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RESEARCH ON HAZARD CLASSIFICATION OF NEW LIQUID ROCKET PROPELLANTS

FINAL REPORT
VOLUME II

TITAN II MODEL MISSILE TESTS

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.
6633 CANOGA AVENUE, CANOGA PARK, CALIFORNIA

CONTRACT AF 33 (616) - 6939
PROJECT NO. 3148
TASK NO. 314801

OCTOBER 1961

ROCKET TEST ANNEX
SPACE SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

EDWARDS AIR FORCE BASE, CALIFORNIA

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FOREWORD

This is Volume II of the Final Report which was prepared for the Space Systems Division, Air Force System Command, Edwards AFB, California. The report covers work performed on Supplement 3 of Contract AF33(616)-6939, PN 3148, TN 314801. Mr. F. S. Forbes (DGPL), Edwards AFB, is Project Officer. Mr. W. M. Smalley of Aerospace Laboratories, Los Angeles, California provided technical direction for this special study concerned with Titan II hazards. Mr. D. J. Hatz of Rocketdyne is Project Engineer and directed the test effort with the assistance of Mr. A. Chambers and Mr. T. R. Spring. Mr. Hatz extends his appreciation for the cooperation received from personnel of Aerospace Laboratories and from the test support personnel of Edwards AFB.

ABSTRACT

This report, Volume II of the final, presents the results of a special test program designed to determine the hazards of Titan II propellant handling mishaps. Twenty model missile spills using total propellant quantities of 50 and 300 lb and two large-scale spills using total propellant quantities up to 1600 lb were made at Haystack Butte, Edwards AFB. The Titan II propellants, nitrogen tetroxide and mixed hydrazine, were also spilled in quantities up to 2.5 lb of total propellant in a series of small-scale tests conducted at the Propulsion Field Laboratory. A biological study was performed on one large-scale test at Haystack Butte.

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

At the request of AFBMD, the model missile failure studies in both the above ground and insilo configurations were undertaken as part of Contract AF33(616)-6939 to expedite the accumulation of data on the hazards of spills in large missile silos. The propellants nitrogen tetroxide and a mixture of hydrazine and UDMH, (50-50 by weight), were used in the model missiles in a mixture ratio of 2 to 1 oxidizer to fuel ratio by weight. Two silo model sizes, 1/10 and 1/18 linear scale of the full-scale Titan II system were fabricated for this test series. The simulated missile tanks for the 1/10 and 1/18 scale model silos have capacities of .1 percent and .017 percent of the total propellant quantity of a Titan II missile.

The principal objectives of this program are to determine safety criteria and silo design criteria for the Titan II launch complex. Temperature and pressure measurements, together with photographic coverage were used to examine the fire, blast and toxic hazard potentials of the underground missile silo.

Concurrent with the model silo studies, small-scale spills were conducted to provide preliminary evaluation and description of hazards that may accompany propellant handling mishaps. Pressure measurements and photographic coverage were used to determine the fire and blast potentials under controlled propellant mixing conditions.

The model-missile failure studies and the small-scale tests have previously been published in a Special Titan Report, R-2849. This final report includes, in addition to these tests, the large-scale tests which had been postponed. These tests are propellant mixing spills using up to 1600 pounds of the Titan II propellants. Temperature, pressure, and toxic vapor measurements were made and photographic coverage was taken to determine the hazards associated with large spills. A biological study conducted by the Huntington Memorial Hospital was performed on one large-scale spill.

The final report describes the testing conducted during the period from 4 October 1960 through 9 August 1961.

SUMMARY

SMALL-SCALE TESTS

Nine small-scale multiple and three singular spills were made with the Titan II propellants (a 50/50 mixture of unsymmetrical dimethylhydrazine and hydrazine as the fuel and nitrogen tetroxide as the oxidizer) to determine the possible hazards to personnel and test sites handling these propellants. Multiple spills were made on dry concrete, dirt, and water-covered concrete. Singular spills of the fuel mixture were also run on the three surfaces. Overpressures developed by the multiple spills were detected and measured by two calibrated Photocon microphone pickups and recorded on sound tape; visual evidence of the tests was recorded with high-speed color motion picture film.

The propellant combination ignited within a few milliseconds after contact under all conditions tested. Overpressures as high as 1.67 psi were recorded at a distance of 10 ft from the spill pad using quantities of 1.5 to 2.5 lb of propellants. Two of the spills, an oxidizer lead on dry concrete and a fuel lead on water-covered concrete, did not develop overpressure at either the 10- or 15-ft distances. Spills on dirt with either a fuel or oxidizer lead and a simultaneous spill on water-covered concrete produced only a few distinct overpressure peaks, while the other four tests produced several distinct peaks during the duration of the spill. Maximum overpressure values were reached with a simultaneous spill and a fuel lead on dry concrete; minimum values occurred with oxidizer leads on all surfaces and with a fuel lead on water-covered concrete. The TNT equivalent for the simultaneous spill on dry concrete was 0.48 percent.

It was apparent from the overpressure measurements and motion pictures of the tests, that the overpressures were not due directly to the combustion of the liquid phases of the propellants. The sequence of events identified by the color motion pictures, indicated that the overpressures were initiating 3 to 4 ft above the spill surface. These results, along with the severity rating of the different tests, indicate that the overpressures are a result of vapor phase explosions from a hydrazine vapor-air mixture.

A singular spill of the fuel mixture on dry concrete resulted in the formation of a cloud of vapors covering the spill surface a few minutes after the spill. With dirt as the spill surface, a smalier volume of vapors were evolved in approximately the same period. The dirt appeared to absorb the fuel quite readily. Some vapors also appeared over the surface on the spill of the fuel onto water-covered concrete; however, the amount appeared to be less than that of the two previous singular spills.

MODEL-MISSILE SPILLS

Twenty scale-model missile spills were conducted using the Titan II propellants. The propellants, nitrogen tetroxide and 50-50 percent mixture of hydrazine and UDMH were spilled from volumetric models identified as 1/10 and 1/18 scale model missiles. The models were placed in frangible silos, in the spill tray above ground, and in scale-model, rigid-steel silos with underground tunnels to study fire, blast, and toxic hazard potentials of this propellant combination. Pressure and temperature measurements were taken on the spills conducted in the scale-model steel silos. Motion picture coverage was obtained for visual evidence on all tests.

Six spill tests were conducted in 1/10- and 1/18-scale frangible silos. On two of these tests, craters were formed at the top of the silo. It was observed on this test series that oxidizer leads and simultaneous spills gave more violent reactions than fuel leads. In the case of fuel leads, the sand at the bottom of the silo absorbed the hydrazine and reduced the violence of the reaction. After-fires continued to burn for 20 minutes on fuel lead tests.

Five aboveground spills were made using the 1/10-scale missile models. On two of these tests, overpressures were measured. The overpressures recorded were equivalent to 0.21 lb of TNT, which is a yield of 0.07 percent. Maximum fireball radius reached was 32 feet. The growth rate was greater on the simultaneous spill, taking 1.5 sec to reach the maximum radius, as compared to 1.85 sec for the spill having a 2-sec oxidizer lead. The difference in the growth rates was attributed to the higher overpressures that resulted on the simultaneous spill. Fuel-lead spills in the tray resulted in immediate ignition due to the highly oxidized condition of the steel plates.

Nine tests were conducted in the rigid steel silos; blast measurements were taken on all tests. The overpressure results confirmed observed variations in reaction violence. Confinement of the propellants in the silo gave yields up to 0.67 percent, which is 0.6 percent greater than spills with 300 lb propellant quantities above ground. Increase in propellant weight did increase reaction violence on spills made under simultaneous and oxidizer-lead conditions; however, spills with fuel leads showed a 0.06 percent decrease in yield. Comparison of overpressures from the simultaneous spills showed maximum equivalent yields for the 1/10- and 1/18-scale tests of 2 lb and 0.2 lb, respectively, which is a 0.27 percent yield increase for the 1/10-scale spills. Higher overpressures were recorded in the silo tunnels than in the main body of the silo. The tunnel pressures were consistently 50 to 100 percent higher than the pressure measured at the silo wall, with pressure buildups in the tunnels exceeding 500,000 psi per sec. The most reasonable explanation of this phenomenon (higher tunnel pressures) is that the sensing units were measuring the reflected wave; however, the possibility of detonative explosions being triggered in the tunnels cannot be ruled out.

The addition of water to the bottom of the silo was found to reduce both temperatures and overpressures resulting from the reaction of the propellants.

LARGE-SCALE TESTS

Two large-scale mixing spills were made with the Titan II propellants (a 50-50 mixture of unsymmetrical dimethylhydrazine and hydrazine as the fuel and nitrogen tetroxide as the oxidizer) to determine possible hazards to personnel and test sites handling these propellants. The first mixing spill was made to study the effects on reaction violence when a water deluge is employed, the second to determine the physiological effects on hamsters. Measurements of blast, temperature, and toxic-cloud concentrations were taken. Visual evidence of the tests was recorded by normal and high-speed color motion pictures.

On the first test, 300 lb of the fuel mixture and 1300 lb of the oxidizer were spilled. A water deluge system was actuated two seconds after the initial tank rupture. Explosions, though audible, were not detected by the blast instrumentation because of their low magnitude. Temperatures less than 240 F were indicated by temperature-sensitive paint. Heavy nitrogen tetroxide clouds were observed; the toxic vapor-detection instrumentation recorded concentrations exceeding 25 ppm at a distance of 250 ft.

The propellants spilled on the second test were allowed to react completely. Propellant quantities were 500 lb of fuel and 800 lb of oxidizer. A large fireball resulted from the reaction which persisted for approximately 10 seconds. Fourteen explosions were detected and recorded by the blast instrumentation. The highest overpressure recorded on the sixth pulse was equivalent to a 0.15-percent yield. The temperature grid, composed of tabs coated with temperature-sensitive paint, recorded a maximum temperature of 445 F. This heat of reaction stacked the unreacted propellants well above ground level. Propellant vapors were detected only during the propellant transfer operations prior to the spill, resulting in extremely low exposures to the test animals on the biological study.

MEDICAL STUDY

The biological study was conducted by the Institute of Medical Research, Huntington Memorial Hospital. The animals were placed in downwind positions on the second large-scale spill and the concentration of toxic gases at each animal position was measured and recorded by toxic vapor detectors. The results of the study indicate that most animal deaths were caused by heat of the hot desert environment, although there was some evidence of exposure to the fuel vapor.

DISCUSSION

To expedite the dissemination of information on the model-missile spills and the small-scale spills, a special report, Rocketdyne Report R-2849, was published without the inclusion of test results from two large-scale spills. These two spill tests were postponed until direct recording toxic vapor detection equipment became available. They were conducted later with tests of the basic spill program and the results are included as a separate discussion titled, "Large-Scale Tests."

In addition, a more complete discussion of the aboveground model-missile tests are included, giving fireball growth rates and picture sequences. This material was requested by personnel on the Dyna-Soar Project Team.

In the discussion of test results, the words "explosion" and "detonation" will not be used interchangeably. The reactions of the Titan II propellant combination will be described as either undergoing normal explosion (which will be termed simply "explosion"), or detonative explosion. Normal explosions are characterized by gradual buildup of pressure not exceeding 10,000 psi per sec, with resulting final pressures usually below 100 psi. Detonative explosions are characterized by rapid increases in pressure which exert a directed blow rather than a gradually applied force. Pressure buildups exceed 10,000 psi per sec with peak pressures 20 times the pressure produced by normal explosions. Detonative explosions are reflected upon impact with solid surfaces. Such reflections may momentarily multiply the pressure in the detonation front by a value of two or more, depending upon the angle of impact.

The evaluation of blast effects from propellant explosions is usually based on the relative effects of equivalent quantities of TNT. In the analysis of overpressure results, the following empirical relation was used (Ref. 1).

$$P = \frac{4120}{Z^3} - \frac{105}{Z^2} + \frac{39.5}{Z} \qquad (1)$$

and

$$Z = \frac{R}{W^{1/3}} \qquad (2)$$

where

P = side-on pressure, psi

R = radial distance, feet

W = weight of TNT charge, pound

The solution of the above equations can be simplified by the use of the nomogram shown in Appendix D. Side-on pressure is defined as the peak overpressure behind the blast shock front. Measurement of side-on pressure is made by placing the sensing element with its face parallel to shock flow. A position normal to shock flow results in a measurement of reflected pressure. Overpressure measurements were predominantly made with side-on orientation of the sensing element, except on the small-scale tests where face-on measurements were made.

SMALL-SCALE TESTS

The small-scale tests were conducted at Rocketdyne's Propulsion Field Laboratory. The tests were performed to determine the reaction characteristics of nitrogen tetroxide and 50-50 percent UDMH-hydrazine when spilled both singly and together on materials of construction. The following tests comprise the program scope.

Multiple Spills:

1. Four tests on dry concrete
2. Three tests on dirt
3. Two tests on wet concrete

Singular Spills UDMH-Hydrazine (50-50)

1. One test on dry concrete
2. One test on dirt
3. One test on wet concrete

Test Equipment

Spill Tanks. The system utilized for these tests had been constructed for the original small-scale hazard determination tests. The spill system consists of four 1.5-gallon tanks with associated control valves mounted to a facility panel (Fig. 1). Only two of the tanks, the nitrogen tetroxide and hydrazine, were used on the Titan II tests. Each spill tank is equipped with a gaseous nitrogen pressurization and purge system. The spill tanks are filled by pressurizing the propellant from small storage drums into the tanks.

Spill Tray. A 4 foot x 4 foot x 1/2-foot-deep concrete tray was used to contain the propellant spills. A drain opening into the main laboratory drain was used to wash out unburned propellants and combustion products. Surfaces other than concrete are placed in the pit as needed. Figure 2 shows the concrete spill tray.

Valves and Lines. The two 1/2-in. propellant lines extend within 8 in. of the spill surface, and impinge in a radius of two to four inches. The propellant main valves are opened, as needed, by a verbal and manual countdown. In a simultaneous dump of two propellants, the main valves are actuated at the same time, while a lead of one propellant is accomplished by actuating its main valve 500 to 1000 msec before the actuation of the second propellant's main valve. Flow is maintained by a 50-psi

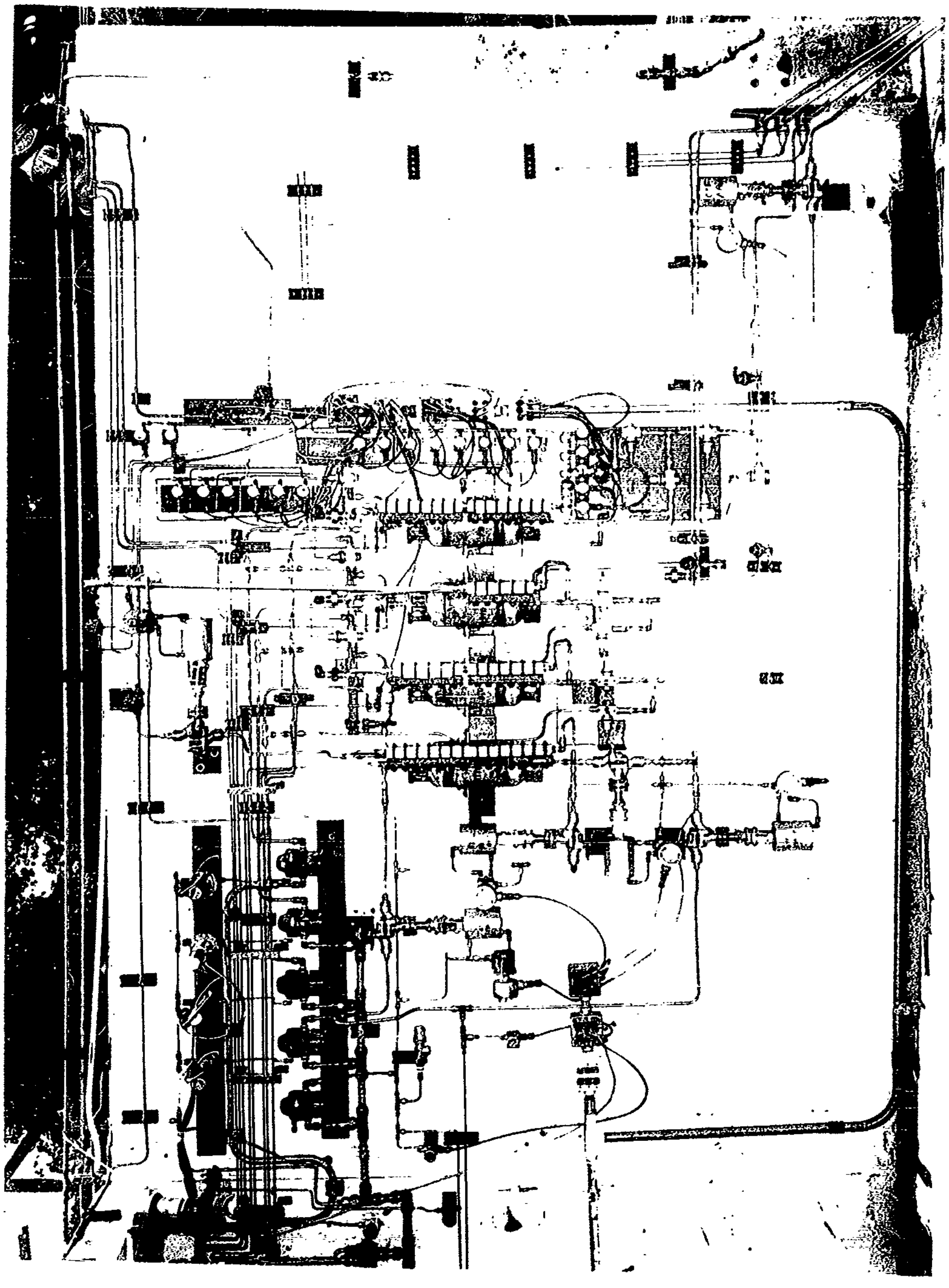

Figure 1. Small-Scale Hazard Determination Test System

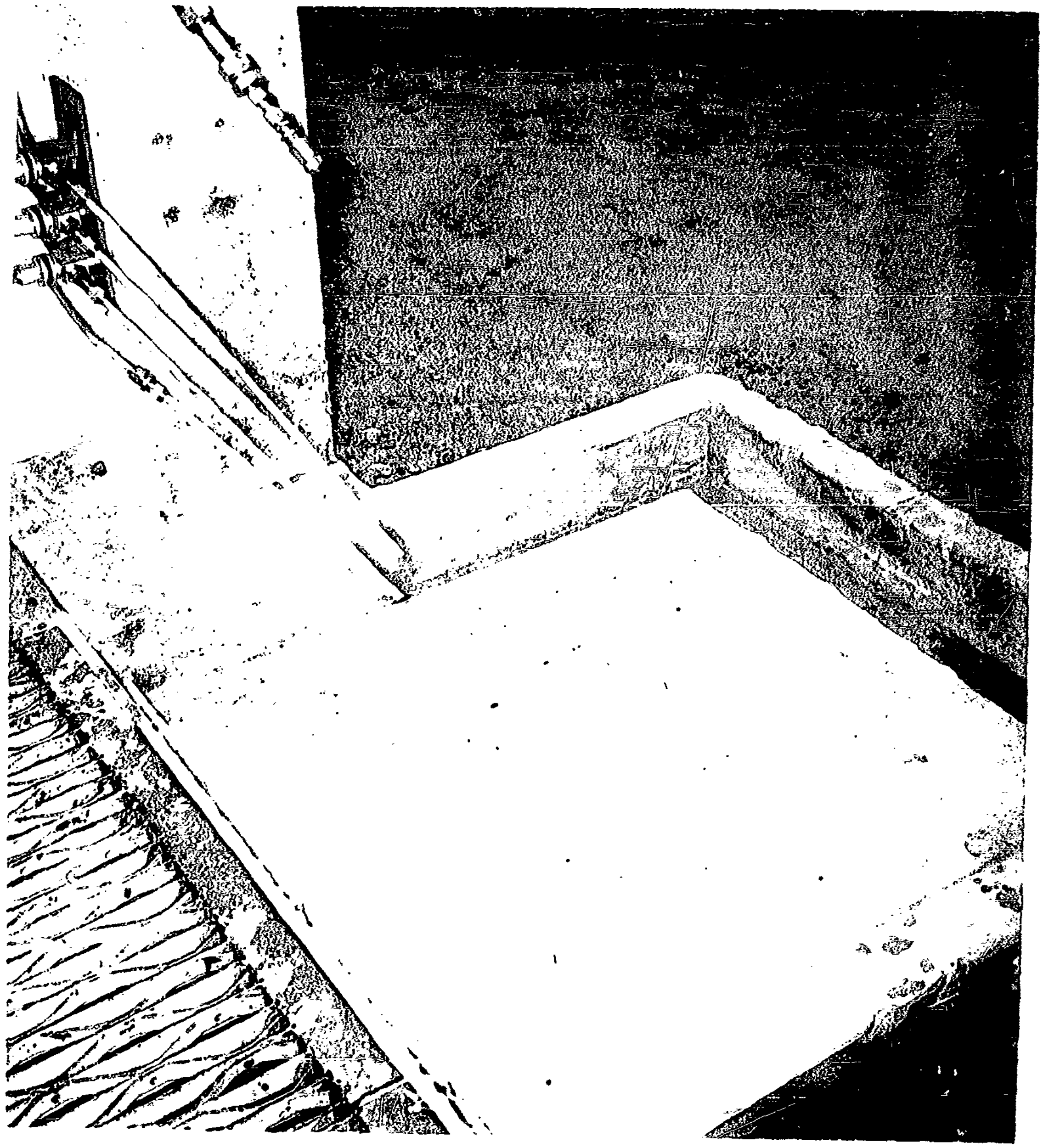

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Figure 2. Spill Tray

pressure head on the propellant tanks and is continued for 1000 to 2000 msec. Water is supplied to the pit by means of a deionized water line terminating in a spray nozzle, three feet above the pit. Figure 3 shows a schematic of the system.

Instrumentation

Blast Measurement. Two Photocon microphones with ranges of 0 to 5 psi were used to detect the overpressure pulses. In the first test, microphone No. 1 (M-1) was located 10 ft from the expected ignition source with the face located directly toward this point of origin, while microphone No. 2 (M-2) was located 6 in. to the left of M-1 with its face in the same plane formed by M-1. Both microphones were one foot above ground level in a plane 14 to 18 in. above the actual spill surface. In the remainder of the tests, M-2 was located 15 ft from the point of origin with its face in a direct line to this point for obtaining a "face-on" measurement. A photocell was located approximately 10 ft from the spill pad with its sensing device directed toward the spill circle. The overpressures are sensed by the microphone pickups and relayed through a Photocon Dynagage to sound tape. The tape is re-played through a Tektronics 535A oscilloscope, and photographs are taken at various locations of interest by a Polaroid Land camera. Overpressure values measured by face-on placement of the microphones should be reduced by one-half for comparison with overpressure values measured by side-on placement of the microphones.

Camera Coverage. Color motion pictures of the tests were made with a Traid camera, operating at 200 frames per second, located approximately 20 feet from the spill pad.

Test Results

Multiple Spills. Overpressure measurement results of all multiple spills are tabulated in Table 1 with listed quantities of the propellants spilled throughout each test. In all tests the overpressures occur with

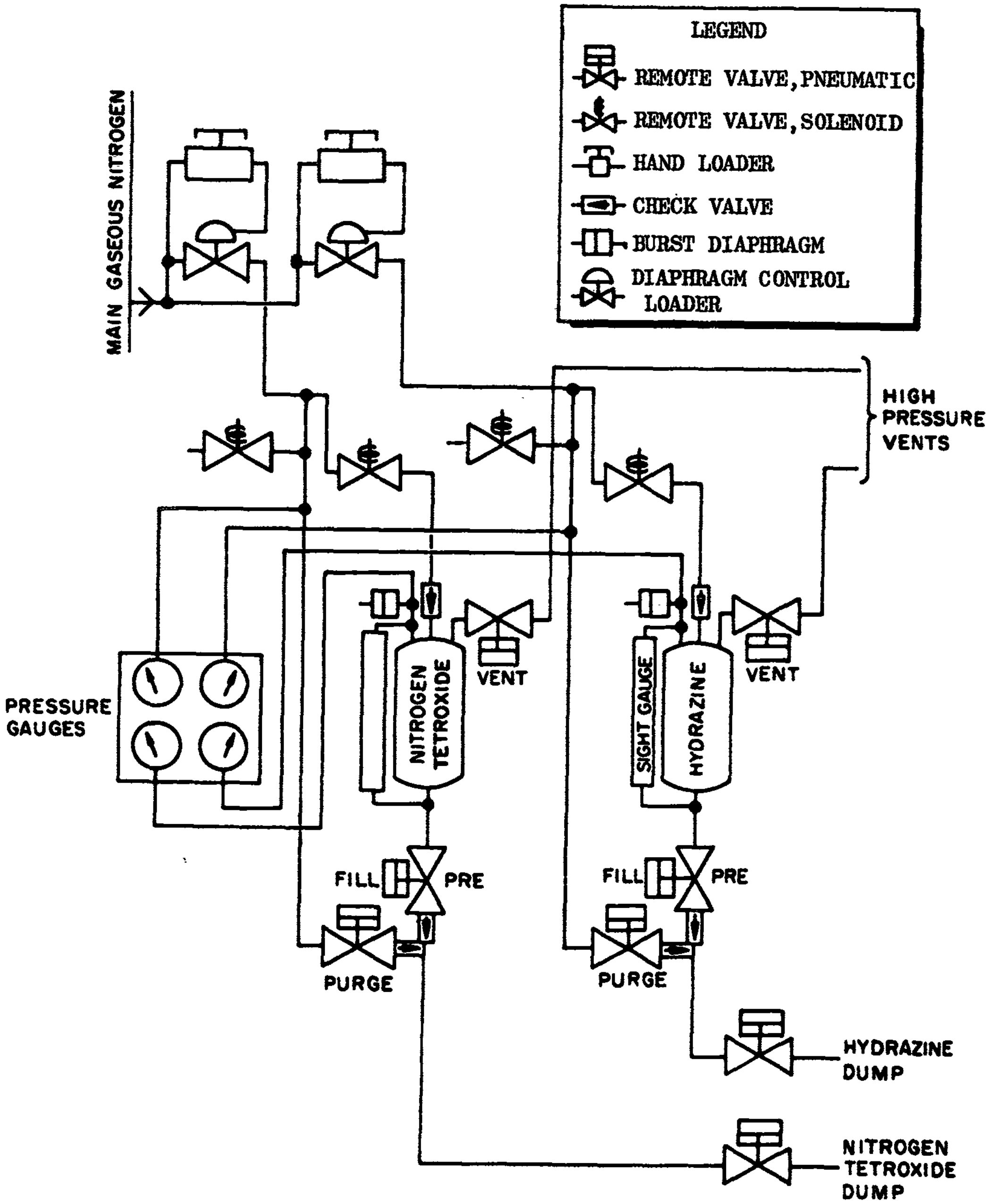


Figure 3. Small-Scale Hazard Determination System Schematic

TABLE 1

SPILL TEST OVERPRESSURE RESULTS

Test No. 1 - Simultaneous Spill on Dry Concrete
W_o = 1.5 lb, W_f = 1 lb

Microphone	Position	Time, msec*										
		610	810	925	960	1025	1065	1175	1255	1295	1330	1400
M-1 psi	10 ft	1.65	1.23	0.73	0.70	1.30	1.67	1.18	0.67	0.73	0.30	0.47
M-2 psi	10 ft	1.49	0.62	0.76	0.44	1.06	1.56	1.11	0.44	0.71	0.32	0.29

Test No. 2 - Simultaneous Spill on Dry Concrete
W_o = 1.5 lb, W_f = 1 lb

Microphone	Position	Time, msec*										
		440	520	585	610	690	730	760	910	930	965	1065
M-1 psi	10 ft	0.27	0.37	0.43	1.33	0.27	1.57	0.93	0.35	1.63	1.27	0.63
M-2 psi	15 ft	0.14	0.22	0.29	0.54	0.13	1.48	0.57	0.22	0.67	0.70	0.41

Test No. 3 - Oxidizer Lead on Dry Concrete
W_o = 2 lb, W_f = 0.50 lb, Time = msec*

Microphone	Position	No overpressures recorded
M-1 psi	10 ft	
M-2 psi	15 ft	

Test No. 4 - Fuel Lead on Dry Concrete
W_o = 1 lb, W_f = 1.50 lb

Microphone	Position	Time, msec*							
		470	625	695	730	960	1030	1130	1200
M-1 psi	10 ft	0.57	0.97	0.67	1.67	0.57	1.45	0.67	1.20
M-2 psi	15 ft	0.35	0.57	0.38	1.41	0.29	0.75	0.48	0.60

1

TABLE 1

... TEST OVERPRESSURE RESULTS

Time, msec*

	1025	1065	1175	1255	1295	1330	1400	1480	1510
	1.30	1.67	1.18	0.67	0.73	0.30	0.47	0.60	0.92
	1.06	1.56	1.11	0.44	0.71	0.32	0.29	0.35	0.60

Time, msec*

	690	730	760	910	930	965	1065	1355	1620	1690
	0.27	1.57	0.93	0.35	1.63	1.27	0.63	0.63	0.93	1.12
	0.13	1.48	0.57	0.22	0.67	0.70	0.41	0.35	0.38	0.53

d

e, msec*

	960	1030	1130	1200
	0.57	1.45	0.67	1.20
	0.29	0.75	0.48	0.60

TABLE 1
(Continued)

Test No. 5 - Simultaneous Spill on Dirt
W_o = 1.50 lb, W_f = 1 lb

Microphone	Position	Time, msec*							
		100	130	180	225	265	310	355	410
M-1 psi	10 ft	trace	0.40	0.28	0.78	0.47	0.80	1.17	0.80
M-2 psi	15 ft	trace	0.25	0.22	0.46	0.38	0.48	0.60	0.54

Test No. 6 - Oxidizer Lead on Dirt
W_o = 2 lb, W_f = 0.50 lb

Microphone	Position	Time, msec	
		260	290
M-1 psi	10 ft	trace	0.55
M-2 psi	15 ft	trace	0.40

Test No. 7 - Fuel Lead on Dirt
W_o = 1 lb, W_f = 1.50 lb

Microphone	Position	Time, msec*		
		070	260	755
M-1 psi	10 ft	0.52	0.77	0.37
M-2 psi	15 ft	0.50	0.52	0.13

Test No. 8 - Simultaneous Spill on Water-Covered Concrete
W_o - 1.50 lb, W_f = 1 lb

Microphone	Position	Time, msec*		
		025	050	225
M-1 psi	10 ft	0.50	0.87	0.40
M-2 psi	15 ft	0.29	0.44	0.25

Test No. 9 - Fuel Lead on Water-Covered Concrete
W_o = 1 lb, W_f = 1.5 lb, Time = msec*

Microphone	Position	No overpressures recorded
M-1 psi	10 ft	
M-2 psi	15 ft	

NOTE: W_o and W_f are approximate quantities spilled during the duration of the spill.

* = Time is from actuation of photocell.

a gradual buildup and decline of a series of peaks occurring within a few milliseconds and return to normal prior to the next overpressure disturbance. In every instance, evidence for the initiation of the overpressures could be seen in the motion pictures approximately 2 to 4 ft above the spill surface, and correlated with the sound tape record. Combustion of the propellants appeared as a yellow-orange color on film, while the explosions were located as a brilliant white flash.

Spills on Dry Concrete. Four spills were made with total propellant quantities of 2.5 lb on dry concrete. The following spill conditions were obtained; two simultaneous, one oxidizer lead, and one fuel lead.

Test 1 was a simultaneous dump of the two propellants to check sequencing and instruments. Approximately 1 lb of fuel and 1.5 lb of oxidizer were dumped over a period of 2 seconds, resulting in the detection of 13 distinct overpressure peaks on each of the two microphone pickups. Magnitudes of the pressure ranged from 0.29 to 1.67 psi with microphone M-2 recording slightly lower pressures than microphone M-1 whose sensing element was located in a direct line with the overpressure origin. However, the first overpressure wave was not detected until 610 msec after detection of ignition on the photocell (Fig. 4). The motion picture of the run corroborated these data. Overpressures appeared to originate from small ignitions 3 to 4 ft above the spill surface.

Test 2 was a repeat of the previous simultaneous spill test except that microphone M-2 was moved to a distance of 15 ft from the spill point. Again, approximately 1 lb of fuel and 1.5 lb of oxidizer were dumped over a period of 2 sec. Fourteen overpressure peaks were detected by each of the microphone pickups. M-1 recorded overpressures ranging from 0.27 to 1.63 psi; M-2 measurements ranged from 0.13 to 1.49 psi. M-2 measurements appeared to be approximately 60 percent of those of M-1. Again, the first overpressure peak was not detected by M-1 until 440 msec after the photocell detected ignition (Fig. 5). The motion picture record of the test indicated again that the overpressures appeared to originate a few feet above the spill surface

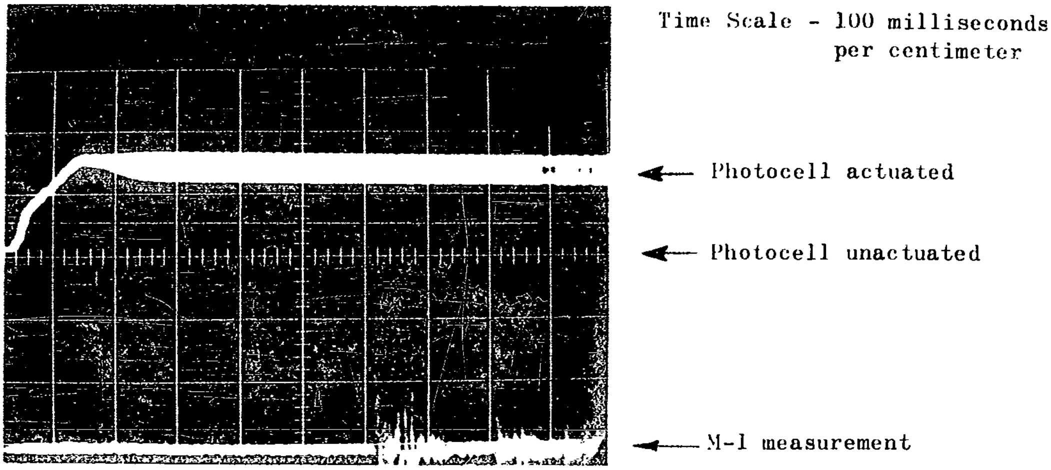


Figure 4. Overpressure Sequence of Test 1, Simultaneous Spill on Dry Concrete

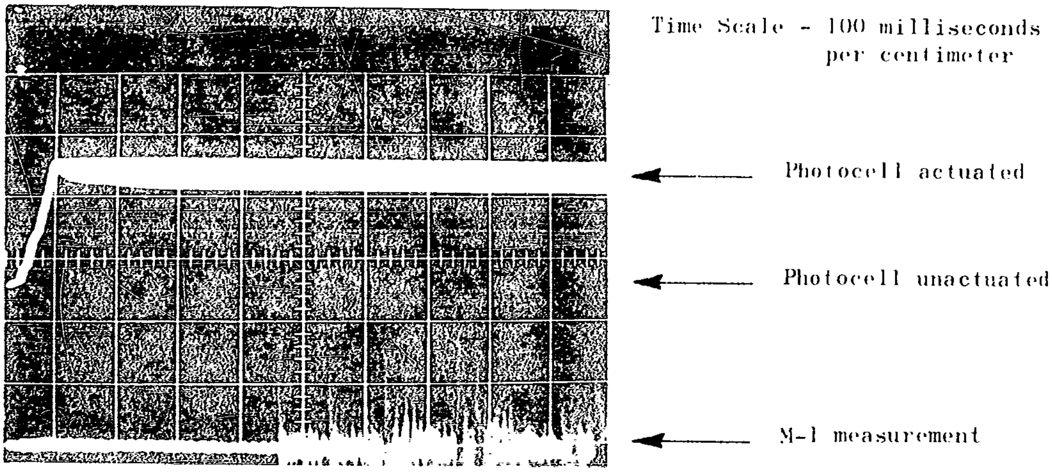


Figure 5. Overpressure Sequence of Test 2, Simultaneous Spill on Dry Concrete

A 830-msec lead of oxidizer on dry concrete was used in test 3. Although a fire occurred when the fuel was ejected, no overpressure measurements were recorded on either microphone pickups. No indication of explosions were observed either during the test by test personnel or in the motion picture summation of the test.

A fuel lead was used in test 4 on the same surface and eight overpressure peaks were recorded. The first peak occurred 470 msec (Fig. 6) after ignition and the peaks ranged from 0.57 to 1.67 psi as measured by M-1. M-2 measurements were on the average approximately 60 percent of the magnitude of these measurements and ranged from 0.35 to 1.14 psi.

Spills on Dirt. Three spills were made with total propellant quantities of 2.5 lb on dirt. The dirt was 3 in. deep on the surface of the concrete tray. A simultaneous spill, and oxidizer lead, and a fuel lead were obtained.

Test 5, a simultaneous spill of the propellants, resulted in a trace measurement 100 msec (Fig. 7) after the photocell indication and a measurable overpressure 130 msec after the ignition. Six more overpressure shocks were detected and ranged from 0.28 to 1.17 psi on M-1 and from 0.22 to 0.60 psi on M-2.

Test 6 used a 1120-msec lead of oxidizer on dirt. A very small pressure was sensed 260 msec after ignition by M-1 (Fig. 8). Thirty milliseconds later, a second overpressure peak of 0.55 and 0.40 psi occurred at M-1 and M-2, respectively. These were the only explosions that appeared during this test.

A 290-msec lead of fuel in test 7 resulted in three overpressure peaks with maximums of 0.77 and 0.52 psi recorded on M-1 and M-2, respectively. The first overpressure was recorded 70 msec after ignition (Fig. 9). Ignition on all of these tests appeared to be instantaneous with the contact of the two propellants.

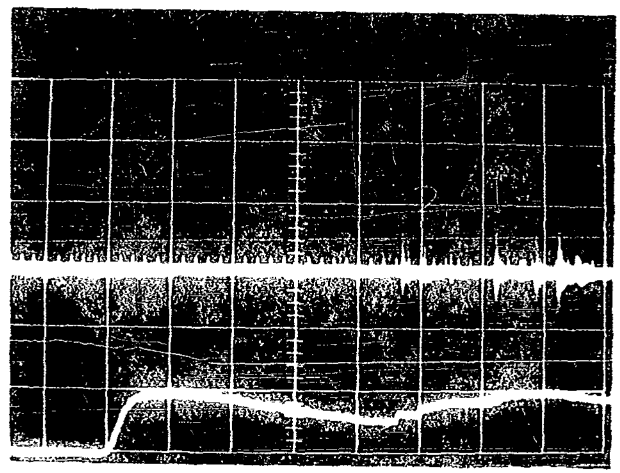


Figure 6. Overpressure Sequence of Test 4, Fuel Lead on Dry Concrete

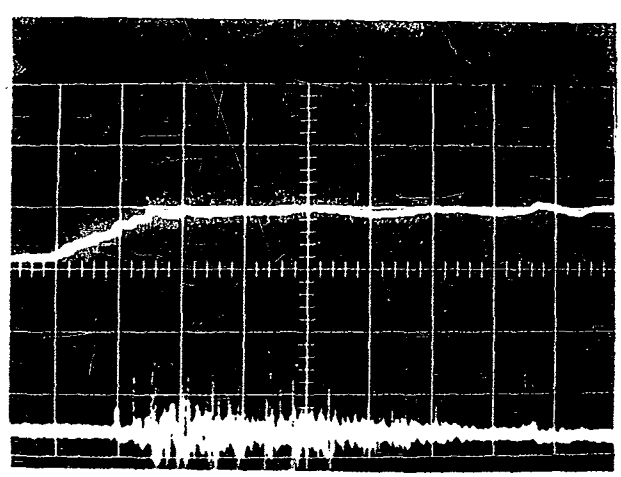


Figure 7. Overpressure Sequence of Test 5, Simultaneous Spill on Dirt

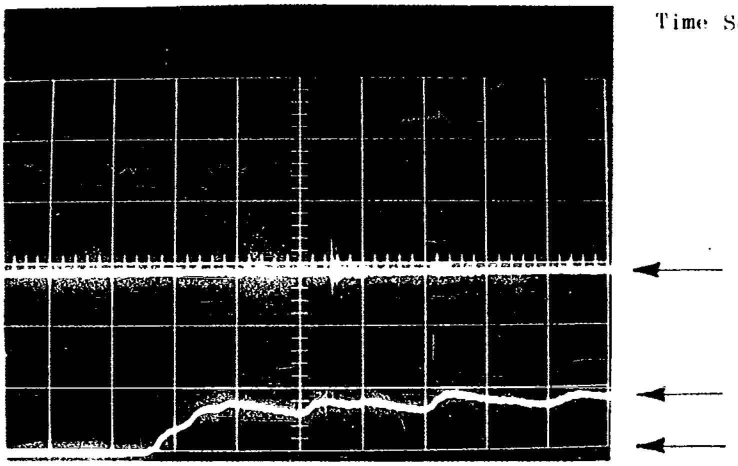


Figure 8. Overpressure Sequence of Test 6, Oxidizer Lead on Dirt

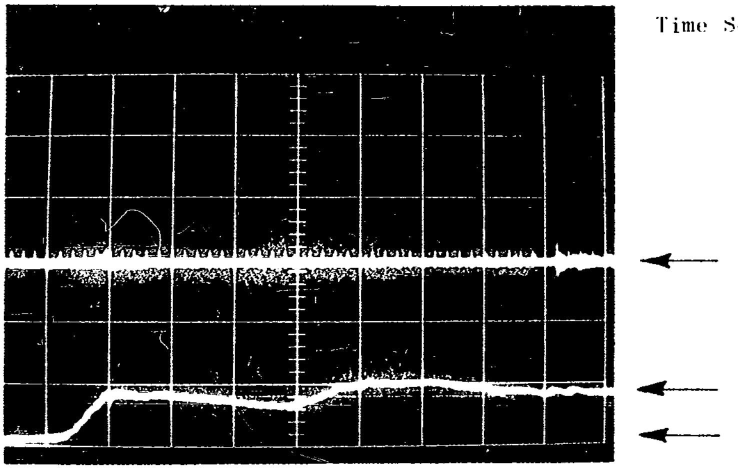


Figure 9. Overpressure Sequence of Test 7, Fuel Lead on Dirt

Spills on Wet Concrete. Two spills were made with total propellant quantities of 2.5 lb on wet concrete. The concrete surface of the spill tray was covered with 1 to 2 inches of water. A simultaneous spill and a fuel lead spill were obtained.

On the simultaneous dump of the fuel and oxidizer, test 8, a very slight delay in the ignition of the propellants was noted. The first overpressure peak was measured 25 msec after ignition by M-1 (Fig. 10), while continued dumping of the 1 lb of fuel and 1.5 lb of oxidizer resulted in two additional explosions reaching 0.87 and 0.44 psi on M-1 and M-2, respectively.

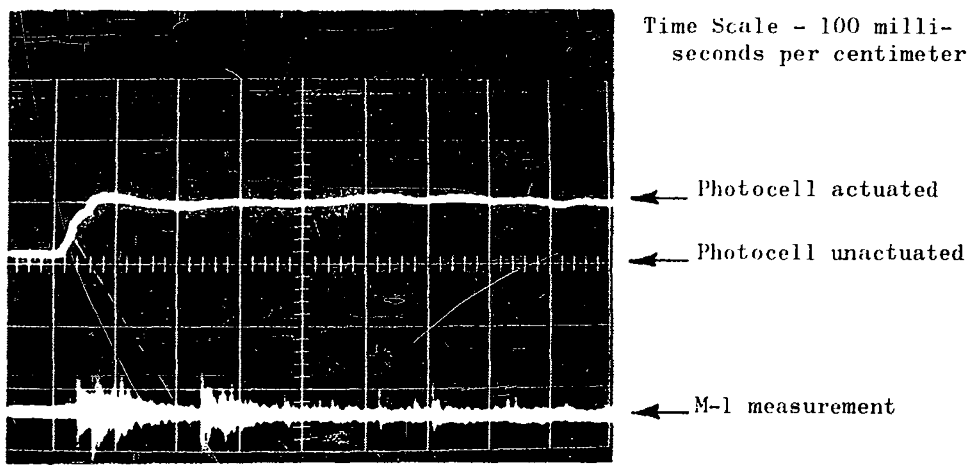


Figure 10. Overpressure Sequence of Test 8, Fuel Lead on Water-covered Concrete

Test 9 used a 230-msec lead of fuel. After a very slight ignition delay, combustion of the propellants occurred and continued without measurable overpressure shocks.

Singular Spills. Singular spills of the fuel were made on dry concrete, dirt, and the water-covered concrete in the fourth test series. In each case, the propellant was allowed to stand for a few minutes before it was removed from the spill pit. A spill of the fuel mixture on dry concrete resulted in the formation of vapors over the immediate spill area which lasted until the propellant was washed away. Dirt caused an initial delay in the formation of the vapors; however, after a short time they appeared to be as dense as on the dry concrete surface. In either case, the fuel did not appear to decompose in a rapid manner. Spills of the fuel on water-covered concrete resulted in the least amount of vapors from the spill surface.

Analysis

A simple relation is reported for the conversion of "reflected" to "side-on" shock overpressures (Ref. 2); this relation is as follows:

$$pr = (2\,P) \left[(7\,P_o + 4\,P) / (7\,P_o + P) \right] \qquad (3)$$

where

pr = face-on refelected pressure, psi

P_o = ambient pressure (ahead of shock), psia

P = side-on pressure, psi

For the weak overpressure shocks experienced on the small-scale tests, the equation was simplified to:

$$P = pr/2 \qquad (4)$$

This simplification will not introduce significant error when used for very weak shocks only.

The explosive potential of a propellant combination, in pounds of TNT, was obtained by converting the reflected pressures to side-on overpressures with Eq. (4). In turn, the quantity of TNT was found by use of Eq. (1). The equivalent yield was calculated by the simple relation:

$$W = X \frac{W_t}{100} \qquad (5)$$

where

W = weight of TNT charge, lb

X = TNT equivalent yield, percent

W_t = total weight of propellant spilled, lb

A maximum TNT equivalent of 0.48 percent in a simultaneous spill on dry concrete was reached. It was apparent that shocks originated from vapor-phase reactions,in the product cloud, a few feet above the spill surface. Combination spills produced overpressures under most of the conditions studied. Motion pictures showed a succession of white flashes within the product cloud; these flashes were correlated directly with pressure records by time sequencing.

The conditions of the Titan II propellant spills can be rated in accordance with observed severity. Simultaneous spillage and fuel leads resulted in higher amplitude overpressures than did the oxidizer leads. Also, a test on dry concrete resulted in stronger shocks than similar tests on dirt or water. With these classifications and the photographic records as evidence, it seemed possible to conclude that vapor-phase explosions were a consequence of reacting fuel-air mixtures.

The visible cloud of fuel vapors over the spill area was most dense when spills were made on nonporous surfaces, such as concrete. Dirt and water surfaces absorbed fuel and/or cooled scattered droplets to retard vaporization. The formation of explosive fuel-air mixtures was hindered also by oxidizer leads which gave rapid vaporization and resulted in smoother reaction with the fuel after its appearance.

MODEL-MISSILE STUDIES

The model missile studies were conducted at the Haystack Butte Hazards Determination Spill Site at Edwards Air Force Base. A plot plan of the site is shown in Fig. 11. The spill tests were performed in 1/10- and 1/18-scale-size silo models and aboveground in the spill tray. The model missile spill tanks for each model size were scaled by volume and do not represent the scale dimensions of the actual missile tank configuration. These volumetric models of the Titan II missile will be identified as 1/10- or 1/18-scale model missiles. The scaled volumes for the 1/10- and 1/18-scale models are 0.1 percent and 0.017 percent, respectively, of the full-scale Titan II Weapon System. The propellant combination was nitrogen tetroxide and 50-50 UDMH-hydrazine.

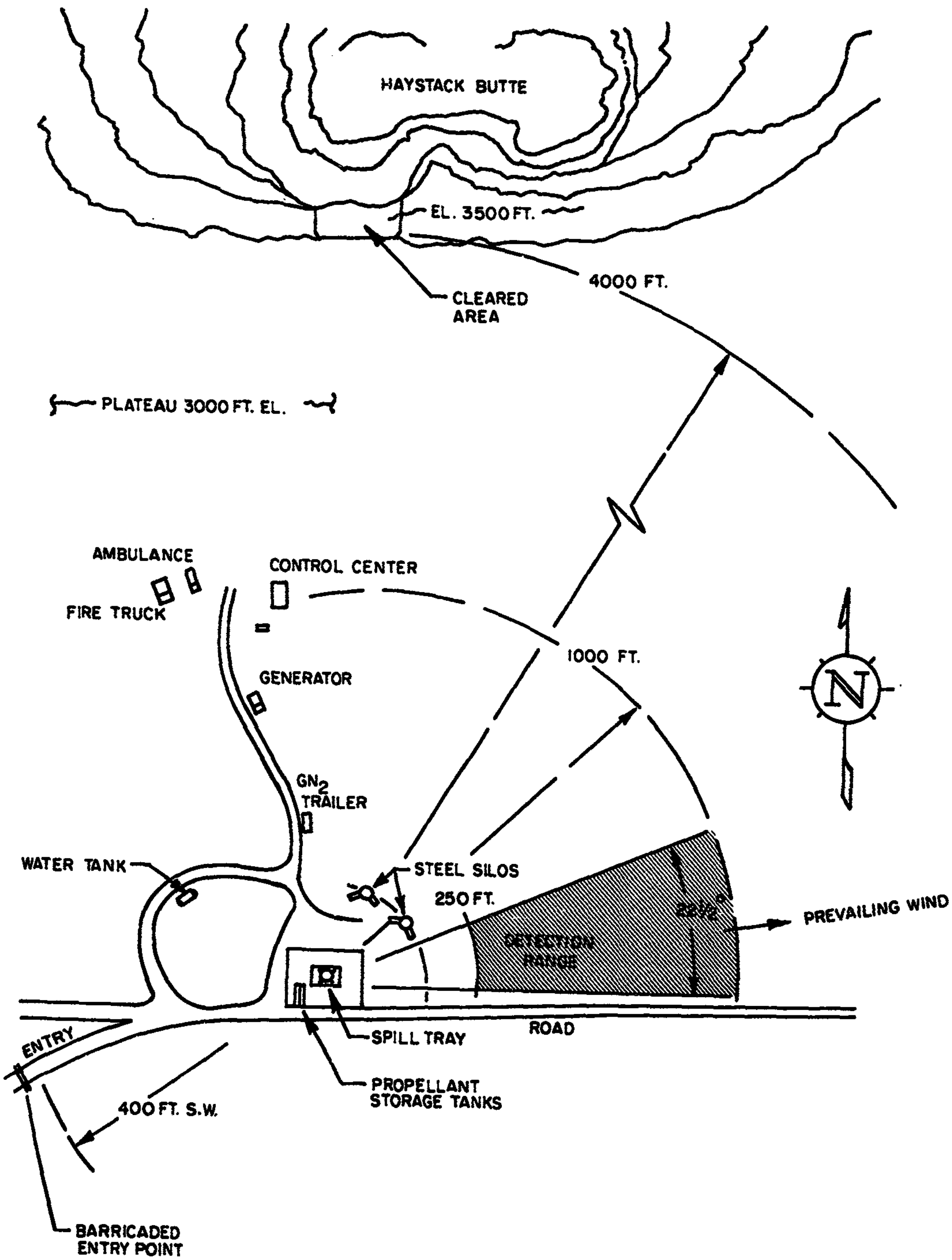


Figure 11. Plot-Plan of the Haystack Butte Propellant Hazard Determination Test Area

The following tests comprise the program scope:

Spills in Frangible Silo (Unreinforced Hole):

1. Three tests with 300 lb of total propellant (1/10 scale)
2. Three tests with 50 lb of total propellant (1/18 scale)

Spills Aboveground (In Spill Tray):

1. Three tests with 300 lb of total propellant (1/10 scale)

Spills in Rigid Silo (Carbon Steel Liner)

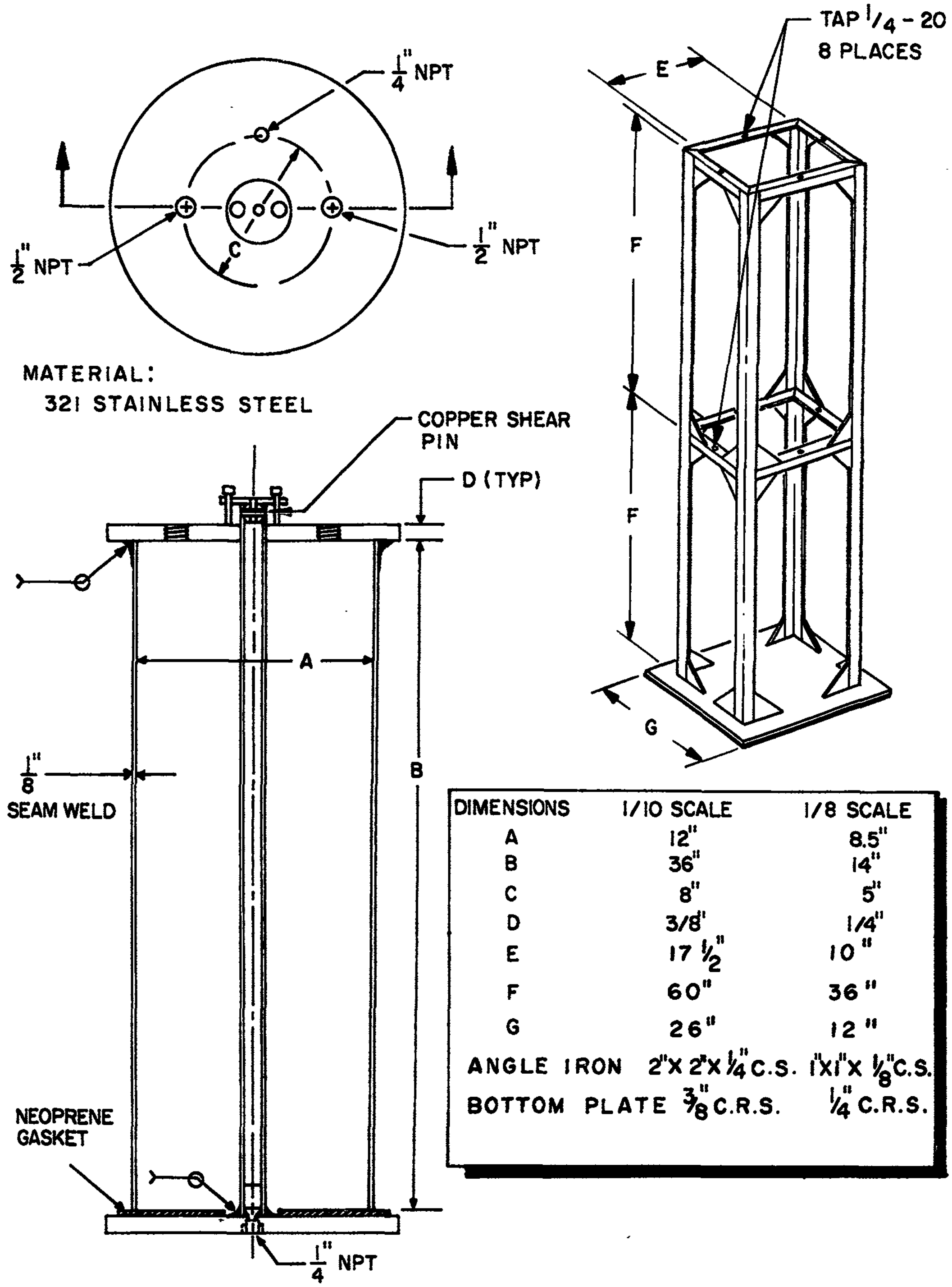
1. Three tests with 300 lb of total propellant (1/10 scale)
2. Three tests with 50 lb of total propellant (1/18 scale)

Test Equipment

Spill Tanks. The propellant tanks for these tests are of cylindrical construction (Fig. 12). The bottom end plates are separated from the cylinder by high-pressure gaseous nitrogen to give instantaneous propellant spill. The cylindrical tanks for the 1/10-scale model have capacities of 200 lb of nitrogen tetroxide and 100 lb of (50-50 percent) UDMH-hydrazine. The 1/18-scale model tanks have capacities of 33 lb of nitrogen tetroxide and 17 lb of 50-50 percent UDMH-hydrazine. Dimensions of the test stand structure which supports the tanks are given in Fig. 12. Figure 13 shows the propellant tanks placed in the test stand structure and the oxidizer fill, fuel fill, vent, and pressurization lines plumbed to their top flanges. The spill tanks are filled remotely by pressurizing the propellant from the storage tanks.

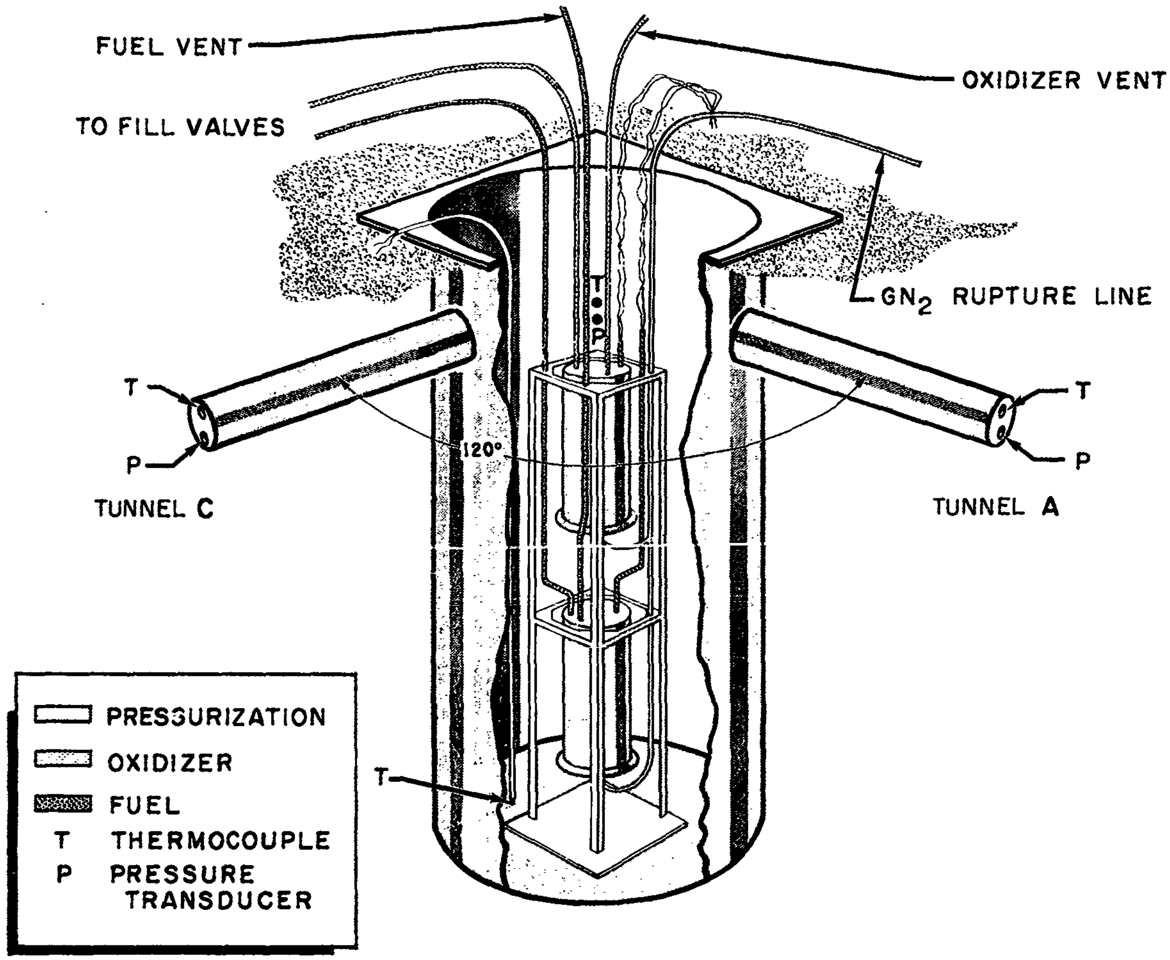
Silos. Holes for the silos were drilled in the decomposed granite subsoil to the northeast of the spill pad and tray. The frangible silo holes for the 1/10- and 1/18-scale models are 5 ft in diameter by 15 ft deep and 3 ft in diameter by 9 ft deep, respectively. The dimensions of the rigid steel silo with tunnel offshoots are given with accompanying perspective drawing in Fig. 13. Lowering of a 1/10-scale model missile tank assembly into a silo is shown in Fig. 14.

Spill Tray. The aboveground spills were conducted in a steel tray approximately 20 ft by 20 ft by 2 ft deep, of all welded construction. Figure 15 shows the 1/10-scale model missile tanks positioned in the spill tray for an aboveground spill test.



DIMENSIONS	1/10 SCALE	1/8 SCALE
A	12"	8.5"
B	36"	14"
C	8"	5"
D	3/8"	1/4"
E	17 1/2"	10"
F	60"	36"
G	26"	12"
ANGLE IRON	2"X 2"X 1/4" C.S.	1"X1"X 1/8" C.S.
BOTTOM PLATE	3/8" C.R.S.	1/4" C.R.S.

Figure 12. Dimensions of Model-Missile Spill Tanks and Tank Support Structure



DIMENSIONS	1/10 SCALE	1/18 SCALE
SILO DIA.	5'	3'
SILO DEPTH	15'	9'
TUNNEL DIA.	1'	.5'
TUNNEL LENGTH	15'	9.5'
TUNNEL DISTANCE BELOW SILO TOP	3'	2'

Figure 13. Rigid Steel Silo for Model-Missile Spill Tests

Figure 14. Test Stand with 1/10-Scale Tanks Being Lowered into Silo

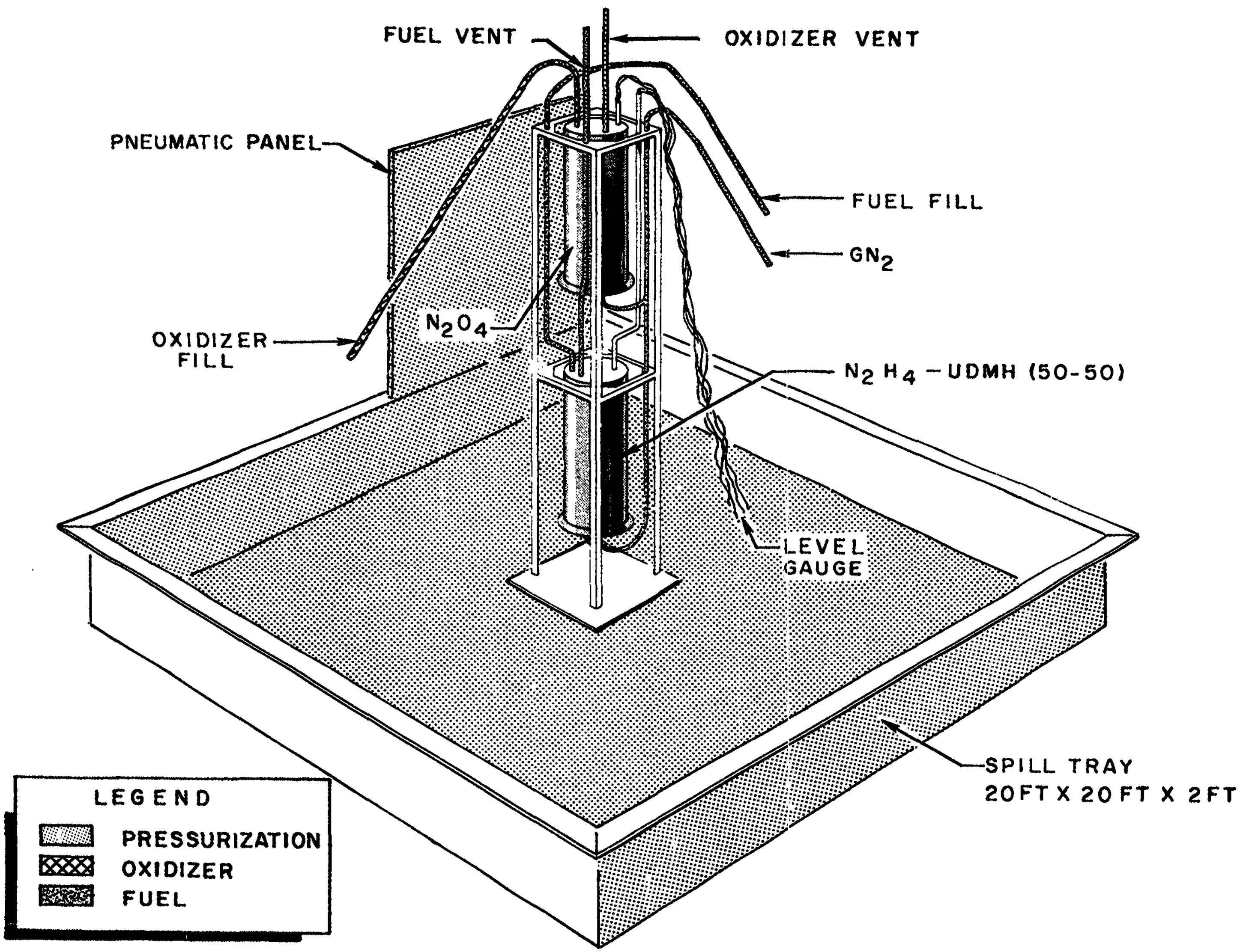


Figure 15. Placement of 1/10-Scale Model Missile Tanks for Aboveground Spills

Valves and Lines. Pneumatically controlled 1-inch Annin valves are used for propellant transfer and vent purposes. Pressurizing lines are controlled by 1/4-inch Robbins and Grove shutoff valves and have 1/4-inch Southwestern check valves installed downstream for gaseous nitrogen system protection. All valves are of stainless-steel construction with Teflon or Kel-F seals, with the exception of the regulators and Grove shutoff valves that use synthetic rubber seals. Stainless-steel tubing and fittings have been used for plumbing to the tanks in the silos, to prevent unnecessary replumbing due to the melting of aluminum lines. These lines connect with the lines used for propellant spills in the tray and utilize the same control valves. Figure 16 shows a schematic of the model-missile spill system.

Instrumentation

Blast Measurements. Blast instrumentation was used to record overpressures on the rigid-steel silo tests and two aboveground spills. Measurements were made at ground level at distances of 25, 35, 50, and 75 ft from the reaction zone. Figure 17 shows the location of the pressure measurement field. Model 304-A Photocon pressure microphone transducers were mounted in the capped end of a steel pipe and the pipe was buried flush with the ground surface for a "side-on" pressure measurement (Fig. 18). In-silo blast measurements were made using Photocon Model 307 pressure transducers. The transducers have a response range of from 0 to 300 psi. Figure 18 shows the locations of the Model 307 transducers in the model silos. The overpressures sensed by the pickups are relayed to Ampex tape recorders. The taped records are later replayed and recorded by a Miller Cathode Ray oscillograph to obtain the oscillograms included in the Data Appendix. The blast measurement system was calibrated by use of a 10-lb charge of TNT and was found to agree with standard quantity-distance relationships. Additional TNT charges were detonated inside the silos for correlating the overpressures obtained of the rigid silo spill tests to those of TNT. A 50-lb TNT charge was also set off at the bottom of a 1/18-scale model frangible silo which resulted in a 6-ft-diameter crater extending down through the loose sand topsoil to the decomposed granite subsoil approximately 2-1/2 ft below the surface. The hole was filled with sand to a depth of 5 feet. The portion of the original wall which remained exposed was not damaged.

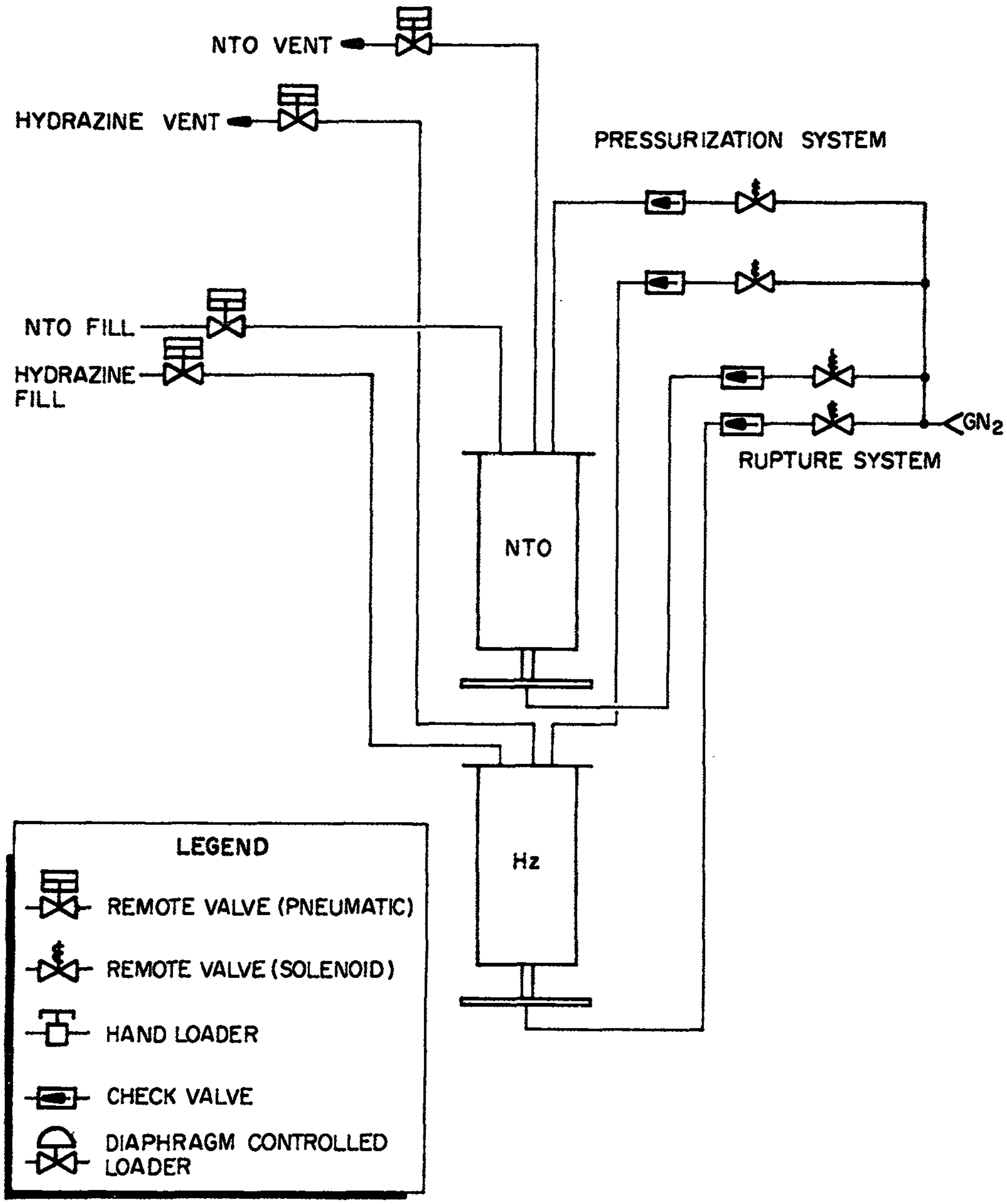


Figure 16. Model-Missile Spill System Schematic

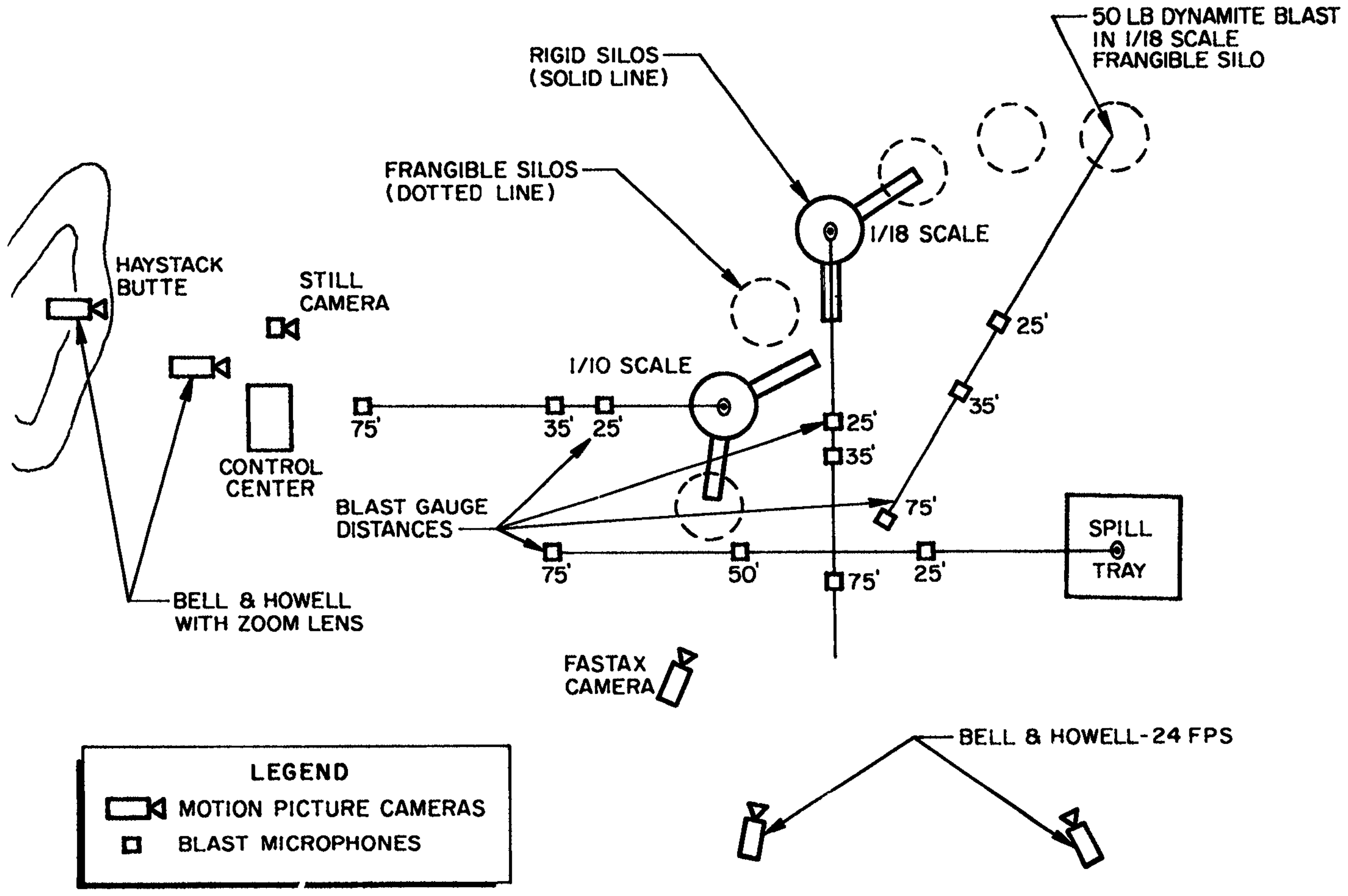
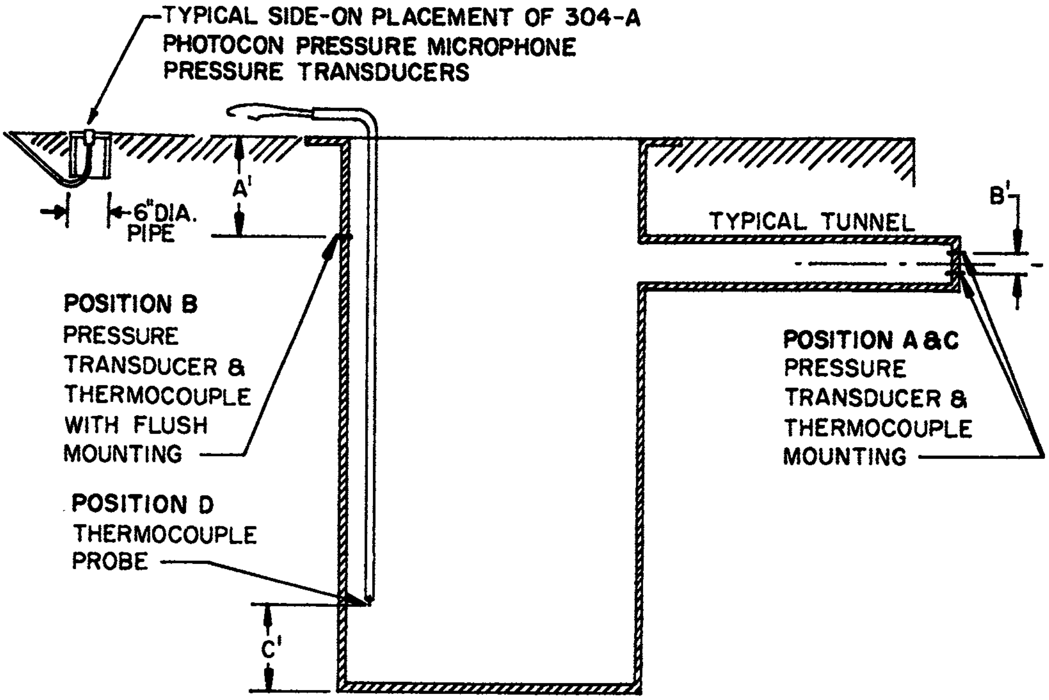


Figure 17. Location of Blast Instrumentation and Photographic Coverage at Haystack Butte During Model-Missile Spill Tests



DIMENSIONS	1/10 SCALE	1/18 SCALE
A'	38"	21"
B'	4"	2"
C'	24"	18"

Figure 18. Cross section Showing Instrumentation Locations in Rigid Steel Silo and at Ground Level

Data Appendix D gives the pressure-time histories for all TNT charges used for purposes of calibration or correlation. Included for ready reference in Appendix D is a nomogram giving peak blast pressure as a function of distance and weight of explosive. Blast measurements for this chart were made with the pressure pickups "side-on" to the blast wave.

Temperature Measurement. Temperatures were measured in the rigid silos by use of Chromel Alumel thermocouples mounted in the walls of the silo. Figure 18 shows the locations of the thermocouples in the rigid silo. A temperature measurement was also made at the bottom of the silo by use of a thermocouple mounted in a stainless-steel probe. An oscillograph was used to record the temperature measurements.

Camera Coverage. Edwards AFB provided the camera coverage for all tests in Supplement 3 conducted at the Haystack Butte Spill Area. The camera locations are shown in Fig. 17.

Test Results

Frangible Silo.

One-Tenth-Scale Silo. Three spills were made with 300 lb of total propellant. One fuel lead and two oxidizer leads were obtained.

On the fuel-lead spill test 1, the 50-50 percent UDMH-hydrazine soaked into the sand at the bottom of the silo. When the nitrogen tetroxide was dropped 180 sec later, a column of fire rose 25 to 30 ft above the ground. Several small explosions resulted. A small fire continued to burn about 20 min because the sand was saturated with fuel. No camera coverage of the initial fire was obtained. The silo walls were not damaged.

The two tests having nitrogen tetroxide leads resulted in more violent explosions. The explosions and rapid expulsion of gases formed craters in the top soil, extending down to the decomposed granite subsoil.

On the first of these, test 2, an oxidizer leak developed before the fill operation was completed. An estimated 150 lb of oxidizer was on board when the propellant was spilled. An explosion resulted immediately, throwing large quantities of sand into the air. This was followed by several smaller mid-air explosions. The flame reached 35 ft above the hole. Inspection of the silo after the test revealed an excess of nitrogen tetroxide vapors, indicating that nearly all of the fuel was burned during the initial reaction. Figure 19a gives the dimensions of the crater.

The second of the tests having an oxidizer lead, test 3, resulted in an initial violent explosion with several loud mid-air explosions occurring within 5 sec of the initial explosion. The oxidizer led the fuel by 30 sec on this test. Fire rose 100 ft above the silo (Fig. 20) and parts of the tanks were thrown 150 ft in the air. The dimensions of the resulting crater are given in Fig. 19b.

<u>One-Eighteenth-Scale Silo</u>. Three spills were made with 50 lb of total propellant. A fuel lead, a simultaneous spill, and an oxidizer lead were obtained.

On the fuel lead, test 5, 50-50 percent UDMH-hydrazine was spilled approximately 15 sec before the nitrogen tetroxide. There were a few minor explosions, with very slow burning of the fuel. No damage to the silo resulted.

The simultaneous spill of the propellants, test 6, resulted in an explosion with a column of fire extending 50 ft out of the silo. The fire lasted from 2 to 4 seconds. Figures 21 and 22 show the silo and test hardware before and after the spill. No damage occurred to the silo.

On the oxidizer-lead spill, test 4, the nitrogen tetroxide led the hydrazine by 45 seconds. A very small explosion occurred when the fuel was spilled. The explosion was observed to take place entirely within the

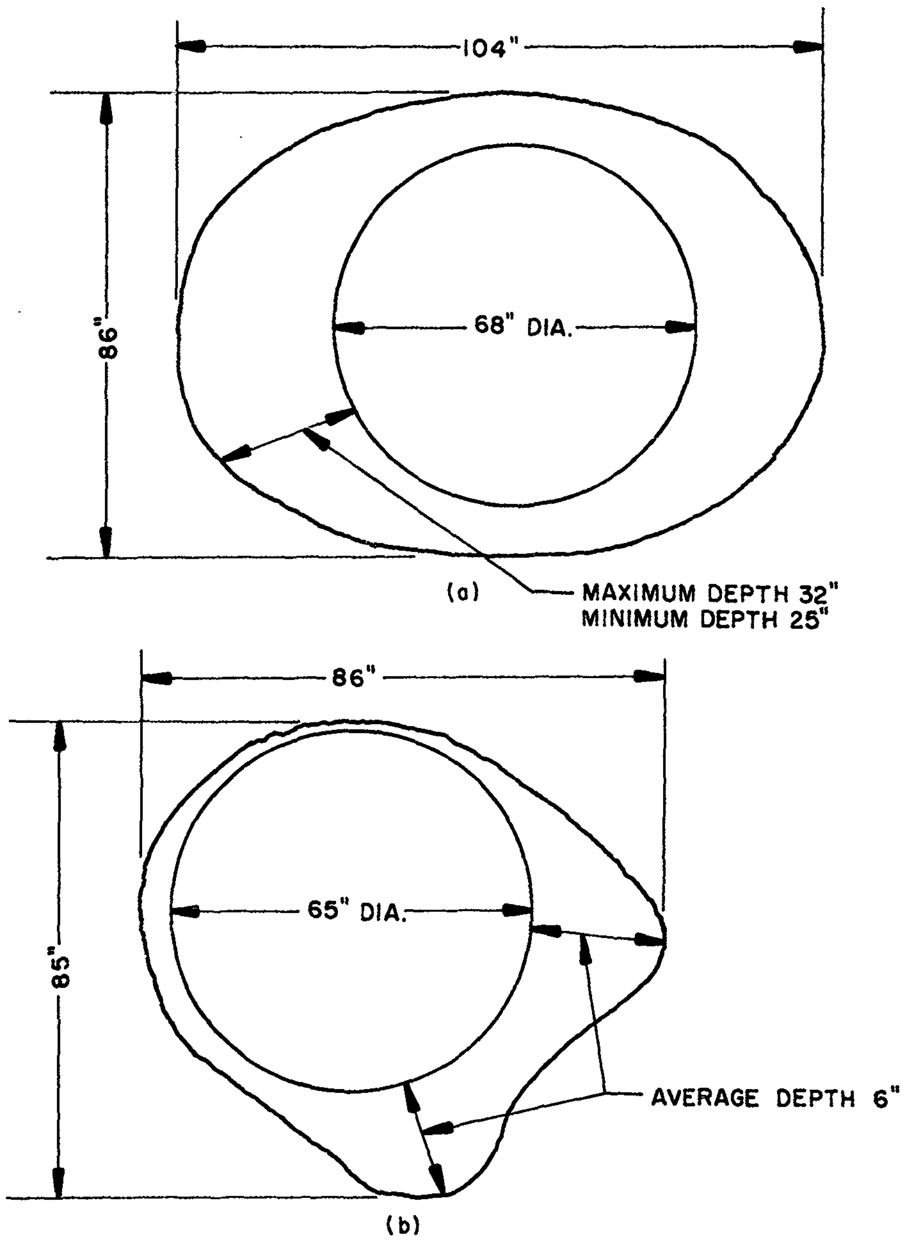


Figure 19. Crater Dimensions for Two Spills in Frangible Silo (1/10 scale)

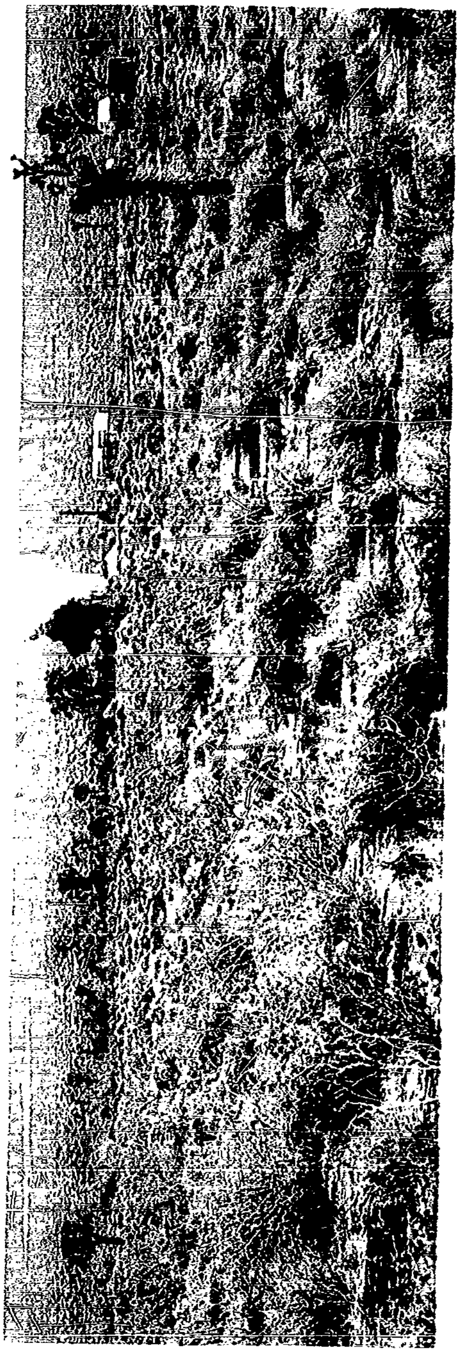


Figure 20 . 100-Ft Column of Fire Resulting from Spill of 200 lb of NTO with 100 lb of (50-50) UDMH-Hydrazine (30-sec oxidizer lead)

Figure 21. 1/18-Scale Test Hardware Before Spill in Frangible Silo

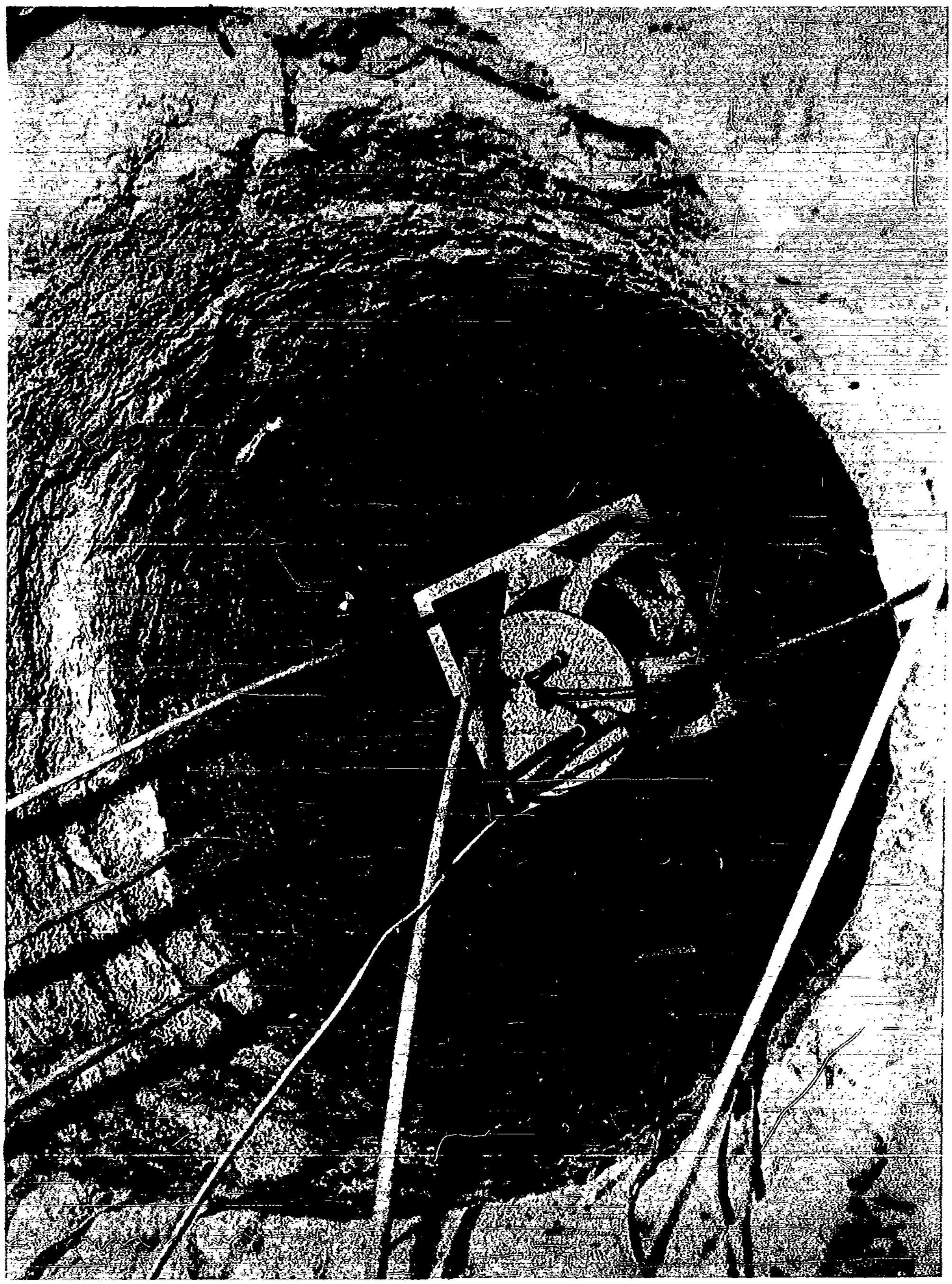


Figure 22. 1/18-Scale Test Hardware After Spill in Frangible Silo

silo. The flame extended 10 ft above the ground and lasted for approximately 10 seconds. No crater was formed by the explosion.

Aboveground Spills. Five spills, each using 300 lb of total propellant, were made in the spill tray. Pressure measurements were obtained on two of these tests. A fuel-lead spill, a simultaneous spill, and three oxidizer-lead spills were obtained.

On the fuel lead, test 7, the hydrazine was ignited by contact with the rust on the spill tray bottom. The nitrogen tetroxide was spilled approximately 1 minute later. No explosion resulted.

The simultaneous spill of the propellants resulted in the formation of a large fireball. Several large explosions were audible. The overpressures recorded are shown in Data Appendix A under test 11. Figure 23 shows the spill reaction. The ball of fire reached a maximum radius of approximately 32 feet within 1.5 sec after rupture. Table 2 gives the ball-of-fire growth rate for test 11.

Of the three spills with oxidizer leads, tests 9 and 10 resulted in only rapid burning with no explosions. On these two tests, the oxidizer led the fuel by approximately 1 minute. On the third test, having an oxidizer lead, the nitrogen tetroxide led the hydrazine by 2 seconds. Several large midair explosions and a number of smaller explosions were audible. The overpressures recorded are shown in Data Appendix A under test 8.

Figure 24 shows the film sequences of the growth of the fireball which resulted from the propellant reaction on test 8. Table 2 gives the ball-of-fire growth rate for this test.

The test hardware sustained no damage on the aboveground spills. Model tanks were reusable, requiring only replacement of the bottom gasket to ready them for the next test.

Figure 23. Simultaneous Spill of 200 lb of NTO with 100 lb of (50-50) UDMH-Hydrazine in Spill Tray

TABLE 2

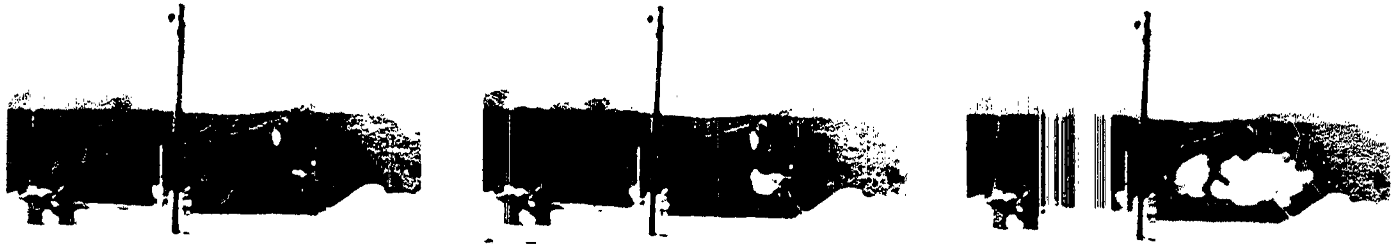
BALL-OF-FIRE GROWTH RATES

Test 1] Simultaneous Rupture			Test 8 2-Second Oxidize[illegible]d		
Time, sec	Ball-of-Fire Radius, ft	Remarks	Time, sec	Ball-of-Fire Radius, ft	.emarks
0	...	Rupture	0	0.5	ire first noticeable
0.25	1.5		0.01	2.0	
0.275	2.5		0.05	3.0	
0.3	3.5		0.1	5.0	
0.325	4.0		0.15	6.0	
0.35	4.0		0.2	8.0	
0.375	4.0		0.25	10.0	
0.4	4.0		0.3	10.0	
0.425	4.0		0.35	10.0	
0.45	4.0		0.40	10.0	
0.475	4.0		0.45	10.0	irst noticeable
0.5	4.0	First noticeable	0.5	15.0	ressure pulse
0.625	6.0	overpressure pulse	0.55	15.0	

TABLE 2

(Continued)

Test 11 Simultaneous Rupture			Test 8 2-Second Oxidiz[illegible]ad		
Time, sec	Ball-of-Fire Radius, ft	Remarks	Time, sec	Ball-of-Fire Radius, ft	Remarks
0.75	10.0		0.75	17.5	
0.875	15.0		0.85	20.0	
1.0	20.0		0.95	22.5	
1.12	22.0		1.25	25.0	
1.25	25.0		1.5	25.0	
1.375	30.0		1.6	30.0	
1.5	32.0		1.85	32.0	Ball of fire starts rising
2.0	32.0	Ball of fire starts rising			



(1) First Fire, 0 Second

(2) 5-Ft Radius, 0.1 Second

([illegible]) [illegible]-Ft Radius, 0.2 Second

(4) 10-Ft Radius, 0.4 Second

(5) 15-Ft Radius, 0.6 Second

(6) [illegible] Radius, 0.9 Second

(7) 22-Ft Radius, 1.2 Seconds

(8) 25-Ft Radius, 1.4 Seconds

(9) [illegible]t Radius, 1.6 Seconds

Figure 24. Ba[illegible]-of-Fire Growth Rate, Test 8

Rigid Steel Silo.

One-Eighteenth-Scale Silo. Five spills were conducted using 50 lb of total propellant. The following spill conditions were obtained; a simultaneous spill into burning hydrazine, two simultaneous spills into a dry silo, one oxidizer-lead spill, and one simultaneous spill into [illegible] for each test of this series are presented in Table 7. The pressure-time and temperature-time histories are shown in Data Appendix B under the appropriate test number.

Test 14, the simultaneous spill into burning hydrazine, resulted in mild burning of the propellants. A small leak occurred in the fuel system during the fill operation which allowed the hydrazine to drip on the oxidized floor of the silo and be ignited. Several overpressures were recorded. An after-fire continued to burn for 10 min after the initial spill reaction. No temperature measurements were made on this test.

The two simultaneous spills, tests 12 and 15, resulted in violent burning. A flame column extended 50 ft above the silo on each test. Figure 25 shows the spill reaction on test 15. Overpressures were recorded on both tests. Fires continued to burn in the silos for approximately 10 min after the initial spill reaction. No temperature measurements were made.

On test 13, the oxidizer-lead spill, nitrogen tetroxide led the hydrazine by 30 sec. The reaction resulted in violent burning with flame extending 50 ft above the silo. Oscillograms of the thermocouple response show a maximum temperature of 494 F. No temperatures above ambient were recorded from response of the thermocouples mounted in the tunnels. An afterfire was observed to burn for 10 min after the initial propellant reaction.

The simultaneous spill of propellants into 50 lb of water, test 16, resulted in rapid burning with flame extending 30 ft above the silo. Two small explosions occurred and were recorded. The violence of the reaction

TABLE 3

ONE-EIGHTEENTH-SCALE SILO OVERPRESSURE AND TEMPE

Microphone and Thermocouple Position-Pulse	Test 12 Three Overpressures Pressure, psi	Time From Zero, msec	Test 13 Three Overpressures Pressure, psi	Time From Zero, msec	Test 14 Three Overpressures Pressure, psi	Time From Zero, msec	Two O Pressur psi
Tunnel A-1	22	9	11.5	9	9	10	19
A-2	11	144	22	316	22	200	33
A-3	68	661	39	417	88	2027	
Silo B-1	19	0*	7	0*	13.5	0*	15.
Wall B-2	17	134	13.5	309	13.5	191	37
Upper B-3	22	654	35	412	18	2021	
Tunnel C-1	14.5	8	13.5	9	13.5	10	17.
C-2	11	145	27.5	316	17	201	24.
C-3	43.5	662	37	417	37	2029	
Silo D-1	Not taken		Not taken		Not taken		Not tak
Wall D-2							
Lower D-2							
Field 25-1	—	—	—	—	—	—	—
25-2	—	—	—	—	—	—	0.
25-3	0.9	674	0.85	431	0.8	2041	
Field 35-1	—	—	—	—	—	—	—
35-2	—	—	—	—	—	—	0.
35-3	—	—	—	—	—	—	
Field 75-1	0.15	65	0.15	66	—	—	1.
75-2	0.15	219	0.22	379	—	—	0.
75-3	0.32	717	0.28	473	—	—	

NOTE: – = No response from pickup
* = No time mark, zero time is when first overpressure occurred

TABLE 3

ILO OVERPRESSURE AND TEMPERATURE RESULTS

Test 14		Test 15		Test 16		
Overpressures		Two Overpressures		Two Overpressures		
re,	Time From Zero, msec	Pressure, psi	Time From Zero, msec	Pressure, psi	Temperature, F	Time From Zero, msec
	10	19	1462	12	ambient	1210
	200	33	1565	11.5	ambient	2868
	2027					
.5	0*	15.7	1454	8	ambient	1200
.5	191	37	1556	7.5	337	2858
	2021					
.5	10	17.5	1462	13	ambient	1208
	201	24.0	1563	11.5	ambient	2866
	2029					
t ken		Not taken		Not taken	263 215	1200 2858
---	---	---	---	0.6	Not taken	1223
---	---	0.85	1576	0.6	Not taken	2881
.8	2041					
---	---	---	---	---	Not taken	---
---	---	0.3	1593	---	Not taken	---
---	---					
---	---	1.0	1524	0.12	Not taken	1266
---	---	0.3	1621	0.15	Not taken	2926
---	---					

ed

Figure 25. Simultaneous Spill of 33 lb NTO with 17 lb of (50-50) UDMH-Hydrazine in 1/18-Scale Rigid Steel Silo

was noticeably reduced on this test, compared to the preceding tests of this series. No after-fire was observed. The maximum recorded temperature in the silo was 337 F.

<u>One-Tenth-Scale Silo</u>: Four spills were conducted with 300 lb of total propellant. The following spill conditions were obtained; one [illegible]

On the fuel-lead spill, test 19, the hydrazine led the nitrogen tetroxide by 180 sec. The hydrazine was ignited on contact with the oxidized silo floor. The heat of combustion ruptured the nitrogen tetroxide tank and resulted in an intense fire which burned for 20 min. No explosions resulted. Temperatures exceeded 2000 F in the main silo body, deflecting the recording galvanometers offscale. Damage was sustained by the test hardware; the model tank support structure was twisted when heat caused the angle iron members to lose structural rigidity.

The two simultaneous spills were each conducted under slightly different conditions. Spill test 18 was made into an atmosphere containing light nitrogen tetroxide vapors. The reaction of the propellants resulted in violent burning with flame extending 100 ft above the silo. Numerous explosions were audible. Pressure measurements show 12 distinct overpressures. Tabulated values of overpressures recorded are given in Table 4 together with the temperature-time measurements obtained. Spill test 20 was made in an atmosphere containing light fuel vapors, resulting in violent burning. A 100-ft column of flame extended above the silo. Figure 26 shows the flame column and nitrogen tetroxide cloud formation. Several minor explosions were audible. Tabulated values of pressure and temperature measurements recorded on this test are given in Table 5. Pressure-time and temperature-time histories for both spills are shown in Data Appendix C. Both spills had after-fires which continued to burn for 15 min after the initial spill reactions.

On the oxidizer-lead spill, nitrogen tetroxide led the hydrazine by 1 sec. The initial reaction resulted in violent burning with several large

TABLE

ONE-TENTH-SCALE SILO RECORDED O

Spill Test 18, Twelve

[illegible] and Thermocouple Position-Pulse		Pressure, psi	Temperature, F	Time from Zero, msec	[illegible] and Thermocouple Position-Pulse	
Tunnel	A-1	—	—	—	Tunnel	C-1
	A-2	12	ambient	840		C-2
	A-3	12	ambient	889		C-3
	A-4	10	ambient	934		C-4
	A-5	12	ambient	1037		C-5
	A-6	10	ambient	1131		C-6
	A-7	12	ambient	1238		C-7
	A-8	18	ambient	1360		C-8
	A-9	20	ambient	1617		C-9
	A-10	28	ambient	1746		C-10
	A-11	32	ambient	1946		C-11
	A-12	88	ambient	2518		C-12
Silo	B-1	12	ambient	629	Silo	D-1
Wall	B-2	8	314	829	Wall	D-2
Upper	B-3	8	520	879	Lower	D-3
	B-4	8	730	923		D-4
	B-5	—	—	—		D-5
	B-6	10	276	1121		D-6
	B-7	10	292	1224		D-7
	B-8	14	391	1351		D-8
	B-9	14	830	1609		D-9
	B-10	18	276	1739		D-10
	B-11	22	276	1938		D-11
	B-12	55	322	2510		D-12

– = No response from pickup
* = No pressure recorded at floor of silo

TABLE 4

NE-TENTH-SCALE SILO RECORDED OVERPRESSURE AND TEMPERATURE

Spill Test 18, Twelve Overpressures Recorded

Time from Zero, msec	Microphone Thermocouple Position-Pulse	Pressure, psi	Temperature, F	Time from Zero, msec	Microphone Position-Pulse	Pressure psi	Time from Zero, msec
----	Tunnel C-1	---	---	---	Field 25-2	0.4	849
840	C-2	10	ambient	840	25-3	0.4	899
889	C-3	16	ambient	889	25-4	0.6	942
934	C-4	20	ambient	933	25-5	0.5	1049
1037	C-5	12	ambient	1037	25-6	0.8	1140
1131	C-6	16	ambient	1131	25-7	0.7	1246
1238	C-7	12	ambient	1233	25-8	1.0	1369
1360	C-8	24	ambient	1363	25-9	0.7	1629
1617	C-9	24	ambient	1619	25-10	0.9	1756
1746	C-10	24	ambient	1747	25-11	2.1	1957
1946	C-11	38	ambient	1946	25-12	2.5	2530
2518	C-12	84	ambient	2519	Field 35-7	0.5	1250
					35-8	0.4	1378
629	Silo D-1	*		----	35-9	0.4	1638
829	Wall D-2	*	360	829	35-10	0.4	1768
879	Lower D-3	*	570	879	35-11	0.75	1967
923	D-4	*	555	923	35-12	0.75	2538
----	D-5	*	---	----	Field 75-2	0.1	898
1121	D-6	*	314	1121	75-3	0.13	942
1224	D-7	*	276	1224	75-4	0.25	987
1351	D-8	*	322	1351	75-5	0.2	1092
1609	D-9	*	262	1609	75-6	0.3	1186
1739	D-10	*	300	1739	75-7	0.2	1290
1938	D-11	*	338	1938	75-8	0.5	1414
2510	D-12	*	812	2510	75-9	0.2	1674
					75-10	0.4	1802
					75-11	0.5	2002
					75-12	0.65	2574

ilo

Figure 26. NO_2 Cloud Formed After Simultaneous Spill of 200 lb NTO with 100 lb UDMH-Hydrazine in 1/10-Scale Rigid Steel Silo

TABLE 5

ONE-TENTH-SCALE SILO OVERPRESSURE AND TEMPERATURE RESULTS

Microphone and Thermocouple Position	Spill Test 17			Spill Test 20		
	Pressure, psi	Temperature, F	Time From Zero, msec	Pressure, psi	Temperature, F	Time From Zero, msec
Tunnel A-1	14	ambient	-677**	24	ambient	1560
A-2	10	ambient	-525	28	ambient	2664
A-3	52.5	ambient	11	11	ambient	3576
A-4	—	—	—	10	ambient	3709
Silo B-1	12	—	-691	13	ambient	1548
Wall B-2	10	—	-540	17	595	2657
Upper B-3	44	—	0	14	1470	3568
B-4	—	—	—	6	1570	3698
Tunnel C-1	14	ambient	-678	17	ambient	1560
C-2	12	ambient	-515	21	ambient	2666
C-3	65.5	ambient	11	13	ambient	3578
C-4	—	—	—	10	ambient	3711
Silo D-1	*	805	-691	*	463	1548
Wall D-2	*	970	-540	*	210	2657
Lower D-3	*	445	0	*	140	3568
D-4	*			*	190	3698
Field 25-2	0.5	Not taken	-522	1.25	Not taken	2675
25-3	2.0	Not taken	19	0.35	Not taken	3587
Field 35-2	—	Not taken	—	0.5	Not taken	2682
35-3	0.47	Not taken	28	—	Not taken	—
Field 75-2	0.3	Not taken	-478	0.4	Not taken	2718
75-3	2.0	Not taken	63	0.2	Not taken	3631

* = No pressures recorded at floor of silo.

— = No response from pickup.

** = Negative time due to delayed actuation of timing mark.

explosions. A column of flame extended 100 ft above the silo; burning continued for 15 min after this initial reaction. Table 5 gives the tabulated values of overpressure and temperature recorded. Pressure-time and temperature-time histories are shown in Data Appendix C under test 17.

A summary of the tests performed is given in Table 6 together with the date so that film coverage by Edwards AFB may be correlated. A brief [illegible]

Analysis

The measured overpressures from the model-missile studies were plotted and the slope of the resulting curve was established by equivalent TNT curves plotted from values obtained from the nomogram shown in Appendix D. The equivalent yield was then calculated by the following simple equation:

$$W = X \frac{W_t}{100} \qquad (5)$$

where

W = weight of TNT charge, lb

X = TNT equivalent yield, percent

W_t = total weight of propellant, lb

Aboveground Spills. The overpressures recorded on the aboveground spills are plotted in Fig. 27. All data points are plotted; it can be seen that the 35- and 50-ft data points are not usable. Using the 25- and 50-ft overpressure measurements recorded on tests 11 and 8, it is evident that the simultaneous spill condition generated overpressures equivalent to a 0.21-lb charge of TNT; considerably greater than those resulting from the oxidizer-lead spill condition. Considering the 300 lb of total Titan II propellants, this results in a maximum TNT equivalent yield of 0.07 percent. This greater yield is attributed to more complete propellant mix conditions on the simultaneous spill. High-speed camera coverage of

SUMMARY OF TESTS PERFORMED ON TITAN MODI

	and Type	Date	Lead sec
1.	Frangible	4 October	Fuel, 180 sec
2.	Silo (1/10 scale)	6 October	Simultaneous with heavy concentration oxidizer
3.		12 October	Oxidizer, 30 sec
4.	Frangible	11 October	Oxidizer, 45 sec
5.	Silo (1/18 scale)	13 October	Fuel, 15 sec
6.		24 October	Simultaneous
7.	Above	18 October	Fuel, 60 sec
8.	Ground	19 October	Oxidizer, 2 sec
9.	(1/10 Scale)	19 October	Oxidizer, 60 sec
10.		20 October	Oxidizer, 60 sec
11.		20 October	Simultaneous
12.	Hard	1 November	Simultaneous
13.	Silo (1/18 scale)	2 November	Oxidizer, 30 sec
14.		3 November	Simultaneous with small amount of fuel burning
15.		8 November	Simultaneous
16.		9 November	Simultaneous with water on the floor
17.	Hard	10 November	Oxidizer, 1 sec
18.	Silo (1/10 scale)	15 November	Simultaneous with light oxidizer vapors
19.		16 November	Fuel, 180 sec
20.		22 November	Simultaneous with light fuel vapors

TABLE 6

PERFORMED ON TITAN MODEL MISSILE SPILL STUDIES AT HAYSTACK BUTTE, EDWARDS AFB

		Maximum	Pressure			
Lead, sec	Description	Wall	Tunnel	Tunnel	27 Ft	Time, min
, 180 sec	Burning with small reports	—	—	—	—	Yes, 20 min
ltaneous with heavy entration oxidizer	35-ft column of flame with explosions	—	—	—	—	No
izer, 30 sec	100-ft column of flame with explosions	—	—	—	—	No
izer, 45 sec	Small explosion inside the silo	—	—	—	—	No
, 15 sec	Small explosions with slow burning	—	—	—	—	Yes, 10 min
ltaneous	50-ft column of flame with explosions	—	—	—	—	No
, 60 sec	Fuel ignited on contact with rust	—	—	—	—	No
izer, 2 sec	Large fireball with midair explosions	—	—	—	0.5	No
izer, 60 sec	Slow burning with no explosions	—	—	—	—	Yes, 5 min
izer, 60 sec	Slow burning with no explosion	—	—	—	—	No
ltaneous	Large fireball with midair explosions	—	—	—	1.0	No
ltaneous	Violent burning with 50-ft flame column; several large explosions	22	68	43	0.9	Yes, 10 min
izer, 30 sec	Violent burning with 50-ft flame column; several large explosions	35	38	38	0.6	Yes, 10 min
ltaneous with small nt of fuel burning	Mild burning with several large explosions	18	88	37	0.8	Yes, 10 min
ltaneous	Violent burning extending 50 ft; several large explosions	37	33	24	0.85	Yes, 10 min
ltaneous with water he floor	Rapid burning extending 30 ft in air; minor explosions	8	12	13	0.7	No
izer, 1 sec	Violent burning extending 100 ft; several large explosions	44	52	65	2	Yes, 15 min
ltaneous with light izer vapors	Violent burning extending 100 ft; twelve large explosions	55	88	84	2.5	Yes, 15 min
, 180 sec	Mild burning; no explosions	—	—	—	—	Yes, 20 min
ltaneous with light vapors	Violent burning extending 100 ft; several minor explosions	17	28	21	1:25	Yes, 15 min

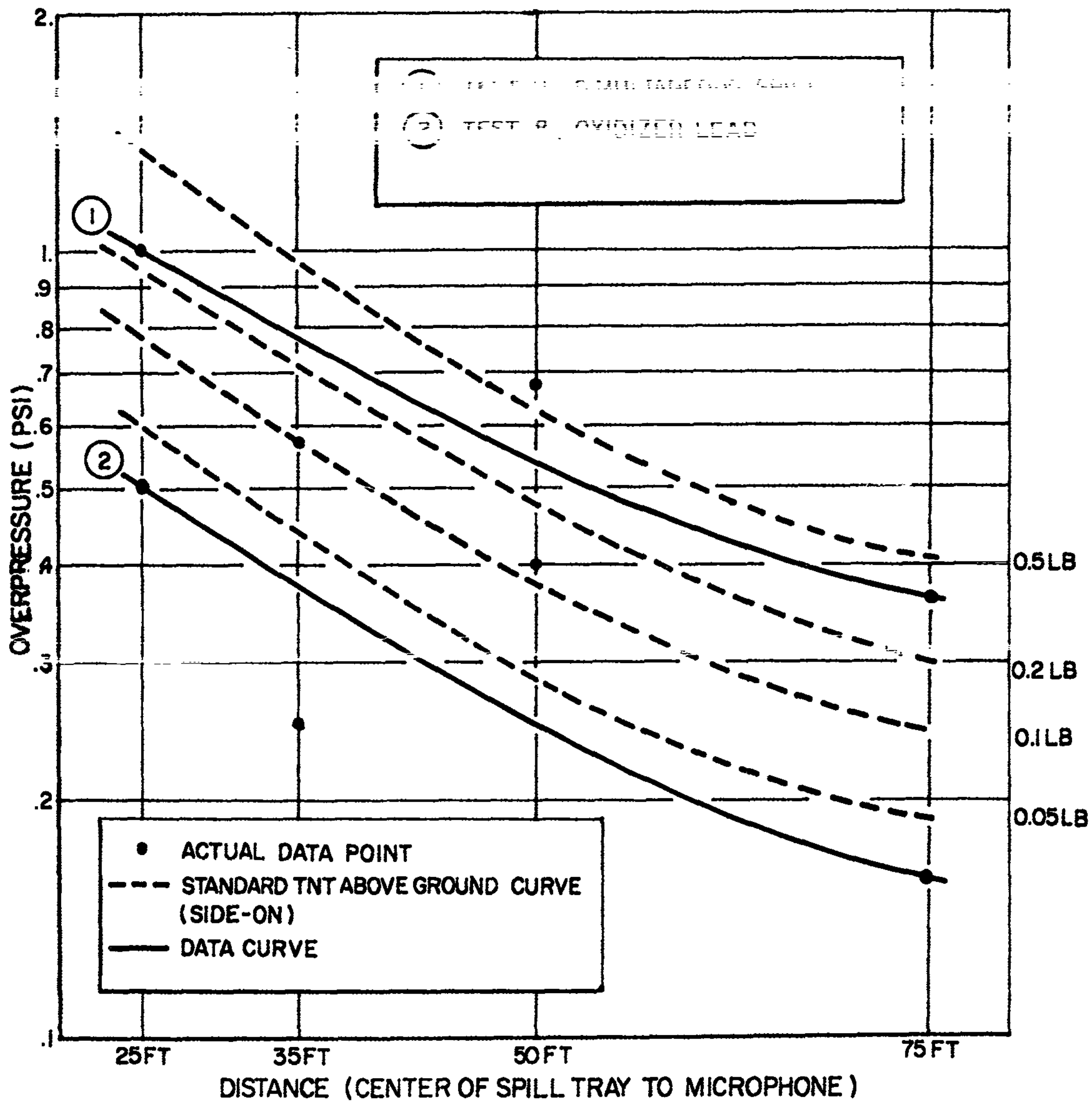


Figure 27. Overpressure Results for Above-Ground Spills

the spills showed that on the simultaneous spill the propellants were fanned outward from the tanks, resulting in an initial reaction occurring in an area over 10 feet in diameter. The fireball growth rates were estimated by inspection of the motion picture coverage. Comparison of the rate of growth on aboveground spills, tests 11 and 8 are shown in Table 2. The oxidizer-lead spill was more rapid in growth during the [illegible] initial growth, the fireball remained unchanged for approximately 0.[illegible] seconds. Further increase to maximum size was noticeably effected by the overpressure pulsations that occurred within the ball-of-fire. Comparison of the final phase of formation of the ball-of-fire on the aboveground spills shows the growth rate to be higher on the simultaneous spill than on the oxidizer-lead spill. Apparently the growth of the fireball was accelerated by the higher overpressures that resulted on the simultaneous spill.

Silo Spills. The frangible silo tests, which were performed while the rigid steel silos were being fabricated and blast instrumentation installed, did demonstrate the low equivalent TNT yield obtained from the Titan II propellant combination. Although cratering occurred on two spills in the frangible silo, it was a result of rapid erosion of loose topsoil by high-velocity gases rather than any rupture of the soil. The silo walls in the decomposed granite subsoil were not damaged on these tests.

A plot of the overpressures recorded on the spills in the 1/18-scale silo are shown in Fig. 28 . Pressures at the 35-ft measurement position were not usable. As shown, simultaneous spill test 12, with overpressures equivalent to 0.2 lb of TNT, resulted in the most violent reaction of the Titan II propellants. Considering the 50 lb of total propellant, this is a maximum TNT equivalent of 0.4 percent. To demonstrate the effect of water in reducing reaction violence, overpressures from test 16 were plotted in Fig. 28 for a comparison. It can be seen that the overpressures are considerably lower on the test using the water floor; equivalent to less than 0.05 lb of TNT.

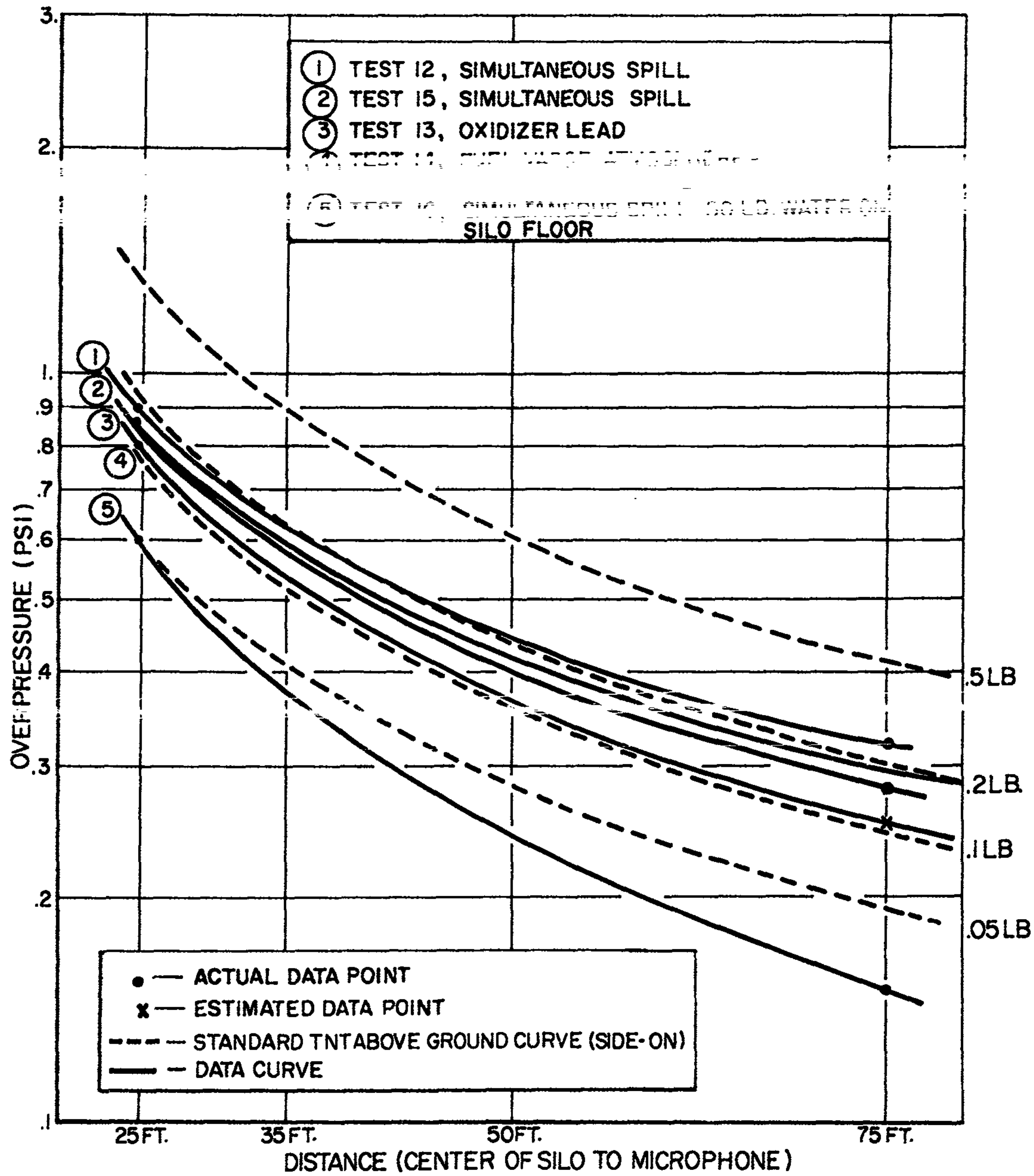


Figure 28. 1/18-Scale Silo Overpressure Results

Plots of overpressures recorded on spills in the 1/10-scale silos are shown in Fig. 29. Pressures measured at the 35-ft pressure transducer were not usable. Again, the simultaneous spill condition provided the maximum overpressures, equivalent to a 2-lb charge of TNT. A maximum TNT equivalent of 0.67 percent was calculated using a total propellant weight of 300 lb.

The model-missile tests indicated that reaction violence of the [illegible] propellants is dependent on the degree of mix obtained. Simultaneous spills provided the most intimate mix and resulted in increased vaporization of the hydrazine. Thus, hydrazine vapors were available to form explosive mixtures with oxygen in the air or in the oxidizer. Spills into an oxidizer atmosphere resulted in overpressures of a magnitude just under those resulting from the simultaneous spill condition, while fuel-lead spills were the least violent. In the case of fuel-lead spills, the retarded reaction is apparently the result of the fuel reaching the floor of the spill tray or silo before nitrogen tetroxide is released. The reaction would then be restricted to the interface constituted by the surface of the fuel and the oxygen-rich atmosphere. On all fuel-lead spills, hydrazine remained burning at the bottom of the tray or silo after the initial hypergolic reaction; this would support the above analysis.

Inspection of the overpressure results on silo spills presented in Tables 3, 4 and 5 shows that a particularly interesting blast wave phenomenon was occurring in the tunnels, generally, tunnel pressures exceeding main body pressures by 50 to 100 percent. On spill test 13, the third overpressure peak (shown in oscillogram labeled 13-C-3, 13-B-3, and 13-A-3 in Appendix B) indicates an initial pressure buildup in the main silo body of 9000 psi per sec with the maximum pressure reaching 13.5 psi. This would be termed a normal explosion of low yield; however, 6 msec later an overpressure occurred in tunnel A which resulted in a pressure buildup of 180,000 psi per sec and reached 39 psi maximum pressure before decay. During decay, several pressure spikes occurred which correspond to similar spikes in the opposite tunnel and in the main silo body; these

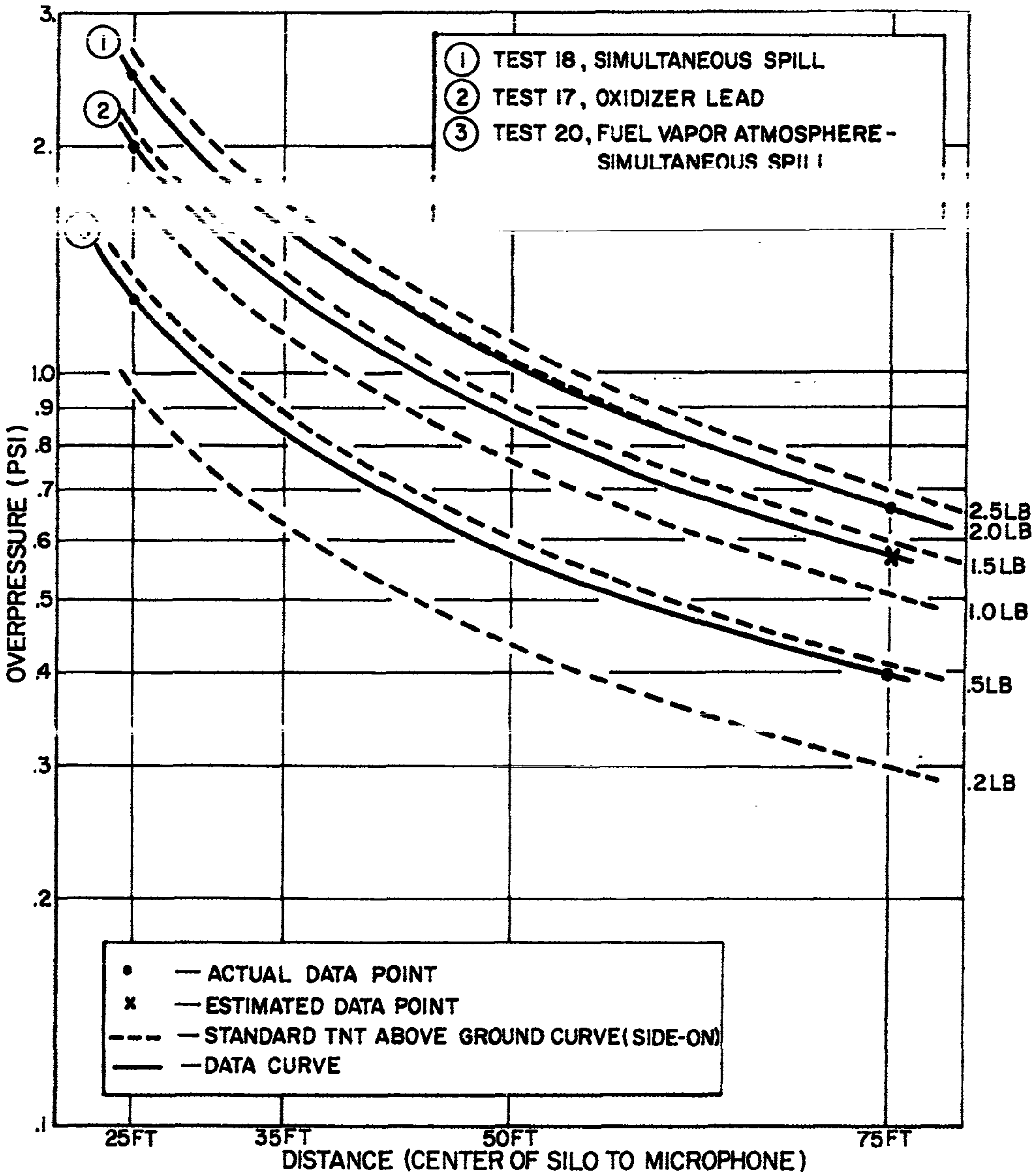


Figure 29. 1/10-Scale Silo Overpressure Results

pressure spikes reached a maximum value of 41 psi. Not all tunnel pressures were greater than main silo pressures--test 15 is such an example. The oscillogram shown in Appendix B labeled 15-A-1, 15-B-1, and 15-C-1 shows a pressure rise in the main silo body of 5200 psi per sec with maximum pressure reaching 15.7 psi. Eight msec later, the tunnel pressures rise with a slightly higher rise time of 9500 psi per sec, reaching a maximum value of 19 psi in tunnel 15-A-1. Inspection of Fig. 18 shows that by mounting the pressure transducer at the end of the tunnel with [illegible]

[illegible]

tunnel pressures measured in the two examples described above, tests 13 and 15, were converted to equivalent side-on pressures by use of the following equation:

$$pr = (2\ P)\ (7\ P_o + 4\ P)\ /\ (7\ P_o + P) \qquad (3)$$

where

pr = reflected overpressure, psi

P_o = ambient pressure (ahead of shock) = 14.7 psia

P = side-on pressure, psi

Calculation of the equivalent side-on tunnel pressure on test 15 shows that the tunnel did provide attenuation; the side-on tunnel pressure being approximately 7.8 psi, or a little less than one-half the silo pressure.

Calculation of the equivalent side-on pressure on test 13, using the tunnel pressure of 39 psi, results in a side-on pressure of 13.9 psi which is approximately equivalent to the main body pressure. However, the pressure spikes which followed gave equivalent side-on pressures up to 14.9 psi or 1.4 psi greater than the measured pressure in the main body of the silo. In addition, the pressure rise-times were much faster on these spikes. Two explanations are possible for this phenomenon; either a separate detonative explosion is occurring in the tunnel, or the overpressure pulse in the main silo body is occurring on the level of the tunnels which would eliminate any attenuation of the wave front. The latter explanation is the most reasonable; however, it does not account for the higher pressure that was recorded on the pressure spikes. Also supporting the second explanation is that the pressures in each tunnel were usually of the same magnitude, indicating an explosion at the axis of symmetry. Additional tests would be necessary for conclusive proof.

The random nature of the overpressure pulses is readily apparent from Fig. 30 which shows a plot of pressure pulse vs time for all silo spills. No correlation between spill condition and pulse time is evident.

Since the simultaneous spill condition provided the maximum yield under all spill configurations, the overpressures recorded were plotted on the same scale (Fig. 31). An analysis of the significance of these curves is as follows:

1. The effect of confinement of the Titan II propellants is apparent from Fig. 31. A comparison of 1/10-scale silo spill test 18, with 1/10-scale aboveground spill test 11, shows an increase in equivalent yield for the silo spill. A TNT equivalent yield of 0.67 percent had been calculated for test 18, as compared to 0.07 percent for the aboveground spill. This 0.6 percent increase is due to more intimate mixing of the propellants when confined.

2. A comparison of 1/10-scale silo spill test 18 with 1/18-scale silo spill test 12, shows an increase of 0.27 percent in the TNT equivalent yield for the larger propellant quantity. The expected decrease in yield with increasing propellant weight occurred only on the fuel-lead tests where a 0.06 percent decrease in TNT equivalent yield occurred. An explanation of this effect is that the blast potential from the explosive hydrazine-vapor phase mixture is greater on tests having simultaneous and oxidizer leads, where the propellants obtain a more intimate mix. This causes a breakup into droplets which offers greater surface area for vaporization. Fuel-lead spills do not present proportionally increased surface areas since the propellant volume is contained within the confines of the silo, resulting in a reaction restricted to the interface of the fuel and the oxidizer-rich atmosphere above.

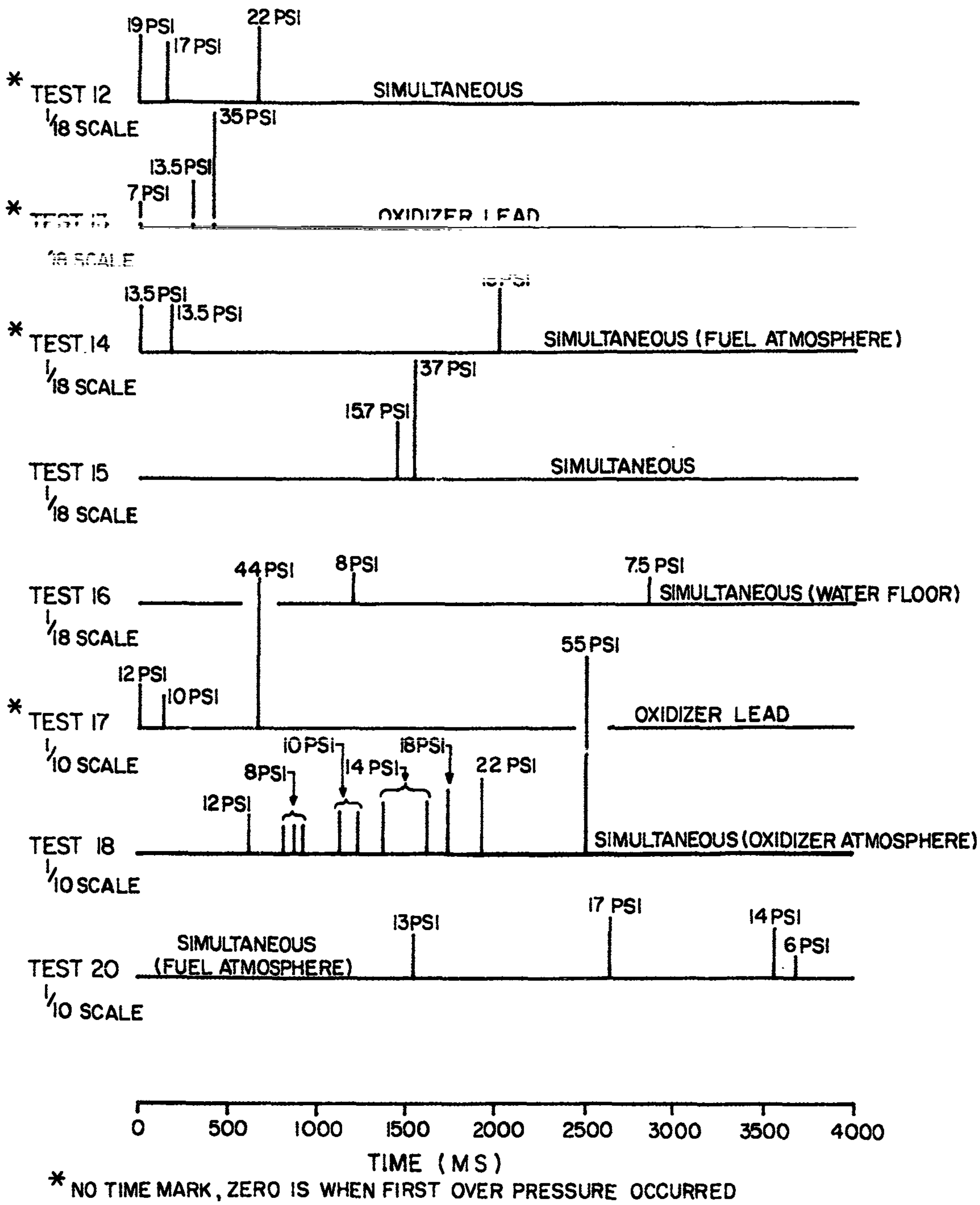


Figure 30. Silo Main Body Overpressure Pulse vs Time

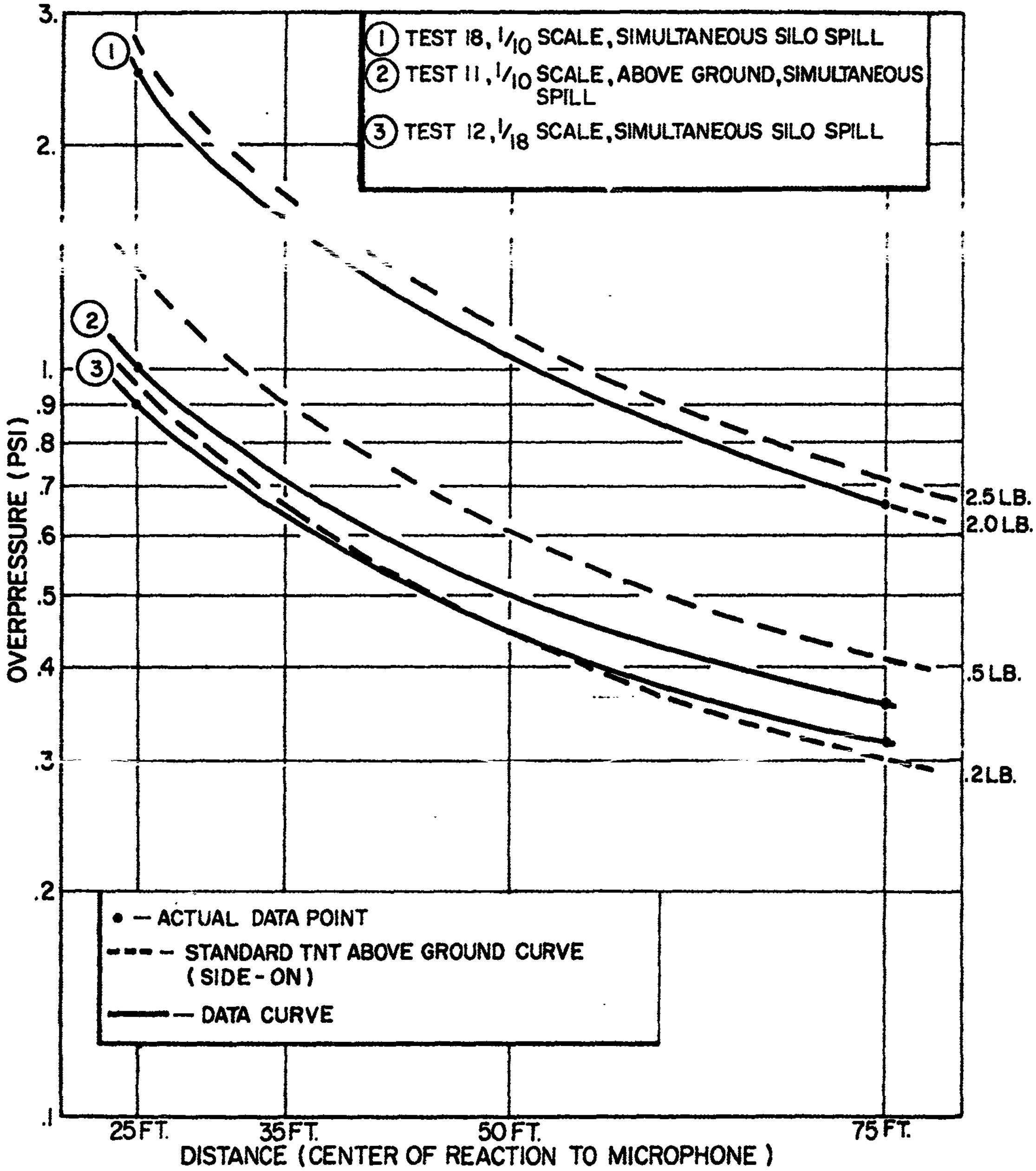


Figure 31. Comparison of Maximum Overpressure Results

Before any extrapolation of model-missile spill data to full-scale conditions could be made, a larger model size would need to be tested. This third point should be of sufficient propellant quantity so that a TNT equivalent yield decrease would occur due to decreased propellant mixing efficiency. Since an increase in yield resulted on the 1/10-scale tests, no upper limit could be placed on Titan II spills in silos

LARGE-SCALE TESTS

The two large-scale tests were conducted at the Haystack Butte Hazards Determination Spill Site using the Titan II propellant combination of nitrogen tetroxide and (50-50) UDMH-hydrazine. There was no simulation of missile configuration on these two tests. A description of each test is given below:

Test 1: Spill of 300 lb of fuel and 1300 lb of oxidizer, followed by a water deluge

Test 2: Spill of 500 lb of fuel and 800 lb of oxidizer with biological study

The biological study is presented in Appendix F. A brief introduction to this work accomplished by the Huntington Memorial Hospital follows the discussion of Large-Scale Tests.

Test Equipment

Spill Tanks. The propellant tanks for these tests consisted of 150-gal carbon steel and stainless-steel tanks. Tanks of carbon steel construction (Fig. 32) were used to contain the fuel mixture while stainless-steel tanks (Fig. 33) contained the oxidizer. The spill tanks, as shown in Fig.34 were positioned in the tray at 20 degrees from vertical so the propellant discharging from the 6-inch ports would impinge at the

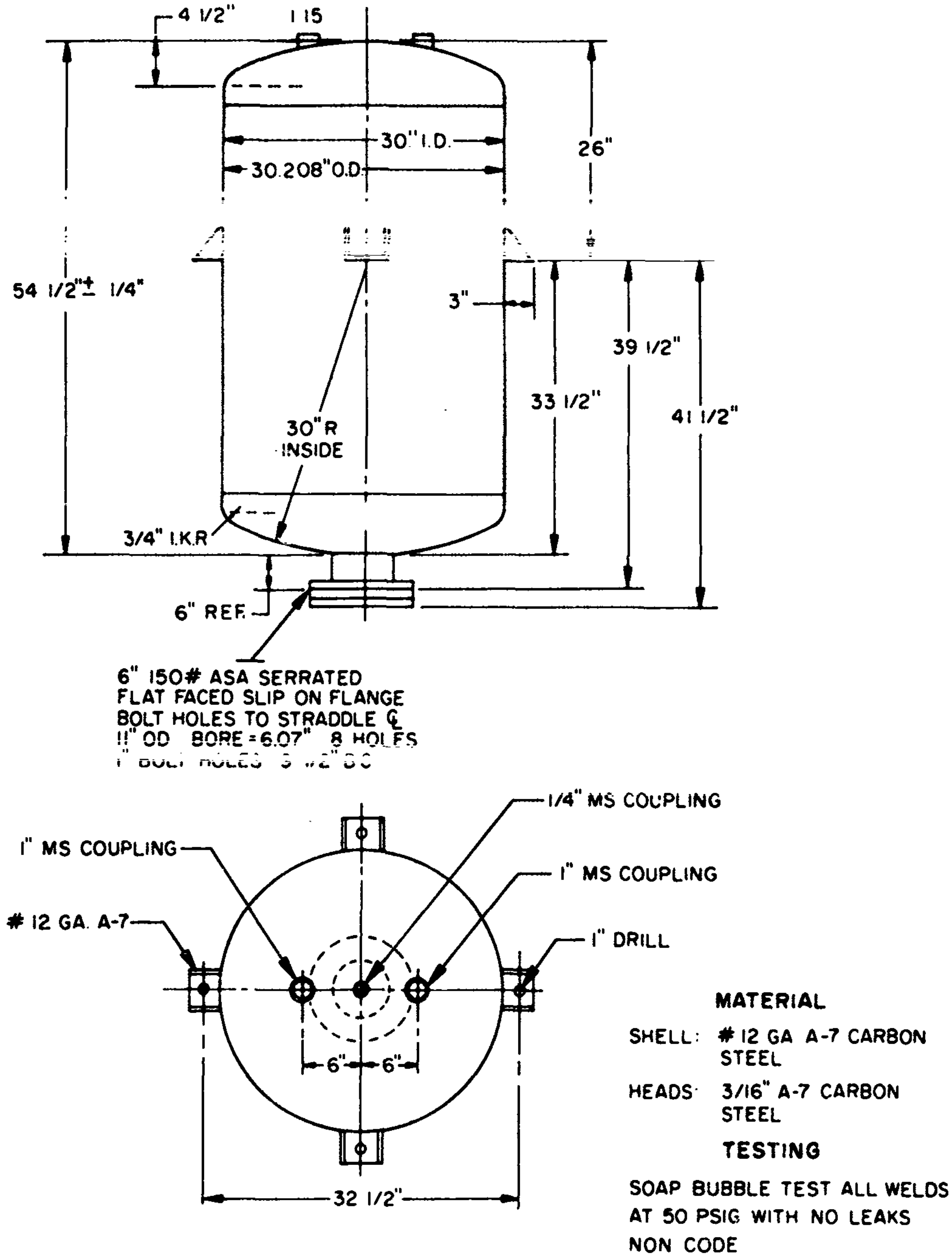


Figure 32. 150-gallon Carbon-Steel Spill Tank For Hydrazine

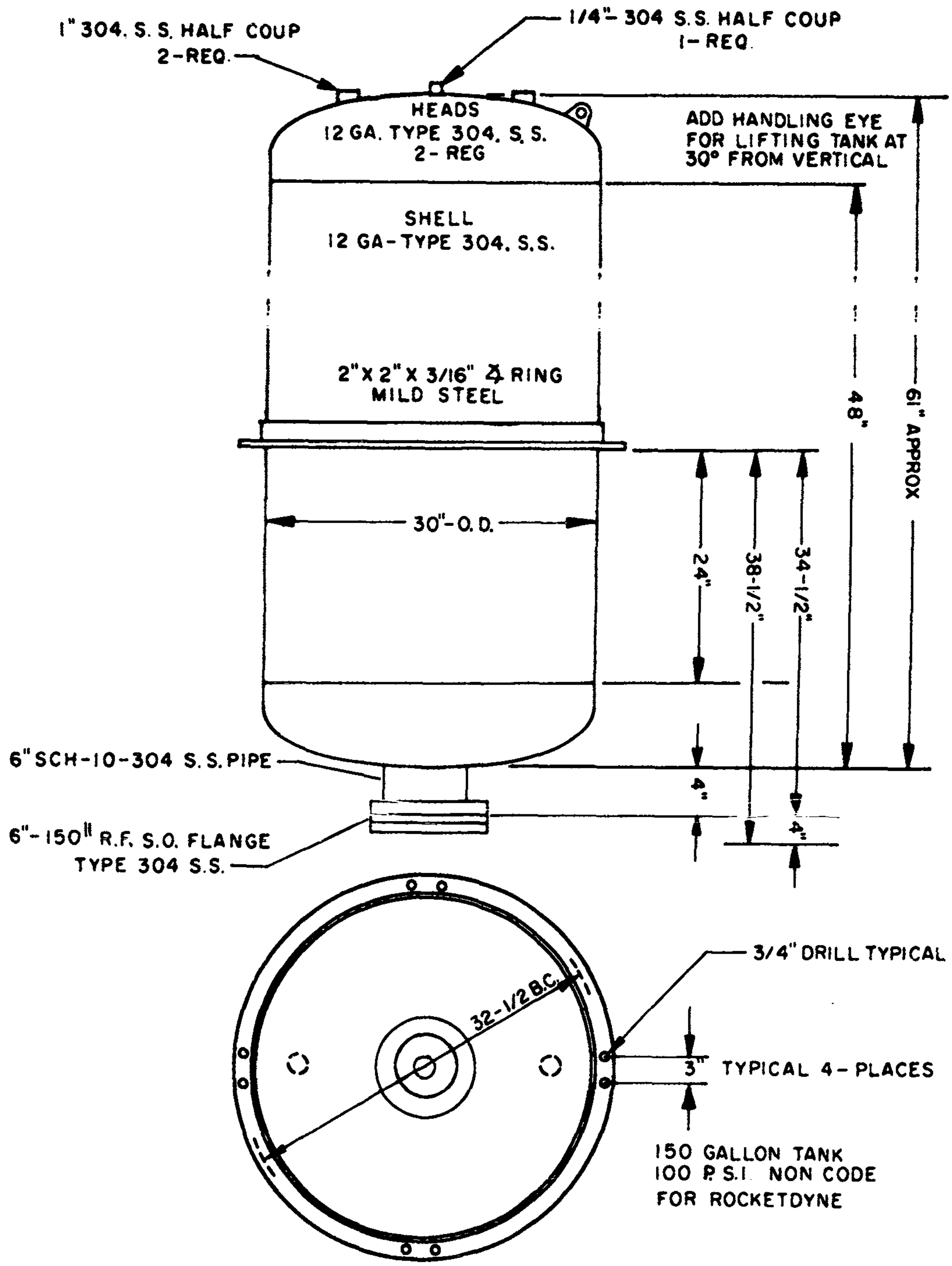


Figure 33. 150-gallon Stainless Steel Spill Tank for Nitrogen Tetroxide

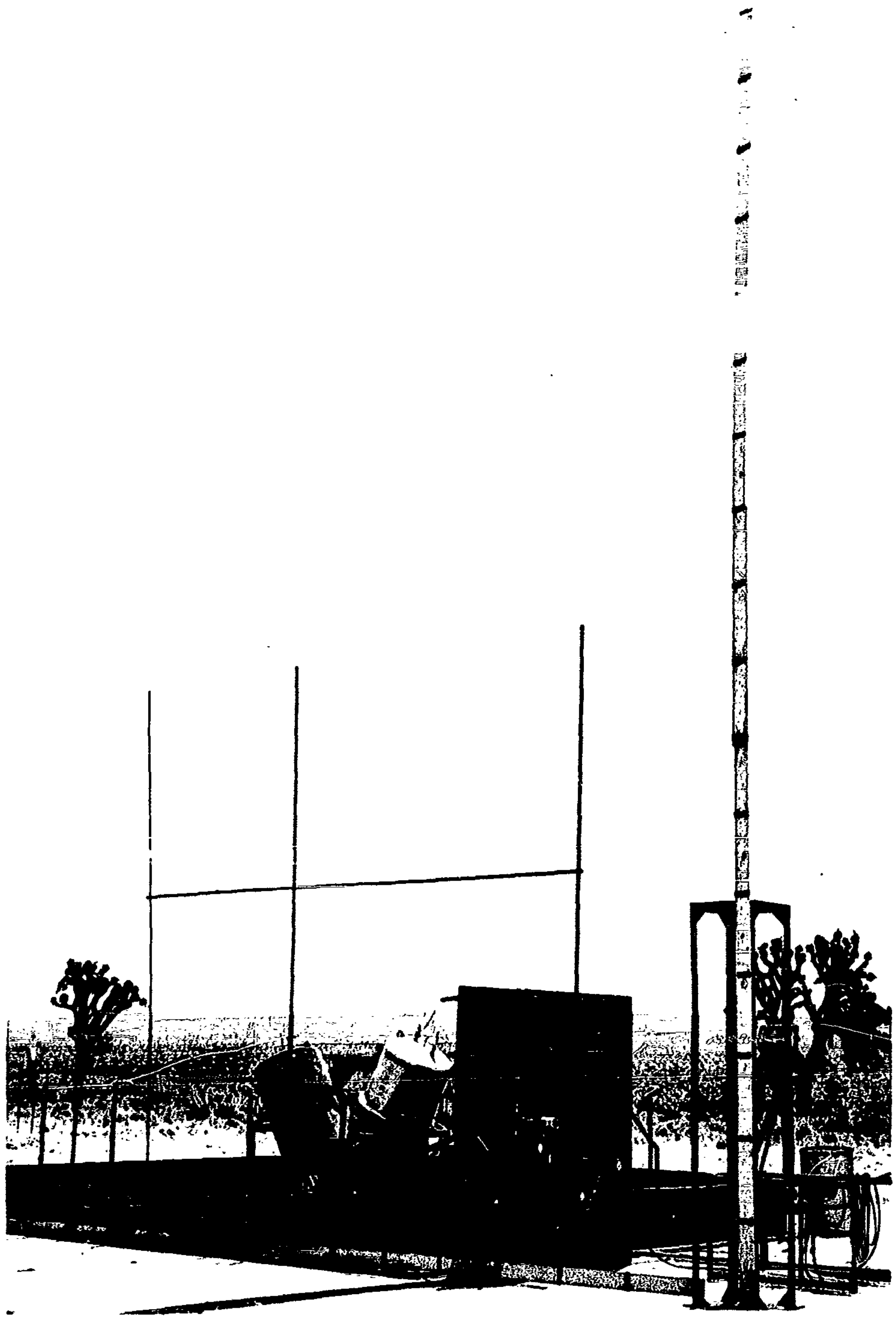


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Figure 34. Two 150-gallon Spill Tanks Positioned for Propellant Mixing Spill

center of the tray. Thin metal diaphragms mounted to the bottom flange were ruptured by a cleaver device (Fig. 35), actuated by an Annin air cylinder. The tanks were pressurized to 50 psia to assure complete rupture of the diaphragms and rapid expulsion of the propellant.

Spill Tray. The dimensions of the carbon-steel spill tray are 20 ft x 20 ft x 2 ft. The pneumatic control panel is located on the vertical plate which is attached to the west side of the tray. Nitrogen gas at 2000 psi was supplied from a gaseous nitrogen trailer to the panel, where regulators provided low-pressure nitrogen for pressurization, purges, and pneumatic valve operation. Water deluge for the spill tray was provided by four Firex nozzles; two on each side of the tray.

Valves and Lines. A complete test system schematic showing propellant transfer, pressurization, and purge lines, together with all valving is presented in Fig. 36.

Instrumentation

Blast Measurement. Blast instrumentation was used to record overpressures at distances of 25, 50, and 75 ft from the reaction zone. Figure 37 shows the orientation of the pressure-measurement field. Model 304-A Photocon pressure microphone transducers were mounted in the capped end of a steel pipe and the pipe was buried flush with the ground surface for a "side-on" pressure measurement. The overpressures are sensed and the responses relayed to Ampex tape recorders. The taped records are later re-played and recorded by a Miller Cathode Ray oscillograph to obtain the oscillograms included in the Data Appendix. The blast measurement system was calibrated by use of 6- and 12-pound charges of TNT. Data Appendix D gives the pressure-time histories for the TNT charges used for calibration.

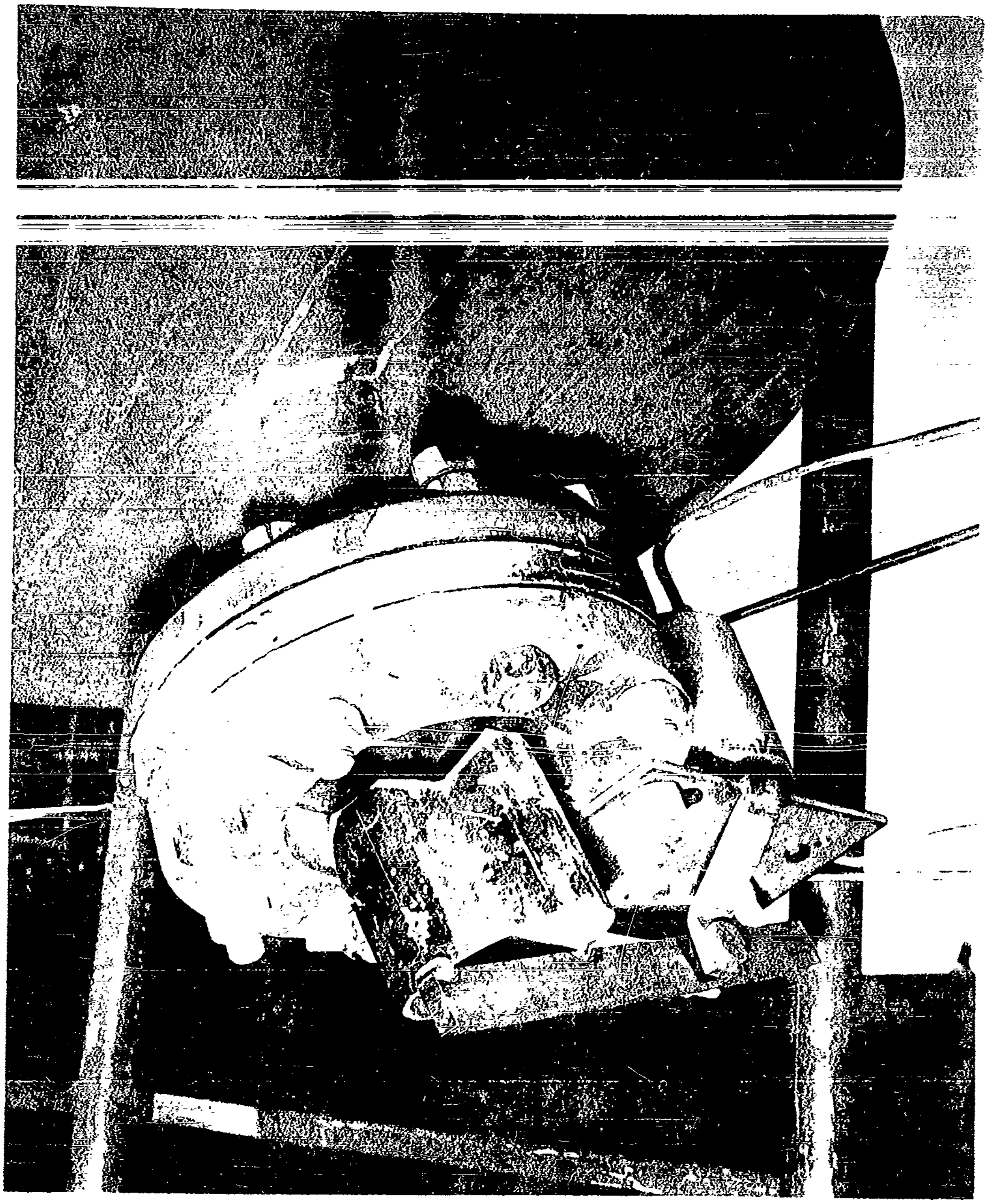
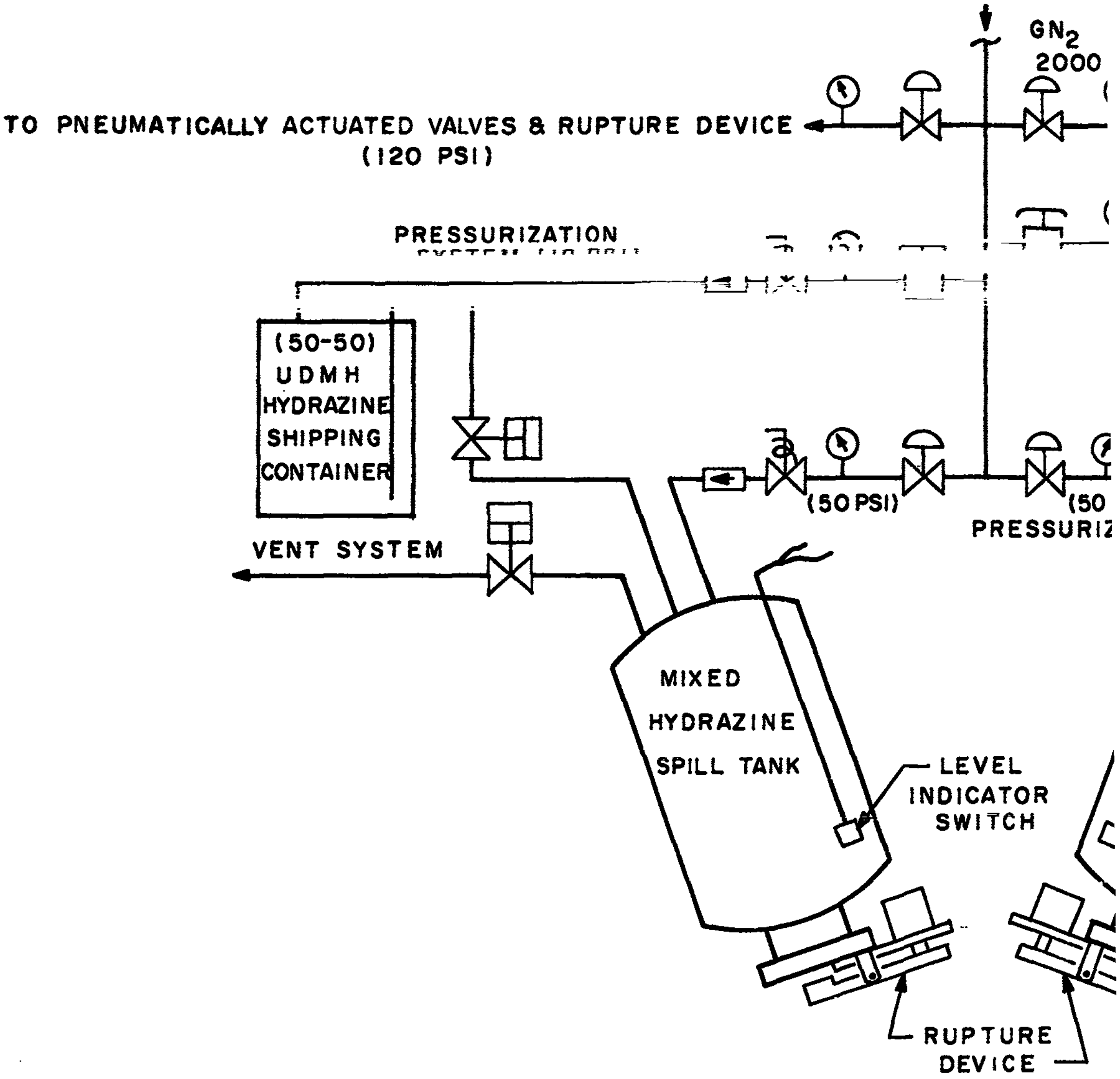


Figure 35. Spill Rupture Device



GN2
2000
TO PNEUMATICALLY ACTUATED VALVES & RUPTURE DEVICE
(120 PSI)
PRESSURIZATION
(50-50)
UDMH
HYDRAZINE
SHIPPING
CONTAINER
(50 PSI)
(50
PRESSURI
VENT SYSTEM
MIXED
HYDRAZINE
SPILL TANK
LEVEL
INDICATOR
SWITCH
RUPTURE
DEVICE

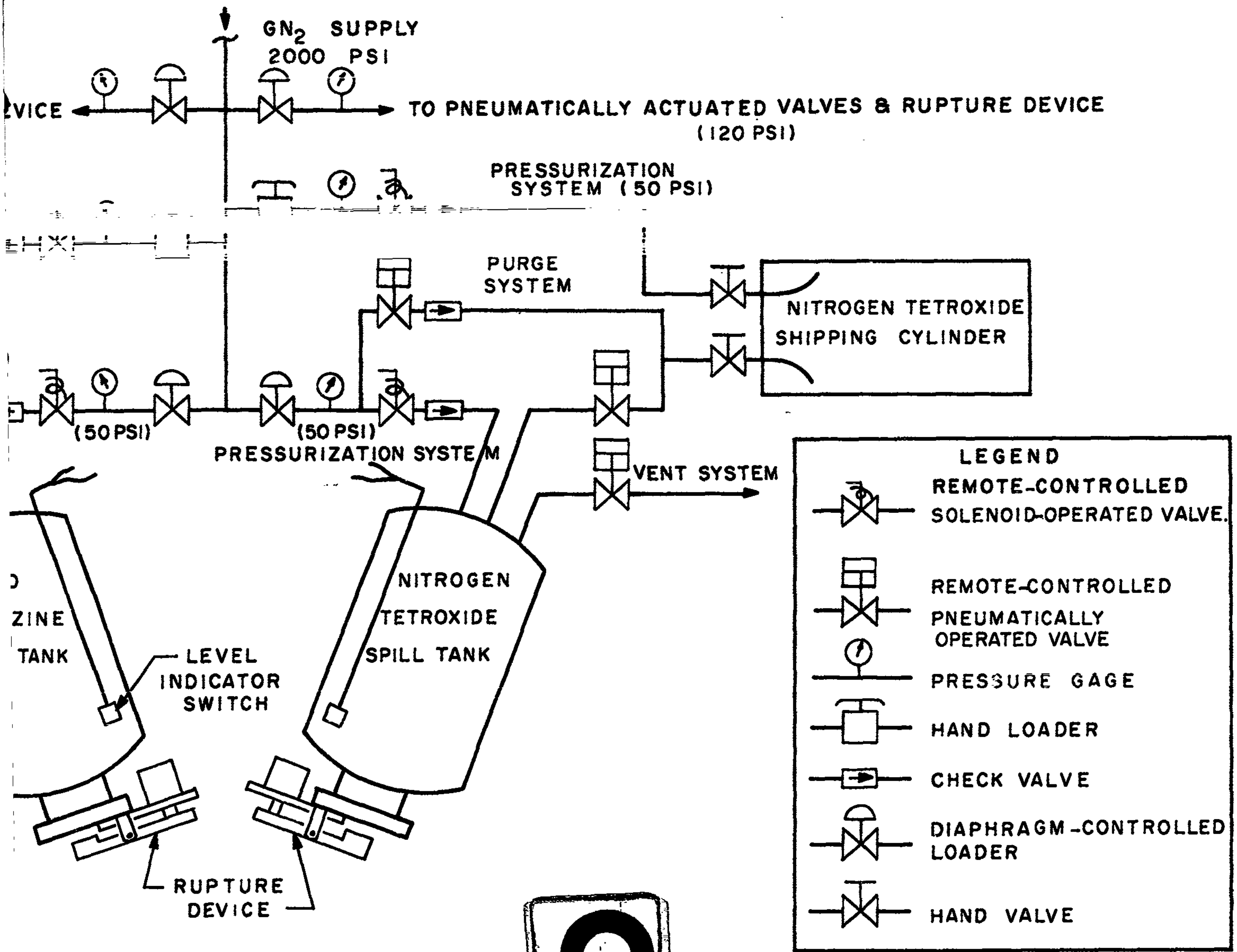


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Figure 36. Large-Scale Spill System Schematic

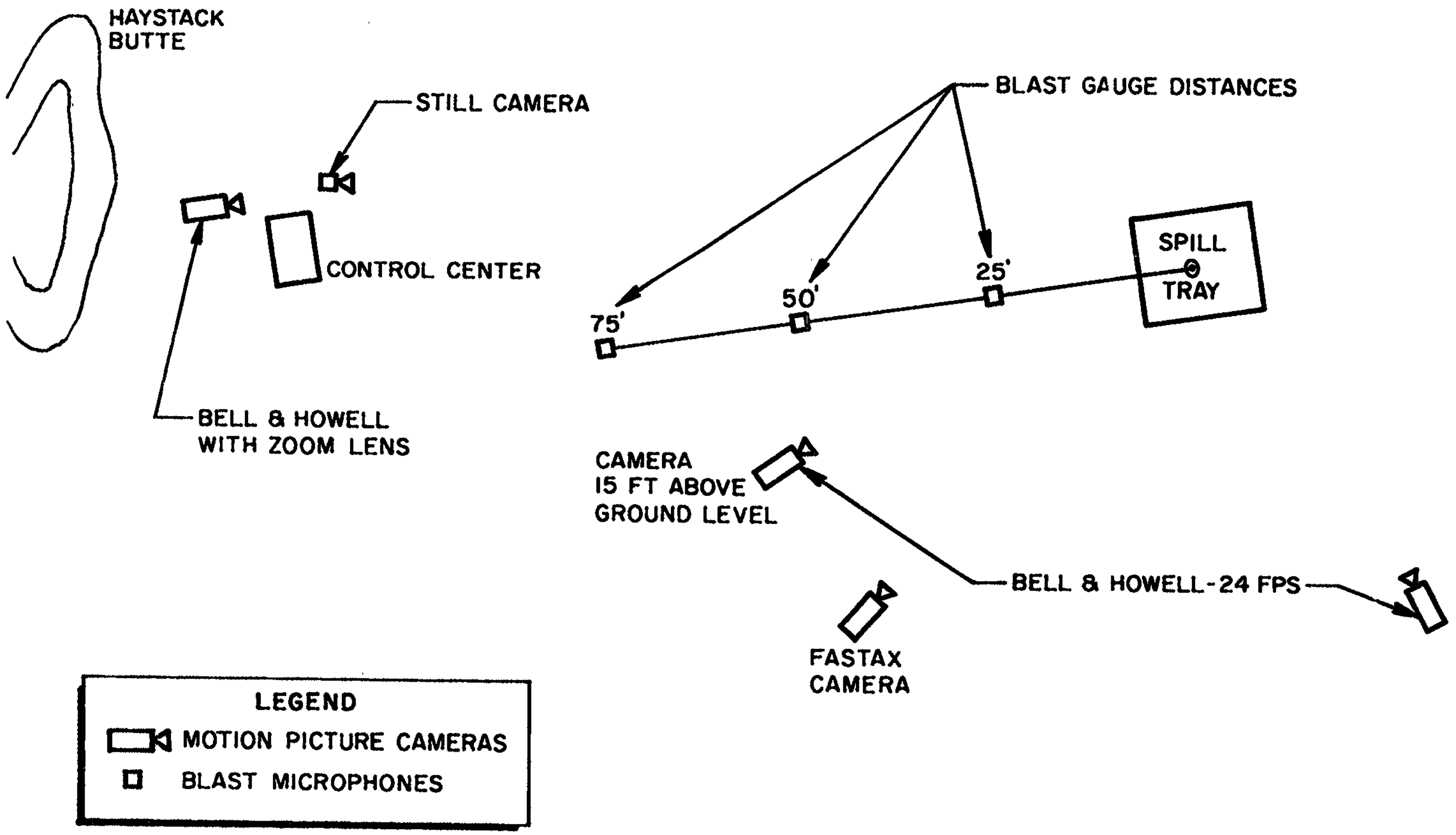


Figure 37. Position of Blast Instrumentation and Photographic Coverage During Large-Scale Tests at Haystack Butte

Temperature Measurement. Temperatures were measured using temperature-sensitive paint. The paint was applied to aluminum tabs spaced on the grid framework shown in Fig. 34 positioned above the spill tray.

Camera Coverage. Edwards AFB provided camera coverage for the tests. Camera locations are shown in Fig. 37. A graduated wood scale was placed horizontally and vertically along the tray to assist in measurement of the fireball size from inspection of film sequences as shown in Fig. 34 .

Toxic Vapor Detection. Downwind vapor concentrations of nitrogen dioxide and mixed hydrazine vapors were detected by Mine Safety Appliance (MSA) and American Systems Incorporated (ASI) instruments. These direct-recording vapor detectors were being given their initial evaluation in a field environment. The MSA instrument utilizes an ionization chamber to detect an aerosol which is formed from the propellant vapor, while the ASI instrument utilizes an electrolyte with which the incoming propellant vapor reacts to change cell impedance. Figure 38 shows detector positions.

Test Results

Mixing Spill, Water Deluge. Test 1 consisted of a simultaneous mixing of the fuel with the oxidizer. The propellant discharge rate from the tanks was approximately 900 lb/sec of hydrazine and 875 lb/sec for nitrogen tetroxide. The 300 lb of fuel was emptied in less than 0.5 second, while the 1300 lb of oxidizer required 1.5 sec. After 2 sec, a water-deluge system was actuated which delivered 100 gpm into the spill tray. The water was directed toward the reaction zone by Firex spray nozzles. Several weak explosions were audible from a distance of 1000 ft; however, the blast instrumentation did not detect these small overpressures. The temperature tabs on the measurement grid were unchanged, indicating that no temperatures above 240 F were reached on the angle-iron grid framework. The mitigation of the reaction by the water was very apparent as shown in Fig. 39. Table 7 gives the growth rate of the ball-of-fire accompanying the reaction. Rapid boiloff of the nitrogen tetroxide was visually

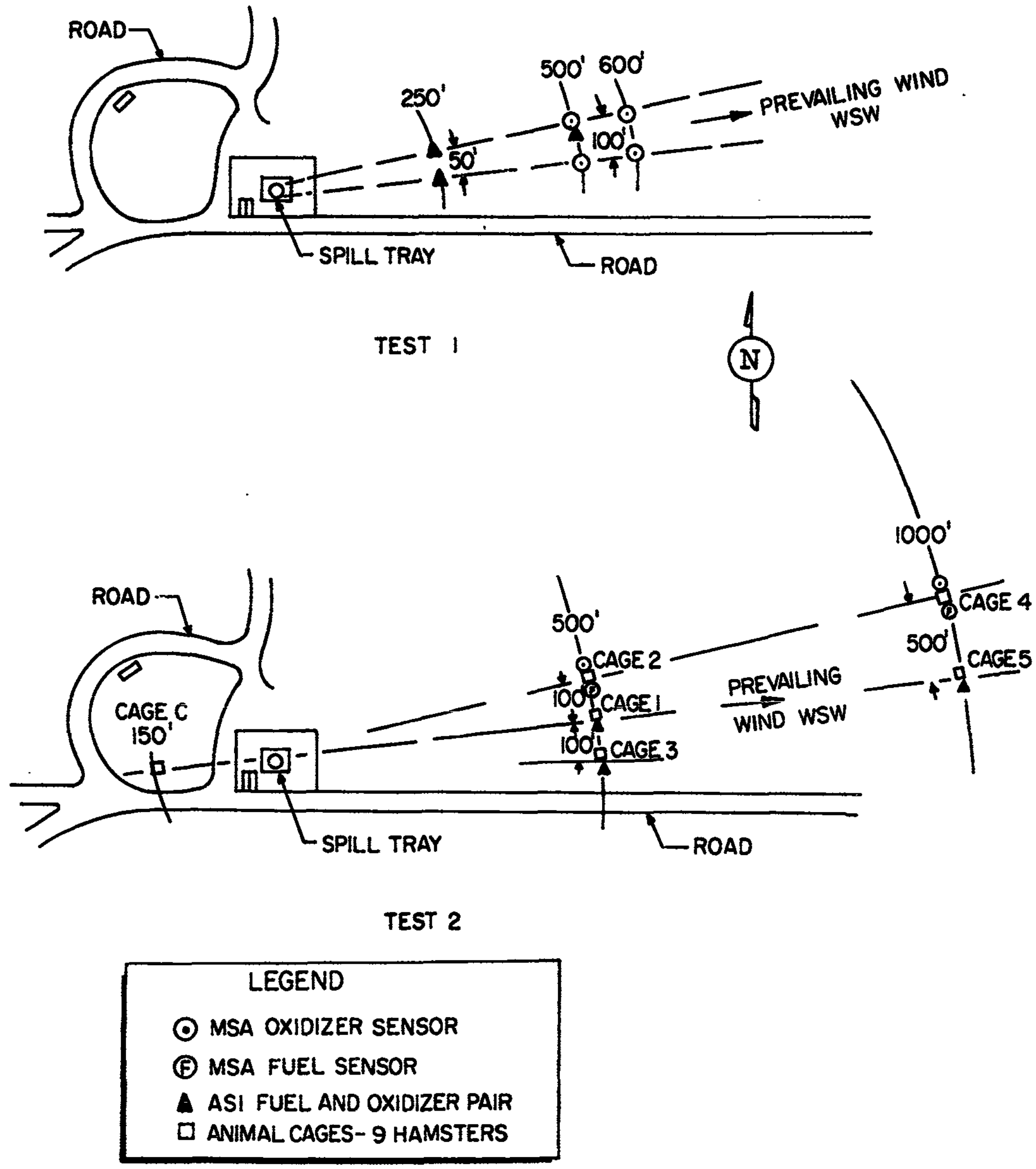


Figure 38. Placement of Toxic Vapor Detectors and Hamster Cages on the Large-Scale Tests at Haystack Butte

Figure 39. Reaction Resulting From Spill of 300 lb of (50-50) UDMH-Hydrazine and 1300 lb of Nitrogen Tetroxide With Water Deluge

evident. Only one vapor detection instrument recorded useful information on this test. This instrument verified the heavy toxic vapor concentrations. The records from the ASI vapor detectors were not usable. A post-test inspection of the test hardware found no damage.

Mixing Spill, Dry Condition. Test 2 consisted of a simultaneous mixing of propellants, allowing the reaction to proceed without impediment. Flowrates were 800 lb/sec for the mixed hydrazines and 1070 lb/sec for nitrogen tetroxide. The 500 lb of fuel were emptied in approximately 0.625 sec, while the 800 lb of nitrogen tetroxide required 0.75 sec. The reaction resulted in a large fireball (Fig. 40) which persisted for approximately 10 sec; the growth rate of the fireball is given in Table 7 . Numerous explosions were audible and blast instrumentation detected fourteen overpressure pulses. Table 8 gives the overpressure recorded on each pulse. The highest overpressure occurred on the sixth pulse with the succeeding pulses becoming weaker. Inspection of the motion pictures revealed that the later pulses were occurring above a low corner of the spill tray where the mixed hydrazines had accumulated. Oscillograms showing each recorded pulse are included in Data Appendix E. The temperature grid shown in Fig. 41 recorded a maximum temperature of 445 F. The heat of reaction was sufficient to stack the unreacted nitrogen tetroxide and hydrazine to a height well above the vapor-sensing instruments as shown in Fig. 42.

Three of the four MSA detectors gave useful information. No records were usable from the ASI detectors. The instruments detected fuel and oxidizer vapors downwind only during the propellant transfer operations when the vents were opened. No propellant concentrations were detected after rupture of the tanks. Post-test inspection of the hardware showed no damage to spill tankage. The tanks were displaced, however, from their pre-test positions by the explosions.

Figure 40. Reaction Resulting From Spill of 500 lb of (50-50) UDMH-Hydrazine and 800 lb of Nitrogen Tetroxide

TABLE 7

BALL-OF-FIRE GROWTH RATES

Test 1 (Water Deluge)			Test 2 (Dry)		
Time From Ignition, sec	Fireball Radius, ft	Remarks	Time From Ignition, sec	Fireball Radius, ft	Remarks
0	0	First fire	0	0	First fire
0.037	3		0.010	3	
0.062	5		0.017	5	
0.087	6		0.025	8	
0.112	7		0.030	9	
0.137	8		0.037	10	
0.162	9		0.062	11	
0.187	9		0.087	13	
0.212	9		0.112	14	
0.237	9		0.137	15	
0.262	10		0.162	16	
0.287	10.5		0.187	16	
0.312	10.5		0.212	16.5	
0.337	11		0.237	17	
0.362	11		0.262	17.5	
0.387	11.5		0.287	18	
0.412	12		0.312	18	
0.437	12		0.337	18	
0.462	12.5		0.362	19	
0.487	13	NO_2 Cloud forming; fire-ball dying out	0.387	19	
			0.412	19	
			0.437	19	
			0.462	19	
			0.487	19	
			0.500	19	
			0.55	20	
			0.6	20	

TABLE 7

(Continued)

Test 2 (Dry)		
Time From Ignition, sec	Fireball Radius, ft	Remarks
0.65	20	
0.70	20	
0.75	21	
0.8	21	
0.85	21	Fireball begins to rise
0.90	21	
0.95	21	
1.0	22	Fast rising fireball

TABLE 8

LARGE-SCALE OVERPRESSURE RESULTS, TEST 2

Microphone Position and Pulse	Pressure, psi	Time From Zero, sec
1-25	0.40	0
1-50	0.65	
1-75	0.32	
2-25	0.70	0.45
2-50	0.55	
2-75	0.32	
3-25	1.40	1.69
3-50	0.75	
3-75	0.67	
4-25	1.15	3.48
4-50	0.45	
4-75	0.32	
5-25	0.40	5.16
5-50	0.35	
5-75	0.25	
6-25	2.20	12.68
6-50	1.50	
6-75	0.67	
7-25	0.32	14.09
7-50	0.40	
7-75	0.30	
8-25	0.65	16.36
8-50	1.05	
8-75	0.55	
9-25	0.23	19.0
9-50	0.45	
9-75	0.40	

TABLE 8

(Continued)

Microphone Position and Pulse	Pressure, psi	Time From Zero, sec
10-25	0.23	21.73
10-50	0.30	
10-75	0.30	
11-25	0.25	25.62
11-50	0.45	
11-75	0.25	
12-25	0.23	27.79
12-50	0.30	
12-75	0.30	
13-25	0.25	31.61
13-50	0.30	
13-75	0.25	
14-25	0.25	32.0
14-50	0.30	
14-75	0.32	

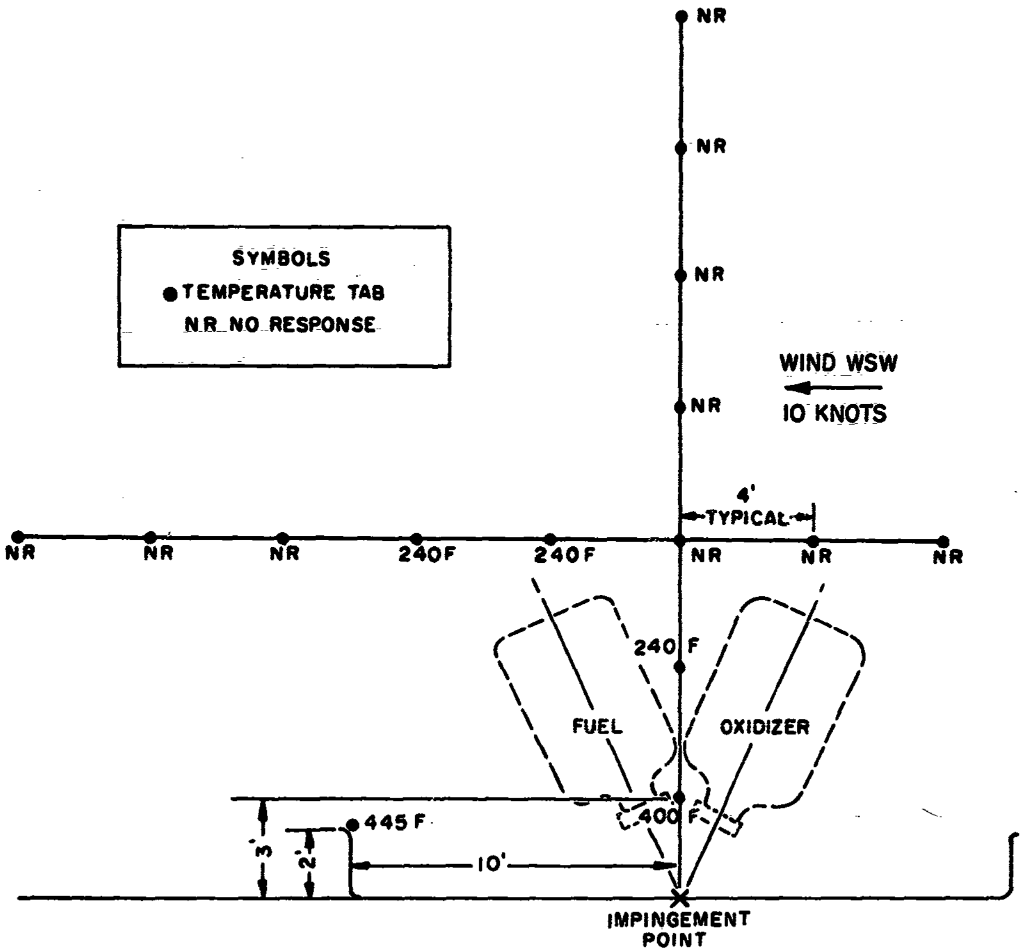
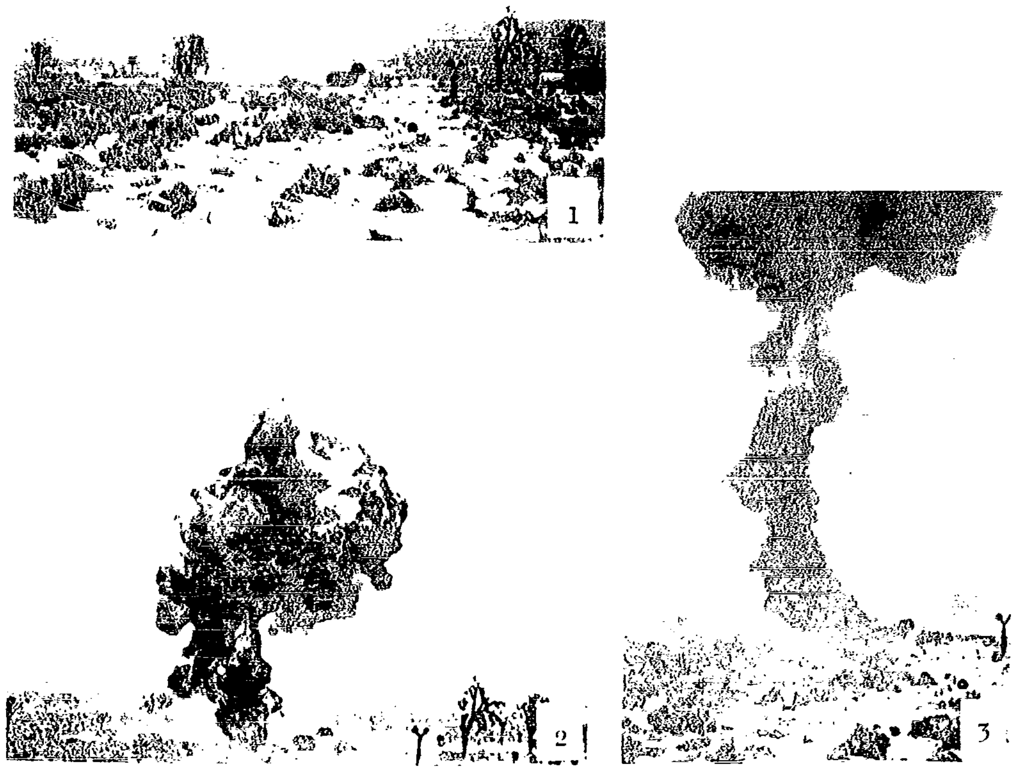


Figure 41. Temperature Measurements on Test 2,
Made With Temperature-Sensitive Paint



Sequence 1: Initial Ball of Fire From Hypergolic Reaction

Sequence 2: Ball of Fire Rising

Sequence 3: Propellant Vapors Stacked Above Surrounding Terrain. Base of cloud approximately 200 feet above tray.

Figure 42. Reaction Resulting From Spill of 300 lb of UDMH-Hydrazine and 800 lb of Nitrogen Tetroxide

Analysis

Water reduced the reaction violence on test 1; resulting in no detected overpressures and temperatures below 240 F in the spill tray. Actual reaction temperatures were much higher but due to their transient nature, they did not indicate on the temperature-sensitive paint. The toxic hazards were increased, however, because very little of the nitrogen tetroxide was consumed in the reaction with the water-diluted hydrazines. This resulted in an increase in boiloff as the water reacted with the nitrogen tetroxide. The low temperatures prevented formation of fast-rising thermals above the tray, and resulted in heavy concentrations of nitrogen dioxide vapor downwind at ground level. A plot of the data from the one MSA oxidizer detector which gave useful information is shown in Fig. 43. The detector verified the heavy vapor concentration. The instrument, positioned 250 feet downwind on the northern line, was pegged off-scale for 1 second following the tank rupture.
This off-scale movement indicated concentrations above 25 ppm. During the next 25 minutes, the response ranged from 0 to 20 ppm. Nitrogen tetroxide loading operations in preparation for the spill exceeded 25 ppm on one occasion.

Fourteen overpressure pulses were generated on the spill without water. A plot of the sixth pulse is shown in Fig. 44. The pressure measurement at the 50-ft microphone position was not usable. As shown, the curve is similar in slope to a curve plotted from overpressures generated by a 2.0-lb TNT charge. The maximum TNT equivalent yield from this test is 0.15 percent, using a total propellant quantity of 1300 lb. A comparison of this yield with that of the 1/10-scale aboveground test shows an increase of 0.09 percent yield on the large-scale test. This increase is significant, since it shows that the propellant mixing was more efficient with the technique employed on the large-scale tests; i.e., impinging propellant streams. Figure 45 presents the data obtained from three MSA detectors. As shown, no toxic vapor concentrations were detected after tank rupture which verifies the visual observation that the unreacted propellant vapors were elevated above the surrounding terrain by the heat of reaction. As a result, the animals

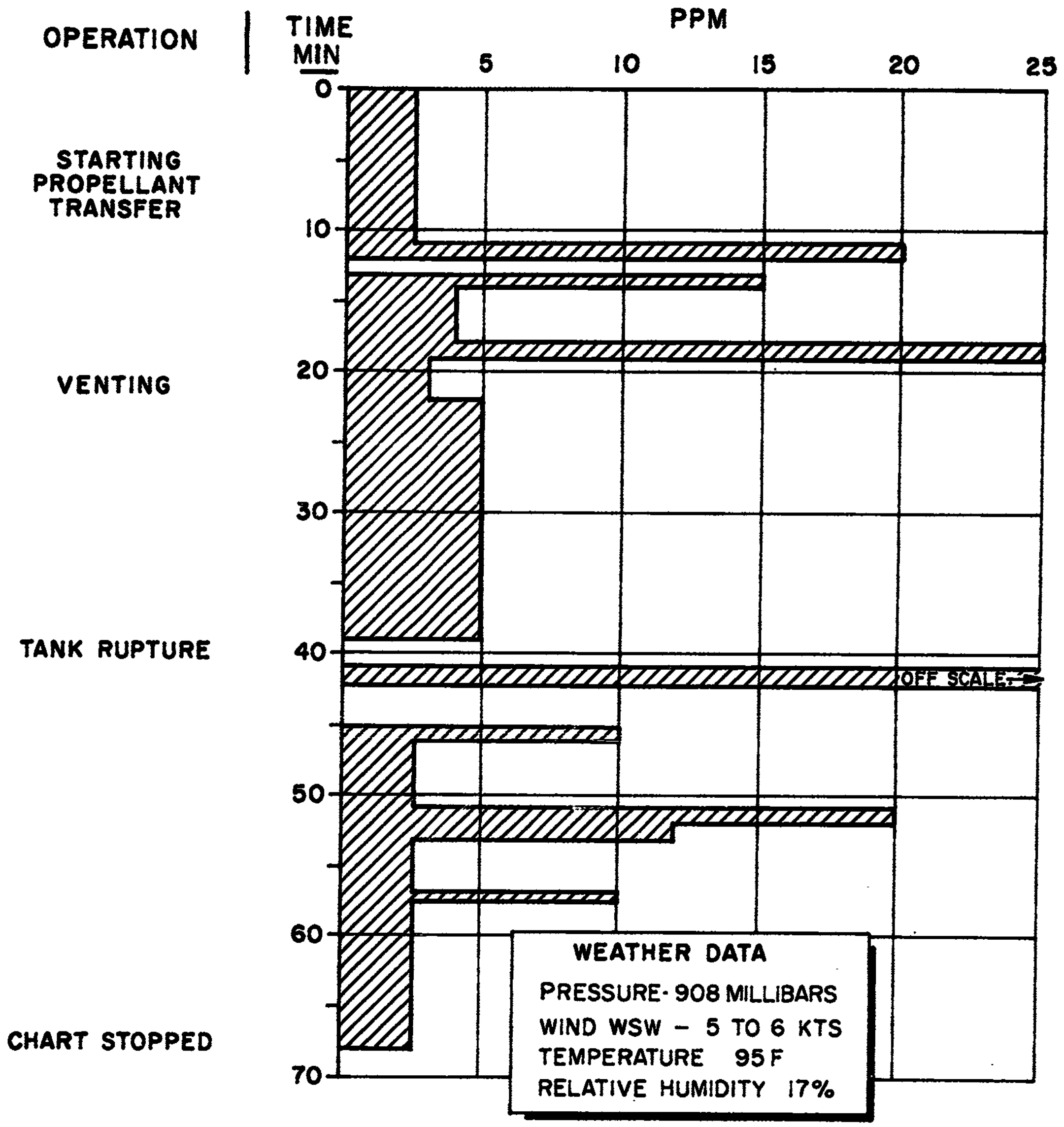


Figure 43. Nitrogen Dioxide Concentration Downwind on Test 1, Instrument on Northern Radial 250 ft From Spill Tray

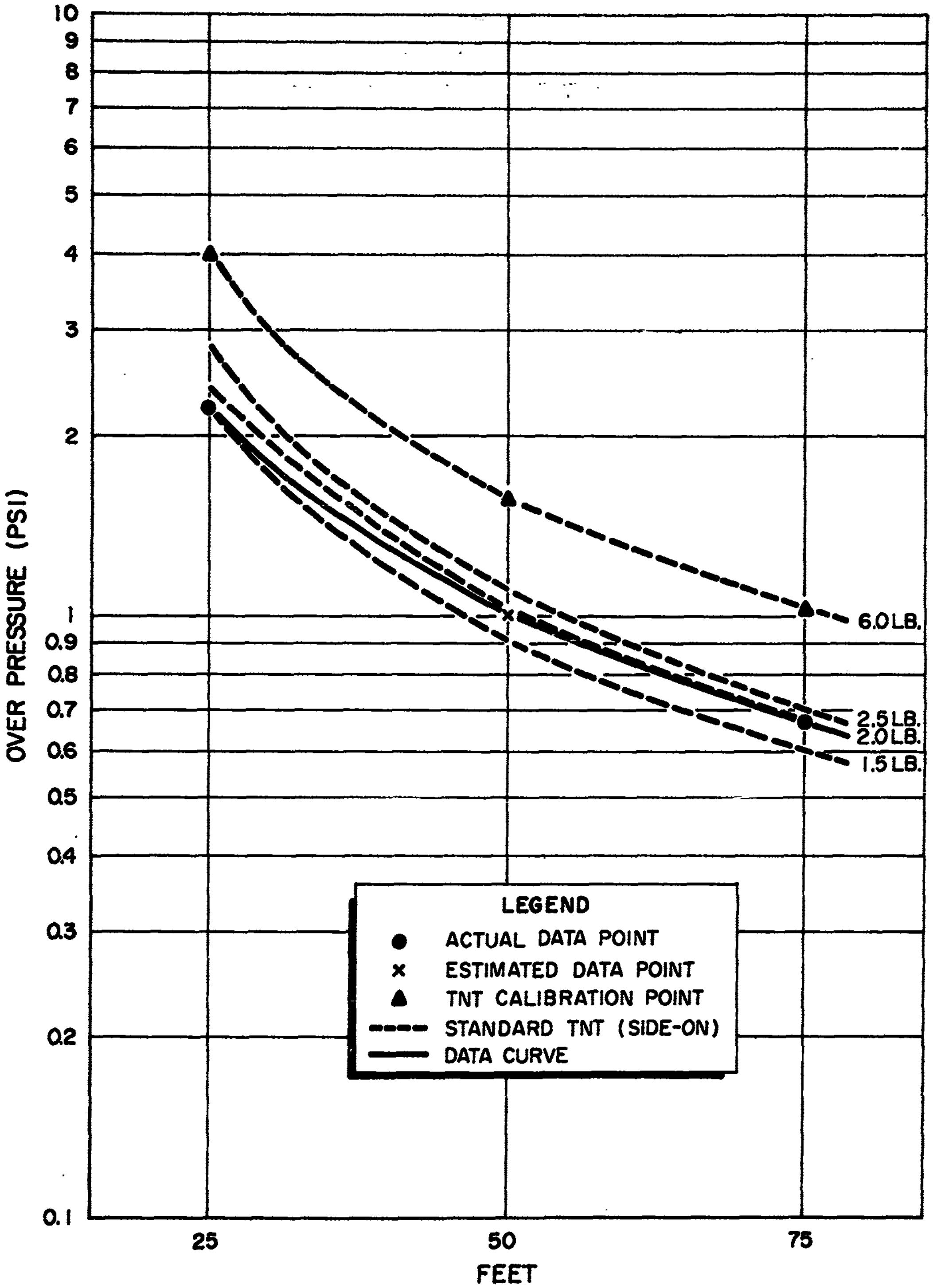


Figure 44. Overpressure Results on Test 2--Shown as Solid Line

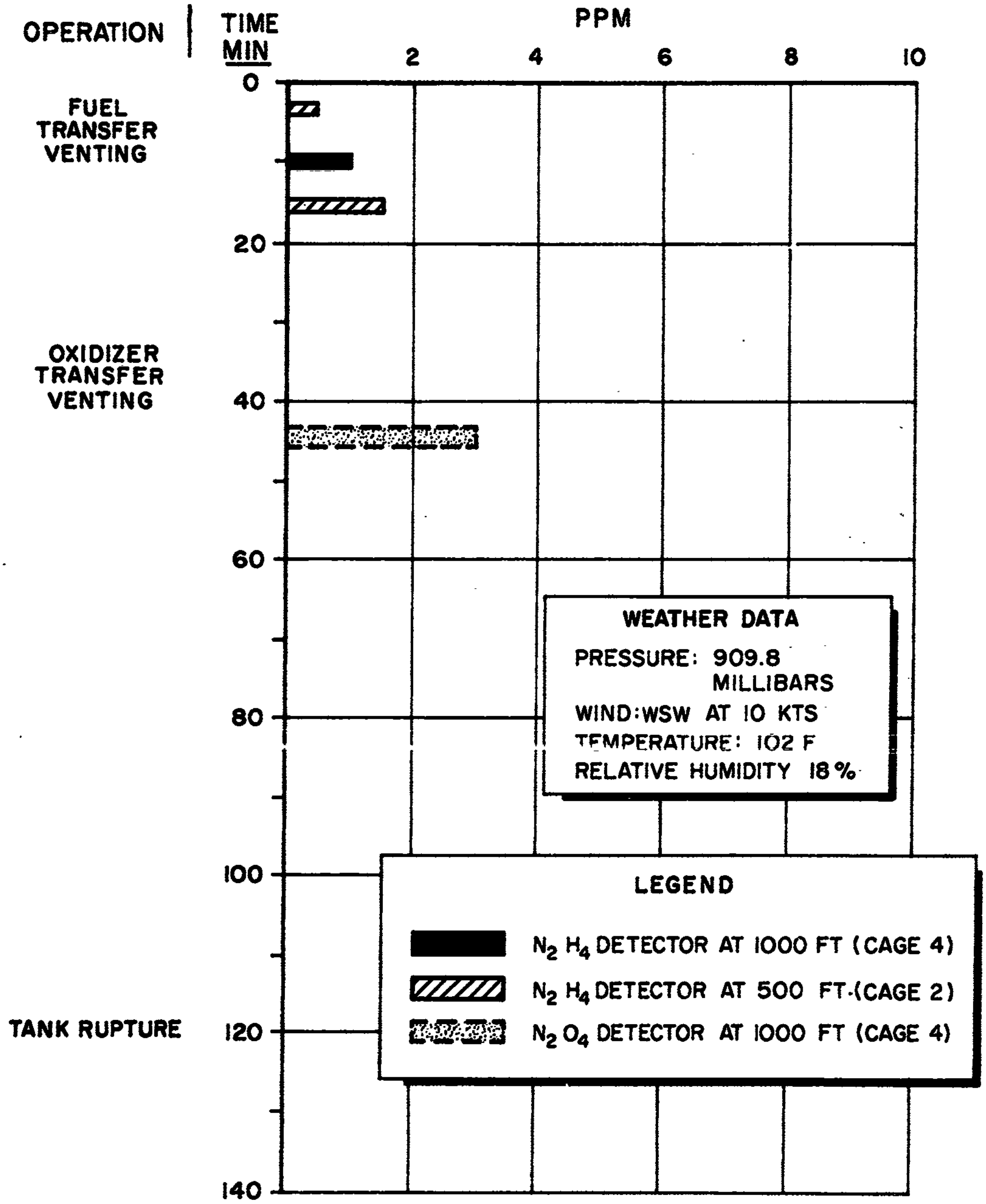
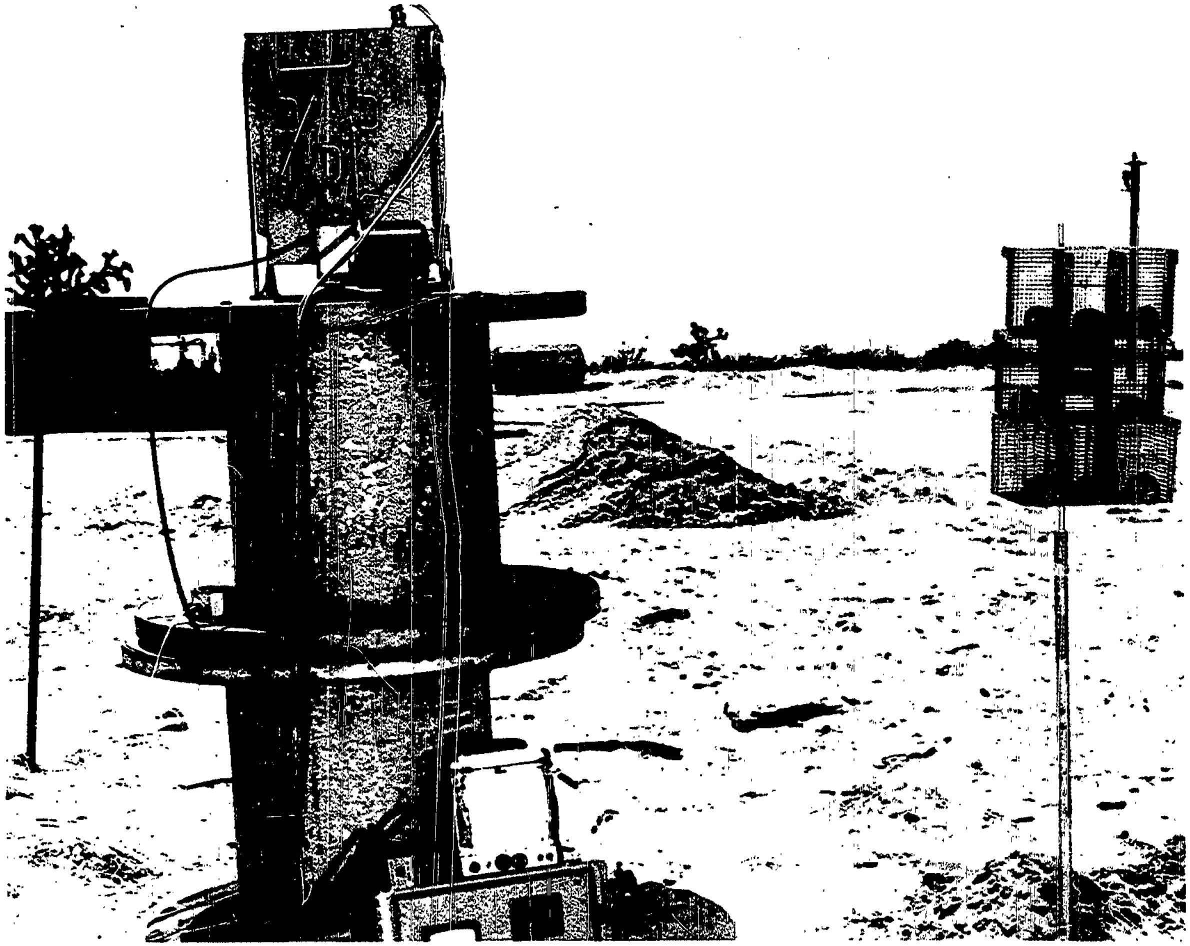


Figure 45. Toxic Vapor Concentrations Downwind on Test 2

which were used for the biological study on this test, were exposed to low concentrations of propellant vapors. These low concentrations of toxic vapors were recorded downwind on the propellant transfer operations. Although generally, the animals died from heat, the autopsy of surviving animals did indicate a possible exposure to fuel vapors. This possibility was verified at cage 2 and cage 4 where MSA detectors recorded low concentrations of fuel vapor during the transfer operations.

MEDICAL STUDY

The biological study was conducted by the Institute of Medical Research, Huntington Memorial Hospital. The animals were placed in downwind positions on large-scale spill test 2 as shown in Fig. 38. Control animals were placed 150 ft upwind from the spill site. The cages were elevated approximately 5 ft above ground level. Nine animals were exposed at each position. The concentration of toxic gases at each animal position was measured and recorded by MSA and ASI toxic vapor detectors placed adjacent to the cages (Fig. 46). The animals were placed in position one hour prior to the spill test. After exposure, the animals were returned to the Institute where an autopsy was performed to study the physiological effects of the short-term, high-concentration exposure. Results of the biological study are presented in Appendix F.



4,263 61 GAFFTC

Figure 46 . Placement of Hamster Cages and Continuous-Recording Toxic Vapor Detector for Biological Tests

CONCLUSIONS

SMALL-SCALE SPILLS

Multiple spills of nitrogen tetroxide and the 50-50 percent UDMH-hydrazine fuel mixture in an unconfined area will result in the development of overpressure waves under some conditions. It is also very apparent that the overpressures are initiated by a vapor-phase reaction of the fuel-air and/or fuel-oxidizer mixtures. This is indicated not only by the motion pictures which show the explosions to occur a few feet above the spill area but also by the overpressure measurements which indicate that the explosions are occurring several milliseconds after ignition. It is further theorized that these vapor-phase explosions are a result of the fuel-air mixtures. The motion picture record indicates that a white flash characterizes the explosions, while combustion of the fuel and oxidizer results in a yellow-orange flame.

Although it is impossible to attach an absolute value of overpressure to a particular quantity of propellant from this study, the conditions of the spills can be rated as to their resulting severity. The simultaneous spill of the propellants and the fuel lead results in higher overpressures than the oxidizer lead, while the overpressure rating for spills on dry concrete is much higher than on either the dirt or water-covered concrete. The combination of these two conditions; i.e., simultaneous spill on dry concrete produced the maximum yield TNT equivalent of 0.48 percent. These ratings can again be attributed to the particular sequence of the test events that lead to development of overpressures. The formation of hydrazine vapors over the spill area is retarded by the absorbent qualities of the dirt and the cooling or damping effects of the water, while a large surface of oxidizer exposed to contact with the fuel results in the spontaneous ignition and combustion of most of the fuel with smaller amounts of fuel vapor in the air.

MODEL-MISSILE SPILLS

The explosive yield during a spill was observed to be related directly to spill conditions that effect the propellant mix. No liquid-phase detonations occurred. All explosions, as reported in the small-scale spills, appear to result from hydrazine-air or a tricomponent hydrazine-air-nitrogen tetroxide vapor reaching the detonation mixture ratio. The following observed variations in reaction violence have been supported by analysis of pressure measurements.

1. The confinement of nitrogen tetroxide with 50-50 percent UDMH-hydrazine in the silo extends the time of intimate mix and intensifies the violence of their reaction. Blast instrumentation shows that the above-ground spills with 300 lb of propellant gave a maximum TNT equivalent of 0.21 lb for a yield of 0.07 percent, as compared to silo spills of 300 lb of propellant which gave a maximum TNT equivalent of 2.0 lb for a yield of 0.67 percent.

2. Silo spills with hydrazine leads were less severe than either the oxidizer lead or simultaneous spill; the latter resulted in the most violent explosions. Apparently a spill of hydrazine into a nitrogen tetroxide atmosphere results in more complete mixing, with increased vaporization of hydrazine. This vaporized hydrazine is then available for combining with air or with the nitrogen tetroxide atmosphere tc form mixtures in the detonation range. On fuel leads, the hydrazine covers the floor of the silo, limiting the zone of reaction to the interface constituted by the fuels surface and the nitrogen tetroxide vapors. This results in the combustion of hydrazine, with very little

hydrazine vapors available for obtaining mixtures in the detonation range.

3. Increase in propellant weight did increase reaction violence on spills made under simultaneous and oxidizer lead conditions; however spills with fuel leads resulted in a 0.06 percent decrease in yield. Comparison of overpressures from simultaneous spills shows maximum equivalent yields for the 1/10-scale and 1/18-scale tests of 2 lb and 0.21 lb respectively, which is a 0.27 percent yield increase.

4. The addition of water to the bottom of the silo was found to reduce maximum temperatures and pressures resulting from the reaction of the Titan II propellants.

Measured tunnel pressures were consistently 50 to 100 percent higher than pressures measured in the main silo body. This effect is most likely the result of the propagation of the blast wave down the length of the tunnel which causes a face-on or reflected wave measurement by the pressure transducer in the tunnel. If this assumption is correct, the tunnels did provide attentuation in most cases when the tunnel pressures were converted to side-on pressures. The degree of attenuation depends on the height at which the explosion occurs in the main body. The possibility of a secondary explosion occurring in the tunnels should not be excluded since on several pulses the converted side-on tunnel pressure was actually higher than the silo main body.

Recorded temperatures at the ends of the underground tunnels did not exceed ambient; however, this may be a result of thermocouple response time, as high temperatures could be occurring instantaneously.

Unreacted nitrogen tetroxide was observed in heavy concentration on most tests. The nitrogen tetroxide cloud rose rapidly as a mushroom shape about the flame column. Apparently the heat of reaction coupled with explosive surge of gases out of the silo, pushed the vaporized nitrogen tetroxide out of the zone of reaction.

The fireball which resulted on each aboveground spill of the Titan II propellants appears to have three distinct stages in its growth. These stages are:

1. The initial hypergolic reaction which causes the most rapid expansion of the fire ball.
2. A period without growth where the fire ball remains unchanged in size. On the two tests conducted, this period was approximately 0.2 sec in duration.
3. The beginning of the third period and the end of the second period occurs at the initiation of the overpressure pulses. Expansion of the ball of fire to maximum size occurs during this last stage in the growth.

The validity of extrapolating the recorded pressures from the scale-model tests depends on how well the scale-model tests actually simulate the conditions that would exist in a full-scale silo. The following factors can influence the amount of explosive vapor-phase mixture that is available for ignition.

1. Physical shape for missile tankage
2. Mode of missile failure
3. Silo configuration
4. Support equipment in silo
5. Temperature of air, silo walls, missile structure, and any support equipment

Because a decrease in yield was not obtained with spills of larger propellant quantities, it cannot be assumed that the upper limit was reached on the TNT equivalent yield; i.e., 0.67 percent yield obtained on the 1/10-scale silo spill is not the upper limit. Further model testing with larger propellant quantities would be necessary to establish an upper limit and provide data for possible extrapolation to full-scale conditions.

Methods to prevent the accumulation of explosive vapor-phase mixtures in silos were apparent from the results of model spills and are listed as follows:

1. Dilution of spilled hydrazine by water spray and by use of a water floor.

2. Limiting the amount of air over the surface of the fuel by use of an inert gas blanket or purge. This method warrants further investigation to determine what effect raising the flammability limits would have on a potential explosive gas-phase mixture of hydrazine in air.

LARGE-SCALE SPILLS

From the results of the two large-scale mixing spills, the following conclusions can be drawn:

1. The use of water to retard or control the reaction of nitrogen tetroxide and mixed hydrazines was tested and revealed the following:

    a. The dilution of hydrazine by water will prevent or mitigate the blast hazard by reducing the amount of fuel vapor present in the air above the fuel surface. The spill with the water deluge had no recorded overpressures, although several weak explosions were audible.

b. Water accelerated the boiloff of nitrogen tetroxide and thereby increased the toxicity hazard.

2. Toxic gas concentrations at ground level downwind of the reaction zone were decreased due to the heat of reaction on the test without water deluge. The heat elevated the remaining unreacted propellants, effectively releasing them above the surrounding terrain.

3. Vapor-detection systems, to be effective in measuring concentrations of toxic gases, must be in a closely spaced grid around the critical points of the system being monitored and each instrument must have rapid response characteristics since the vapor concentrations were observed to change rapidly over very short distances and time in an outdoor environment.

4. The blast instrumentation indicated a maximum yield of 0.15 percent TNT for the large-scale mixing test conducted without a water deluge. This is greater than the yield obtained from the 1/10-scale aboveground spills conducted with the model missiles, indicating more efficient propellant mixing with this larger propellant quantity.

MEDICAL STUDY

Please refer to Appendix F for the conclusions drawn by the Institute of Memorial Research on the results of the biological study.

RECOMMENDATIONS

1. More definitive information might be gained by additional small-scale investigations of the vapor-phase reaction mechanisms, as well as the formation of the vapors under various conditions. It would be possible from such a study to develop methods to prevent or suppress the formation of the fuel-air vapor mixtures by design features incorporated in systems handling the Titan II propellants.

2. The results of the model-missile studies indicate the following areas where further investigation would be of great value:

   a. A study of the phenomenon of tunnel overpressures. These investigations would include:

      (1) Conducting silo spills with the primary objective of obtaining pressure profiles along the length of the tunnels by side-on placement of transducers

      (2) Shock tube studies with hydrazine-air and hydrazine-nitrogen tetroxide mixtures to determine what gas-phase reactions could be triggered in the tunnels

   b. Establishment of a third point on the scale-model tests. This scale-model investigation should be no less than 1/5 scale. This third point, together with the results of the 1/10- and 1/18-scale models, would allow extrapolation of the data to determine the overpressures that would be encountered under full-scale propellant spill conditions.

   c. Investigation of the use of a water floor to reduce the fire and blast hazards for in-silo spills. One such test was conducted on the 1/18-scale missile model and results indicate a reduction in reaction violence.

3. The results of the large-scale tests indicate several areas where further investigation would yield meaningful information. These areas are:

   a. Determination of downwind toxic vapor concentrations by use of the modified Sutton Equation. By measuring the release rates of the propellants under normal and accelerated conditions, the downwind concentrations can be calculated, allowing reliable quantity-distance values to be determined without the need of field measurements. These field measurements by toxic vapor detectors were shown to be difficult to perform with existing equipment.

   b. Further study of the use of complete mixing and reaction heat to reduce downwind air contamination at ground level by stacking the unreacted Titan II propellants. This would be a useful technique in low-altitude missile aborts. Possible detrimental effect would be the overpressures generated by such a complete reaction.

   c. Spills of the Titan II propellants in the silo would best be handled by dilution with water. Further study of this technique on specific designs would be required to prove its usefulness. A possible detrimental effect would be the temporary increase in the rate of release of nitrogen tetroxide, causing a downwind air contamination problem.

4. The results of the biological study illustrate the difficulty in obtaining known animal exposures in an outdoor environment. Controlled animal-exposure studies performed under laboratory conditions would provide more useful information.

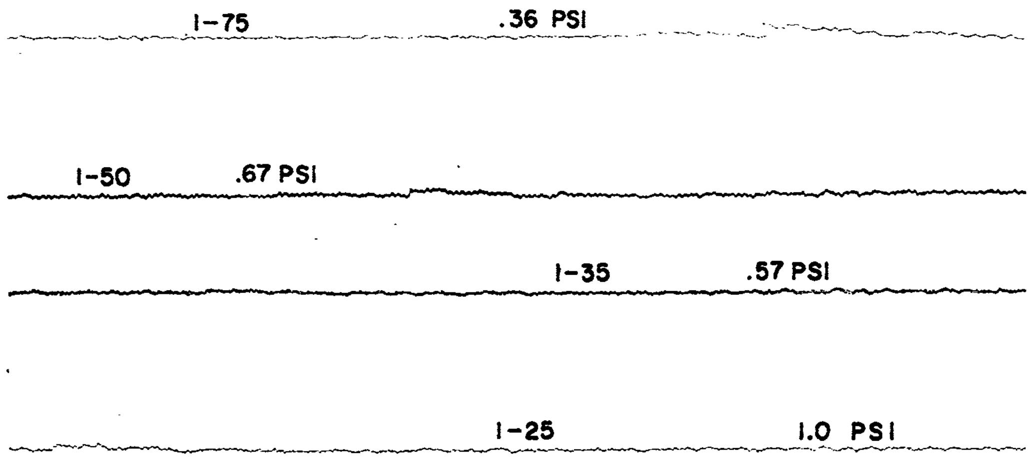
REFERENCES

1. Bleakley, Walter: Weapon Data: Fire, Impact, Explosion, OSRD No. 6053, Division 2, NDRC, Office of Scientific Research and Development, September 1945.
2. Glasstone, S.: The Effects of Nuclear Weapons, U. S. Department of Defense, June 1957.

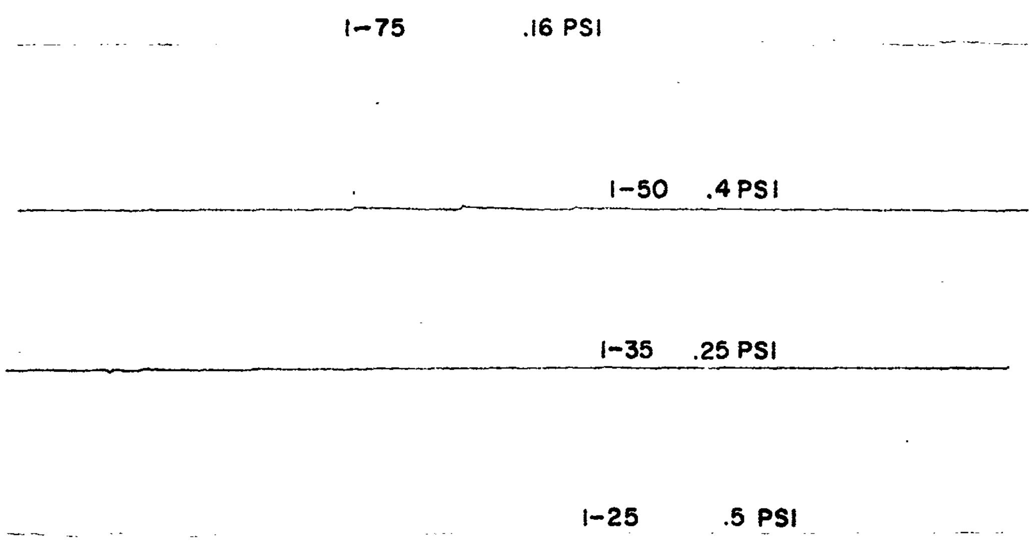
DATA APPENDIX A

1/10 SCALE ABOVEGROUND SPILL TESTS

NOTE: OSCILLOGRAM PAPER SPEED 100 IPS; TIME LINES 0.001 SEC



Test 11. Simultaneous Spill of 200 lb of Nitrogen Tetroxide and 100 lb of UDMH-Hydrazine (50-50) in Spill Tray

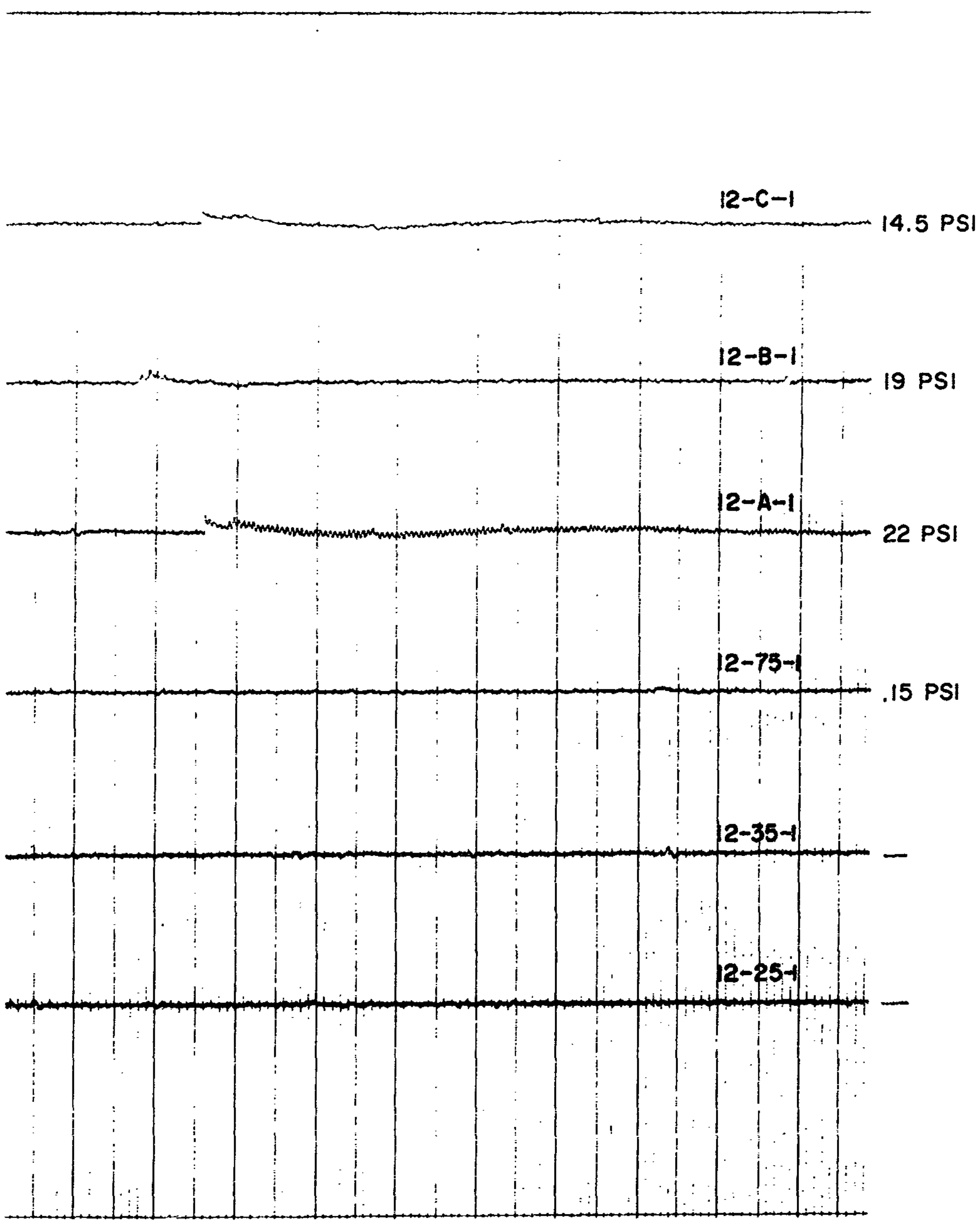


Test 8. Blast Pressure Measurements from Spill of 200 lb of Nitrogen Tetroxide and 100 lb of UDMH-Hydrazine (50-50) in Spill Tray. NTO led fuel by 2 Seconds

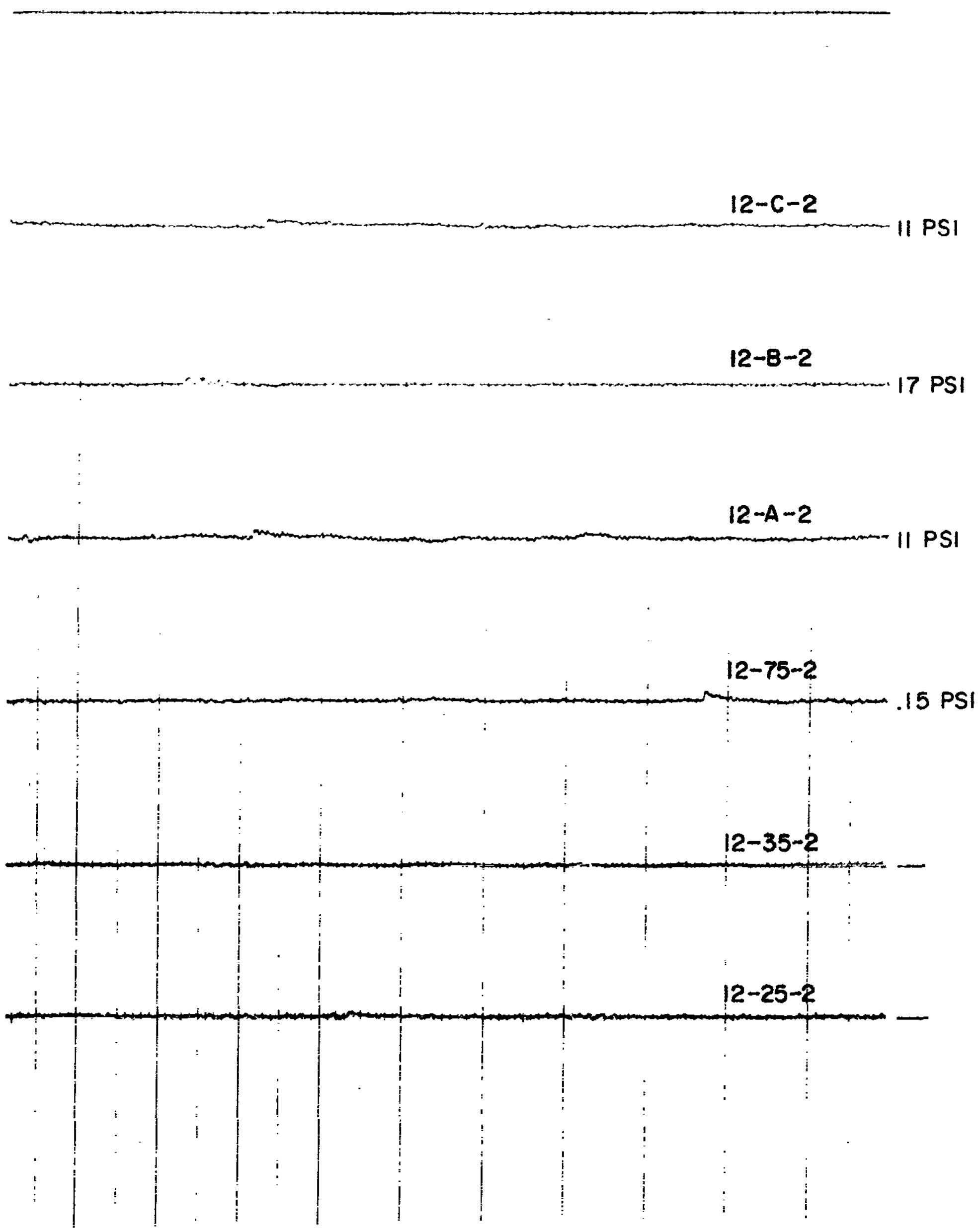
APPENDIX B

1/18-SCALE SILO SPILLS

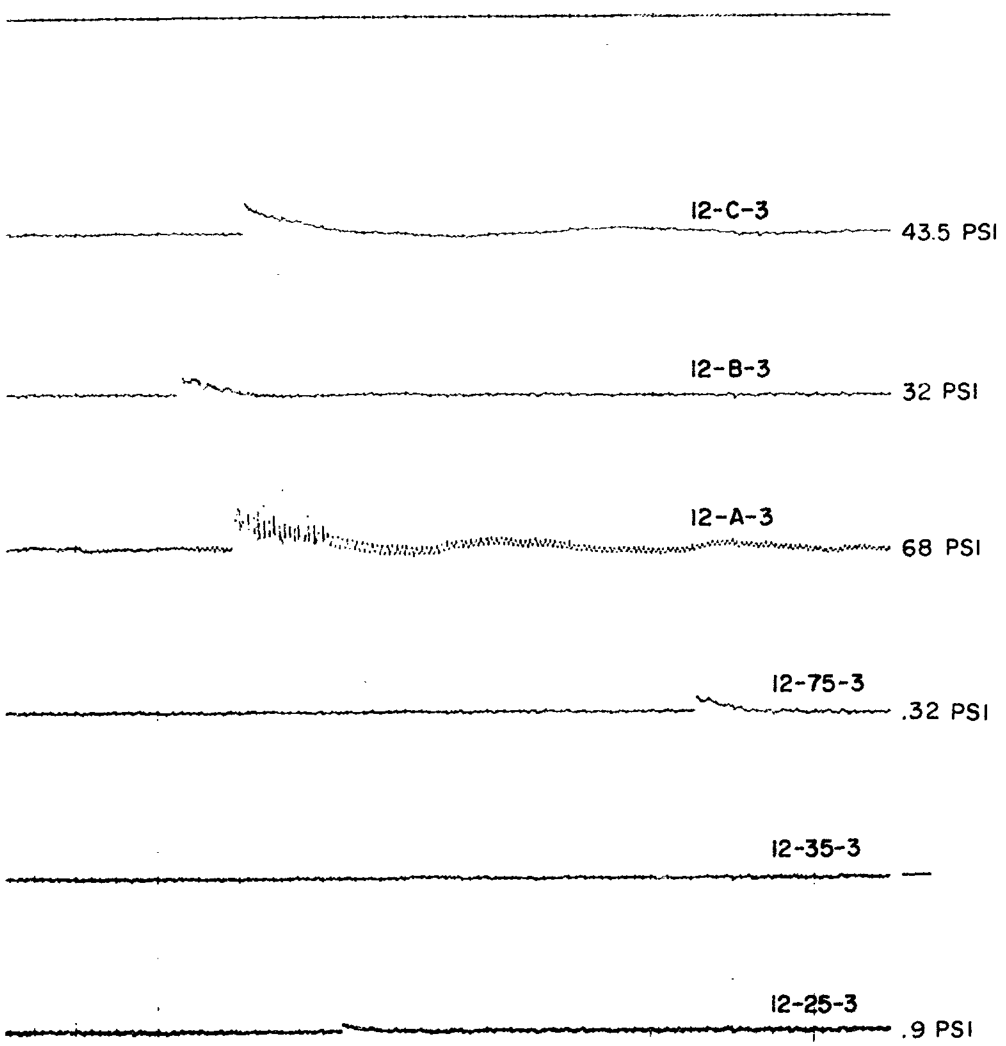
NOTE: OSCILLOGRAM PAPER SPEED WAS 50 IPS EXCEPT AS NOTED.
TIME LINES, 0.001 SEC



Spill Test 12



Spill Test 12 (Continued)



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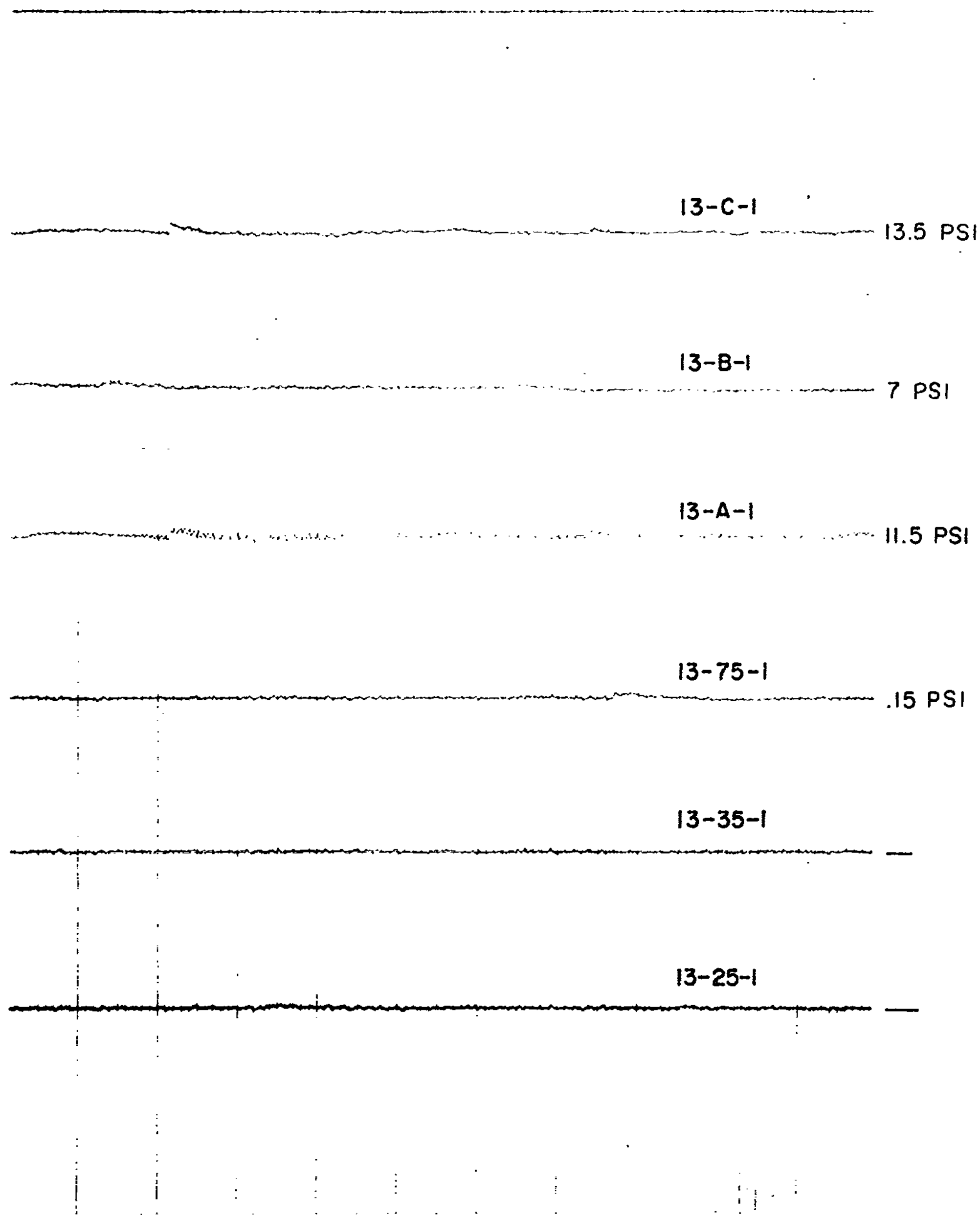
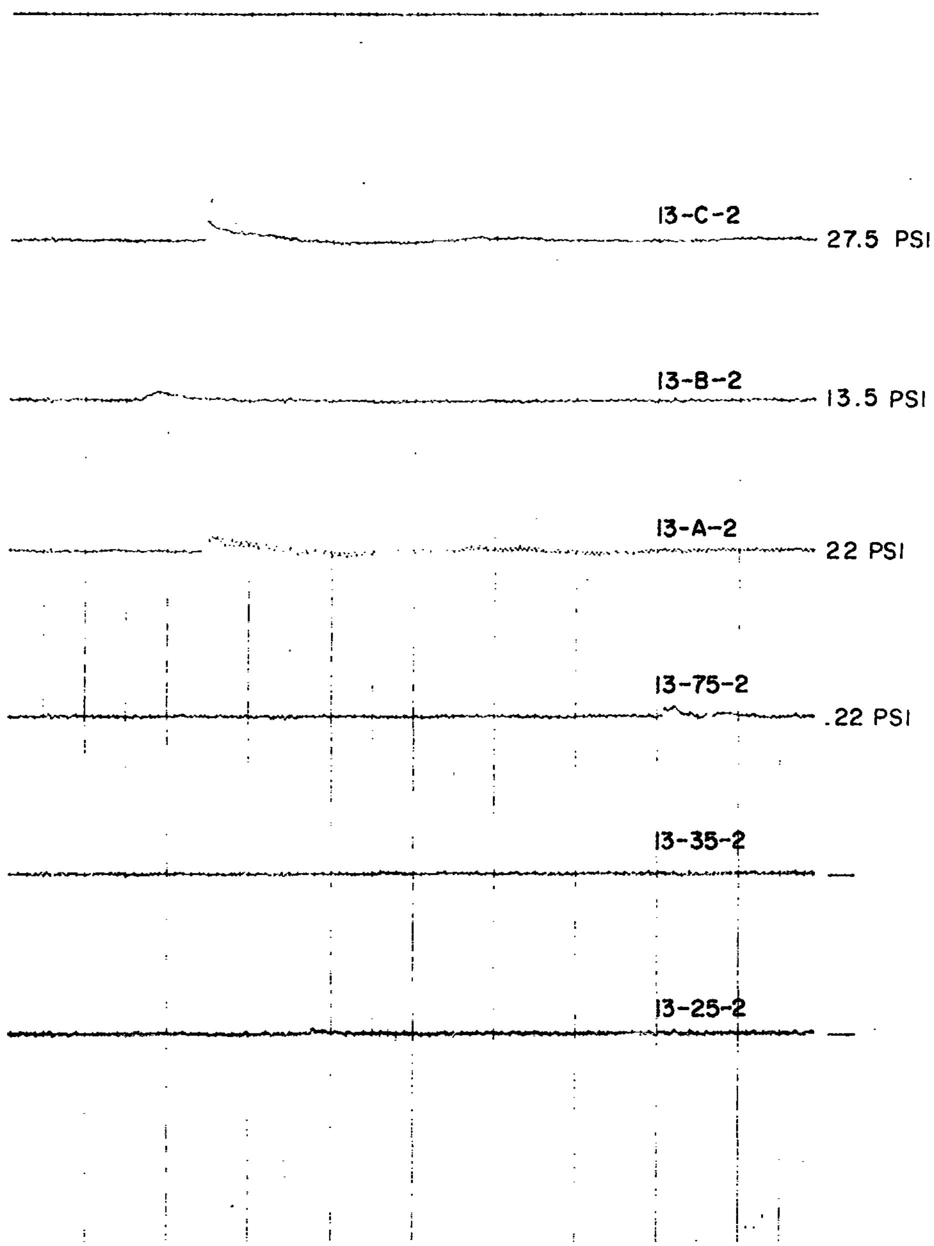
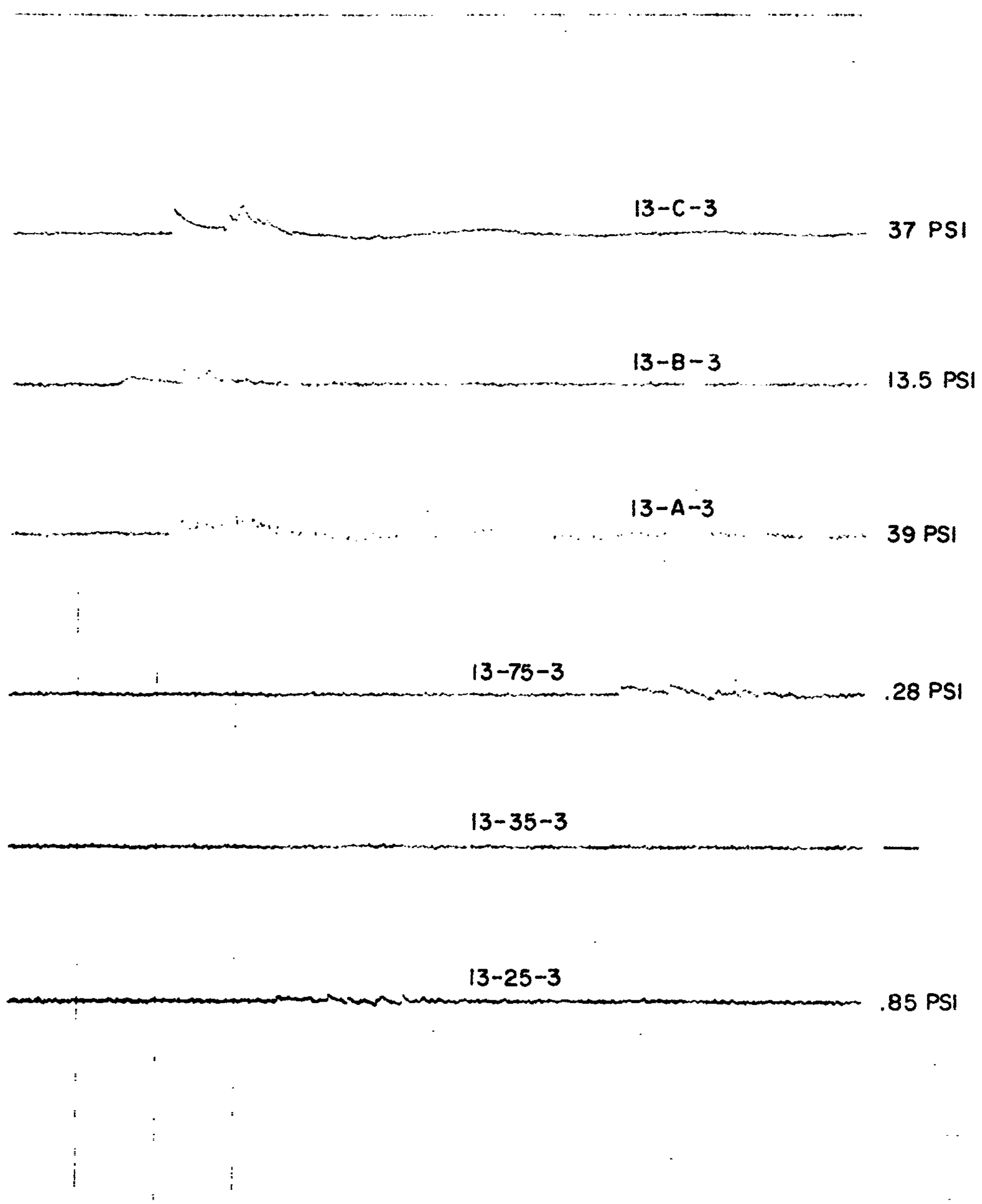


Spill Test 13



Spill Test 13 (Continued)



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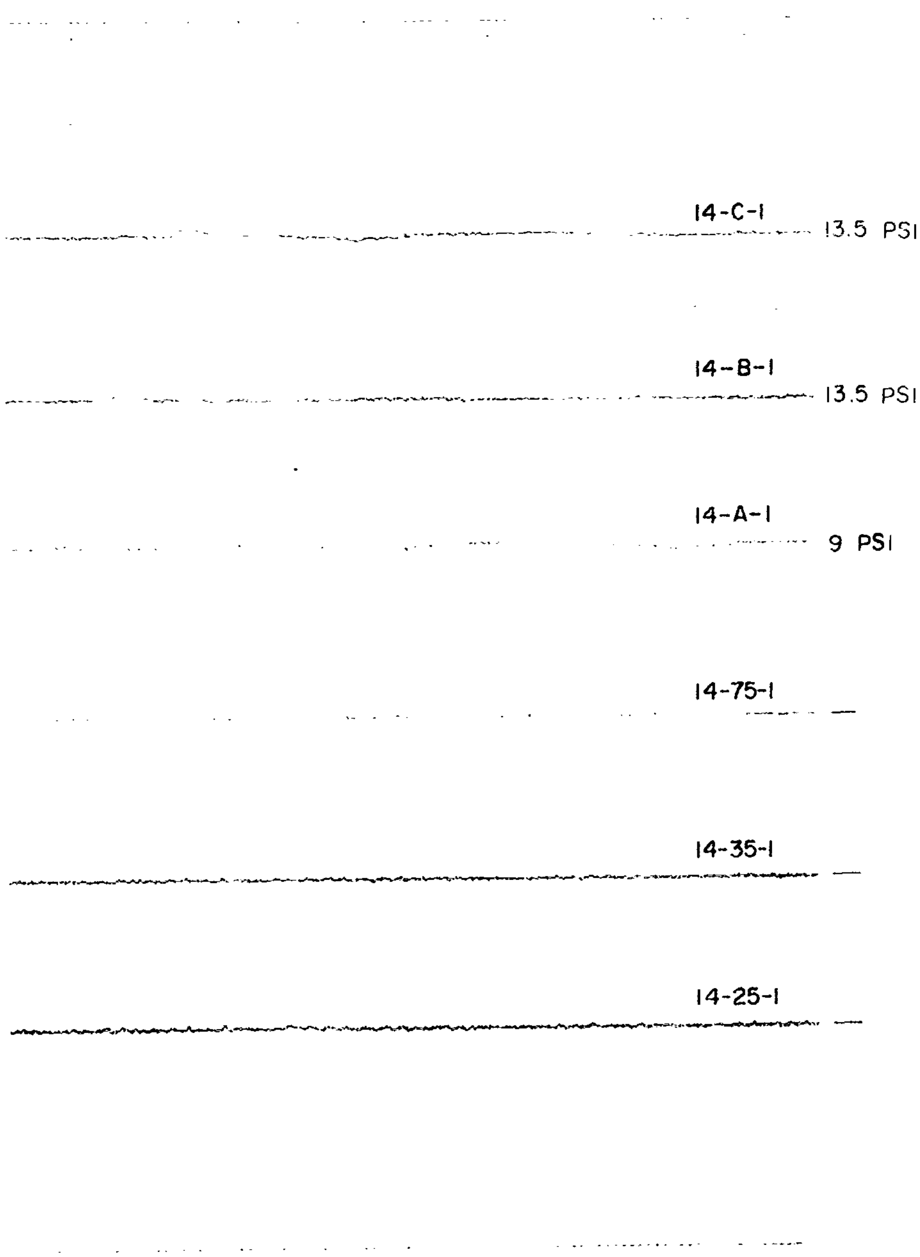
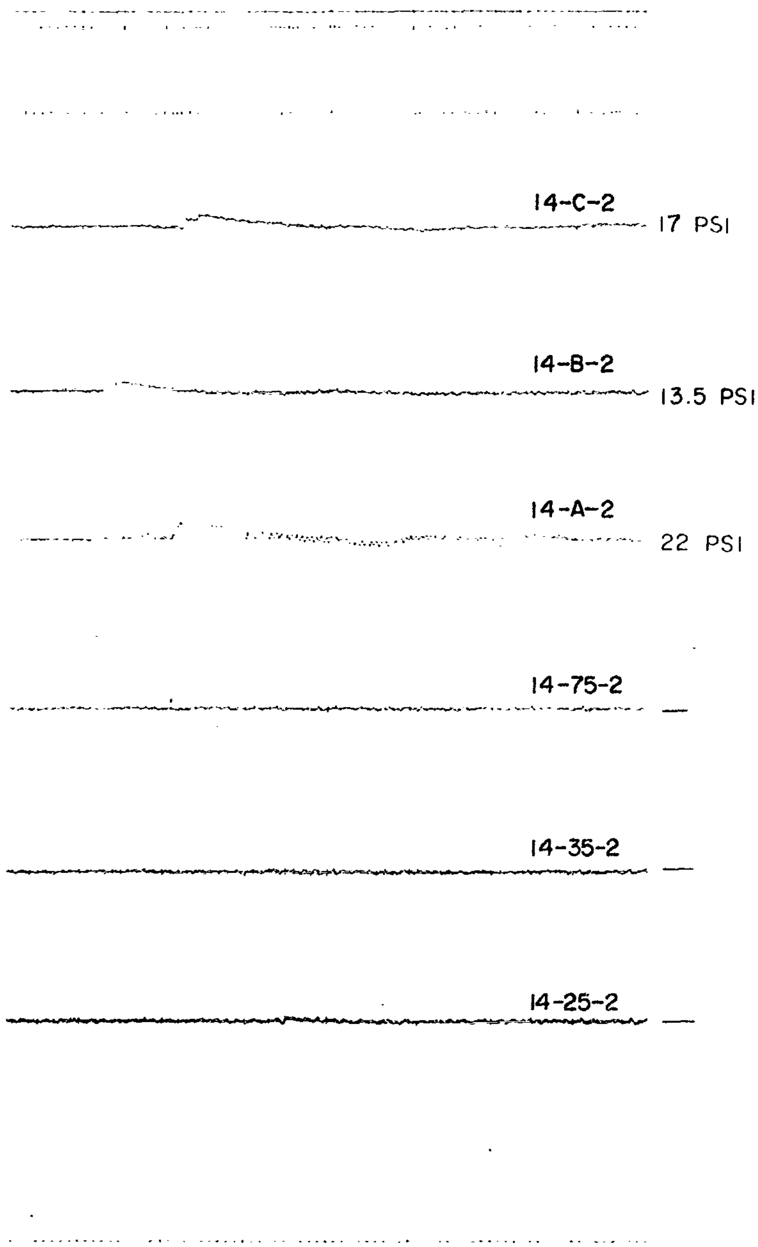


Spill Test 14



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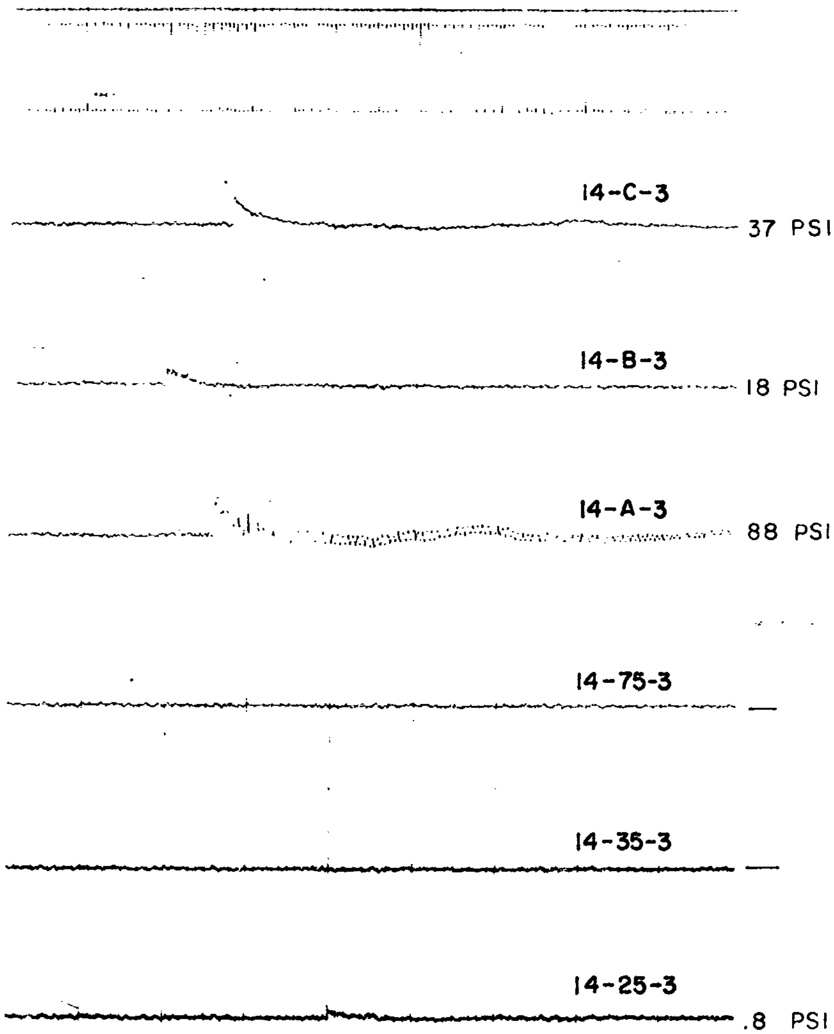

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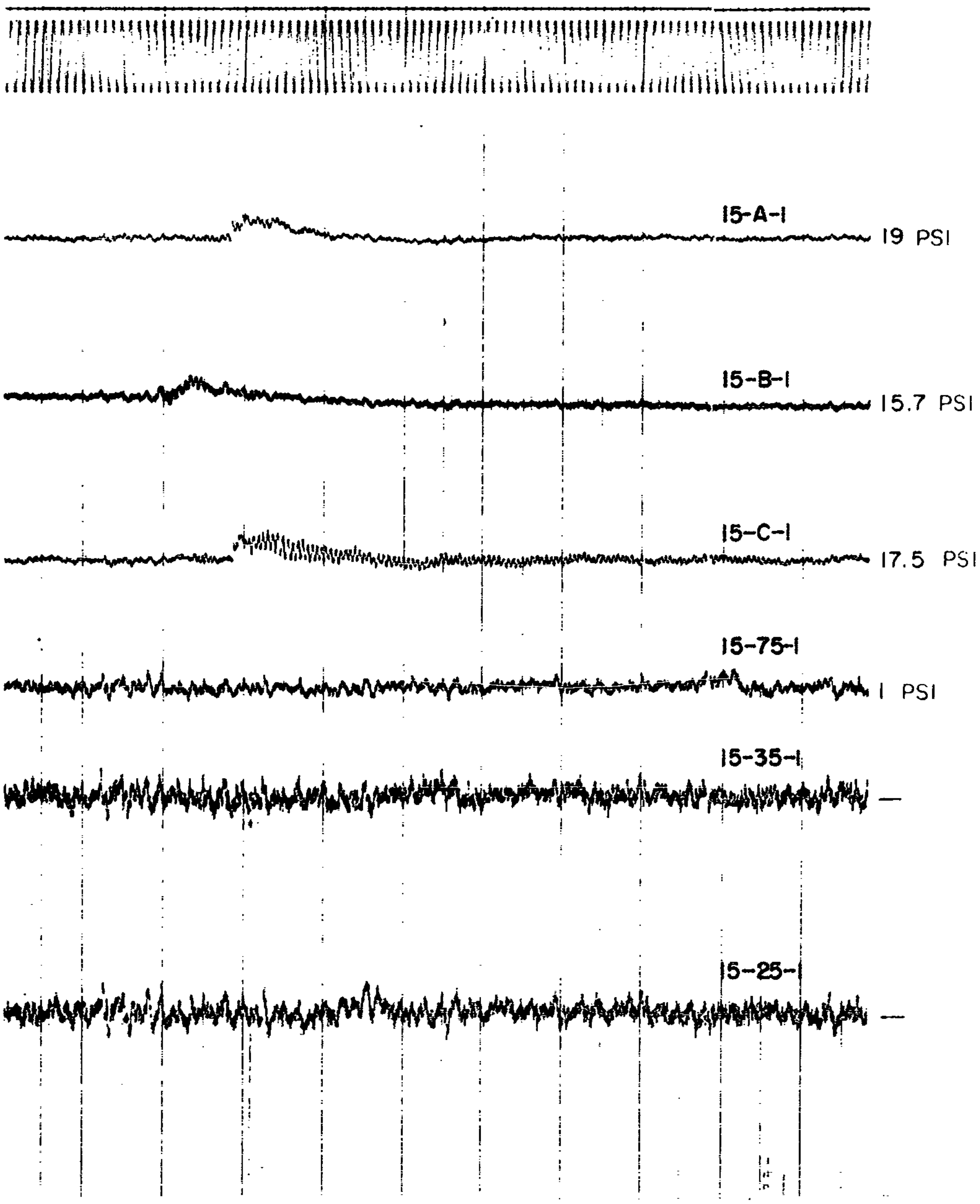
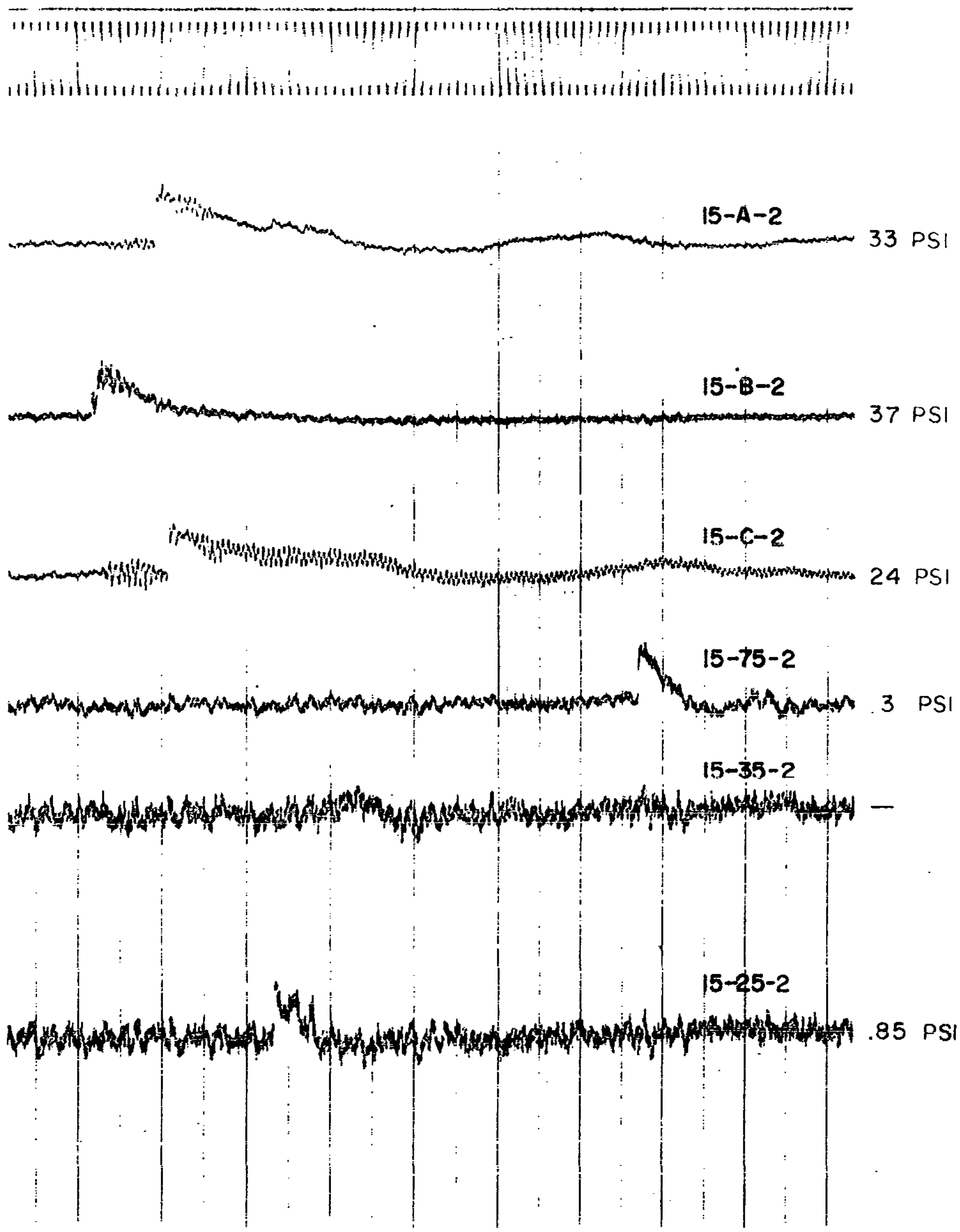
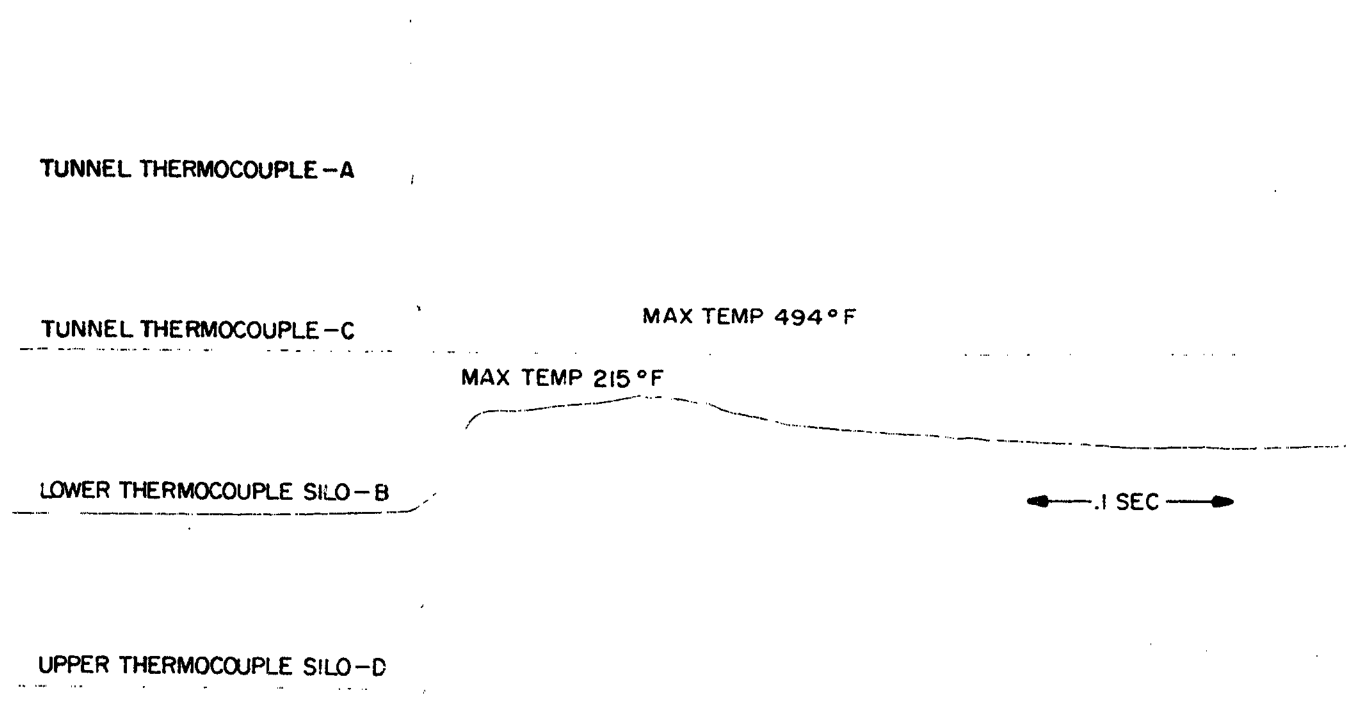


Spill Test 15



Spill Run 15 (Continued)



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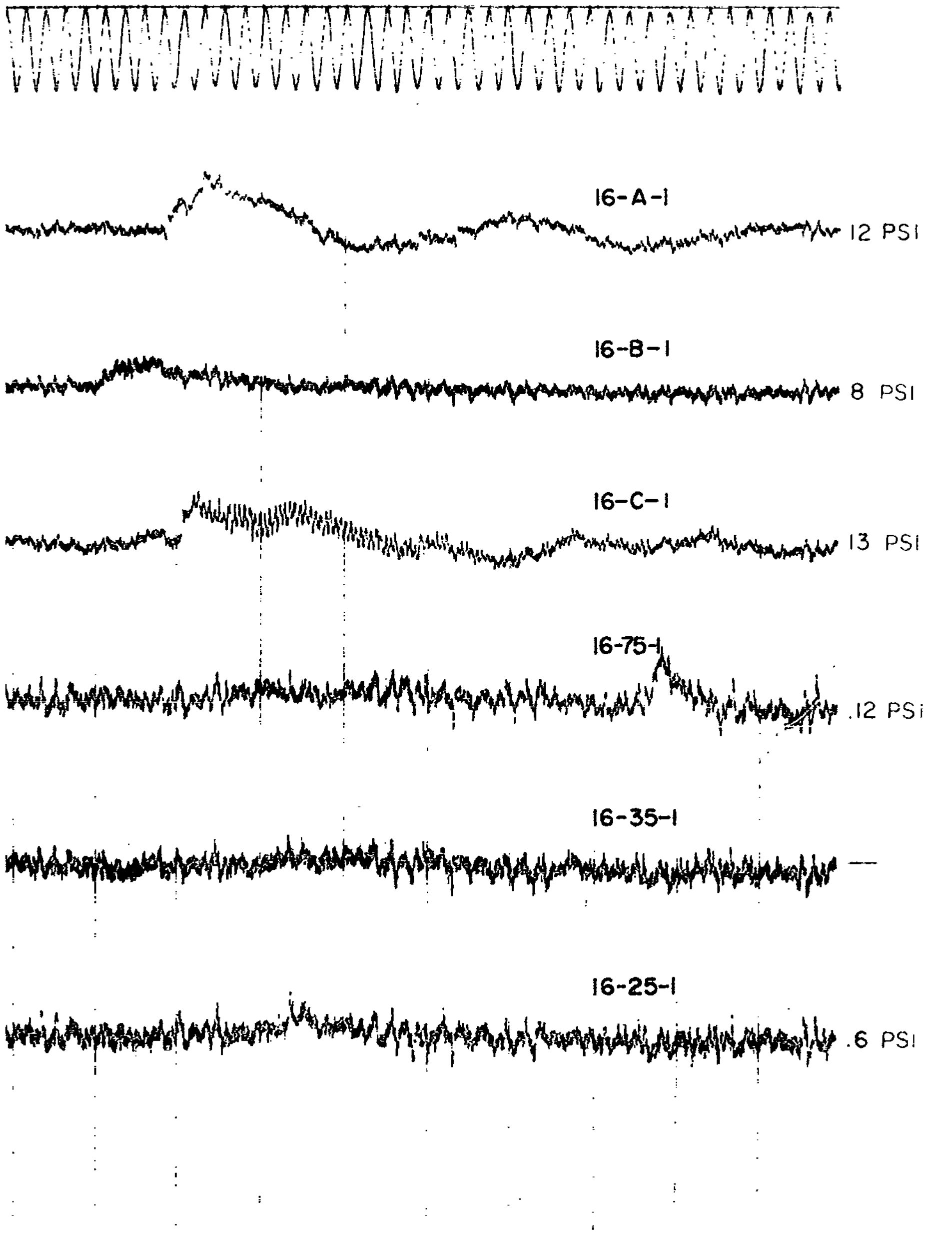
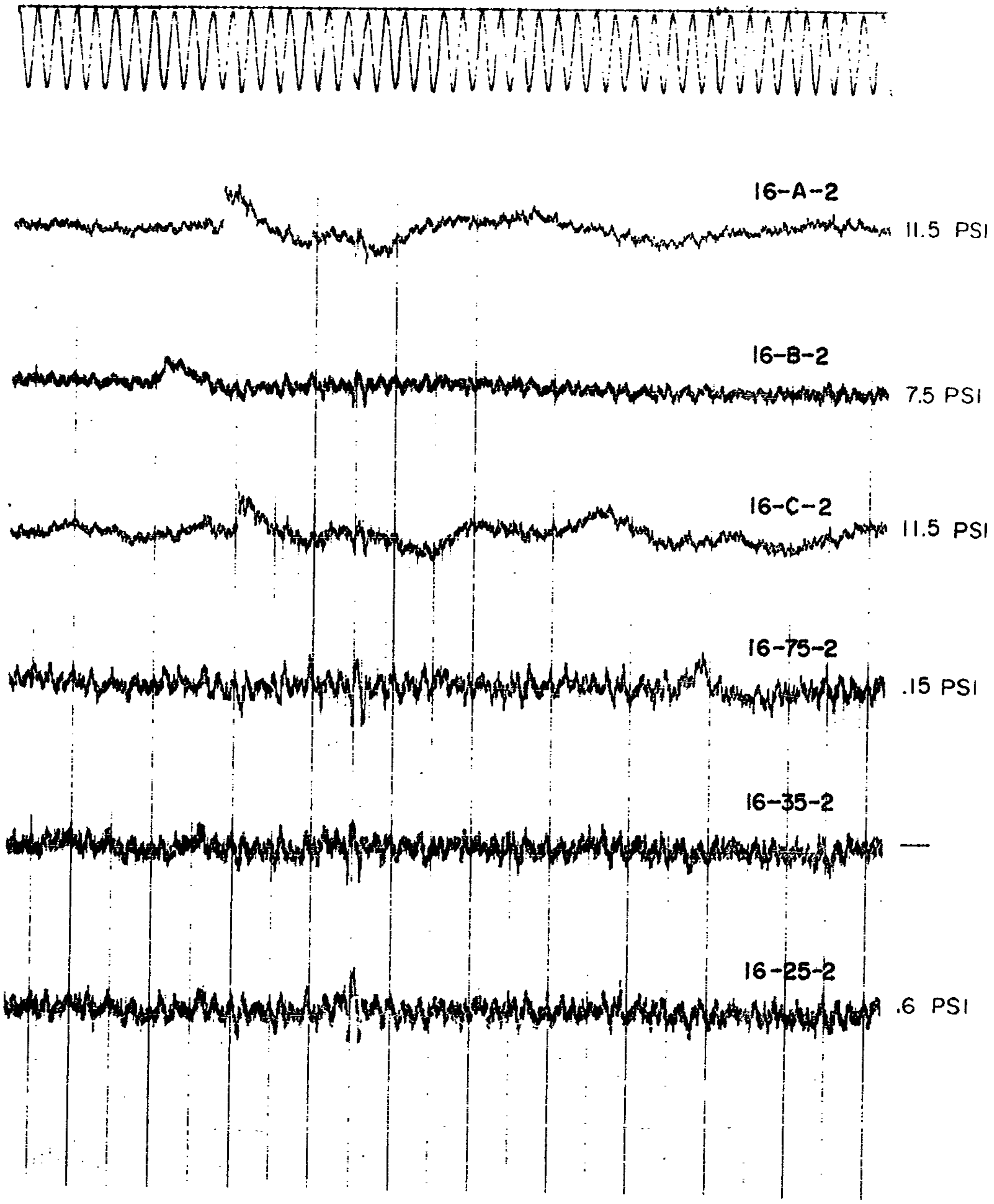


Spill Test 16



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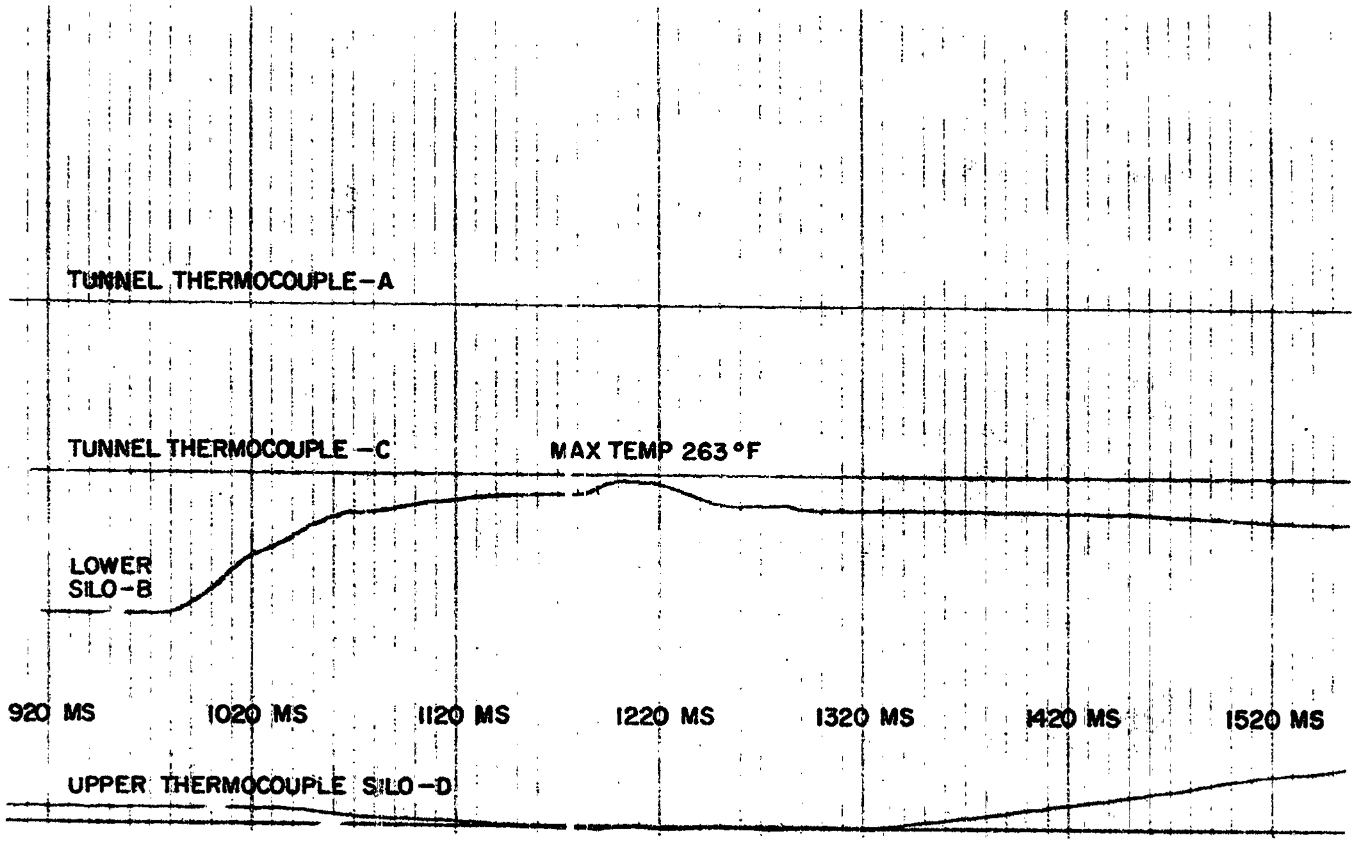

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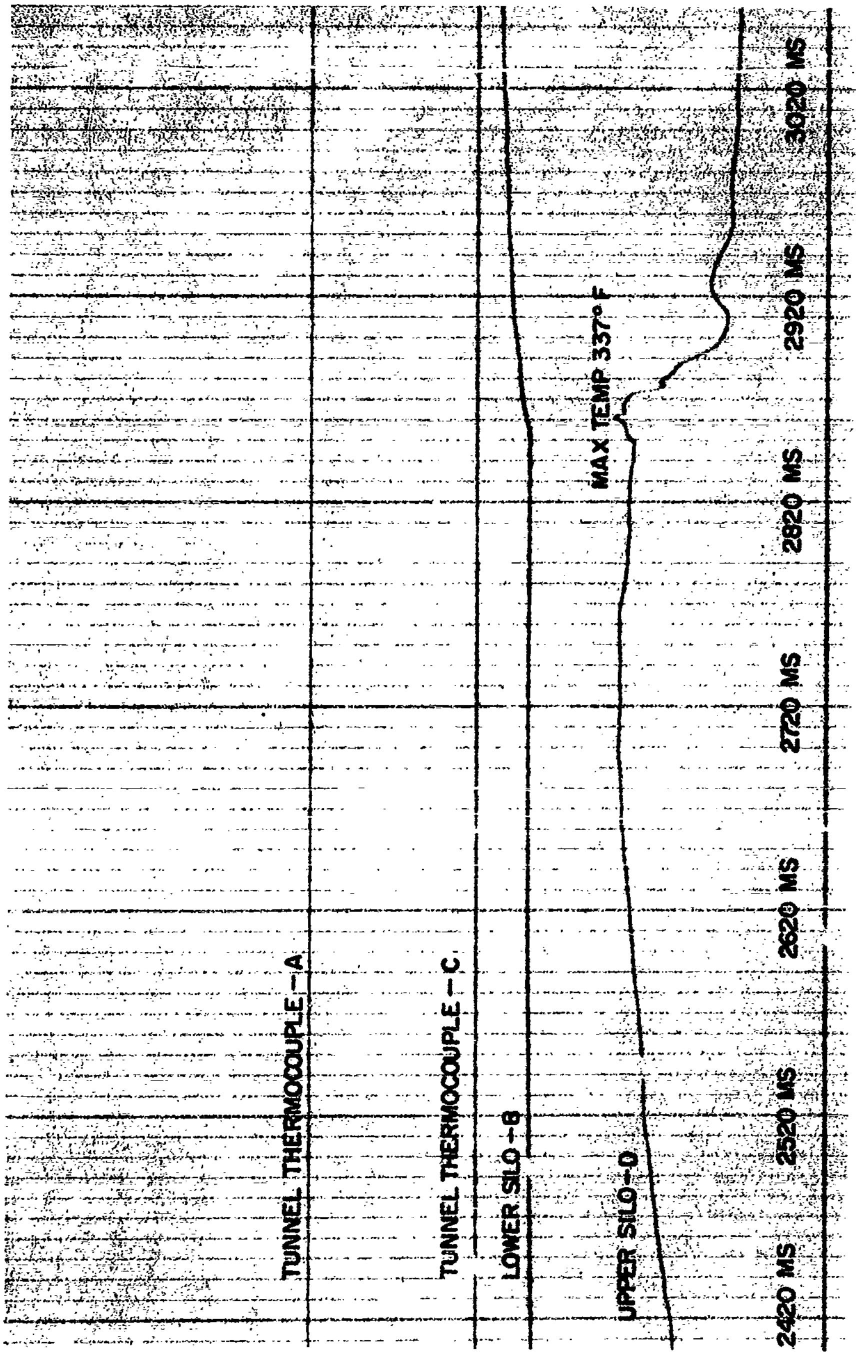
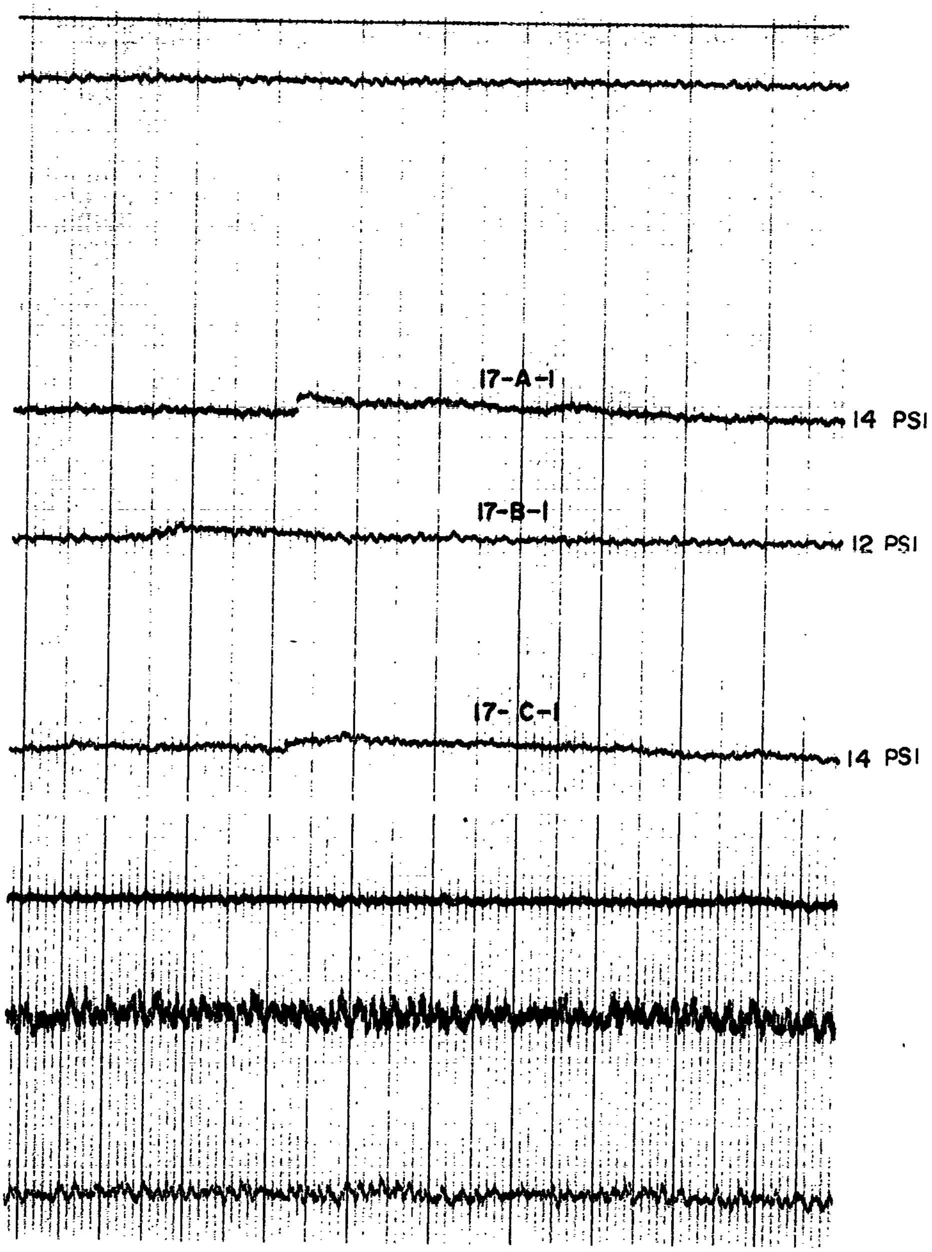


Spill Test 16 (Continued)

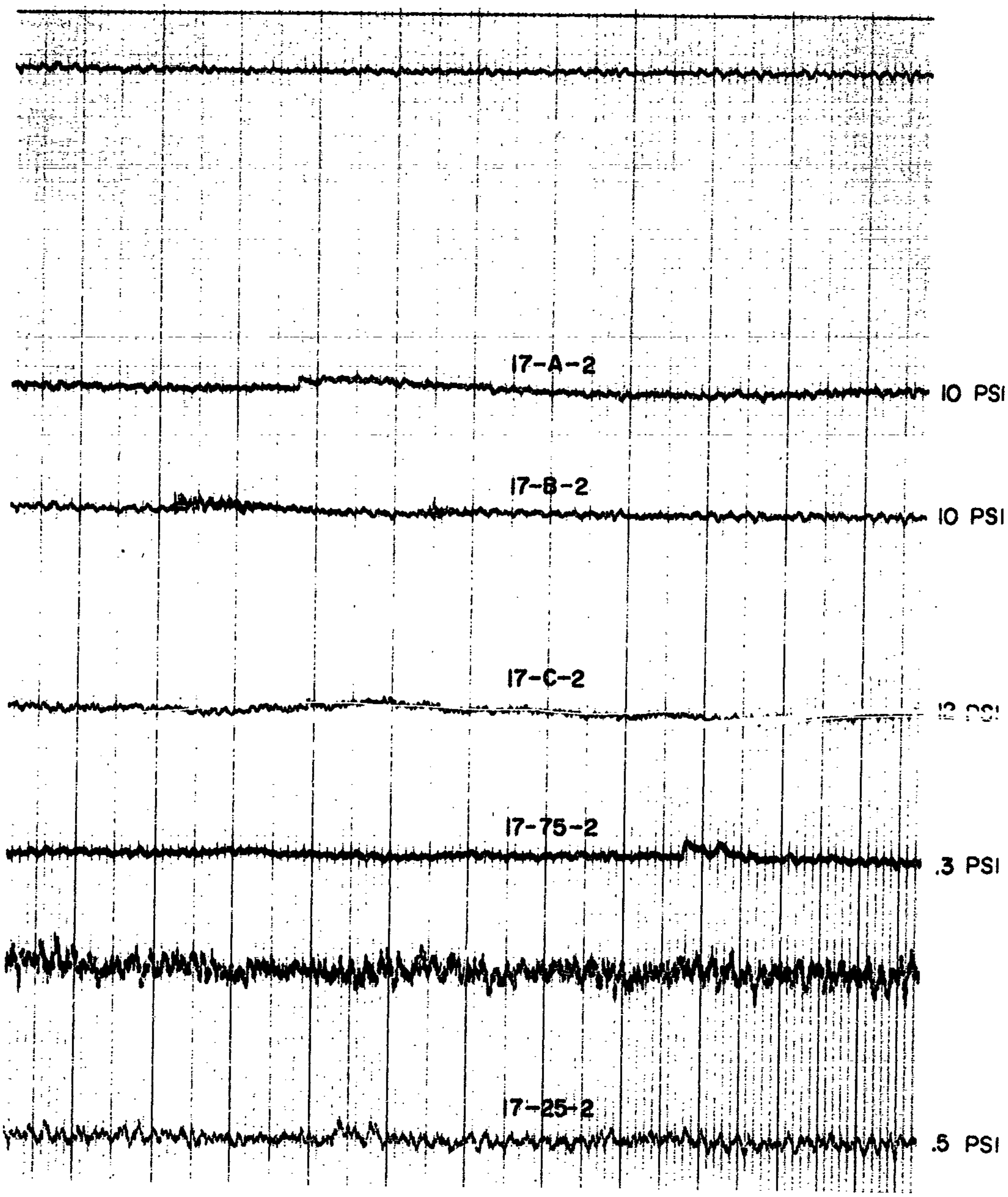
DATA APPENDIX C

1/10-SCALE SILO SPILLS

NOTE: Oscillogram paper speed 50 ips; times lines .001 sec except as noted.



Spill Test 17



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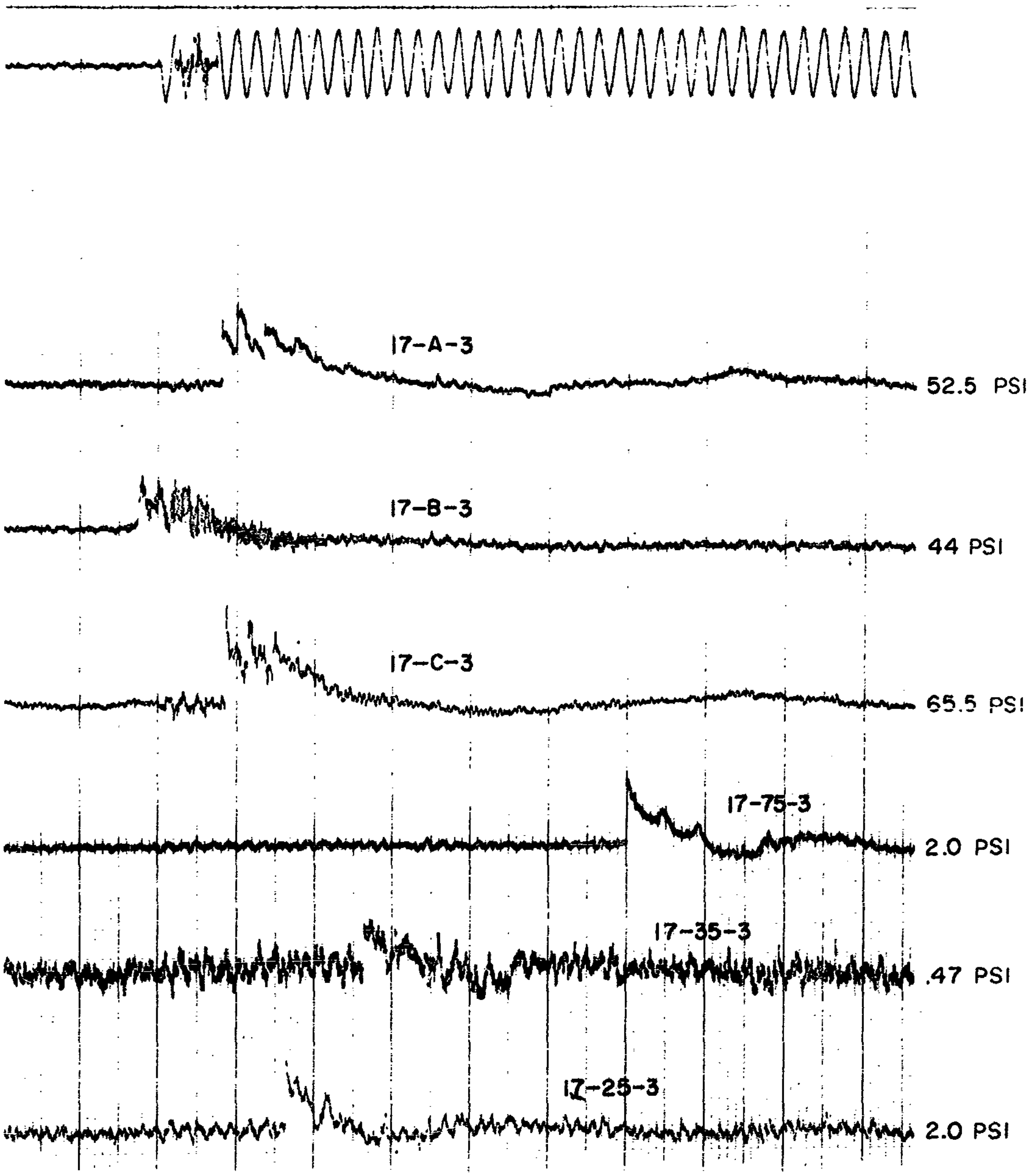

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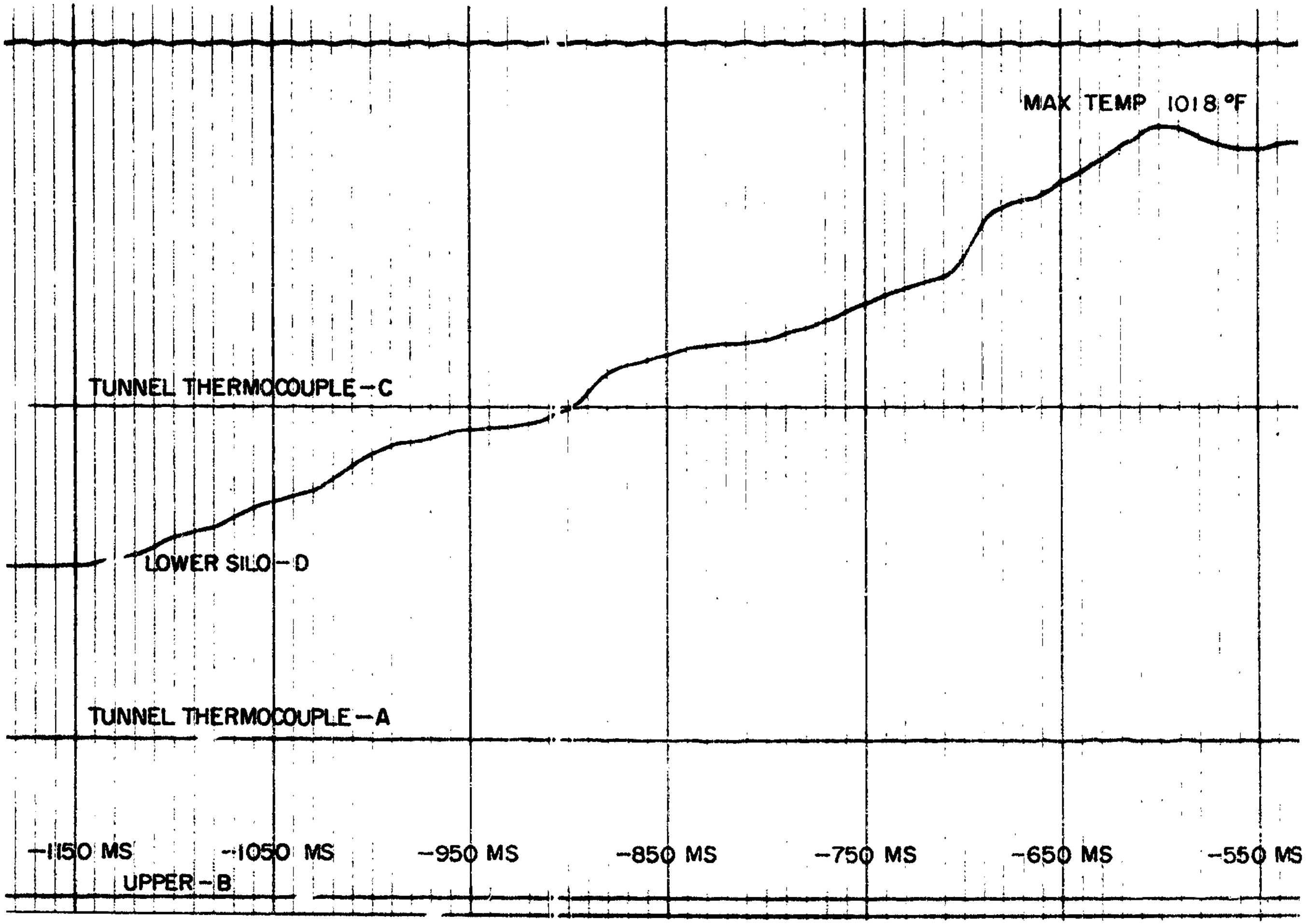

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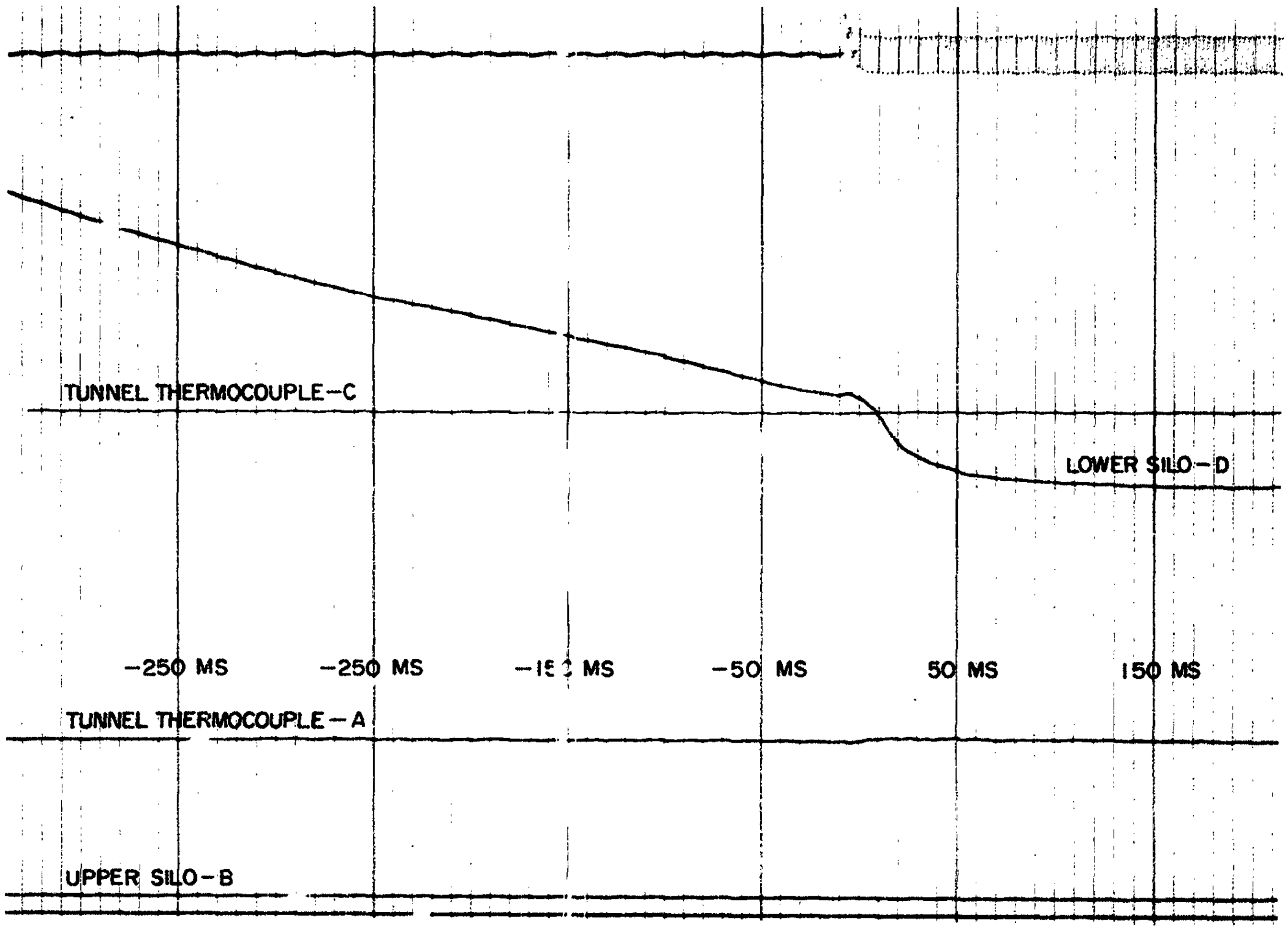
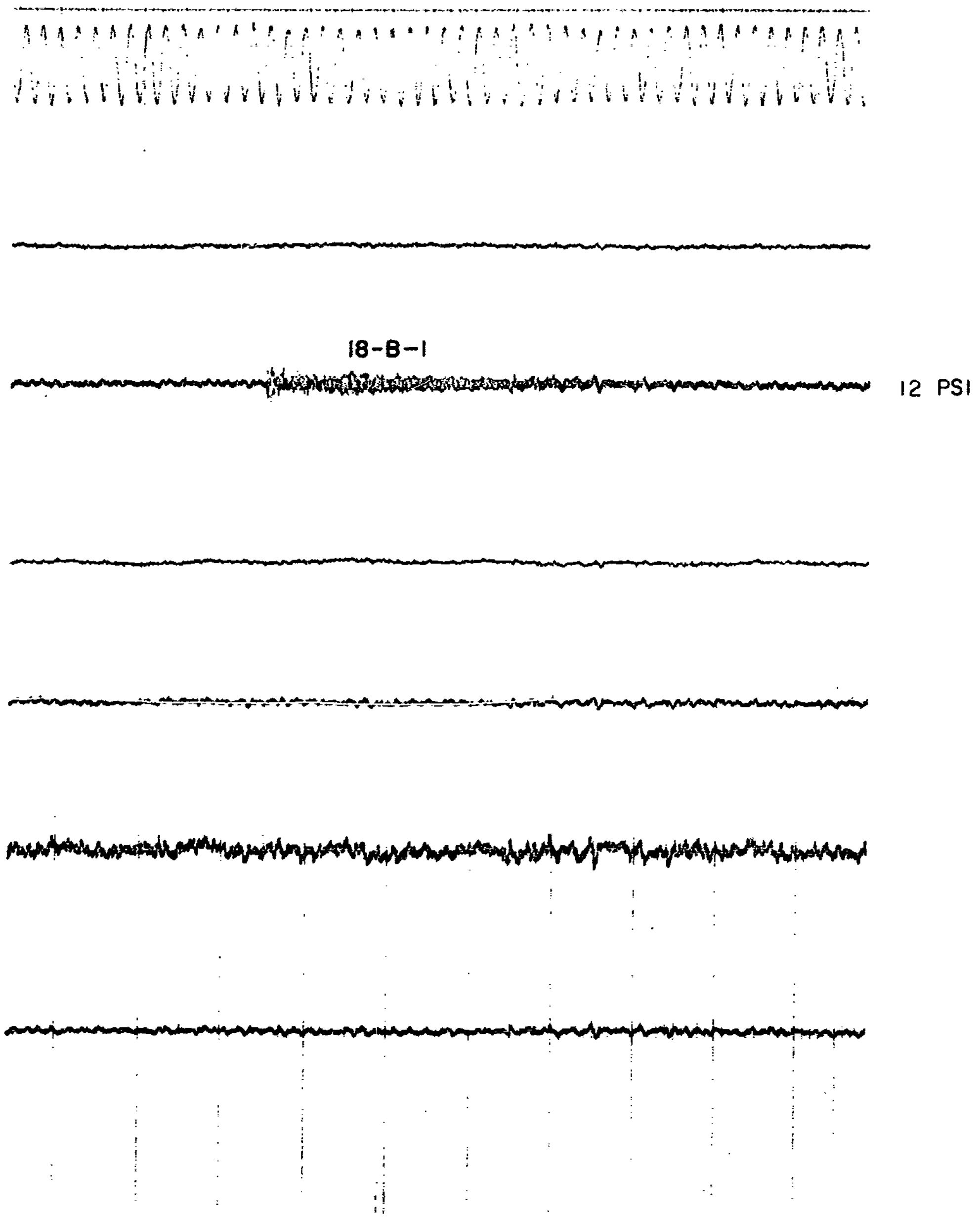
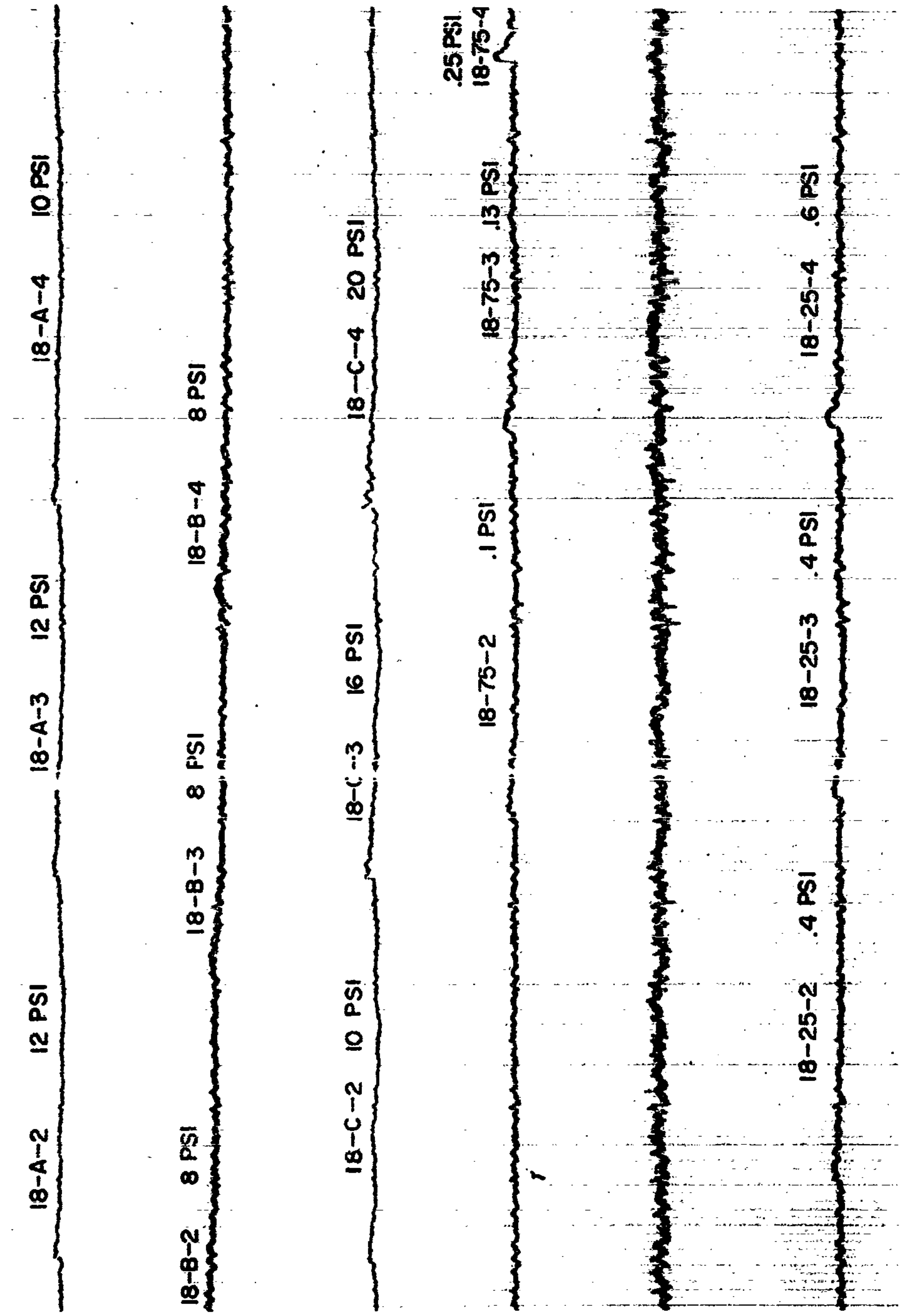


Spil. Test 17 (Continued)



Spill Test 18



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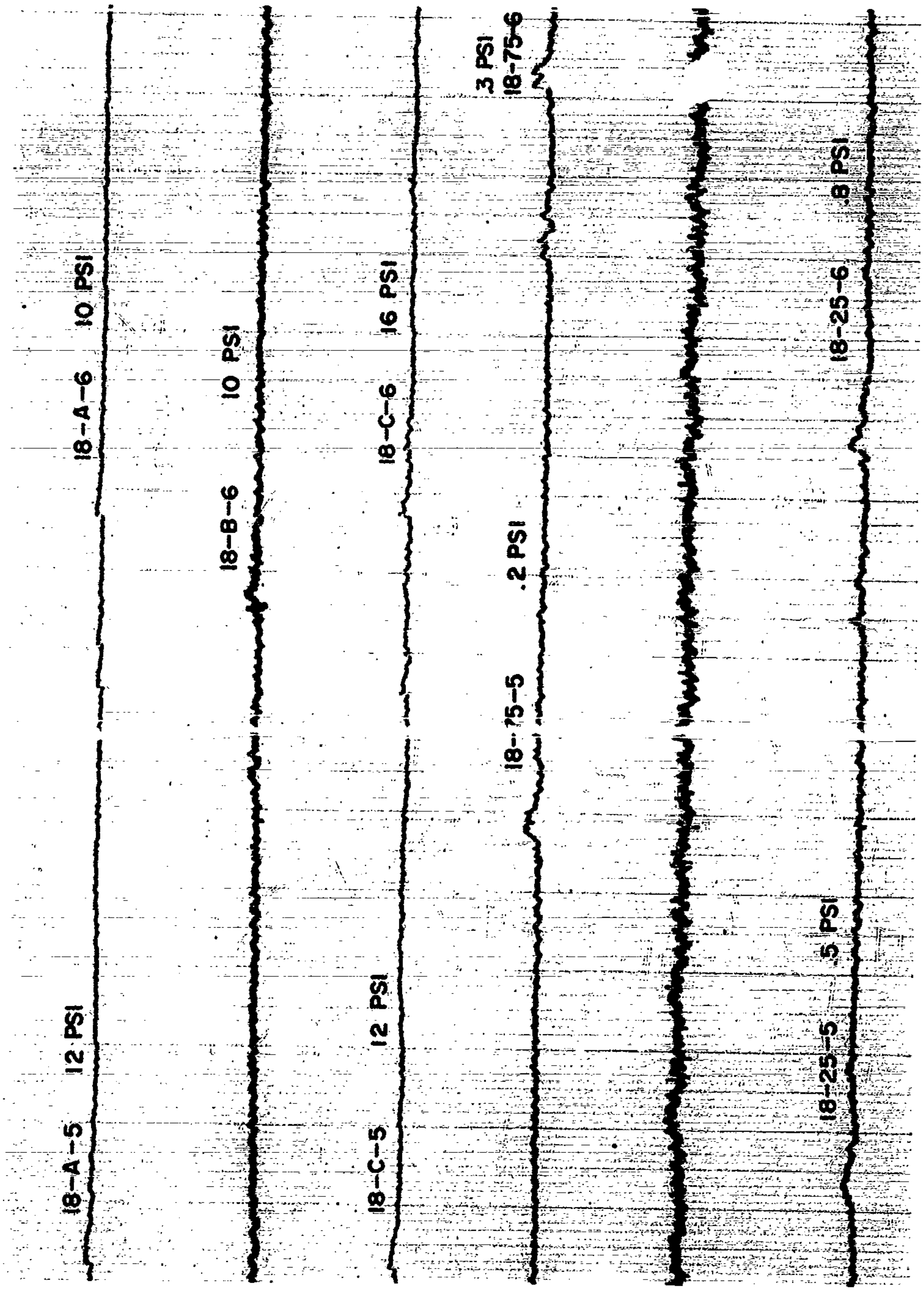

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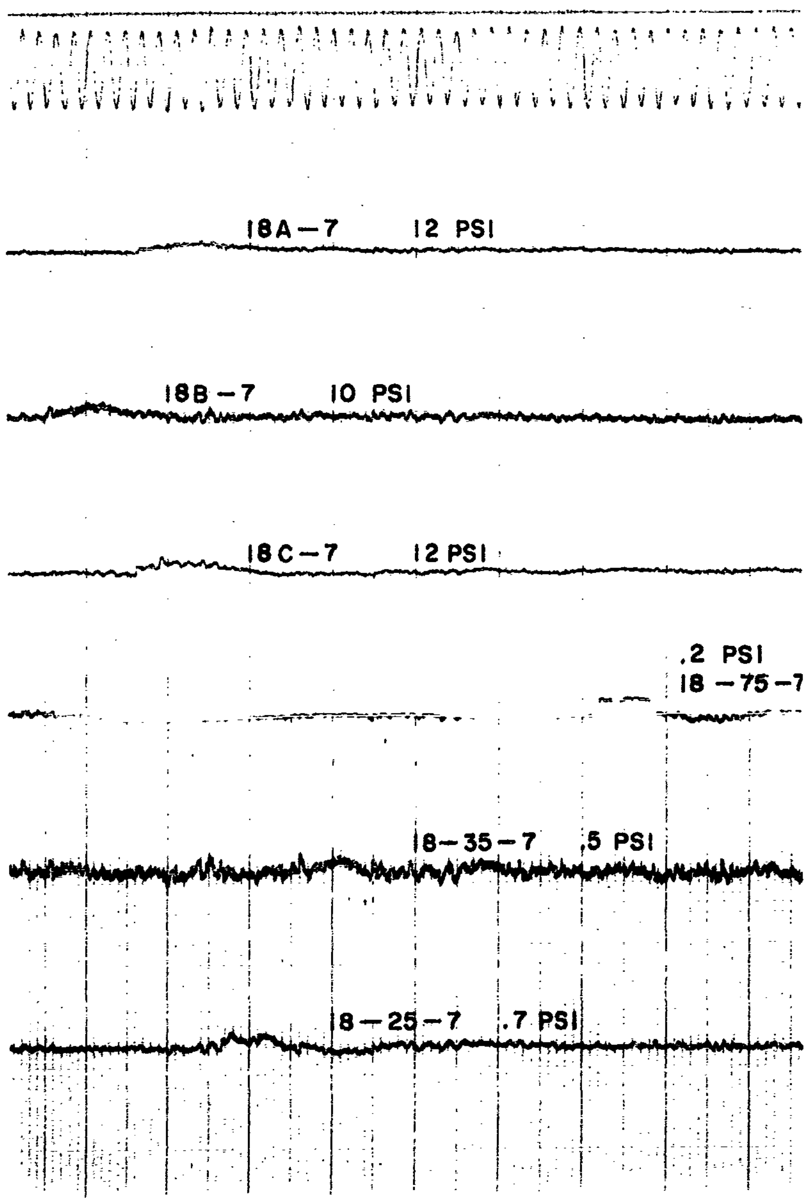

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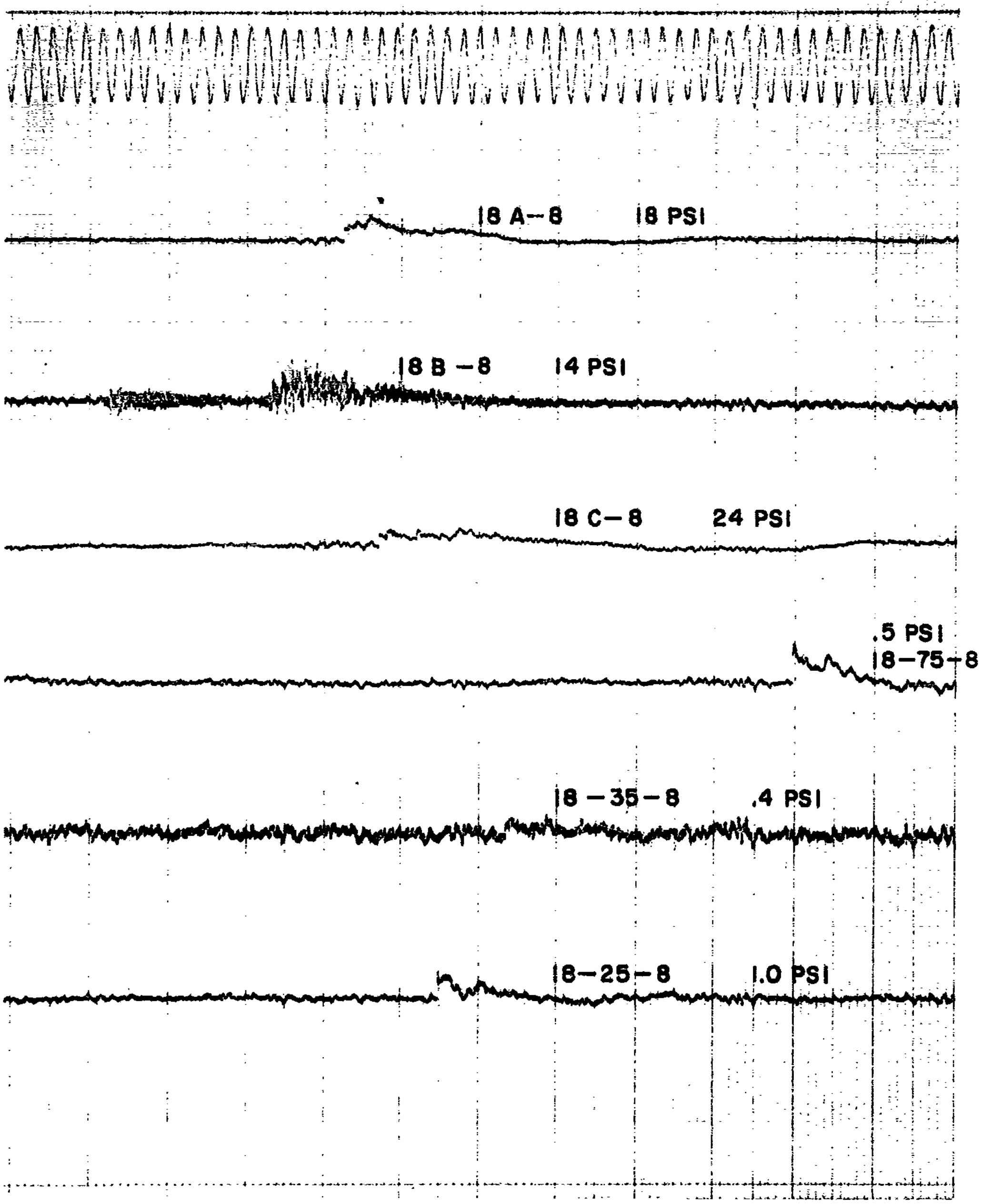

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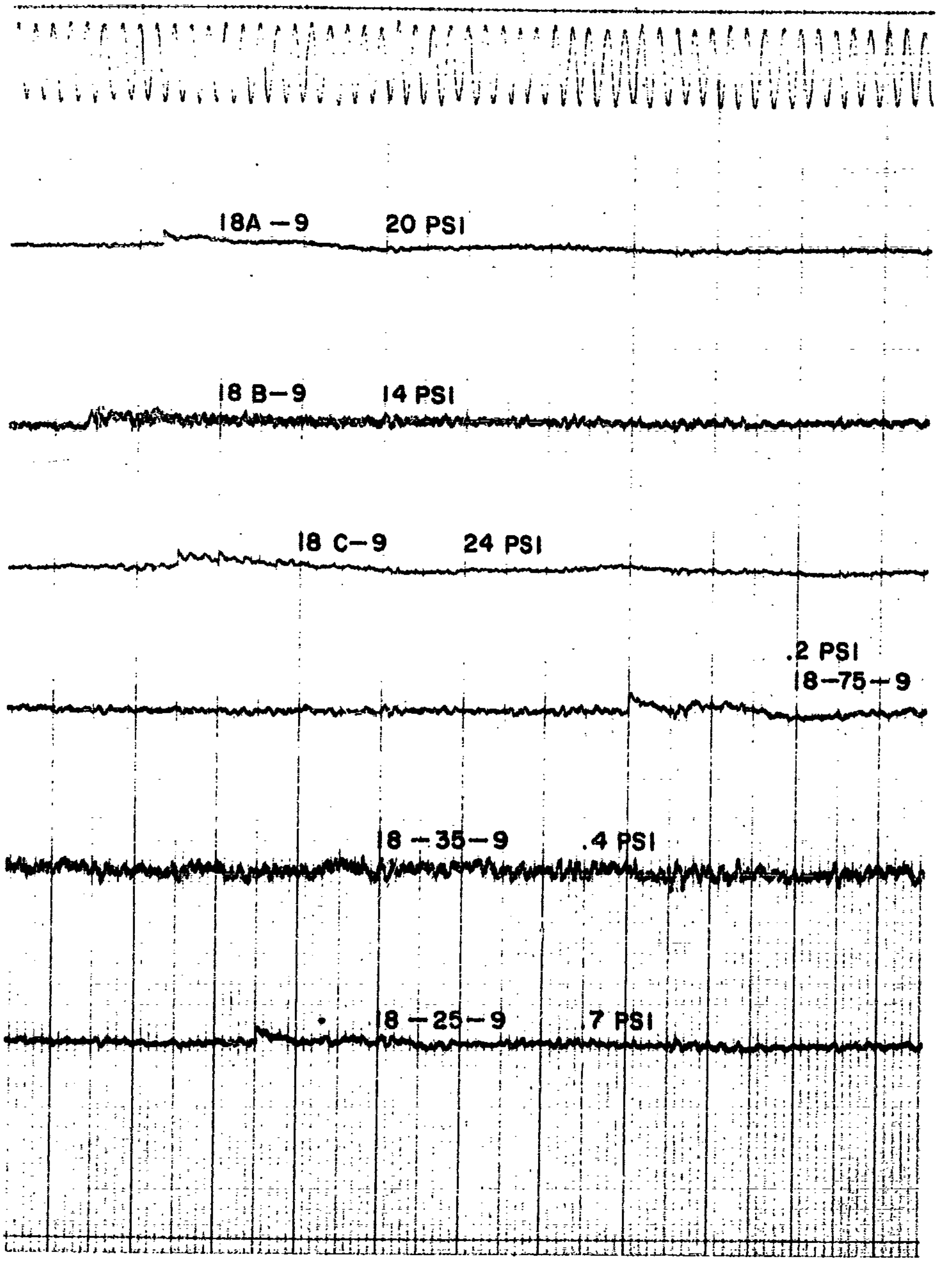
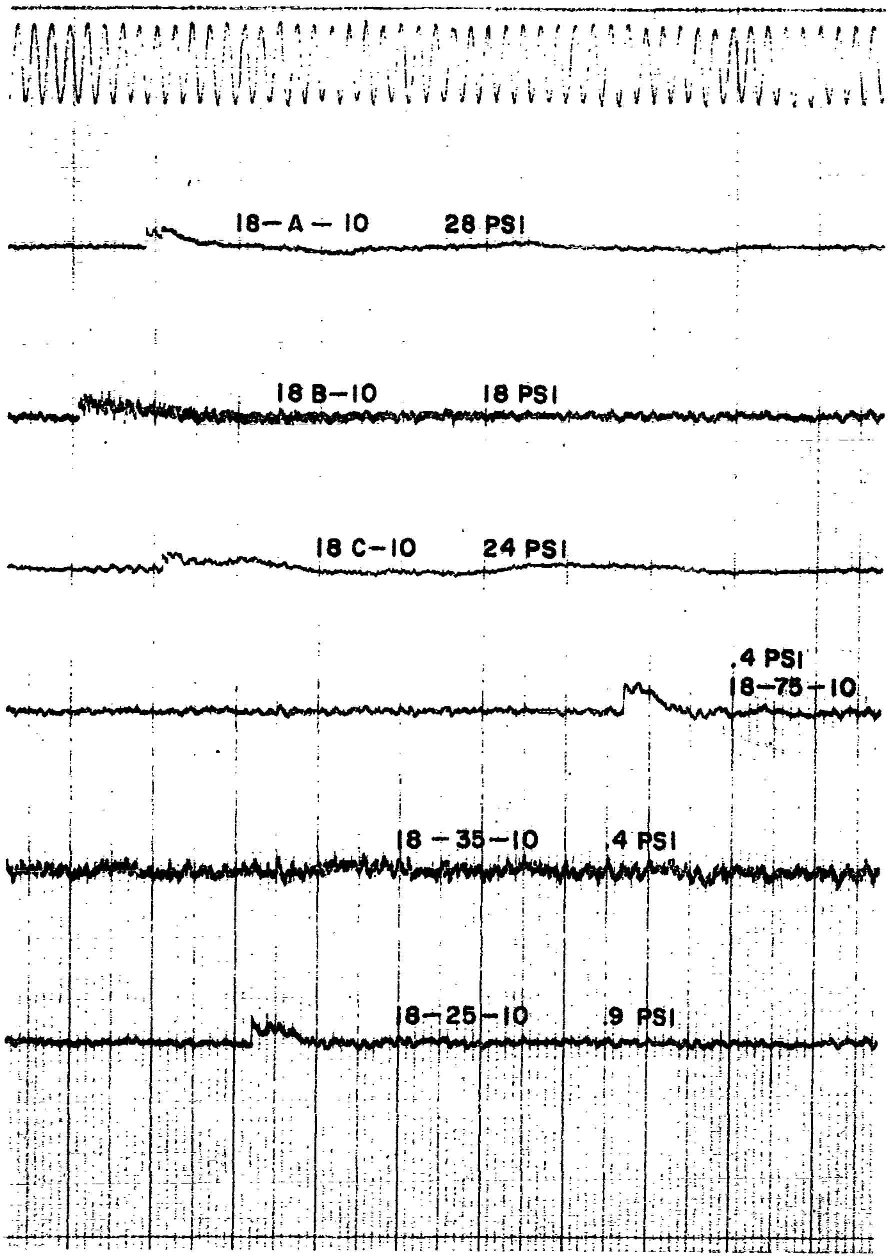


Spill Test 18 (Continued)



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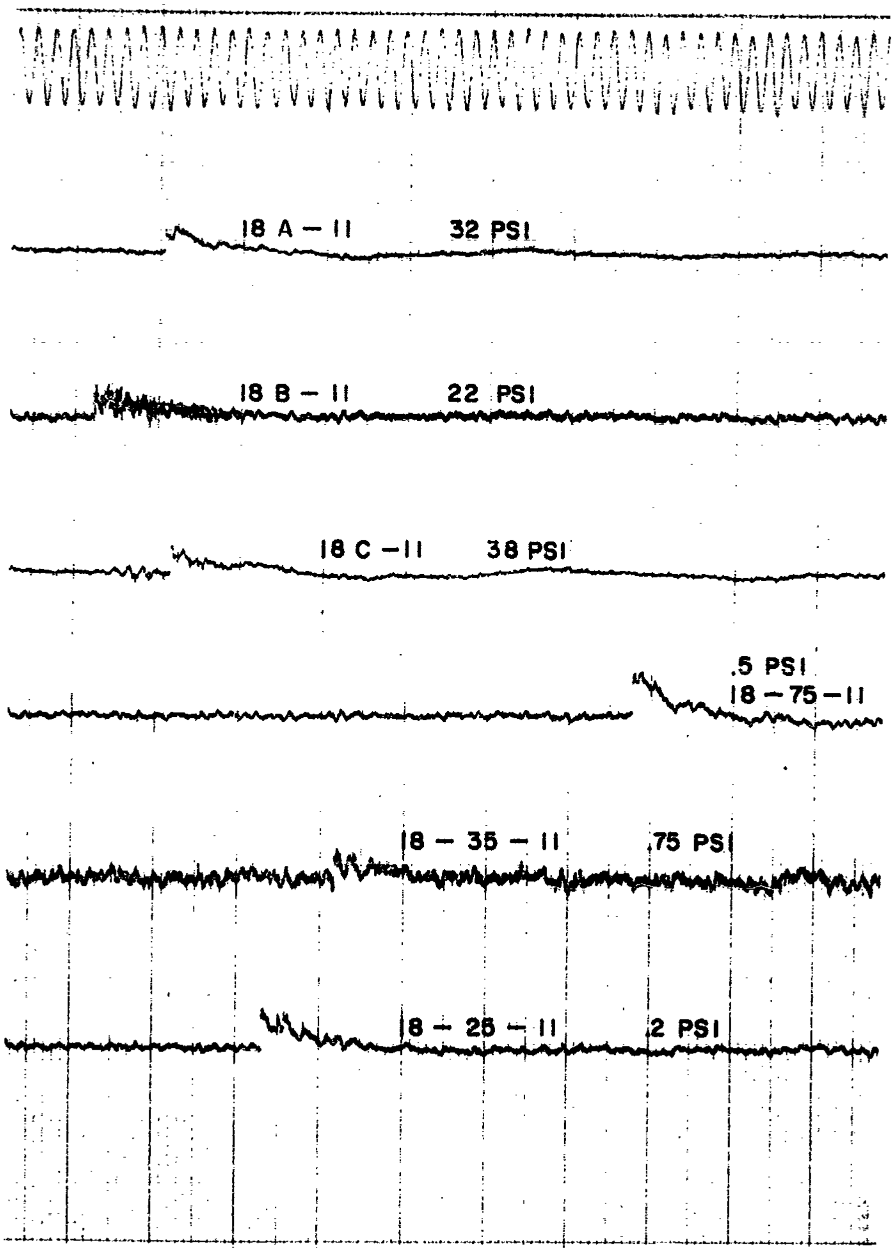
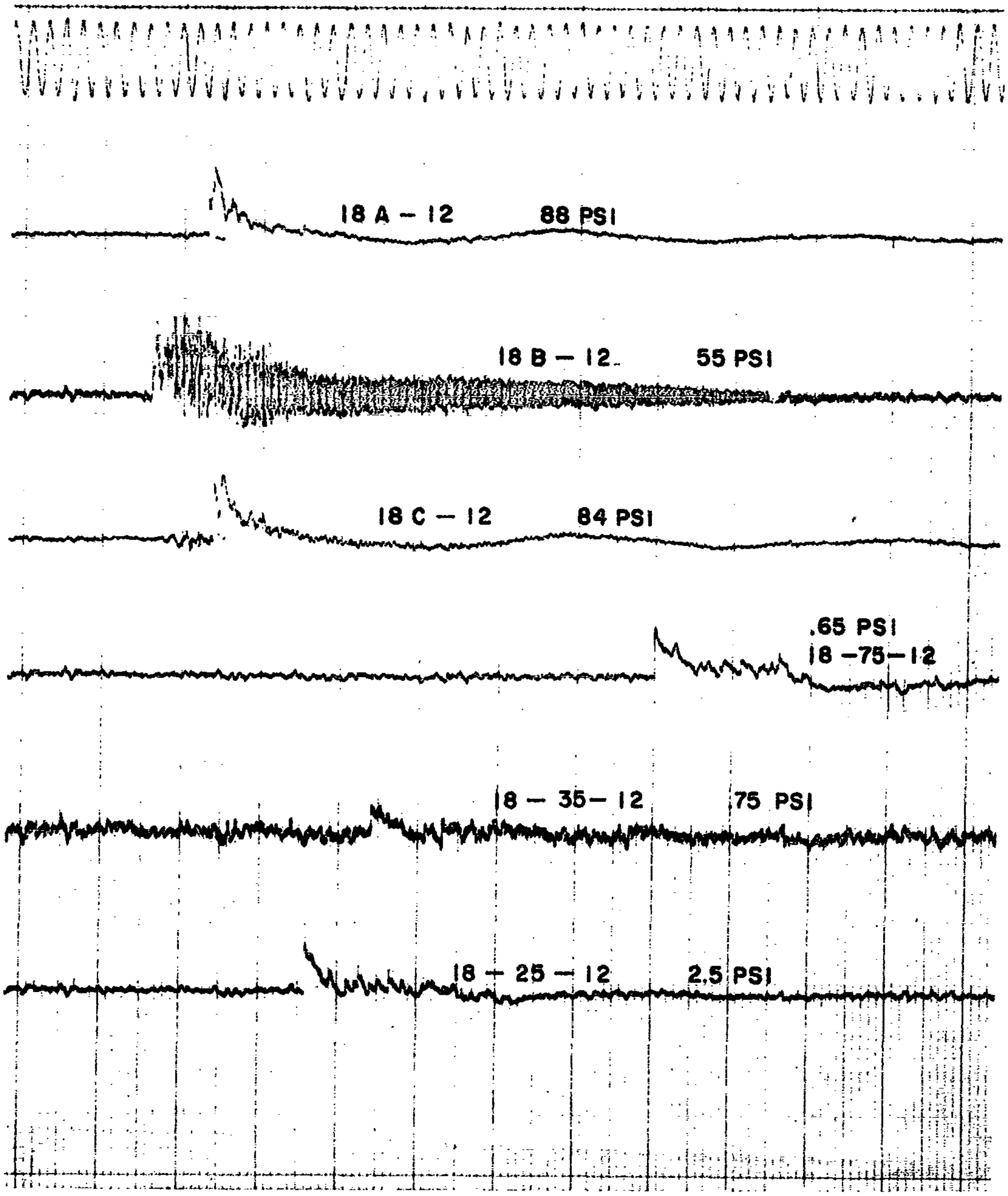
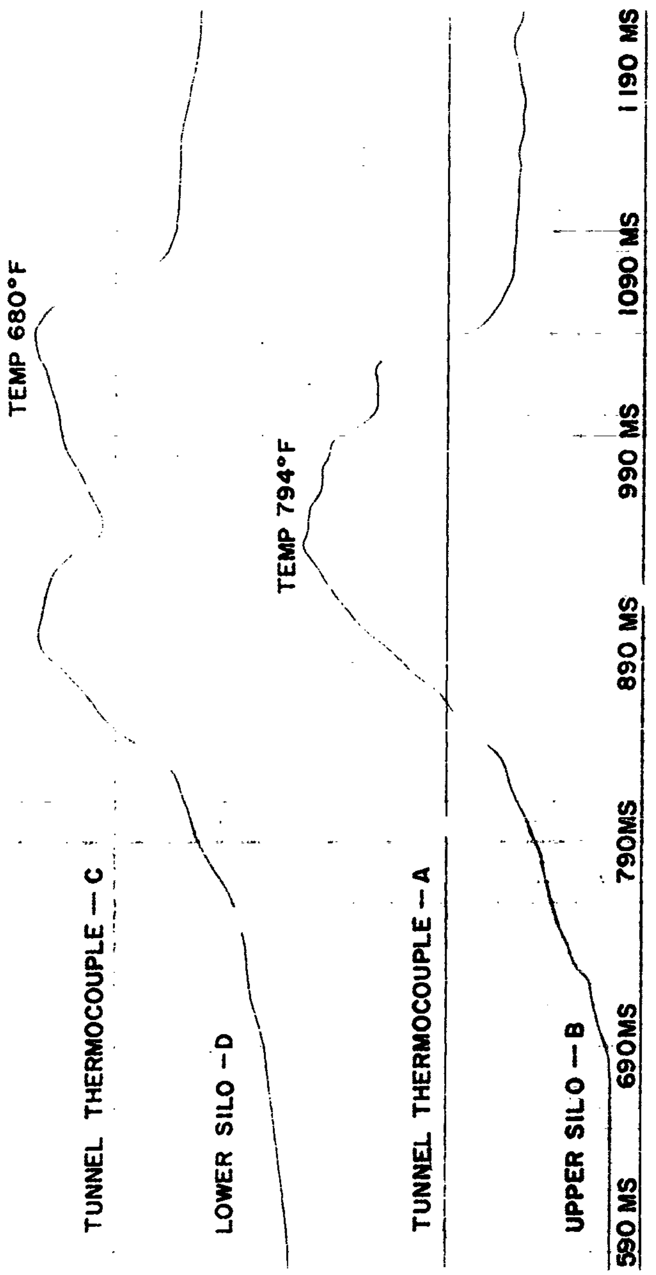


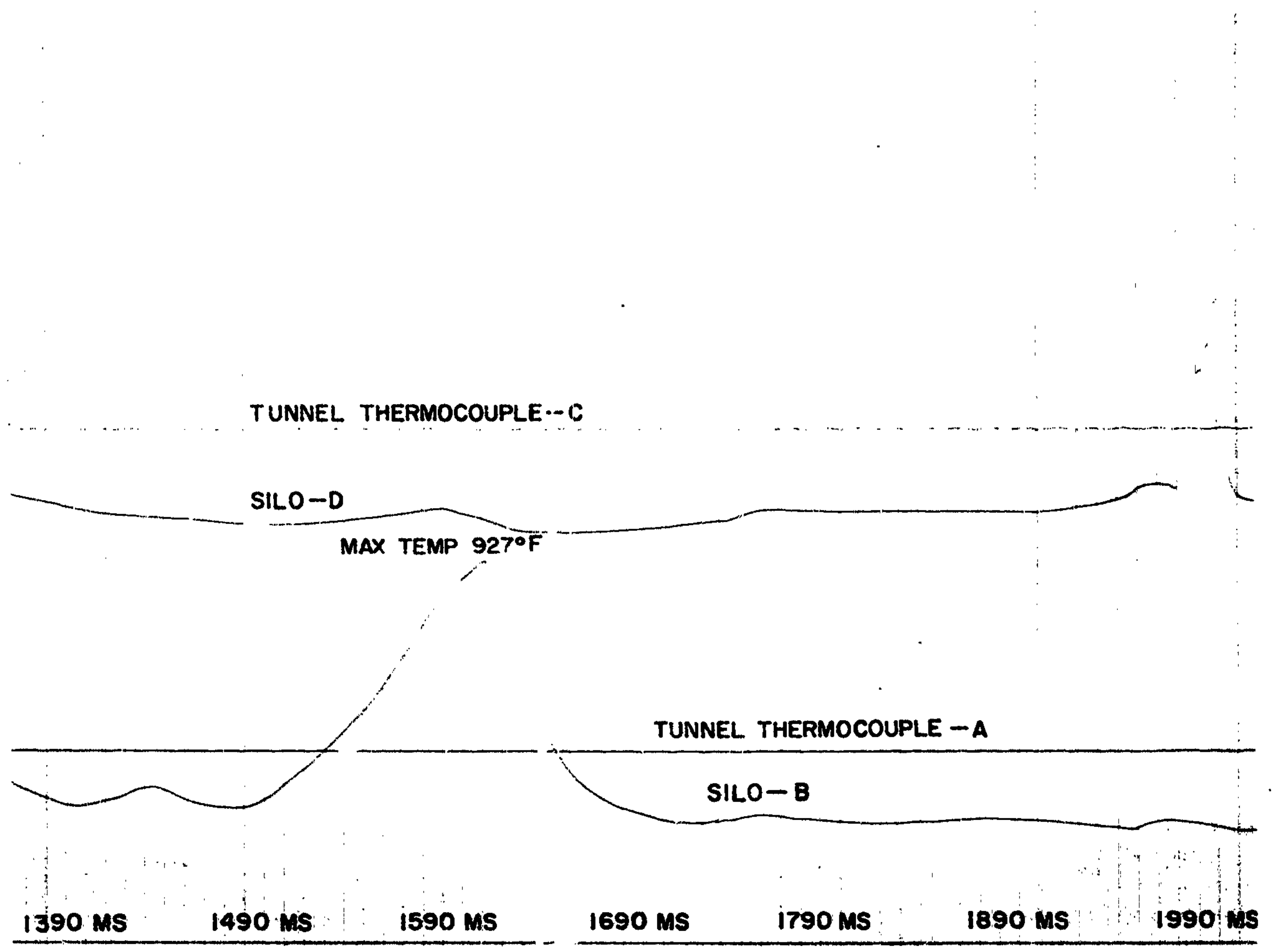
Spill Test 18 (Continued)



Spill Test 18 (Continued)



TUNNEL THERMOCOUPLE — C
LOWER SILO — D
TUNNEL THERMOCOUPLE — A
UPPER SILO — B
TEMP 680°F
TEMP 794°F
590 MS
690MS
790MS
890 MS
990 MS
1090 MS
1190 MS



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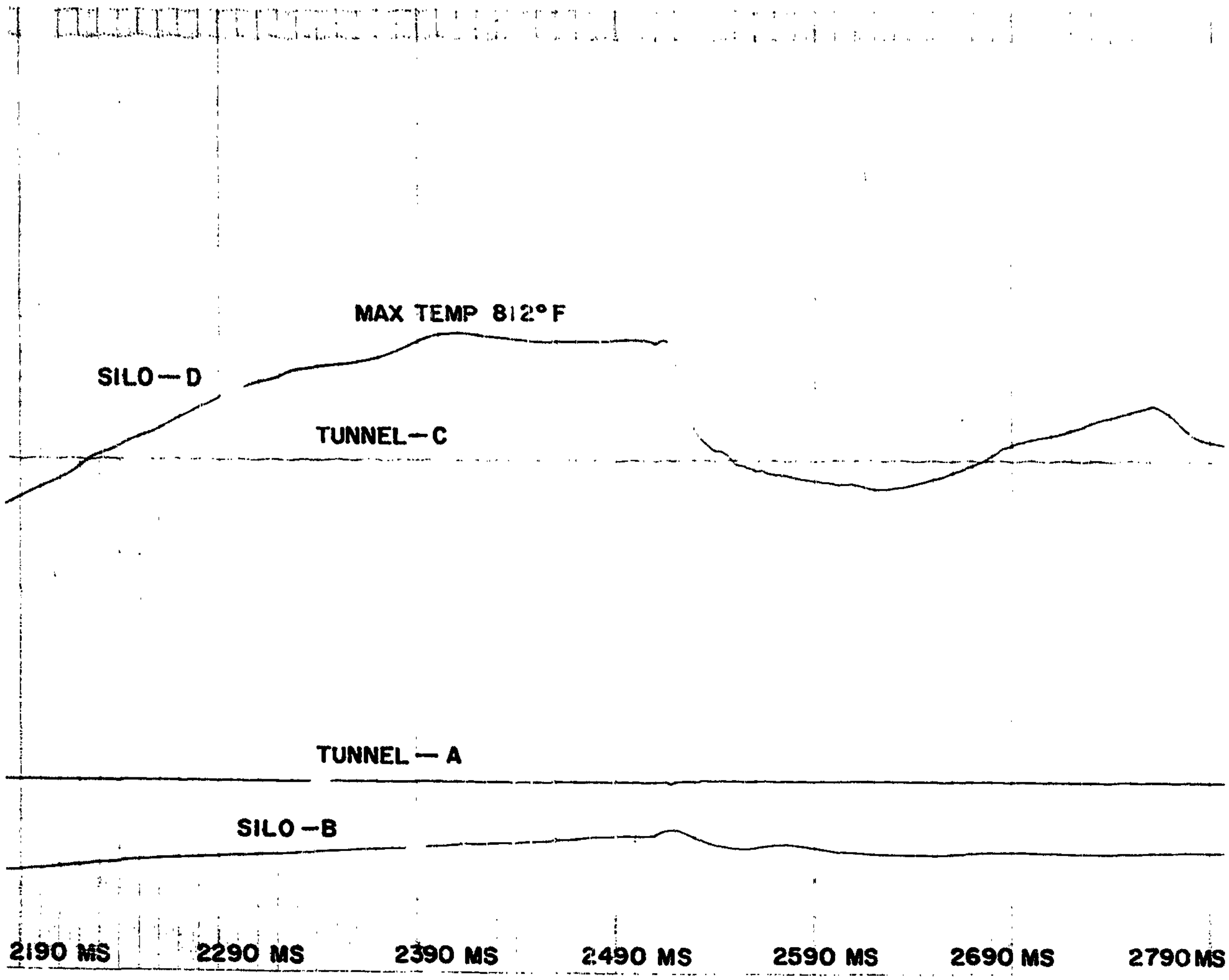
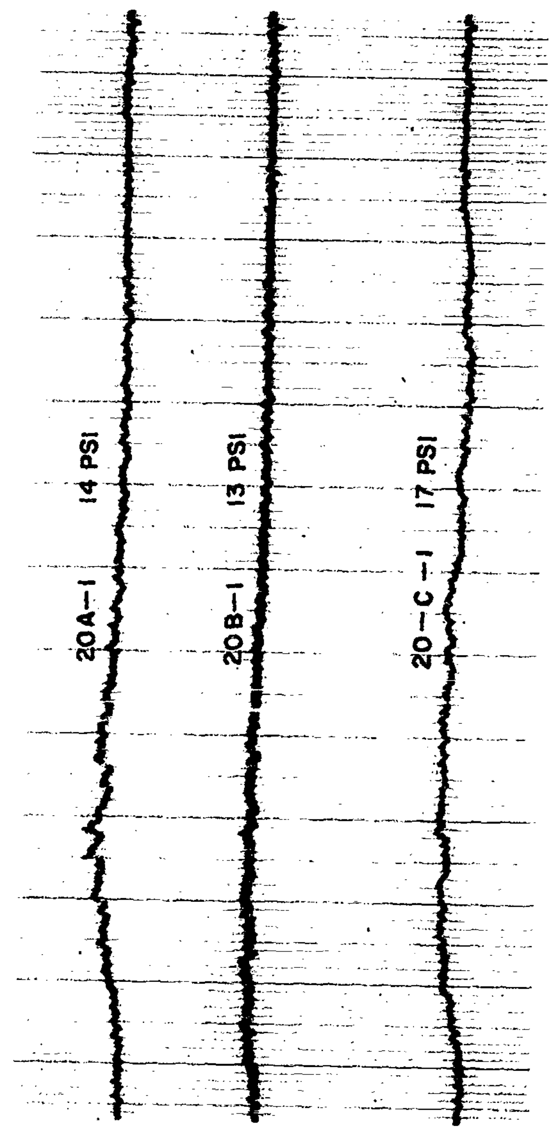
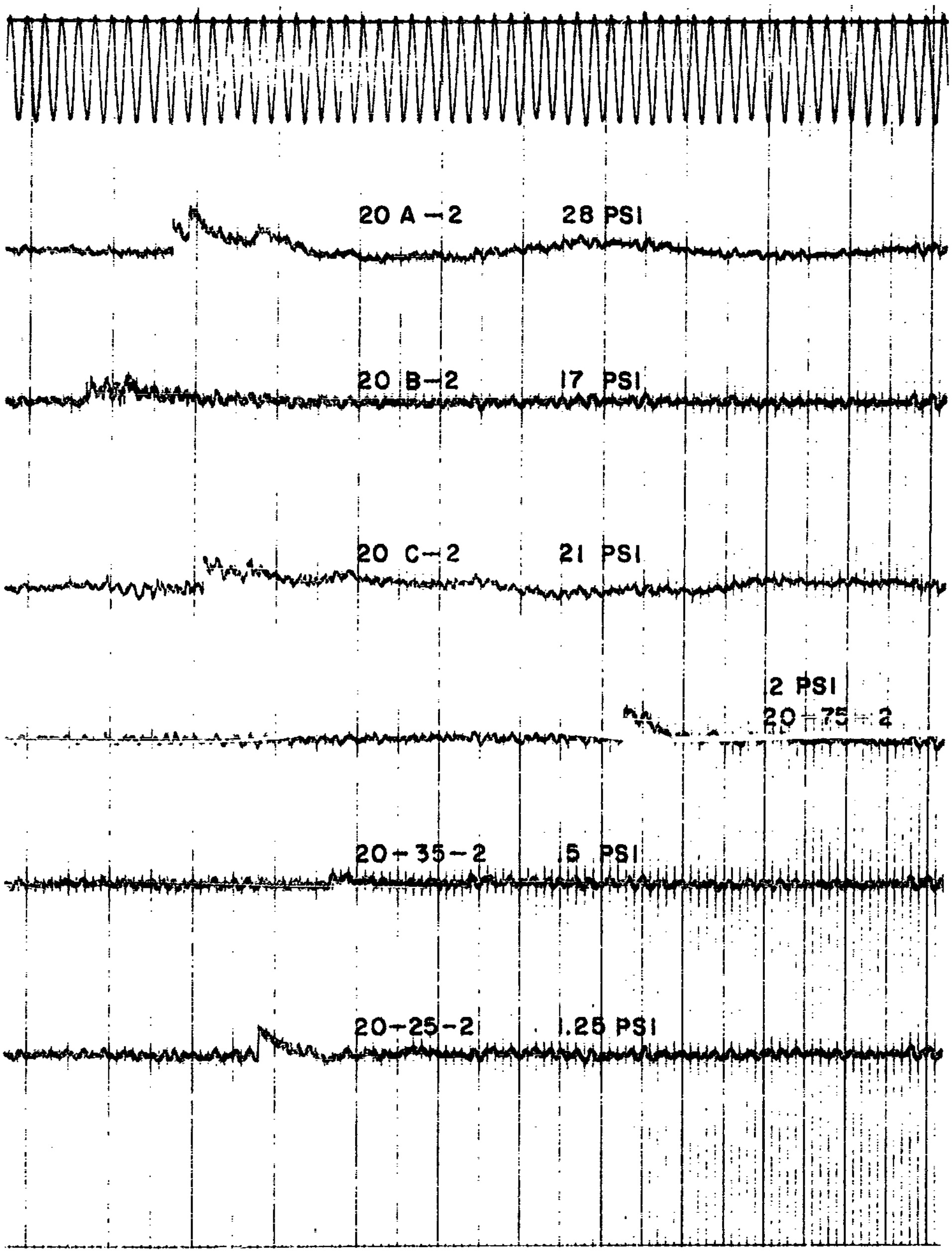


Spill Test 18 (Continued)



Spill Test 20



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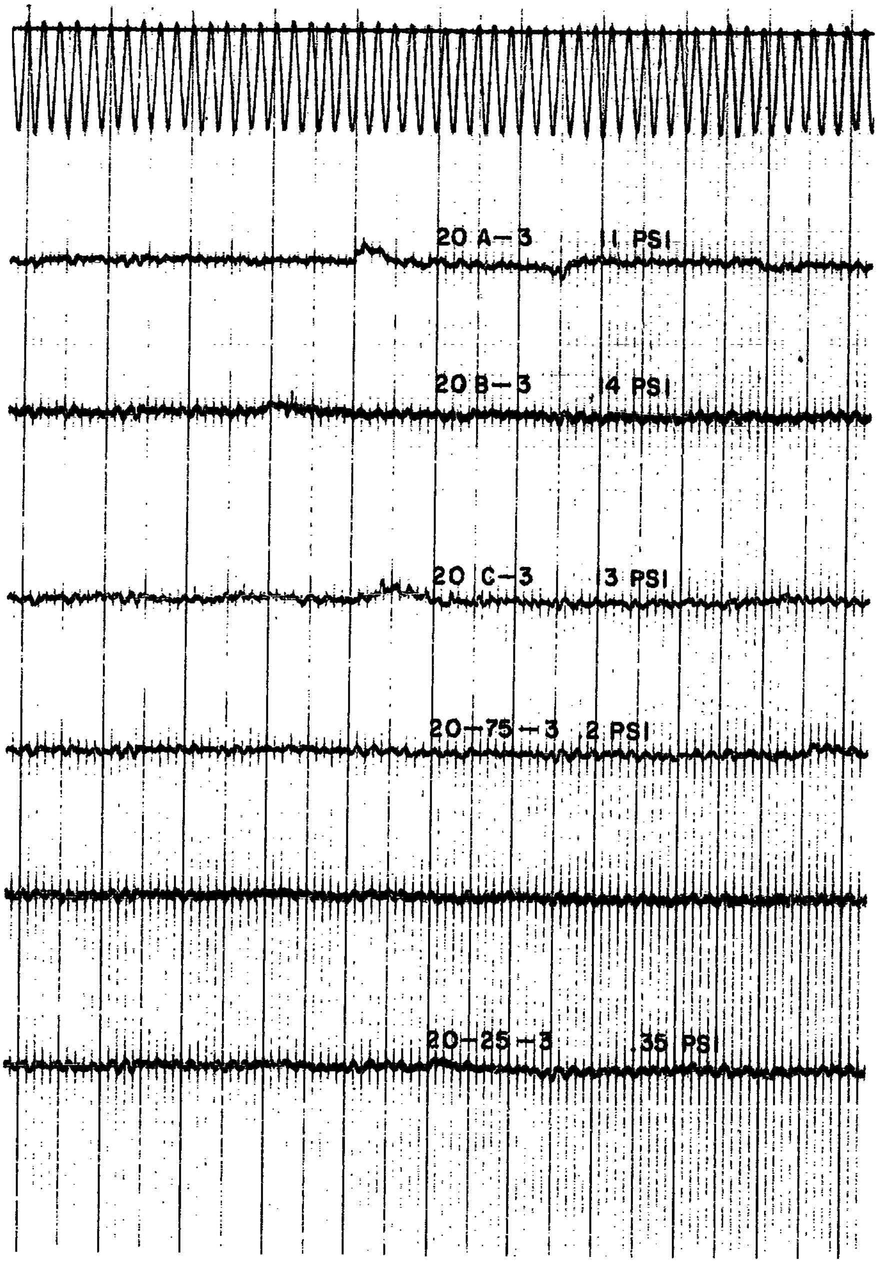

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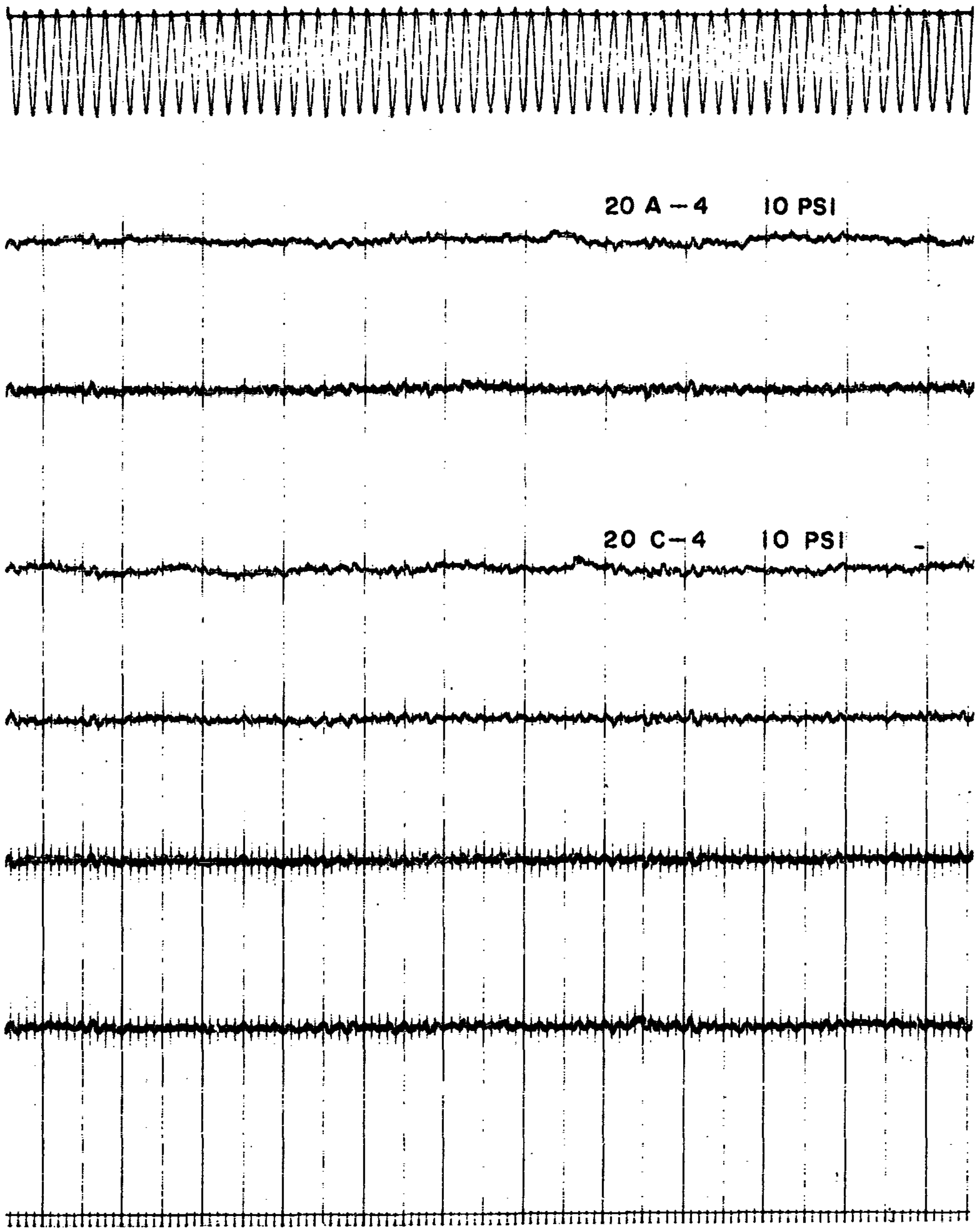

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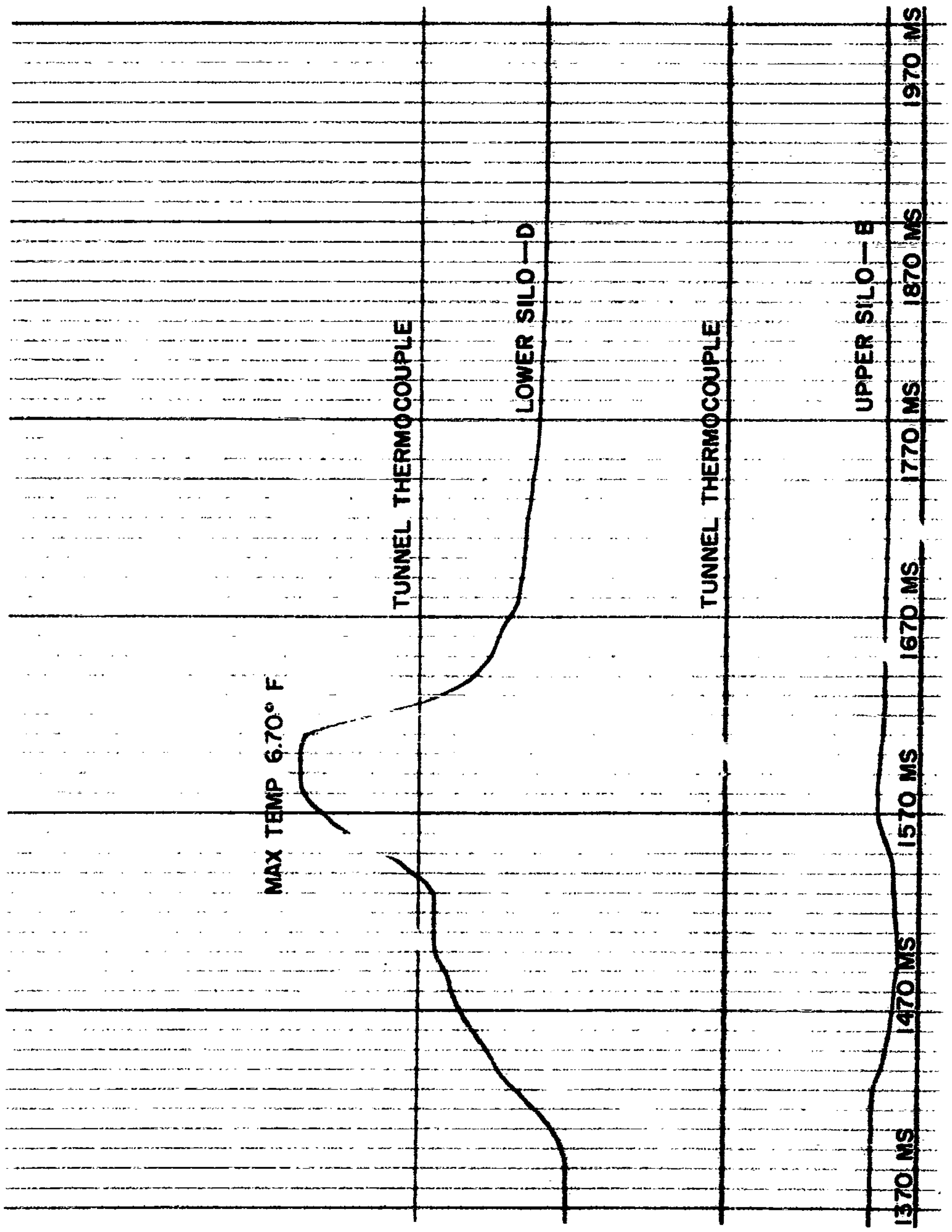

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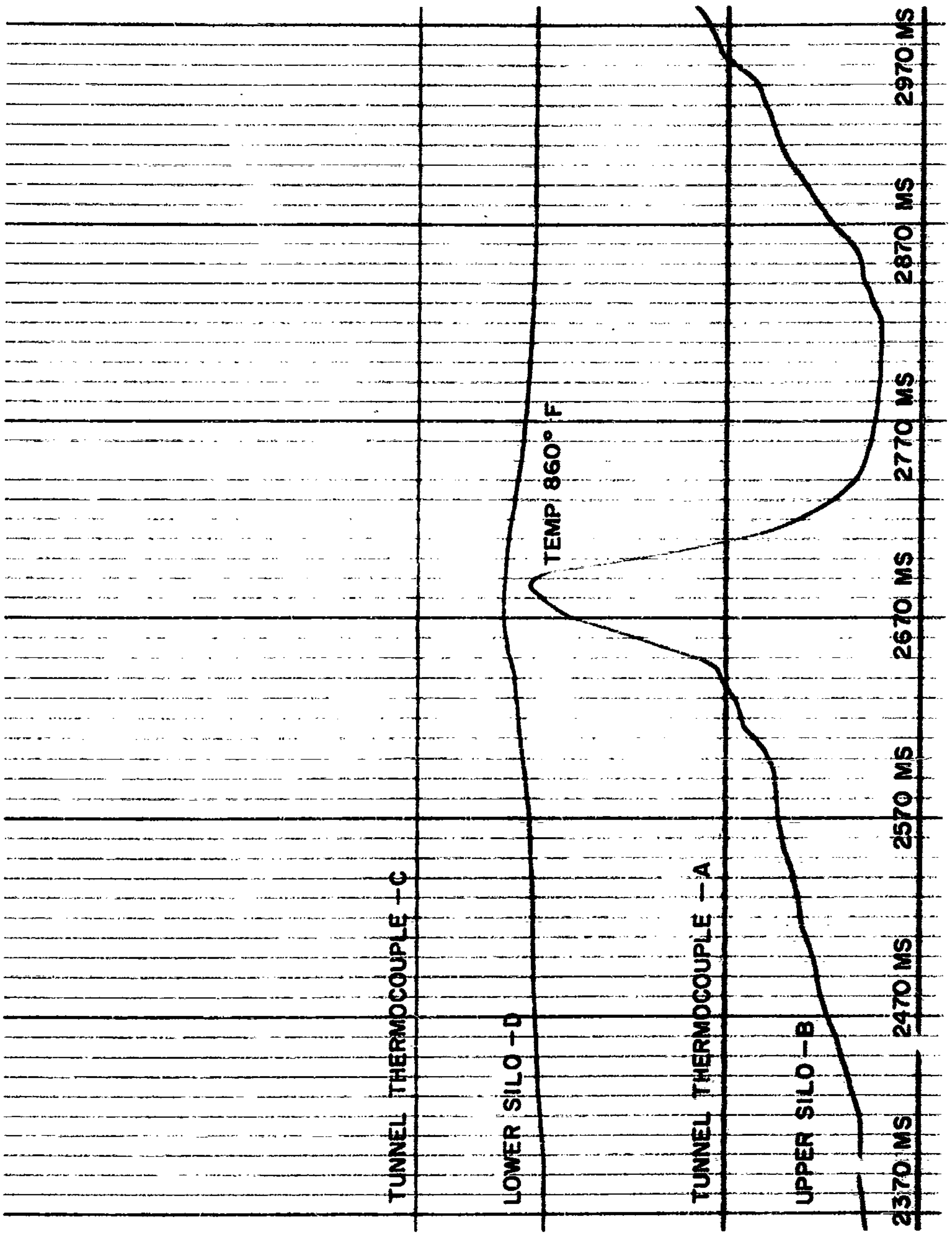
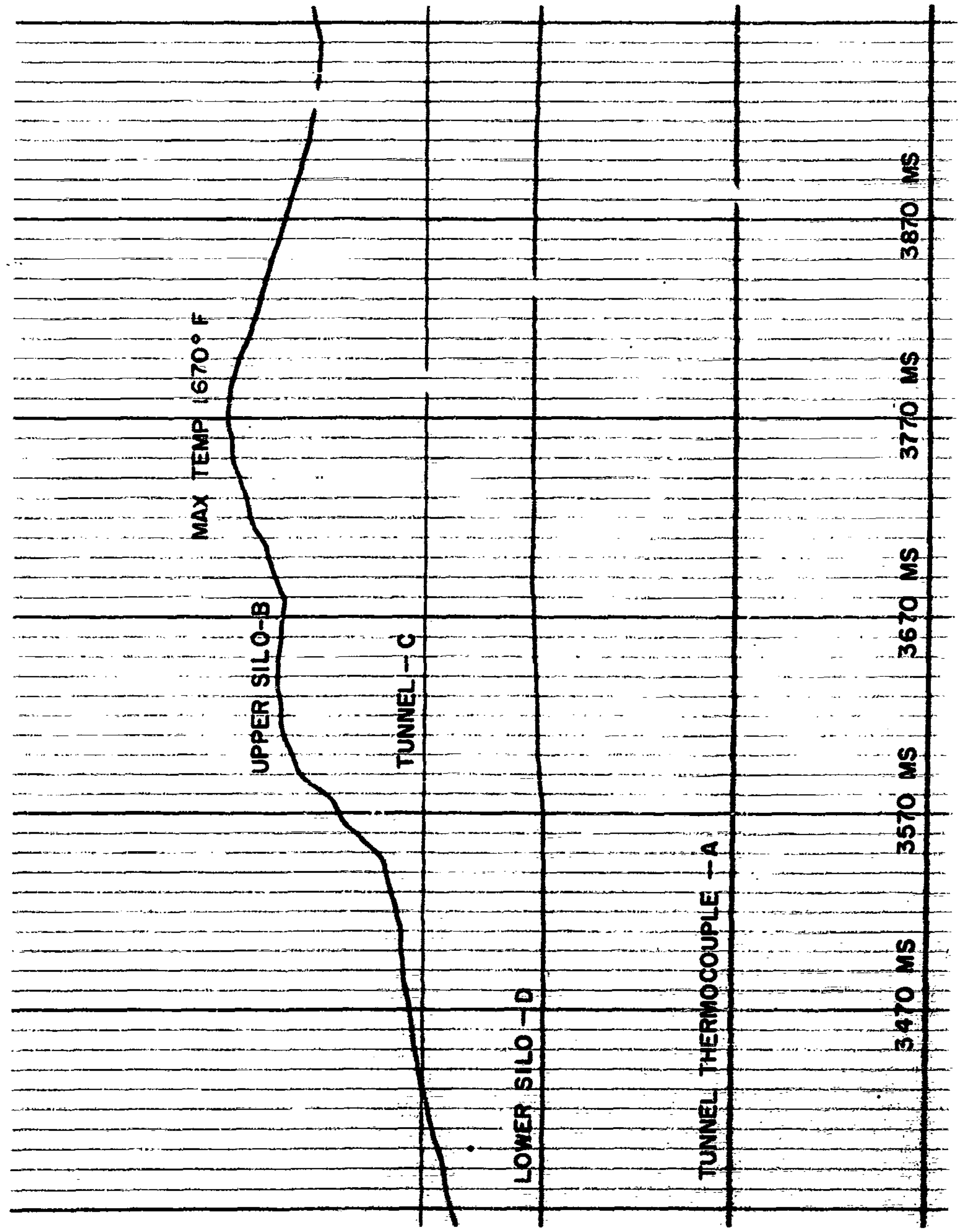


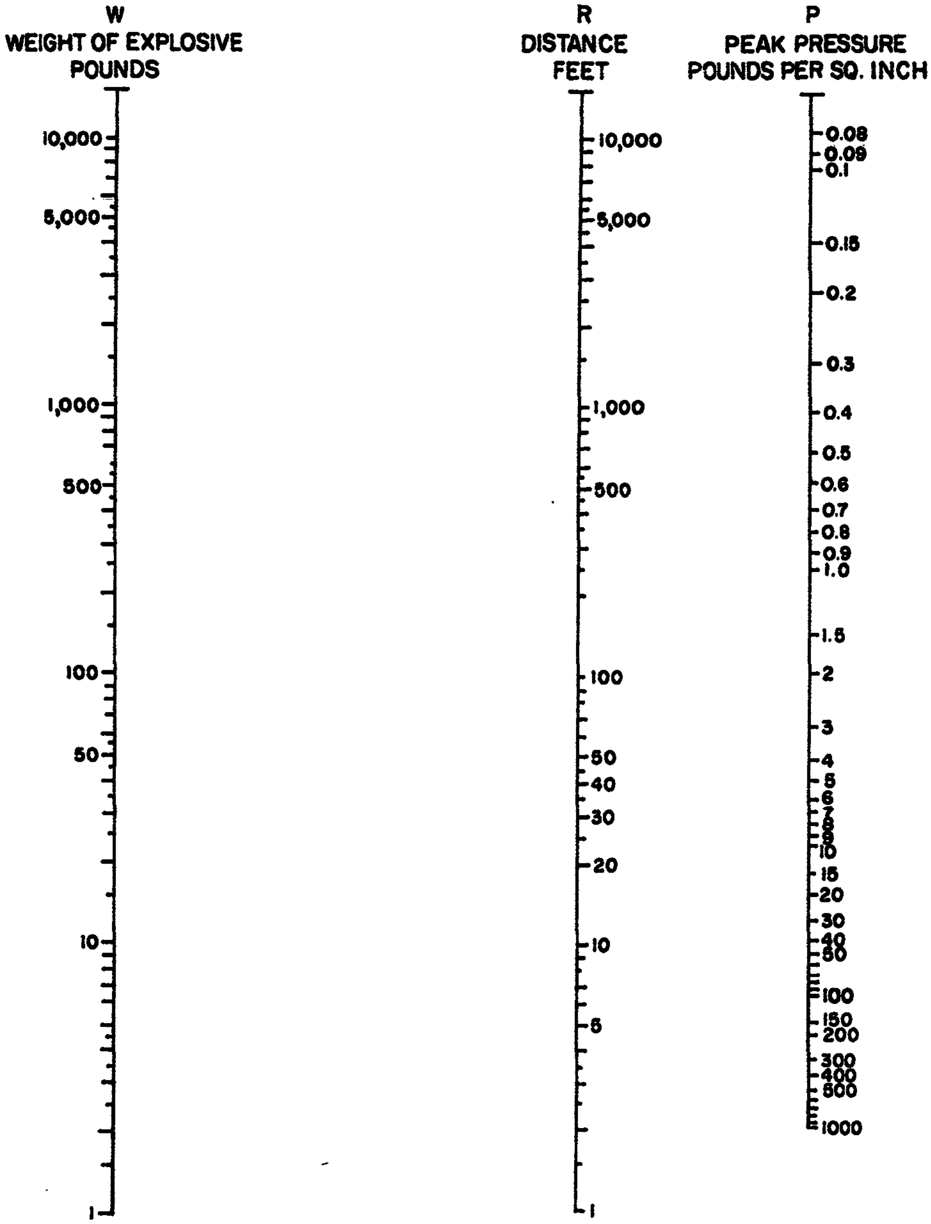
TUNNEL THERMOCOUPLE —C
LOWER SILO—D
TEMP 860° F
TUNNEL THERMOCOUPLE —A
UPPER SILO—B
2370 MS
2470 MS
2570 MS
2670 MS
2770 MS
2870 MS
2970 MS


MAX TEMP 1670° F
UPPER SILO—B
TUNNEL—C
LOWER SILO—D
TUNNEL THERMOCOUPLE—A
3470 MS
3570 MS
3670 MS
3770 MS
3870 MS

APPENDIX D

TNT CORRELATIONS

NOTE: OSCILLOGRAM PAPER SPEED, 50 IPS; TIME LINES, 0.001 SEC EXCEPT WHERE NOTED

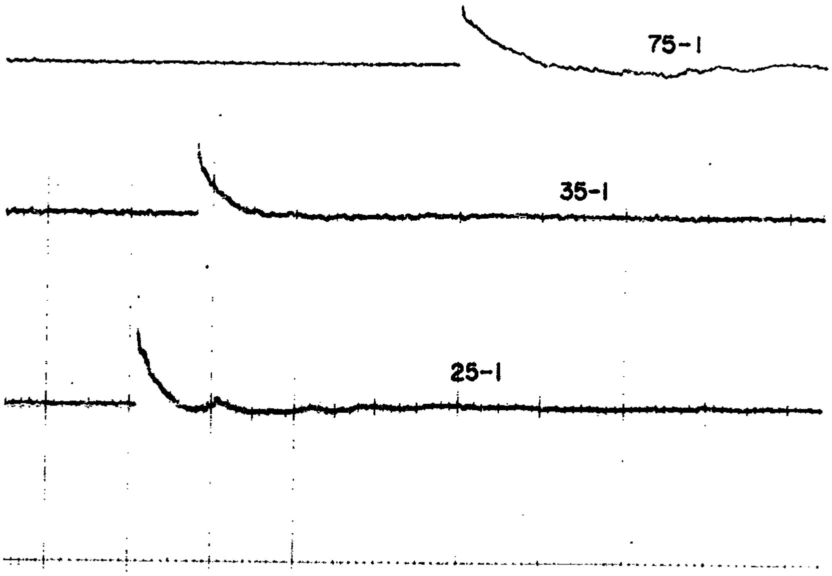


Peak Blast Pressure as a Function of Distance and Weight of Explosive

Note: Values are estimated accurate to about 25 percent. Readings taken with gage "side-on" to the blast wave; for "face-on" gage, pressure value should be approximately doubled.

OVERPRESSURE RESULTS FROM 50 LB OF TNT
DETONATED IN 1/18 SCALE FRANGIBLE SILO

Position	Pressure, psi	Time from First Pulse, ms
25-1	15.83	0
35-1	8.8	7
75-1	3.68	39



OVERPRESSURE RESULTS FROM 10 LB OF TNT DETONATED AT GROUND LEVEL

Position	Pressure, psi	Time from First Pulse, ms
25-1	11.0	0
50-1	4.0	11.7
75-1	1.92	45.8

1-75 1.92 PSI

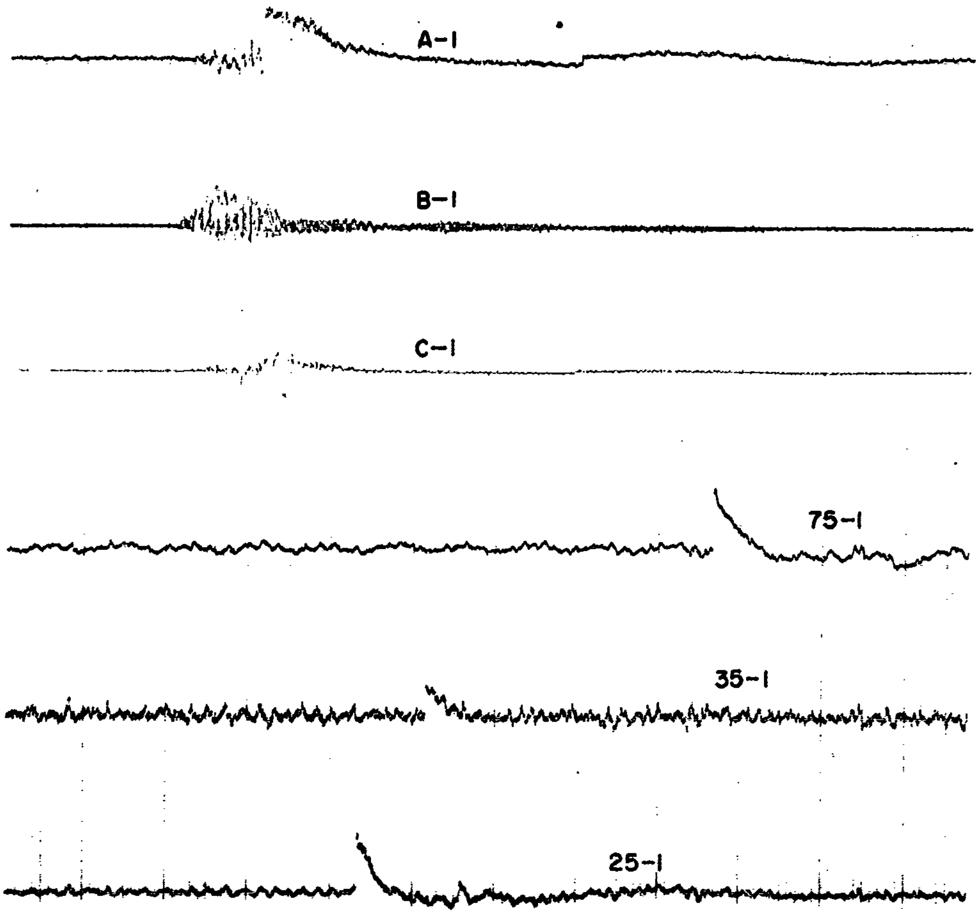
1-50 4.0 PSI

1-25 11.0 PSI

NOTE: OSCILLOGRAM PAPER SPEED WAS 100 IPS; TIME LINES, 0.001 SEC

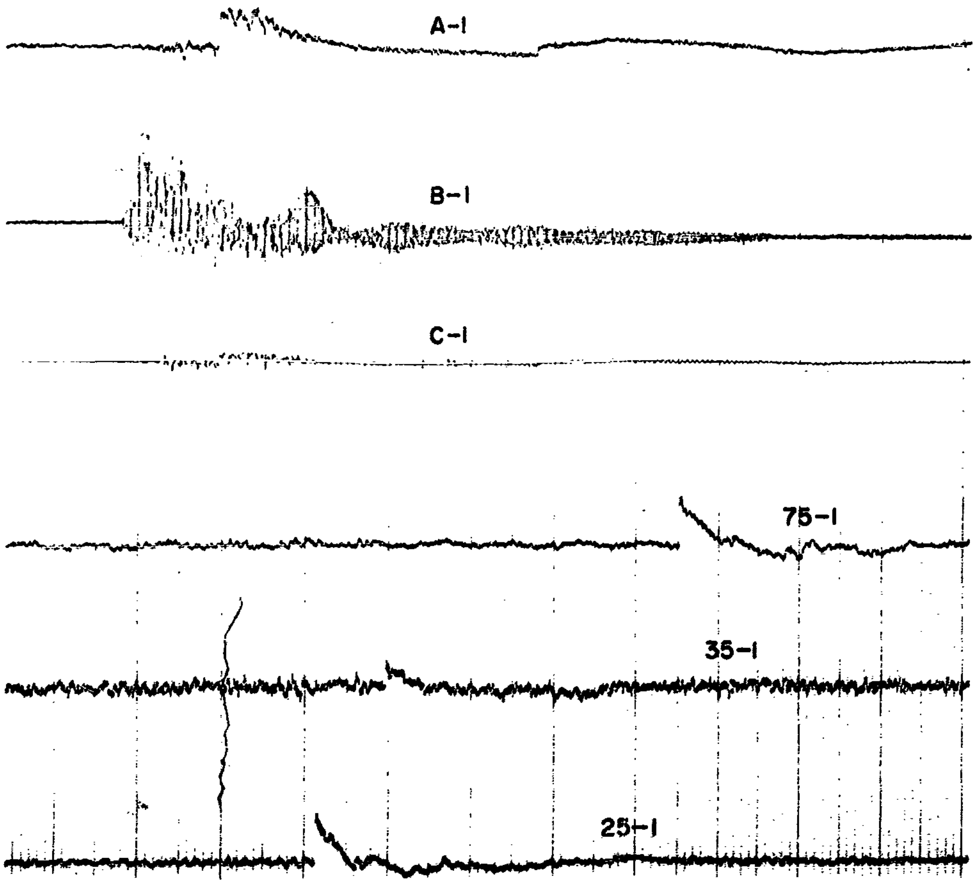
OVERPRESSURE RESULTS FROM 2 LB OF TNT
DETONATED IN 1/10 SCALE RIGID STEEL SILO

Position	Pressure, psi	Time from Silo, B-1 pulse
C-1	120	11
B-1	300	......
A-1	60	11
25-1	3.63	21
35-1	0.96	30
75-1	0.8	64



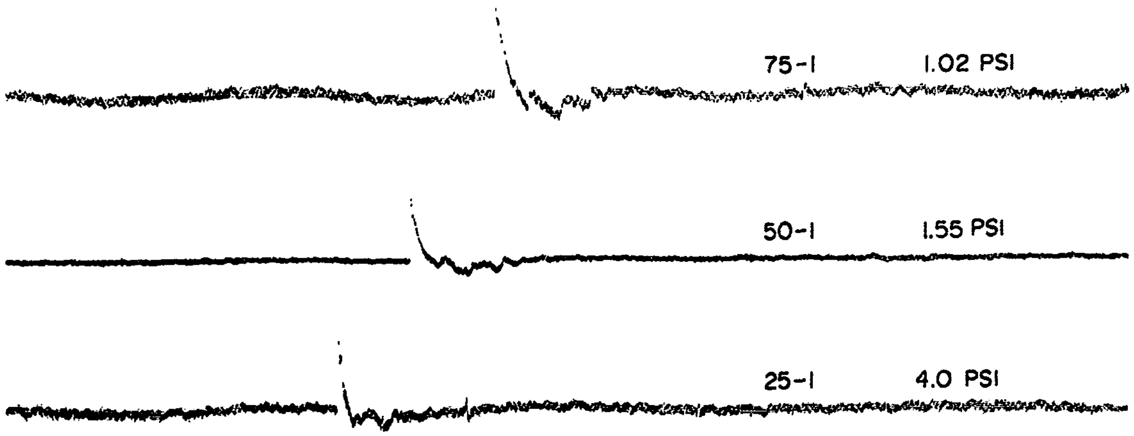
OVERPRESSURE RESULTS FROM 1.5 LB OF TNT
DETONATED IN 1/10 SCALE RIGID STEEL SILO

Position	Pressure, psi	Time from Silo, B-1 pulse
C-1	60	11
B-1	224	......
A-1	48	11
25-1	2.7	23
35-1	0.72	32
75-1	0.6	67



OVERPRESSURE RESULTS FROM 6-LB TNT
DETONATED AT SPILL TRAY CENTER
FOR CORRELATION OF LARGE-SCALE SPILL TESTS

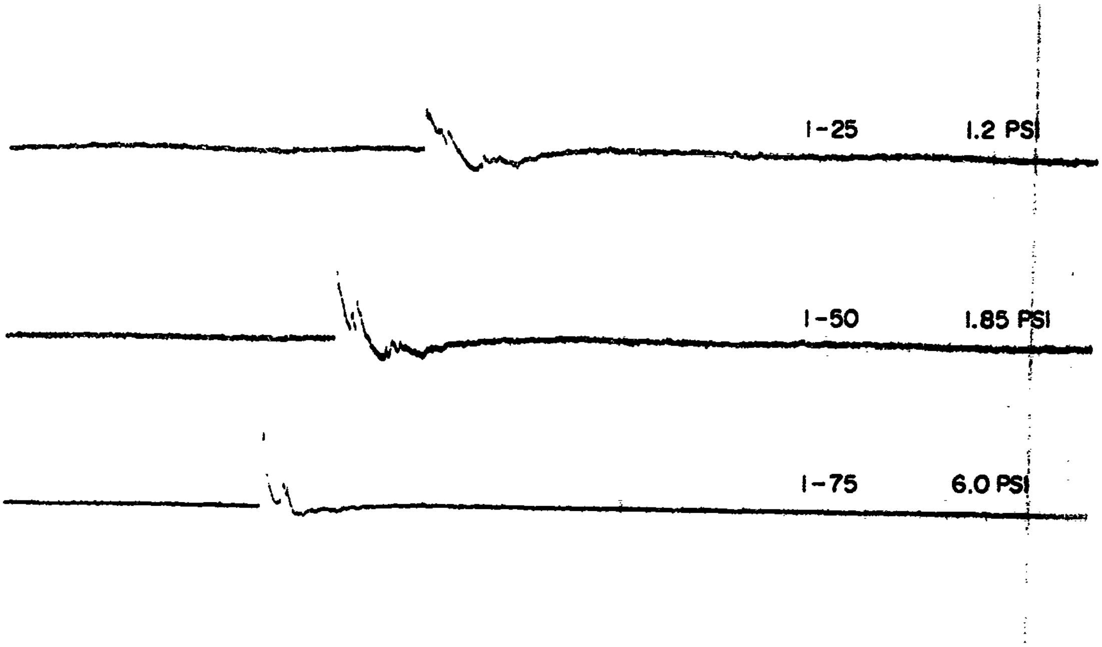
Microphone Position	Pressure, psi
25-1	4.0
50-1	1.55
75-1	1.02



NOTE: OSCILLOGRAM PAPER SPEED, 25 IPS; TIME LINES, 0.01 SEC

OVERPRESSURE RESULTS FROM 12-LB TNT
DETONATED AT SPILL TRAY CENTER
FOR CORRELATION OF LARGE-SCALE SPILL TESTS

Microphone Position	Pressure, psi
25-1	6.0
50-1	1.85
75-1	1.2



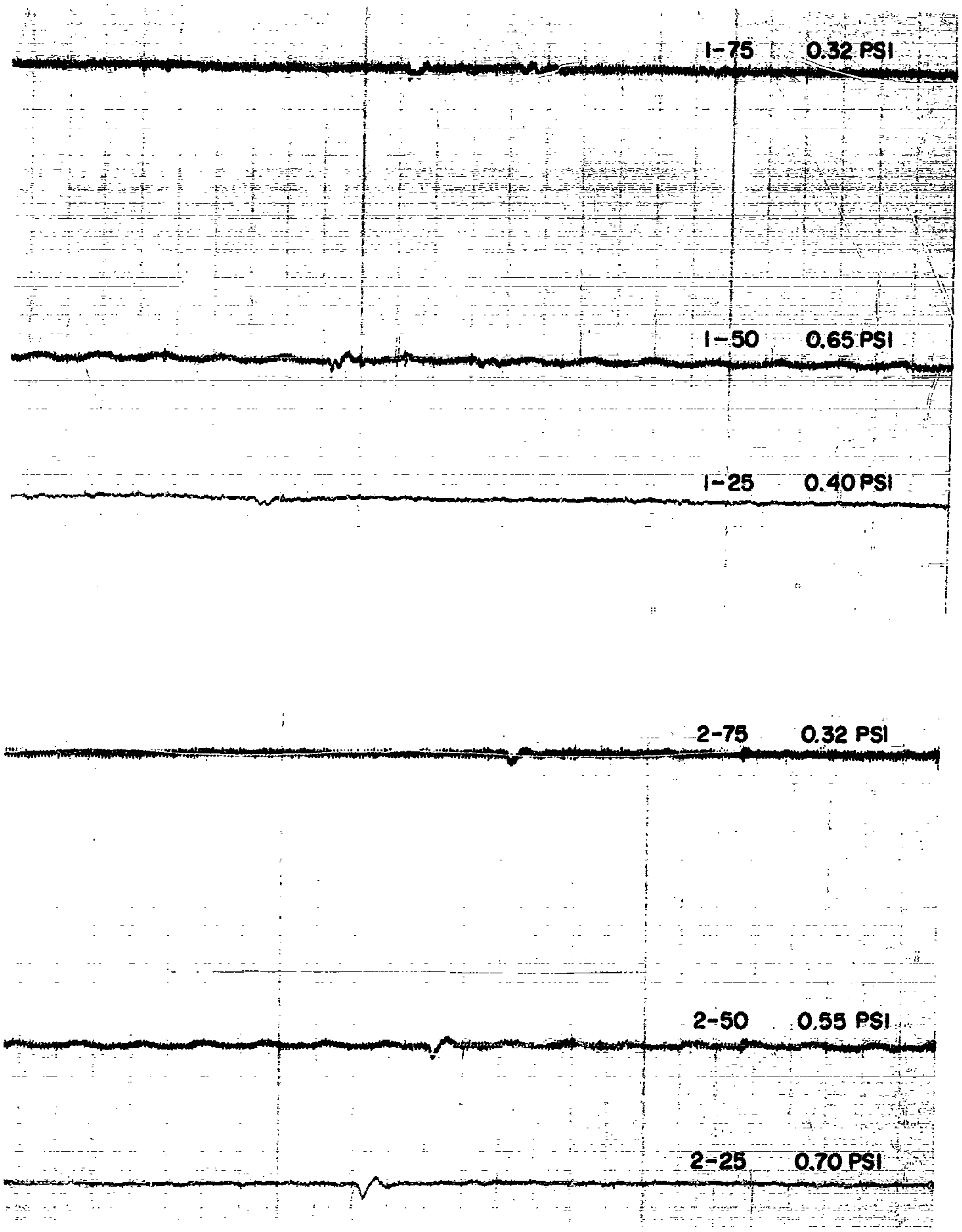
NOTE: OSCILLOGRAM PAPER SPEED, 25 IPS; TIME LINES, 0.01 SEC

APPENDIX E

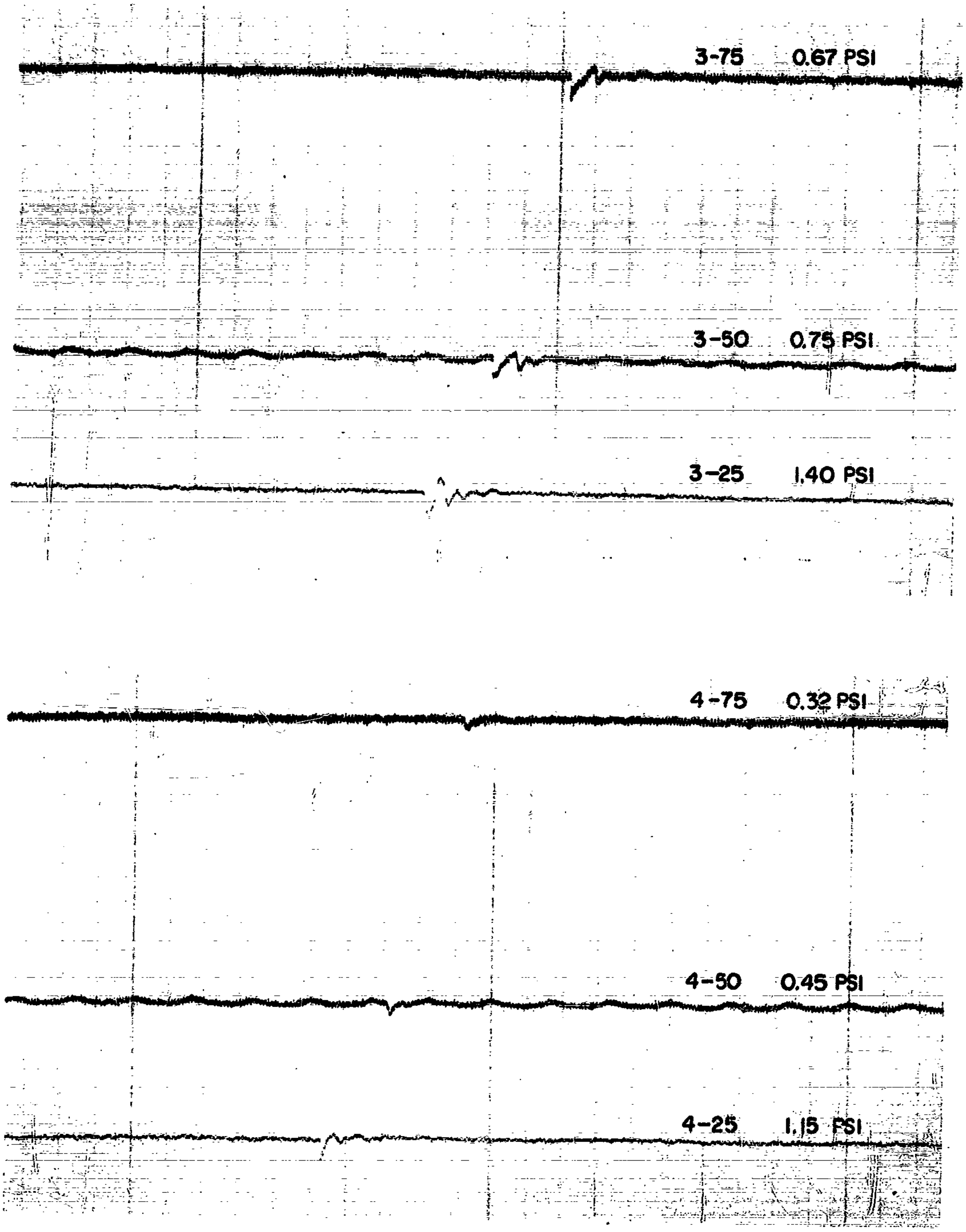
LARGE-SCALE

MIXING SPILL, DRY, TEST 2

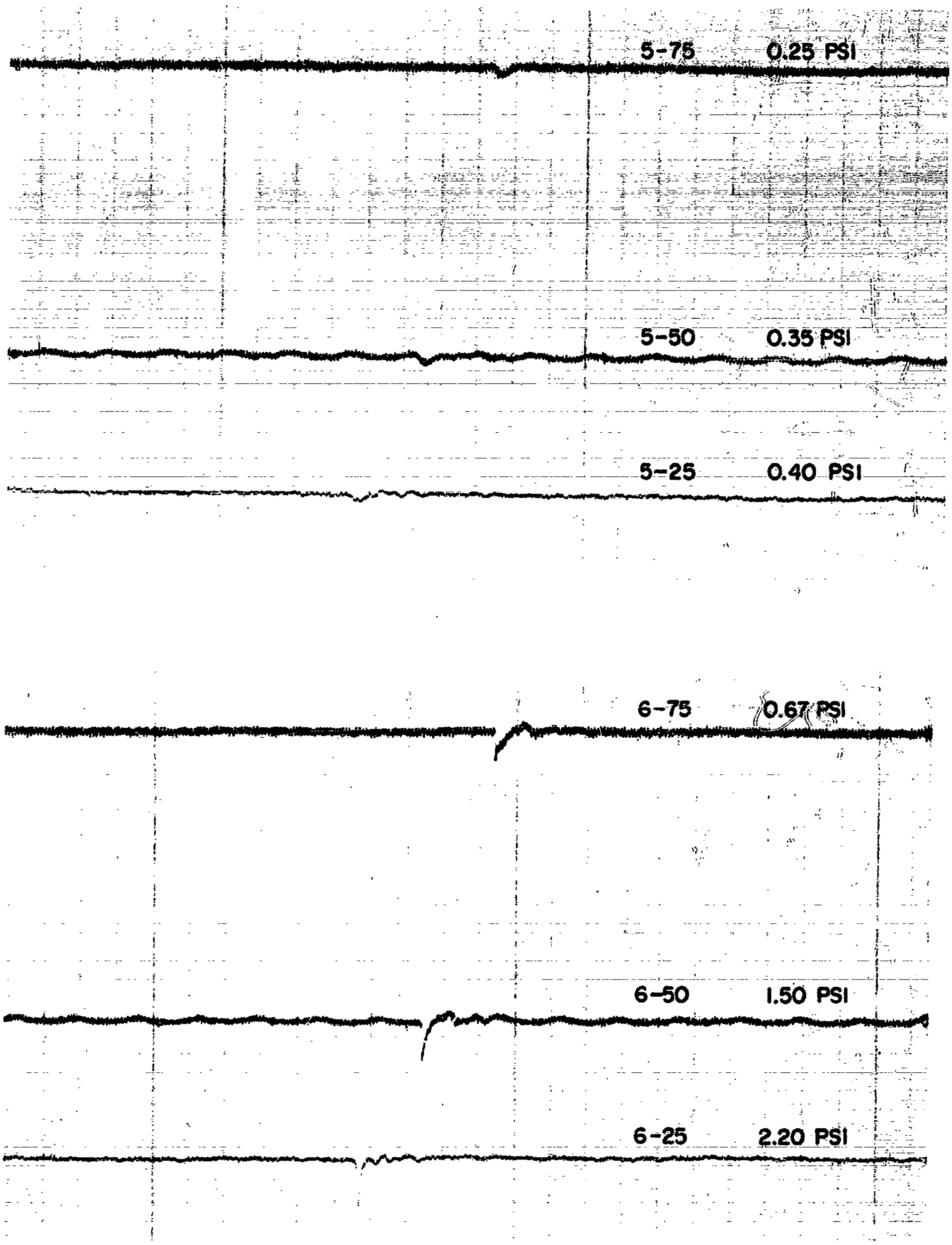
NOTE: OSCILLOGRAM PAPER SPEED, 25 IPS; TIME LINES, 0.01 SEC


1-75 0.32 PSI
1-50 0.65 PSI
1-25 0.40 PSI
2-75 0.32 PSI
2-50 0.55 PSI
2-25 0.70 PSI

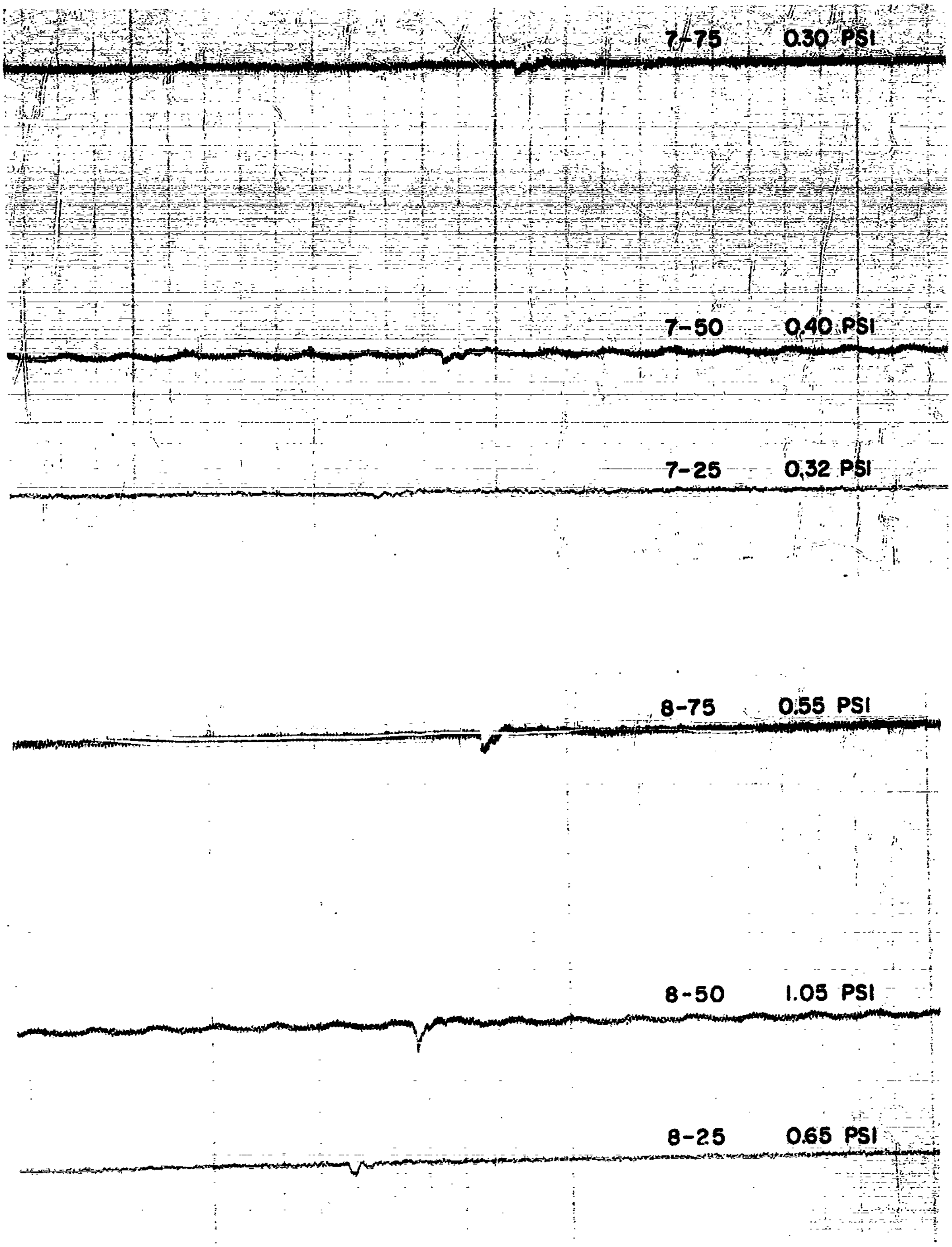
Spill Test 2



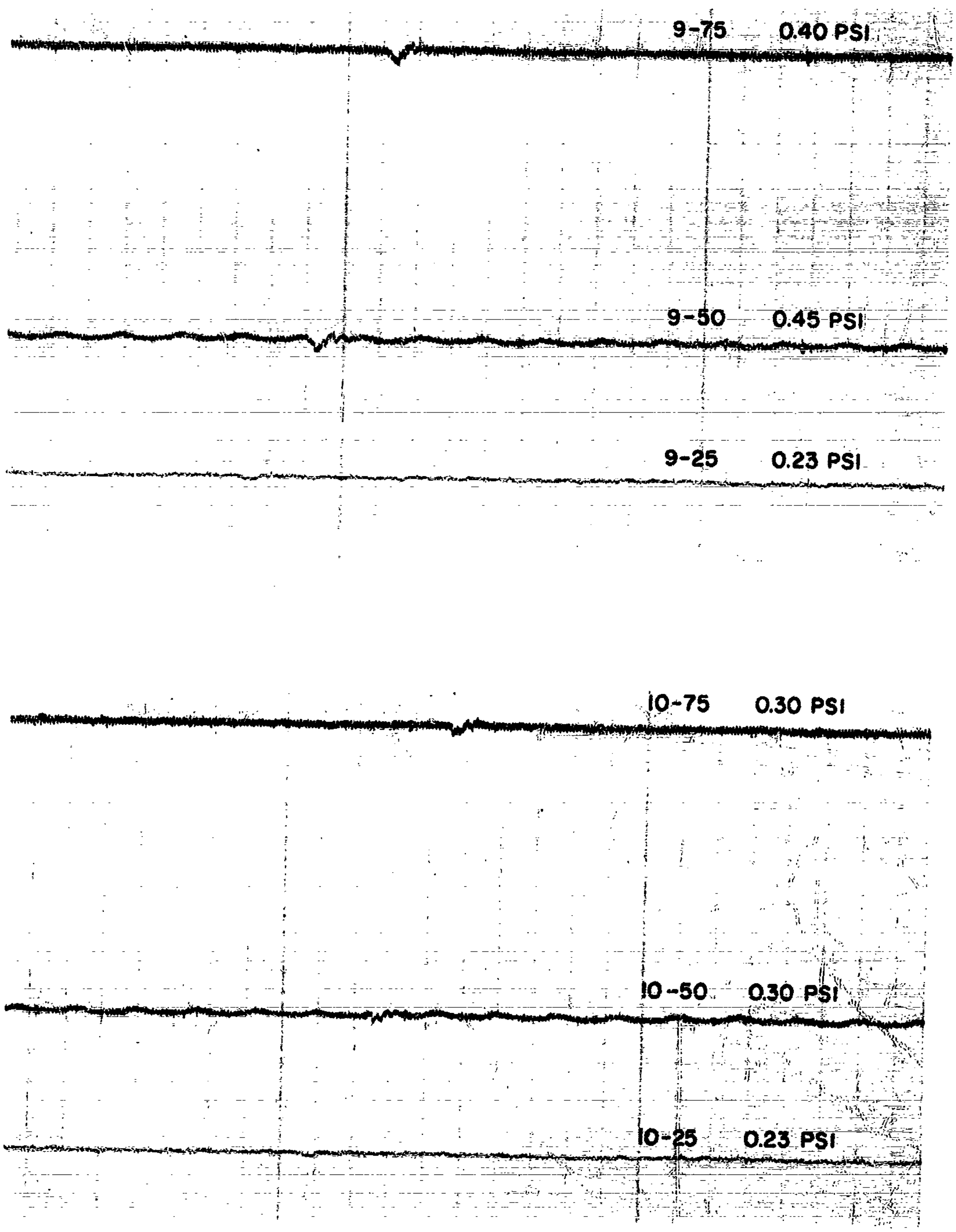
Spill Test 2 (Continued)



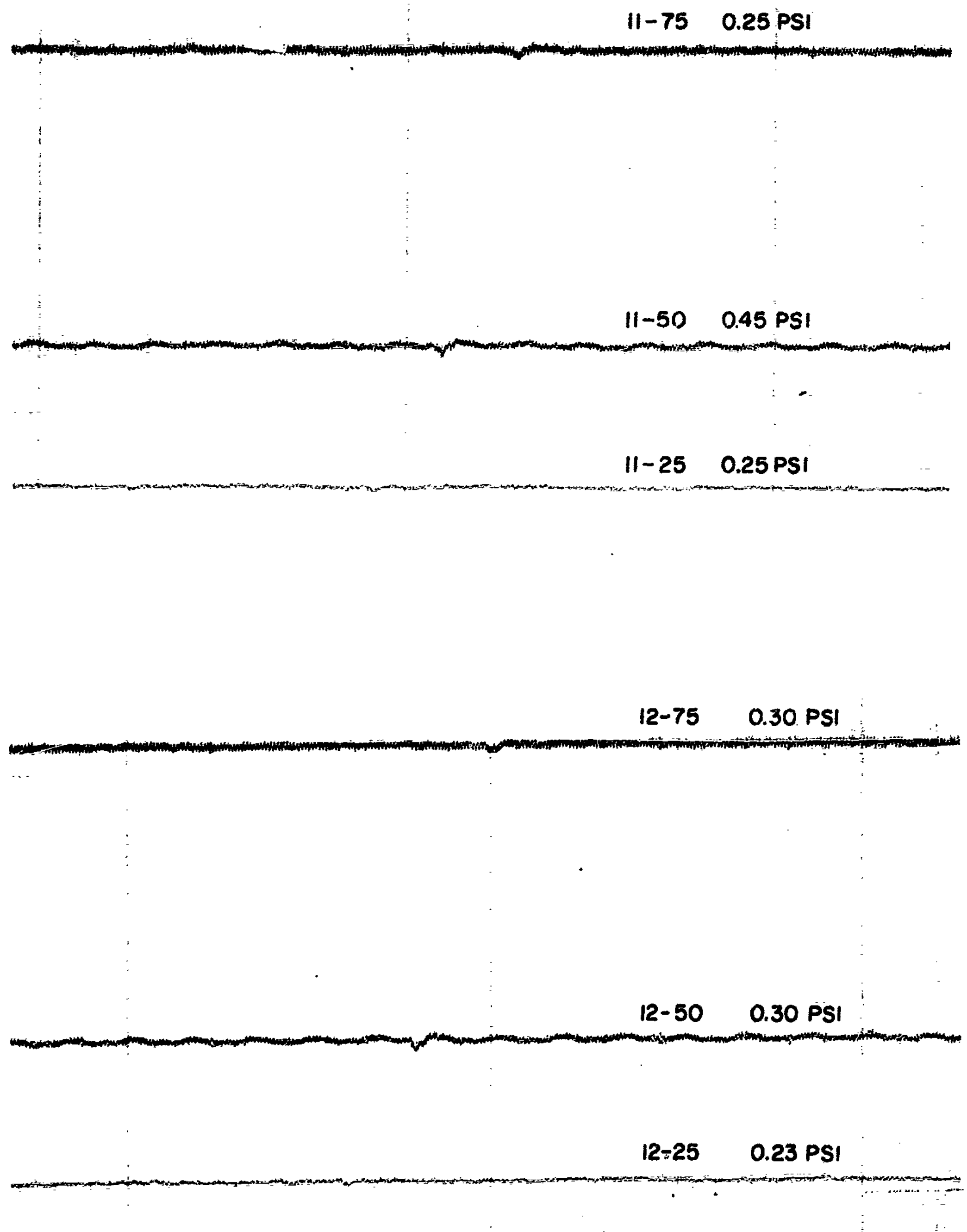
Spill Test 2 (Continued)



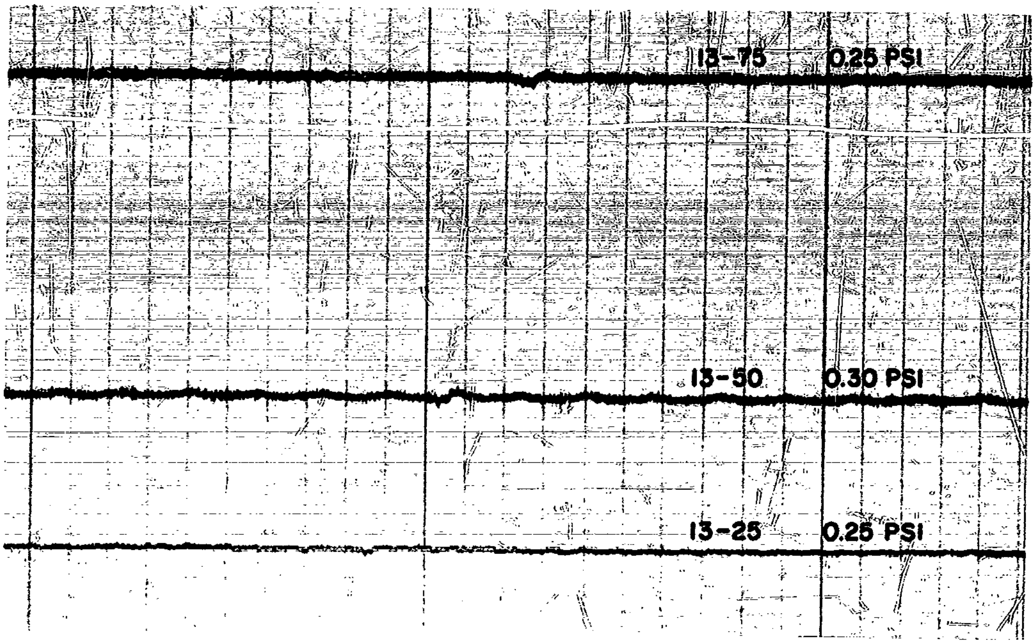
Spill Test 2 (Continued)

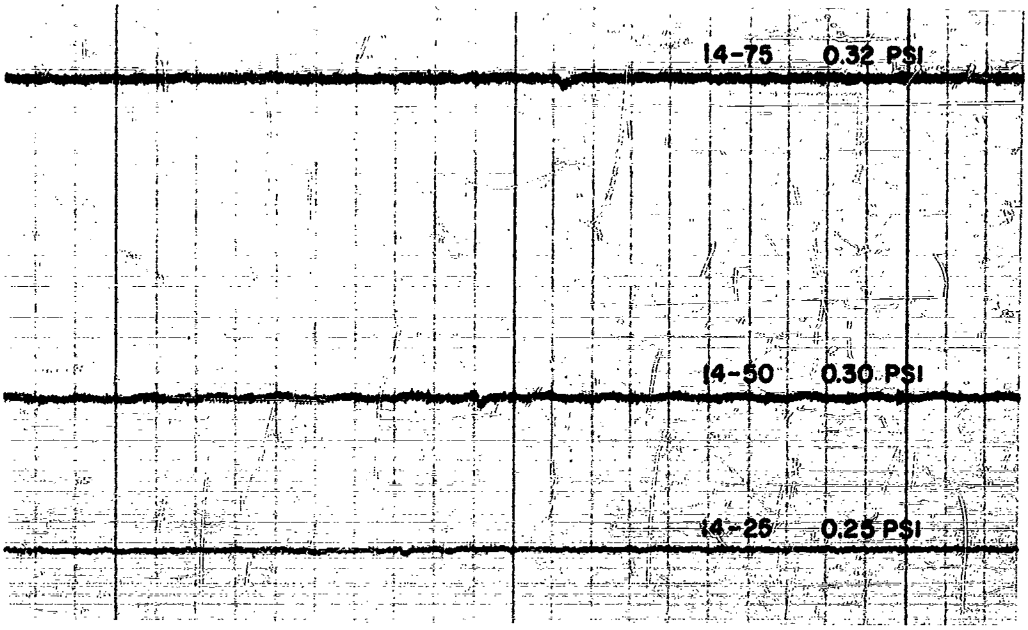


Spill Test 2 (Continued)



Spill Test 2 (Continued)





Spill Test 2 (Continued)

APPENDIX F

MEDICAL STUDY

MEDICAL STUDY

Medical studies were performed by personnel of the Institute of Medical Research, Huntington Memorial Hospital, 734 Fairmount Avenue, Pasadena, California. The following paragraphs describe the results of the animal tests which were performed on 9 August 1961.

PLACEMENT OF ANIMALS AT TEST SITE

The biological study group from the Institute of Medical Research, Huntington Memorial Hospital, arrived at Edwards Air Force Base at approximately 9:00 p.m., August 9, 1961 with the hamsters to be exposed in the nitrogen tetroxide-hydrazine spill test. Because of unforeseen difficulties, it was nearly 11:30 a.m. before the biological study group reached the test site. During this time, the hamsters were shaded but still exposed to the heat of the day. Fifty-four hamsters were placed in their cages at the sampling positions at approximately 1:00 p.m. The spill took place near 2:00 p.m. When collected from the sampling sites, only seven animals were found alive. Both dead and living animals were returned to the Institute of Medical Research, refrigerated, and autopsied on August 10, 1961. Placement of the animals at the test site is illustrated in Fig. 38.

PATHOLOGICAL FINDINGS

Gross Pathology

Gross pathological findings are summarized in Table F-1; unless the date of death is specified, the animal was found dead at the sampling site. Dark red lungs which failed to collapse when the thorax was opened (findings indicative of hyperemia, edema, and hemorrhage of the lung) were found in all animals which died at the test site. In addition, these animals had either wet hair around the nose and mouth (this is not included in Table F-1) or bloody nasal discharges. This may be considered additional evidence of pulmonary edema and hemorrhage. Pale kidneys and livers were found in nearly all of these animals. With the exception of hamster No. 160 which died on August 11, 1961, no gross pathology was found in any of the animals which survived exposure at the test site.

Microscopic Pathology

Tissues were taken from all animals and mounted in paraffin blocks. However, because of the similarity of the gross findings among the animals which died at the test site and the urgency of this report, only a limited number of tissues have been cut, stained, and studied microscopically. Those studied include all hamsters which survived the exposure and died, or were sacrificed at a later date, and one animal which was found dead immediately after exposure from each sampling site. The animals which were found dead at the sampling site and have been studied microscopically are: No. 194 (Cage C), No. 197 (Cage 1), No. 151 (Cage 2), No. 154 (Cage 3), No. 200 (Cage 4), and No. 196 (Cage 5).

The findings of the microscopic examination of these animals which died at the sampling sites were as follows:

1. Lung: All of these hamsters showed severe hyperemia, edema, and some hemorrhage.
2. Liver: Hyperemia, usually most intense in centrolobular region, was a constant finding. Hamsters No. 197 and 200 also showed some perivascular fibroblast and lymphocyte infiltration.
3. Kidney: Glomeruli were usually found engorged with blood. The medulla of the kidney of No. 154 was hyperemic. However, the kidney findings may be considered negative.
4. Spleen: The spleens of these animals were normal.
5. Adrenals: The adrenals of these animals were normal; however, hyperemia of the adrenal medulla was noted in hamsters No. 194 and 196.
6. Heart: The hearts of these animals were normal.

7. <u>Nasal mucous membrane</u>: No. 197 showed some erosion of the epithelium along the nasal septum, hyperemia of the underlying connective tissue, and some cellular debris in the nasal cavity. The nasal mucous membranes of the other hamsters were negative.

The following are the observations of abnormalities in the tissues of the animals which survived the exposure and died, or were sacrificed at a later date:

No. 161 (Cage 1): The heart showed areas of cellular infiltration, predominantly fibroblasts. These areas are extensive. Some lymphocytes and a few polymorphonuclears were also noted. The kidney, adrenal medulla, and liver were hyperemic.

No. 174 (Cage 1): The liver showed cloudy swelling and vacuolization of the hepatic cells. In addition, there was noted lymphocyte, polymorphonuclear, and fibroblast infiltration perivascularly with connective tissue formation and the development of many new bile ductules.

No. 212 (Cage 1): Some areas of hyperemia were noted. Considerable interlobular fibrosis with loss of lobular architecture and new bile ductule formation was found. Some hyperemia of the adrenal medulla and the kidney was seen.

No. 155 (Cage 2): Cloudy swelling and vacuolization of liver cells was noted. Slight hyperemia of the kidney and adrenal medulla was seen.

No. 160 (Cage 3): The liver showed some centrolobular cloudy swelling of the hepatic cells and hyperemia. Hyperemia of the kidney and the adrenal medulla and cortex was noted.

No. 169 (Cage 3): The lung showed some hyperemia, emphysema, subpleural hemorrhage, and intense cellular infiltration. In the liver, there was cloudy swelling and vacuolization of the hepatic cells; the lobular architecture was disorganized and there was much fibrous infiltration with many newly formed bile ductules.

CONCLUSIONS

It seems likely that those animals which died at the sampling sites died from circulatory collapse resulting from hyperthermia. These findings are quite similar to those of July 18, 1961 in which all animals died, apparently from the heat. The cause of the liver changes in those animals which survived is not determined; however, it should be noted that they were found to some extent in five of the seven survivors and could be related to exposure to the fuel vapors, although other factors may well be responsible.

TABLE F-1
GROSS PATHOLOGY

Cage	No.	Lung Hyperemia, Edema, and/or Hemorrhage	Liver, Pale	Kidneys, Pale	Other Findings
C	181	X	X	X	
	186	X		X	Red fluid around nose
	194	X	X	X	Bloody discharge from nose
	198	X	X	X	
	205	X	X	X	Bloody discharge from nose
	207	X	X	X	
	208	X	X	X	
	210	X	X	X	
	214	X	X	X	Bloody discharge from nose
1	161				Died 8/11/61 with no gross abnormalities
	162	X	X	X	
	170	X	X	X	
	174				Sacrificed 8/16/61; no gross abnormalities
	180	X	X	X	
	197	X	X	X	
	201	X			Lung abscess; liver had mottled appearance but color good
	212				Died 8/11/61 with no gross abnormalities
	213	X	X	X	Bloody discharge from nose
2	151	X	X	X	
	153	X	X	X	
	155				Sacrificed 8/16/61; no gross abnormalities
	163	X	X	X	
	164	X	X	X	
	165				Sacrificed 8/23/61; no gross abnormalities
	166	X	X	X	
	172	X	X	X	
	173	X	X	X	

TABLE F-1
(Continued)

Cage	No.	Lung Hyperemia, Edema, and/or Hemorrhage	Liver, Pale	Kidneys, Pale	Other Findings
3	152	X	X	X	
	154	X	X	X	
	156	X	X	X	
	159	X	X	X	
	160	X			Died 8/11/61; kidneys red, bloody urine, hemorrhage in small intestine
	167	X	X	X	
	168	X	X	X	
	169				Sacrificed 8/16/61; no gross abnormalities
	171	X	X	X	
4	177	X	X	X	
	179	X	X	X	
	200	X	X	X	
	202	X	X	X	
	204	X	X	X	
	209	X	X	X	
	211	X	X	X	
	216	X	X	X	
	217	X	X	X	
5	158	X	X	X	
	176	X	X	X	Bloody discharge from nose
	182	X	X	X	
	184	X	X	X	
	189	X	X	X	
	192	X	X	X	
	195	X	X	X	Bloody, frothy discharge from nose
	196	X	X	X	Blood in stomach
	203	X	X	X	

AD -

Rocketdyne, a division of North American Aviation, Inc., Canoga Park, California, RESEARCH ON TITAN II PROPELLANT HAZARDS, FINAL REPORT, VOLUME II, by T.R.Spring, A.E.Chambers, and D.J.Hatz, October 1961, incl. illus.
(Proj. 3148, Task 30196)
(AF/SSD-TR-61-40)
(Contract AF33(616)-6939)

Unclassified Report

This report presents the results of a special test program to determine the hazards resulting from the bulk (over)

UNCLASSIFIED

1. Titan II propellant hazards
2. Liquid propellants

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II. Chambers, A.E.
III. Hatz, D.J.

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