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EVALUATION OF SMALL ARMS PROPELLANTS IN LOADING HOPPER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The U.S. Army is currently involved in a production base modernization program under which many new explosive and propellant production facilities are being built and others are being renovated and modernized. Significant attention is being given to both increased safety and production efficiencies for the in-process operations. Small arms ammunition plants use hoppers for in-process storage of propellants in ammunition loading operations. As long as the height of the propellant in the hopper is below a "critical" level,

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any accidental burning initiation of the propellant will not result in either an explosion or a detonation of the propellant. This program was structured to verify that the in-process storage heights of IMR 8208, WC 818 and WC 844 propellants were below the "critical height".

Hoppers and feed pipes were fabricated to be representative of the in-plant hopper/feed pipe configurations, as specified by ARRADCOM drawings. Experiments determined that IMR 8208 and WC 818 propellants were at, or below, their critical height at 27 kg of propellant in the conventional hopper. WC 844 propellant, at a weight of 68 kg and above, was above the critical height in the SCAMP hopper. At 45 kg, the WC 844 propellant is below its critical height. Feed pipe explosions resulted from the ignition of IMR 8208 and WC 818 propellants. No feed pipe explosions were encountered with the WC 844 propellant.

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INTRODUCTION

In the manufacture of small arms ammunition, propellant is stored temporarily in hoppers to facilitate continuous loading operations. The hoppers, in turn, have feed tubes which convey the propellant to the loading position. There exists a potential fire hazard if the propellant is ignited accidentally. If the propellant in the hopper is above the critical height, the burning reaction can change into an explosion or a detonation, thereby increasing the hazard potential significantly. Similarly, the propellant in the feed tube can change into an explosion or a detonation if the proper conditions are present, e.g., confinement, length and diameter.

The objective of this program was to ascertain if any of three propellant types (IMR 8208, WC 818 and WC 844) would change from burning into explosion or detonation reactions when initiated at weights, hopper configurations, and feed tube configurations which are representative of in-process conditions.

Specifically, the following propellant/hopper configurations were evaluated:

- 27 kg of IMR 8208 propellant in the conventional hopper
- 27 kg of WC 818 propellant in the conventional hopper
- 91 kg of WC 844 propellant in the SCAMP hopper

DISCUSSION OF EXPERIMENTS - EQUIPMENT AND TECHNIQUES

Ten tests were conducted with each propellant to confirm that the height used would not result in a burning-to-explosion/detonation transition. The equipment and techniques used in the experiments are described below.

Hoppers

The initial hoppers were fabricated according to figures 1 and 2 except that legs were added for support. The stack was made independent of the hopper to facilitate loading the propellant. A second set of hoppers was made similar to the initial configuration except: 1) the stack of the conventional hopper was welded to the conical section to provide better structural integrity; 2) the conical section thickness, for the conventional hopper, was increased from 28 gauge to 6.3 mm to increase the hopper strength; and 3) loading ports were added immediately above the hopper section, on each type, to facilitate propellant loading. The ports were made from the same material as the hopper stack and were held in place by four 16-mm bolts. The door size for the conventional hopper was 470-mm across by 406-mm high. The SCAMP hopper port was 508-mm square. Figure 3 shows the emplaced conventional hopper and figure 4 shows the emplaced SCAMP hopper.

The feed pipe was specified as 32-mm OD brass pipe. Steel pipe was substituted for brass because brass pipe was not readily available. Similarly, radiator hose was substituted for gum rubber in the hopper-feed pipe connection. The substitutions did not adversely affect the experiments.

Propellant

Three propellant types were evaluated: IMR 8202, WC 818 and WC 844. IMR 8208 is a single-base, tubular propellant. WC 818 and WC 844 are double-base, spherical propellants. IMR 8208 has the lowest burning rate and WC 844 has the highest rate. The IMR 8208 and WC 818 were evaluated in the conventional hopper and the WC 844, in the SCAMP hopper.

Ignition Source

The ignition source for each of the tests was an Atlas 300 Electrical Match supplemented with 3.2 g of black powder. The ignition source was placed 102 mm above the bottom of the cone (apex) of the hopper.

Photographic Coverage of Tests

Real time, high speed, and still pictures were made of selected tests. Real time motion pictures were taken to provide an overview of the burning sequence and the subsequent reaction of the hopper and the feed pipe. High speed movies were taken of the hopper to attempt to get a better understanding of the burning rate, or flame spread, as it takes place within the propellant bed. Still pictures were used to record the experimental set-up and provide a pictorial history of the unexpected test results. The real time and the high speed motion pictures were made on 16-mm color film. The still pictures were made on 35-mm color film; real time pictures were taken with a Canon 16-mm Scoopic camera, and high speed pictures were taken with a Hycam camera, Model No. 41-004.

Pressure and Temperature Measurements

Pressure measurements were made at locations of 510 mm above the bottom of the conventional hopper and 749 mm above the bottom of the SCAMP hopper. Pressure transducers were purchased from Celesco Industries, Canoga Park, California. The particular type used was the LD 25 Blast Pressure Transducer with a 20,684 kPa maximum pressure capability. The rise time capability of the gauge is 1 μ sec, which is adequate for the intended use. The gauge is relatively inexpensive and expendable. Four gauges were purchased and all were damaged in the experimental program. The gauge sensitivity was in the order of 0.022 V/kPa, which was below that desired for the pressure regime encountered.

Temperatures were measured by the use of Teletemp Temperature Recorders Model 110, purchased from Teletemp Corporation, Fullerton, California. Teletemp strips were pasted to the outside of the hopper at locations of 305, 610 and 914 mm above the conic base of hopper (fig. 5). When attempts were made to monitor the hopper temperature at or below the propellant height, the temperatures exceeded 260°C (the maximum temperature of the recorders used).

Propellant Burning Measurements

Several schemes to monitor the burning of the propellant within the hopper were considered. None were satisfactory within the fiscal constraints of the program. The scheme was to drill a series of 25-mm diameter holes on 51-mm centers in the lower section of the hopper; back the holes with 12-mm-thick clear plastic to seal the holes; and monitor the flame spread with a high speed camera. Within limits, this scheme provided some insight into the flame spread within the hopper. Framing rates from 400 to 2000 pictures per second were tried. A frame rate of 1000 pictures per second appears to be satisfactory as well as convenient for data reduction.

RESULTS OF THE PROGRAM

Overview

As initially scheduled, the test program was to consist of 30 tests, 10 with each propellant,, IMR 8208, WC 818 and WC 844. If a detonation reaction occurred with a propellant type the tests were to be suspended for that type. To gain some insight into what could be expected, the first three tests of the program evaluated each of the three propellant types. This preliminary series indicated that the conventional hopper would survive the IMR 8208 burning tests with little difficulty. However, the conventional hopper, in its initial configuration, was severely damaged by the explosive reaction of the 27 kg of WC 818 propellant. This hopper configuration was subsequently reworked, as described in the previous section of this report. The SCAMP hopper, with a charge of 91 kg of WC 844 propellant, was destroyed by an explosive reaction.

Additional hoppers were fabricated and testing was resumed. The strategy was to evaluate the IMR 8208 propellant first, in the conventional hopper, and then to evaluate the WC 818 in the same hopper. Since the WC 818 has a higher burning rate than the IMR 8208, the slower burning propellant was evaluated before risking the hopper to the more vigorous propellant. However, ten tests of each propellant were completed without loss of the hopper.

Because of the negative results, the charge weight of the WC 844 was reduced to 68 kg as the "minimum acceptable" by ARRADCOM. This weight was evaluated in the SCAMP hopper amd resulted in an explosion reaction which once more destroyed the hopper. A third SCAMP hopper was fabricated and the test series was completed with WC 844 propellant at a charge weight of 45 kg.

No explosions or detonations were encountered in the feed pipe with WC 844 propellant. Explosion reactions (possibly detonations) occurred in the feed pipes when IMR 8208 and WC 818 propellants were used. Explosions occurred after a significant delay following the ignition of the propellant in the hopper. These delays were typically in the order of 1 to 2 minutes.

The experimental procedure used was as follows:

1. The feed pipe was taped at the discharge end to retain the propellant.

2. The feed pipe was filled with propellant. Approximately

2.8 kg of propellant was placed in the feed pipe. (This includes the propellant in the hose.) The 2.8 kg is typical for all three of the propellants evaluated.

3. The hose connecting the hopper with the feed pipe was secured to the feed pipe, then to the hopper.

4. An Atlas 300 Electric Match, with 3.2 g of black powder added, was placed in the hopper at a location of 102 mm above the bottom of the hopper. For this program the "bottom of the hopper" was defined as the junction of the conic section, or pyramid section, of the hopper with the 51-mm-long extension.

5. The hopper was loaded with the requisite propellant weight. The propellant height was recorded. For the IMR 8208 and WC 818 propellants, 27 kg was loaded into the conventional hopper for each test. For the WC 844 propellant, the initial load was 91 kg. This was reduced to 68 kg, and finally to 45 kg before a non-violent reaction in the SCAMP hopper was demonstrated.

6. The hopper loading port was secured by four 16-mm bolts, the area was cleared of personnel, and the electric match was initiated.

Teletemp temperature measurements were made on each shot. Pressure and film recordings were made on selected shots. Test results are summarized in table 1.

An observable difference was expected in the flame spread, or apparent burning distance, measured for the three propellants. This difference, however, was not apparent in the data recorded. An inspection of the Hycam film records indicated that, for the most part, smoke obscured the fire of the burning propellant as viewed through the holes in the hopper base. However, the smoke emission formed a hole-to-hole sequence that was measurable. The Hycam records were reduced and the linear distance of the smoke emission sequence was plotted against time. These data are shown in figure 6. On two test records flame could be seen through some of the holes. The "flame distance" was also plotted (fig. 6). The straight line, which is the upper plot, illustrates the flame linear distance-time relationship. The lower line illustrates the smoke distance-time relationship. In addition:

- The flame distance-time relation appears to be linear. That relationship was not necessarily expected.

• The smoke-distance time relation closely follows the flame distance-time relation in the early times, then falls away as time increases.

• The smoke distance and the flame distance-time relations were observed to be independent of the type of propellant. This is unexpected since it was reasonable to expect the flame spread to relate to the propellant burning rate.

If the curves in figure 6 are differentiated, the apparent burning rates are determined. These relationships are shown in figure 7. The flame spread rate (upper curve) is about 7.4 m/sec. The apparent burning rate observed for the smoke is somewhat less, 6.2 m/sec, but this represents only an approximately 16% difference from that of the flame observed rate and tends to confirm the general magnitude of the flame spread rate within the hopper.

IMR 8208 Propellant

The first test and test series were conducted with IMR 8208 propellant. Since IMR 8208 has the lowest burning rate of the three propellants investigated, it was assumed that would be the least likely to cause hopper overpressure. This assumption was verified on the basis of the tests. The burn was relatively quiet and the peak pressure measured was consistently at 3.4 kPa for the six tests in which measurements were taken. The low gauge sensitivity resulted in a noisy pressure record, which was inadequate. A typical pressure-time record is shown in figure 8. In this record of test no. 8, each vertical division represents 5.58 kPa and each horizontal division represents 250 ms. In each of the pressure records a double pressure pulse is indicated, with the second pulse being the highest. This could indicate that the burning reaction causes propellant grains to be ejected up into the hopper stack where they are ignited. The greater propellant surface area of this action could cause the higher pressure of the second pulse. Figure 9 shows the pressure gauge location of the hopper. The gauge is located immediately to the left of the loading port. A garden hose was used to shield the gauge cable from the fire.

In several of the tests, the loading port blew open either by shearing the door material at the attach points or by stripping the bolts. One such incidence is shown in figure 10. Subsequently, a stronger port was used. there was no perceptible difference in the hopper pressure-time records between the two ports.

Figure 11 shows the teletemp locations used on the conventional hopper. As with the pressure records, the temperature records indicated a reproduciblity of temperature distribution from test to test. The temperature gradient was slight (table 1), indicating about a 3°C gradient in about 1 m along the hopper stack. Temperature measurements taken below the propellant level on the hopper, indicated temperatures of 260°C or greater.

The burning reaction was not a problem in the hopper, but was in the feed pipe. On the second test of the IMR 8208 series, an explosion (or detonation) took place in the steel feed pipe about 1 m from the discharge end between 60 and 90 seconds after the initiation of the propellant in the hopper. Pipe fragments were found about 150 m from the test site. Figure 12 shows the feed pipe after the test. The large fragment which was recovered is also shown in the figure.

To reduce the confinement of the feed pipe and the hazard potential to equipment and material stored within 200 m of the test, PVC pipe was substituted for the steel pipe. The PVC pipe appeared to reduce the explosion frequency; however, two out of five feed pipes did explode. The reduction in frequency from 50% to 40% in the change of feed pipe material is not considered to be significant. The severity of the explosion, however, was reduced significantly in that PVC pipe fragments were usually found within 10 m of the test site. Typical PVC pipe fragments from this test series, are shown in Figure 13.

WC 818 Propellant

The test series with WC 818 propellant was expected to produce higher reactions within the hopper than the IMR propellant. Indeed, in the initial exploratory tests, a test with WC 818 damaged the hopper so severely that a new hopper had to be made. The initial hopper configuration (before the test) is shown in figure 14. The hopper damage (fig. 15) was confined, primarily, to the hopper-stack junction. This damage was caused by the two-body action of the hopper and the sack during the propellant burning process which was compounded by the constraints placed by the guy wires used to support the hopper.

The modified conventional hopper (with one-piece construction and a loading port) sustained the burning reactions of the 27 kg of WC 818 without incident. Typically, the pressure-time records of the WC 818 propellant tests were slightly higher (4.2 kPa) than those of the IMR 8208 propellant tests. One test (Shot No. 13), however, exhibited a peak pressure in the order of 8.3 kPa which is about twice that normally encountered. The burning also sounded somewhat louder than for the IMR 8208 propellant. Most of the pressure traces show multiple pulses. A typical pressure record for WC 818 propellant is shown in figure 16. Each vertical division represents 5.58 kPa and each horizontal division represents 250 ms.

Hopper temperatures recorded for the WC 818 propellant were reproducible from test to test, and averaged about 15° to 20°C higher than for IMR 8208 propellant (table 1).

The feed pipe is a hazard source with WC 818 propellant, as it is with IMR 8208 propellant. The frequency of occurrence, however, appears to be lower for the WC 818 propellant. Of four tests with the steel feed pipe, one exhibited the explosive reaction (or possibly a detonation) of the propellant within the pipe. The explosive reaction took place 305 mm from the discharge end of the pipe. As before, the fragments were relatively large and were ejected over a wide area. The feed pipe was propelled about 10 m from its original location. Five tests were conducted using a PVC feed pipe. No explosions were encountered. Each of the pipes burned through and were distorted by the heat. A typical PVC pipe, after the test, is shown in figure 17.

WC 844 Propellant

No feed pipe explosions were encountered with the steel pipe and WC 844 propellant. In each test, the propellant was completely burned in the pipe. No tests were conducted with PVC pipes and WC 844 propellants.

The SCAMP hopper propellant load was initially specified at 91 kg. That charge was placed into the hopper and initiated (figs. 19 through 23). Side panels of the hopper were separated from the hopper and blown a distance of about 9 m. The damage necessitated the fabrication of another hopper. The shape of the side panel (fig. 22) indicated that a secondary reaction, located about halfway up the stack, may have caused the hopper explosion.

The SCAMP hopper propellant load was reduced to 68 kg as the "minimum acceptable" for process operations. To that end, the 68 kg propellant charge was placed in the hopper and initiated. Figure 24 illustrates the distribution of segments of the hopper following the explosion. Figures 25 through 30 are photographs of the hopper segments after the test. The pressure trace for this test is shown in figure 31. The "peak pressure" is in the order of 37.2 kPa. The trace shows a fairly rapid pressure excursion during the primary impulse followed by several smaller pulsations. Each vertical division represents 11.07 kPa and each horizontal division is 500 ms. Following this, test portions of the hopper were salvaged, a new stack was fabricated, and ten tests with the 45 kg of WC 844 propellant were completed without an overpressure incident.

Ten tests were conducted with 45 kg of WC 844 propellant in the SCAMP hopper without an overpressure incident. Typical temperature levels at the 305, 610, and 914 mm temperature positions were 152°, 138° and 127°C, respectively. Test-to-test variations of about 27°C were encountered. The temperature readings for the WC 844 propellant were significantly below those of the IMR 8208 and WC 818 propellants. Peak pressures were typically in the order of 4.8 kPa. This value is slightly higher than that experienced with the other two propellants. The WC 844 propellant burned with audible pulsations. These pulsations are reflected in the pressure traces. A typical pressure trace is shown in figure 18. Two traces are shown. The upper pressure trace is from a gauge mounted midway up the stack. Each vertical division represents 10.07 kPa for the upper trace and 9.24 kPa for the lower trace. Each horizontal division is 250 ms. The upper gauge was added after it appeared that secondary reactions may be taking place near the middle of the stack. This is discussed further below.

CONCLUSIONS

1. A height of 381 mm for IMR 8208 and WC 818 propellants did not produce a detonation in the conventional hopper. This height relates to 27 kg of propellant in the hopper as used in the plant's operation.

2. A height of 356 mm of WC 844 propellant produced no deflagration-to-detonation reaction in the SCAMP hopper. This height relates to 45 kg of propellant in the hopper.

3. The feed pipe of the conventional hopper represents an explosion hazard when filled with IMR 8208 or WC 818 propellant.

4. The feed pipe of the SCAMP hopper was found not to be an explosion hazard when filled with WC 844 propellant.

5. The use of a schedule 40 plastic feed pipe (PVC) reduced the severity, but did not appreciably change the frequency, of the feed pipe explosion hazard for IMR 8208 propellant.

6. There was insufficient testing to determine the explosion hazard reduction potential of a plastic feed pipe with WC 818 or WC 844 propellant.

7. As complete systems (hopper and feed pipe), the conventional hopper with 27 kg of IMR 8208 or WC 818 propellant and the SCAMP hopper with 68 kg of WC 844 propellant (the "minimum acceptable") must be considered to be an explosion hazard.

8. The vent pipe, as installed in these tests for the conventional and SCAMP hoppers, has questionable utility.

RECOMMENDATIONS

Based on the initial program requirements, the test conditions, the program results, and the conclusions drawn, it is recommended that:

1. The maximum height of the WC 844 propellant within the SCAMP hopper be reduced from its present in-process height of 546 mm to 346 mm; this corresponds to a change in the propellant weight from its present in-process weight of 91 kg to 45 kg.

2. A program be initiated to design and test effective venting for both the conventional hopper and the SCAMP hopper.

3. A program be initiated to design and test a feed pipe configuration that reduces or eliminates the explosion hazard potential.

4. A program be initiated to relate the critical heights of propellants in hoppers and feed pipes, to hopper and feed pipe configurations as well as propellant properties.

Table 1. Summary of test results

Number Of Tests	Propellant Type	Propellant Weight (kg)	Propellant Height (mm)	Teletemp Position (mm above Base of Cone)	Max. Temp. (°C)	Peak Pressure (kPa)	Comments
10	IMR 8208	27	381	305	243	3.4	Hopper burn is quiet. Feed pipe exploded in 43% of the tests.
				610	240		
				914	240		
10	WC 818	27	381	305	260	4.2	Hopper burn is slightly louder than with IMR 8208. Feed pipe exploded in 11% of the tests.
				610	260		
				914	260		
10	WC 844	45	356	305	152	4.8	Hopper burn pulsates loudly. No feed pipe explosions in 12 tests.
				610	138		
				914	127		
1		68	4[illegible]2	305	N.R.	37.2	Propellant explosion in hopper.
1		91	546	305	154	N.R.	Propellant explosion in hopper.

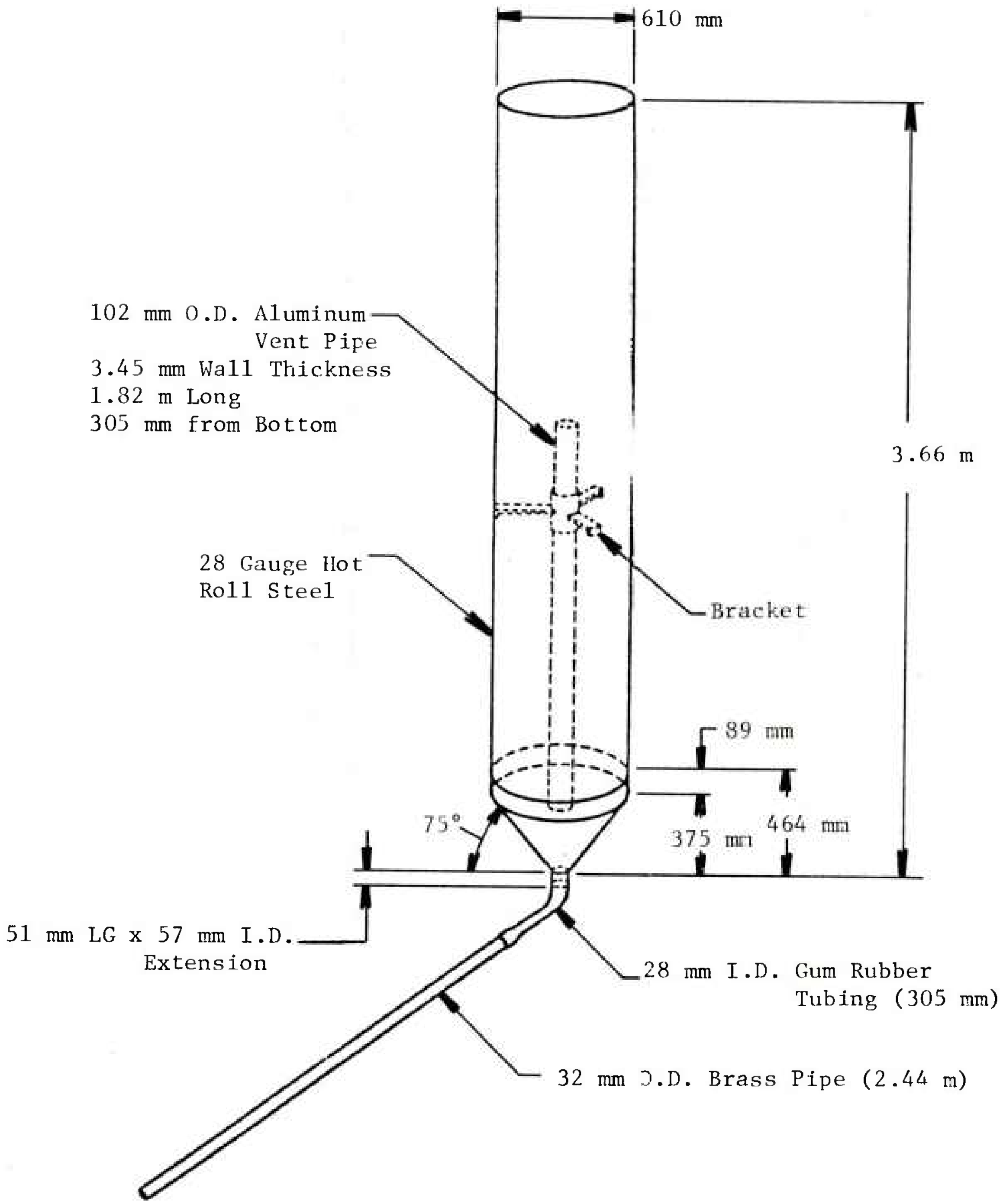

Figure 1. Conventional loading hopper

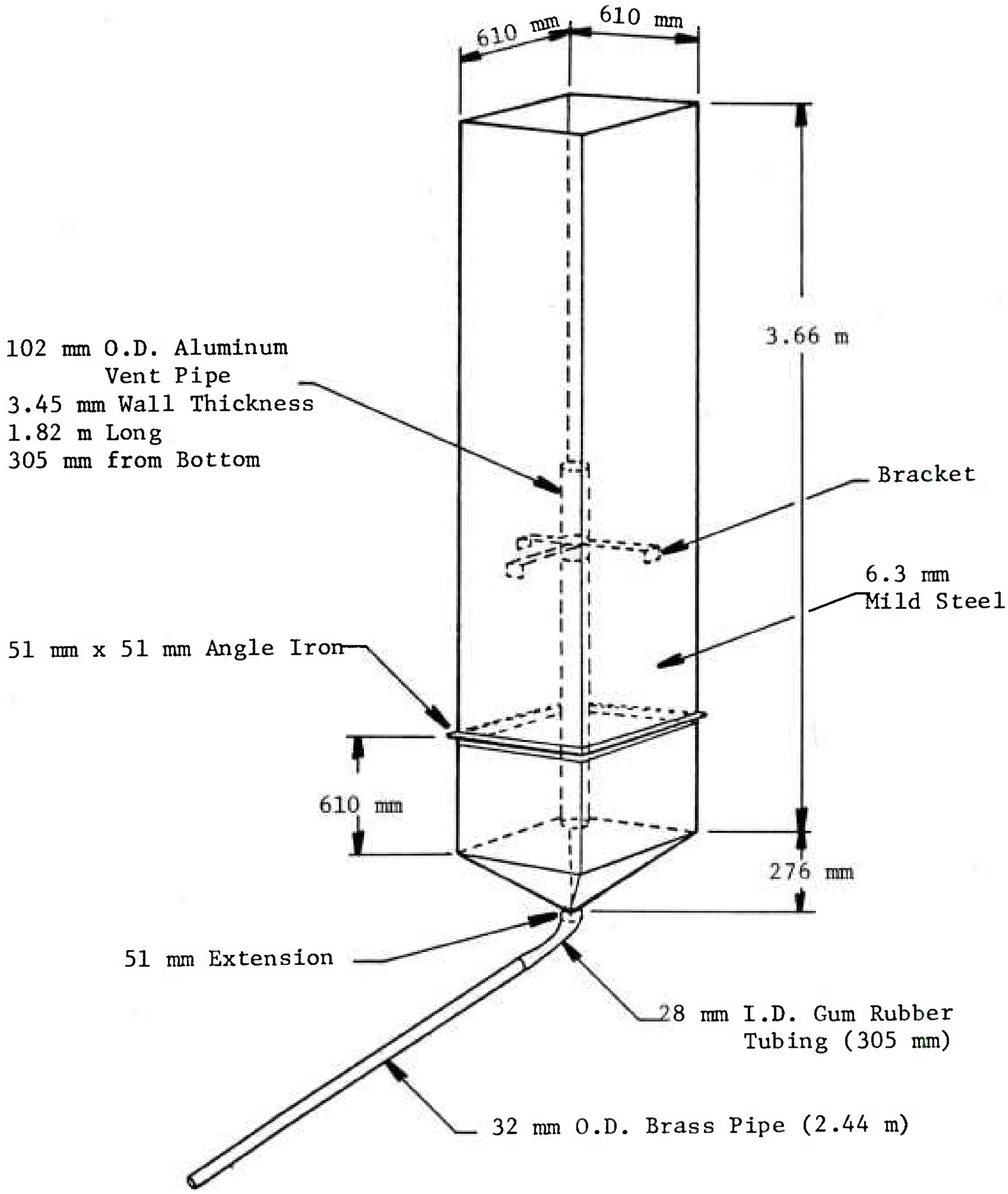

Figure 2. SCAMP loading hopper

Figure 3. Emplaced conventional hopper

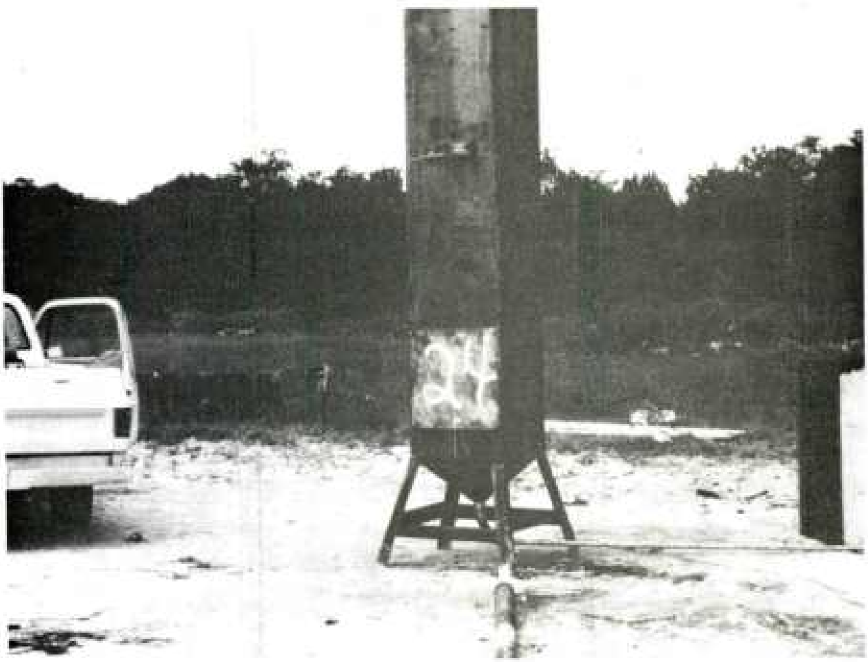

Figure 4. Emplaced SCAMP hopper

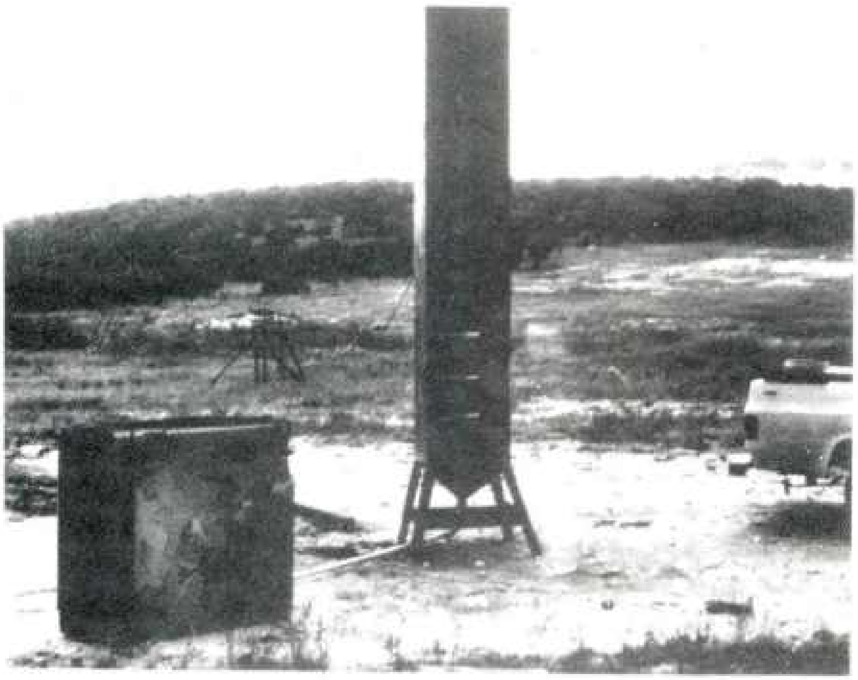

Figure 5. Typical temperature recording locations

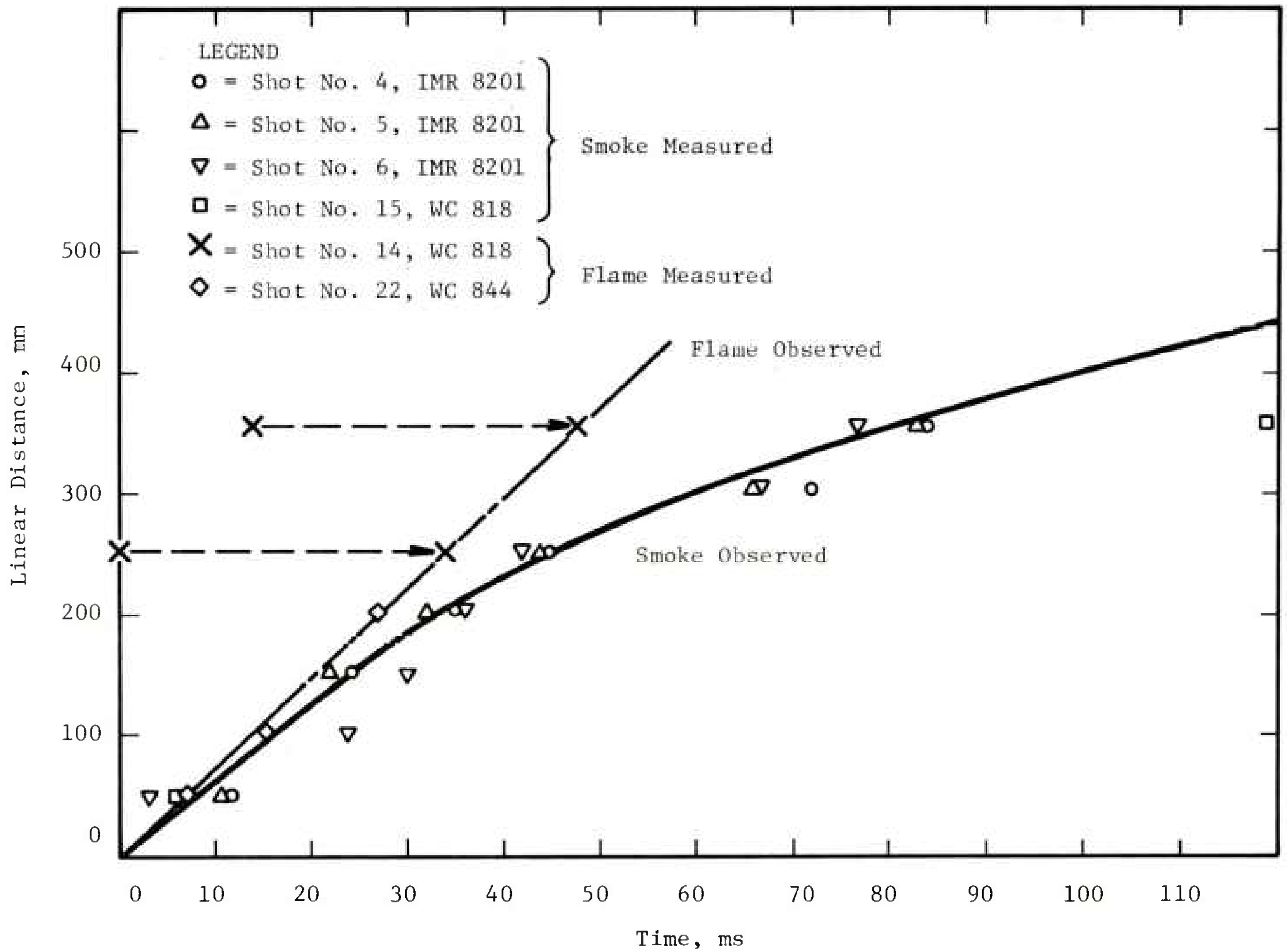

Figure 6. Apparent burning distance versus time

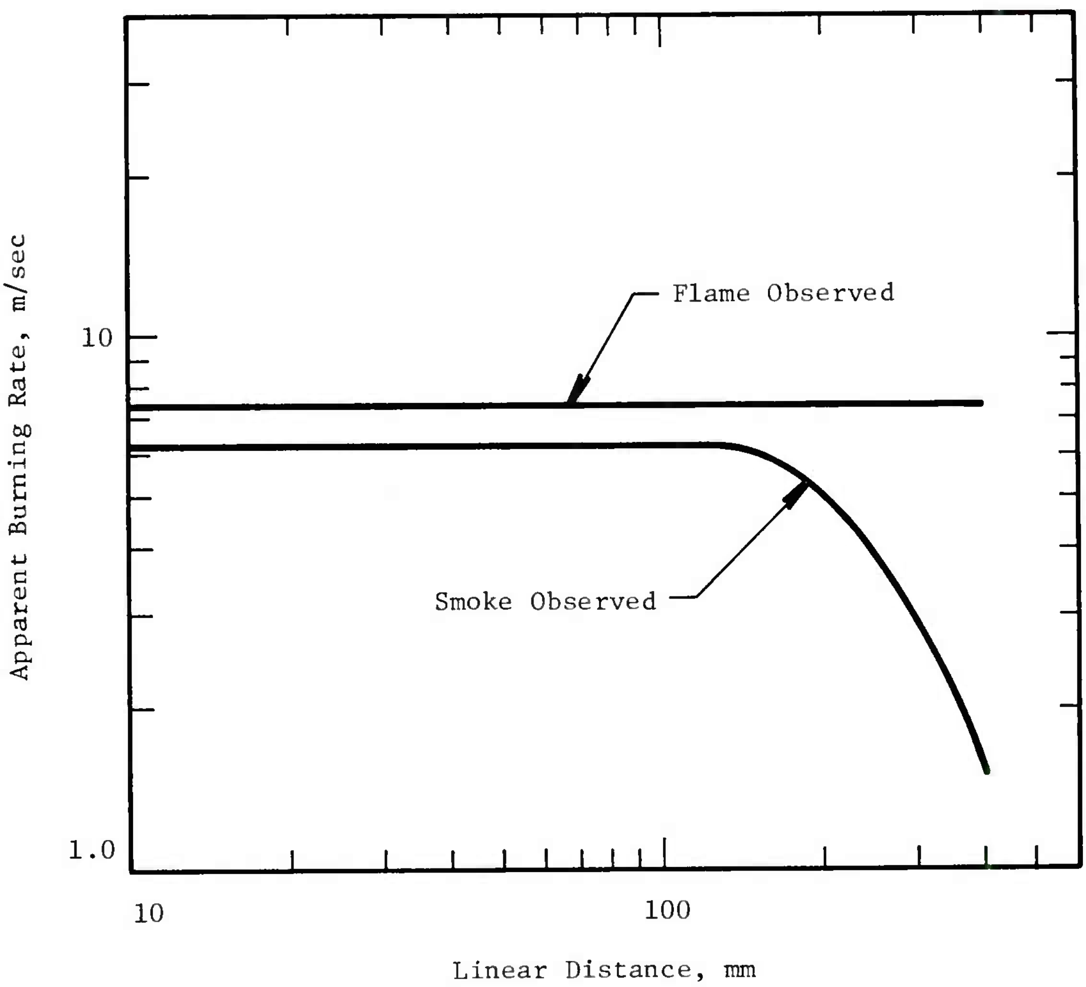

Figure 7. Apparent burning rate vs linear distance burnt fire in hopper, bottom ignition

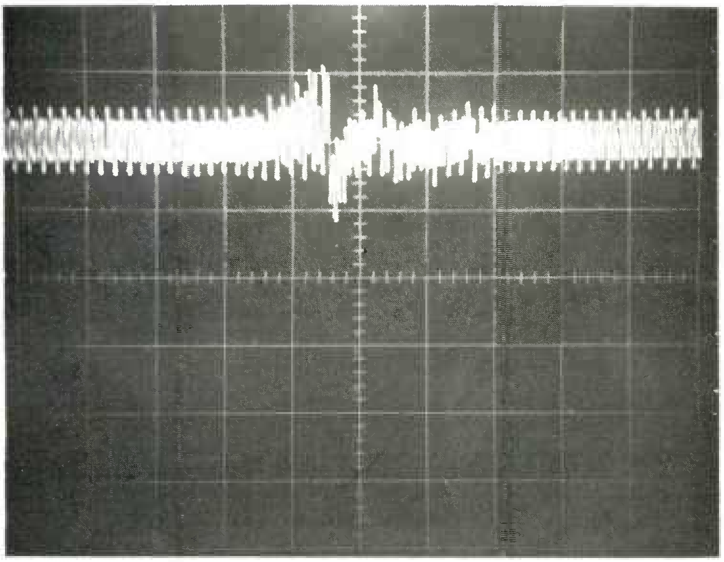

Figure 8. Typical hopper pressure record for IMR 8208 propellant

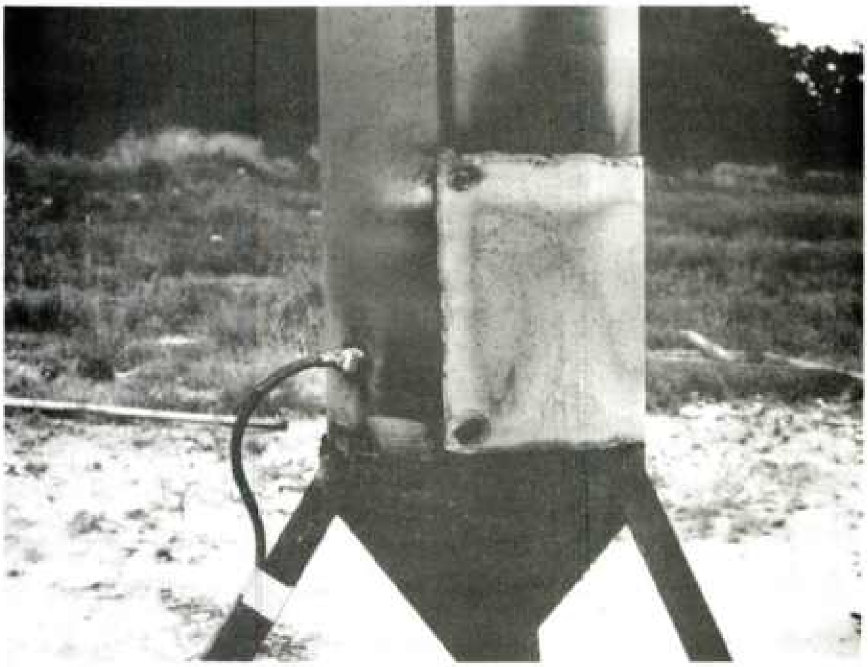

Figure 9. Pressure gauge location, conventional hopper

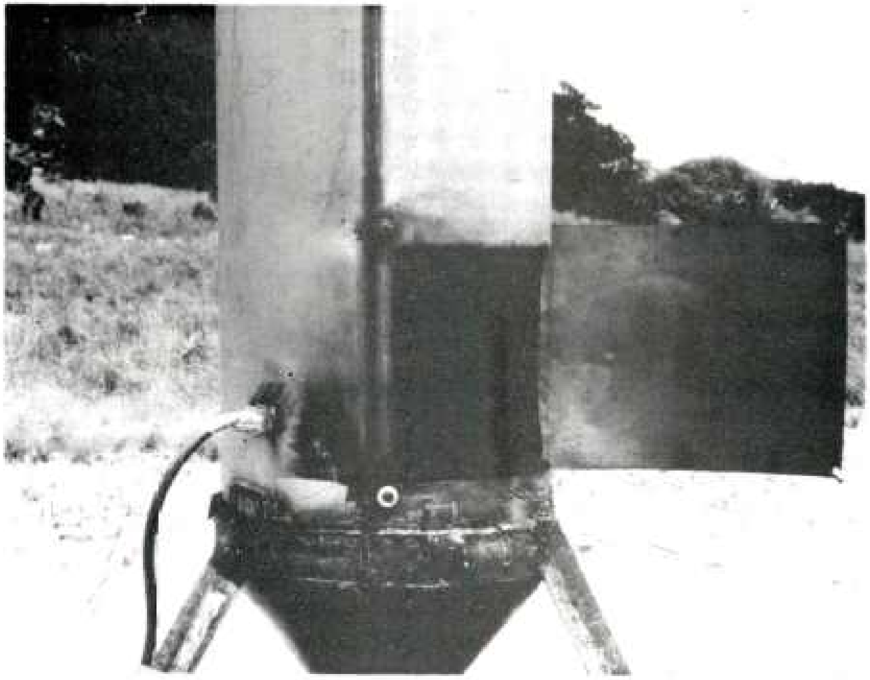

Figure 10. Loading port open after test with IMR 8208 propellant

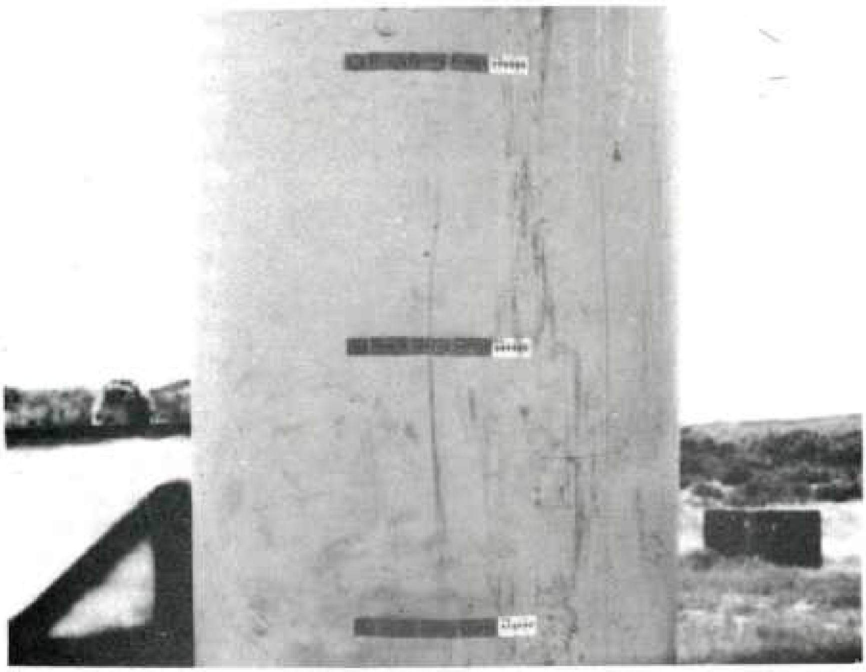

Figure 11. Teletemp locations on the conventional hopper, after a test

Figure 12. Steel feed pipe and fragments after explosion reaction of IMR 8208 propellant within the pipe

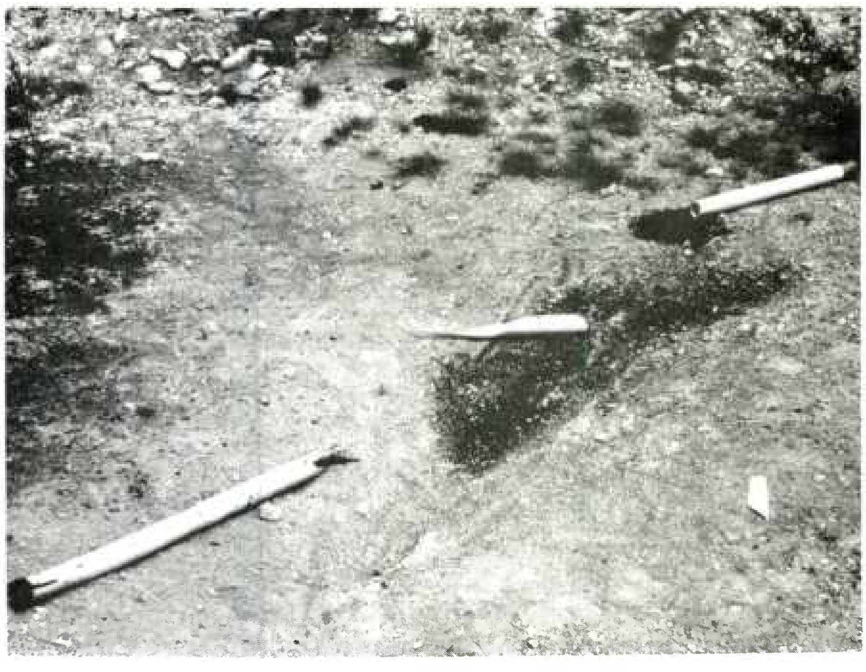

Figure 13. Typical PVC feed pipe fragments, IMR 8208 propellant test series

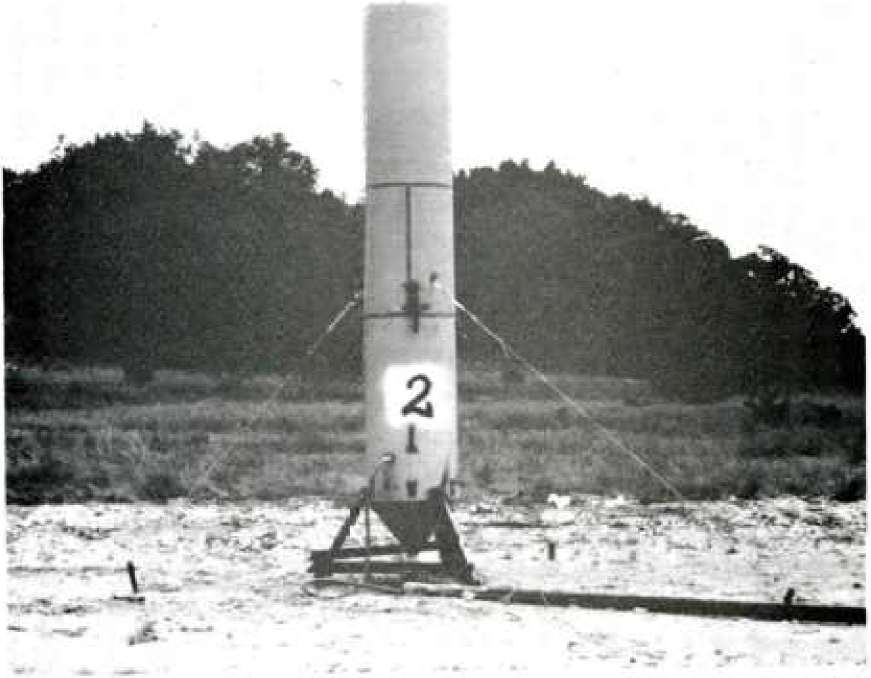

Figure 14. Initial conventional hopper prior to test with WC 818 propellant

Figure 15. Initial conventional hopper after test with WC 818 propellant

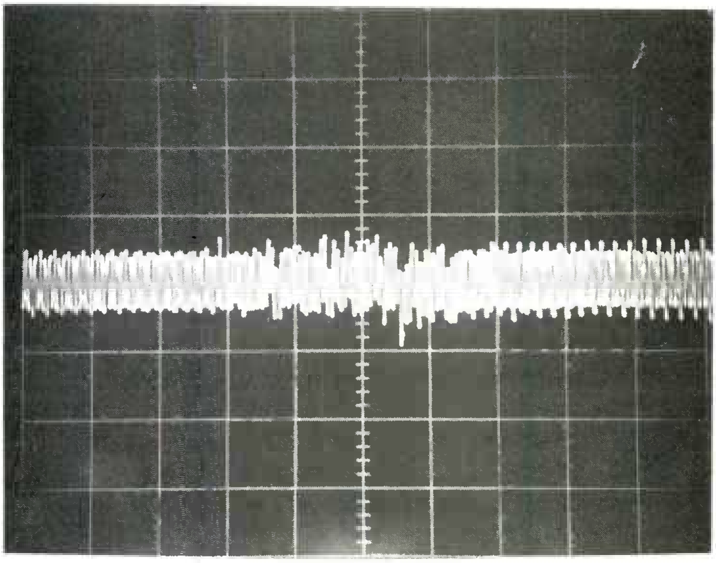

Figure 16. Typical hopper pressure record for WC 818 propellant

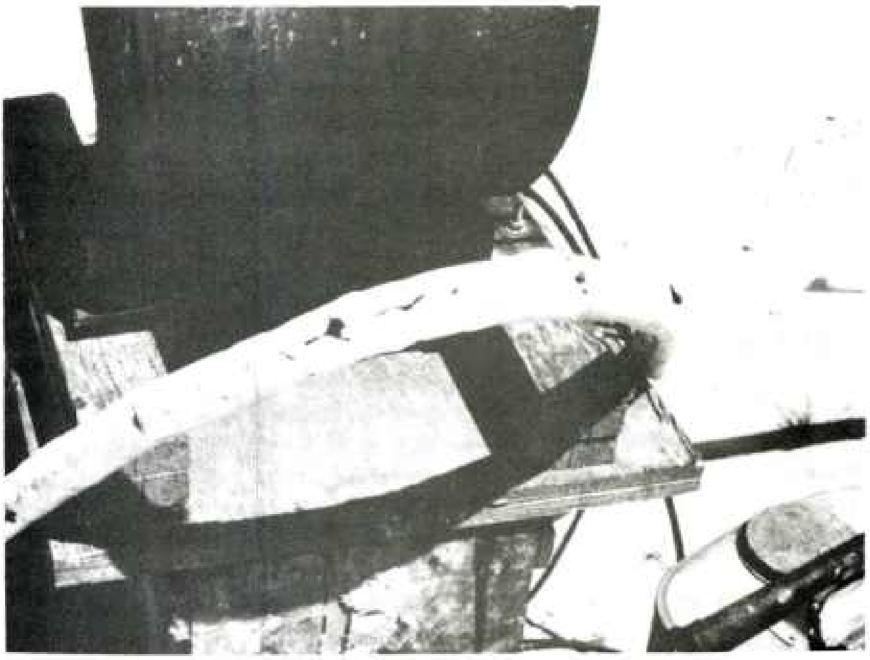

Figure 17. Typical PVC feed pipe after WC 818 propellant test

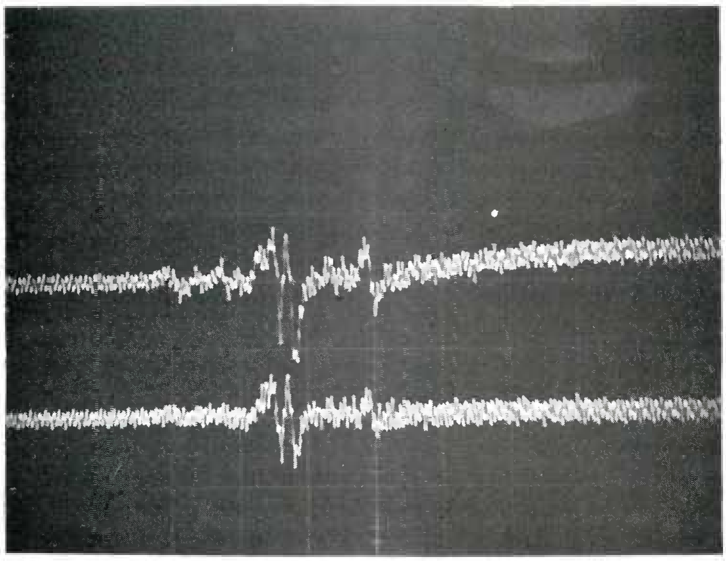

Figure 18. Pressure traces from SCAMP hopper with 45 kg of WC 844 propellant

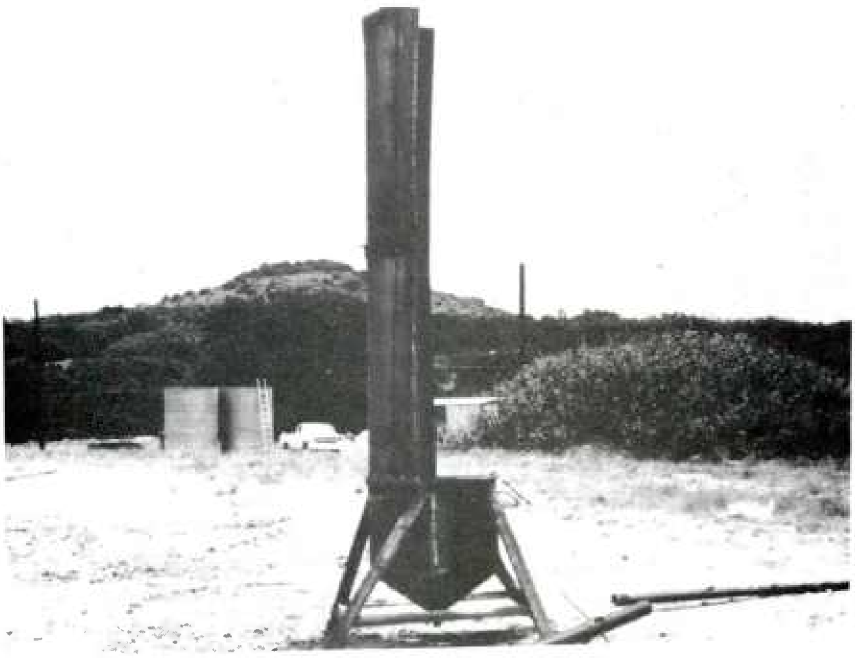

Figure 19. SCAMP hopper after 91 kg of WC 844 propellant were initiated in hopper

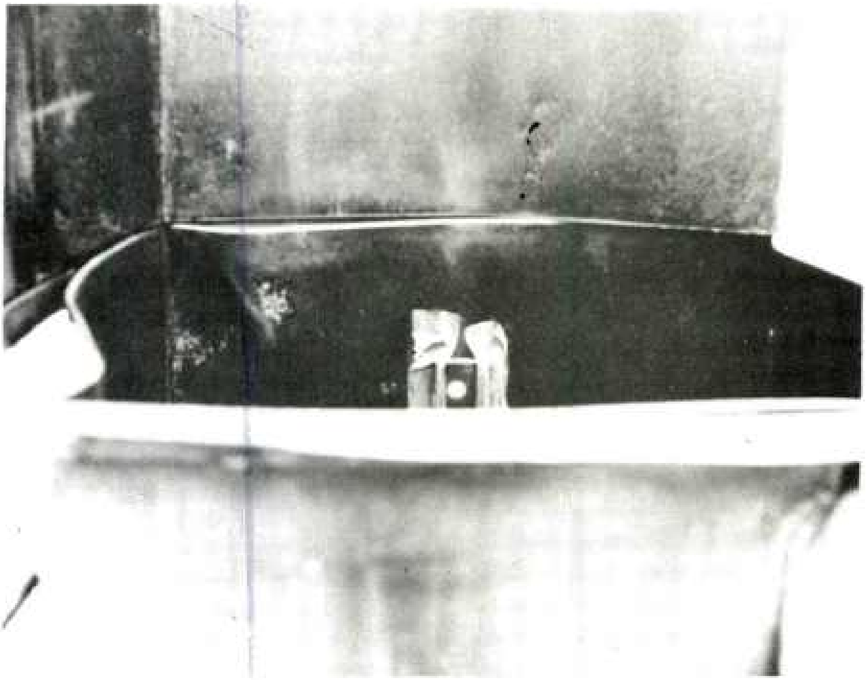

Figure 20. Hopper-stack junction after 91 kg of WC 844 propellant were initiated in SCAMP hopper

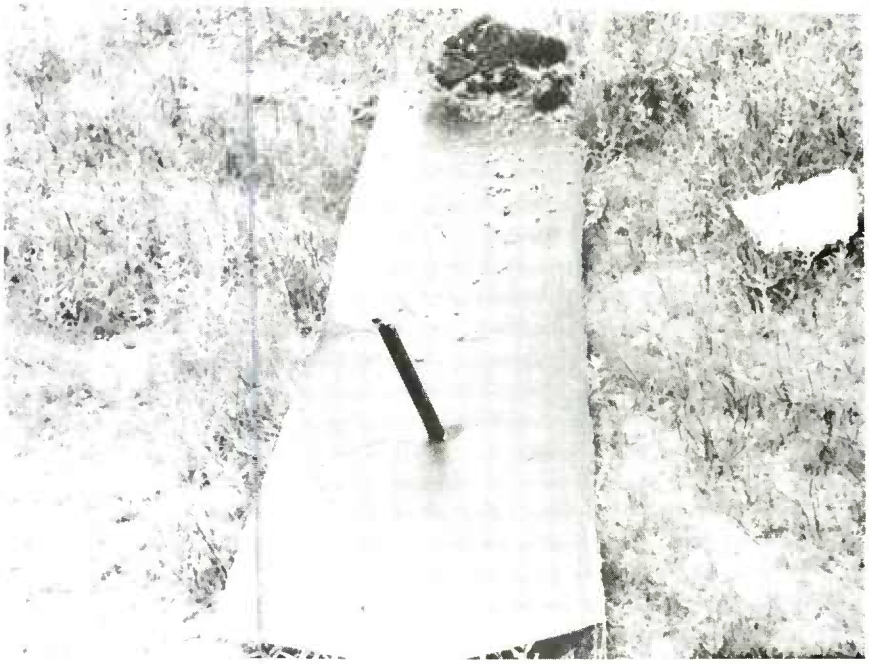

Figure 21. Second stack panel from SCAMP hopper after 91 kg of WC 844 propellant were initiated

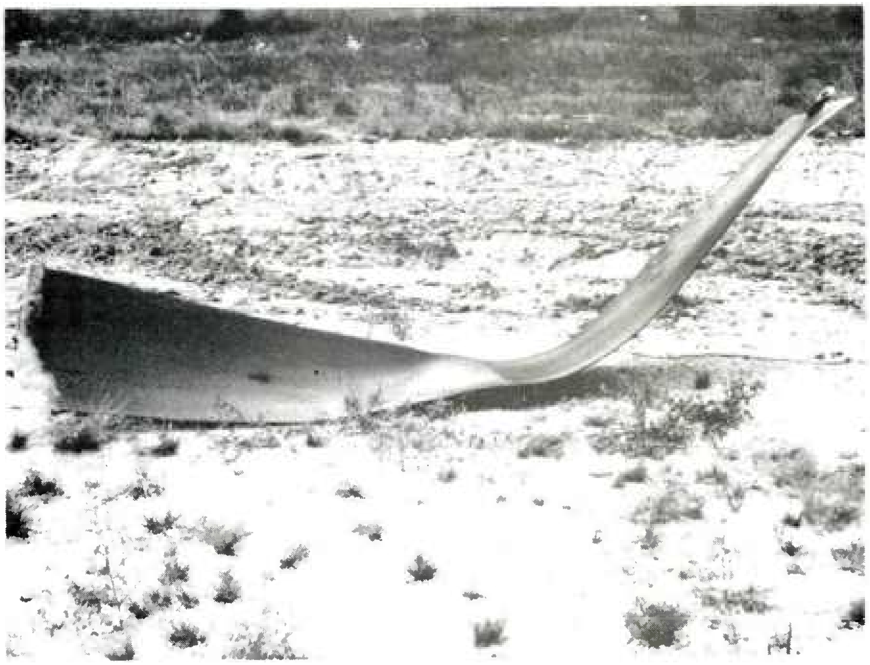

Figure 22. Stack panel after 91 kg of WC 844 propellant were initiated in SCAMP hopper

Figure 23. "Vent pipe" of SCAMP hopper after 91 kg of WC 844 propellant were initiated in hopper

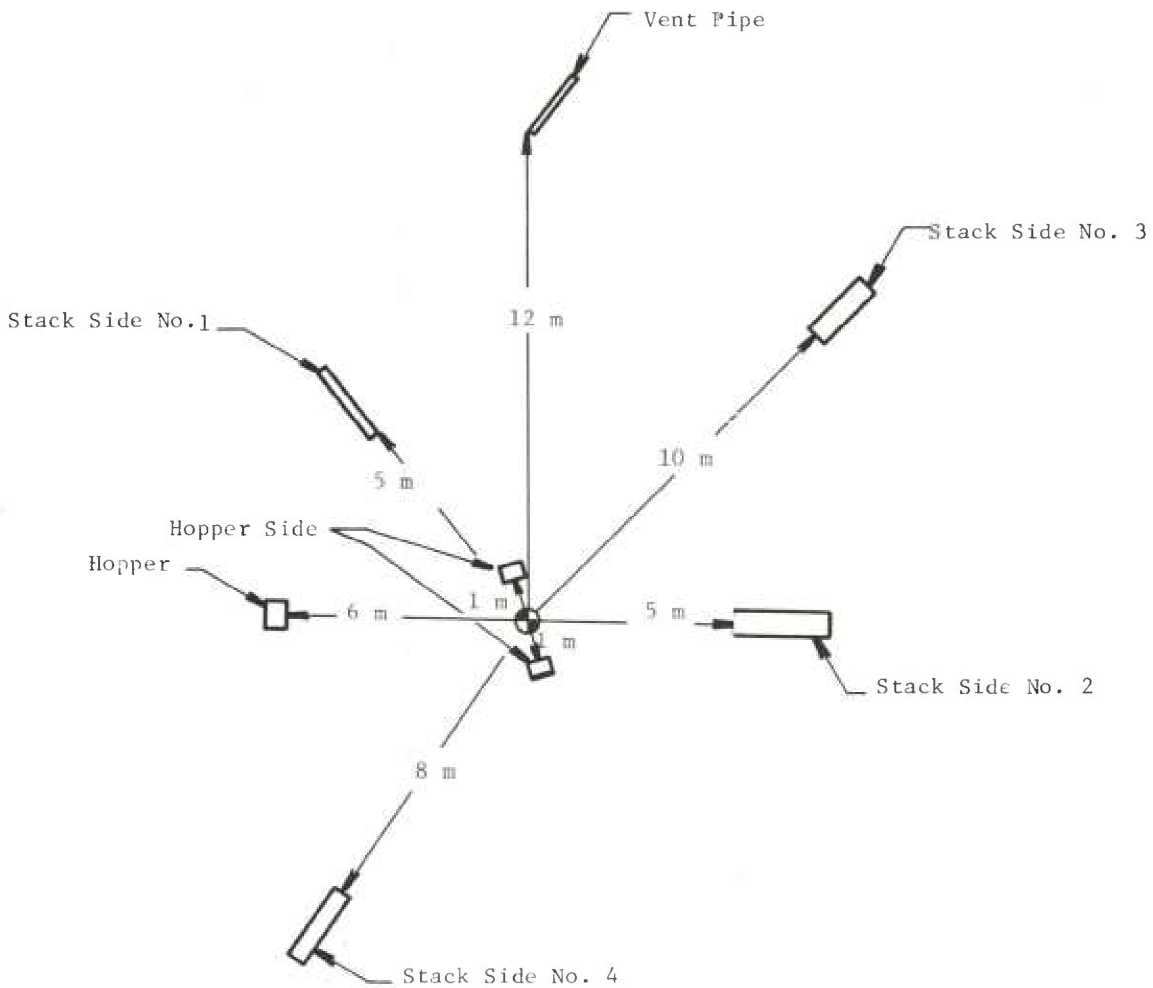

Figure 24. SCAMP hopper debris distribution following test with 68 kg of WC 844 propellant

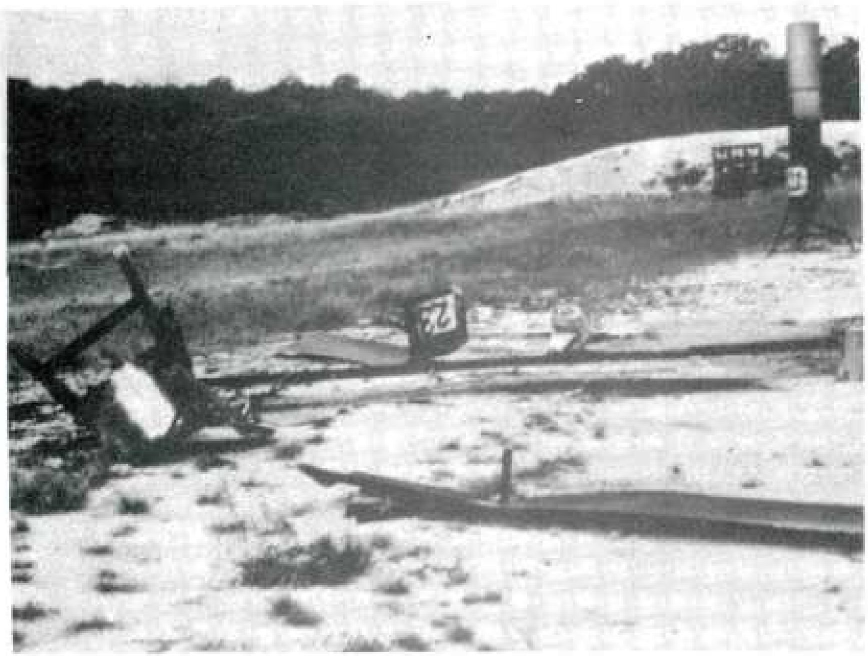

Figure 25. SCAMP hopper debris after initiation of 68 kg of WC 844 propellant (stack panel no. 4 in foreground)

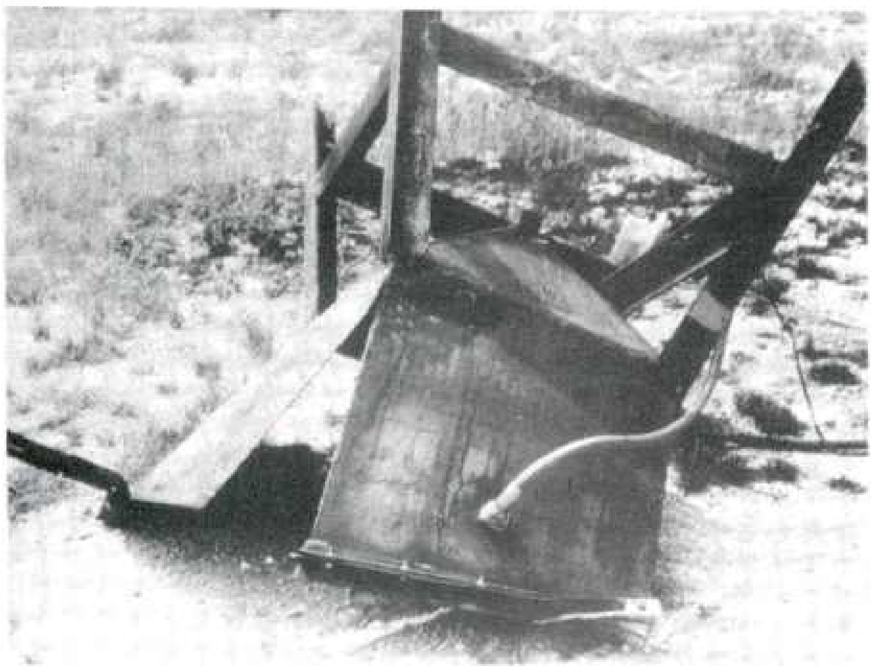

Figure 26. SCAMP hopper base after initiation of 68 kg of WC 844 propellant

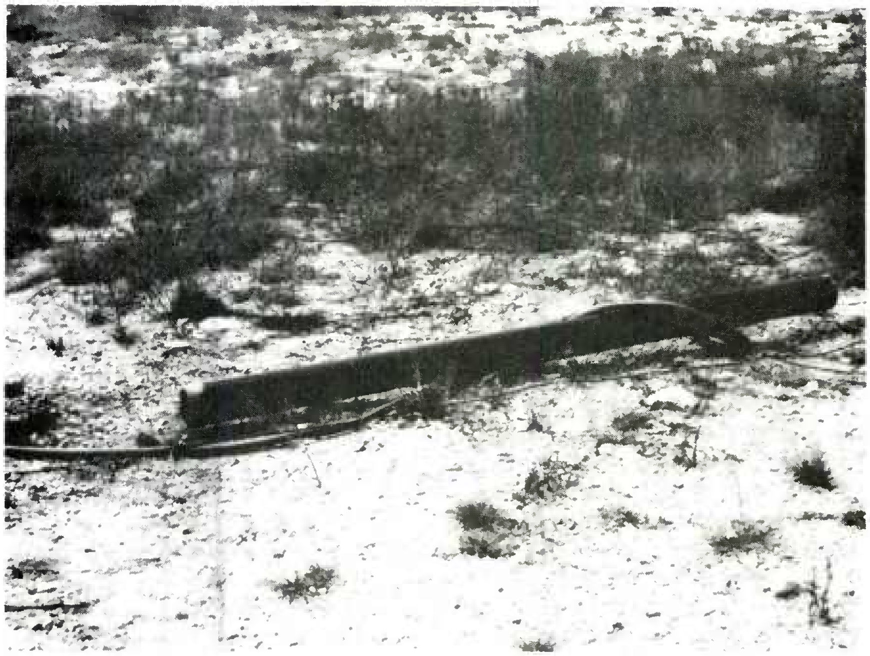

Figure 27. SCAMP hopper "vent pipe" after initiation of 68 kg of WC 844 propellant

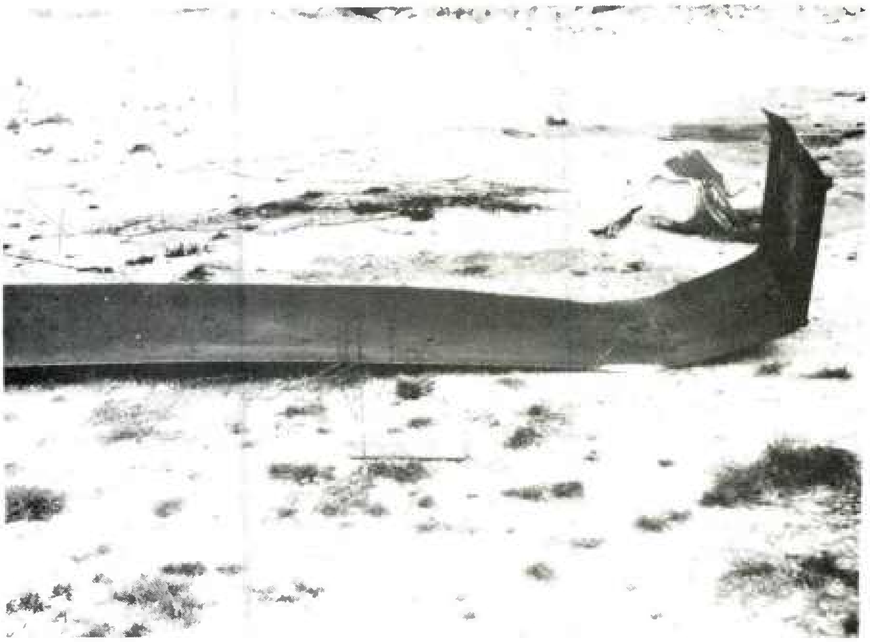

Figure 28. SCAMP hopper stack panel no. 1 after initiation of 68 kg of WC 844 propellant

Figure 29. SCAMP hopper stack panel no. 2 after initiaon of 68 kg of WC 844 propellant

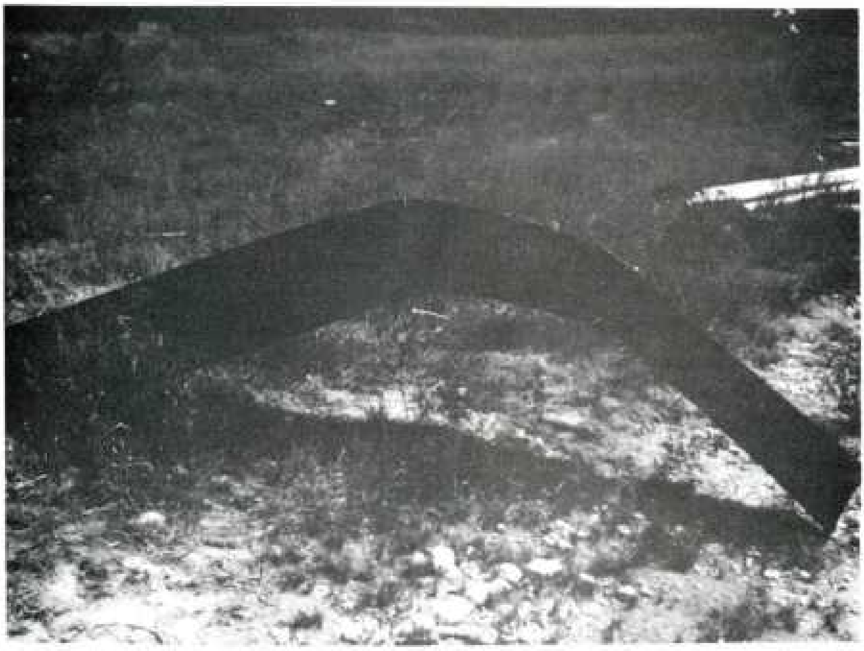

Figure 30. SCAMP hopper stack panel no. 3 after initiation of 68 kg of WC 844 propellant

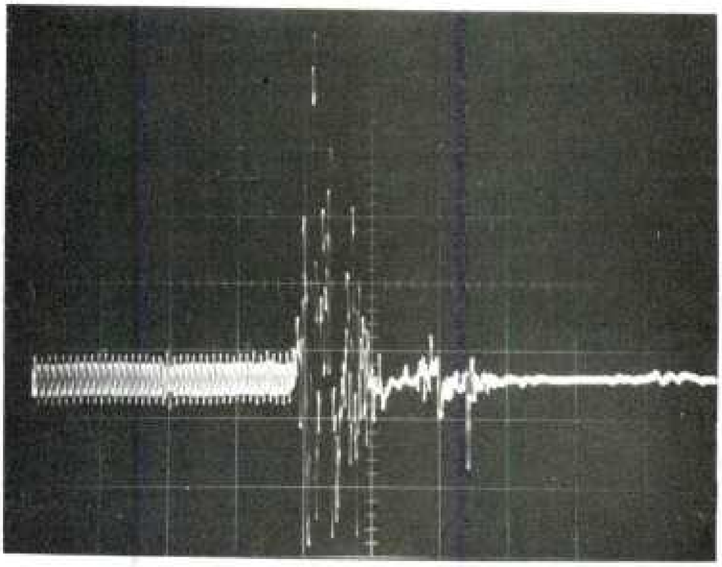

Figure 31. Pressure trace from SCAMP hopper with 68 kg of WC 844 propellant

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