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Sandia Labs.

PRE-HYBLA GOLD HE TEST, FINAL REPORT

22 February 1978

DTL-79,0073

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WJH

File : HE Tests
Sandia Laboratories

date: February 22, 1978

Albuquerque, New Mexico
Livermore, California

to: LCDR. C. L. Christensen, FC/DNA

from: J. D. Plimpton - 1116, and H. M. Miller - 1123

subject: Final Report, Pre-HYBLA GOLD HE Test

Enclosed is the Pre-HYBLA GOLD Final Report. You are free to use it in any further publications. General questions may be directed to the editors, JDP and HMM, while detailed questions should go to the individual experimenters.

JDP:1116:HMM:1123:efh

Enclosure: (1) Final Report, Pre-HYBLA GOLD HE Test

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FINAL REPORT
PRE-HYBLA GOLD HE TEST

Background

At the request of Field Command, Defense Nuclear Agency (FC/DNA), Sandia Laboratories conducted an HE test to provide a test bed for gages from various agencies proposed for use on the HYBLA GOLD event at the Nevada Test Site. The test was conducted 1 July 1977, at the Sandia Labs Coyote Test Field. Participating agencies were as follows:

Kaman Sciences Corporation (KSC)
Colorado Springs, Colorado
Stanford Research Institute (SRI)
Menlo Park, California
Systems, Science and Software (SSS)
La Jolla, California
TRW Systems (TRW)
Redondo Beach, California
Sandia Laboratories (SLA)
Albuquerque, New Mexico

FC/DNA provided a 0.91 m I.D. by 2.44 m long section of concrete pipe similar to that to be used on the HYBLA GOLD test. Instrument holes were drilled in the pipe by the University of New Mexico Civil Engineering Research Facility (CERF) located in Coyote Test Field.

Test results, conclusions and recommendations as provided by each agency are included as appendices to this report. Some editing was done by the authors of this report. Responsibility for any errors is borne by them.

Test Bed Configuration

The Pre-HYBLA GOLD test bed configuration is shown in Figure 1. The concrete pipe was placed vertically in an excavated pit with 1.83 m of pipe below the surface. The explosive

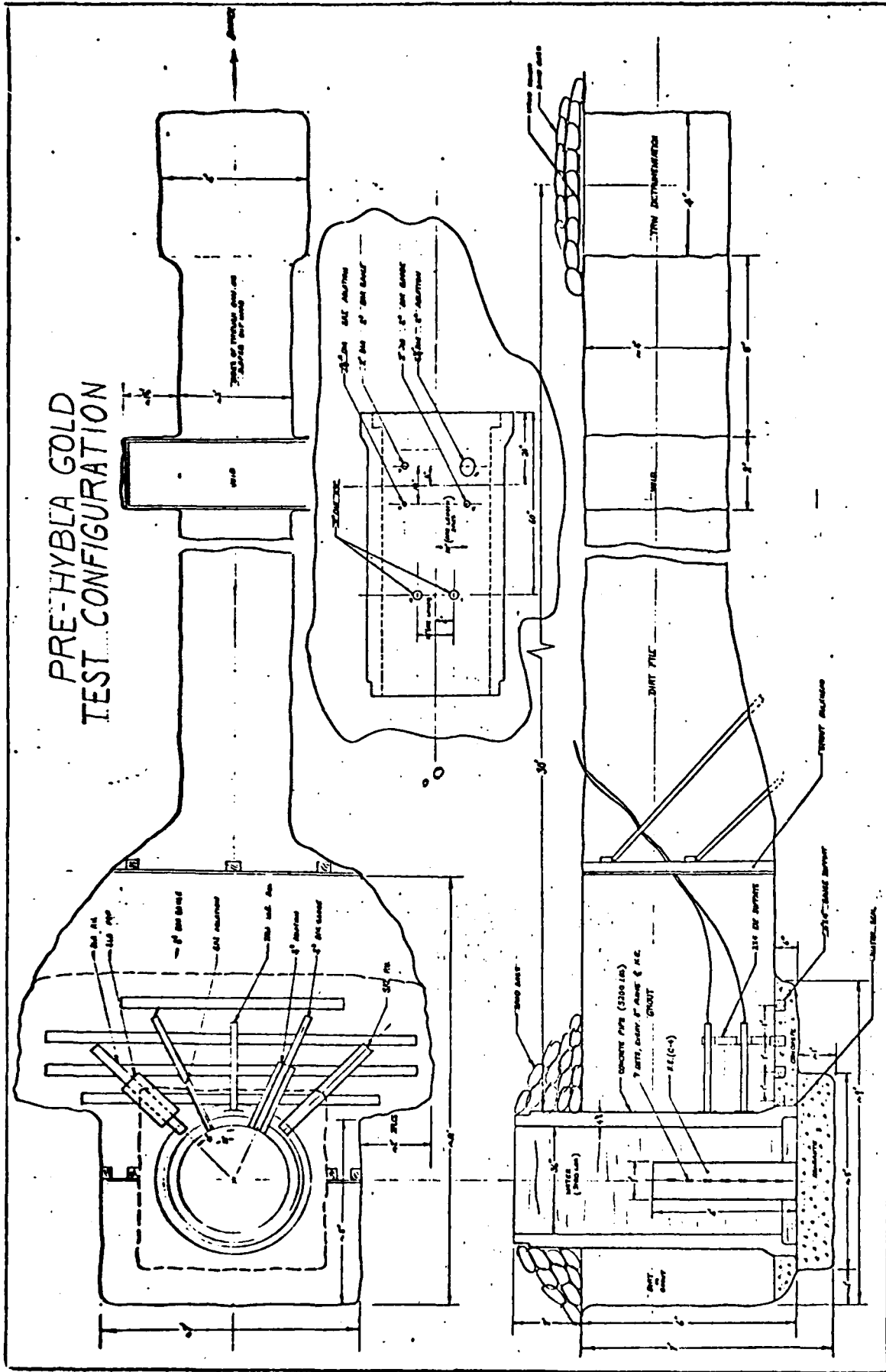


Figure 1. Pre-HYBLA Gold Test Bed

driver was supplied by 140 kg of COMP C-4 high explosive packed in a 0.30 m diameter by 1.22 m long steel cylinder with 1.59 mm wall thickness. The cylinder was placed coaxially at the bottom of the concrete pipe. Seven detonators, fired simultaneously, were placed at 0.15 m intervals along the axis of the HE. After emplacement of the HE, the concrete pipe was filled with water to the top.

Gages were installed in or near the pipe around a 90° arc. Six gage holes of various sizes were drilled into the pipe. The remaining gages were located against or at various distances from the pipe. In addition, a 9 m long trench extended from the pipe to a pit dug to house the TRW instrumentation.

On D-5, after installation of all gages, the area surrounding the concrete pipe and gages was completely filled with grout. The grout was made of 68% plaster sand, 17% cement, and 15% water. This is a standardized, easily-mixed material that is basically concrete without aggregate.

Signal and power cables extended from the gages to an underground recording bunker located 150 m from the shot. Additional recording and A&F control was accomplished in the control center located 800 m from the recording bunker.

Documentary coverage was provided with still cameras and motion picture cameras.

Shock Wave Predictions

Predictions were run by SLA on CSQ, a two-dimensional hydrodynamics code. Two initial problems were run. They both involved the shock driven down a 0.91 m I.D. concrete pipe by a 0.30 m thick disk of TNT placed at one end. The first calculation utilized an air-filled pipe (Fig. 2) and the second involved a water-filled pipe (Fig. 3).

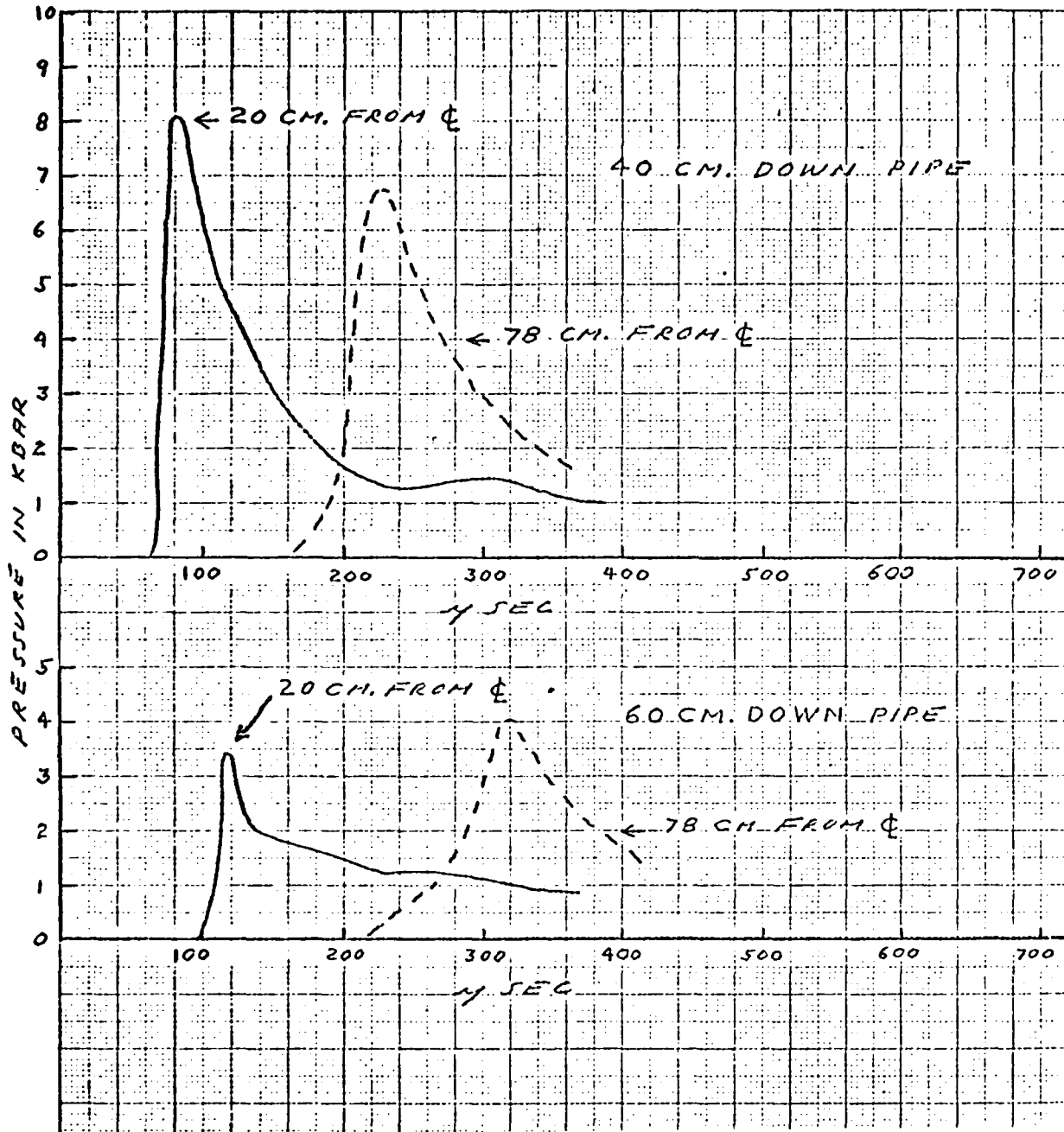


Figure 2. Air-Filled Pipe, 30 cm HE

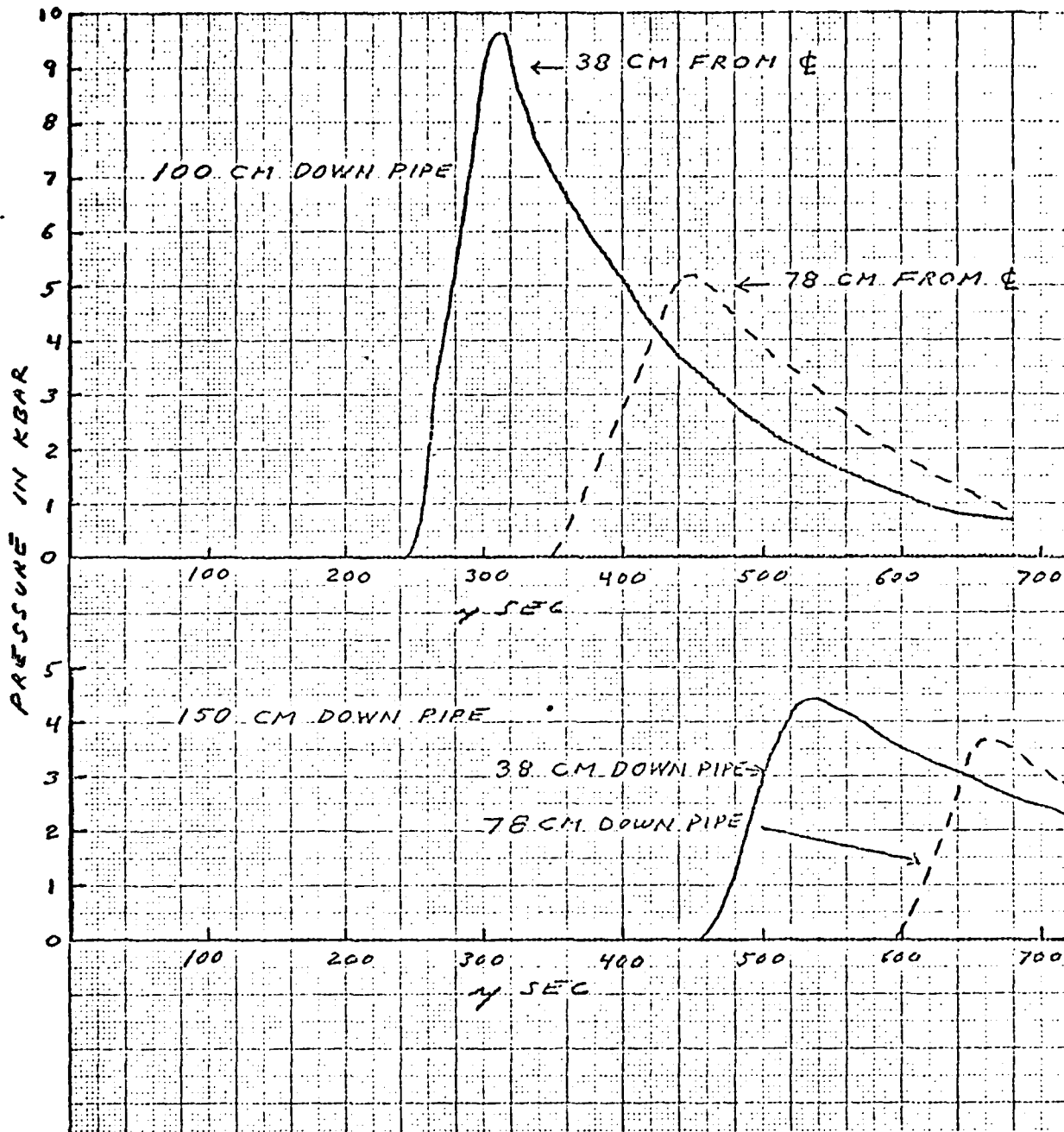


Figure 3. Water-Filled Pipe, 30 cm HE

In Figure 2, the problem shows edits at 0.40 m and 0.60 m down the pipe and at 0.20 m and 0.78 m out from the pipe centerline. The air shock pressure dips sharply from 8 kbar at 0.10 m from the surface of the HE to slightly over 3 kbar at 0.30 m distance. The shock velocity is 6 mm/ μ sec. A second edit at 0.78 m from the centerline is also shown. High pressures (4 kbar) seen there indicate a direct shock arrival through the medium from the HE rather than a shock arrival radially outward from the pipe.

To reduce the rapid fall-off of pressure with distance, the air was replaced with water in the second run. In Figure 3, the water-filled pipe, the problem shows edits at 1.00 m and 1.50 m down the pipe and 0.38 m and 0.78 m from the pipe centerline. As shown, a pressure of approximately 10 kbar at 0.70 m from the surface of the HE drops to about 4 kbar at 1.20 m distance. Pulse widths are increased by a factor of two over the case of the air-filled pipe. Pipe wall displacement over the one millisecond duration of the problem was predicted to be 0.10 m at the 1.00 m distance, and 0.05 m at 1.50 m distance.

The distance from the shot site to the recording bunker is dictated by the amount of HE to be detonated from safety considerations. In order to reduce the length of signal cables required by decreasing the amount of HE used, a third problem was run using a water-filled pipe with a 0.15 m thick disk of HE. The results are shown in Figure 4. Pressures at the edited distances decreased by about 30%.

It was then noticed that by changing the HE from a disk to a cylinder, higher pressures uniform over a larger area of pipe wall might be achieved. The final problem involved a 1.22 m long by 0.30 m diameter HE-filled cylinder placed coaxially at one end and inside of a water-filled 0.91 m I.D. concrete pipe.

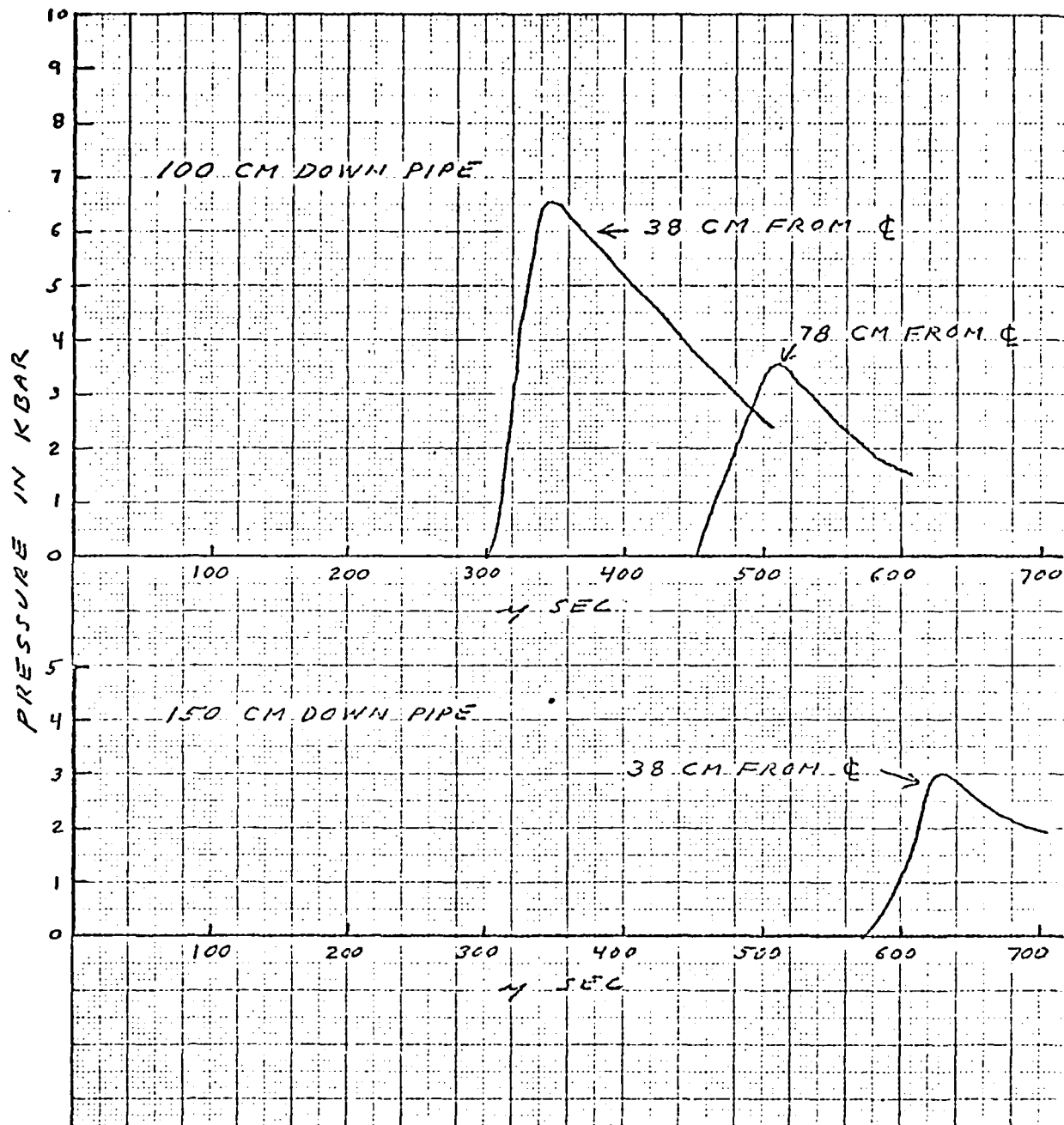


Figure 4. Water-Filled Pipe, 15 cm HE.

Detonation was simultaneous along the centerline of the HE. Results are shown in Figure 5. Edits were made at 0.61 m and at 1.52 m from the base of the HE. At the 0.61 m location, edits were made at the water/concrete pipe interface, the pipe/grout interface, and 0.23 m out from the pipe wall in the grout. Pressures of 12-14 kbar were predicted near the pipe wall. This design proved to be acceptable and was the one employed.

All of the above predictions were made with uncertainties of factors of two. These stem from uncertainties in the equation-of-state of the explosive and the grout

Gage Layout

The number and types of gages installed by each agency and the locations are given in Table 1. The installed gages are shown in Figure 6.

Instrumentation

All agencies involved in the Pre-HYBLA GOLD test provided and installed their own transducers, power supplies, and signal conditioning. Recording equipment, arming and firing, and photographic support were provided by SLA.

All data were recorded on a magnetic disk recorder located in the underground bunker. The 36-channel recorder operates at an FM center frequency of 5 MHz with a deviation of ± 2 MHz. The frequency response is 300 kHz. Total recording time is 28 msec. In addition, all data were paralleled into a 216 kHz $\pm 40\%$ VCO system which was transmitted via hardwire to the control building located 800 m from the shot. Data were recorded there on two Ampex FR1400 magnetic tape recorders and on an oscillograph.

Results

The pipe was emplaced and the gages installed and checked out in June 1977. After HE insertion and final instrumentation

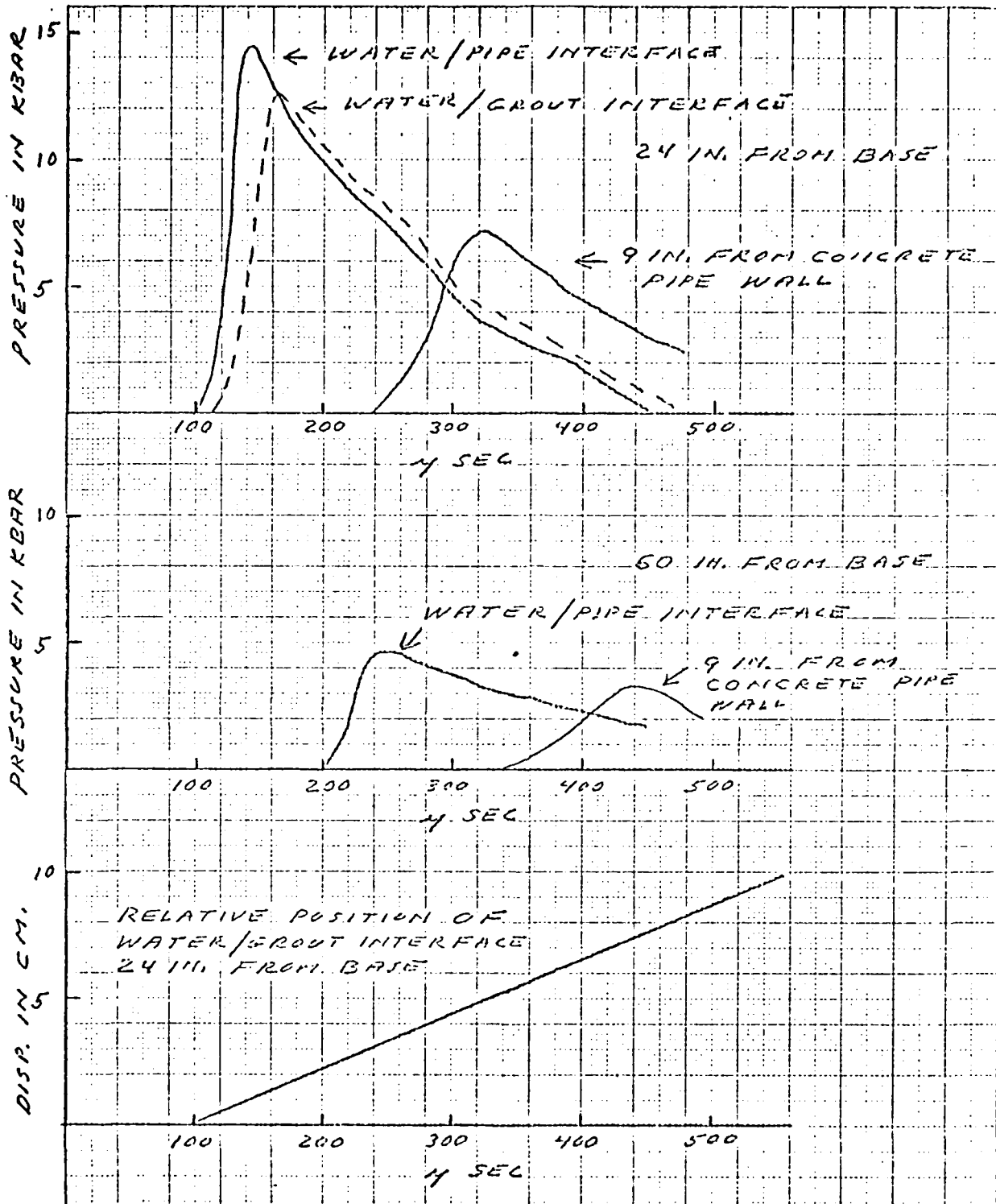


Figure 5. Water-Filled Pipe, Cylindrical HE

No.	Designation	Type	*Arc Dist. from Pipe C.L. (mm)	Dist. from Bottom of Pipe (mm)	Radial Dist. from Pipe Surface (mm)
1	KSC-D-1	Diaphragm	-152	1524	Hole #1
2	KSC-D-2	Diaphragm	+152	1511	Hole #2
3	KSC-D-3	Diaphragm	+203	1486	0
4	SRI/SLA-Man	Manganin	+120	~ 550	0
5	SRI-PV	Particle Veloc.	-495	457	0
6	SRI-Man-1	Manganin	-500	~1000	0
7	SRI-Yb-1	Ytterbium	+120	~ 800	0
8	SRI-ABX	Ablation	+260	768	Hole #4
9	SSS-BG-1	Bar Gage	-254	762	Hole #3
10	SSS-BG-2	Bar Gage	+254	457	Hole #6
11	SSS-ABX	Ablation	-254	457	Hole #5
12	TRW-1	Waveguide	0	603	0
13	TRW-2	Waveguide	0	857	0
14	SLA-Yb-1	Ytterbium (FCP)	+445	470	209
15	SLA-Yb-2	Ytterbium (FCP)	+445	470	209
16	SLA-Yb-3	Ytterbium	+406	648	0
17	SLA-Yb-4	Ytterbium	0	444	197
18	SLA-Yb-5	Ytterbium	+711	635	0
19	SLA-PV	Particle Veloc.	+559	686	0

* Arc length from zero degree reference shown in Fig. 1.

TABLE 1.

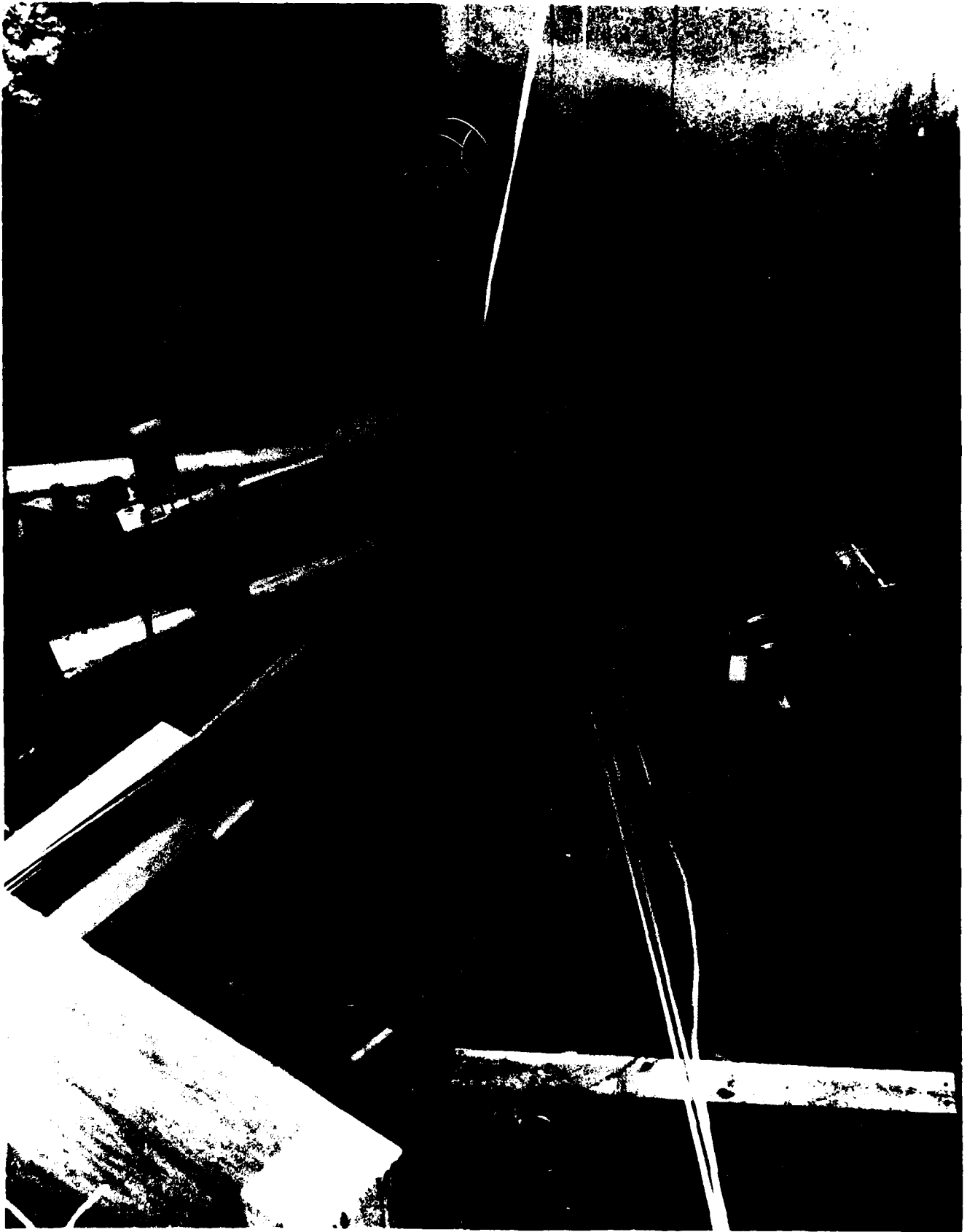


Figure 6. Gages Installed on Pipe

checkout, detonation occurred at 1320 on 1 July 1977. The motion pictures showed a spatially-symmetric plume. Preliminary results were immediately available and were reported in a memo on 8 July 1977 (Appendix A). Final results and individual recommendations of the specific agencies are included in further appendices.

These results are summarized in Figure 8, Time-of-Arrival Data, and Figure 9, Stress vs. Distance. The TOA data indicate a shock velocity of about 2.2 mm/ μ sec in the grout. The stress levels fall on a curve that can be approximated by the equation:

$$\sigma(\text{kbar}) = 3.8 R(\text{m})^{-2.5}.$$

This can be compared to the predicted curve:

$$\sigma(\text{kbar}) = 3.8 R(\text{m})^{-1.6}.$$

The general conclusion remains as stated in the preliminary memo: the test achieved the goal of exercising the various systems and the quantitative results are in essential internal agreement. While the measured stress is greater than was predicted, it is within the uncertainty of the calculations.

Acknowledgments

We would like to thank R. Bass, 1111, for running the calculations, T. L. Towne, 1123-1, for the instrumentation, W. R. Drake and P. D. Walkington, 9335, for handling the construction, logistics and recording, and R. K. Peterson's group, 9412, for the motion-picture photography.

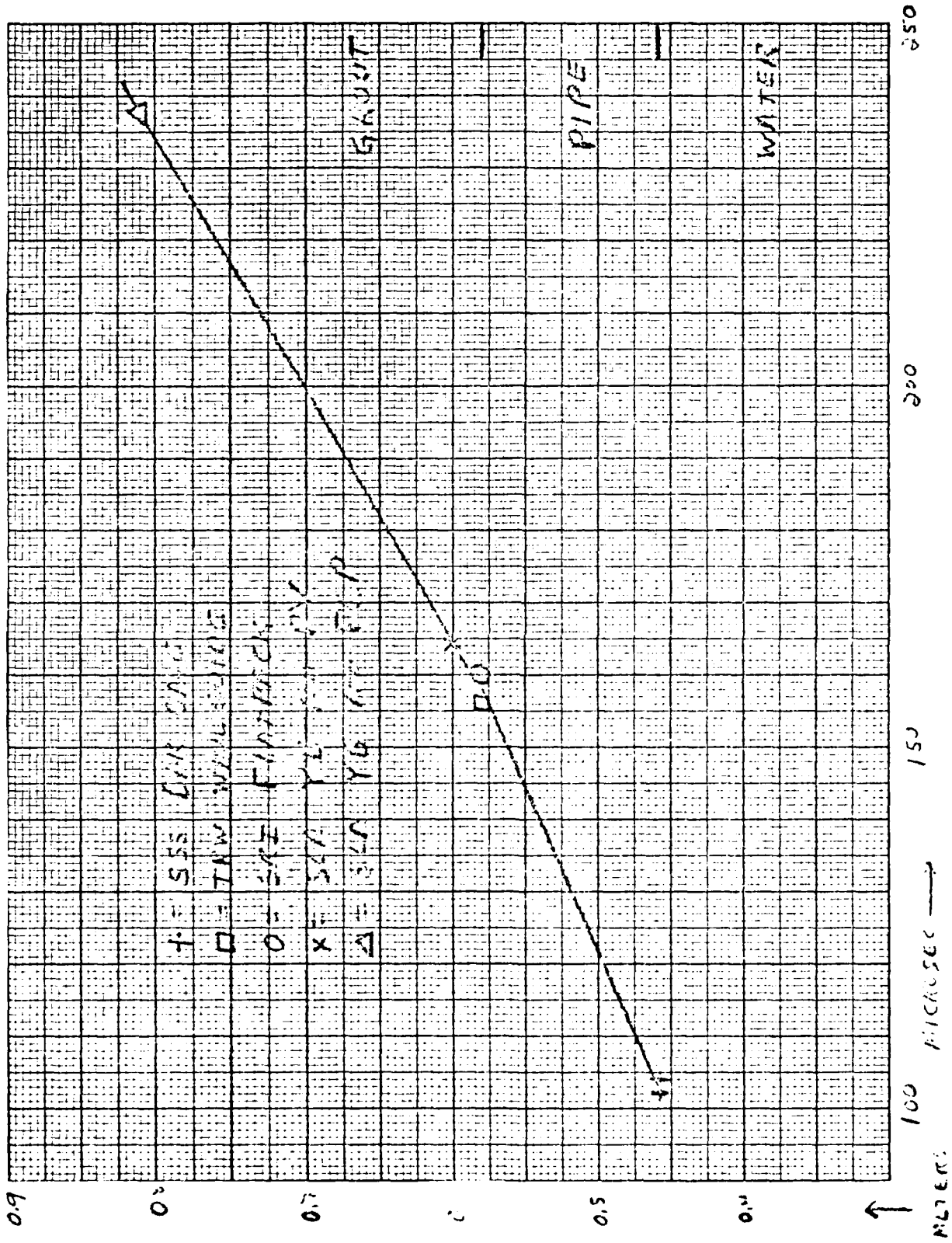


Figure 8. Time-of-Arrival Data

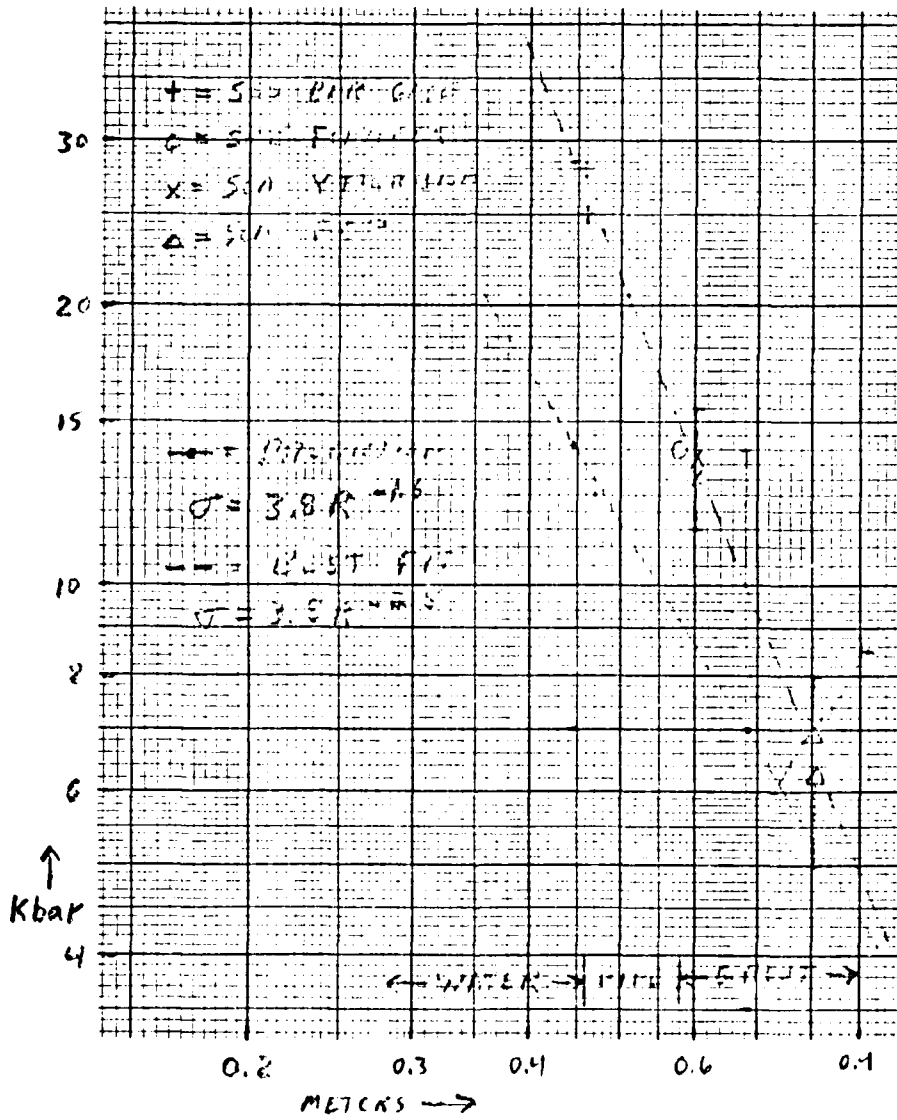


Figure 9. Stress vs. Distance

APPENDIX A
PRELIMINARY REPORT *

The Pre-HYBLA GOLD HE test was conducted 1 July 1977 at the Sandia Labs Coyote Test Field. The object was to provide a test bed for prototype gages from the various agencies which are intended for use on HYBLA GOLD. The experiment consisted of a water-filled concrete pipe set vertically in an excavation. The explosive driver was a cylinder of COMP C-4 placed coaxially at the bottom of the pipe. Around the periphery of the pipe midsection were attached about 20 transducers to measure stress, particle velocity and to check their survival. The excavation was then filled with grout to the top of the pipe, completely covering the gages and cables to provide a realistic simulation of the NTS emplacement.

A two-dimension CSQ calculation (ltr, JDP to Dist., dtd 14 June 1977) predicted a peak pressure in the first grout zone of about 13 kbar arriving at about 160 μ sec after HE fidu. Particle velocities of 0.25 mm/ μ sec were also expected. A first look at the results of the various measurements indicates that these values were achieved or exceeded in general. A brief summary of the individual experiments will now be given.

1. Kaman Sciences Corporation

- a. Two diaphragm gages on the pipe 1.5 m up at a predicted level of 5 kbar. The gages saw excessive pressures (~ 10 kbar) which ruptured the diaphragms. The observed signals are not considered to be valid at this time and investigations are continuing.

* Memo, J. D. Plimpton to Distribution, dated 7/8/77.

2. Stanford Research Institute

- a. An ytterbium flat-pack (steel) on the pipe. A clean signal of nominal amplitude (13 kbar) arriving at 160 μ sec was seen. The release was followed to many 100's of μ sec.
- b. A manganin flat-pack (aluminum) on the pipe. This gage apparently broke early and gave no stress information.
- c. An inductively-coupled particle velocity gage on the pipe. Higher-than-predicted particle motion drove this gage to band-edge. Nevertheless, the concept proved viable.
- d. An ablation gage on the pipe. The gage survived adequately for about 300 μ sec.

3. Systems, Science and Software

- a. Two bar gages on the pipe projecting through holes into the water. Pressure peaks of about 20 kbar were seen arriving at 175 μ sec. After 30 μ sec or so, a second increase to much higher levels was noted on both records. This latter is considered to be unphysical and is under discussion.
- b. An ablation gage on the pipe. Adequate survival for 100's of μ sec was observed.

4. TRW Systems

- a. Two wave-guide gages on the pipe. The systems performed well and the records appear to contain wall-motion data. The analysis is underway.

5. Sandia Laboratories

- a. Two ytterbium stress gages on the pipe. Good pressure peaks of 17 kbar arriving at 160 μ sec were seen

on both gages. The releases were followed for 200 μ sec.

- b. An ytterbium gage 0.20 m off the pipe. A peak stress of 10 kbar was seen where 7 kbar was expected. The arrival time of 230 μ sec was nominal.
- c. A fluid-coupled plate (FCP) containing two Yb sensors 0.20 m off the pipe. The records left the base-line at 240 μ sec and reached band-edge (10 kbar) a few μ sec later. This is consistent with a larger stress than was predicted. The recovered gage shows evidence of strain.
- d. An end-on oriented manganin gage fielded on the pipe in conjunction with SRI. This gage went to negative band-edge at the 160 μ sec shock arrival.
- e. An inductively-coupled particle velocity gage on the pipe. A clean offset beginning at 160 μ sec and persisting for 77 μ sec indicated a maximum velocity of 0.35 mm/ μ sec.
- f. Candidate steel tubing for the cavity-pressure measurement. Observation of the recovered sections showed survival to at least 15 kbar. Thus plans can proceed.

We conclude that the test achieved its major objective of exercising the logistics. Also, significant quantitative results were obtained that are in essential agreement. At this time, it appears that the shock environment in the grout was somewhat more severe than was predicted.

APPENDIX B KSC REPORT

Details of the experiment test configuration as relate to the KSC pressure measurements on the Pre-HYBLA GOLD HE test are shown in Figure B.1. The original test plan was to place one active and one dummy transducer at the 5-6 kbar peak pressure level. These measurements would be complemented with a passively-terminated cable exposed to the same environment to evaluate the shock sensitivity of the RG-178 cable that was selected for use on HYBLA GOLD event.

A block diagram of the KSC pressure measurement system is given in Figure B.2. Three channels were fielded: Channel D-1 was an active pressure transducer with a recessed front face; Channel D-2 was also considered to be an active pressure transducer but with about half the sensitivity of D-1; Channel D-3 consisted of an identical electronic system but with the sensor replaced with a resistor. The original plan to field a dummy gage at D-2 was abandoned because the dummy transducer design was found to be sensitive to pressure effects. This was not expected.

Figure 6 in the Main Report shows the KSC pressure transducers installed in the concrete pipe test section. Note the two variations of cable exit from the probes. Installation D-1 used a spiral section behind the probe whose design allows for compression along the axis of expected motion. D-2 and D-3 come away from the probe with a sweeping arc (not shown clearly in this view). Figures B.3a and B.3b show physical details of the pressure transducer installation and of the cable termination (D-3).

Results of the experiment were somewhat disappointing. The pressure environment was evidently more than twice the

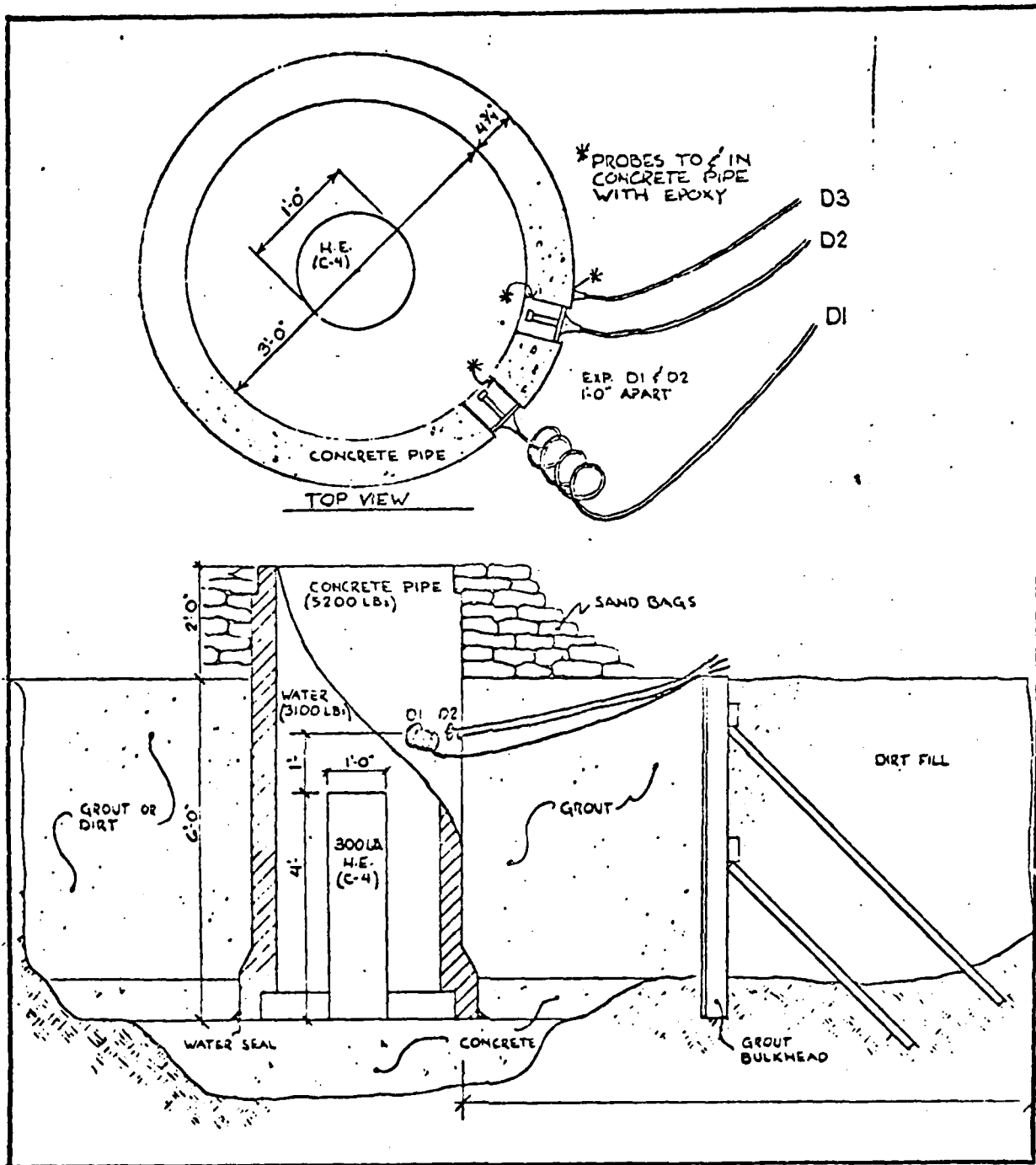


FIGURE B.1. PRE-HYBLA GOLD HE TEST CONFIGURATION

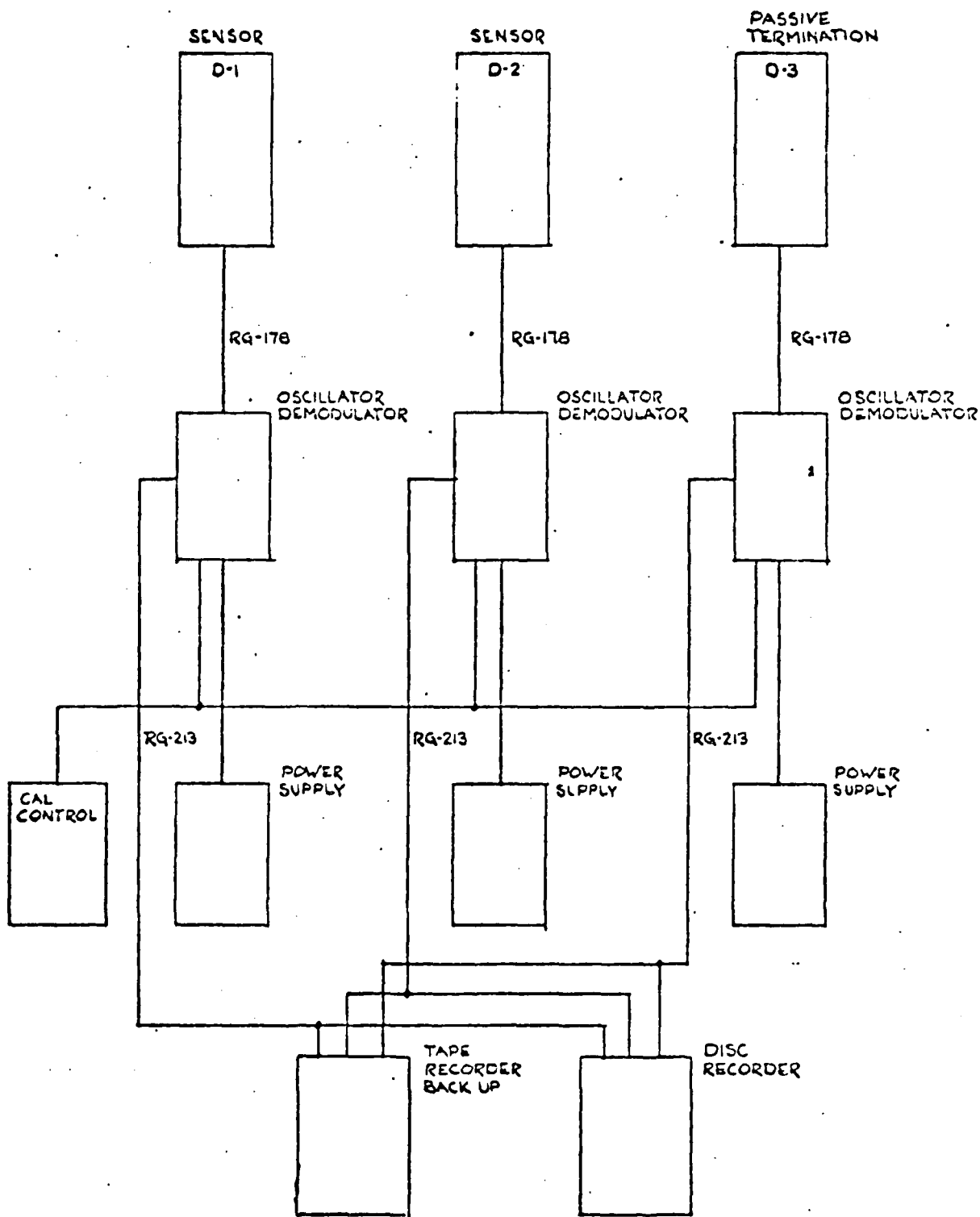


Figure 3.2. Pre-HYBLA GOLD Experiment Block Diagram - KSC Pressure.

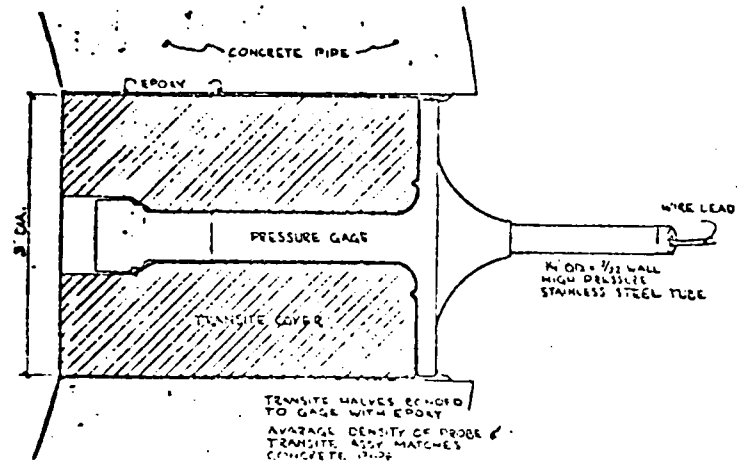


Figure B.3a. Active Gage Installation

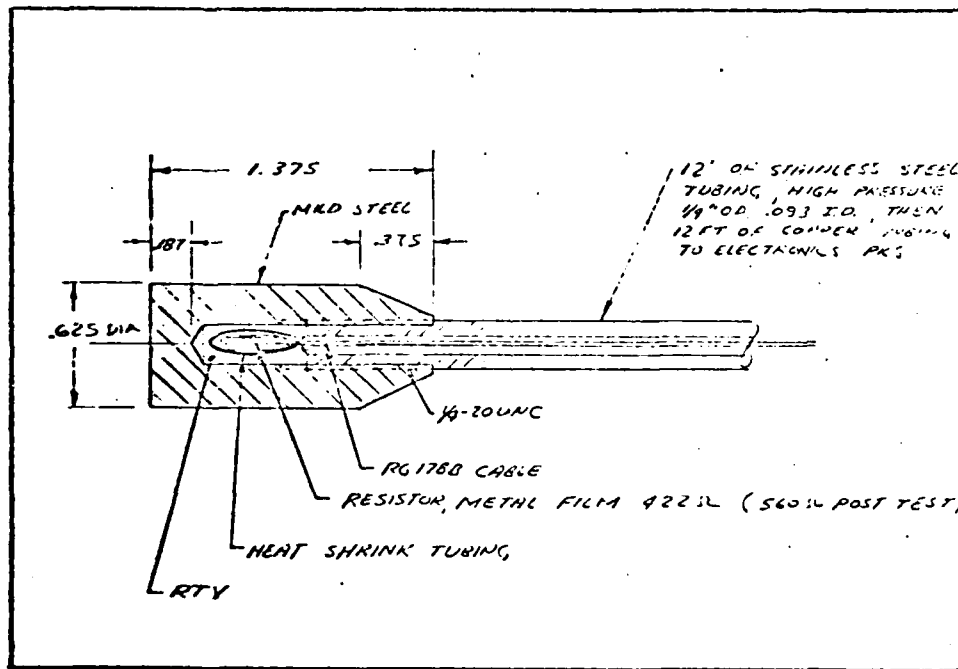


Figure B.3b. Passive Cable Termination

predicted value with the result that both pressure gages were over-ranged beyond the material strength of the diaphragm. In addition to this, the passive cable termination suffered permanent resistive change, thus invalidating that experiment.

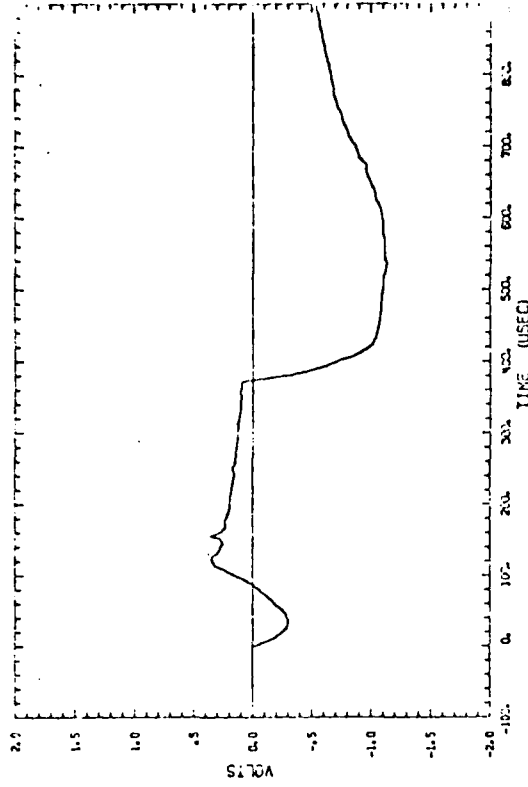
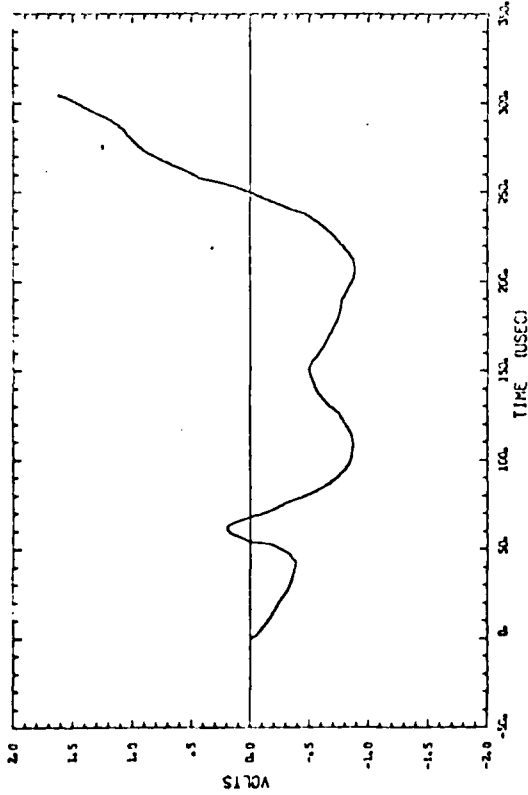
Recorded test data are presented in Figure B.4. Due to that posttest assessment that the gages were over-ranged and observation that the calibration was clearly inappropriate, the data have not been converted to physical units of pressure.

Several observations are made from the test data.

1. The bandwidth of the measurement system is extremely low. A check revealed that due to an oversight at KSC the output circuits in the signal conditioning package had not been modified and the standard 10 kHz output filter was used.
2. The initial negative response of D-1 is inconsistent with physical reality. It is speculated that the initial fast positive response is not observed due to the aforementioned 10 kHz bandwidth and the response seen in Figure B.4a is the destruction of the sensor from overpressure.
3. The cable survival for the spiral treatment was over 300 μ sec in contrast to less than 90 for the sweeping arc. In all objective fairness, it should be noted that the cable experiment D-3 survived the total record time of the disc recorder (T + 8 msec). Inspection of the backup record shows that continuity was maintained throughout the duration of the test.
4. No other conclusions have been drawn from the cable data because of the permanent change in the termination resistance.

All of the gages and cables were recovered and several important observations and conclusions were drawn from

KSC-D-1 D 7/8/77 C 07/11/77 14.35.49.
FAST PLOI KSC-D-3



KSC-D-2 D 7/8/77 C 07/11/77 14.35.51.

SLOW PLOT KSC-D-3

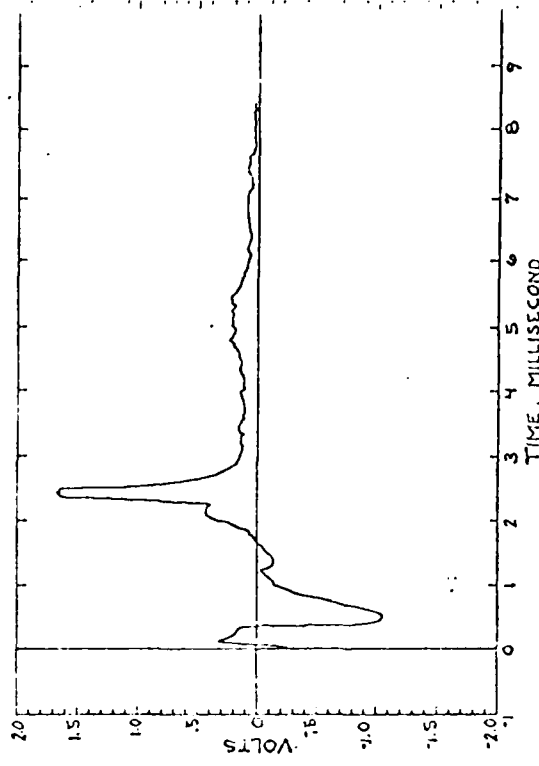
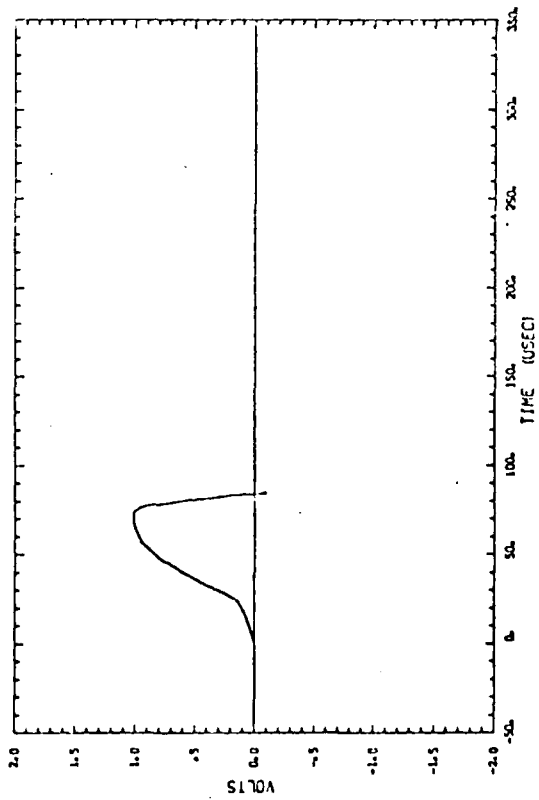


Figure B.4. HE Test Data

physical inspection of these items.

1. A comparison of damage to the two configurations showed that the spiral cable arrangement (D-1) is clearly superior to the sweeping arc (D-2 and D-3). While the weld broke at point of transition from flange to cable tubing on probe D-1, the cable did not suffer any kinks. Probes D-2 and D-3 show very severe kinks resulting from the cable tube buckling under axial load. The cable tube of D-2 also fractured at the point of transition.
2. The shank of probe D-1 is seen to have buckled from axial loading.
3. The diaphragm of sensor D-1 was observed to have failed both in bearing and shear. Similar damage was observed on sensor D-2 diaphragm. A rough calculation predicted the shear failure seen at approximately 175 000 psi (12 kbar) static loading. An experiment was conducted to verify this prediction. The test procedure was to apply a known load and inspect the diaphragm for damage, increasing the load until failure. The shear failure mode which occurred in the HE test was duplicated at a test load of 187 000 psi (13 kbar). Under dynamic loading conditions the failure level would normally be expected to be somewhat above the static level.

From observations 1 and 2, it was decided to use spiral tubing on the HYBLA GOLD event. The transition from probe flange to tubing was strengthened with an additional tapered sleeve. The manufacturing tolerance will be tightened in an effort to eliminate the collapse of the probe shank experienced on this test.

Further, with the evidence from observation 3, it is

believed that the Pre-HYBLA GOLD test was an extreme overtest; however, much useful information was obtained related to failure modes of the sensor, probe and cable assemblies. This information was applied to design modifications for the HYBLA GOLD experiment that were tested on subsequent HE shots.

APPENDIX C
SRI REPORT

SRI fielded two flatpacks, a mutual inductance particle velocity gage, and an ablation gage on the pipe. The results of these measurements are as follows:

1. The steel flatpack with four-terminal Yb element worked very well. The gage survived for 1.3 msec, i.e., until the ground shock reached the cable connections. Post-shock dissection of the recovered gage showed the gage element to be in excellent condition. The peak stress recorded by the gage was approximately 14 kbar; the stress at the pipe wall decayed to zero over a period of about 300 μ sec (Fig. C.1).
2. No record was obtained from the aluminum flatpack with the two-terminal manganin element. The disc recorder was driven to band-edge at power supply turn-on. The back-up tape recorder showed that the magnitude of the voltage offset corresponded to that expected for an open gage circuit. However, post-shot dissection of the gage revealed that it was still in good condition...the element was somewhat deformed but was still electrically continuous. Since this gage worked perfectly when pulsed in dry runs, it appears that the gage was disconnected between the last dry run and the shot. We suspect that someone may have brushed against a cable connector and knocked it loose.
3. The ablation gage with a constantan element survived for about 200 μ sec (Fig. C.1); until the shock arrived at the cables. No significant stretching of the gage element occurred during this period.
4. The mutual inductance particle velocity gage worked well, indicating a peak particle velocity of about

0.35 mm/ μ sec. This particle velocity was higher than expected; the disc recorder was driven to band-edge, but we did get a low resolution record from a back-up tape channel. The purpose of this experiment was to obtain independent particle velocity diagnostics and to serve as a control for SLA's test of a shielded particle velocity gage.

We consider that the data obtained by all experimenters are in superb agreement, when suitable corrections for gage range differences are made. We intend to use the present version of the steel flatpack and the ablation gage on HYBLA GOLD.

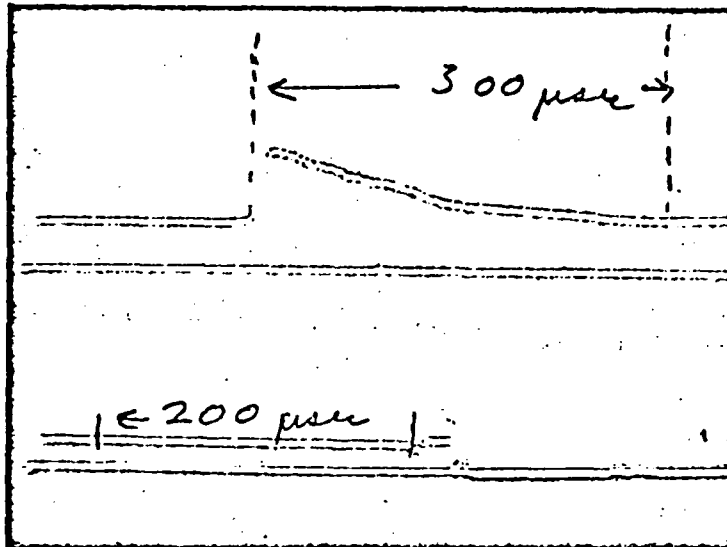


Figure C.1. Test Survival Times

APPENDIX D SSS REPORT

The SSS bar gage has been extensively modified for use in HYBLA GOLD. In particular, the sensor is an ytterbium grid, the input bar is immersed in a water jacket, and the front end of the input bar consists of several weakly-bonded cylinders designed to break off as they are exposed to the flow during pipe expansion. These changes were tested individually in several small HE tests during the early months of this project.

As a result of the technical review meetings for the HYBLA GOLD, a "production model" of the bar gage was not produced until just before the Pre-HYBLA GOLD HE test at SLA. Figure D.1 shows the principal features and Table D.1 gives the detailed specifications for the two instruments fielded for that shot. The results, Table D.1 and Figure D.2, were nearly identical. The 6 μ sec risetimes are as expected for the frequency dispersion in the one-half inch tungsten carbide rod and the peak pressures are consistent with other observations at greater ranges. Both gages failed prematurely 27 to 29 μ sec after shock arrival.

After that test, a number of gage failure hypotheses were tested in subsequent HE shots. An improved lead support and the elimination of flexure wave propagation into the sensor led to a survival for 60 μ sec on the last HE test.

Figure D.3 shows the final design for the Yb grid.

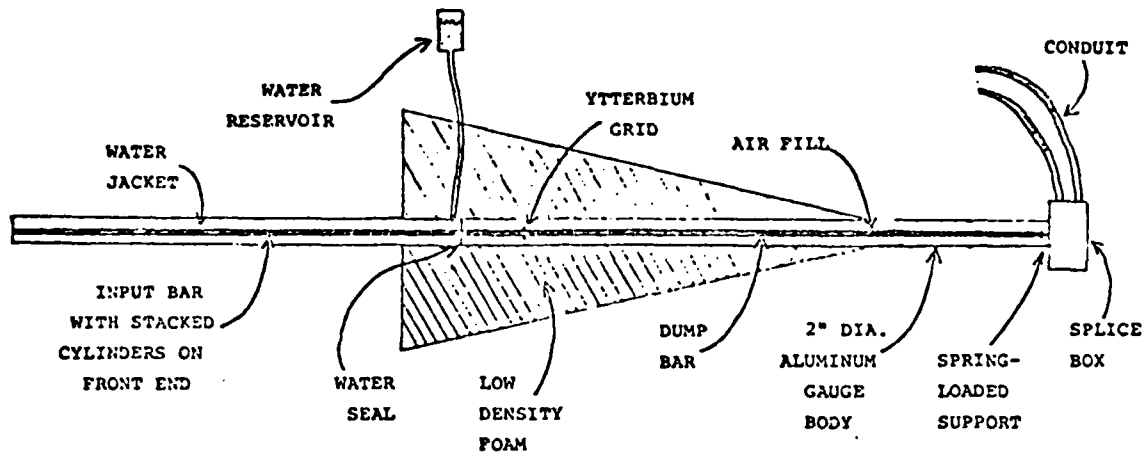


Figure D.1. Bar Gage-Schematic Section View

SUMMARY OF GAUGE FEATURES FOR PRE-HYBLA GOLD SHOT

- SOURCE:** Cylindrical C4 Charge, 30.4 cm in diameter; centered in water filled concrete pipe, 91.4 cm ID, 116 cm OD; pipe and attached gauges grouted in sand pit.
- RANGE:** 61.0 cm, charge surface to input bars; predicted peak pressure varies as $R^{-1.57}$, 14 kB at pipe's interior wall.
- GAUGES:** (Tungsten Carbide, GE Grade 883, Input Bars; Titanium 6Al-4V Alloy Dump Bars; 1.27 cm dia.)
 #1 and #2: Four input chips, 1.9 cm each; 31.1 cm solid input; 1.9 cm Lucalox base for Yb grid; 1.27 cm Lucalox disk; 50.8 cm dump; full aluminum gauge body with 23.5 cm water jacket around input bar.
- RESULTS:** Arrival times and peak pressures consistent with gauges at greater ranges, $P \sim R^{-1.87}$.

GAUGE	INPUT DELAY	DUMP REFLECTION TIME	O B S E R V E D		
			ARR	PEAK	FAILURE
#1	60 μ s	202 μ s	113 μ s	26 kB	142 μ s
#2	60 μ s	202 μ s	112 μ s	28 kB	139 μ s

Table D.1

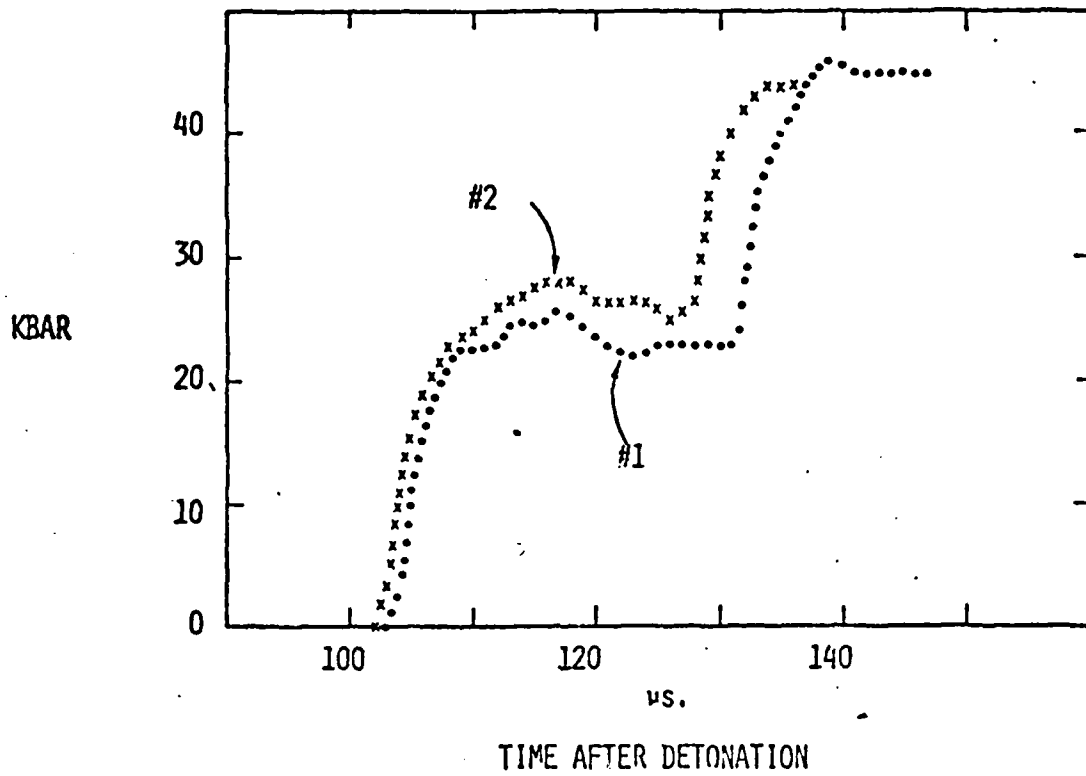


Figure D.2. Results of SSS Bar Gages

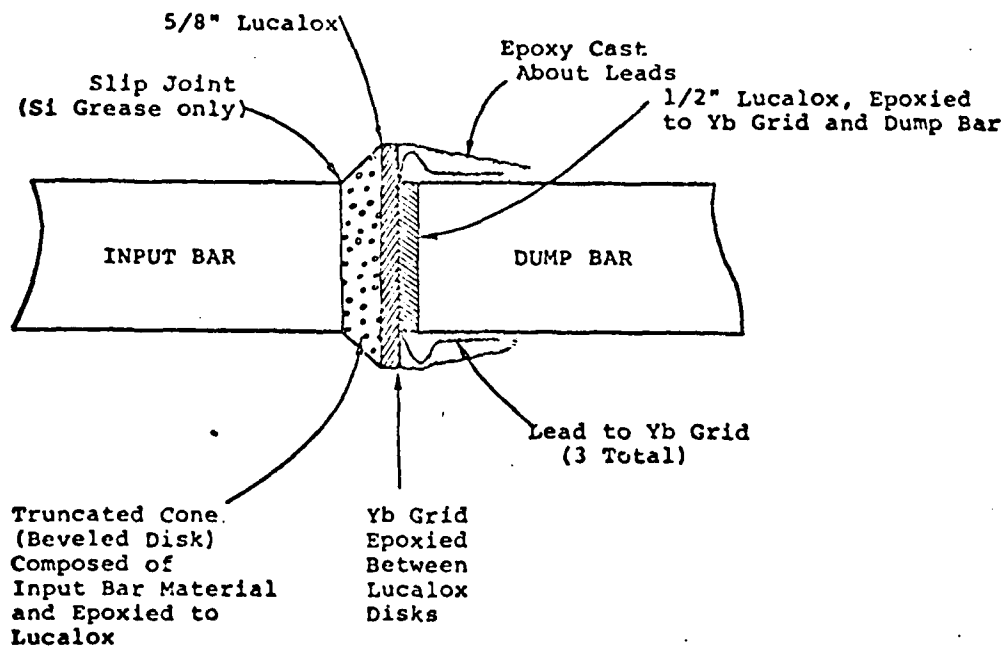


Figure D.3. Detail of Bar Gage Pressure Sensor

APPENDIX E TRW REPORT

The dielectric-filled metal waveguide is simply an 11 mm x 23 mm X-band hollow metal waveguide ($\lambda_g = 18$ mm at 12 GHz) with a metal foil covered teflon rod that is inserted into the end of the hollow waveguide. To assure structural integrity under stress loading, a teflon sheath surrounds the outside. Figure E.1a shows that the waveguide is attached to the concrete wall by an epoxied aluminum flange that also serves as the metal target reflector.

The dielectric/dielectric open waveguide consists of a high dielectric constant ($K=10$) core composed of Eccoflo powder from Emerson and Cumings Inc., and a lower dielectric constant ($K=2.2$) sheath. The rectangular core dimensions are 19.8 mm x 3.99 mm. The sheath dimensions are 19.8 mm x 3.99 mm for the inside rectangle and 50.80 mm for the outside diameter. The entire waveguide is enclosed in an aluminum circular cylindrical tube 57.15 mm outside diameter and 3.175 mm thick ($\lambda_g = 12$ mm at 12 GHz). These are shown in Figure E.1b. Also shown is the transition from dielectric/dielectric waveguide cross-section to hollow metal rectangular waveguide.

The excavations for the microwave waveguide measurement include the pit containing the water-filled concrete pipe, the pit for the air gap for reducing the ground motion at the downstream instrumentation bunker, and the pit for the microwave instrumentation (Fig. 1 in the Main Report).

The instrumentation system is shown in Figure E.2. The electronics are soft mounted in their pit on horse hair pads and are protected from overhead shrapnel by a plywood plank and sandbags. The instrumentation pit centerline is 9 m from the edge of the concrete pipe, and is 1.2 m by 1.2 m across and 1.2 m deep. The air gap pit is 0.6 m wide along a line from the pipe, 1.5 m wide normal to a line from the pipe and 1.2 m

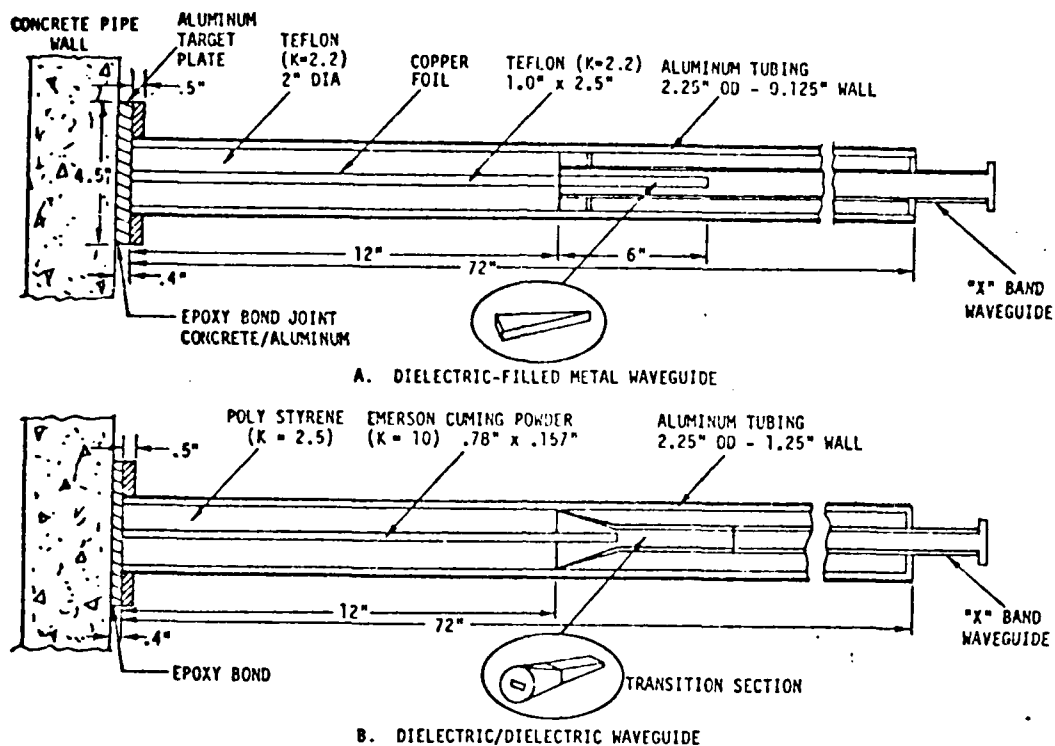


Figure E.1. Waveguide Sensor Detail

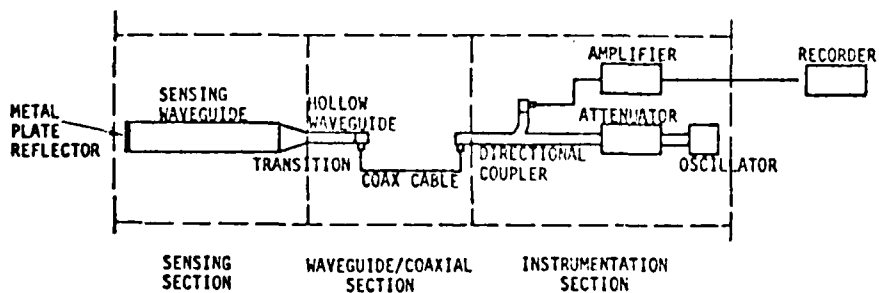


Figure E.2. Instrumentation System

deep. Recording was done on the Sandia 5 MHz disk.

Figure E.3a shows the voltage history from the dielectric-filled metal waveguide. The top trace shows the slower display at 20 μsec per 20 mm. The data record starts at 10770 μsec referenced to a zero fidu at 10615.5 μsec . The middle trace shows the faster and more expanded time display at 5 μsec per 20 mm. Point A on the upper trace corresponds to Point A on the lower trace. The bottom trace is the calibration. Figure E.3b is in the same format for the dielectric/dielectric waveguide.

The data reduction is straightforward for a waveguide that undergoes one-dimensional crushing along its longitudinal axis, that does not suffer a change in waveguide wavelength, and that does not change its crushing velocity in the measure time interval. The metal target velocity (U) is obtained from the dynamic measured time interval between minima of the voltage history date (Δt), and the static measurement of the waveguide wavelength performed in earlier laboratory test (λ_g), as follows:

$$U = \frac{\lambda_g}{2\Delta t}$$

The data depicted in Figures E.3a and E.3b show a high frequency and low amplitude signal superimposed on a low frequency and large amplitude signal which is characteristic of a mismatch between the compressed waveguide wavelength (λ_{g2}) and the unperturbed waveguide wavelength (λ_{g1}). This requires a more complex data reduction, including the sequence of:

1. An estimate of shock velocity (W) from the high frequency signal (Δt_2) and the unperturbed waveguide wavelength (Δ_{g1}) given by:

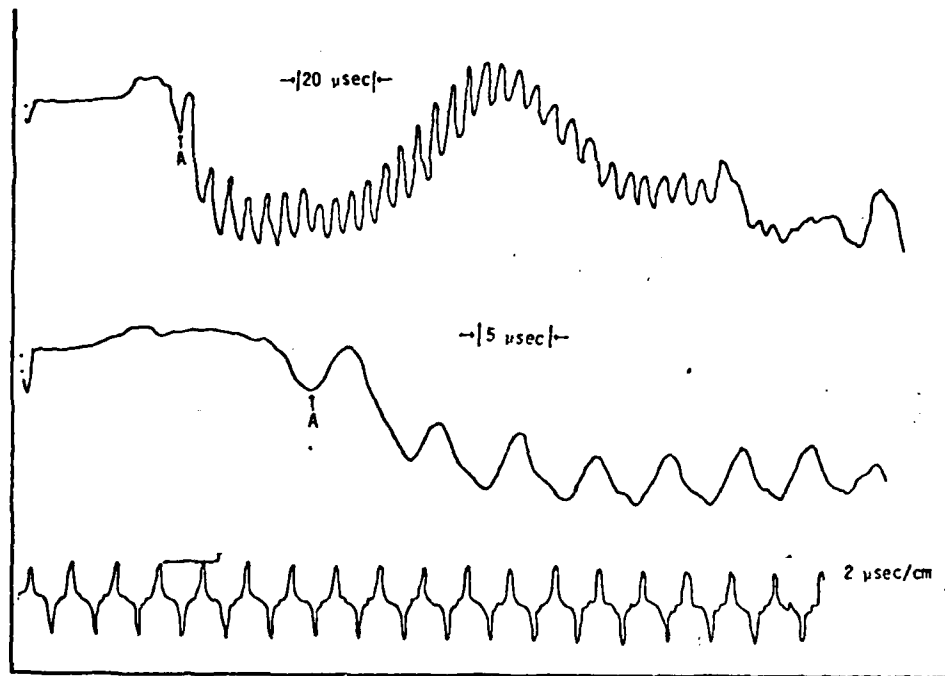


Figure E.3a. Voltage History of M/D Waveguide

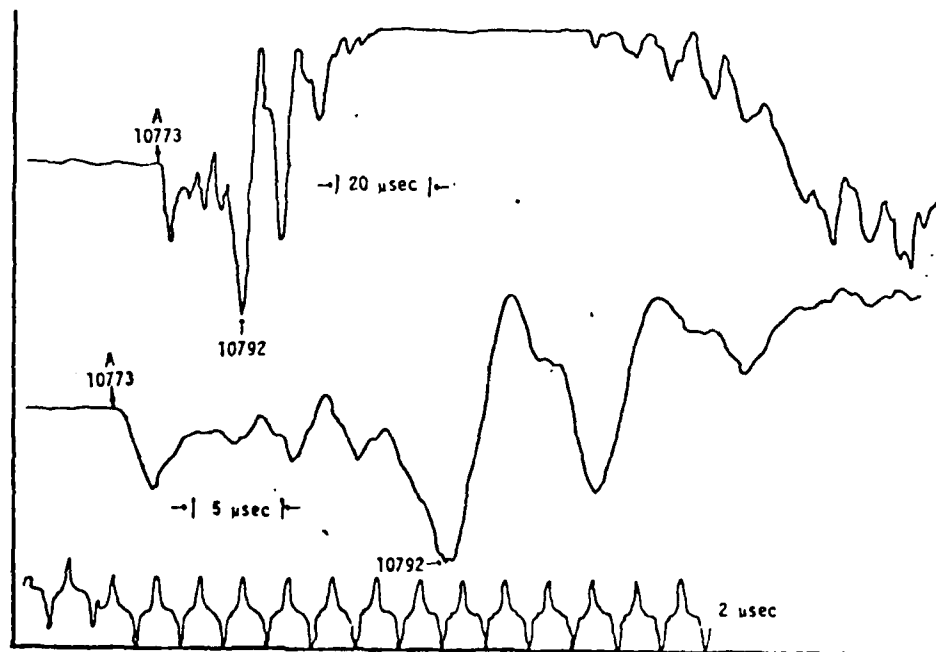


Figure E.3b. Voltage History of D/D Waveguide

$$W = \frac{\lambda_{g1}}{2\Delta t_2},$$

2. an estimate of the initial particle velocity (U) from the equation of state of the waveguide material which relates U to W ,
3. an estimate of the shock compressed waveguide wavelength (λ_{g2}) from the low frequency signal Δt and the relation:

$$U = \frac{\lambda_{g2}}{2\Delta t_1} + W \left(1 - \frac{\lambda_{g2}}{\lambda_{g1}} \right),$$

4. an estimate of the time constant (T) of the exponential decay of the target plate velocity:

$$U = U_0 \exp(-t/T), \text{ and}$$

5. an iteration of the computer program for the estimated values of U_0 , W_0 , T , λ_{g1} , λ_{g2} , $\tan\omega_1$ and $\tan\omega_2$.
Estimates of the shock compressed loss tangent, $\tan\omega_2$, can be obtained by noting the time to achieve no voltage swing on the data record, and varying $\tan\omega_2$ to match this time to no voltage swing. Values of $\tan\omega_1 = 4 \cdot 10^{-4}$ and $\tan\omega_2 = 10^{-3}$ are good initial values.

Considering first the dielectric-filled metal waveguide (TRW-1), and using a low frequency time interval $\Delta t_1 = 82 \mu\text{sec}$, a high frequency time interval $\Delta t_2 = 4 \mu\text{sec}$, and a previously established laboratory resonance wavelength $\lambda_{g1} = 18.16 \text{ mm}$, the preliminary estimates are:

$$W_0 = \frac{\lambda_{g1}}{2\Delta t_2} = 2.27 \frac{\text{mm}}{\mu\text{sec}}$$

$$U_0 = \frac{\lambda_{g2}}{2\Delta t_1} + W_0 \left(1 - \frac{\lambda_{g2}}{\lambda_{g1}}\right) = 0.28 \frac{\text{mm}}{\mu\text{sec}}$$

The value of λ_{g1} is assumed to be about 8% different from λ_{g2} . These values started a series of iterative computer runs where U_0 was varied. When the exponential decay time constant of 150 μsec is introduced, then $W_0 = 2.27 \frac{\text{mm}}{\mu\text{sec}}$ and $U_0 = 0.28 \frac{\text{mm}}{\mu\text{sec}}$ still fit the low frequency data record best.

The initial pressure can be calculated from $P_0 = \rho W_0 U_0 = 14 \text{ kbar}$, where the density (ρ) of teflon was used for the over-all waveguide density. Incidentally, the values of P_0 , W_0 and U_0 are consistent with the Hugoniot of teflon.

In the case of the dielectric/dielectric waveguide, the high frequency data are not clear. The low frequency data show a time interval of 16.2 μsec at early time.

These data should not be reduced since they are so complex. At best, one can only assume part of the required result and check if it is consistent with the measured 16.2 μsec . Say

$$W = 3 \text{ mm}/\mu\text{sec} \text{ and } \left(1 - \frac{\lambda_{g2}}{\lambda_{g1}}\right) = 0.16 ,$$

then

$$U = \frac{\lambda_{g1}}{2\Delta t} + \left(1 - \frac{\lambda_{g2}}{\lambda_{g1}}\right) W = .82 \text{ mm}/\mu\text{sec},$$

and the resulting initial pressure is $P_0 = \rho W_0 V_0 = 26 \text{ kbar}$.

This pressure, particle velocity and shock velocity, however, are not consistent with the equation of state of polystyrene.

The data reduction assumes that the metal target plate crushed along the longitudinal axis. However, the post-shot recovered metal target plate was only slightly dished inward, and the shield attached to the target plate showed no permanent deformation associated with crushing. Thus this strong structural version of the displacement history gage should not have been used at the 10-20 kbar range, only at higher stress ranges.

We conclude that both the microwave waveguides underwent alteration of their waveguide wavelengths under shock compression. The metal-filled dielectric waveguide data reduction was complex as a result of this waveguide wavelength alteration. Approximately half of the particle velocity value came from the coupling of the shock velocity and the shock compressed waveguide wavelength. This is undesirable, and is a property of teflon already noticed in earlier CERF explosives tests. But with calibration, this undesirable effect can be handled.

The dielectric/dielectric waveguide data reduction was not possible. The waveguide wavelength alteration under pressure was so severe that the particle velocity data became masked. About 75% of the particle velocity value came from the coupling of the shock velocity and the shock compressed waveguide wavelength. This is unacceptable. This behavior of polystyrene and Eccoflo powder did not occur in earlier tests at IITRI and it should be suspected that there is a difference in the various grades of polystyrene and powder used in the past and current waveguide. The Emerson and Cuming, Inc. Eccoflo powder may also have been altered between the past and current waveguide.

An overriding effect in this test was that the dielectric/

dielectric waveguide did not crush inward along its longitudinal axis as is required for its operation. The post-shot recovered waveguide showed the shield was too thick and the shield structure resisted the waveguide crushing. The metal target reflector plate was therefore restrained from moving toward the detector in its planned mode of operation.

APPENDIX F
SLA REPORT

Figure F.1 shows a top view of the placement of the SLA gages with respect to the concrete pipe. The individual gage results follow.

1. Fluid Coupled Plate (FCP)

The FCP gage on Pre-HYBLA GOLD received an input which was higher than the capability of the gage. However, useful information was obtained from the test. Gage failure occurred 20.3 μ sec after the arrival of the stress pulse which was 14 μ sec after the peak of the pressure pulse. Essential data points are tabulated below:

	<u>Yb-1 (FCP)</u>	<u>Yb-2(FCP)</u>
Pulse Arrival	238 μ sec	238 μ sec
Pulse Risetime (0-100%)	6.3 μ sec	6.3 μ sec
Peak Stress	11.4 kbar	10.6 kbar
Bellows Failure	20.3 μ sec*	---
Impact of Plate on Sensor	27.2 μ sec*	---
Est. Cable Failure	\sim 140 μ sec*	---

* Time after arrival of pulse.

The recorded pulses are depicted in Figures F.2 and F.3. Hydrocode calculations of the response of this type of gage to strong fast-rising shocks have shown a significant initial overshoot. Specifically, the overshoot was a factor of 1.7 for a rise-time of 120 μ sec, and had a width of a few 10-s of μ sec. Since the expected pulses had comparable rise-times, and the measure pulse shapes had comparable widths, we feel that the free-field peak stress was substantially less than that recorded by the gage. Simply applying the 1.7 factor gives 6.5 kbar. An uncertainty of like \pm 30% seems reasonable.

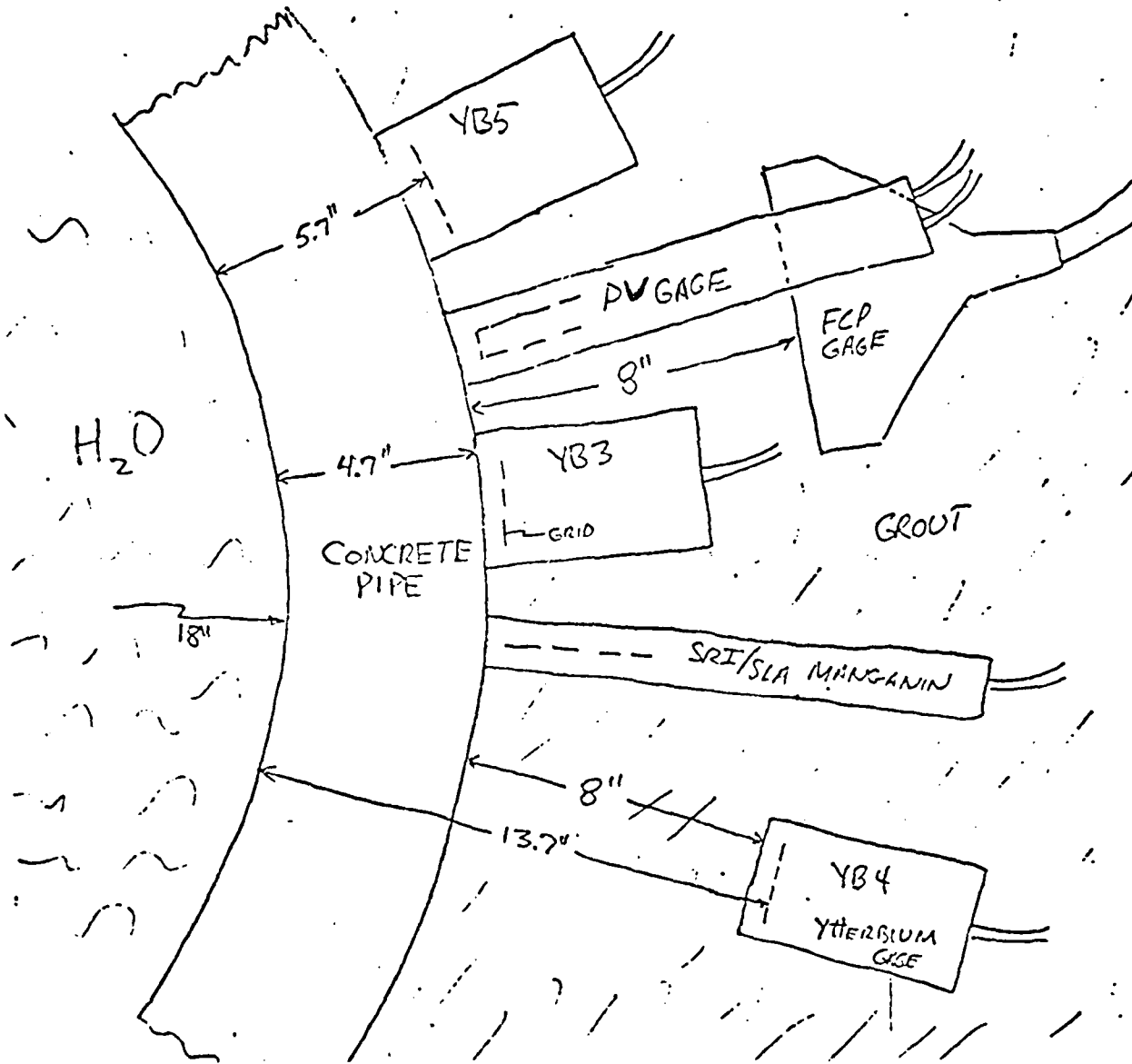


Figure F.1. Top View of SLA Gages on Pipe

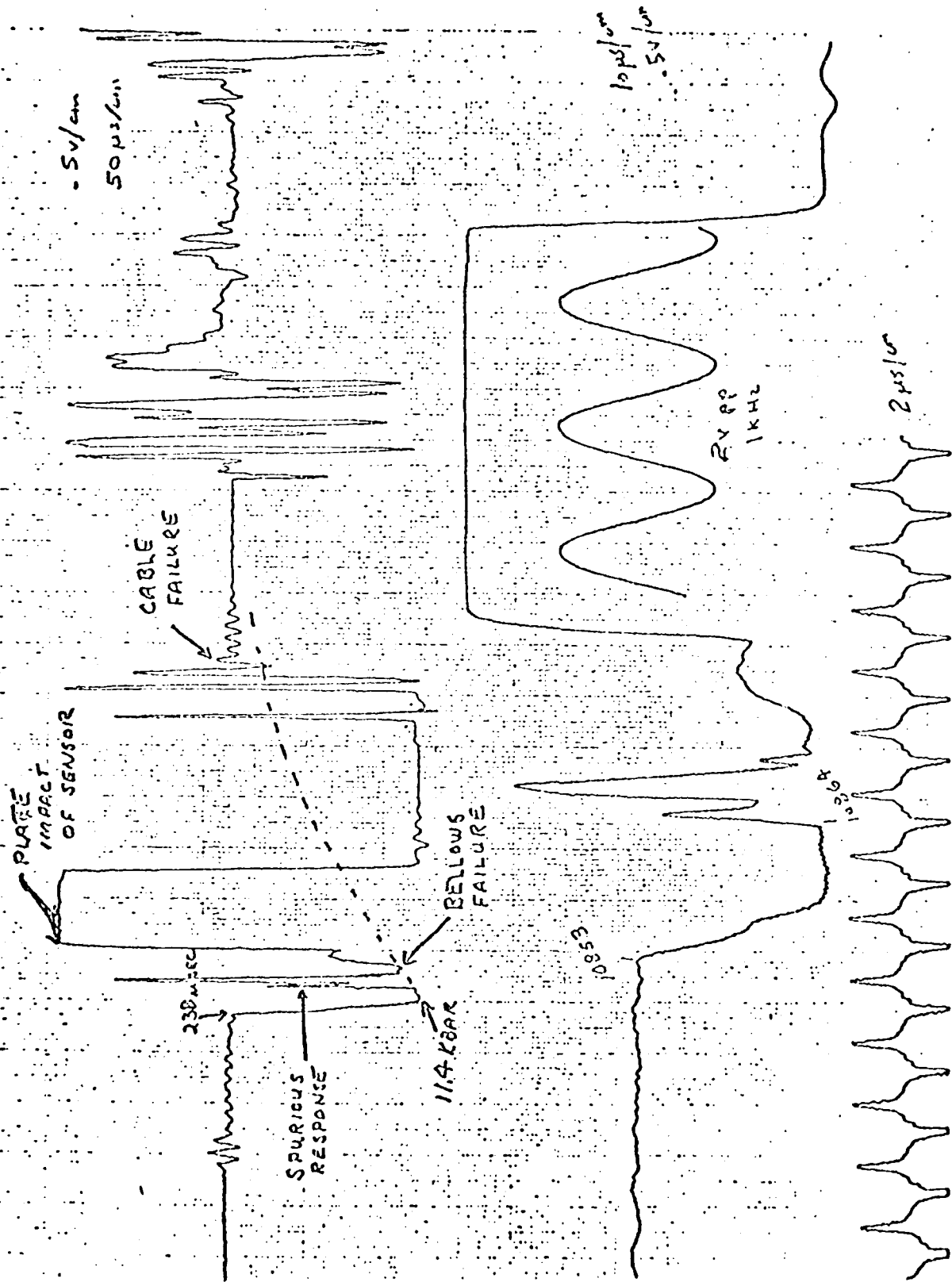


Figure F.2. FCP-1 Voltage Record

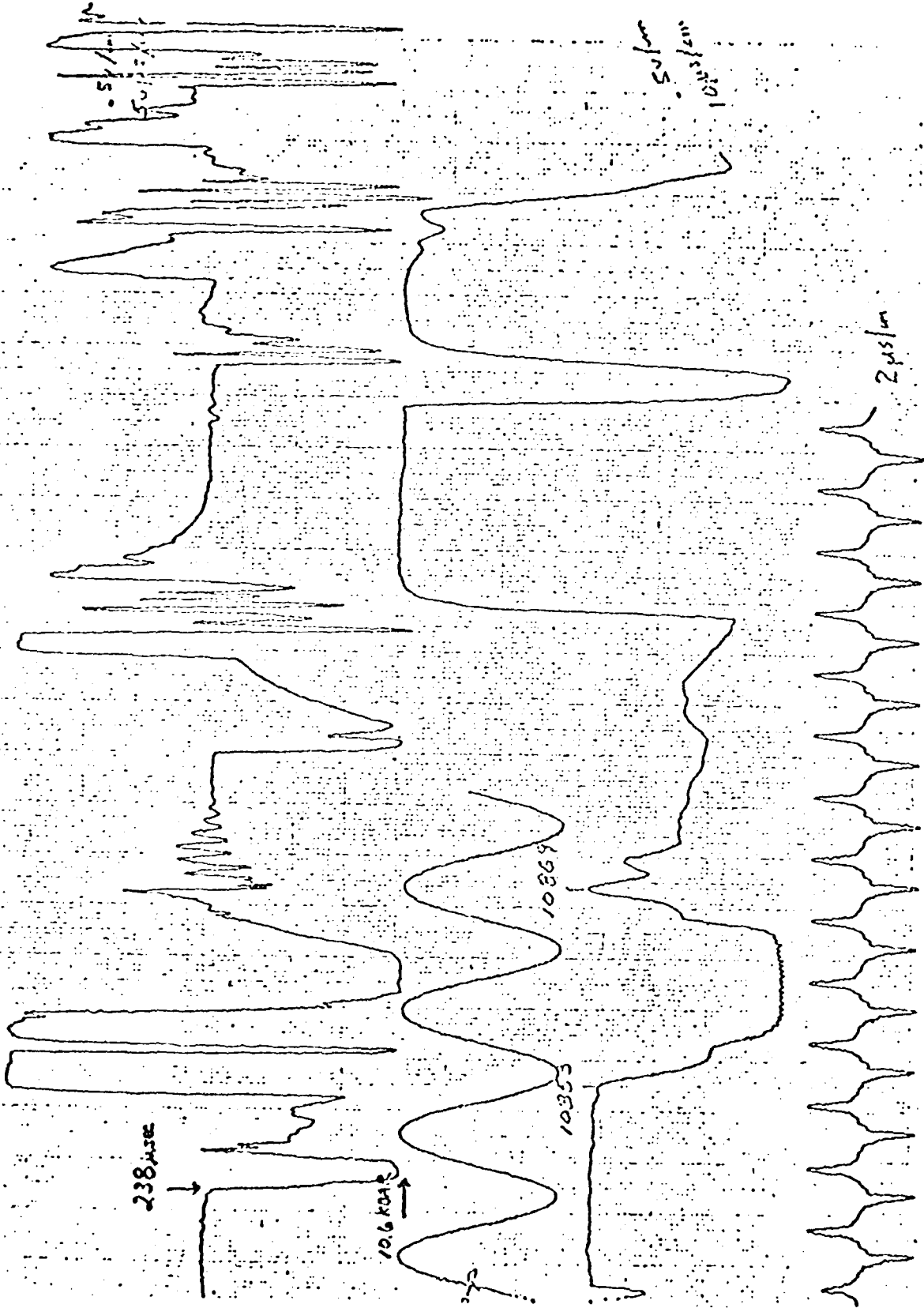


Figure F.3. FCP-2 Voltage Record

2. Cavity Pressure Tubes

Two types of potential tubes were passively evaluated on Pre-HYBLA GOLD. The types were as follows:

- 9.53 mm O.D. by 3.43 mm I.D., 304 stainless steel
- 9.53 mm O.D. by 3.43 mm I.D., 4130 steel

Seven of eight samples fielded were recovered. Four samples were fielded in the water (standing) along the inside of the concrete pipe. Four samples were fielded in the grout with one end against the concrete pipe near the center line of the charge. Two tubes in each group were grooved at 0.30 m intervals. These grooves were intended to provide stress concentrations which would allow the tubes to break rather than be twisted. Inspection of the recovered tubes indicates the following:

	<u>304-SS</u>	<u>Steel 4130</u>
Clean Breaks at Grooves	yes	yes
Length closed in water	1.38 m	1.22 m
Max pressure at which tube remained open	*	15-16 kbar

* The tube which will give this data has not been inspected.

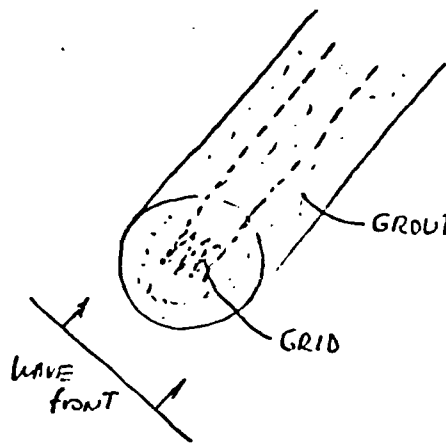
Based on the preceding it is concluded that the 4130 is superior to the SS for the cavity pressure measurement. Also the stress at which the tube remained open indicates that the HYBLA GOLD experiment has a reasonable chance of working.

Two other observations can be made from the tubes (radial) in the grout.

- a. Each section near the pipe was shortened. The first three were shortened about 25 mm each.
- b. There is a gradual closing of the tube along the pressure gradient, i.e., no opening at 15-16 kbar: less than 0.4 mm diameter change at 6-7 kbar (I.D. >3.05 mm).

3. Stress and Motion

The ytterbium gages (Yb 3, 4, and 5) consisted of 50 ohm grids cast in Epoxy (REN) cylinders. The cylinders were 114 mm in diameter by 152 mm long; the grids were 25.4 mm back from the front face of the cylinders. The 305 mm long particle velocity coils were potted in an aluminum can with the same grout recipe used to backfill the pit. The sensing portion of the gage was 25.4 mm back from the front surface of the can. Unfortunately the can was not coated, hence there is the possibility of the cement reacting with the aluminum to form gas bubbles. The SRI/SLA manganin gage was fabricated by SRI and fielded by SLA. It consisted of a 50 ohm manganin grid on an "end on" configuration as shown in the sketch. This unusual orientation was chosen to enhance survivability in a strongly divergent field. The grid and its fiberglass-epoxy substrate were potted in a treated aluminum can with grout.



The following table gives time-of-arrival and peak measurements.

<u>Gage</u>	<u>TOA (μsec)</u>	<u>Peaks</u>
Yb3	164	17.1 kbar
Yb5	163.5	17.4 kbar
Yb4	239	10.1 kbar
Mang.	163.5	-
PV	165	0.36 mm/ μ sec

Figure F.4 shows an x-t plot of the TOA data. The slope of the line between the gages on the pipe and the Yb4 gage gives a wave front velocity of 3 mm/ μ sec. Figure F.5 shows a stress attenuation plot. The solid line is pre-shot, design calculation. The x points are the ytterbium measurements, the circles are the ytterbium measurements roughly corrected, using impedance match techniques, for the difference in impedances of the REN epoxy and the grout.

Figures F.6a and F.6b show the two ytterbium gages on the pipe. These waveforms differ only in minor unloading detail. Yb3 broke at 390 μ sec at which time the wave front was about 635 mm beyond the sensing element. (In reducing the ytterbium data a linear reduction was used, i.e., no attempt was made to adjust for the gage hysteresis.)

The Yb4 gage, shown in Figure F.7a, was 0.20 m out from the pipe. Its rise and peak are credible, although the origin of the detail just before the peak is unknown. On the unloading, however, something strongly affected the stress field observed by the gage. There was a waveguide less than 0.1 m from the gage, which may have been air-filled

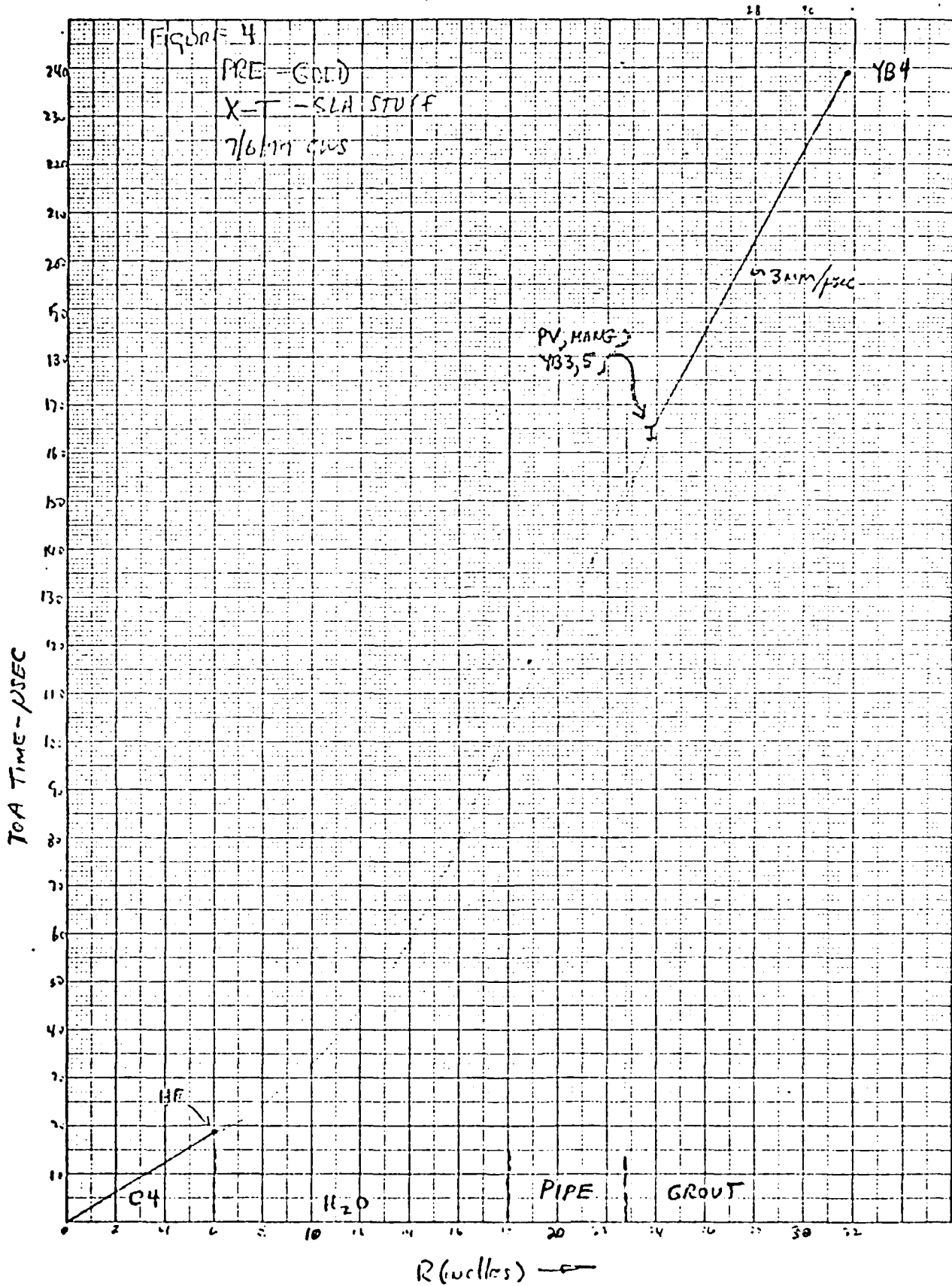


Figure F.4. Time-of-Arrival Data

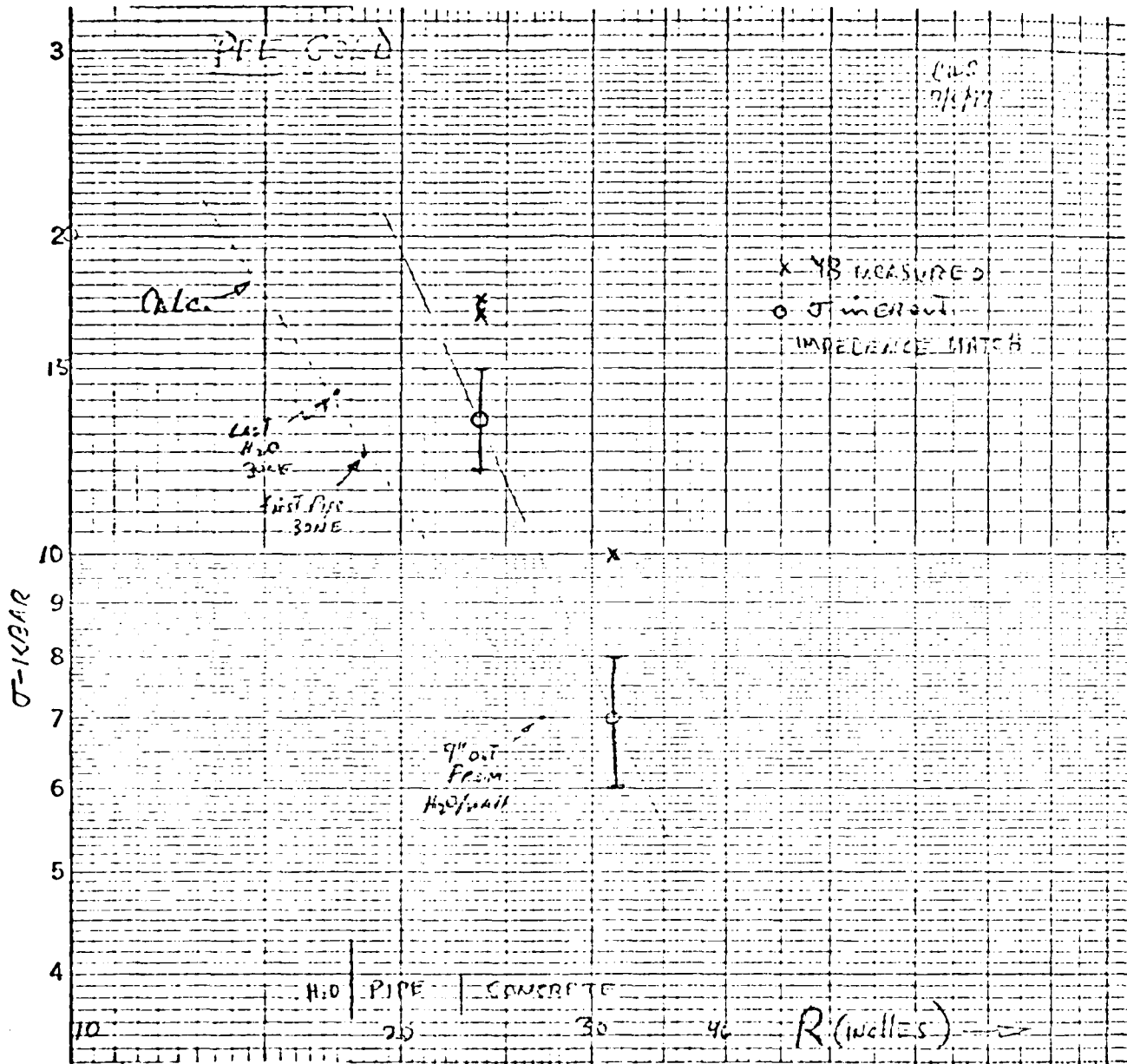


Figure F.5. Stress Attenuation

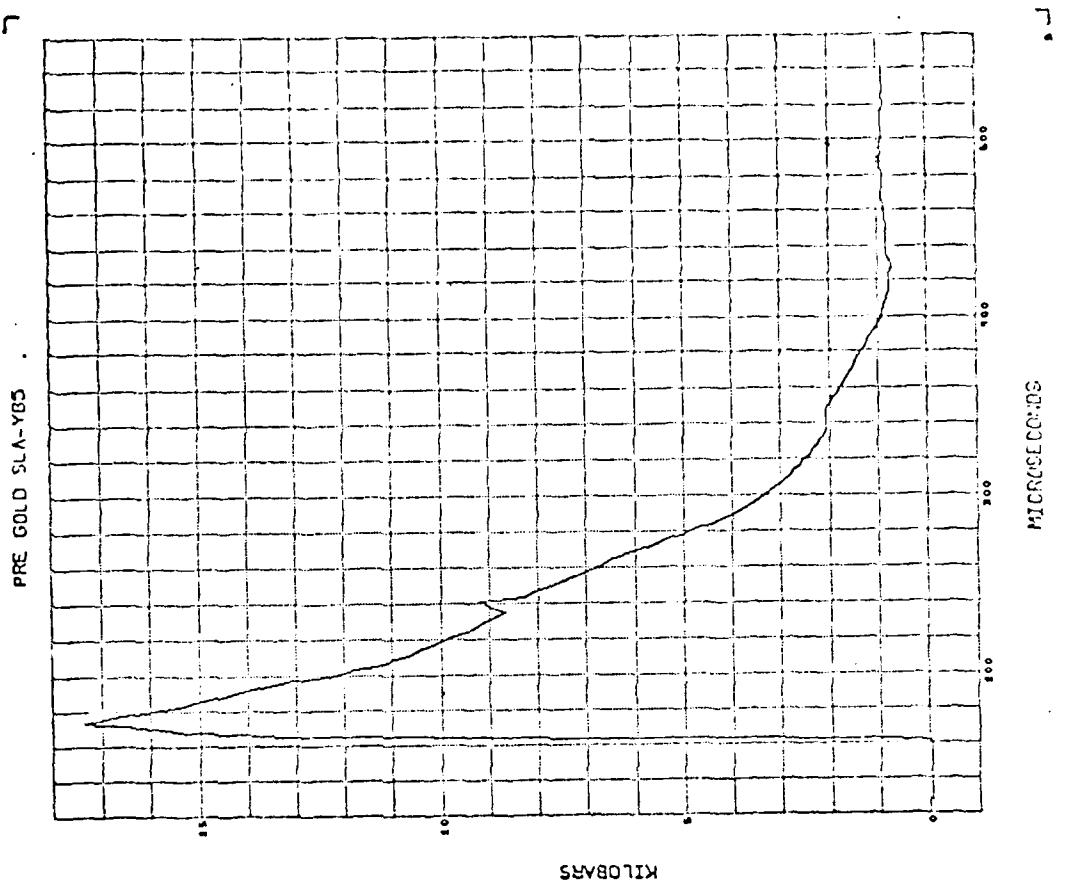


Figure F.6.b. Yb5 Record

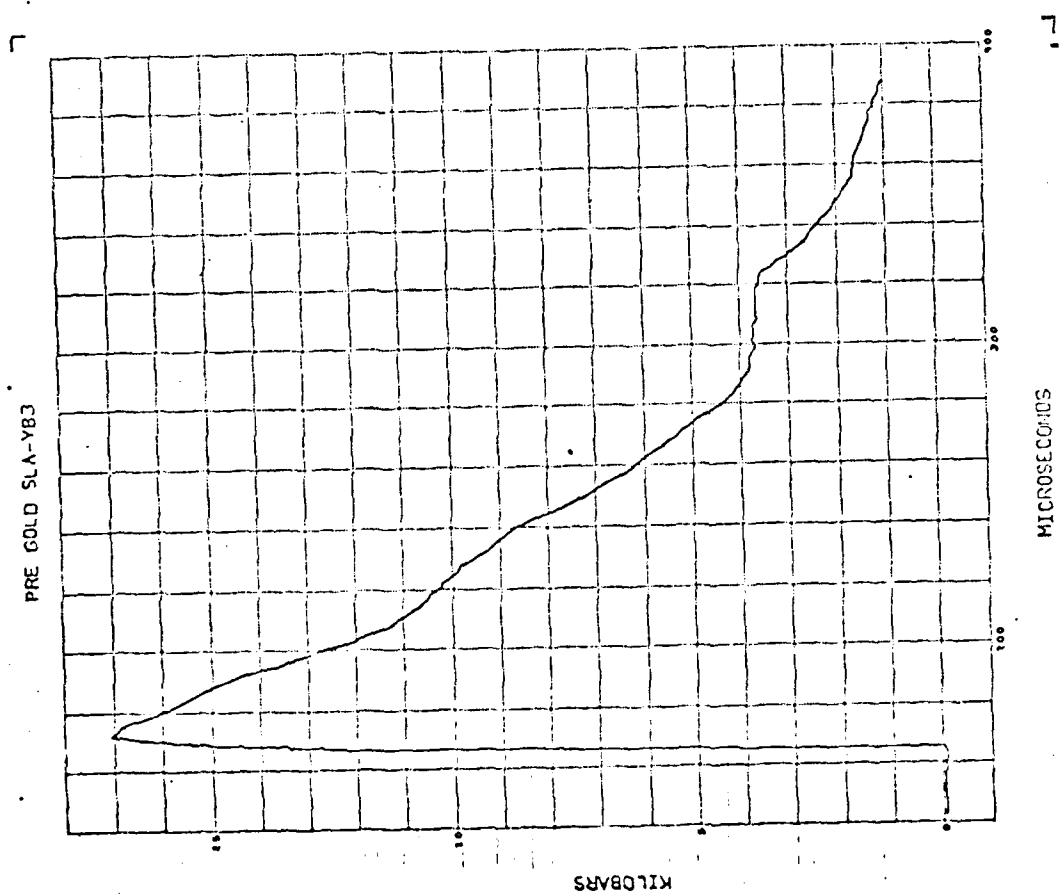


Figure F.6a. Yb3 Record

at this range. The crushing of this item could easily have reduced the local stress field and, when fully crushed, the stress increased. This argument is speculative.

The SRI/SLA manganin gage failed electrically at TOA for unknown reasons. SRI feels that the grout in the tube may have pulled away from the tube leaving air spaces. Such spaces give rise to high accelerations which often destroy electrical leads. Similar gages for HYBLA GOLD will use epoxy to pot the grids in an aluminum can.

The particle velocity gage record displayed in Figure F.7b, showed the right TOA for its location, the trace rose to 0.36 mm/ μ sec, and after about 100 μ sec of unloading, a current lead broke. (At breakage time the wave front was about 178 mm behind the sensing element.) The "ripples" on the top of the waveform are probably associated with the "crumpling" of the wire coils. This gage was not recovered, hence we were unable to do any post shot analysis on the current break problem. In density 2.15 Mg/m³ grout, a shock velocity of 2.9 mm/ μ sec and a particle velocity of 0.36 mm/ μ sec imply a pressure of 22 kbar which is in qualitative agreement with the measured stress.

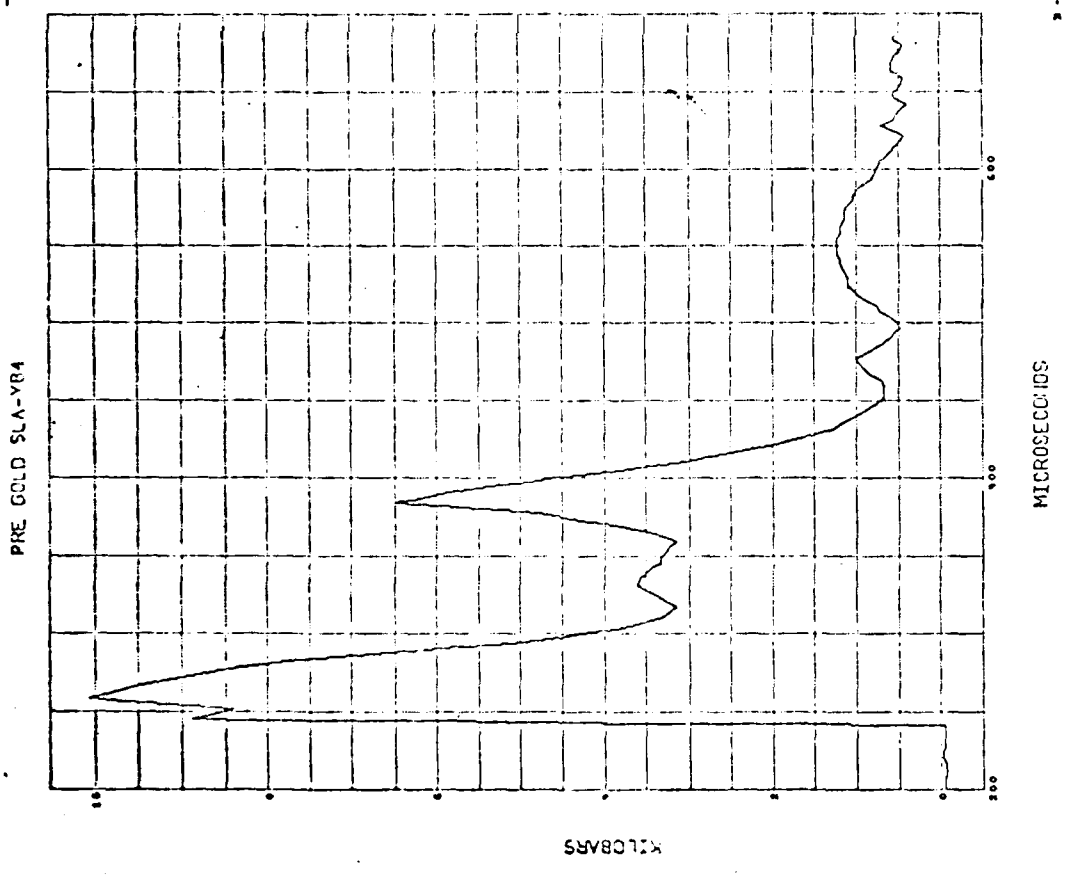
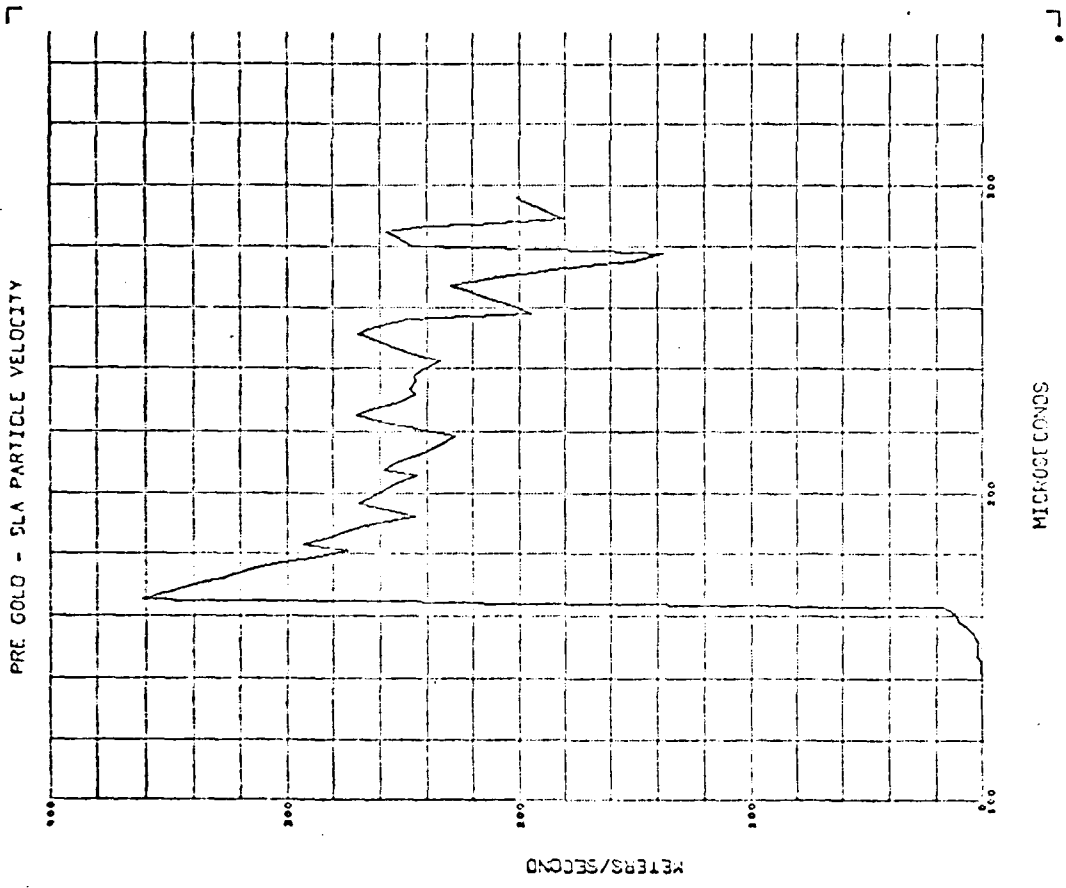


Figure F.7b. PV Gage Record

Figure F.7a. Yb4 Record

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