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DIABLO HAWK EVENT: CAVITY PRESSURE SENSORS PACKAGE GROUND SHOCK--ETC(U)

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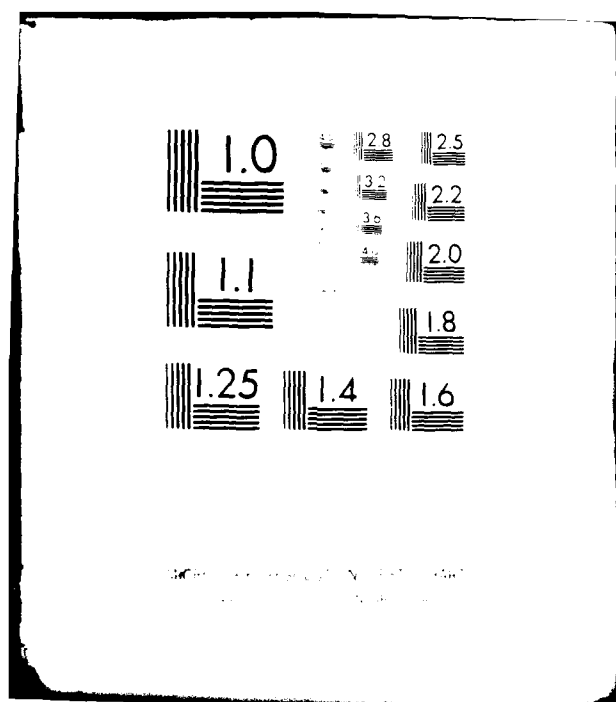
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DIABLO HAWK EVENT

Cavity Pressure Sensors Package Ground Shock Isolation Experiment

Systems, Science and Software

P.O. Box 1620

La Jolla, California 92038

30 November 1978

Final Report for Period 20 June 1977-30 November 1978

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20. ABSTRACT (Continued)

is terminated at the recording trailers. The shock isolation package was mounted to the end-of-stemming bulkhead located in the TAPS crosscut (the cross-drift leading to the TAPS from the by-pass drift). To evaluate the effectiveness of the shock isolation system, two high g rated accelerometers were attached to the stemming bulkhead and two lower rated accelerometers were attached inside the package. Continuous signals were recorded from each of the four accelerometers as well as from the two pressure gauges from minus two minutes until the recording trailer power was terminated at plus five minutes. The two bulkhead-mounted accelerometers showed good agreement with groundshock arrival at 72 ms after zero time and a peak acceleration of 71g. Inside the shock isolated package the first acceleration was recorded at 77 ms and the peak acceleration was 10.8g. The two package mounted accelerometer signals were essentially identical. The two pressure gauge outputs remained constant through the recording time. The electronic signal conditioning equipment for each of the six sensors used was the 4 to 20 mA type transmitter. With no stimulus the current transmitter has a constant output of 4 mA for the pressure and 12 mA for the acceleration; thus the output of pressure channels and the output of the acceleration channels before and after the acceleration signals were recorded proved that the signal cables stayed intact.

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SUMMARY

DIABLO HAWK was an underground tunnel test to investigate the effects of a nuclear explosion on various structures and systems.

Systems, Science and Software fielded an experiment to demonstrate the feasibility of mounting pressure gauges with built-in electronics in a manner to effectively isolate the ground shock and permit continuous output (pressure reading) for a period starting prior to zero time and continuing until power is terminated at the recording trailers. The shock isolation package was mounted to the end-of-stemming bulkhead located in the TAPS crosscut (the cross-drift leading to the TAPS from the by-pass drift). To evaluate the effectiveness of the shock isolation system, two accelerometers were attached to the stemming bulkhead and two lower rated accelerometers were attached inside the package. Continuous signals were recorded from each of the four accelerometers and the two pressure gauges from a minus two minutes until the recording trailer power was terminated at plus five minutes. The two bulkhead-mounted accelerometers showed good agreement with groundshock arrival at 72 ms after zero time and a peak acceleration of 71g. Inside the shock isolated package the first acceleration was recorded at 77 ms, and the peak acceleration was 10.8g. These two accelerometer signals were essentially identical. The two pressure gauges output remained constant through the recording time. The electronic signal conditioning equipment for each of the six sensors used was the 4 to 20 mA type of transmitter which has a value other than zero when no signal is applied to the transducer, thus the constant output of the pressure channels and the constant output of the acceleration channels before and after acceleration signals prove that the signal cable stayed intact.

PREFACE

Within Systems, Science and Software (S³), the project number for this program was 11081. The Project Manager was Edward A. Day. Test construction and fielding were carried out by Mr. Day and Warren W. Ginn.

The recording of data was performed by Science Applications, Inc. (SAI) under the direction of Kenneth Sites under a separate contract with Defense Nuclear Agency (DNA).

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1. INTRODUCTION

1.1 BACKGROUND

When a nuclear device is detonated underground, a hot, high-pressure gas-filled cavity is formed which grows in size until constrained by the medium. The cavity usually collapses at some later time and becomes filled and cooled with earth materials. The pressure history within such a cavity, if known in detail, is very useful information in understanding and predicting event behavior. Historically, most attempts to measure cavity pressure have been less than successful. Two of the weak links are sensing the pressure that is coupled to the dynamic cavity and transmitting signals to a remote recording station. Techniques for coupling to the cavity with high-pressure tubing appear to have been successfully developed.

Cavity pressure measurements have previously been attempted in DINING CAR, DIAMOND DUST, DIAMOND MINE, HUSKY ACE, HYBLA FAIR, HUSKY PUP, and HYBLA GOLD. No data were retrieved for DINING CAR, HUSKY ACE or HUSKY PUP; a signal of questionable data was recorded for 440 minutes during HYBLA GOLD ^[1], but good data were recorded during HYBLA FAIR for a period of 2.2 seconds ^[2]. It is reasonably certain that the loss of data in the DINING CAR and HUSKY ACE events resulted from cable damage by ground shock in the region at or near the pressure transducers. Pressure transducer damage was encountered in HYBLA GOLD ^[1]. The signal in HYBLA FAIR was terminated by an intermittent power failure which turned off the tape recorders ^[2]. DIAMOND DUST and DIAMOND MINE yielded good cavity pressure measurements; however, the cavity conditions were such that little cavity wall displacement occurred so that the measurement conditions were more favorable than in most tests. Good cavity pressure data in the HYBLA GOLD event were obtained by utilizing a prepressurized

capillary tube running from the vicinity of the cavity (where it was melted open) to a recording station outside the stemming plug^[3].

The capillary-tube technique for cavity pressure measurement was fielded on DIABLO HAWK. As a backup for the capillary-tube technique for future events, it was deemed prudent to field a pressure-sensing system which could potentially indicate the pressure in an oil-filled line coupled to an explosion cavity, as previously accomplished^[2], and transmit a current signal to a remote recording station.

1.2 OBJECTIVE

The objective of the experiment reported here was to obtain time-dependent signals from strain-gauge pressure transducers for a period from minus two minutes to plus five minutes, to transmit these signals from the electronics built into each pressure transducer, and to isolate the pressure transducers and their built-in electronics sufficiently from the ground shock to assure their survival. To assist in the diagnosis of the results, acceleration versus time measurements were to be made both on the mounting bulkhead and in the sensor package.

SECTION 2

DESCRIPTION OF THE EXPERIMENT

For this experiment, two identical pressure transducers were mounted in a metal box which in turn was secured to the bulkhead in the TAPS crosscut drift by means of a shock-isolating system. No pressure connection to the cavity region was attempted because adequate time and space were not available. The pressure sensors were both rated to 69 MPa (10,000 psi). With the built-in electronic transmitter supplied, the output current is 4 mA with zero pressure on the gauge and 20 mA when pressurized to full rating. Thus, without a changing pressure signal, a constant current of 4 mA is recorded in each circuit. Accelerometers were mounted both in the pressure transducer package and on the bulkhead to indicate the shock attenuation of the isolation system.

Figure 1 shows the drift configuration and the location of the cavity pressure-sensor package. The stemming bulkhead, located in the crossdrift between the bypass drift and the TAPS, was oriented $\sim 37^\circ$ from a line to the working point (WP). Due to this angular relationship, the front of the ground shock traveled along the bulkhead as indicated in Figure 2. The bulkhead presented a free surface, and hence, a displacement vector normal to its plane was expected. Experience has shown that bulkheads of this design and location are expected to survive the ground shock without appreciable plastic deformation. Therefore, the total displacement component of the center of the bulkhead normal to its surface, relative to the surrounding rock and strong grout, was expected to be on the order of 25 mm (1 in) or less. In other words, the bulkhead moves with the mountain. Velocity data from a previous test indicated the rate of change of velocity was equivalent to a peak acceleration of $<500g$ and the total displacement, during the period when the acceleration was a few-hundred g,

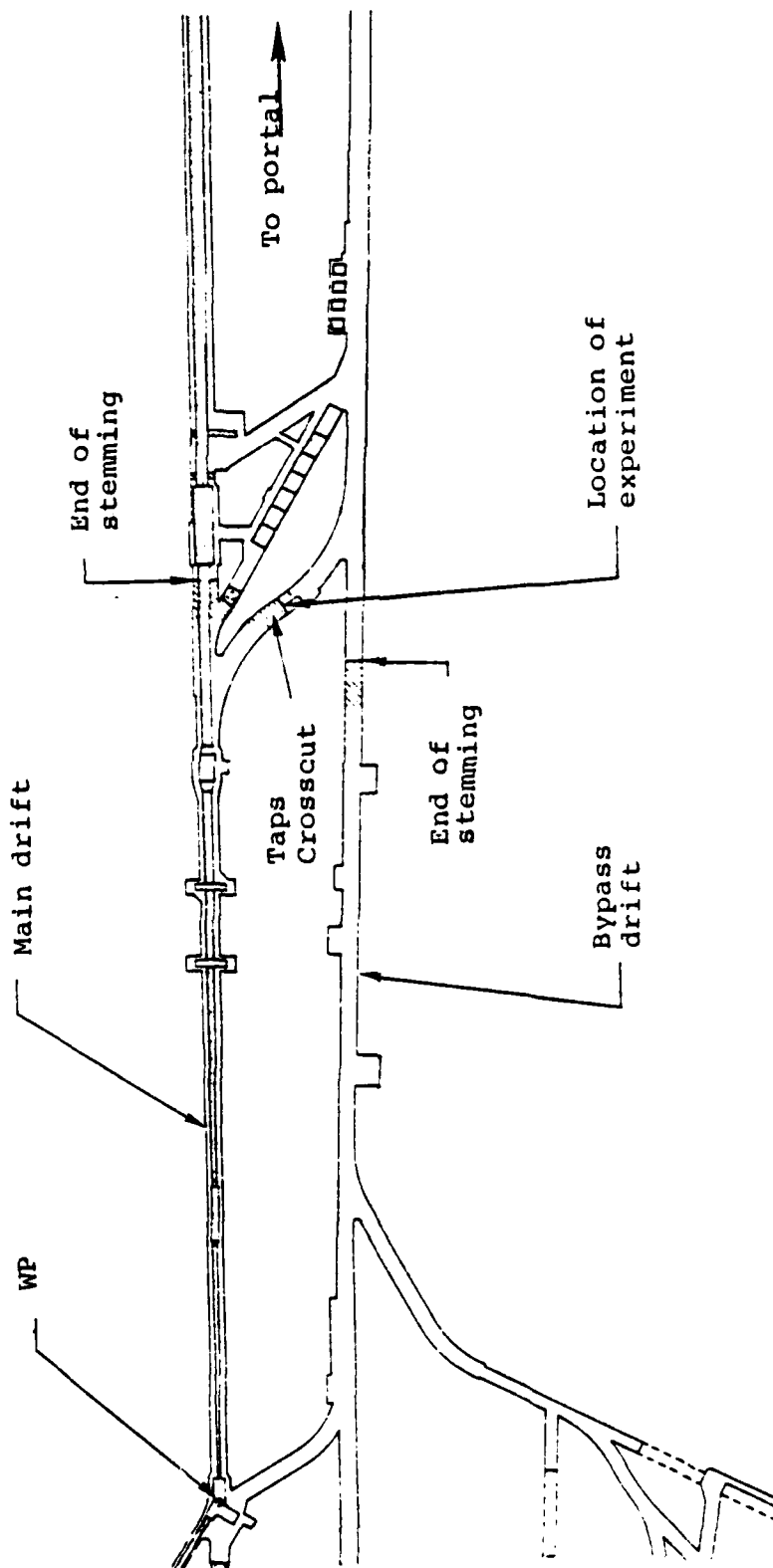


Figure 1. Portion of DIABLO HAWK tunnel layout showing location of cavity pressure instrument package isolation experiment

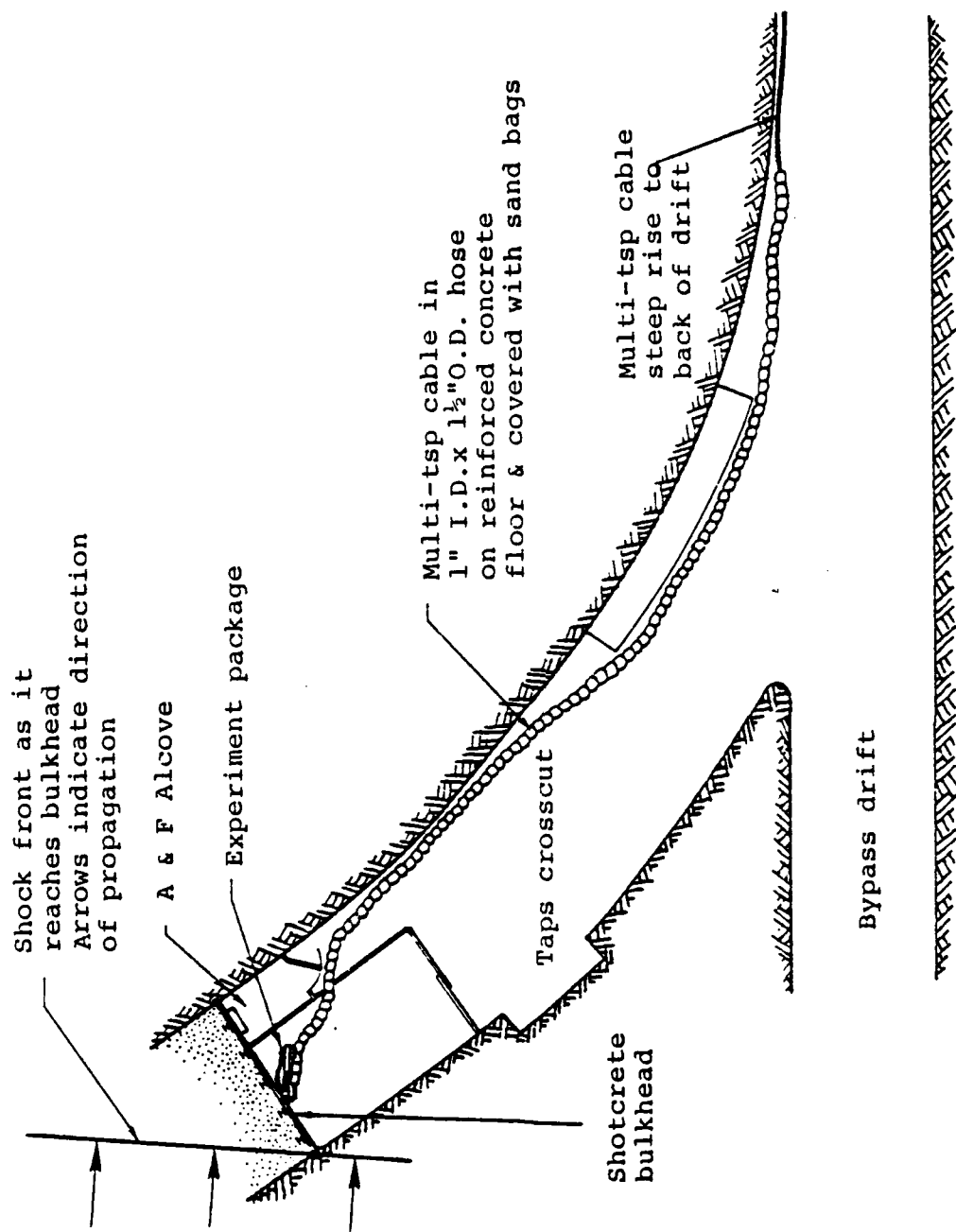


Figure 2. Plan view of taps crosscut showing location of experiment and instrument cable run.

was ~5 mm (.2 in). The expected total displacement of the DIABLO HAWK bulkhead was <23 cm. This displacement was based on calculations which used data on more pourous tuffs than were expected in the DIABLO HAWK area^[4]. However, for MIGHTY EPIC, the calculated displacement was ~12 cm due to higher-strength rock in that test.

To compensate for the free-surface effect on the local displacement at the center of the bulkhead, the sensor package support was positioned at 45° as shown in Figure 3. This figure also shows the installation of the shock-isolated instrument package and the protected instrumentation cable run in the vicinity of the bulkhead. Figure 4 is a sketch of the isolation structure for the instrument package. The support structure consisted of a horizontal member and a vertical member. The horizontal member was attached to the bulkhead by a ball-and-socket type joint. This joint was cushioned with rubber to permit ~2 cm (1 in) displacement before the transmitted force produced 300g, the lateral acceleration limit of the dashpot (the passenger-bus shock absorber having the stiffest piston rod commercially available). Pivoted at the outer end of the horizontal member was the upper end of the vertical member, which carried the instrument package on trunion-like supports at its lower end. The horizontal member was held level by an appropriate tension spring. The bus shock absorber (Monroe #74003) was situated between the vertical and horizontal members at a 45° angle. The function of the shock absorber was to prevent free swinging of the instrument package relative to the bulkhead by permitting relatively free displacement of the bulkhead toward the package but restricting movement in the opposite direction. The spring provided support against gravity and yet permitted freedom of motion by the horizontal member. To control excessive swing of the package and the horizontal member, constraint was effected by 6 mm (1/4 in) unstretched nylon tethers secured to the left rib of the drift and the right side of the bulkhead.

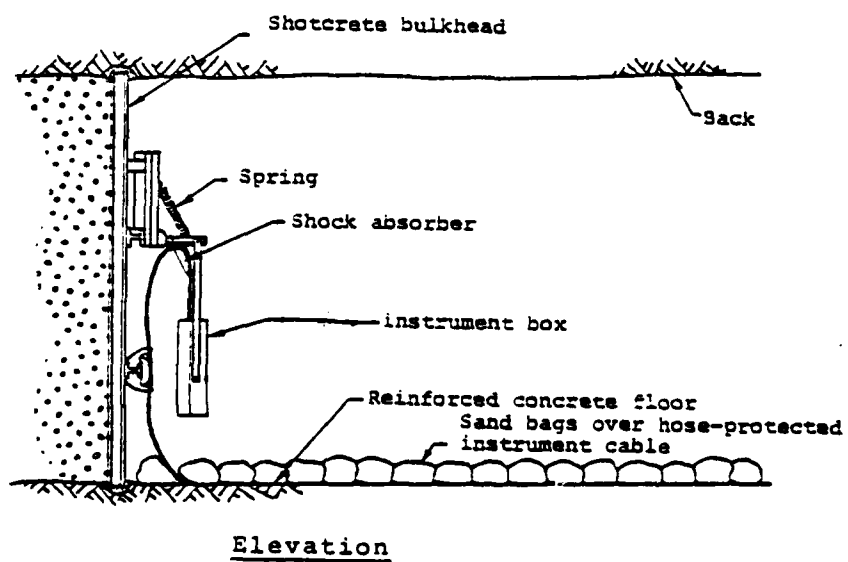
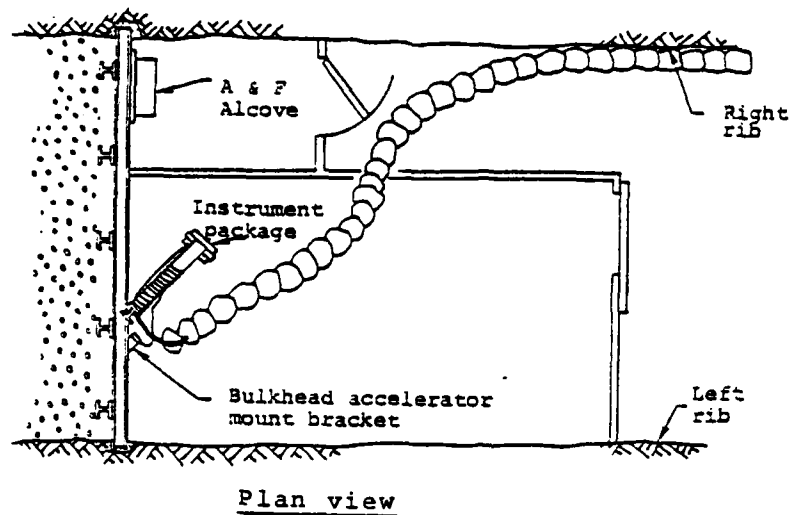


Figure 3. Installation sketch showing sensor package support on stemming bulkhead and cable runs.

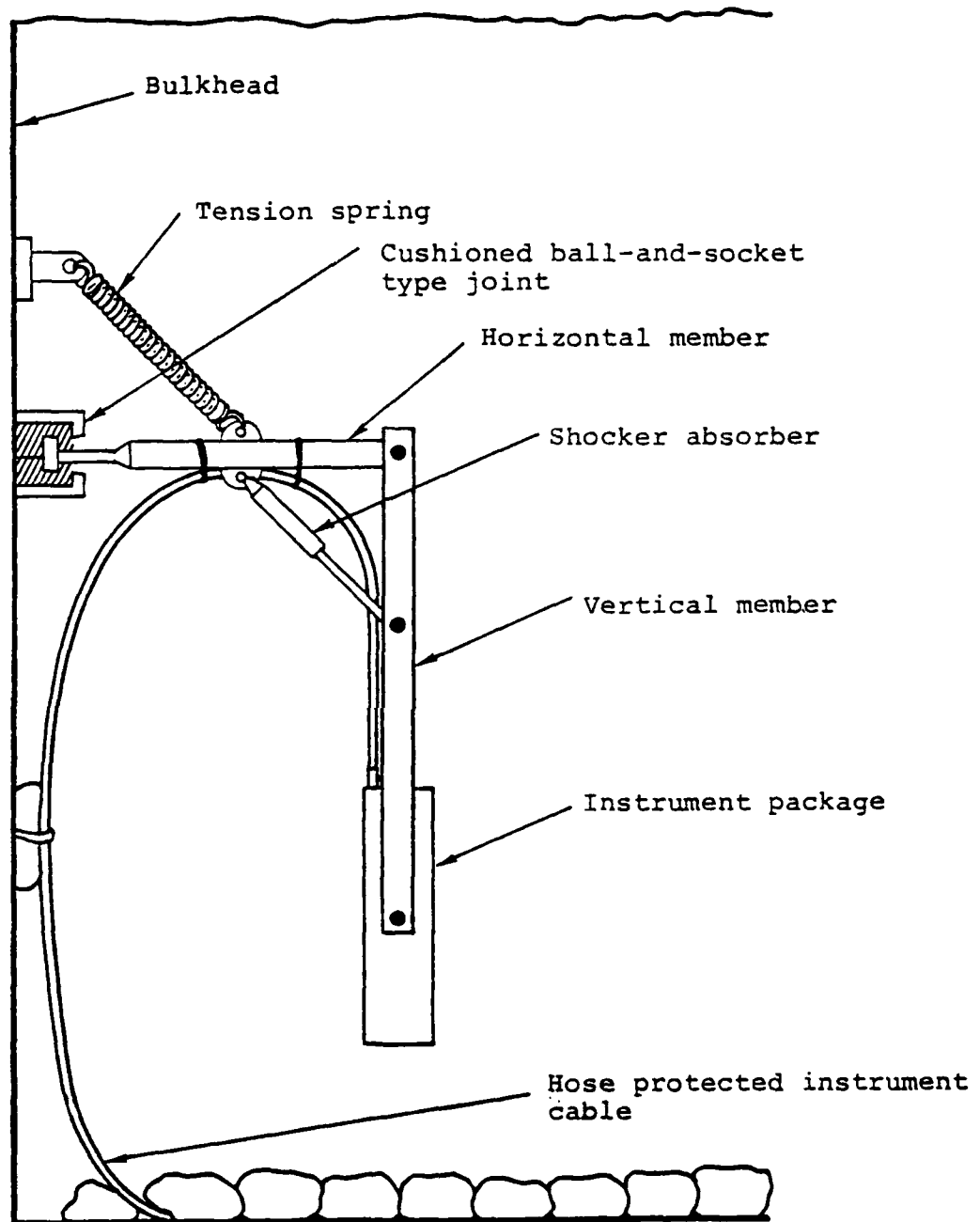


Figure 4. Isolation structure for instrument package.

The instrument package was an 8x8x36-in. wiring trough with a water-tight rf gasket. A trunion plate was attached to each side of the trough at its vertical center of gravity. The trunions fitted into the forked lower end of the vertical member. This arrangement essentially eliminated rotational-inertial forces during ground-shock response. The minimum clearance between the nearest projection on the instrument package and the bulkhead was 50 cm (20 in).

Two piezoresistive accelerometers (Endevco Model 2264-150, rated at 150g full scale) were mounted in the sensor package to measure the acceleration imparted through the shock isolation/support structure. Also mounted in the package were two pressure sensors, (Senso-Metrics Model SP-976C 10,000G-6.1). These pressure sensors had strain-gauge elements and built-in electronics to convert the signal to current. This is a convenient arrangement to use with long transmission lines because it does not require a regulated power supply nor is the signal recorded at the end of the transmission line attenuated by the cable. For this test, we had planned to produce a step in the output signal by opening a small bottle of pressurized nitrogen and apply a pressure of approximately 10 MPa (1500 psi) to the pressure gauge, this would have caused the circuit current to increase from 4 mA to approximately 6.4 mA. However, this operation was abandoned because of noise pickup from the power supply for the valve operating motor. Even without the pressure step, positive indication of the functioning of the pressure gauge and the continuity of the circuit were indicated by the 4mA signal. Damage to the pressure transducer or the signal cable would have been observed by a change or disruption of the 4 mA signal.

Two accelerometers were mounted on the bulkhead at a location near the anchor of the support system. Like the accelerometers located in the sensor package, these also had

piezoresistive sensing elements. The range of each of these bulkhead-mounted accelerometers was $\pm 2000g$.

The bulkhead-mounted accelerometers and the sensor-package-mounted accelerometers were fitted with signal conditioners (Sensometrics Model No. 610079) which converted the acceleration signals to a current signal. With 24 to 50 volt dc input, 12 mA output represented zero acceleration, 20 mA represented full-scale positive acceleration and 4 mA full-scale negative acceleration. All four signal conditioners were mounted inside the shock isolated sensor package. The signal leads from the two bulkhead-mounted accelerometers to their signal conditioners in the shock-isolated package were protected by threading them through a length of 1/2" ID x 7/8" OD doubly-reinforced multipurpose rubber hose (Gates No. 19B). The ends of the hose were clamped to metal tubular fittings on the accelerometer housing and the shock isolated package. This hose conduit was dressed along the support structure and loosely secured with nylon line.

The dc power supplies for the four accelerometers and the two pressure gauges were located in a recording trailer on the mesa. The instrument leads running from the trailer to the shock isolated sensor package consisted of 22-shielded-twisted-pairs in a single plastic protective sheath. From the sensor package to a position in the bypass drift, the cable was dressed through a 1" ID x 1.5" OD high-pressure air hose laid on the invert and covered with sand bags, and thence it was dressed high on the right rib near the back of the drift to a position about 800 feet from the WP. From this location to the trailer, the instrument cable was run in the standard cable bundle. At the bulkhead, the hose protected cable was run from the invert along the bulkhead and the support structure into the sensor package, where the hose was clamped to a metal tube welded to the top of the steel box.

Figure 3 shows the cable run in the vicinity of the sensor package.

A schematic layout of the signal handling and recording system is shown in Figure 5. Table 1 tabulates the sensor installation and recording equipment.

During installation of the two bulkhead accelerometers, the threads of one of the mounting screw holes for gauge No. 2 was stripped and could not be repaired for use with a longer screw. Therefore, a larger hole was drilled and tapped, and the gauge mounted on an adaptor plate. This made the mounting details of the two accelerometers slightly different.

Prior to the shot, calibrations representing 4 levels of sensor signals were applied to each signal channel and recorded on the test tape in the trailer. During the shot the tape recorder was turned on at -2 minutes and run at 30 ips for seven minutes.

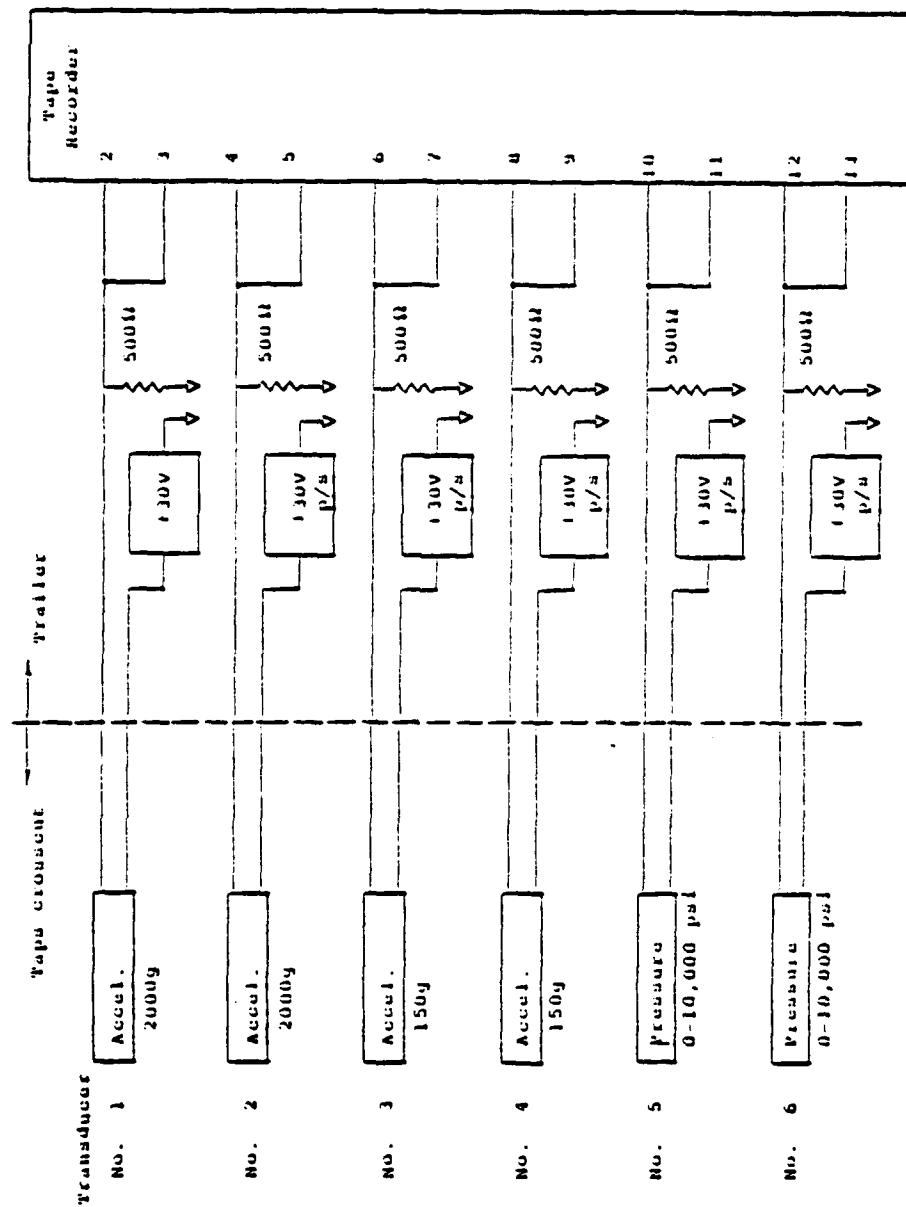


Figure 5. Block diagram of gauge power supply and recording system

Table 1. DIABLO HAWK cavity pressure experiment
Sensors and signal recording

Sensor No.	Location	Experiment No.	Transducer Make*	Range	Tape Track No.
1	Bulkhead	701	End	±2000g	2,3
2	Bulkhead	702	End	±2000g	4,5
3	Shock mounted	704	End	±150g	6,7
4	Shock mounted	703	End	±150g	8,9
5	Shock mounted	705	S-M	0-10,000 psi	10,11
6	Shock mounted	706	S-M	0-10,000 psi	12,13

* End - Endevco, Model 2264-2000 and 2264-150
Each with a Senso-Metric Inc. Model 610079 signal conditioner

S-M - Senso-Metrics, Inc. Model SP 976 C 10,000 G-6.1

SECTION 3

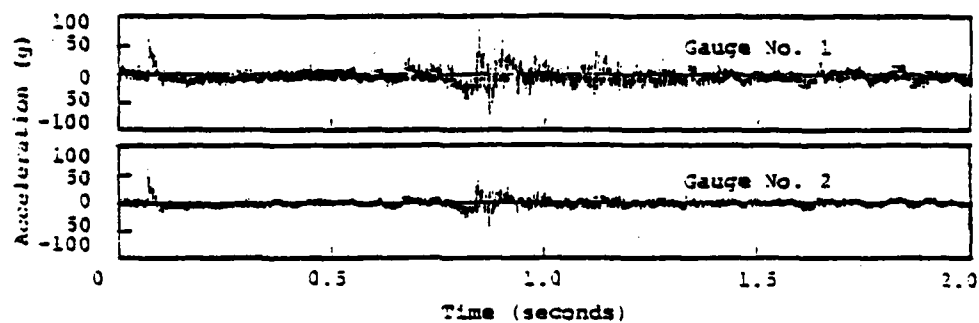
RESULTS

The DIABLO HAWK event was fired on schedule on 13 September 1978. Playback records of the tape recordings indicate that pressure on acceleration signals were transmitted from each of the two pressure gauges and the four accelerometers. All the signals were recorded for the full period from recorder turn-on until the recorder power was terminated. Figure 6 shows the six signals with a common time abscissa. The first signal arrived at the bulkhead accelerometers at 72 ms and an additional 5 ms passed before the first signals appear at the sensor package. This indicates a 5 ms transit time through the isolation structure. The average ground shock velocity was 8681 ft/s ($625 \div .072$). When the groundshock reached the trailer at ~800 ms, recorder writing noise is evident in all the signals.

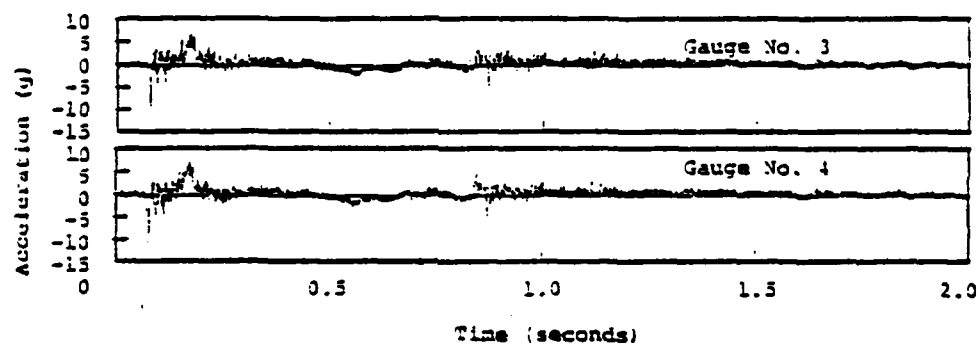
Figure 7 shows an enlarged drawing of the actual acceleration signals at the bulkhead. Here it is seen that 71g is the maximum acceleration away from the WP (positive signal) as indicated by gauge No. 1. Gauge No. 2, which had a mounting variation described above, indicated only 65g away from the WP. The acceleration toward the WP (negative signal) was <15g. By close inspection of Figure 7, a shock precursor is seen starting at about 68 ms.

The enlarged signals from the accelerometers located inside the isolation package are shown in Figure 8. The maximum signal is toward the bulkhead (negative signal) with a value of 10.8g. Values of 7.4g and 8.0g were recorded for acceleration away from the bulkhead (positive signal).

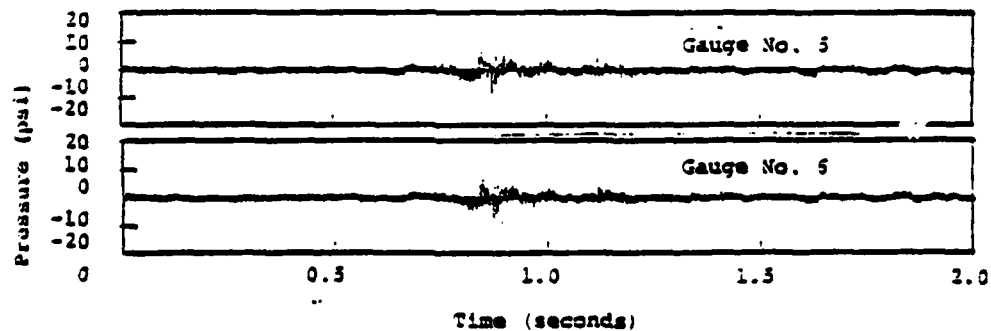
A comparison of the peak values of the two pairs of accelerometers shows attenuation factors of up to 6.6



A. Bulkhead-mounted, 2500g Accelerometers



B. Shock-mounted, 150g Accelerometers



C. Shock-mounted, 10,000 psi Pressure Gauges

Figure 6. Recorded Signals From Indicated Channels

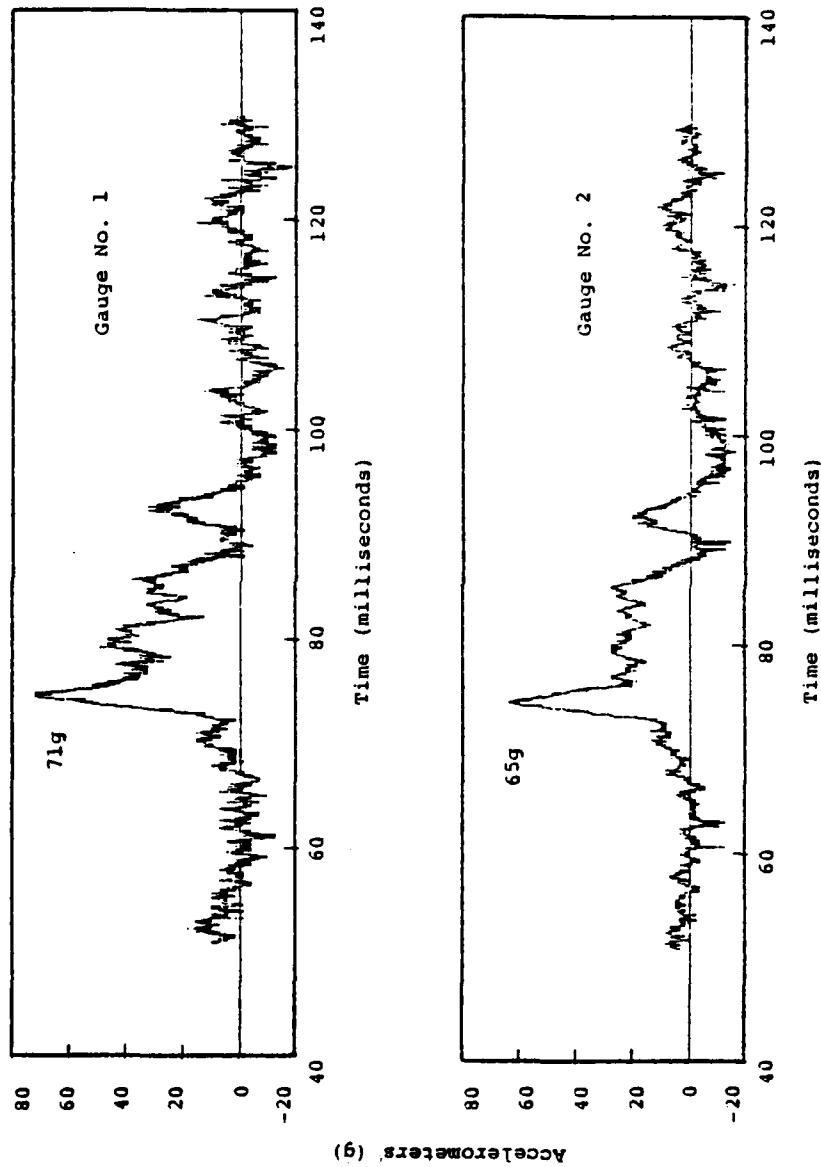


Figure 7. Expanded Signals From Bulkhead-mounted Accelerometers.

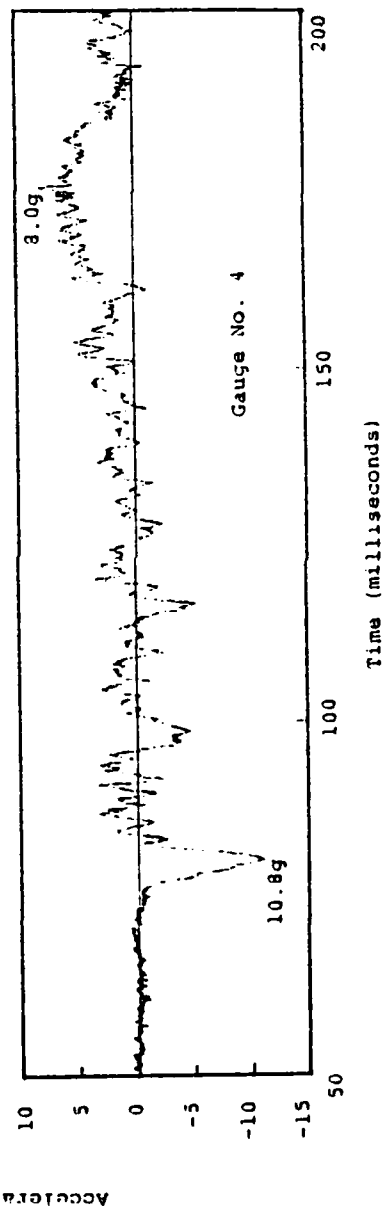
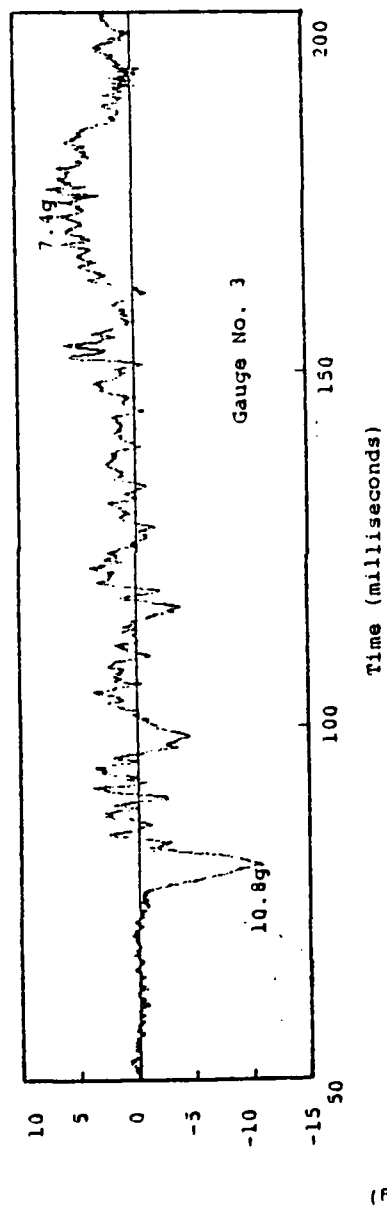


Figure 8. Expanded Signals From Accelerometers Mounted in the Shock Isolation Package.

resulting from the isolation support system. There was no accelerometer evidence that the instrumentation package was struck by any flying debris of substantial size or that there was any impact with the bulkhead.

The constant output signals of the two pressure gauges are a clear indication that the sensors/transmitters worked normally for the situation where no pressure change was applied to the gauges. This also shows that the signal leads were adequately protected and remained intact during and after the ground shock action. This is also made evident by the fact that the accelerometer circuits returned to their zero acceleration value (12 mA current) after the passage of the ground shock, and remained constant until the recorder power was terminated at +5 minutes.

SECTION 4

DISCUSSION AND RECOMMENDATIONS

Analysis of the results of attempts to measure the cavity pressure history by the technique of sensing the pressure at the end of an oil-filled line that extends from the cavity to the end of the stemming plug indicated the technique for "tapping" the cavity is reasonably well in hand. There have been difficulties obtaining gauges of sufficient ruggedness to permit mounting directly to the end-of-stemming bulkhead so as to minimize damage from flying debris. Also, instrument cable runs have been subject to damage and thus to signal interruption by the effects of ground shock. The DIABLO HAWK test was designed to provide a shock-isolated mount for pressure sensors that could be attached close to the bulkhead and yet permit the use of readily available pressure gauges with build-in electronics. In addition, the instrument cable was specially protected against flying debris resulting from ground shock.

The shock isolation mount worked well as indicated by good accelerometer data from the bulkhead and the package itself, and by the fact that the pressure gauges sent continuous signals as planned. These pressure gauges were slightly modified versions of those that were mounted rigidly and that failed in HYBLA GOLD.

The shock attenuation was less than expected. However, the peak value of 10.8g was very safe for gauges that are normally rated for a 30g environment. With the good bulkhead acceleration data acquired in this experiment, a shock isolation system can be designed for a considerably lower ground shock value, e.g. ~100g. (71g measured), in lieu of 500g for which the DIABLO HAWK system was designed. Specifically, the dashpot (bus shock absorber) can be replaced by a passenger

car shock absorber and thus "soften" the system to afford more attenuation without reducing its hardness against flying debris.

Protecting the cable in heavy hose and by sand bags on a reinforced concrete floor proved adequate to insure against damage from flying debris and rock motion.

For future tests, the 9/16" OD x 3/16" ID (14.3mm OD x 4.8mm ID) high pressure stainless steel tubing used in HYBLA GOLD could be coupled from the stemming plug to the shock isolated package with a hairpin loop to provide a very rugged and yet flexible conduit for pressure to be transmitted from the cavity to the pressure sensors. This would provide a complete cavity pressure measuring system for future underground nuclear tests.

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