$E = 17.0E6$ PSI
$\nu = .3$

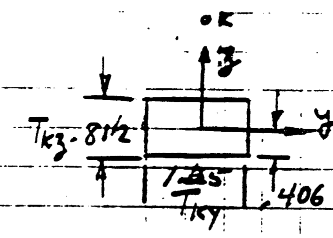


SECTION ①

$A = 1.25(.812)$
$= 1.015\ IN^2$

$I_y = \frac{1.25(.812)^3}{12} = .0558\ IN^4$

$I_z = \frac{.812(1.25)^3}{12} = .1322\ IN^4$



LOADING ON NODES.

NODE			
3	$F_Y = -1000\,(.15) =$		150.0
4	=	(.15+.05) =	200.0
5	=	(.05+.1665) =	216.5
6	=	(.333) =	333.0
7	=	(.333) =	334.0
8	=	(.1665) =	166.5
			1400.0 Per ½ model

2800 TOTAL

ANSYS STIF4 INPUT

PROP	A 1	I_{ZZ} 2	I_{YY} 3	TKZ 4	TKY 5	I_{XX} 8	$S_{HZ}; S_{HY}$ 9; 10	I_y/c
1	1.015	.1322	.0558	.812	1.250	.188	1.2; .62	.1374
2	0.878	.1120	.0447	.843	1.326	.157	↓ ↓	.1061
3	0.957	.1149	.0783	1.181	1.315	.193	↓ ↓	.1326
3	0.834	.1135	.0661	1.181	1.315	.131	↓ ↓	.1119
4	0.896	.1135	.0554	1.012	1.321	.126	↓ ↓	.1095

1-14-97
6-13-97
1,2 Same as Before

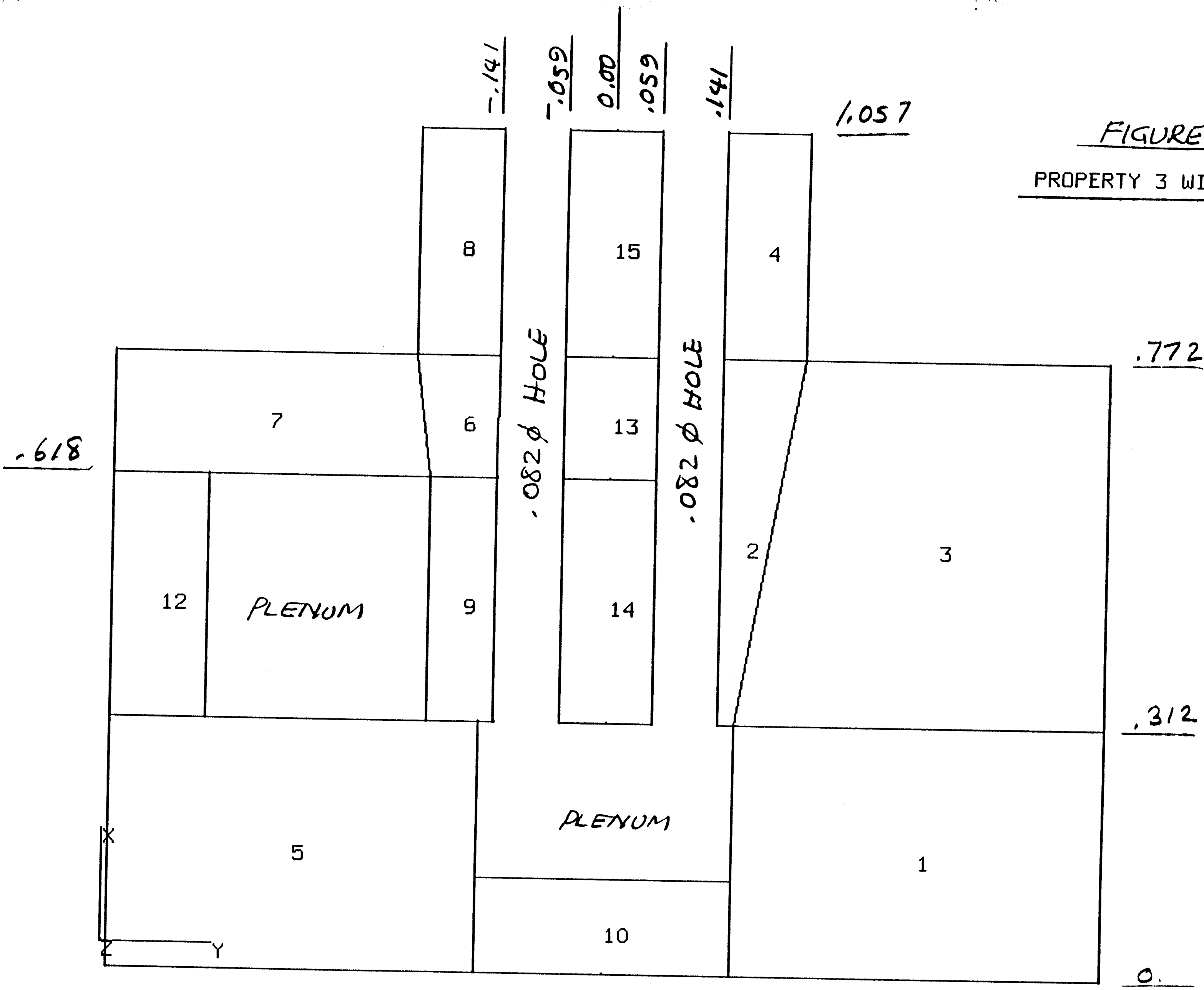


FIGURE 4

PROPERTY 3 WITH HOLES

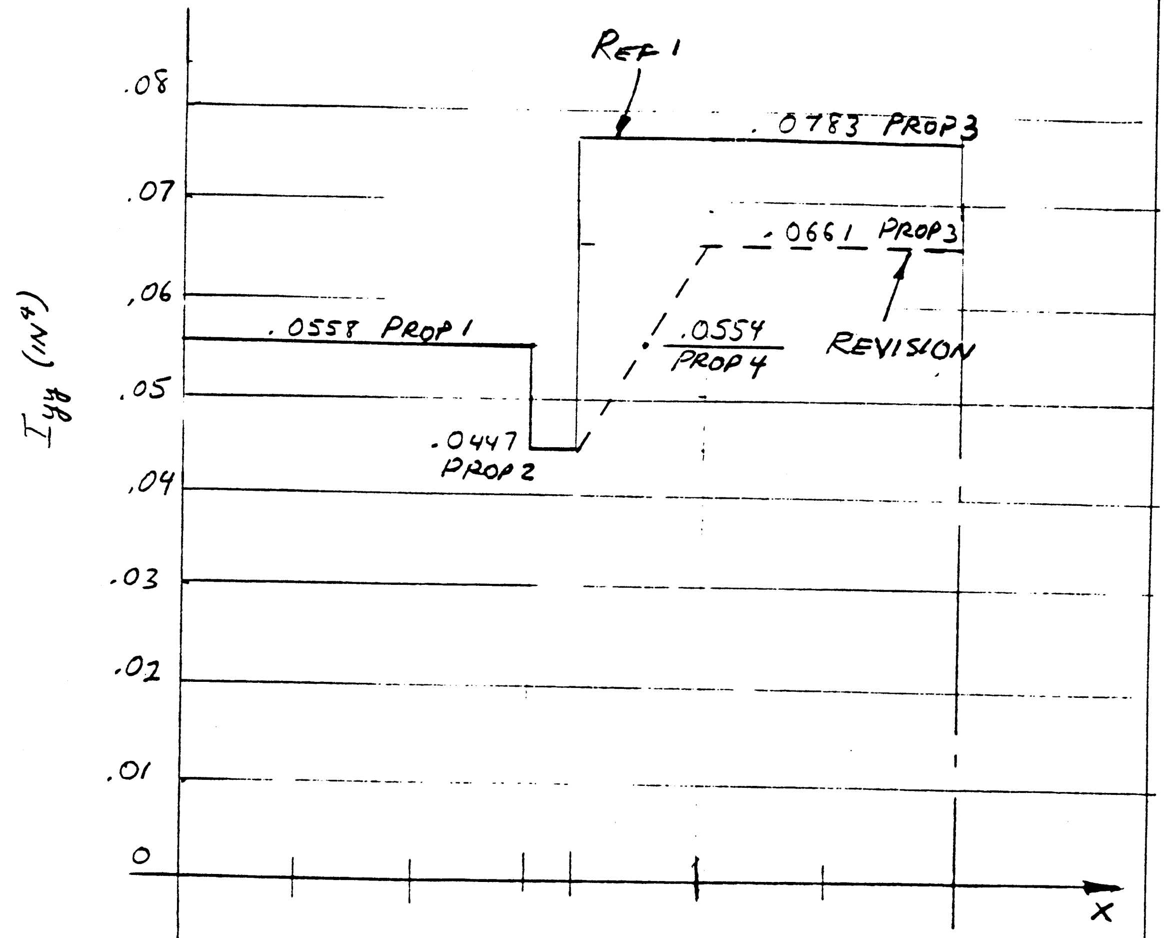
FIGURE 3

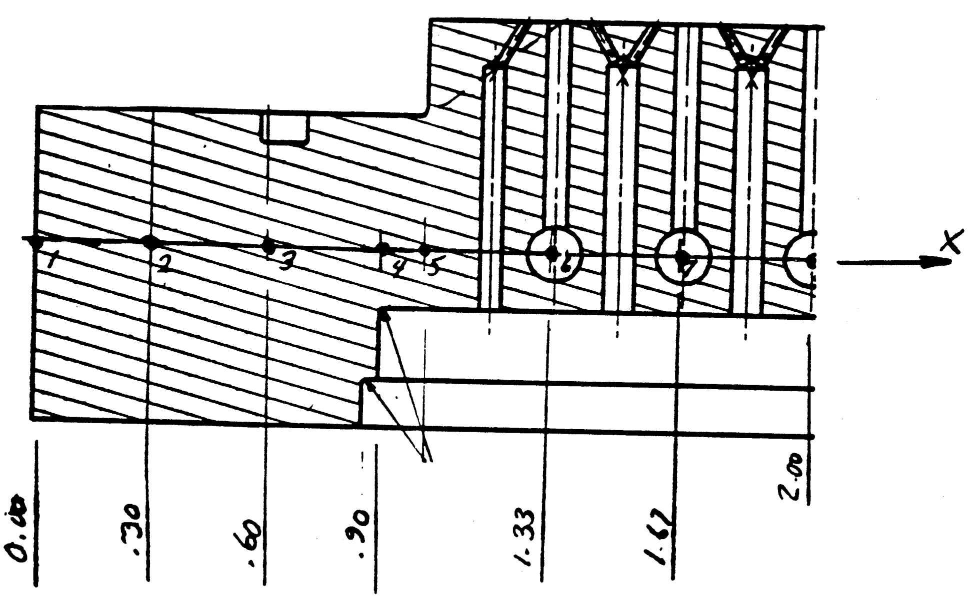
∅5

FIGURE 4

INJECTOR PLATE

BENDING MOMENT OF INERTIA





p7

FIGURE 5

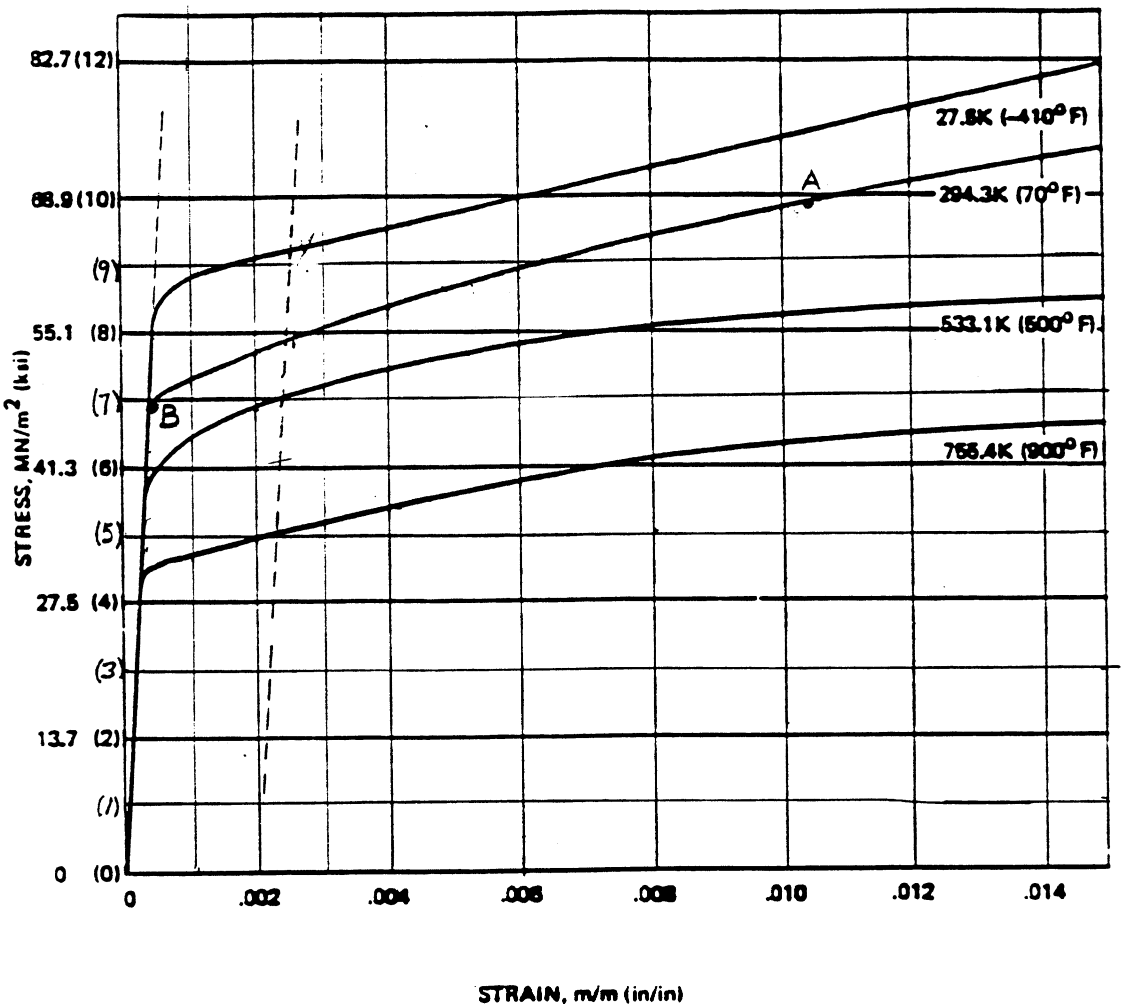


Figure 26 Typical Stress-Strain Curves for OFHC Copper Annealed Condition

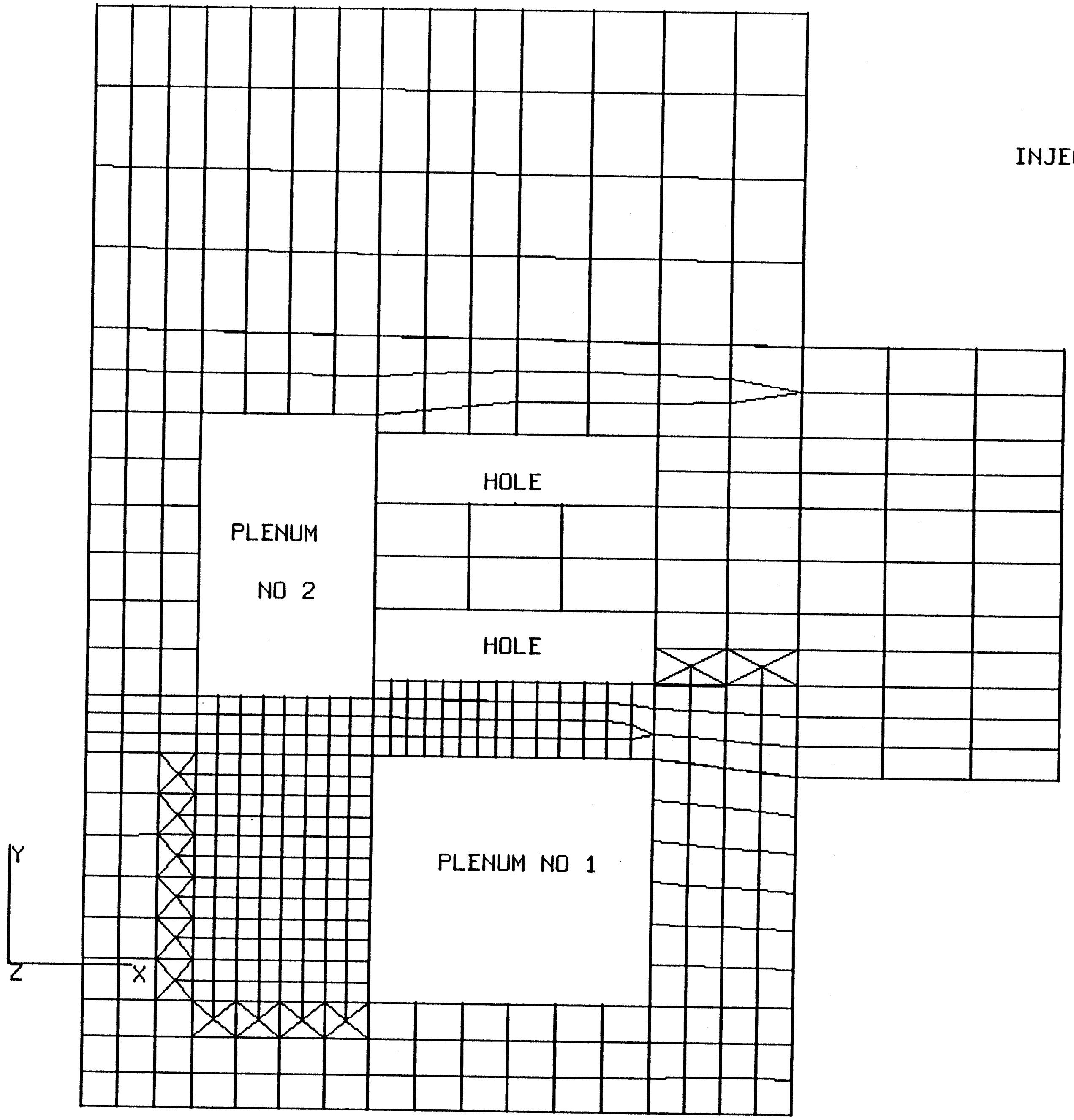


FIGURE 6

INJECTOR CROSS-SECTION

ATTACHMENT III

CALORIMETER FAILURE ANALYSIS BY RON COOK

RBCC
CALORIMETER
FAILURE ANALYSIS

HOT FIRE TEST #R1038

Ron Cook

June 11, 1997

FAILURE MODE

- Cause of Failure
  - LOX in Injector and Facility H_2 Feed System
- Failure Triggered by: (Sequence of Events)
  - Delayed Ignition (by ~ 300 msec)
  - Resulted in Combustor Hard Start
  - High Temperature Combustion Gases Driven into LOX and GH_2 Feed Systems
  - Ignition of LOX/H_2 Mixture in H_2 Feed System
  - Burn-Out of Injector H_2 Feed Tube
  - Major LOX Fire Vaporizes Injector Material Leaving No Traceability of Which Came First

SCENARIO
Ways of Transfering LOX into H_2 System

- Injector Inter-Propellant Leak
- Malfunction of LOX GN_2 Purge Check Valve
  - Failed-OPEN During Start Transient and Mainstage
- Malfunction of GH_2 GN_2 Purge Check Valve
  - Failed-CLOSED During Pre-Test LOX Blowdown (Bleed Through Injector)

ANALYSIS APPROACH

- Review Facility Flow & Instrumentation Schematic
- Review Hot Fire Test Data
  - Indentify Sequence of Events
  - Discuss Pressure & Temperature Levels and Activities
- Review LOX and GH2 Blowdown Data (run # R1003, -4, -5)
  - Discuss Pressure Profiles and Valve Sequencing
- Compare LOX Blowdown Data and Hot Fire Data
  - Point Out Significant Differences
  - Identify Scenario for These Differences
- Define Which Ways are Amenable to Transfer LOX into H2 System
  - Based on Hot Fire Data
- Conclusion
- Recommendations

BLOWDOWN DATA & ANOMALIES

- Hydrogen
  - Crisp & Responsible (as would be expected), P-venturi = 1,700 psi
  - High Run Valve ΔP - H2 Venturi Barely Choked
    - H2 Choked Across Run Valve but Venturi Controls H2 Flowrate)
- Oxygen
  - Run R1004
    - Crisp & Responsive - Good LOX Quality
    - Purge GN2 Pressure Locked-up at 370 psig
    - Very High Injector ΔP = 900 psi
  - Run R1003
    - Crisp & Responsive - Fair LOX Quality (Gas Bubble in System), P-venturi = 1,500 psi
    - Purge GN2 Pressure Locked-up at 370 psig
    - Very High Injector ΔP = 800 psi

LOX BLOWDOWN DATA ANALYSIS

- PROBLEM
  - ΔP Injector ~ 5X Higher Than Expected for LOX Flow Rate Based on Venturi Flowrate for Hot Fire Venturi Throat Area

- CONCLUSION
  - LOX Venturi Throat Area > 2X A* for Hot Fire Test Based on Injector ΔP and Crisp vs. Sluggish Start on Hot Fire Test
    - Good vs. Poor Quality LOX
  - LOX Mass Flow for LOX Blowdown is 2.5 to 3 X of LOX Flow Rate during Hot Fire

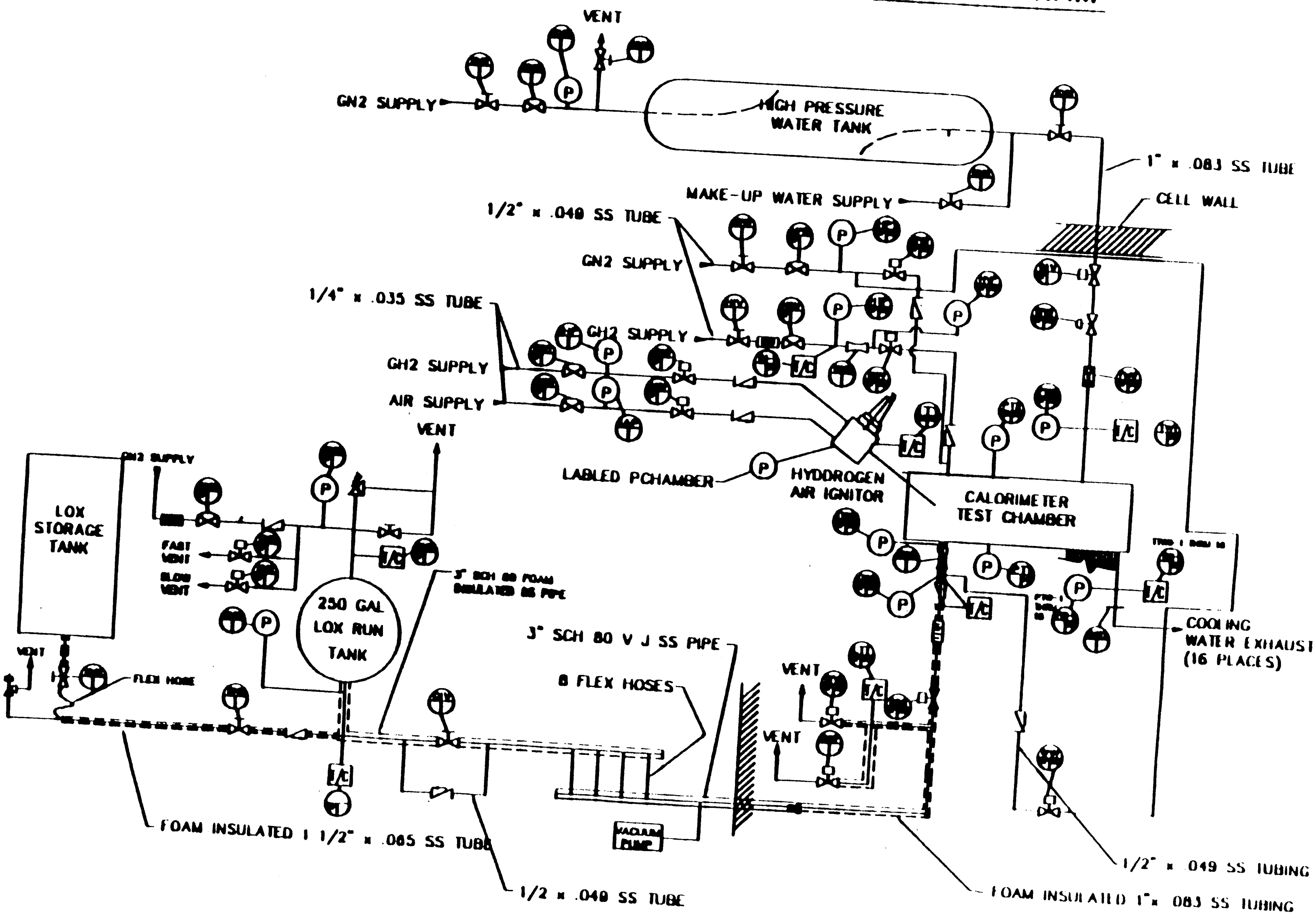
COMPARISON OF LOX GN2 PURGES (LOX Blowdown vs. Hot Fire)

- HOT FIRE DATA
  - P venturi = 370 psig
  - P injector = 80 psig
- LOW BLOWDOWN
  - P venturi = 370 psig
  - P injector = 370 psig
- CONCLUSION
  - GN2 Purge Plumbed Downstream of Venturi for LOX Blowdown
  - GN2 Purge Plumbed Upstream of Venturi for Hot Fire Test

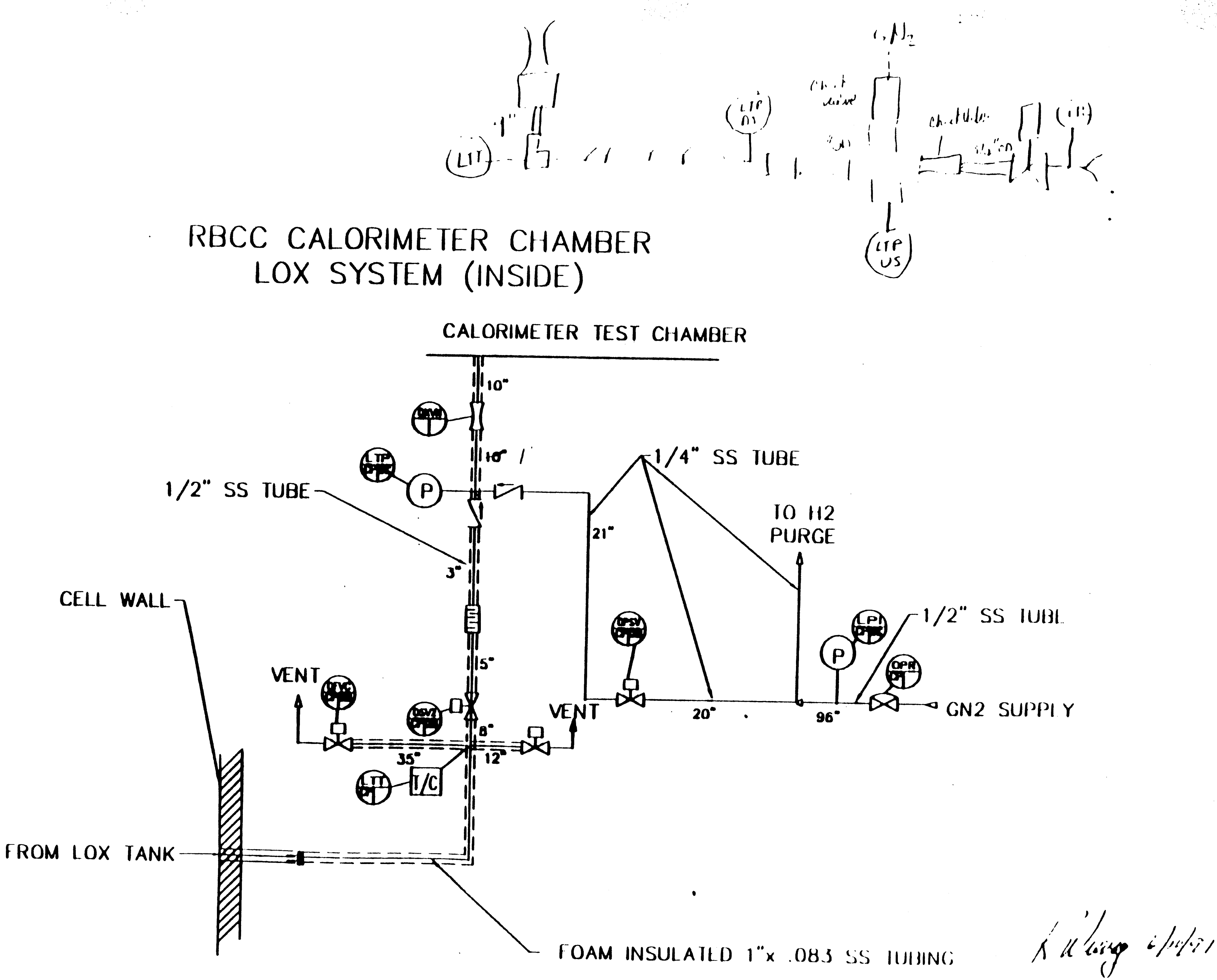
FAILURE MODE
SCENARIO
Analysis of Transferring LOX into GH2 System

- INJECTOR INTERPROPELLANT LEAK
  - LOX Can Not be Transferred to H2 System Since LOX Injection Pressure Never Exceeds H2 Injection Pressure
- MALFUNCTION OF LOX GN2 PURGE CHECK VALVE
  - Enormous ΔP available to transfer LOX into H2 System
- MALFUNCTION OF GH2 GN2 PURGE CHECK VALVE
  - Pc with Purges ON (pre-test) Reflects both LOX and GH2 Purges Working Normal
- **CONCLUSION**
  - LOX was Transferred to the GH2 System by Malfunction of LOX GN2 Check Valve.

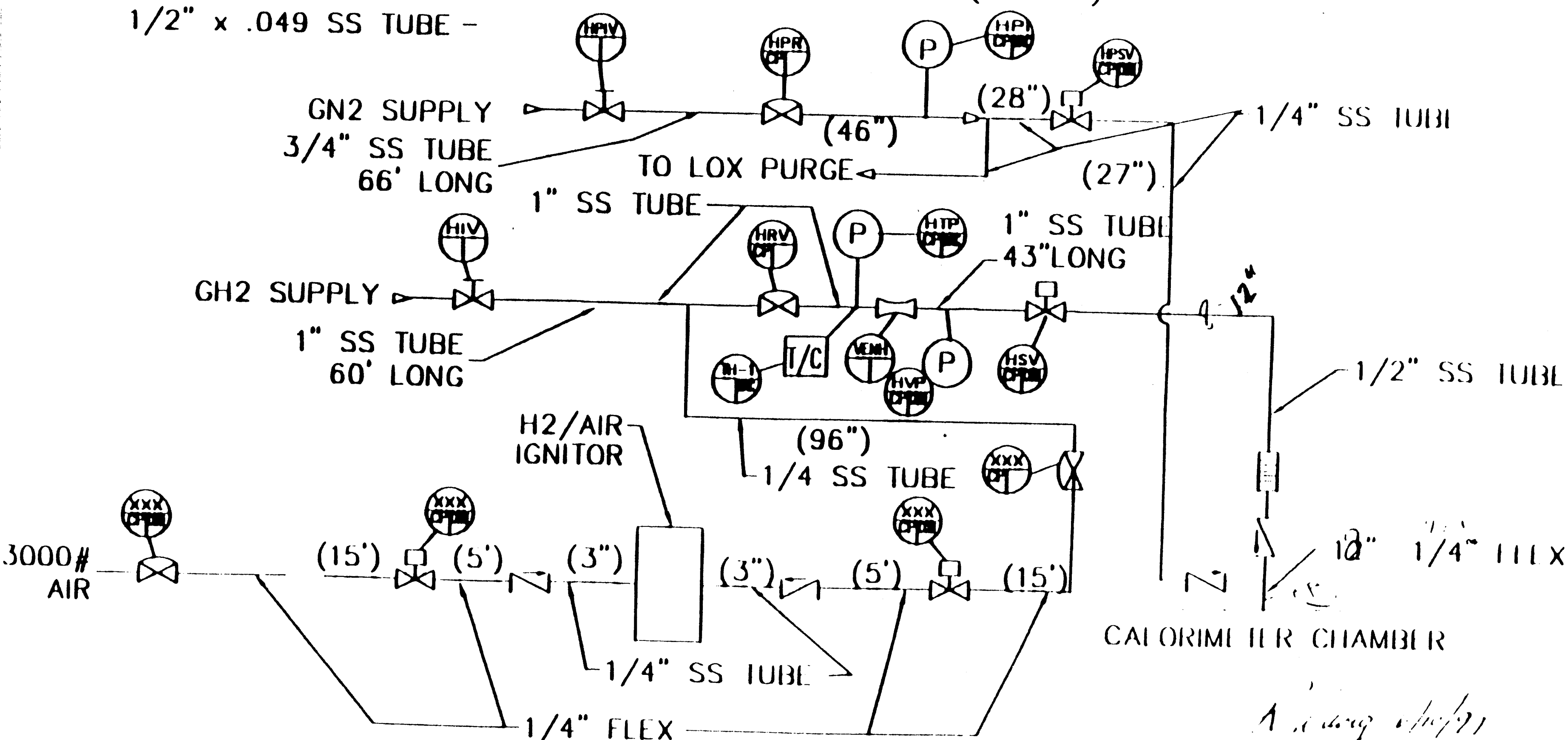
CALORIMETER TEST SET UP
PIPING AND INSTRUMENTATION DIAGRAM

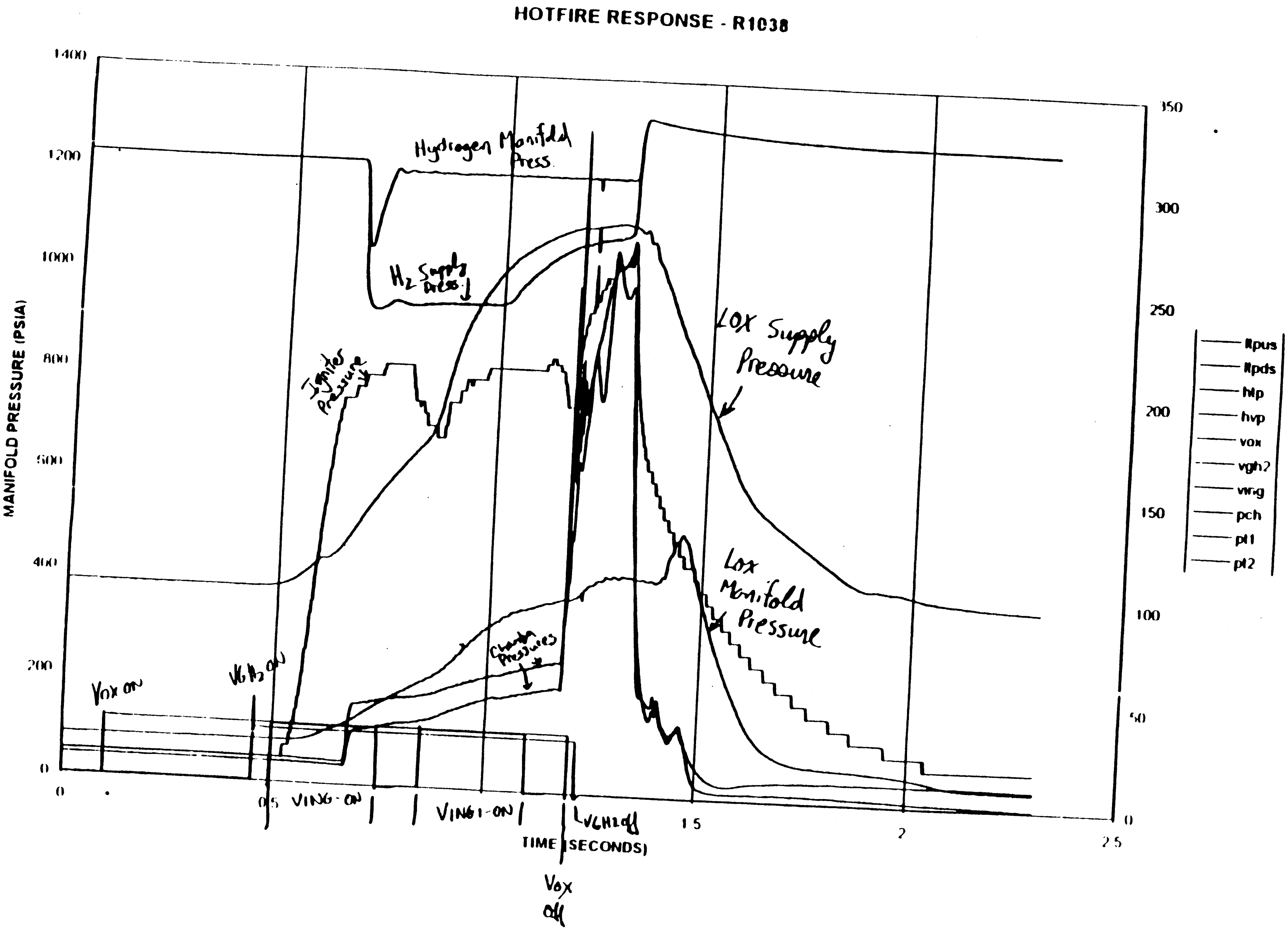


RBCC CALORIMETER CHAMBER
LOX SYSTEM (INSIDE)

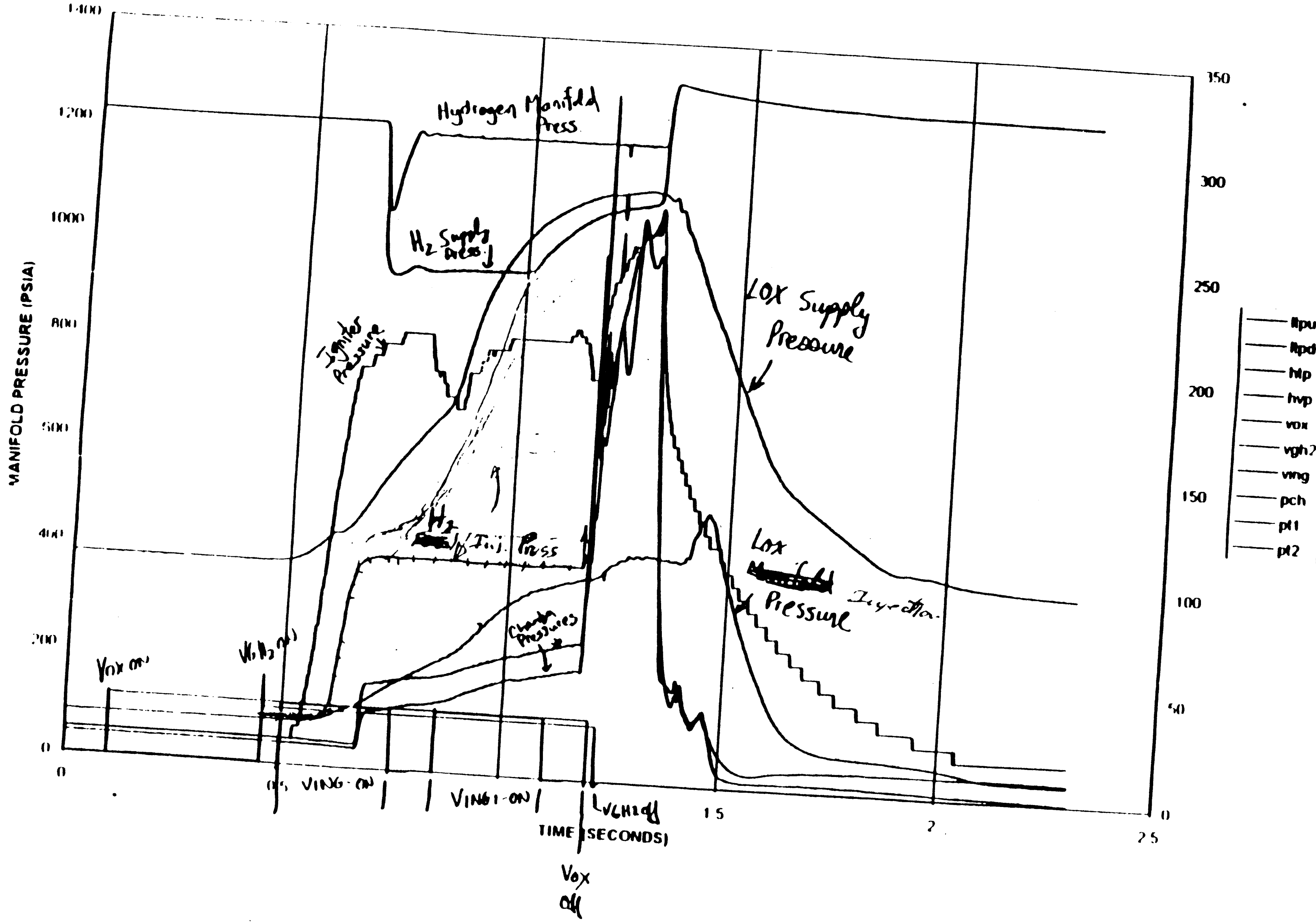


RBCC CALORIMETER CHAMBER
HYDROGEN SYSTEM (FUEL)

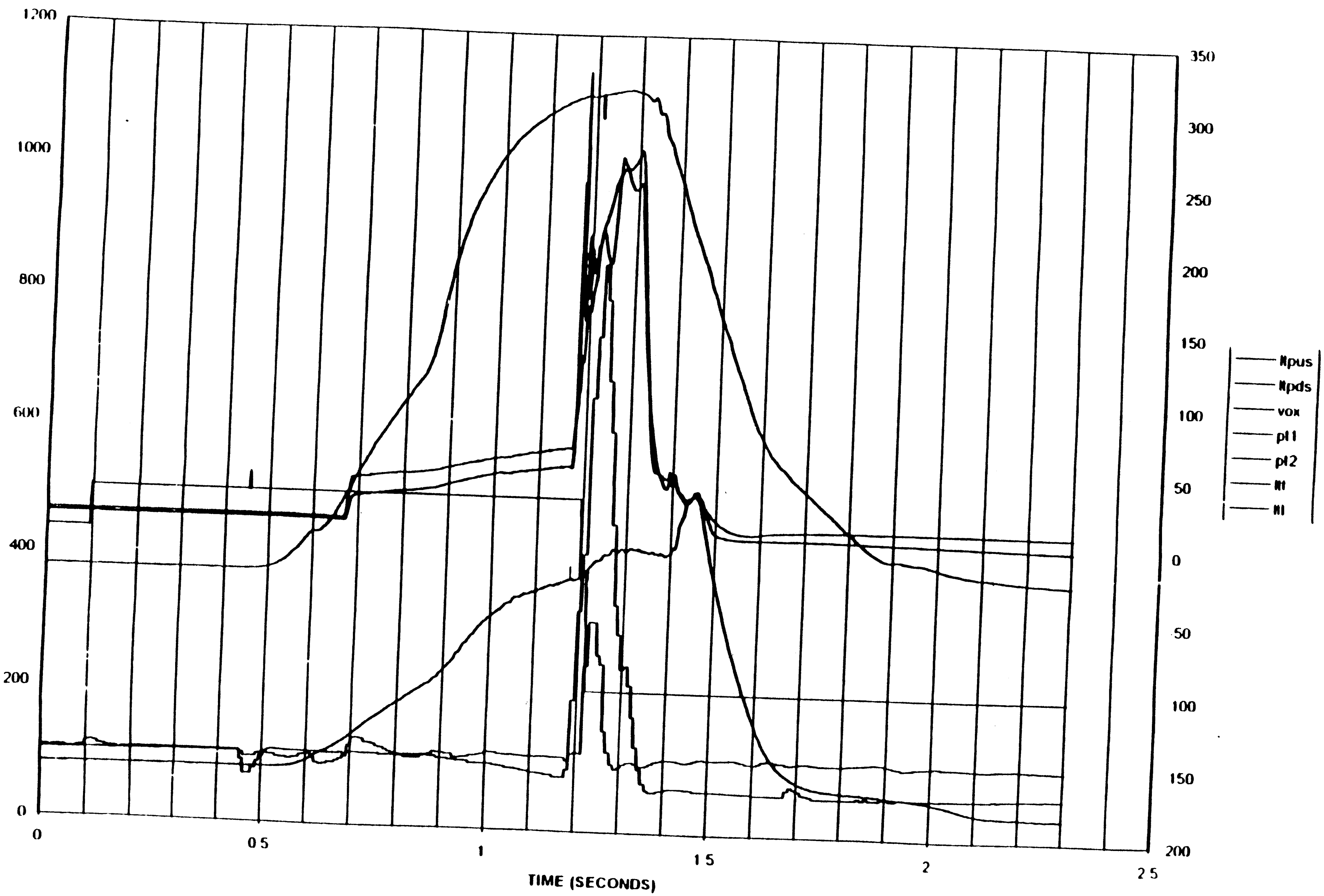



HOTFIRE RESPONSE - R1038
MANIFOLD PRESSURE (PSIA)
1400
1200
1000
800
600
400
200
0
350
300
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
TIME (SECONDS)
llpus
llpds
hlp
hvp
vox
vgh2
ving
pch
pl1
pl2
Hydrogen Manifold Press.
H2 Supply Press.
Igniter Pressure
LOX Supply Pressure
Lox Manifold Pressure
Chamber Pressures
Vox on
VGH2 on
VING-ON
VING1-ON
VGH2 off
Vox off

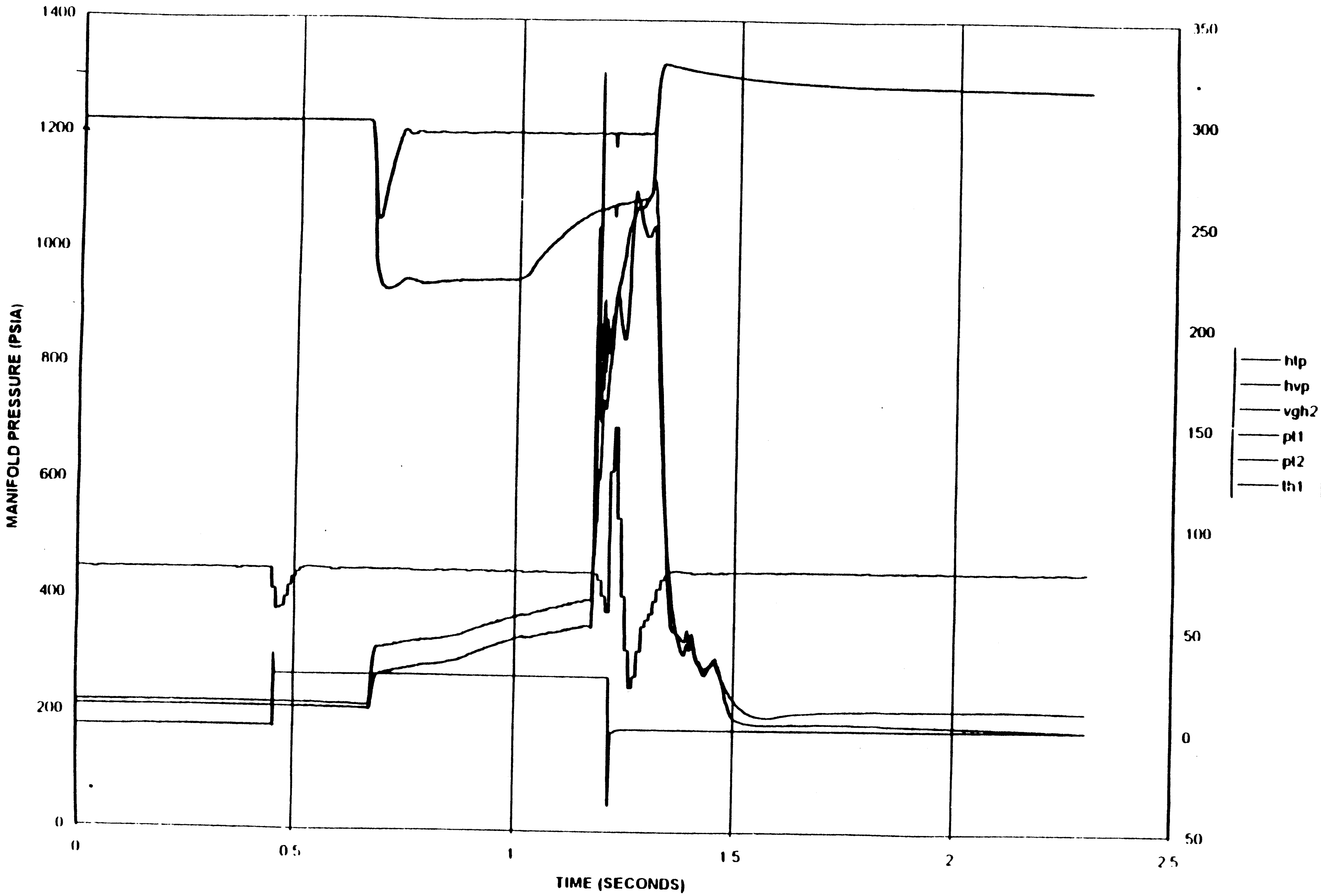
HOTFIRE RESPONSE - R1038



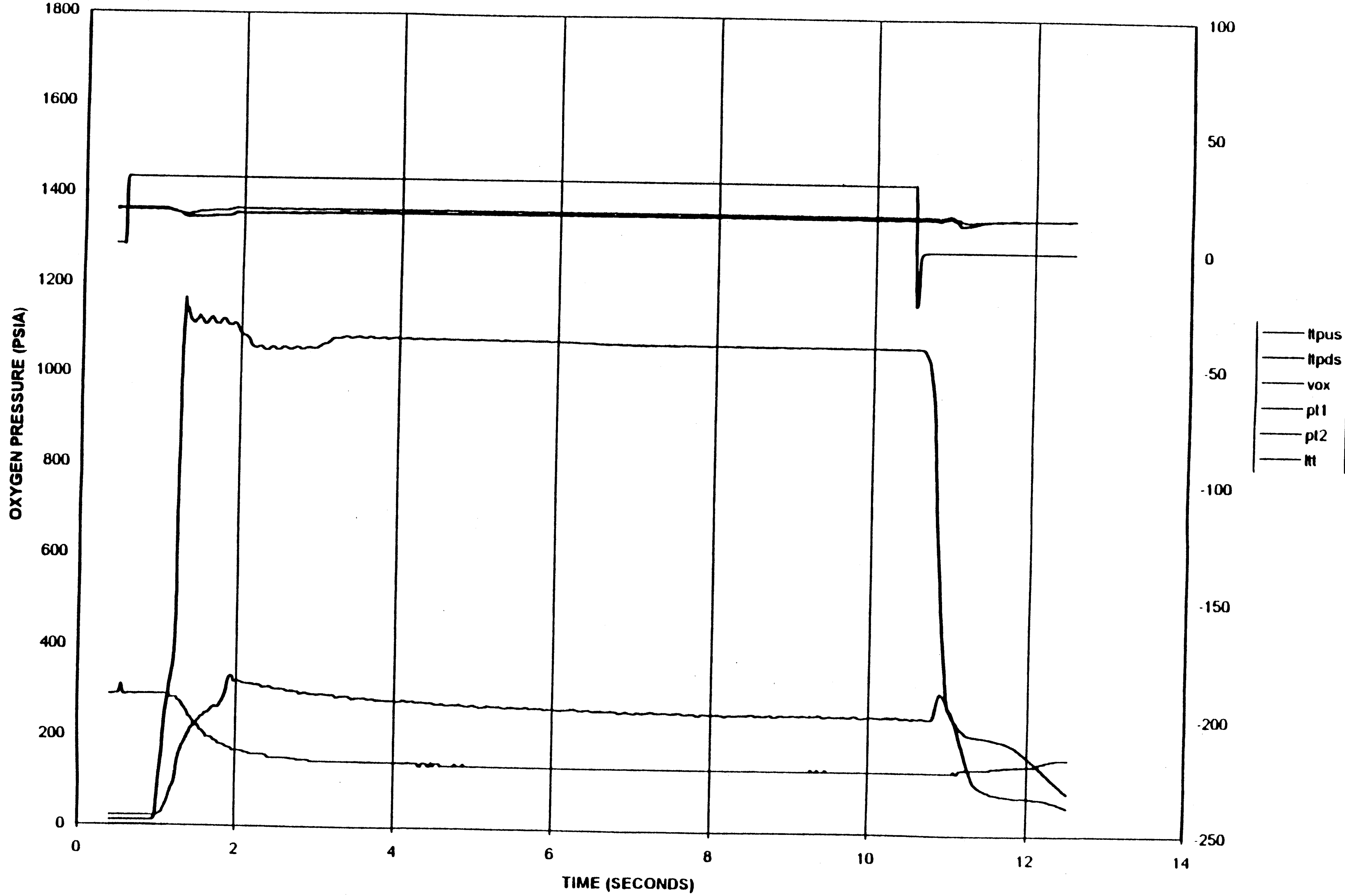
LOX DATA - R1038



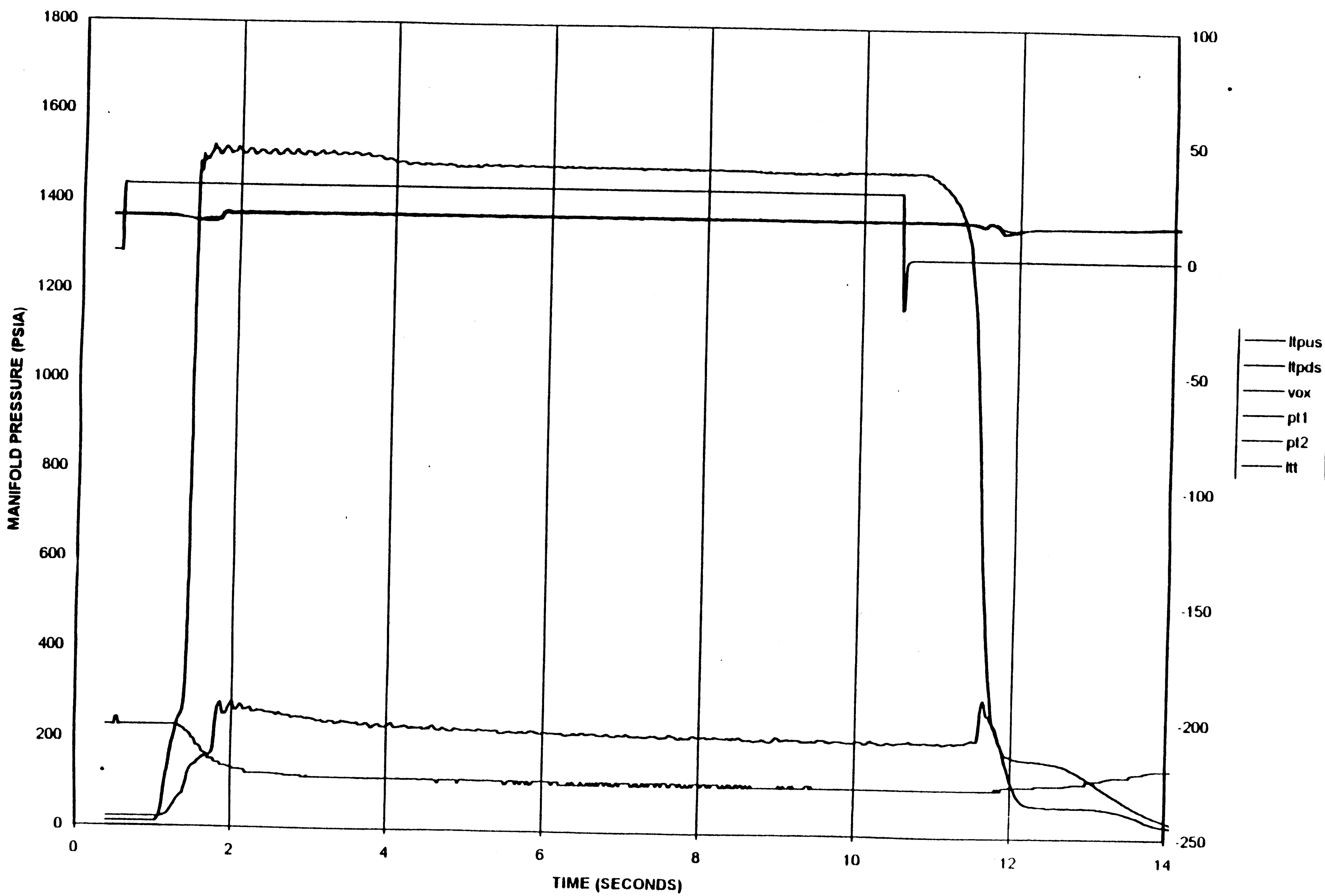
GH2 DATA - R1038



R1032 - LOX COLD FLOW

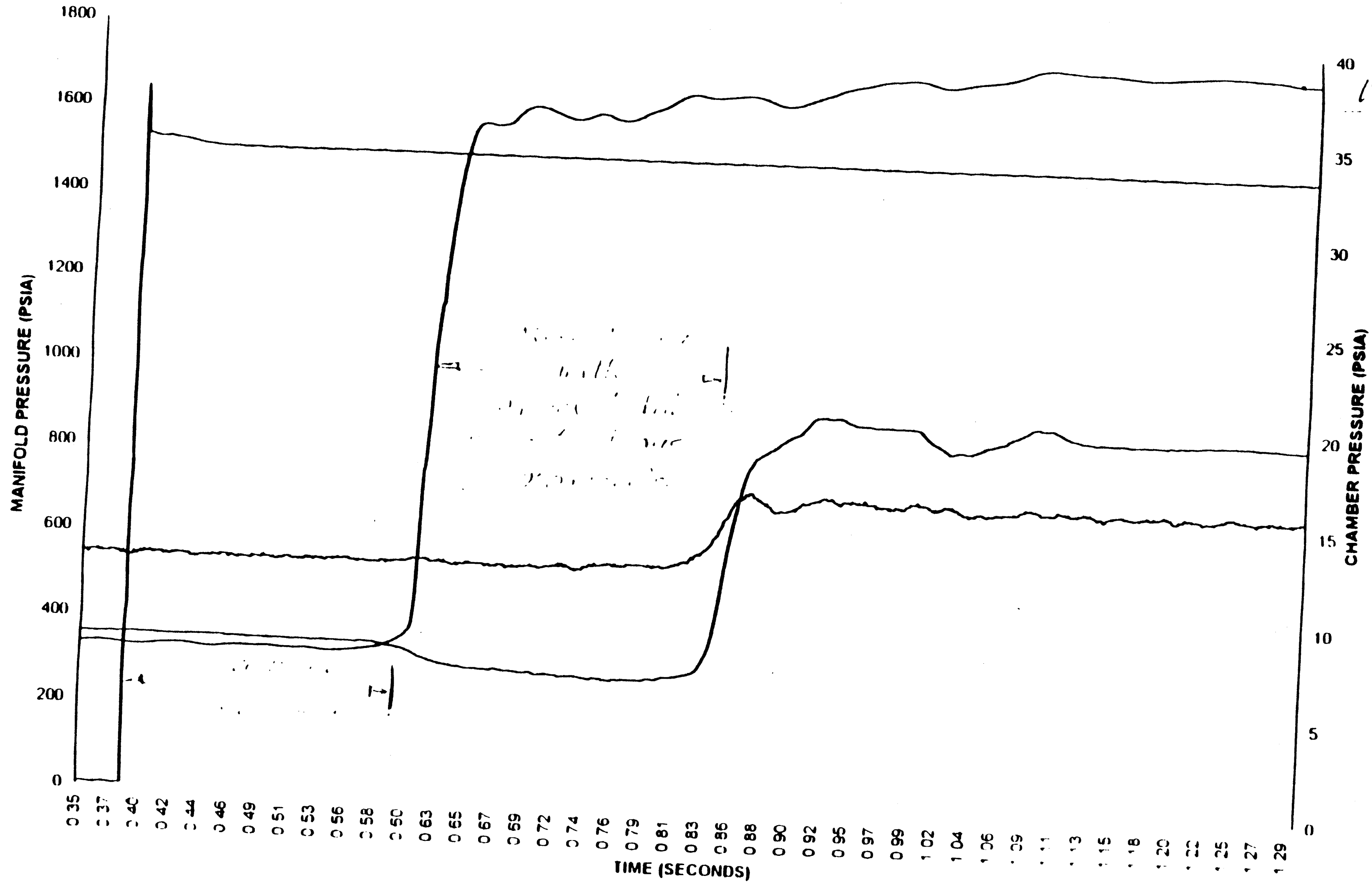


R1036 - LOX COLD FLOW

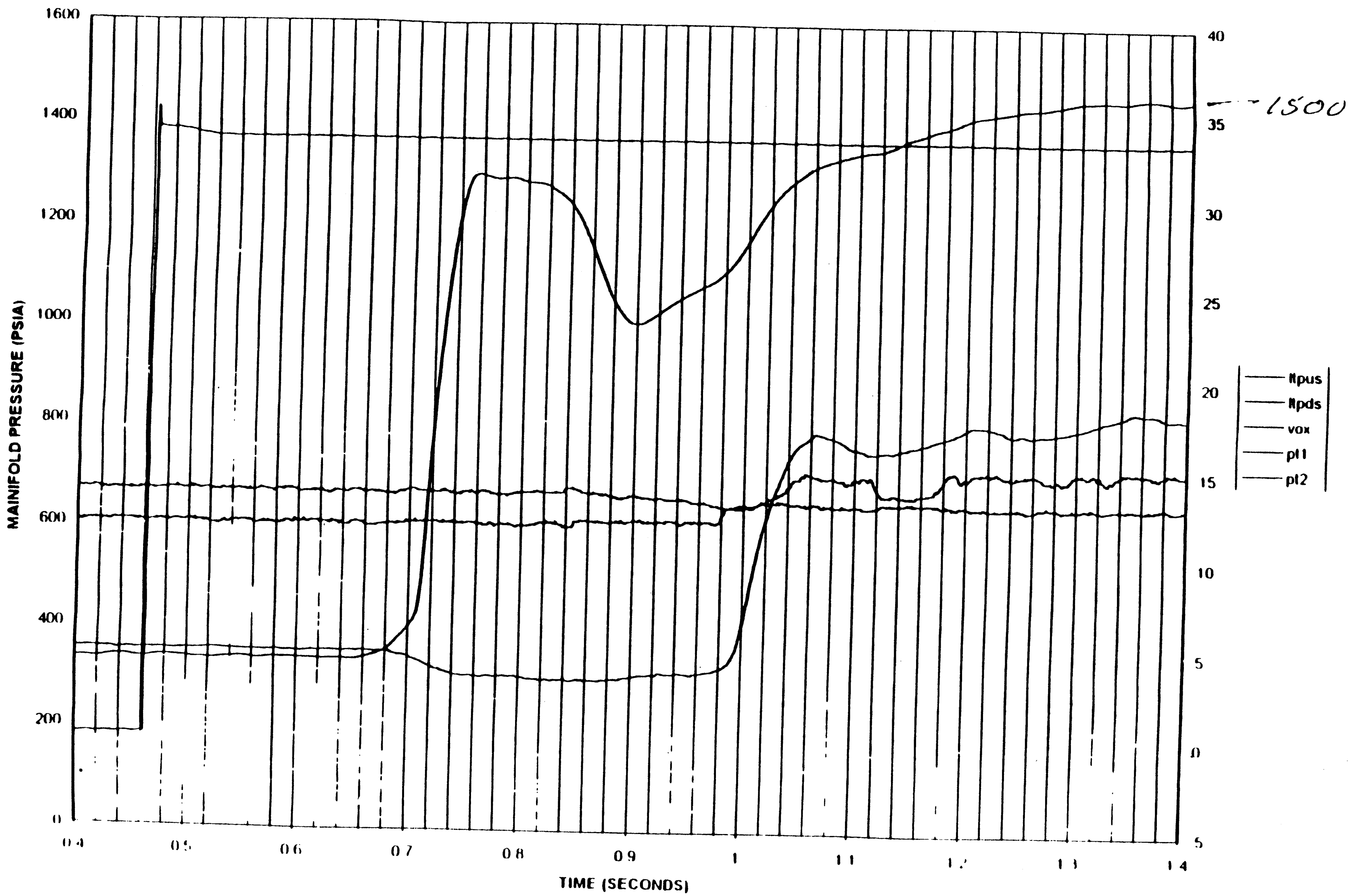


R1004 Chart 1

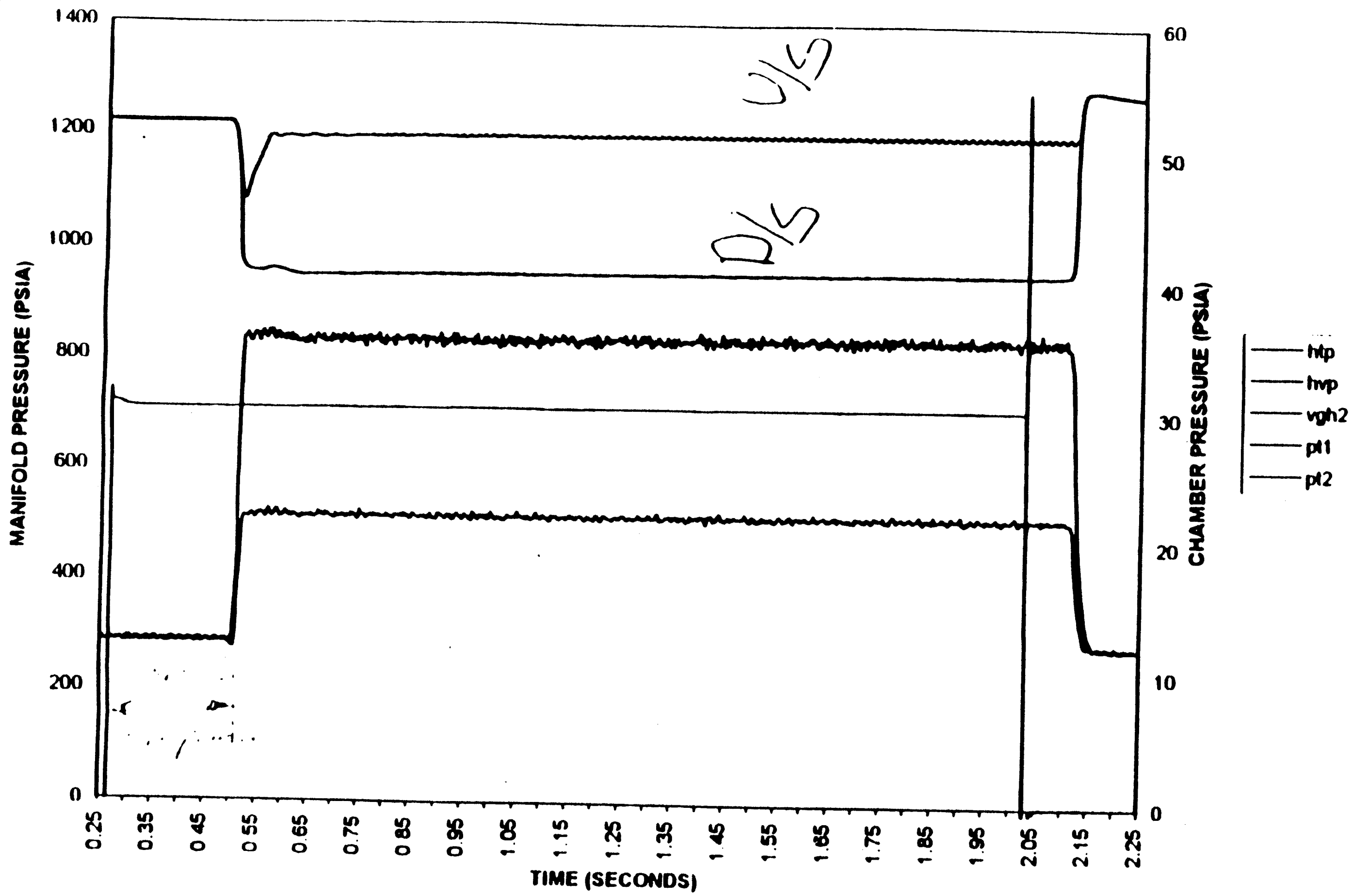
LOX SYSTEM RESPONSE



LOX COLD FLOW RESPONSE - R1003



GH2 RESPONSE - RUN 1005



ATTACHMENT IV

CALORIMETER TEST PLUMBING AND OPERATIONS MODIFICATIONS

KAISER
MARQUARDT

Interoffice Memo

To: Distribution **Date:** 6/19/97

From: R. Wieveg **Ref:** 970619.doc

Subject: Calorimeter Test Plumbing and Operation Modifications

CC:

As a result of the failure investigation following the failure of the calorimeter injector in cell 8, The attached modifications to the plumbing/control system and operation procedures are recommended.

A new, gas/gas start up propellant flow system has been added. This system will allow less violent starts and permit development of a satisfactory start sequence without destroying the test hardware. Gas hydrogen and gas oxygen are admitted to the chamber during the 1st phase of the ignition cycle. This gas mixture is easily ignited by the hydrogen air ignitor prior to introduction of the liquid oxygen and full gas hydrogen flow. Combustion chamber pressure during the gas/gas ignition phase will be controlled to about 75 to 150 psia. After verification by combustion chamber pressure of ignition, the liquid oxygen and high pressure hydrogen flow will be initiated, with constant monitorjng of chamber pressure to insure continuous combustion. A rapid drop in chamber pressure (resulting from flame out) will initiate automatic shut down of propellant flows and initiate nitrogen purges in both the hydrogen and oxygen systems.

The nitrogen purge for the hydrogen system will be moved to enter the hydrogen flow line just upstream of the venturi and the venturi will be moved to a location downstream of the hydrogen flow shut off valve. Double check valves will be installed in both the hydrogen and oxygen purge lines at the point where they enter their respective propellant flow lines. Existing check valves in the purge and propellant lines will be removed and checked for leak free operation before being re-installed.

Additional instrumentation to provide propellant conditions at the entrance to the injector head will be installed. Automatic control of the gas/gas start up flow control valves and the hydrogen and oxygen purge shut off valves will be added to permit accurate timing and sequencing of these important functions.

Distribution:
S. Bartlett, T. Chen, [redacted], W. Kelly, A. Lucci, J. Mays, D. Ruttle

RBCC PLUMBING MODIFICATIONS
6/19/97

1.	Install H_2 venturi downstream of cross (like O_2), Move P and T instrumentation to match.	16 hrs
2.	Move all plumbing from shutoff valves to engine so line lengths are **MINIMIZED.**	16hrs
3.	Install P and T readouts at LOX and GH2 inlet connections on the injector.	16hrs
4.	Move P chamber xducer lines from injector to chamber ports.	6hrs
5.	Move ignitor from injector port to chamber port.	4hrs
6.	Add start up GOX and Gh2 plumbing and controls.	20hrs
7.	Add computer control of start up GOX and GH2 valves and LOX and GH2 purge valves.	10hrs
8.	System Leak, Function, and flow checks.	24hrs
9.	Remove, Test, and replace 4 check valves.	8hrs
10.	Scrounge and clean up 4 check valves, 2 shutoff valves and 3 Regulators	24hrs
	Contingency 10%	14hrs
	TOTAL..	**158**hrs

RBCC CALORIMETER TEST
NEW OPERATING PROCEDURES
6/19/97

LOX COLD FLOW:

1. Turn on cooling water (4.5 #/sec min.)
2. Cool down/fill LOX tank/Line.
3. Set N_2 Purge Static (non flowing) pressure to 500 psia
4. Turn on H_2 and LOX purge valves
5. Pressurize LOX tank to ________ psia.
6. Manually open LOX flow valve
   When LOX temp at injector is <-260°F, set flow pressure at venturi to run condition.
7. Shut off LOX flow valve.
8. Shut off LOX purge and GH_2 purge valves
9. Wait for 5 minutes
10. open LOX purge and GH_2 purge valves
11. Run Automatic(computer controlled) LOX only flow with data recording for 10 seconds.
12. Repeat from step 6. For all 4 LOX flow ponts.
13. Vent and secure LOX system
14. Turn off cooling water
15. Turn off LOX and GH_2 purge valves.

RBCC CALORIMETER TEST
NEW OPERATING PROCEDURES
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GH$_2$ COLD FLOW:

1. Turn on cooling water (4.5 #/sec min.)
2. Turn on exhaust duct water sprays.
3. Turn on exhaust flare
4. Set GN$_2$ purge pressure to 500 psia (static)
5. Turn on GH$_2$ and LOX purge valves
6. Open GH$_2$ run valve and adjust GH$_2$ regulator to five ______ psia Pto at venturi
7. Close GH$_2$ run valve
8. Run Automatic (computer controlled) GH$_2$ only flow with data recording for 10 seconds
9. Repeat from step 6 for all 4 GH$_2$ flow conditions (note GH$_2$ regulator loading pressure at each Pto (venturi) setting
10. Shut off GH$_2$ and LOX purge vlaves
11. Shut off flare
12. Shut off cooling water to test item
13. Shut off exhaust duct cooling water
14. Secure GH$_2$ system

RBCC CALORIMETER TEST
NEW OPERATING PROCEDURES
6/19/97

HOT FIRE RUN:

1. Cool down LOX system to run valve
2. Verify run sequence properly loaded into computer
3. Set GH_2 regulator loading pressure per run sheet
4. Set GN_2 purge pressure to 500 psia (static)
5. Turn on LOX and GH_2 purge valves
6. Turn on test item cooling water
7. Set startup LOX pressure to 300 psia
8. Set startup GH_2 pressure to 150 psia
9. Set ignitor air and hydrogen pressure to 265 psia
10. Start exhausters, open cell air bleed
11. Turn on exhaust cooling water
12. Pressurize LOX tank per run sheet
13. Manually cold flow LOX, set venturi inlet pressure per run sheet after temp at injector inlet is < -260°F
14. Close LOX run valve
15. Light exhaust flare
16. Fire engine (automatic controlled by computer, see auto fire timing sheet)
17. If this is the last run of the series, go to step 21
18. Reset GH_2 regulator for next run condition
19. Turn off exhaust flare
20. Repeat from step 13
21. Turn off LOX and GH_2 purge valves
22. Vent and secure LOX system
23. Turn off cooling water
24. Turn off exhaust flare
25. Secure exhausters
26. Secure GH_2 system

RBCC CALORIMETER TEST
NEW OPERATING PROCEDURES
6/19/97

HOT FIRE TIMING:

Time - Seconds	Function
0.000	close LOX & GH_2 purge valves
0.150	Turn on ignitor
0.200	Turn on start up GOX valve
0.250	Turn on start up GH_2 valve
1.000	Turn off ignitor
	Verify ignition- (Pch > 85 psia)
	If no ignition ---
	Shut off GH_2 and GOX start up valves
	Secure System
	If ignition proved ---
1.150	Open LOX run valve
1.350	Open GH2 run valve
1.600	Verify main ignition (Pch > 400 psia)
	if no ignition ---
	Open LOX and GH_2 purge valves
	Close LOX run valve
	Close GOX start up valve
	Close GH_2 start up valve
	Close GH_2 run valve
	Secure system
	If ignition proved ---
	Open LOX and GH2 purge valves
	Continue run to preselected time limit
Run time limit	Close LOX run valve
	Close GOX start up valve
	Close GH2 start up valve
	Close Gh2 run valve
Run time limit + 30 sec	Close LOX and GH2 purge valves after 30 sec.
	Secure system

RBCC CALORIMETER TEST
NEW OPERATING PROCEDURES
6/19/97

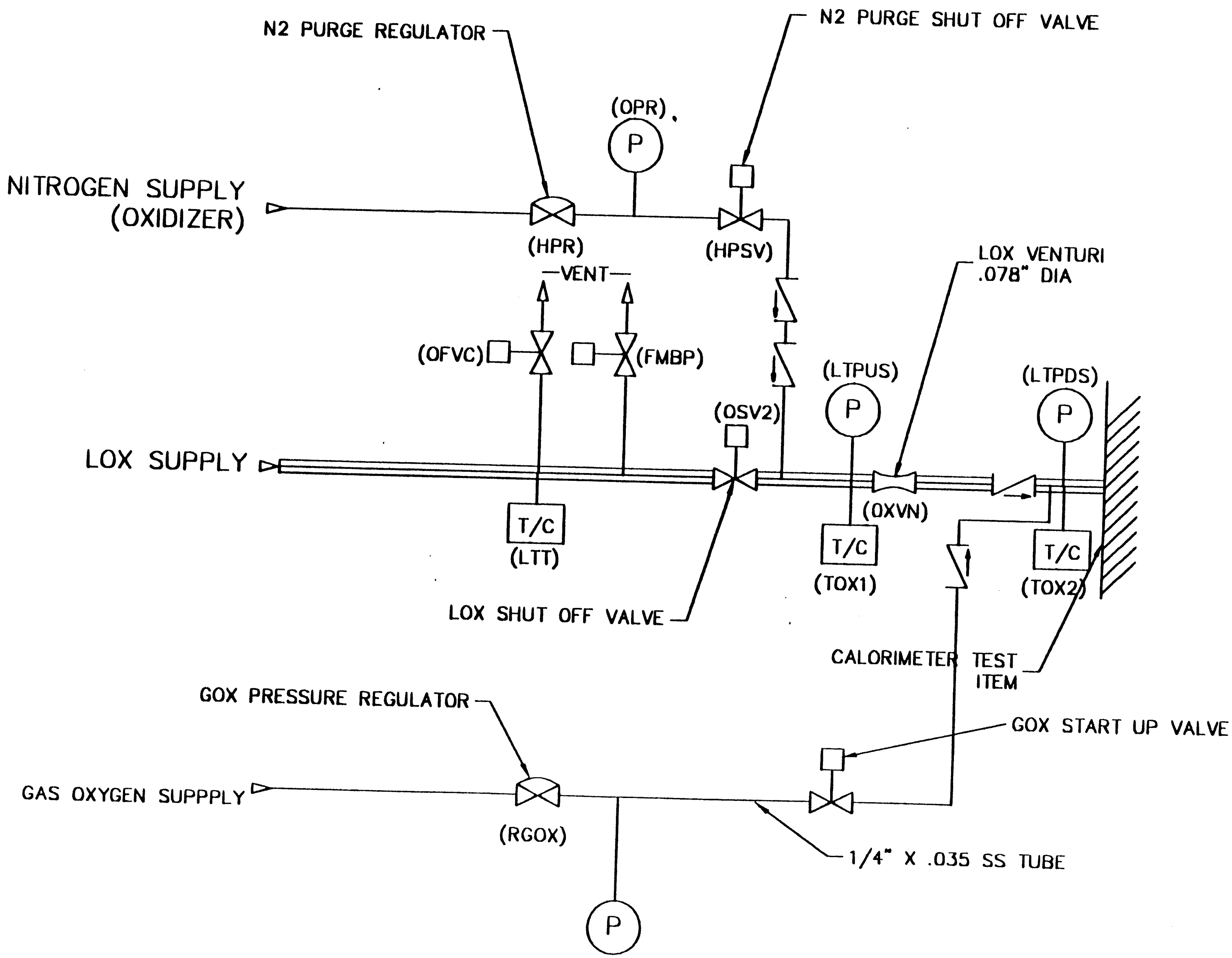
LOX COLD FLOW TIMING:

Time - Seconds	**Function**
0.000	close LOX & GH_2 purge valves
0.200	Turn on start up GOX valve
1.150	Open LOX run valve
1.600	Open LOX and GH2 purge valves
	Continue run to preselected time limit
Run time limit	Close LOX run valve
	Close GOX start up valve
Run time limit + 30	Close LOX and GH2 purge valves after 30 sec.
sec	Secure system

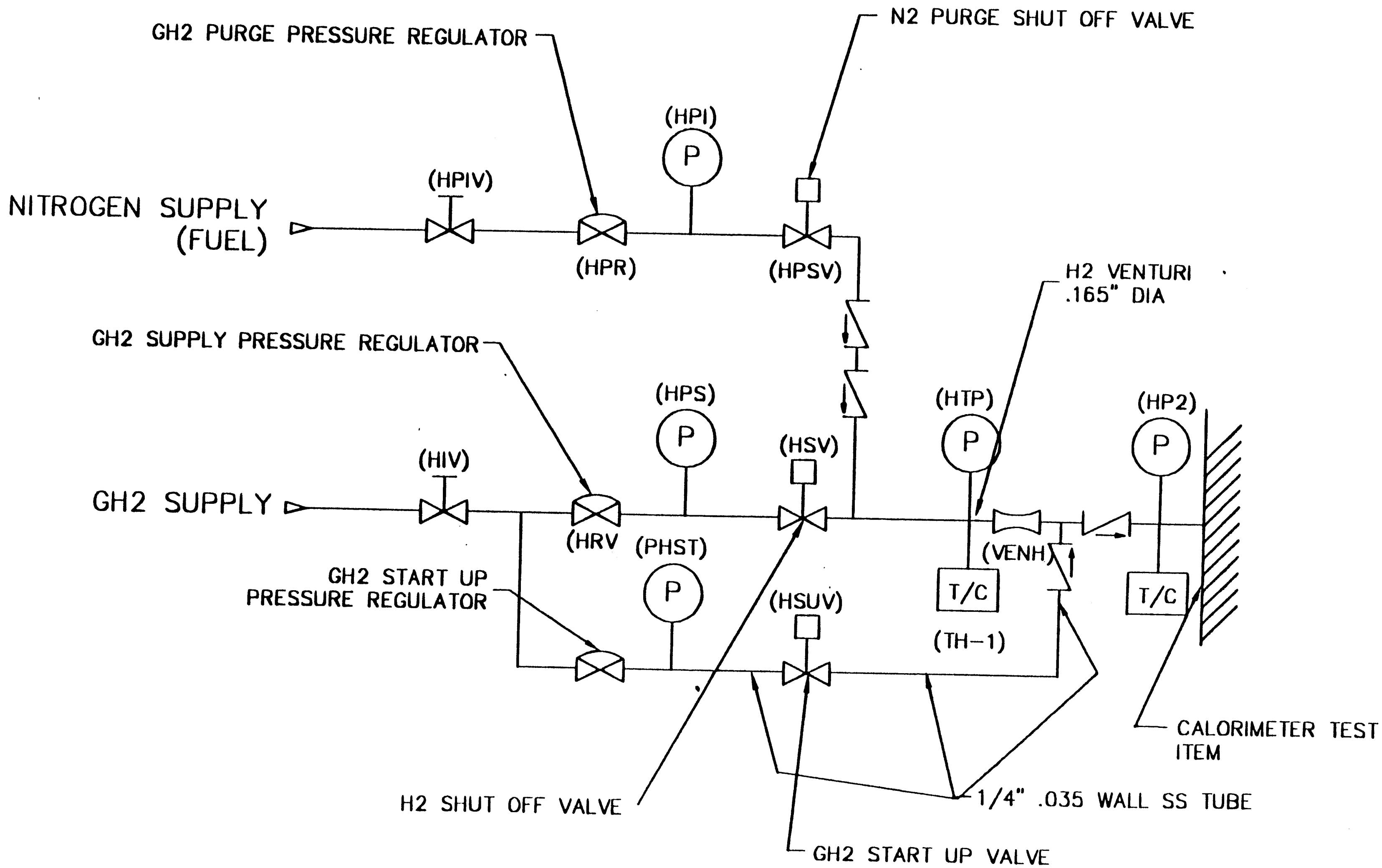
GH2 COLD FLOW TIMING:

Time - Seconds	**Function**
0.000	close LOX & GH_2 purge valves
0.250	Turn on start up GH_2 valve
1.350	Open GH2 run valve
1.600	Open LOX and GH_2 purge valves
	Continue run to preselected time limit
Run time limit	Close GH2 start up valve
	Close Gh2 run valve
Run time limit + 30	Close LOX and GH2 purge valves after 30 sec.
sec	Secure system

CALORIMETER LOX SYSTEM



CALORIMETER H2 SYSTEM



START UP O_2 & H_2 Pressure settings

OXYGEN INJECTOR ORIFICE AREA - 20 ea .036 ϕ HOLES.

HYDROGEN INJECTOR ORIFICE AREA - 10 ea .085 ϕ HOLES.

NOMINAL START UP CONDITIONS. $W_{ox} = .2$ LB/SEC

$K_{O_2} = 2.5$ $W_{H_2} = .05$ or less ($O/F = 4$)

$K_{H_2} = 4.0$

GOX FLOW (Choked.) $A_{H_2} = .056 \text{ IN}^2$

$$W = \frac{.545 \times P_T \times A_{ox} \times C_D}{\sqrt{530}}$$

$A_{ox} = .001018 \text{ IN}^2 \times 20 = .02036$

UNCHOKED

$$\Delta P = \left(\frac{Fl}{D} + K\right)\left(\frac{W}{A}\right)^2 \frac{RT}{2gP}$$

$R = 48.25$

$T = 530°R$

~~SIZE FOR ΔP = 50 PSI @~~

ASSUME $P = 150$ PSIA

$$\Delta P = 2.5\left(\frac{.2}{.02036}\right)^2 \frac{48.25 \times 530}{64.4 \times 150} = 638 \text{ PSI} - \text{CAN'T DO IT.}$$

UNIT CK - $\frac{LB^2}{\cancel{SEC}\ \cancel{IN^2}\ IN^2} \cancel{\frac{FT \cdot LB \cdot SEC^2 \cdot R}{R \cdot FT \cdot LB}}$ OK

TRY USING $\Delta P = 100$ PSI, $P = 200$ PSI

FIND FLOW

$$\left(\frac{W}{A}\right)^2 = \frac{\Delta P \times 2gP}{RTK}$$

$$W = \sqrt{\frac{2\Delta P g P A^2}{RTK}}$$

UNCHOKED $$W = \sqrt{\frac{2 \times 100 \times 64.4 \times 200 \times .02036^2}{48.25 \times 530 \times 2.5}} = .129 \text{ LB/SEC}$$

CHOKED. $$W = \frac{.545 \times 200 \times .02036 \times .75}{\sqrt{530}} = .0722 \text{ LB/SEC.}$$

USE 200 PSI FOR GOX SUPPLY PRESS, SIZE

H_2 PRESS TO GIVE .025 TO .035 LB/SEC @ 100 PSI Pc.

$$\Delta P_{H_2} = 4 \times \left(\frac{.035}{.056}\right)^2 \frac{772 \times 530}{64.4 \times \underline{130}} = 76 \text{ psi}$$

Change P- TO 150,

$\Delta P_{H_2} = 66.$

$P = 166$ USE 150 PSI ON H_2

$$\text{THEN } W_{H_2} = \sqrt{\frac{2 \times 50 \times 64.4 \times 150 \times .056^2}{772 \times 530 \times 4}} = \cancel{.0??}\ .043 \text{ LB/SEC}$$

O_2 Choked @ 200 PSIA

$W_{O_2} = .0722$ LB/SEC

$$O/F = \frac{.0722}{.043} = 1.67$$ – KIND OF FUEL RI[CH]
BUT MAY WORK.
LETS USE 300 ON O_2 PRESS,
SHOULD WORK BETTER

CONCLUSION –

$P_{OX} = 300$ PSIA
$P_{H_2} = 150$ PSIA
IGNITION CONDITION

$W_{TOT} = .043 + .1083 = .1151$ LB/SEC

$$P_{ch} \approx \left(\frac{.1}{.115}\right)^{-1} \times 500 = \underline{57.5 \text{ PS[I]}}$$

Chamber
Press @ Sta[rt]