UNCLASSIFIED

AD NUMBER
ADB029348
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Proprietary Information; 11 AUG 1978. Other requests shall be referred to Army Armament Research and Development Command, Attn: DRDAR-TS, Picatinny Arsenal, NJ 07811.**
AUTHORITY
usaardc notice 23 jan 1979

THIS PAGE IS UNCLASSIFIED

AD-B029 348

LEP-L

AD

AD-E400 139

TECHNICAL REPORT ARLCD-TR-78010

AN EVALUATION OF LIQUID EXPLOSIVES FOR FOXHOLE DIGGING

SHEPHERD LEVMORE
ROBERT T. SCHIMMEL

APRIL 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

LEVEL II

5/18

~~(12)~~ (2)

AD

AD-E400 139

AD B029348

TECHNICAL REPORT ARLCD-TR-78010

AN EVALUATION OF LIQUID EXPLOSIVES FOR FOXHOLE DIGGING

SHEPHERD LEVMORE
ROBERT T. SCHIMMEL

DDC
AUG 24 1978
A

APRIL 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

~~APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED~~.

Distribution limited to U.S. Gov't. agencies only;
Proprietary Info.; 11 AUG 1978. Other requests
for this document must be referred to U.S. ARRADCOM
attn: DRDAR-TS
Dover, N.J. 07801

AD No.
DDC FILE COPY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

⑭ ~~1. REPORT NUMBER~~ ARLCD-TR-78010

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

⑥ ~~4. TITLE (and Subtitle)~~

AN EVALUATION OF LIQUID EXPLOSIVES FOR FOXHOLE DIGGING.

⑨ ~~5. TYPE OF REPORT & PERIOD COVERED~~ Technical rept.

~~6. PERFORMING ORG. REPORT NUMBER~~

⑩ ~~7. AUTHOR(s)~~

Shepherd/Levmore
Robert T./Schimmel

8. CONTRACT OR GRANT NUMBER(s)

ACSFOR
ENSURE Index No. 279-K

~~9. PERFORMING~~ ORGANIZATION NAME AND ADDRESS

ADED, Munitions Engr Division
Picatinny Arsenal
Dover, NJ 07801

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

AMCMS Code No.552C.19.55900

11. CONTROLLING OFFICE NAME AND ADDRESS

ARRADCOM, TSD
STINFO (DRDAR-TSS)
Dover, NJ 07801

⑪ ~~12. REPORT DATE~~ APRIL 1978

13. NUMBER ~~OF PAGES~~ 102

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

⑱ SBIE

⑫ 88p.

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

~~Approved for public release, distribution unlimited~~.

⑲ 1L-E400-259

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Foxhole digger
Cratering
Liquid explosive vs dynamite
Nitromethane paste explosive
Freezing-point depressant
Astrolite LTX-G2
Slurry explosives
DBA-208X
Astro-pak
3.5-inch M28A2 rocket warhead
Shaped charge in permafrost

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

Five new explosive formulations were screened for possible use in foxhole digging. Three of them were based on nitromethane/nitroethane/RDX (NM/NE/RDX), with viscosities varying from liquid through slurry to paste. The other formulations were: (1) a two-part gelled slurry mix, DBA-208X, submitted by the IRECO Chemical Corporation, and (2) a two-part liquid formulation, LLTX G-2, submitted by the Explosives Corporation of America (EXCOA). → over)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

410 163

20. (Cont'd)

After testing, the liquid NM/NE/RDX was selected as the most promising formulation for fulfilling the requirements of ENSURE 279-K because of its superior handling, performance, and sensitivity characteristics, as well as its moderate cost. Suggestions for improving the use of liquid explosives in cratering are also given. Finally, the 3.5-in. M28A2 HEAT rocket warhead is evaluated for its capability to produce boreholes in permafrost as a prerequisite for placing explosive cratering charges.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation and technical assistance received from:

Dr. Richard W. Watson, Mr. V. Edmond Hay, Mr. John Ribovich, and Mr. Carl R. Becker, of the Explosives Research Center, Bureau of Mines, U. S. Department of Interior

Dr. M. Mellor and Mr. P. Selman of the Cold Regions Research and Engineering Laboratories (CRREL), Hanover, N. H., and Mr. W. Simoni of the CRREL Field Office, Fairbanks, Alaska

Dr. Raymond Walker, Mr. Louis Avrami, Mr. Joseph Hershkowitz, Mr. Floyd Hildebrant, Mr. Joel Harris, and Mr. Joseph Pelphrey of the Large Caliber Weapons System Laboratory, ARRADCOM, and the late Mr. Stanley J. Lowell and Mr. John Chovanec of Picatinny Arsenal.

TABLE OF CONTENTS

Tables

Figures

BACKGROUND

The Explosives Corporation of America (EXCOA) advertised an "Instant Foxhole Digger," known as Astro-Pak, in a 1968 Far East edition of the Army-Navy-Air Force Times (Fig 1). Subsequently, ENSURE 279-K, calling for the shipment of 1,000 3-lb Astro-Paks to Korea for field evaluation, was initiated. This ENSURE required that the explosive be usable at extremely low temperatures and in rocky terrain (Ref 1). To define the temperature and other requirements for this application, a list of criteria was prepared (Appendix A) and concurred in by ACSFOR, OCRD, and MUCOM (Ref 2).

Picatinny Arsenal was requested to evaluate EXCOA's Astrolite® G-2[1] Explosive against these criteria, using previous test results. The findings of that evaluation indicated that this liquid explosive could not be mixed at -40°F and that it was rifle-bullet-sensitive, subject to low-velocity detonation (LVD), and probably toxic. Consequently, the order for the ENSURE supply of 1,000 Astro-Paks was placed in abeyance (Ref 3).

The U. S. Army Munitions Command authorized the evaluation of several candidate explosives other than Astrolite to meet the ENSURE 279-K criteria (Ref 4). Meanwhile, EXCOA developed two new low-temperature Astrolite explosive formulations, LTX-G2 and LLTX-G2, which can be mixed at temperatures of -20 and -40°F, respectively. These new formulations were not among the candidates selected for testing under ENSURE 279-K, since it was believed that their safety characteristics had not changed significantly from other known Astrolite formulations. A brief history of Astrolite explosives is given in Appendix D.

Four explosives were fully evaluated: one liquid, two slurries, and a paste. Toward the end of the evaluation, amended criteria for the explosive selection were received from OCRD (Ref 5 and Appendix B). As a result, some testing was conducted also with EXCOA's LLTX-G2 formula. This report includes the work conducted in that evaluation.

DISCUSSION

Five explosive compositions were investigated. Three of them were based on nitromethane/nitroethane/RDX (NM/NE/RDX). The other two were two-part compositions that required mixing prior to use. One, DBA-208X, was submitted by IRECO Chemicals, Salt Lake City, Utah (Appendix C);

---

[1] Astrolite is a registered trademark of ROCKCOR, Incorporated, Redmond, Washington.

the other, LLTX-G2, submitted by EXCOA, Issaquah, Washington, (Appendix D). Their formulations although proprietary, also are shown in Appendix F, along with those of the NM/NE/RDX type.

Two important performance characteristics of an explosive for the foxhole digger application are pourability and functionability at -40° F. Nitromethane was considered a prime candidate as a liquid vehicle for the RDX because of its inherent explosive properties. However, since NM freezes at -29°F, the freezing point of the liquid component was depressed to -40°F by adding 25% by weight of nitroethane (freezing point -91°F).

The basic NM/NE 75/25 solution was mixed with various proportions of RDX, aluminum, and thickeners, to obtain three different consistencies: liquid, slurry and paste. A brief history of the research conducted on nitromethane at Picatinny Arsennal is given in Appendix E.

TESTS AND RESULTS

Sensitivity Tests

Burning

An unconfined burning test on DBA-208X and various NM/NE/RDX formulations was conducted in accordance with Paragraph 3-9 of Reference 6. However, polyethylene bottles containing ½ pound of each explosive were used in place of the specified 2-inch solid explosive cubes. These bottles were placed in a fire of kerosene-soaked sawdust. The DBA-208X appeared to burn more rapidly than any of the NM/NE/RDX formulations. The EXCOA liquid explosive LTX-G2 as well as its liquid and solid ingredients were subjected to a fire test conducted by the Bureau of Explosives (Ref 7). In all cases the bottles melted and the test samples were completely consumed by rapid burning. No explosions occurred.

Card Gap

Card-gap tests were conducted to obtain the relative sensitivity of the candidate explosives to shock initiation by adjusting the thickness of the plastic attenuator required between a donor and an acceptor explosive to obtain a high-order detonation 50% of the time. The larger the gap (the more plastic attenuators) the greater the sensitivity (Ref 8). The acceptor explosive was contained in a 16-inch-long steel pipe with a 0.133-inch-thick wall and a 1.05-inch inside diameter (Fig 2). The LTX-G2 (tested by EXCOA) was contained in a steel pipe of the same diameter but only 3 inches long.

Table 1, Column 4, contains the card-gap data listing the explosives in the order of increasing sensitivity at 77°F. The NM/NE/RDX explosives showed small decreases in sensitivity as the test temperature was reduced from 160°F to -45°F. At 45°F, the DBA-208X was one of the least sensitive, but at 77°F and 160°F it was the most sensitive explosive tested. Unsensitized NM data is shown for reference.

Detonation Rate

The rate of detonation was obtained by insertion of a continuous electric probe in the same steel pipe described above for the card-gap test. The probe consists of a fine insulated wire with a resistance wire wrap. This assembly is embedded in the explosive for its entire length (Fig 2). The explosive is initiated with a 1.00-inch-long by 1.625-inch-diameter tetryl booster. As the detonation progresses, the portion of the resistance wire ahead of the reaction is unaffected while the portion behind the detonation front is electrically shorted, yielding a continuous difference in potential during propagation of the detonation. The rate at which the potential changes is recorded.

(Note: LLTX-G2 was confined in a one-inch inside diameter polyethylene tube, with a 1/8-inch-thick wall, while LTX-G2 was confined in a 0.625-inch inside diameter tube, with a 1/16-inch-thick wall, as tested by EXCOA.)

A high detonation rate is desirable for general demolition; however, its value for cratering purposes is questionable. Table 2 presents the observed data in the order of decreasing detonation velocity.

High- and Low-Velocity Detonation

The card gap and detonation rate tests showed that all of the explosives tested reacted with a high-velocity detonation (HVD). HVD propagations vary from 5 to 9 mm/μsec. To obtain a steady state HVD, most explosives require a shock level of 30 to 120 kilobars. At reduced shock levels, obtained by increasing the attenuator thickness, the detonation velocity of most explosives (including the ones tested in this program) will decelerate. Astrolite LLTX-G2 was not tested; but Astrolite A-1-5, when tested in another project, did propagate by LVD (Ref 9). LVD propagations proceed at a low steady rate ranging from 1 to 2 mm/μsec. They can be initiated at shock levels ranging from 1 to 10 kilobars (Ref 10). Because of the low shock levels required to induce detonations, explosives subject to LVD are normally considered hazardous. However, for this application (and considering the nonhazardous manner in which the two-part Astrolite LLTX-G2 would be carried) the LVD characteristic may be a positive factor. The same degree of sensitivity that makes it LVD-prone contributes to its ability to propagate in cracks smaller than do the other explosives tested. It is also understood that the lower detonation rate that occurs during LVD propagation may enhance the cratering action. Regarding safety in handling, premixed Astrolite A-1-5 passed a 40-foot drop test while in aluminum containers (Table 2 of Ref 9).

Impact

An impact test using the Picatinny Arsenal 2-kilogram drop weight apparatus was conducted on the three NN/ME-based explosves. The paste explosive was the least sensitive, while the liquid was the most sensitive. The drop heights obtained for the liquid, slurry, and paste were 7, 8, and 11 inches, respectively. In comparison, those for RDX and PETN are 8 and 6 inches, respectively.

Rifle Bullet Impact (30 cal)

Rifle bullet impact tests were conducted on half-pound samples of the NM/NE and DBA-208X explosives. The samples, placed in polyethylene containers, were located at a distance of 90 feet from the muzzle of the rifle. No reaction occurred upon impact on ten samples of each explosive.

The LLTX-G2 was tested in the Astro-Pak configuration, which consists of two parts: an inner aluminum can holding an inert liquid, and an outer polyethylene bottle containing both that can and a nonexplosive solid (Fig 3). After the can is punctured and the liquid and solid component become mixed, 1.5 lb of high explosive results. Normally, the explosive would be poured out immediately after mixing. However, if a bullet strikes a loaded metal container inside the lower segment of the prototype Astro-Pak, this explosive reacts 8 out of 10 times. Thus, the LLTX-G2, after mixing, does not meet ENSURE requirement "a" of Appendix A.

Projectile Impact (50 cal)

All the explosives except LLTX-G2 were tested to determine the projectile velocity required to initiate the explosive 50% of the time, using the Bruceton technique. The projectile is a cylindrical brass slug fired from a smoothbore 50-caliber gun (Fig 4 from Ref 11). The explosives were contained in 1½-inch by 3-inch-long steel tubes with a 0.145-inch-thick wall. The tube ends are closed with 0.003-inch-thick plastic caps. Table 2 gives the results and lists the explosives in order of increasing sensitivity. Astrolite-G results are included because Astrolite LLTX-G2 was not tested.

Low-Temperature Cap Initiation

A -40°F initiation test was conducted with the explosives placed in a 3/8-inch-square by 4-inch-long aluminum foil container or "boat". An M6 Blasting Cap was embedded 1/4-inch into one end of the explosive. The loaded container was taped to a 1/2-inch-thick by 4-inch-square aluminum witness plate (Fig 5a). The assembly was conditioned by placing it on dry ice or in a conditioning box. Polyethylene foam insulation was used to maintain its -40°F temperature for the test. All of the explosives detonated as shown by the groove in the witness plate (Fig 5b).

IRECO's two-part explosive DBA-208X was tested in a 1.35-inch inside diameter by 4-inch-long cardboard tube for blasting cap and booster sensitivity. The two-part system is intended to be supplied in the configuration shown in Figure 6. The two parts, A (liquid) and B (dry premix), are intended to be inert when separated. The liquid portion did not initiate with an M6 Blasting Cap, but initiated 2 out of 5 times with a 4-gram Composition C4 booster.

Friction Pendulum

Dried samples of the NM/NE/RDX/A1 formulations were tested with a fiber and a steel shoe. No reactions were obtained with a fiber shoe, but all samples reacted to a steel shoe. Samples of NM/NE/RDX liquid and slurry and DBA-208X were tested with the steel shoe, and no reaction was observed. Since NM/NE/RDX paste produced only crackles in 5 out of 10 samples tested with the steel shoe, no tests were conducted with the fiber shoe. Since dry RDX explodes when tested with the steel shoe while most RDX/TNT/A1 explosives are unaffected, it is apparent that the NM/NE desensitizes the RDX in the friction test.

Electrostatic

The electrostatic sensitivity of the NM/NE/RDX, LLTX-G2, and DBA-208X formulations was determined with the test fixture shown in Figure 7. The results of the tests are shown in Table 4. This test method subjected the explosive to an electrostatic discharge through a variable air gap from a capacitor charged to a desired voltage with a line resistance of 5,000 or 50,000 ohms. Constants for all tests included a 0.5 microfarad capacitor, a temperature of 70 - 75°F, and a 40 - 50% relative humidity. The test was conducted by subjecting the explosives to the maximum voltage (20,000) and then reducing the voltage until 10 samples in a row failed to initiate. It should be noted that the lowest energy level required for initiation exceeded 48 joules. This is significantly greater than the 0.015-joule level established for acceptance. Any explosive reacting below this latter level is considered potentially hazardous (Ref 12).

Toxicity

EXCOA furnished a report concerning toxicological studies on a similar Astrolite composition, LTX G-2 (Ref 13). That report deals with the use of Astrolite under controlled laboratory conditions, and although extrapolations to field conditions are made, no mention is made concerning the possible absence of water in the field for washing spillages, or to the possible consequences of the Astro-Pak containers being punctured during field handling or storage. The author of the referenced report concludes:

> "It is our opinion that the relatively low toxicity found, when considered in relation to the forseeable (sic) practical exposure circumstances, indicates very little practical hazard for this product. We believe the odor will suffice to limit exposure whenever ventilation is less than excellent."

LLTX G-2 is a hydrazine based explosive. Hydrazine and its compounds are known to cause severe toxic effects on contact and when inhaled or ingested. Consequently, LLTX-G2 fails to meet a basic requirement of ENSURE 279K (Appendix A, Item d.). Also, Picatinny Arsenal personnel reported that, when pouring LLTX G-2 during the cratering tests, an irritating gas, probably ammonia, was given off.

Nitromethane and nitroethane possess only slight local toxicity, and moderate to severe toxic ingestion and inhalation effects. It is recommended that the Office of the Surgeon-General be requested to perform a hazards analysis on any formulation based on these ingredients before their use in a field item is finalized.

Performance Tests

Minimum Propagation Thickness

Propagation of explosives in narrow diameters or thin films is an important factor for a foxhole digger, since the explosive may be required to flow into narrow holes or cracks. The minimum propagation thickness was determined in a modified wedge test. The wedge tapered from ½ inch to zero over a 36-inch length while the explosive was 9/32-inch deep for the entire length (Fig 8). The explosive was initiated at the large end with an M6 Blasting Cap. The termination of the high detonation regime was registered on a steel witness plate. The propagation thicknesses for the NM/NE/RDX formulations are similar. Astrolite LLTX-G2 was not subjected to this test, but concluding from the performance of Astrolite it should do well. DBA-208X exhibited the largest propagation thickness (Table 5).

The conventional wedge test, also used in this program, was originally developed for studying transitions in rate of detonation from high to low velocity in liquid explosive systems and for determining the minimum thickness at which each regime can be sustained (Ref 14). In actual use, an explosive wedge is formed by tilting an open tray containing the liquid material; a continuous velocity probe extending the full length of the tray is used to monitor detonation velocity.

In these experiments, the wedge-shaped charges were formed in a container consisting of a 4-inch-wide by 18-inch-long by ½-inch-thick steel base plate, with 1/16-inch-thick plexiglass sides. The charge taper varied from 0.5 inch to zero in 18 inches. The charges were initiated with a 1.0-inch-long by 1.625-inch-diameter tetryl booster coupled to the center of the 4.0-inch-wide by 0.5-inch-thick end of the wedge; the booster charge was separated from the acceptor charge by 1/16-inch-thick plexiglass, forming the end of the container (Fig 9). Tests were conducted at -45 and 77°F (Table 6).

The observed detonation rates for the explosives at -45°F in the wedge geometry were the same as those obtained in the card-gap tests at the same temperature. At 77°F, the liquid and slurry explosives exhibited essentially the same failure thickness as observed at -45°F, while the paste explosive yielded a value of 0.02 inch at 77°F, compared to 0.06-inch at -45°F. The observed minimum propagation thickness for the DBA-208X explosive at 77°F was 0.13 inch, somewhat less than that of NM, but in excess of the values observed for the liquid, slurry, and paste explosives.

With the exception of the DBA-208X explosive, the observed detonation rates in the wedge test were about the same as those obtained in the card-gap trials at both ambient and depressed temperatures. None of the explosives mentioned above exhibited any tendency to undergo LVD. Astrolite LLTX-G2 was not tested; however, Astrolite A-1-5 in a 1-inch to zero wedge propagated high order to a thickness of 0.19 inch and then transited to an LVD at a thickness of 0.01 inch or less (Ref 9).

Bubble Energy

Underwater tests were conducted to determine the bubble and shock energy of each explosive (Ref 15). Three shots consisting of 950 grams of explosive with a 100-gram tetryl booster each were loaded into a waterproof cardboard carton and centered 12 feet below the surface of a pond 24 feet deep by 200 feet in diameter. Two piezoelectric pressure transducers were located 12 feet from the center of the charge in the same horizontal plane. Table 7 provides the data in order of decreasing bubble energy.

Plate Dent

Plate dent tests were conducted to provide a comparative measure of explosive strength. This characteristic is assumed to be pertinent to general demolition applications. In this test, a cardboard tube of 1.35 inch inside diameter by 4.25 inch length was filled with approximately 0.4 lb of explosive. The loaded tube was placed on two 1-inch-thick by 6-inch-square steel plates and initiated by an M6 Blasting Cap. Table 8 gives the results in order of decreasing explosive output.

Expanding Cylinder

A method for comparing the relative energetics of various explosive systems is to confine the explosive in a metal cylinder and measure the casing expansion velocity when the charge is detonated (Ref 16). The results of such measurements are usually expressed as kinetic energy of the metal cylinder per unit explosive mass in units of joules/gram. Ordinarily, the casing expansion velocities are determined with a high-speed streak camera using back lighting. Recently it was found that the casing velocity also could be measured by mounting a continuous-velocity probe on a lead bar and placing the combination along charge length at a known tilt angle away from the downstream end of the charge (Fig 10). In these experiments the lead bar serves as inertial backing for the continuous-rate probe. It was placed in contact with the 1.05-inch inside diameter by 16-inch-long steel charge container, 2.0 inches from the booster end of the acceptor charge, at an angle of 7° from the charge axis. When used in this manner, the expanding case collapses the probe, producing a pseudo velocity, from which the velocity of the casing can be calculated.

The measurements obtained in the expanding cylinder test are presented in Table 9. The paste explosive produced the highest velocity while DBA-208X produced the lowest. The kinetic energy per unit explosive mass also was highest for the paste explosive and lowest for the DBA-208X slurry. It should be noted that the values of kinetic energy per unit explosive mass does not necessarily rank in the same order as the values of casing velocity. This is primarily due to differences in loading density. For example, the slurry explosive produced a higher casing velocity than the liquid explosive. However, the calculated value of kinetic energy was higher for the liquid than the slurry. Although Astrolite LLTX-G2 was not tested, it is assumed that its casing velocity would be higher than that of Astrolite A-1-5, due to the latter's high aluminum content (Ref 9).

Cratering

In the small-scale cratering tests, ½ lb of explosive was loaded and lightly tamped into each 1¼-inch-diameter by 1-foot-deep pilot hole. The various explosives were tested in alternating holes at an air temperature of 80°F. Five cratering tests were conducted with each explosive; the average dimensions obtained are given in Table 10. An M6 Blasting Cap was placed at the bottom of the hole and then raised approximately one inch The "no fires" recorded for the paste and the slurry explosives may have been caused by the explosive not flowing around the cap due to bridging (which is defined as a closing of the pilot hole by the explosive before it reaches the bottom, due to its own viscosity, probably resting on the top of the blasting cap). In the last three tests with the paste, the blasting cap was inverted (output end up) before loading to reduce that contingency. High-order detonation resulted. The "no fire" recorded for the liquid may have been caused by partial collapse of the bore hole after insertion of the cap (which had not been inverted) but before filling the hole with explosive. The explosives without aluminum (NM/NE/RDX paste and LLTX-G2) produced the smallest craters. Astrolite A-1-5, which contains aluminum but was not included in this project, is probably superior to LLTX-G2 in cratering ability (Table 10).

The cratering test is the most important performance test since it relates directly to the anticipated behavior of the explosive in producing a foxhole. It is noted that the depth of the craters produced by all explosives was closely limited to the depth of the pilot hole. The exceptions were the craters made by the NM/NE/RDX paste whose depths averaged less than that of the pilot hole. This was probably due to the high viscosity of the paste which prevented it from reaching the bottom of the hole. Furthermore, the scatter of the results and the inevitable nonuniformity of natural soils suggest that the behavior of the various explosives in cratering may not be significantly different. The data on the cratering ability of these formulations can be extrapolated on the very rough assumption that the radius of the hole will increase with the cube root of the explosive weight. If this is accepted, it suggests that 3 or 4 pounds of the candidate explosive (properly distributed in 2 or 3 charges) would be the minimum required to provide an acceptable foxhole for a man.

Permafrost Cratering

An opportunity to test the liquid explosive NM/NE/RDX in frozen ground (permafrost) arose through contact with the Cold Regions Research and Engineering Laboratories (CRREL), Hanover, New Hampshire. The tests were conducted at Fort Wainwright, near Fairbanks, Alaska, in March 1971. Six weeks prior, the test site was cleared of a 4-foot-deep snow and organic mat cover to allow deep freezing of the earth (Ref 17).

A 75-lb portable auger was used for drilling 2¼ or 4-inch-diameter boreholes 3 feet deep in the permafrost. The engine was about the size of a lawn mower's, with a flexible shaft attached to the drive; the auger was controlled with a handle bar similar to that of a bicycle. The permafrost (frozen silt) was very easy to drill.

Three pounds of M1 Dynamite was loaded into a 4-inch-diameter hole and fired. An open crater about 1 foot deep by 5 feet diameter was formed (Test 1, Table 11). The true size of the crater could not be determined, since the loose permafrost pieces were too large to remove by hand (Fig 11). The remaining 5 dynamite shots were fired in 2¼-inch-diameter holes. The 5 shots included 1-, 2-, and 3-pound charges. The 1-pound charge formed a 6-inch-high dome of very large pieces and a break diameter of 4 feet (Fig 12, Test 2). The 2-pound charge produced a 6-inch-deep by 3-foot-diameter open crater (free of debris) with large and small pieces filling the remainder of it. The break diameter was 4½ feet (Fig 13, Test 3). Three shots were fired with 3 pounds of dynamite hand-tamped into each shot hole. (The dynamite charges were removed from their wrappers for tamping because the required number of intact sticks would not fit.) The average depth and diameter of the resulting craters were 1.6 and 4.2 feet, respectively (Tests 4-6). The breakup remaining in the craters was mostly small pieces (Fig 14-16). After spending 15 minutes removing the loose material, the actual crater was found to be an average of 2.7 feet deep with a bottom diameter of 2 feet (Fig 17-20). This size crater is inadequate for a 6-foot, 200-pound individual (Fig 17 and 18).

The initial test with the liquid explosive was conducted in a 4-inch-diameter by 3-foot-deep borehole. Neither a single nor a double firing of commercial No. 6 Blasting Cap succeeded in initiating 3 pounds of liquid explosive, and even that cap with a ¼-pound dynamite booster failed. Finally, initiation was attained by a military M6 Blasting Cap, placed at the bottom of a 2¼-inch-diameter borehole (Test No. 7, Fig 21). Two additional shots were fired in this manner (Tests 8 and 9, Fig 22 and 23). All 3 shots resulted in a very good breakup of the permafrost. The average open crater size was 6 feet in diameter by 1 foot 4 inches deep, with a break diameter of 7 feet 4 inches. After cleaning it out, one crater had a depth of 2 feet 10 inches and a bottom diameter of 2 feet 8 inches. The liquid explosive broke the permafrost into smaller pieces than did the dynamite so that shoveling the permafrost from the hole was much easier. Hence, the liquid explosive was considered to have better cratering capability than the dynamite.

SHAPED CHARGES

The 3.5-inch M28A2 Rocket, HEAT Warhead was modified by removing the rocket motor, fuze, and ogive (Fig 24). These modified conical charge heads were fired into the permafrost from standoffs varying from zero to 24 inches (Fig 25). At zero standoff the shot made a small craterlike hole. The other shots (at standoffs of 6, 12, 18, and 24 inches) produced holes 2¼ inches in diameter, tapering to approximately 5/8-inch diameter at a depth of 3 to 3½ feet. The different standoffs did not appear to affect penetration into permafrost.

Three shaped charges were fired into permafrost at 6 inch standoff; in two instances the dirt fell back into the borehole and refroze. The sizes of the holes were:

a. 3½ feet deep, with 8 inches diameter at the surface, tapering to 5/8 inch;

b. 2 feet deep, with 6 inches diameter at the surface, tapering to 1½ inches;

c. 1½ feet deep, with 6 inches diameter at the surface, tapering to 1½ inches.

Three pounds of the NM/NE liquid explosive was poured into holes a and b (Tests 11 and 12, Table 11) and formed craters comparable to those produced by the same quantity of the same explosive poured into the 2¼-inch-diameter boreholes (Fig 26 and 27). Hole c received 2 pounds of that explosive (Test 13, Table 11) and formed a crater (Fig 28) comparable to that produced by 3 pounds of dynamite in a 2½-inch-diameter borehole. However, the breakup produced by the liquid explosive appeared to be better than that produced by an equal quantity of M1 Dynamite.

A 4-inch-diameter, 3-foot-deep drilled borehole received a 3-pound liquid explosive charge (Test 10, Table 11). The resulting crater (Fig 29) constituted a vast improvement over that produced by dynamite: the crater was larger and the breakup was smaller. Two boreholes were drilled, one 4 inches in diameter by 9 feet deep, the other 16 inches in diameter by 10 feet deep. They were loaded with 16 and 30 pounds of liquid explosive, respectively and were not stemmed (Fig 30 and 31).

The performance of the M28A2 shaped charges used in this program is compared with that of other shaped charges for permafrost penetration in Reference 17. A charge weight vs penetration curve shows that the modified M28A2 Rocket Head falls in line with the others (Fig 32). A cone diameter vs penetration curve shows that the M28A2 is slightly better than the other charges tested (Fig 33).

The use of shaped charges for making suitable pilot holes for producing foxholes in permafrost may be impractical in a combat situation since the individual would have to carry and set up the shaped charge (approximately 4 pounds) and the cratering charge (3 pounds) to produce the foxhole. This would be time-consuming and might reveal the individual's position. However, in frozen or rocky terrain shaped charges may be essential if drilling equipment is not available or time is of great importance.

Under arctic conditions one or two bottles (2 pounds per bottle) of the explosive could be readily mixed by shaking each bottle vigorously for approximately 30 seconds. The temperature during the above test period was between zero and 20°F. However, when the 16 and 30-pound shots were fired (8 and 15 bottles, respectively) the mixing operation became a chore. Containers with 5 or 10 pounds of explosive would be desirable for these larger operations.

To improve the performance of the liquid explosive, a method of sealing it within the borehole so that stemming would be feasible would be advantageous. A thin plastic tube, closed at the bottom, could be inserted into the borehole. Then an inverted blasting cap could be lowered into the tube, to be followed by the liquid explosive. The top of the tube could then be folded over and the hole stemmed by filling it with dirt.

GROUND POUR

In a separate demonstration, Astrolite LTX-G2 was poured from 1½-lb Astro-Pak containers onto damp, sandy gravel and allowed to soak in completely. It was detonated by a commercial #6 electric cap to which short strips of detonating cord were taped. All of the explosive detonated disrupting the ground to a depth of 9 in. over a 3 ft diameter area.

Similarly, 1½ lb of Astrolite was poured into a hole of 2 in. diameter by 18 in. depth, dug in deep, loose, wet sand. The Astrolite detonated, disrupting the sand over an area 5 ft in diameter (Ref 18).

RELATIVE MERITS

An adjective rating of the relative merits of the five candidates formulations tested for ENSURE 279-K (Project Foxhole) is given in Tables 12 and 13.

COSTS

The cost of the formulations dealt with in this report, when procured in limited quantities, is high in comparison with that of standard military explosives or commercial blasting agents. The figures given in Table 13 are approximate but, in the case of DBA-208X and LLTX G-2, are based on data provided by industry. Those for LLTX G-2 are for 1000 Astro-Paks in 1½ or 3-pound sizes as quoted by EXCOA.

CONCLUSIONS

1. The liquid explosive NM/NE/RDX/A1 is selected for further evaluation or use because of its effectiveness, ease of handling, and lack of undue sensitivity to initiation.

2. The nitromethane-based slurry and paste explosives are rejected because of their poor viscosity.

3. DBA-208X is rejected because of its inability to propagate in small diameter cracks.

4. LLTX G-2 is rejected because of its sensitivity to bullet impact hit in the aluminum Astro-Pak container after mixing.

5. Due to poor volatility, a nitromethane-based explosive requires vaporproof, non-fragile container to meet long-term storage and field requirements.

6. Portable, gasoline-powered augers successfully drilled bore holes in permafrost.

7. No initiation failures of the liquid explosive occurred when the blasting cap was inverted and lowered to the bottom of the bore hole.

8. Bore holes may become clogged with dirt or rock.

9. Bore holes charged with liquid explosive should not be stemmed (capped with earth) unless the liquid is protected from the dirt.

RECOMMENDATIONS

1. Bore holes in permafrost should be drilled with portable power augers.

2. Blasting caps should be inverted prior to placement at the bottom of a bore hole.

3. To prevent interruption of the bore hole and to provide for stemming, a thin-walled plastic tube (closed at the bottom) should be inserted into the hole prior to filling it with liquid explosive.

4. A vaporproof plastic container for the liquid explosive should be developed.

REFERENCES

1. Msg. 894239, from ACSFOR, CINCUSPAC, for GPOP-DT, Astrolite Explosives (ENSURE), 21 January 69

2. Borum, O.H., from ACSFOR, Astrolite Explosives, DA ENSURE Index No. 279-K, February 1970

3. TT DA907032 from ACSFOR, Subject: Astrolite Explosive (ENSURE 279K) 29 April 69

4. Letter, AMSMU-RE-M, U.S. Army Munitions Command to Picatinny Arsenal, SMUPA-DR, Subject: Explosive for ENSURE 279-K, 6 January 70

5. Letter, CRDPES-EC to AMCRD, Subject: ENSURE 279-K, 29 July 70

6. *Explosives Hazard Classification Procedures,* TB 700-2, Defense Supply Agency, Washington, DC, May 1967

7. Letter, Bureau of Explosives, 2 Pennsylvania Plaza, N.Y., N. Y. 1001 to EXCOA, Issaquah, Washington, 98027, File 3, 16-313, 16-1222, CAG-M, dtd 21 May 1970

8. Ribovich, John; Watson, Richard, and Gibson, Frank, *Instrumented Card Gap Test,* American Institute of Aeronautics & Astronautics Journal Vol 6, No. 7, pp 1260-63, Julay 1968

9. Levmore, S., *Principal Characteristics of the Liquid Explosive Astrolite A-1-5,* Picatinny Arsenal Technical Report 4650, May 1974

10. Wooten, D.C.; Bredfeldt, H.R.; Woolfolk, R.W., and Kier, R.J, *Investigation of low velocity detonation Phenomena,* Stanford Research Institute AFOSR 70-1005 TR, Menlo Park, CA, 94025, March 1970

11. Weiss, Milton, and Litchfield, Elton, *Projectile Impact Initiation of Condensed Explosives,* Bureau of Mines Report 6986, U.S. Department of Interior, July 1967

12. Brown, F. W.; Kusler, D.J., and Gibson, F.C., *Sensitivity of explosives to Initiation by Electrostatic Discharges,* Bureau of Mines Report 5002, September 1953

13. Hart, E. Ross, Ph.D., *Acute Toxicology Studies on Astrolite LTX G-2,* Bionetics Research Laboratories, Inc., 7300 Pearl St., Bethesda, Maryland 20014, June 1970

14. Ribovich, John, *A Wedge Technique for Evaluation of Detonation Hazards of Liquid Explosives,* The N.Y. Academy of Sciences, p-766, Vol 152, 28 October 1968

15. Khristoforov, B. D., *Parameters of Shock Waves and Gaseous Bubbles Arising During Underwater Explosions of Small PETN Charges*, American Rocket Society Journal Supplement, November 1962, p-1788

16. Kury, J. W.; Hornig, H. C.; Lee, E.L; McDonnel, J.L.; Ornellas, D.L.; Finger, M.; Strange, F.M., and Wilkins, M.L, *Metal Acceleration by Chemical Explosives*, Fourth Symposium (International) on Detonation, AGR-126, U. S. Naval Ordnance Laboratory, White Oak, Maryland, October 12-15, 1965, p 3

17. Mellor, M., *Blasting Tests in Frozen Ground*, Cold Regions Research & Engineering Laboratory, Hanover, New Hampshire, 1971

18. DF from Malcolm Mellor, Cold Regions Research & Engineering Laboratory, to Chief, AAB, Subject: Report on Demonstration of Ground Soak Explosions, Hanover, New Hampshire, 2 October 1970

19. Cook, M.A., Dr., *Explosives, A Survey of Industrial and Engineering Chemistry*, Industrial and Engineering Chemistry, Washington, D.C., July 1968, pp 44-45

20. Koos, D.W., et al, *Development of a System to Deliver and Detonate Large Explosive Charges Undersea*, IIT Research Institute, Chicago, Illinois, January 1969

21. Hansen, G.L., *Development and Testing of a Portable Explosives Mixing System*, Contract DAAA21-68-C-0478, IRECO Chemicals, Salt Lake City, Utah, April 1968

22. Levmore, S., *Principal Characteristics of the Liquid Explosive DBA-22M*, Picatinny Arsenal Technical Report 4237, July 1971

23. Levmore, S. et al, *Principal Characteristics of the Liquid Explosive, Astrolite G*, Picatinny Arsenal Technical Report 3633, August 1967

24. Leland, E.P., *Foxhole Digging Aid, Interim Device*, USA Mobility Equipment Research and Development Center, Report 1934, Fort Belvoir, Virginia, September 1968

25. Stanley, A.T., *Preliminary Investigation, Astrolite Liquid Explosive*, US Army Engineer Research and Development Laboratories, Report 1895, Fort Belvoir, Virginia, April 1967

26. Mellor, Malcom, and Sellman, Paul, *Experimental Blasting in Frozen Ground, Cold Regions*, Research and Engineering Laboratory, Hanover, New Hampshire, February 1970

27. DTB 1375-391-12, Demolition Kit, Liquid Explosive: Tunnel Destruct, XM242, Picatinny Arsenal-DC5, Dover, NJ 07801, June 1968

28. Letter, S. Levmore, Picatinny Arsenal, Dover, NJ, to USAMUCOM, AMSMU-SS-SD, Subject: Request for Change in the Hazard Groupings of Nitromethane in AMCR 385-224, 23 July 1968

29. Eskelund, G.R., et al, *Feasibility Study of the Use of Liquid Explosives and Associated Components*, Picatinny Arsenal Technical Report 3513, July 1966

30. Walsh, M.E., et al, *Feasibility Study of the Explosive Exit Concept for Civil Aircraft*, Picatinny Arsenal Technical Report 3427, April 1966

Table 1

50% Card gap values
(inches)

Explosive	Temperature (°F) -45	30	40	77	160
Astrolite G			0.20		
Nitromethane				0.25	
Astrolite A-1-5				> 0.50	
NM/NE/RDX/Al, slurry	0.55			0.65	0.75
Astrolite LTX G-2 (EXCOA data)[a]		0.67			
NM/NE/RDX/Al, liquid	0.65			0.75	0.75
NM/NE/RDX, paste	1.15			1.15	1.65
DBA-208X	0.60			3.55	4.25

---

[a] All other data reported by the Bureau of Mines.

Table 2

Detonation velocity (average)
(mm/μsec)

Explosive	Temperature -45°F	 55°F	 77°F	 160°F
Astrolite LTX G-2[a]		8.0		
NM/NE, paste	8.2		8.1	7.9
Astrolite LLTX G-2[a]		7.8		
Astrolite A-1-5			7.5	
NM/NE, liquid	7.4		7.0	6.8
NM/NE, slurry	7.1		6.8	6.5
DBA-208X	5.9		5.6	5.6
Nitromethane			6.2	

---

[a] Tested in plastic tubing, EXCOA data; velocity of these explosives may be higher in steel confinement. All other data reported by Bureau of Mines.

Table 3

Projectile impact sensitivity
(1/2" x 1/2" brass cylinder)

Explosive	50% Velocity for initiation (m/sec)	
Nitromethane (commercial grade)	1700	No reaction
NM/NE/RDX/Al, liquid	1505	
NM/NE/RDX Al, slurry	1175	
NM/NE/RDX, paste	901	
DBA-208X	200	
Astrolite G	170	

Note: As preported by Bureau of Mines.

Table 4

Electrostatic sensitivity

Explosive	Voltage	Initiations/ number tested	Energy (joules)
DBA-208X	20,000	2/2	100
DBA-208X	18,000	1/2	81
DBA-208X	17,000	1/10	72
DBA-208X	16,000	1/10	64
DBA-208X	15,000	1/2	56
DBA-208X	14,000	0/10	48
IRECO 208X (Part A)[a]	20,000	0/10	100
NM/NE/RDX, liquid	20,000	0/10	100
LLTX G-2	20,000	0/10	100

Note: In all tests the capacitance and resistance were 0.5 µfd and 5000 ohms, respectively.

[a] Liquid part of 2-part DBA-208X system.

Table 5

Modified wedge test

Explosive	Minimum propagation thickness[a] (inch)	(std dev)
NM/NE/RDX/Al, liquid	0.061	0.011
NM/NE/RDX/Al, slurry	0.072	0.010
NM/NE/RDX, paste	0.089	0.016
DBA-208X	0.213	0.047

---

[a] Average of five tests.

Table 6

Wedge test

Explosive	Minimum Propagation Thickness (inches)	
	Temperature	
	-45°F	77°F
Liquid	0.03 (7.4)	0.03 (6.9)
Slurry	0.06 (7.1)	0.05 (6.7)
Paste	0.07 (8.2)	0.02 (7.8)
DBA-208X	No propagation	0.13 (4.3)
Nitromethane (commercial grade)		0.18 (6.3)

NOTES:

1. Container: 4-inch-wide by 18-in-long by 1/2-inch-thick steel base plate with 1/16-inch plexiglas sides
2. Wedge taper: 1/2 inch to zero
3. Booster: 1.0-inch-long by 1.625-inch-diameter tetryl
4. Numbers in parentheses are observed detonation rates in mm/μsec

All data reported by Bureau of Mines.

Table 7

Underwater energy

Explosive	Bubble Energy	Shock Energy
Astrolite A-1-5[a]	1.83	1.38
NM/NE/RDX/Al, slurry	1.50	1.34
NM/NE/RDX/Al, liquid	1.24	1.17
NM/NE/RDX, paste	1.04	1.13
TNT	1.00	1.00
DBA-208X	0.99	0.86

NOTE: All data reported by Bureau of Mines

[a] Because of the high Aluminum content of the A-1-5, LLTX G-2 would probably be lower in bubble energy and higher in shock energy.

Table 8

Plate dent test

Explosive	Average Dent Volume[a] (cc)	Standard Deviation
NM/NE/RDX/Al, liquid	7.0	2.15
NM/NE/RDX, paste	6.4	0.43
NM/NE/RDX/Al, slurry	5.2	1.29
DBA-208X	4.2	0.43

---

[a] Average of five tests each.

Table 9

Expanding cylinder tests

Explosive	Density (g/cm)	Expansion Velocity (mm/sec)	Kinetic Energy per Unit Weight of explosive (joules/g)
NM/NE/RDX, paste	1.50	1.49	3301
Astrolite A-1-5	1.60	1.43	2500
NM/NE/RDX/Al, slurry	1.45	1.30	2616
NM/NE/RDX/Al, liquid	1.34	1.28	2714
Nitromethane (commercial grade)	1.13	1.18	2794
DBA-208X	1.45	0.94	1353

NOTE:

All data reported by Bureau of Mines.

Table 10

Earth cratering tests at Picatinny Arsenal

Explosive	Average Diameter (in.)	Standard Deviation	Average Depth (in.)	Standard Deviation	Average Volume[a] (ft^3)	Remarks
NM/NE/RDX/Al, liquid	41.3	1.46	13.5	1.7	5	1 no fire
NM/NE/RDX/Al, slurry	41.5	0.89	12.5	-	4.9	3 no fires
DBA-208X	38.8	2.91	12.2	0.97	4.2	All fire
NM/NE/RDX, paste	39.7	10.44	11.1	3.28	4	1 no fire 1 low order
Astrolite LLTX G-2	36.5	3.44	12.4	1.5	3.7	All fire

---

[a] Crater volume calculated by assuming that crater forms a paraboloid, where volume = $1/8\ \pi\ h\ d^2$ (h = height, d = diameter).

Table 11

Permafrost cratering tests at Fairbanks, Alaska

Test	Bore Hole		Explosive		Crater Size		
No.	Dia	Depth	Type	Weight	Before Digging	After Digging	Remarks
1	4"	3'	3 lb	M1 dyn	5' x 1'		Very large pieces, could not be excavated by hand
2	2¼"	3'	1 lb	M1 dyn	4' x 0' dome		Very large pieces
3	2¼"	3'	2 lb	M1 dyn	3' x 6"		Large and small pieces
4	2¼"	3'	3 lb	M1 dyn	4' x 1'	4' x 2.5'	Dynamite removed from wrapping and tamped into holes. A few large pieces; the remainder could be shoveled
5	2¼"	3'	3 lb	M1 dyn	4.6' x 1.4'	4.6' x 2.7'	Same as Test No. 4
6	2¼"	3'	3 lb	M1 dyn	4" x .9"	4" x 2.9"	Same as Test No. 4
7	2¼"	3'	3 lb	liquid	6' x 1'		All pieces were small enough to shovel
8	2¼"	3'	3 lb	liquid	5.5' x 1.5'	5.5' x 2.8'	All pieces were small enough to shovel
9	2¼"	3'	3 lb	liquid	6.3' x 1.5'		All pieces were small enough to shovel
10	4"	3'	3 lb	liquid	6.5' x 0'		Small pieces
11	2½" to ½"	3½'	3 lb	liquid	5.0' x 1'		Small pieces
12	6" to ½"	2'	3 lb	liquid	5.0' x 1.5'		Small pieces
13	6" to 1"	1½'	2 lb	liquid	3.5' x 1'		Small and large pieces
14	4"	9'	16 lb	liquid	10' dia		Good breakup; a lot of fly rock
15	6"	10'	30 lb	liquid	15' dia		A lot of fly rock; good breakup, semi-gun[a]

---

[a] "Gun" is the action of an explosive in blowing the stemming material out of a pilot hole with little cratering effect.

Table 12

Adjective rating of candidate formulations sensitivity

Material	Approx. Cost ($/lb)	Toxicity	M6 Blasting Cap	Card Gap	Projectile Impact	Electrostatic Discharge	30 Cal Bullet	Temp Stability
Liquid NM/NE type	2.20	F	G[a]	G	G	G	G	F
Slurry NM/NE type	2.20	F	G[a]	G	G		G	F
Paste NM/NE type	2.75	F	G[a]	F	G		G	F
DBA-208X	1.00	G	G	Q	Q	G	G	F
Astrolite A-1-5	6.00			G[b]				F
Astrolite G	6.00				(P)			F
Astrolite LTX G-2	7.15	(Q)						G
Astrolite LLTX G-2	7.15		G			G	P	G

---

[a] Specific tests for initiation with M6 Blasting cap resulted in all fires. However, in cratering tests, low-order detonation and no fires resulted in some cases. Further tests are required.

[b] Astrolite A-1-5 exhibits LVD, which may be an indication of potentially hazardous sensitivity.

[c] Relative rating based on information developed under other projects or ( ) received from EXCOA.

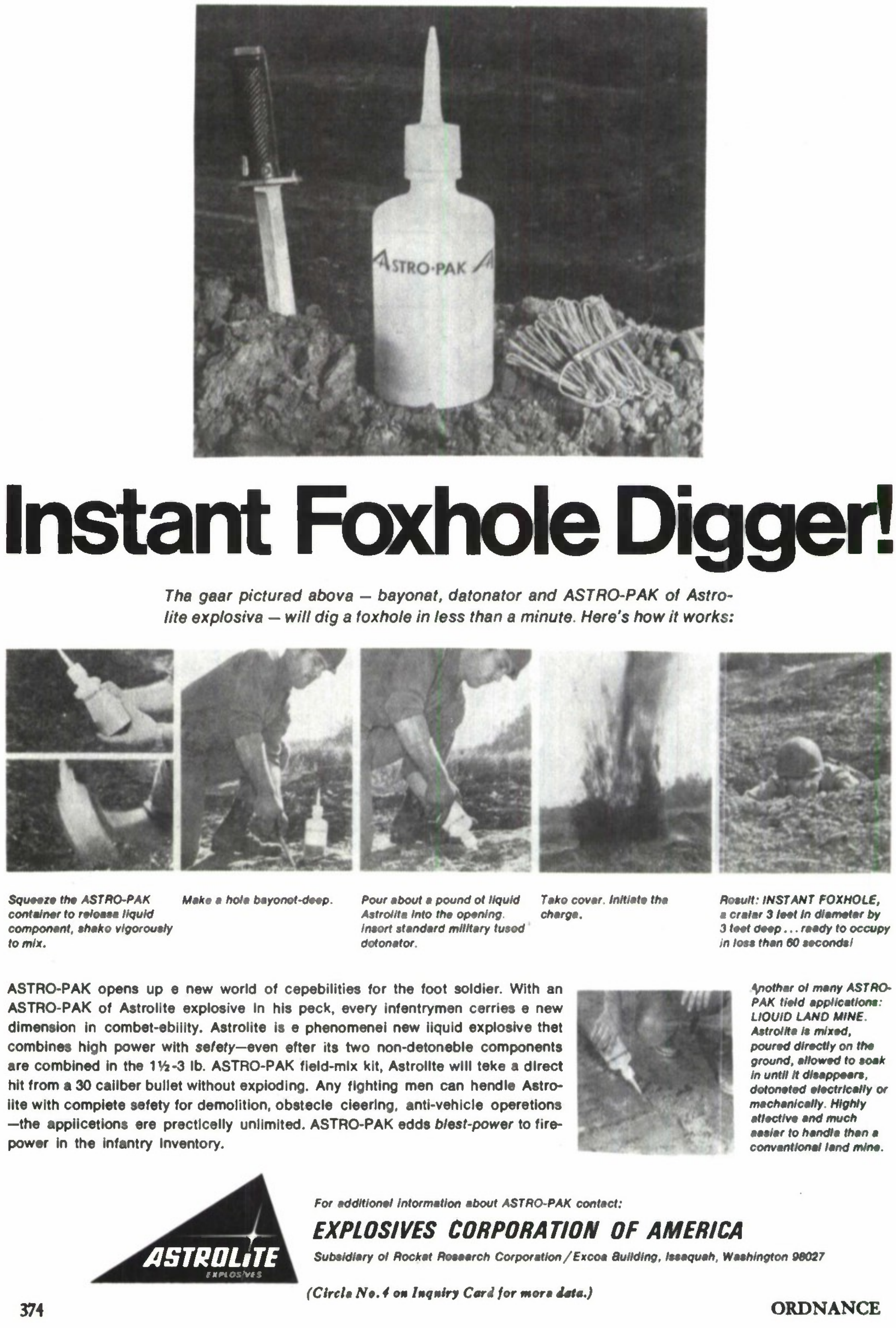
G - Good, acceptable
F - Fair
Q - Questionable
P - Poor, unacceptable

Table 13

Adjective rating of candidate formulations performance

Material	Min Diameter Propagation	Cratering	Expanding Cylinder	Plate Dent	Underwater Energy	Detonation Velocity
Liquid NM/NE type	G	G	G	G	G	G
Slurry NM/NE type	G	G	G	G	G	G
Paste NM/NE type	G	F	G	G	F	G
DBA-208X	P	G	F	F	F	F
Astrolite A-1-5	G		G		G	
Astrolite LLTX G-2		F				G

G - Good, acceptable
F - Fair
Q - Questionable
P - Poor, unacceptable



Instant Foxhole Digger!

The gear pictured above — bayonet, detonator and ASTRO-PAK of Astrolite explosive — will dig a foxhole in less than a minute. Here's how it works:

Squeeze the ASTRO-PAK container to release liquid component, shake vigorously to mix.

Make a hole bayonet-deep.

Pour about a pound of liquid Astrolite into the opening. Insert standard military fused detonator.

Take cover. Initiate the charge.

Result: INSTANT FOXHOLE, a crater 3 feet in diameter by 3 feet deep . . . ready to occupy in less than 60 seconds!

ASTRO-PAK opens up a new world of capabilities for the foot soldier. With an ASTRO-PAK of Astrolite explosive in his pack, every infantryman carries a new dimension in combat-ability. Astrolite is a phenomenal new liquid explosive that combines high power with *safety*—even after its two non-detonable components are combined in the 1½-3 lb. ASTRO-PAK field-mix kit, Astrolite will take a direct hit from a 30 caliber bullet without exploding. Any fighting man can handle Astrolite with complete safety for demolition, obstacle clearing, anti-vehicle operations—the applications are practically unlimited. ASTRO-PAK adds *blast-power* to fire-power in the infantry inventory.

Another of many ASTRO-PAK field applications: LIQUID LAND MINE. Astrolite is mixed, poured directly on the ground, allowed to soak in until it disappears, detonated electrically or mechanically. Highly effective and much easier to handle than a conventional land mine.

For additional information about ASTRO-PAK contact:

EXPLOSIVES CORPORATION OF AMERICA

Subsidiary of Rocket Research Corporation / Excoa Building, Issaquah, Washington 98027

(Circle No. 4 on Inquiry Card for more data.)

374 ORDNANCE

Fig 1 Advertisement of "Instant Foxhole Digger" (Astro-Pak)

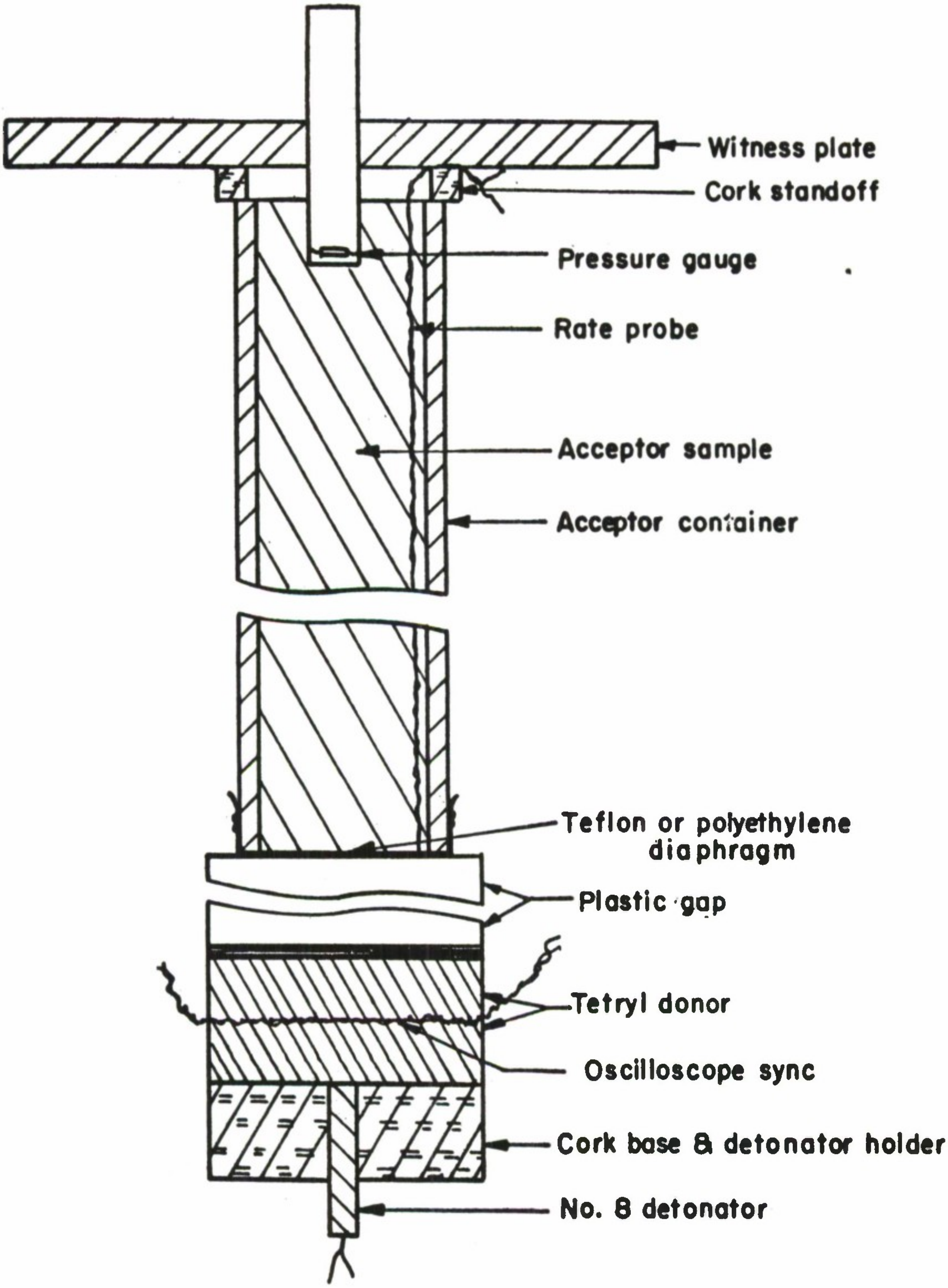


Fig 2 Instrumented card-gap arrangement

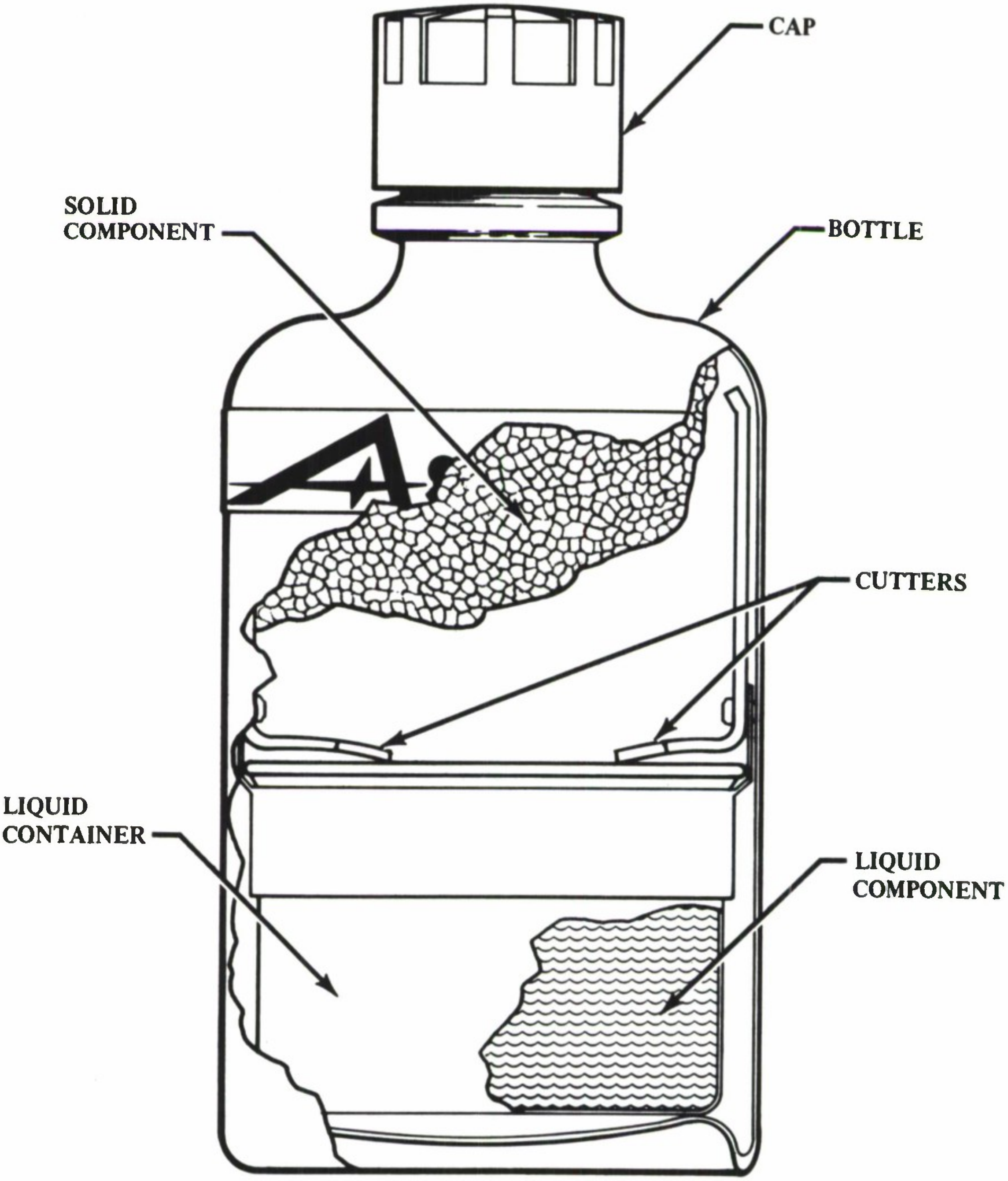


Fig 3 The Astro-Pak

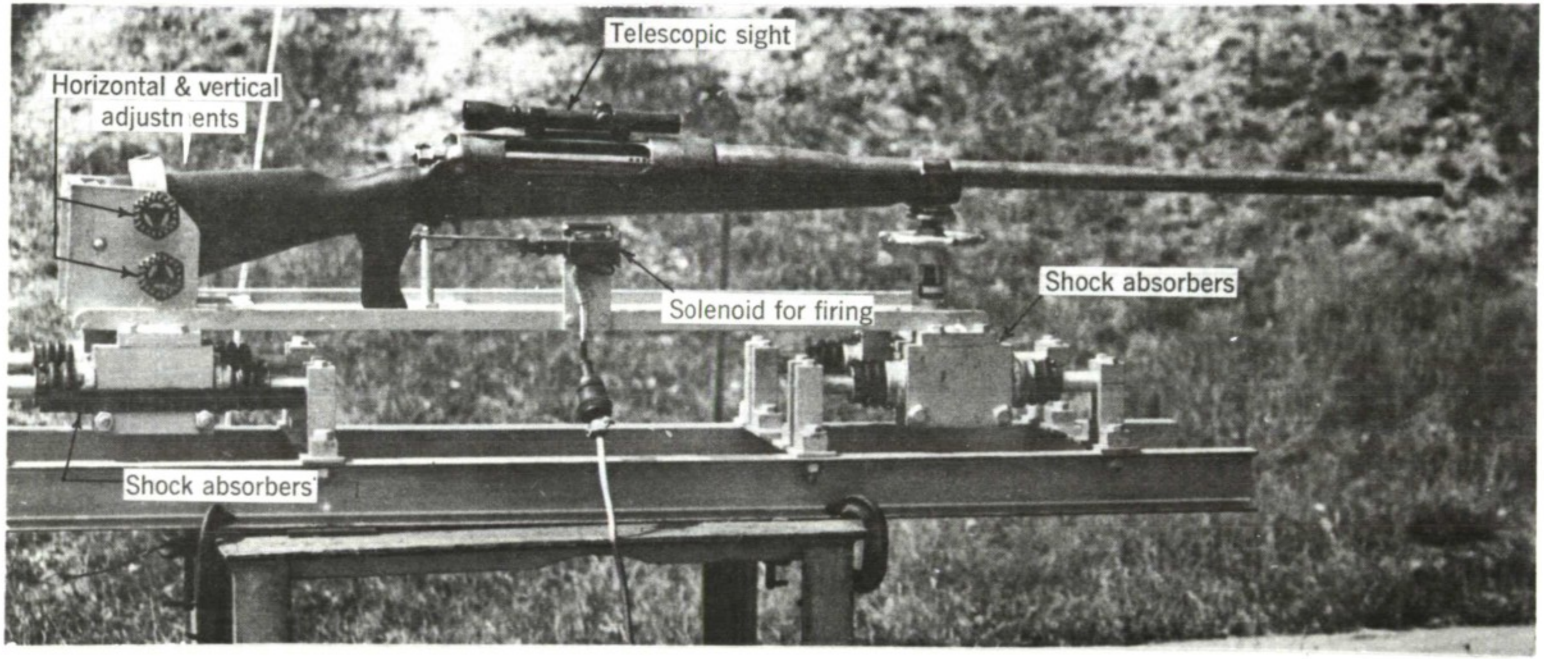


Fig 4a Gun for projectile impact studies

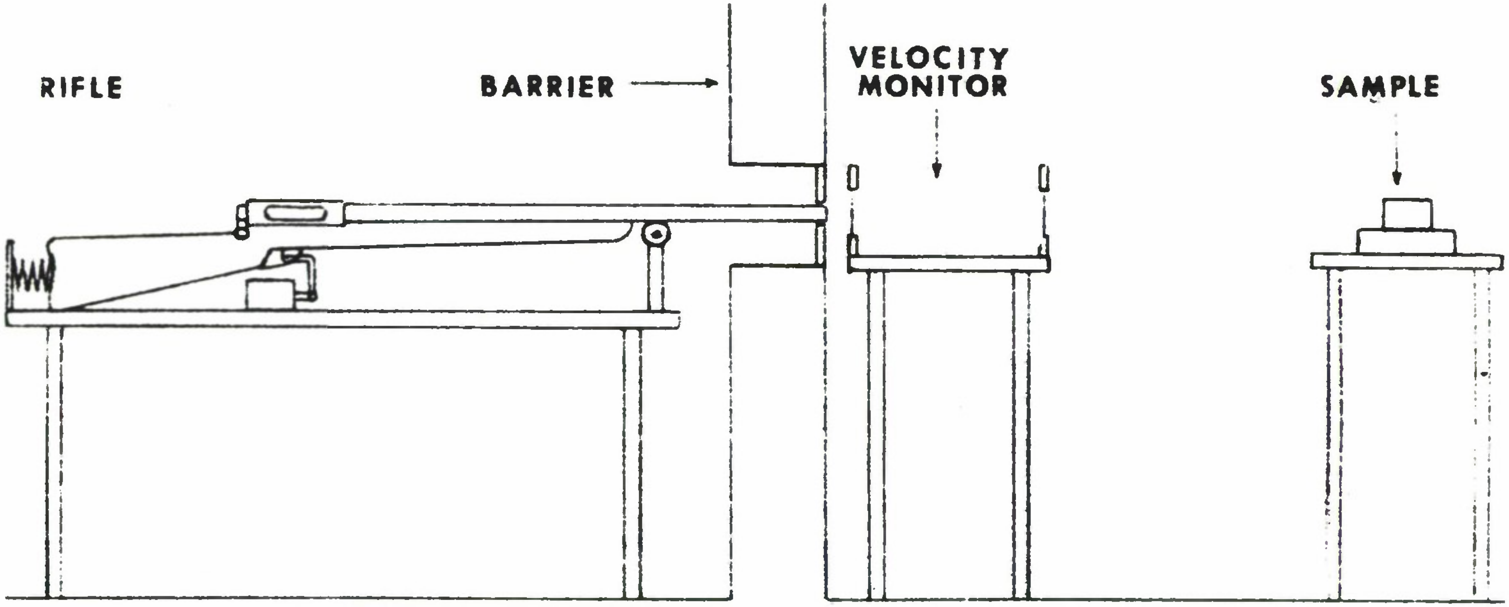
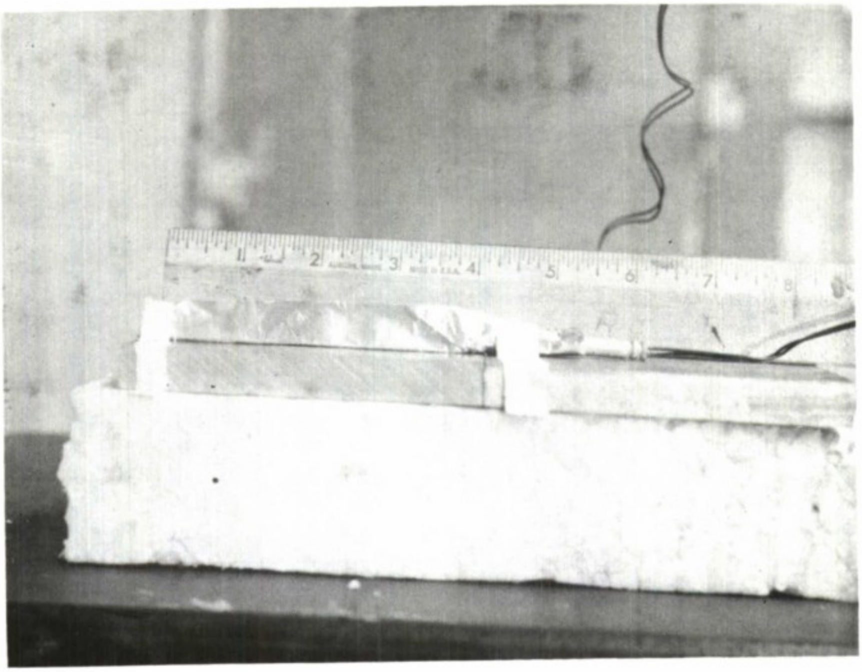
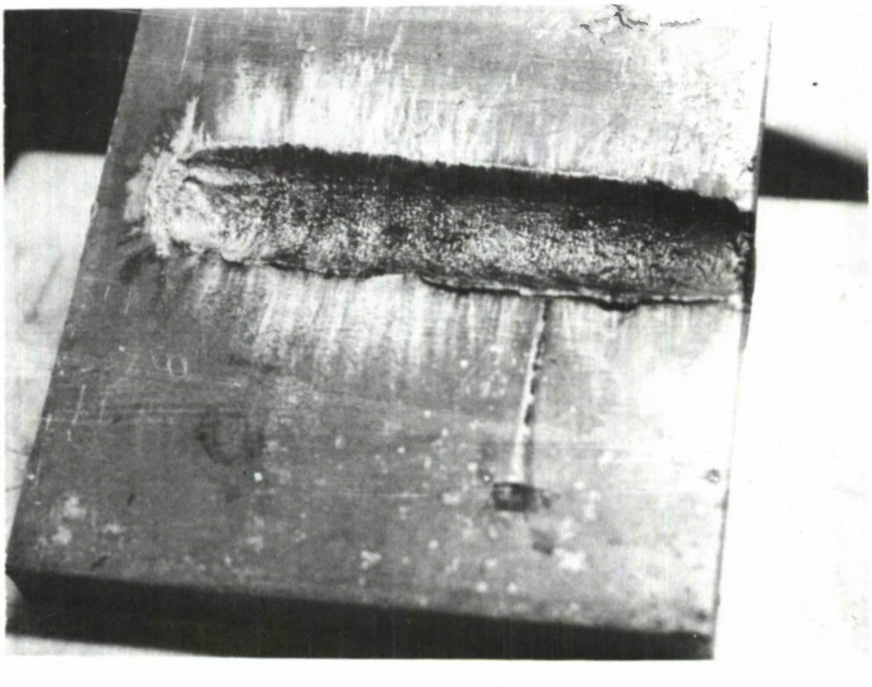


Fig 4b Pictorial of projectile impact sensitivity test



a. Aluminum "boat" on insulation after conditioning at -60°F



b. Groove in aluminum witness plate made by explosive

Fig 5 Low temperature initiation test

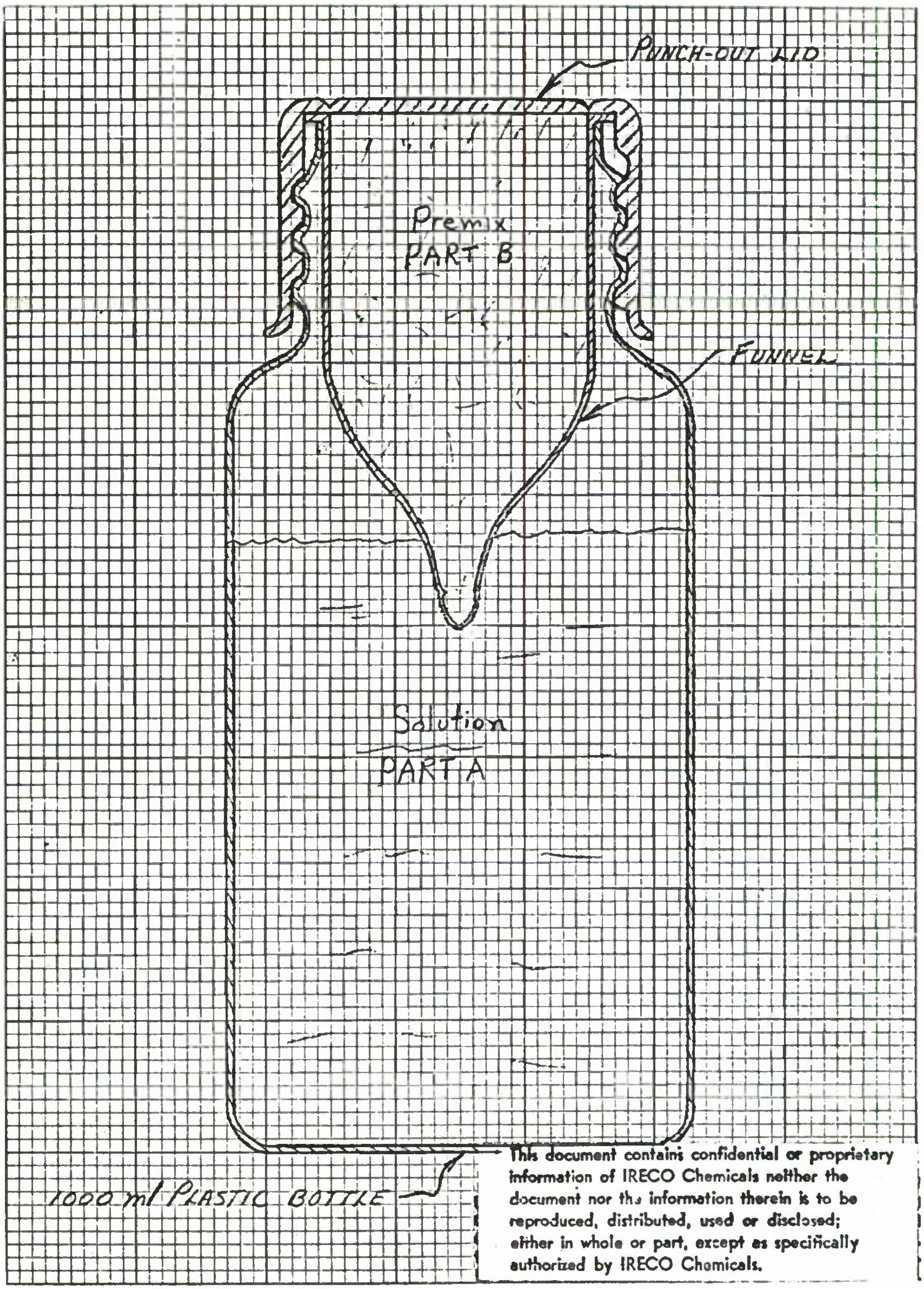


Fig 6 Configuration of two-part system DBA-208X

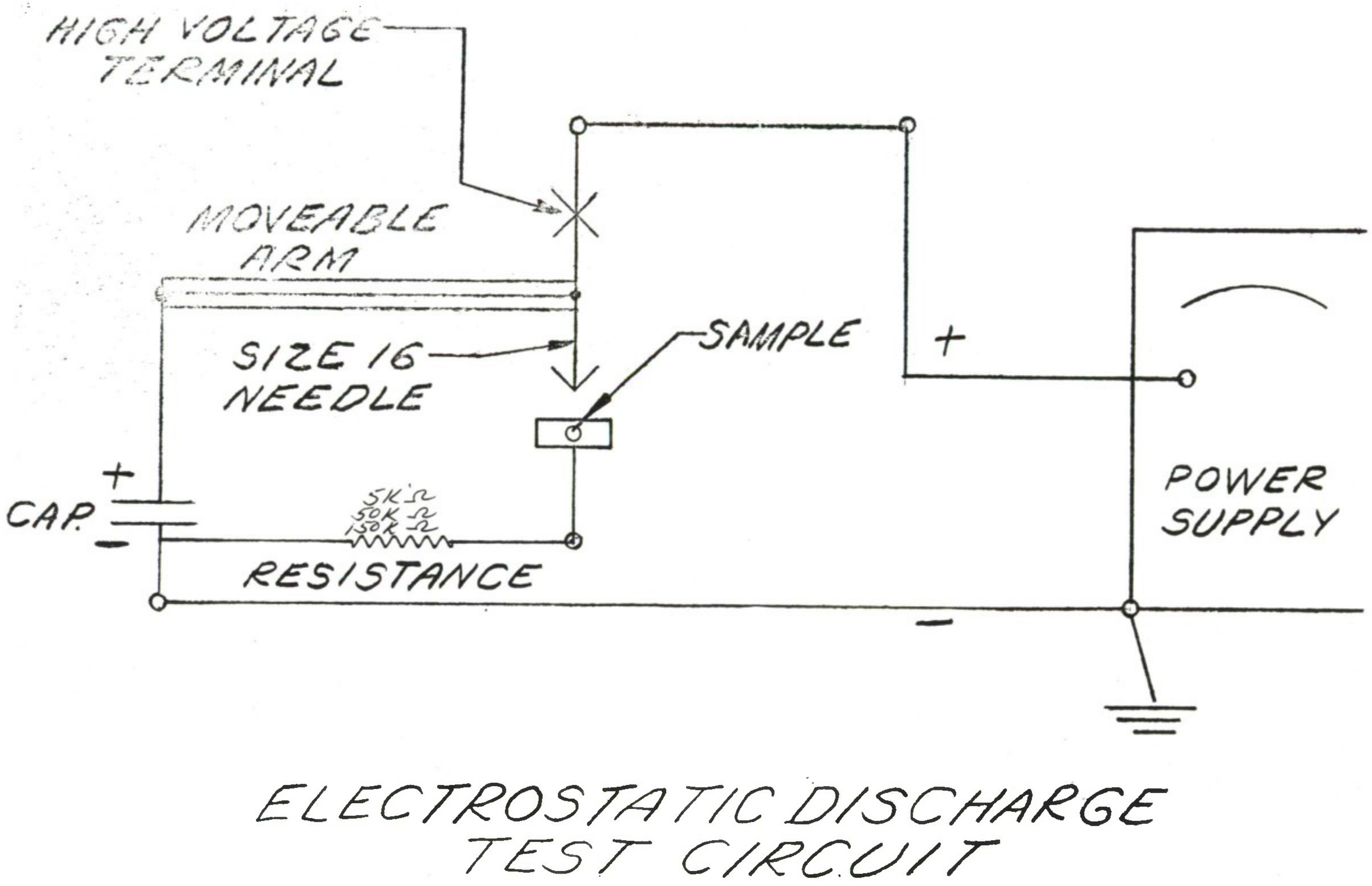


Fig 7 Electrostatic discharge test circuit

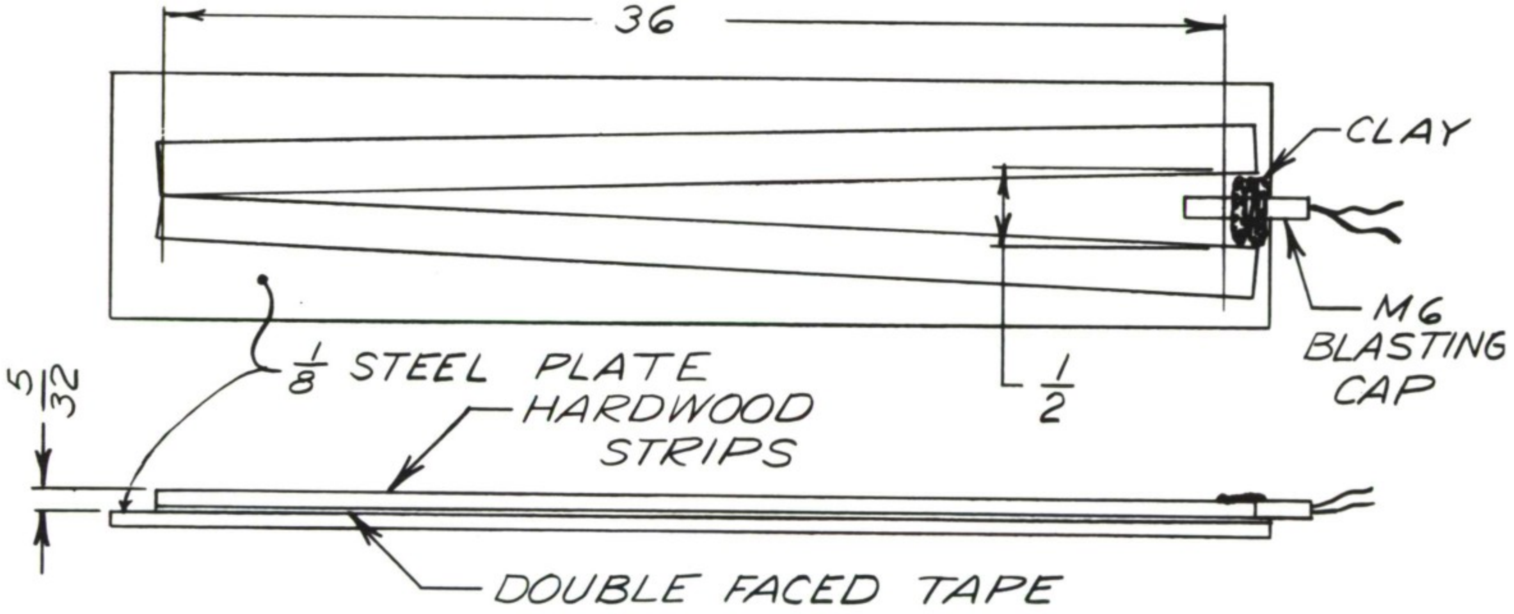
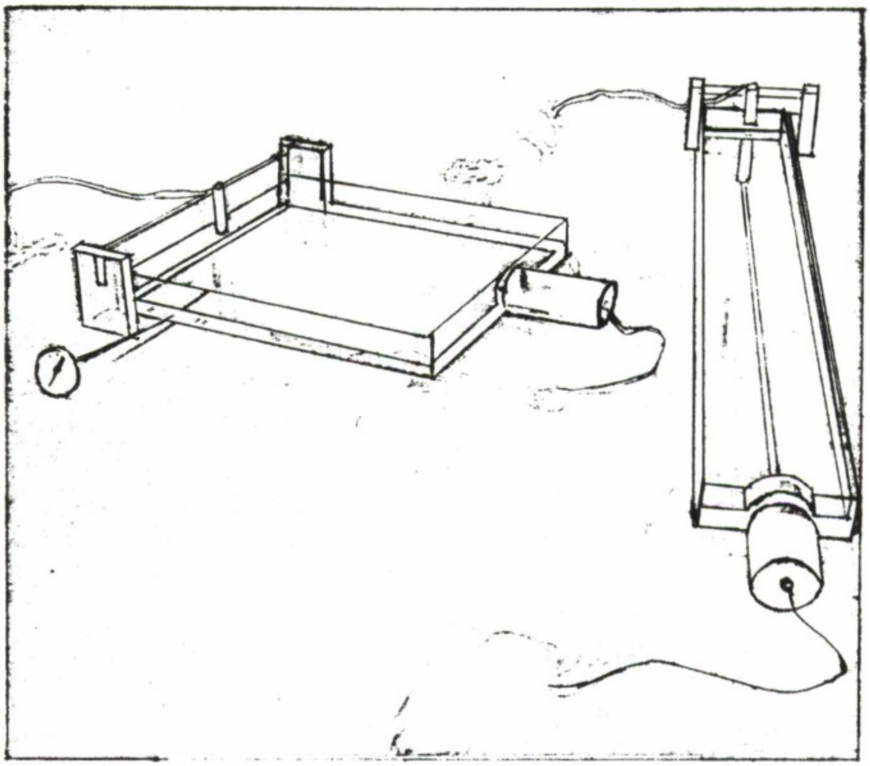
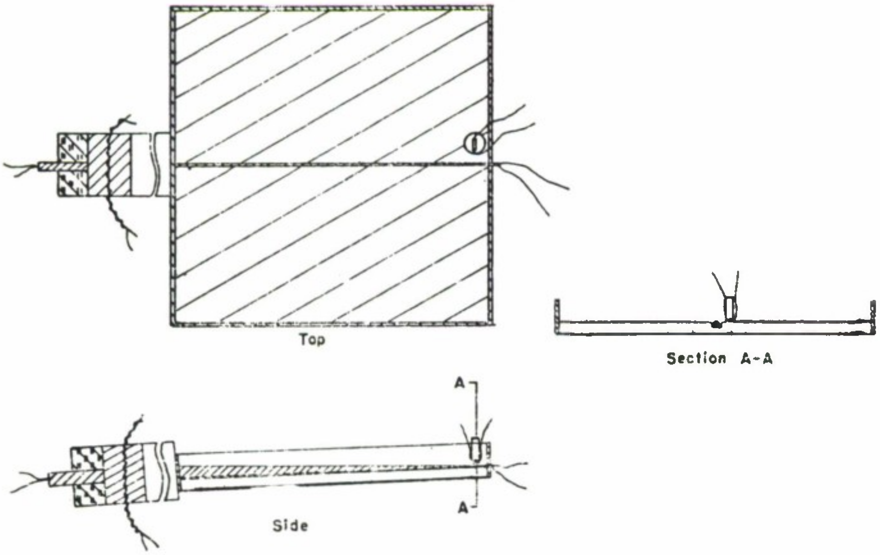


Fig 8 Modified wedge test



WEDGE-SHAPED CHARGE ARRANGEMENTS



SCHEMATIC OF A WEDGE-SHAPED CHARGE

Fig 9 Wedge test setup

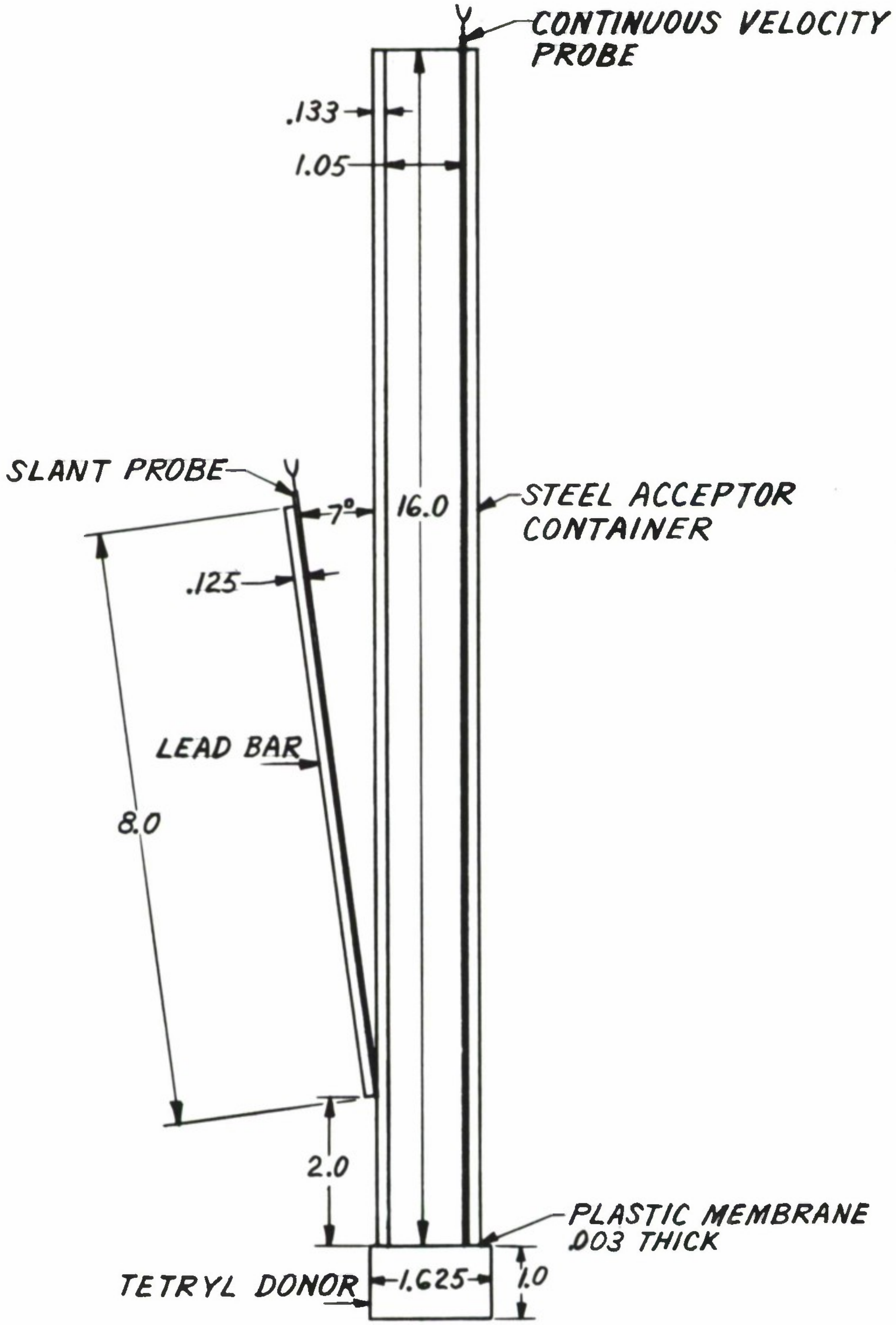


Fig 10 Expanding cylinder test showing detonation and casing velocity probes

Fig 11 Shot #1: Result of 3 lb of M1 dynamite in a 4" dia x 3' deep-bored shot hole

Fig 12 Shot #2: Result of 1 lb of M1 dynamite in a $2\frac{1}{4}$" dia x 3' deep-bored shot hole

Fig 13 Shot #3: Result of 2 lb of M1 dynamite in a 2¼" dia x 3' deep-bored shot hole

Fig 14 Shot #4: Result of 3 lb of hand-tamped M1 dynamite in a 2¼" dia x 3' deep-bored shot hole

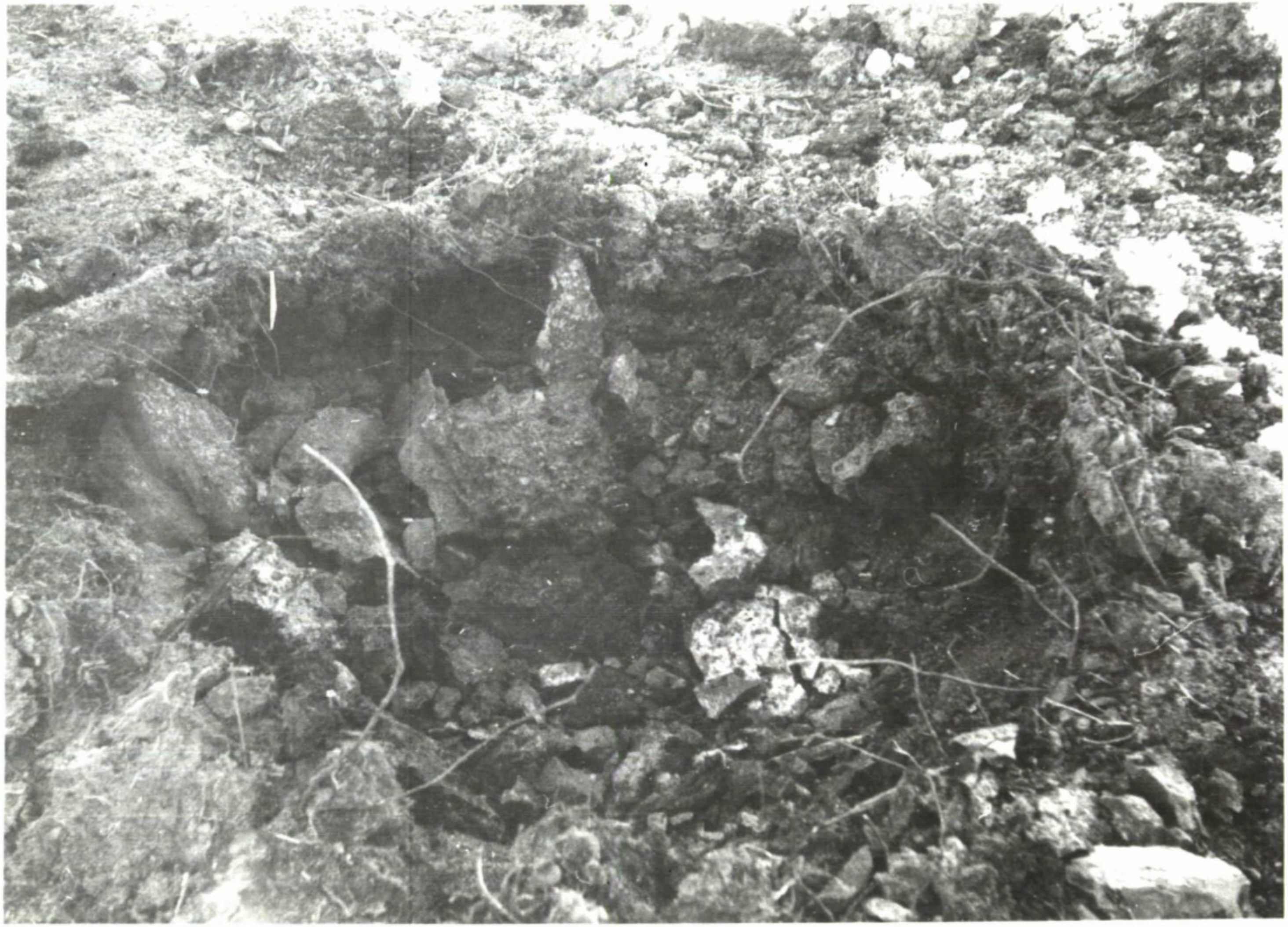


Fig 15 Shot #5: Result of 3 lb of hand-tamped M1 dynamite in a 2¼" dia by 3' deep-bored shot hole

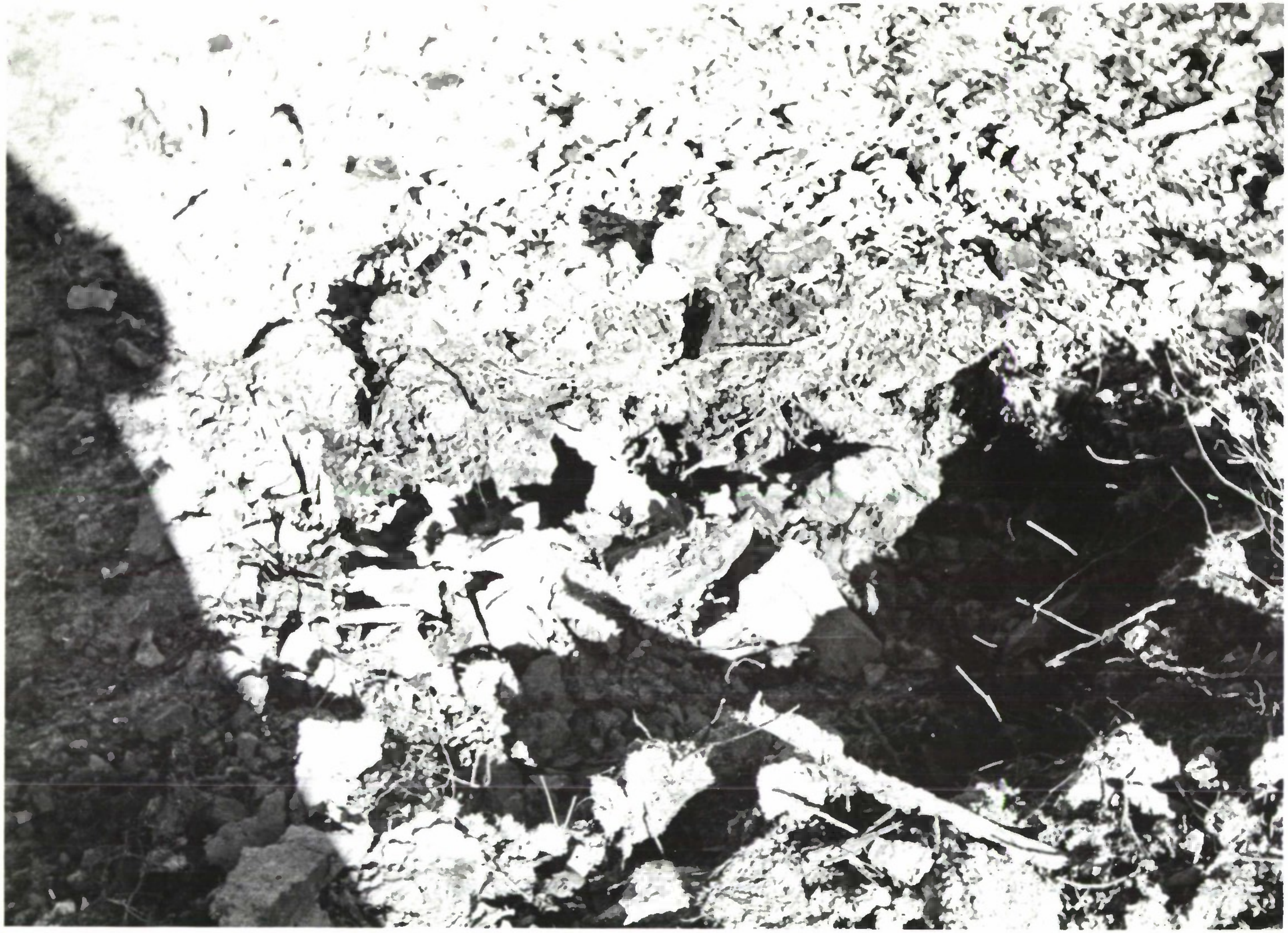


Fig 16 Shot #6: Result of 3 lb of hand-tamped M1 dynamite in a 2¼" dia by 3' deep-bored shot hole

Fig 17 Crater of shot #4 after cleaning out all loose pieces

Fig 18 G.I. in simulated firing position in crater of shot #4

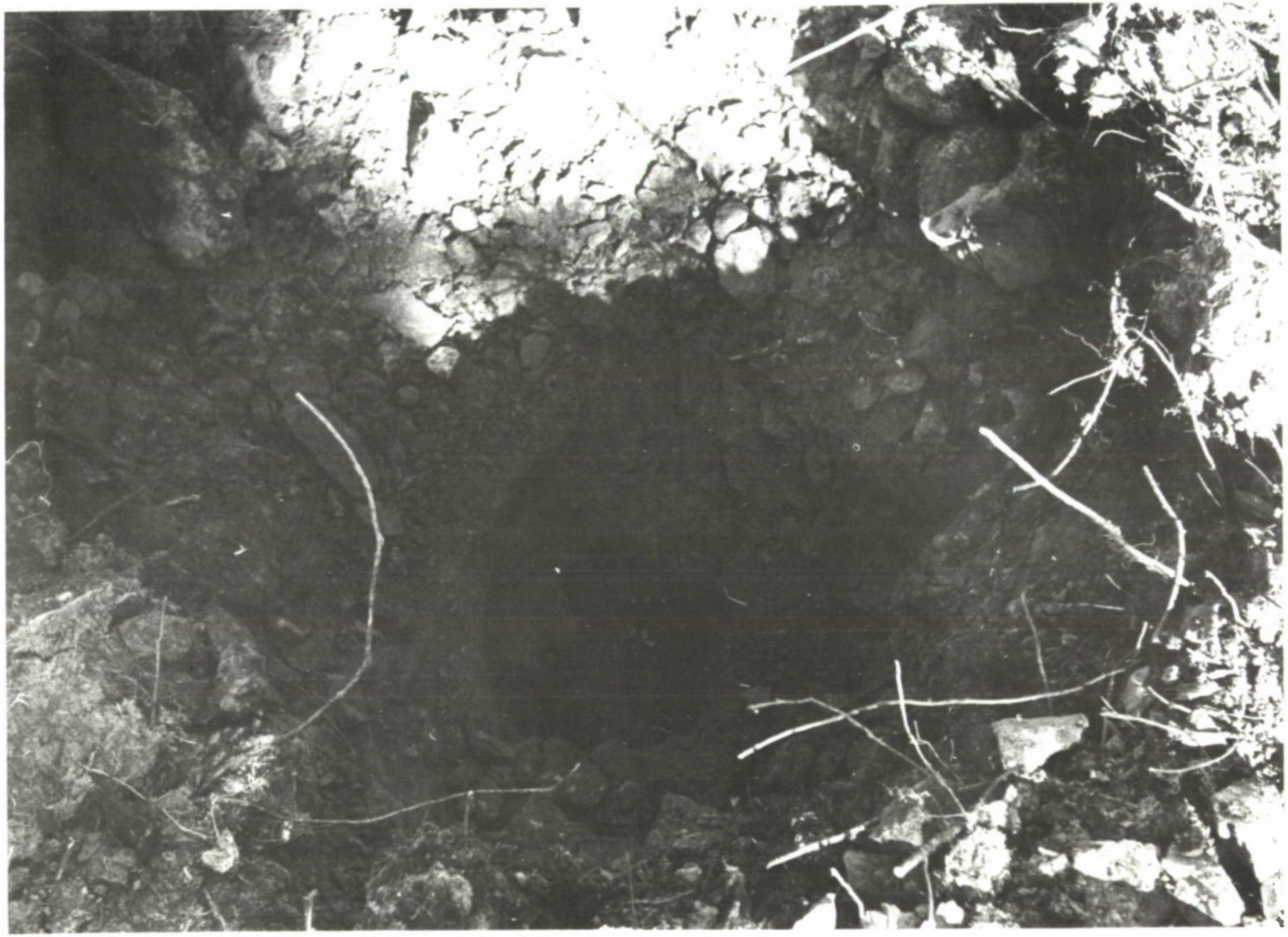


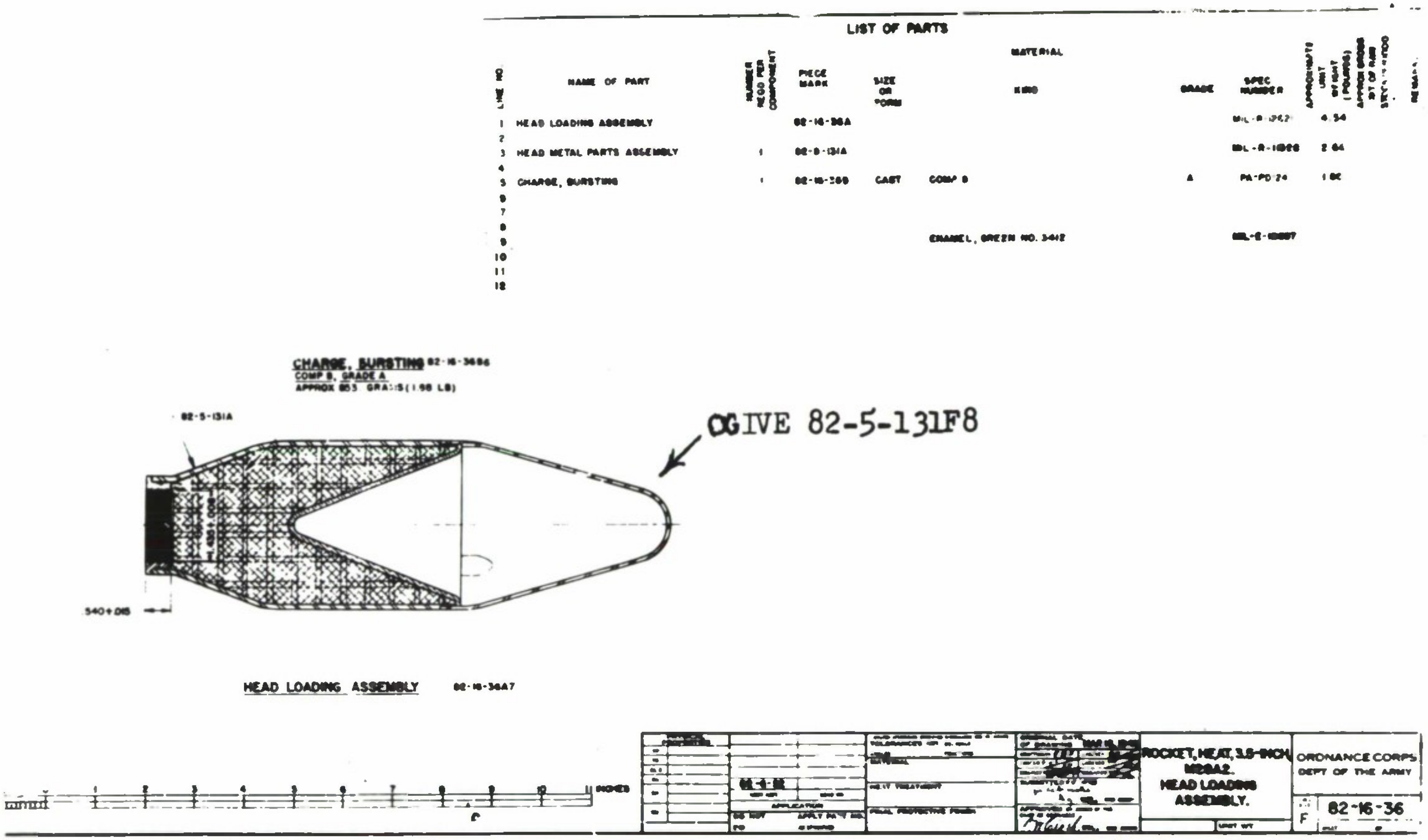
Fig 19 Shot #5: Crater after approximately 5 min of digging

Fig 20 Shot #6: Crater after approximately 5 min of digging

Fig 21 Shot #7: Result of 3 lb of liquid explosive in a 2¼" dia by 3' deep-bored shot hole

Fig 22 Shot #8: Result of 3 lb of liquid explosive in a 2¼" dia by 3' deep-bored shot hole

Fig 23 Shot #9: Result of 3 lb of liquid explosive in a 2¼" dia by 3' deep-bored shot hole



LIST OF PARTS

LINE NO	NAME OF PART	NUMBER REQD PER COMPONENT	PIECE MARK	SIZE OR FORM	MATERIAL KIND	GRADE	SPEC NUMBER	APPROXIMATE UNIT WEIGHT (POUNDS)	APPROX GROSS WT OF RAW STOCK	REMARKS
1	HEAD LOADING ASSEMBLY		82-16-36A				MIL-R-[illegible]	4.54		
2										
3	HEAD METAL PARTS ASSEMBLY	1	82-5-131A				MIL-R-[illegible]	2.64		
4										
5	CHARGE, BURSTING	1	82-16-36B	CAST	COMP B	A	PA-PD-24	1.98		
6										
7										
8										
9					ENAMEL, GREEN NO. 3412		MIL-E-[illegible]			
10										
11										
12										

Fig 24 Rocket, HEAT, 3.5-inch: M28A2, head loading assembly

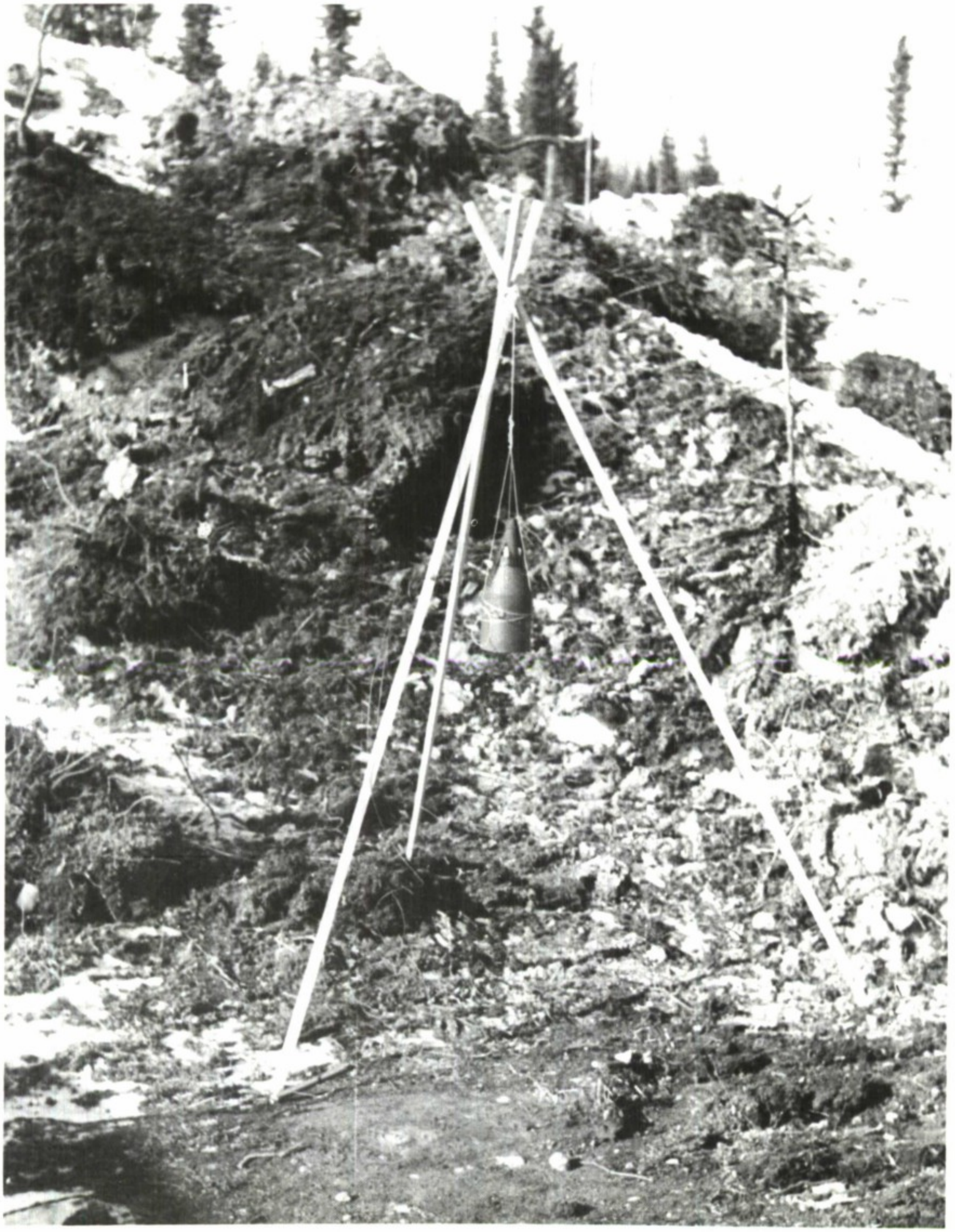


Fig 25 Shot #1: M28A2 HEAT rocket head prior to firing at 2' standoff

Fig 26 Shot #11: Result of 3 lb of liquid explosive in a 3½'-deep hole produced by an M28A2 HEAT rocket head

Fig 27 Shot #12: Result of 3 lb of liquid explosive in a 2'-deep hole produced by an M28A2 HEAT rocket head

Fig 28 Shot #13: Result of 2 lb of liquid explosive in a 1½'-deep hole produced by an M28A2 HEAT rocket head

Fig 29 Shot #10: Result of 3 lb of liquid explosive in a 4" dia by 3' deep-bored shot hole

Fig 30 Shot #14: Result of 16 lb of liquid explosive in a 4" dia by 9' deep-bored shot hole

Fig 31 Shot #15: Result of 30 lb of liquid explosive in a 6" dia by 10' deep-bored shot hole

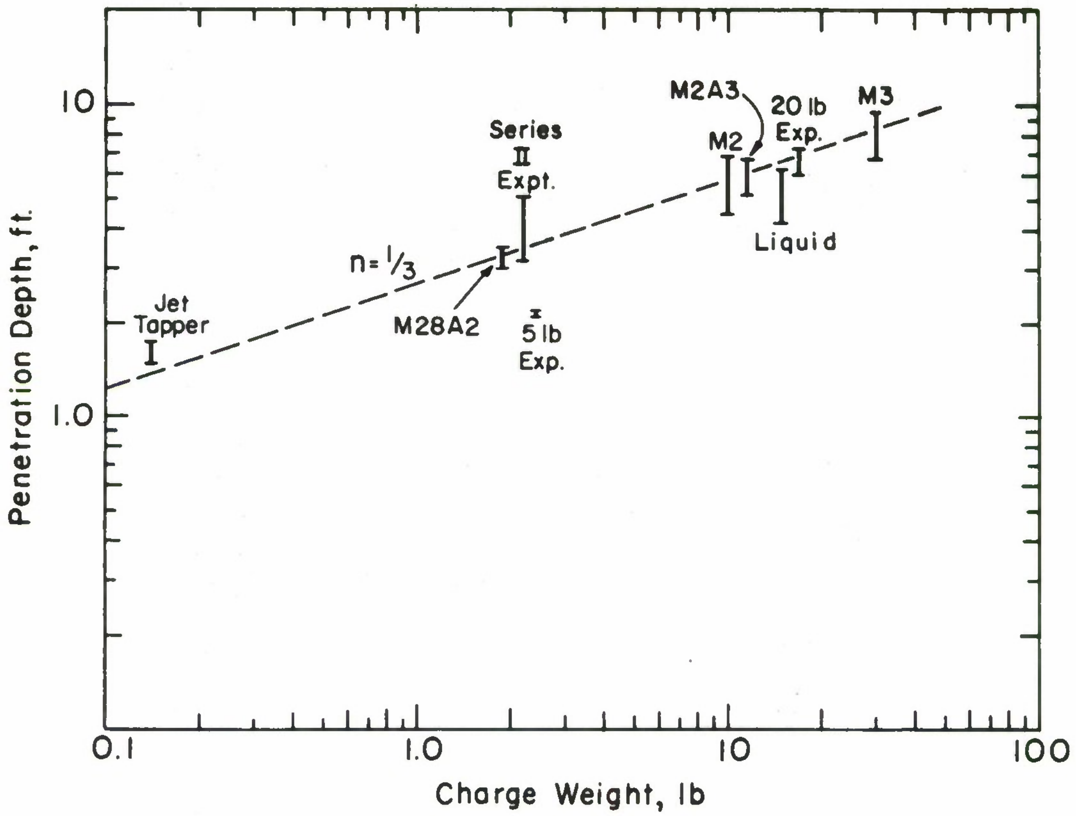


Fig 32 Penetration depth as a function of charge weight for shaped charges penetrating frozen ground (Data from Benert, 1957, 1963; Mellor and Sellmann, 1970; and present tests)

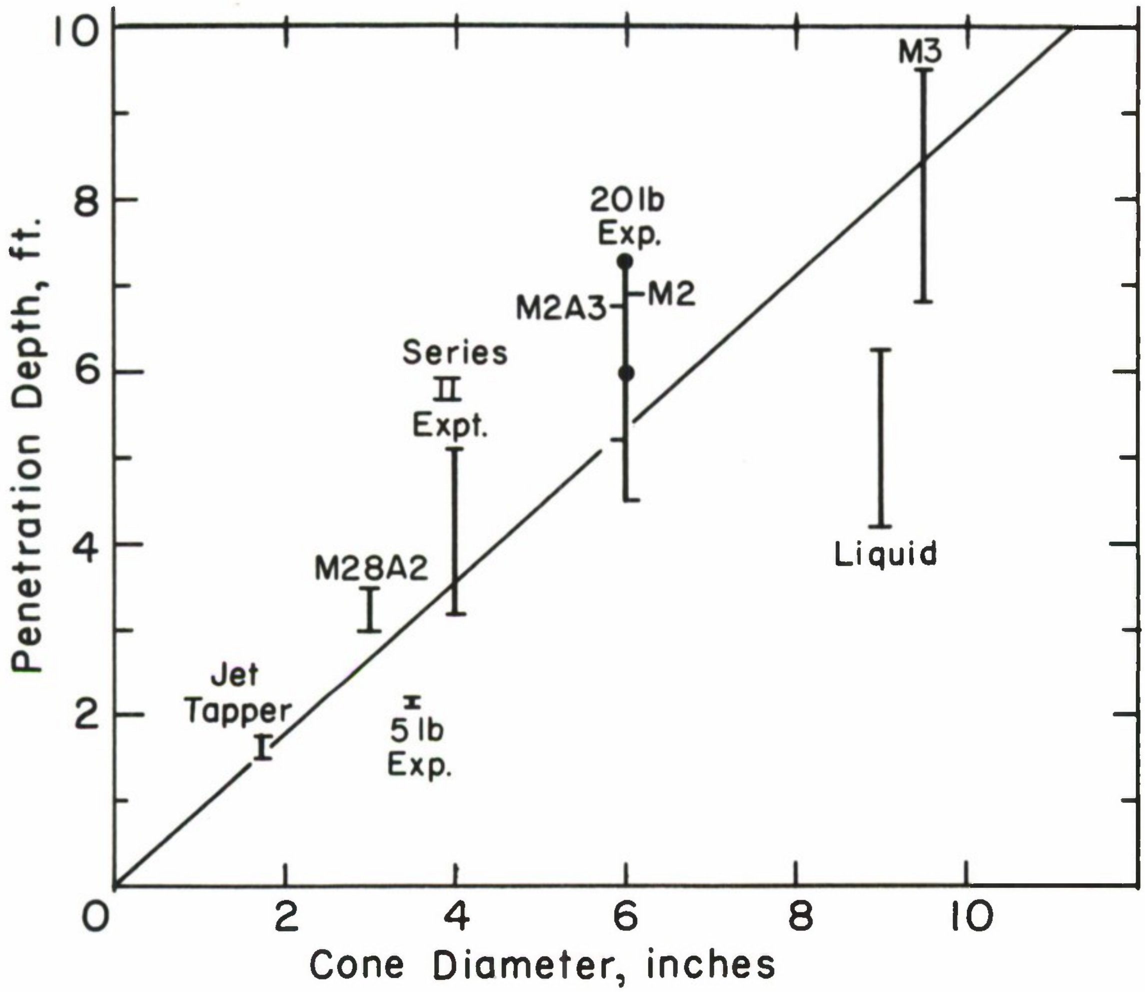


Fig 33 Penetration depth as a function of cone diameter for shaped charges penetrating frozen ground (Data from Benert, 1957, 1963; Mellor and Sellmann, 1970; and present tests)

APPENDIX A

Criteria for Explosives Acceptable for ENSURE 279-K

1. An acceptable explosive, when in its unit pack, must be safe from initiation by a 30 caliber bullet fired from a maximum distance of 90 feet.

2. It should be fully operational (including mixing capability, if multi-part) over the temperature range of -25 (desired: -40°F) to 140°F.

3. It should be capable of being initiated by a standard military blasting cap (J-1, J-2, M-6 or M-7).

4. It (or its constituents if multi-part) should not be toxic.

5. It (or its constituents if multi-part) should be compatible with skin, articles of clothing, container, and blasting cap.

6. It should be capable of being poured or extruded by light hand pressure into small holes or crevices.

7. It should be capable of being initiated and of propagating in a small diameter.

8. It should be effective even when in contact with wet earth.

9. It should have good potential shelf life over the temperature range of -65 to 165°F.

10. It should be man-transportable and usable in warm and in extremely cold weather (-25°F) and in any terrain, and it should require a minimum of new training.

APPENDIX B

Amended Criteria and Tests for Explosives Selection

1. Extracted from Letter from Office of Chief of Research and Development Dated 29 July 1970

a. The Joint Services Evaluation Plan presents the approach for the qualification of military explosives. It includes the preliminary procedures and criteria for the characterization tests needed to screen explosive candidates with respect to their handling, transportation, compatibility and scope of application. As approved by DDR&E it thus represents the current procedures and criteria for screening all Army explosive candidates.

b. All the characterization tests on page 15 of the approved plan need not be carried out if a candidate explosive is eliminated by failure in one or more of the tests.

c. The application being considered for the candidate explosive will govern the selection of procedures and criteria to be applied.

3. The evaluation of all candidate materials requested should be carried out in accordance with the above, and the approved Plan.

4. Upon completion of your evaluation, request that your report comment specifically on those candidate explosives that may have passed and those that may have failed. The report should include detailed information to substantiate your conclusions and recommendations. If none of the candidate explosives fully pass the evaluation, request recommendations as to further candidates or changes in the Ensure requirement that may permit satisfaction of the basic need for an improved Foxhole Digger.

II. Tests of the Joint Services Evaluation Plan

The following summarizes the screening and performance tests specified by the Joint Services Evaluation Plan for the evaluation of candidate explosives for munitions systems:

Characterization Tests

OX Bullet Impact

OX *Projectile Impact

OX Friction

O	Falling Weight (postponed until final candidate selected)
	High rate of Loading
O	Vibration (postponed until final candidate selected)
OX	Card Gap
	Booster
OX	Cap Sensitivity
OX	Wedge
	Rate of Detonation
OX	High Velocity
OX	Low Velocity
OX	Critical Dia for Propagation
OX	High Temperature Exposure (Cook-off)
O	Temperature and Humidity Cycling (postponed until final candidate selected)
OX	Vacuum Thermal Stability (not performed under vacuum)
OX	*DTA
OX	Growth with Temperature
	Exudation
O	Ability to be Loaded (no formal test; general information obtained during test program)
OX	Compatibility
OX	Viscosity

OX Electrostatic Sensitivity

Compressibility

O Toxicity (should be assessed by Office of Surgeon General in final munitions configuration)

Effectiveness (Performance) Tests (Small Scale)

(Note: not official JSEP tests, but relevant tests to indicate performance potential.)

OX Expanding Cylinder

OX Underwater Bubble and Shock Energy

OX Plate Dent Test

OX Cratering

O Appropriate
X Data obtained on some or all of candidates
* Not explicitly a JSEP test

APPENDIX C

Slurry Explosives

Slurry explosives consisting of ammonium nitrate (AN), aluminum, and water were first made in 1956. Due to the technical problem of the aluminum/water reaction, the commercial utilization of slurry explosives was delayed until 1962, when inhibitors were introduced to solve this problem (Ref 19, this report). In the years since, their application in the mining industry grew quickly. The use of this efficient, low-cost, dense blasting agent (DBA) by the military remained, however, sparse.

In November 1966, the Advanced Research Projects Agency engaged the Engineering Mechanics Division, IIT Research Institute, Chicago, Illinois, to conduct an evaluation test of a liquid/slurry explosive, which culminated in the successful loading and initiation of 250 tons of DBA-65T2, an IRECO slurry, for simulating an undersea nuclear detonation (Ref 20, this report).

In late 1967, Picatinny Arsenal ordered a portable machine for mixing slurries in the field (Ref 21, this report). Subsequently, IRECO Chemicals built and demonstrated this machine to the U. S. Army, the Marine Corps, and the Forestry Service (Department of the Interior).

During 1968, the Air Force investigated IRECO's slurry DBA-22M prior to using it for loading large bombs for clearing helicopter landing sites in densely forested areas (Ref 22, this report). Also in 1968, the Atomic Energy Commission (AEC) began the loading of DBA-22M in its "Big Test Vehicle" (BTV). This bomb, having a gross weight of about 45,000 pounds, is used for readiness tests. In the above applications, the slurry is pumped into the huge bomb in one continuous operation by a commercial pump truck normally used for on-site mixing and delivery of slurry explosives directly to the bore hole of a mine.

Advantages of this arrangement are that the inert raw materials may be stored or transported as nonexplosives with increased safety at reduced cost. Also, the formulation can be quickly altered to meet changing requirements.

For Project Foxhole Digger, IRECO submitted a new two-part slurry, DBA-208X. It was designed to be cap-sensitive, bullet-safe, and fluid at -40°F.

A series of cratering tests were conducted by Explosives Services, Inc. of New Orleans, Louisiana, during January 1970 near Fairbanks, Alaska, at -48°F. The materials tested in frozen silt and gravel were:

ANFO[1] (ammonium nitrate with fuel oil); 40% special gelatin dynamite; Pelletol[1] (TNT); Astrolite G-2 and A-1-5; and a mixture consisting of two-thirds ANFO with one-third nitromethane[1].

---

[1] These explosives could not be used in this program because they failed to meet our requirement for blasting cap sensitivity (see Appendix A, para c). An observer from the USA Cold Regions Research and Engineering Laboratory who witnessed the above tests reported that "Astrolite explosives gave little indication of any significant improvement in performance over that of the other explosives" (Ref 26, this report).

APPENDIX D

Astrolite Explosives

In May 1963, a family of liquid explosives was developed by EXCOA. In response to a request from the U.S. Army Materiel Command in 1966, Picatinny Arsenal characterized Astrolite G (Ref 23, this report).

In April 1967, EXCOA conducted cratering tests at Larsons Air Force Base, Moses Lake, Washington, under supervision of the Air Force (AF). Six 500-lb, Mk82 bombs were loaded, two each with one of the following explosives: Tritonal, H-6, and Astrolite A. The bombs were buried 8.5 feet deep, a depth the AF considered optimum for cratering with Tritonal. Craters made by the Astrolite-filled bombs were larger than those made by the Tritonal, and equaled those made by the H-6 bombs.

Additional tests were conducted to compare the cratering capability of Astrolite A with that of PBX-Nl (an RDX/aluminum/nylon composition) which is the explosive used in the Foxhole Digging Aid (Ref 24, this report). For this test, eight 2-inch-diameter pilot holes 30 inches deep and 12 ft apart were used (Ref 25, this report). Astrolite A (164 grams) was poured into a Lucite container of 1 inch ID and 8 inches long (which was equal to the weight and dimensions of the pressed PBX-Nl) and specimens of each explosive were placed into these pilot holes. In four trials Astrolite A proved superior to PBX-Nl as indicated below:

Cratering Test Results

Explosive		Crater Volume (cu inches)				Average
	Trials	1	2	3	4	
PBX-Nl		3,047	2,860	2,729	2,588	2,806
Astrolite A		4,124	3,882	3,781	905	3,173

In 1968, the U.S. Air Force (AFATL) examined Astrolite-A-1-5 for possible use in large bombs and as a napalm igniter (Ref 9, this report). The explosive was accepted as a filler for the igniter.

APPENDIX E

Nitromethane Explosives

Nitromethane (NM) was proposed by Picatinny Arsenal in 1966 for the Liquid Explosive Tunnel Destruct Kit, XM242 (Ref 27, this report). Numerous safety tests had been conducted prior to the introduction of two standard steel drums of NM into each kit. The tests indicated that in 55-gallon steel drums, NM is safe from 30 to 50 caliber bullet impact. It will burn but not detonate when hit by 20-mm HE shell. As a result of a compilation of safety data made during July 1968 by this Arsenal (Ref 28, this report) the Armed Services Explosives Safety Board reduced the hazard group classification of NM from Group 4 (the most hazardous category) to Group 2, Compatibility Group C.

A nitromethane-based proprietary liquid explosive was evaluated by Picatinny Arsenal as a pumpable material in the destruct system of the SATURN missile, (Ref 29, this report). A similar mix is currently being evaluated for blowing out the emergency exits of commercial aircraft (Ref 30, this report).

APPENDIX F

Candidate Formulations

Candidate Formulations

NM/NE/RDX Types

	Percent by weight and state of aggregation		
	Liquid	Slurry	Paste
Nitromethane/nitroethane 75/25	59.5	48	24
RDX (MIL-R-398, Class E)	30	30	15
RDX (MIL-R-398, Class A)	-	-	60
Aluminum (MIL-A-512, Type 3 Class 7)	10	20	-
Nitrocellulose (MIL-N-244A, 12.5%)	-	2	1
Cab-O-Sil, M-5	0.5	-	-

DBA-208X (IRECO)

DBA-208X is a binary composition of sodium perchlorate ($NaC\ell O_4$) oxidizer in solution as Part A and an aluminized dry fuel mixture as Part B.

Astrolite® (EXCOA)*

	A-1-5	G	LLTX G-2	
Hydrazinium nitrate	55.52	-	15	
Hydrazine	.03	48	70	Liquid
Water	-	3	15	
Aluminum	31.81	-	-	
Silicone dioxide	1.93	-	-	
Other	.76	-	-	
Amonium nitrate	-	49	80	
Ammonia	9.95	-	-	Solid
Ammonium perchlorate	-	-	20	

mixed in ratio or
2/1 solid/liquid

---

*Astrolite is a registered trademark of ROCKOR, Incorporated, Redmond, Washington.

DISTRIBUTION LIST

Commander
US Army Armament Research and
  Development Command
ATTN: DRDAR-CG
  DRDAR-LCM-PP, Mr. S. Levmore (6)
  DRDAR-LCM-E, Dr. R. Walker
  DRDAR-LCU-E, Mr. D. Katz
  DRDAR-ED
  DRDAR-TSS (5)
  DRDAR-LCU-P
  DRDAR-SF
Dover, NJ 07801

Commander
US Army Materiel Development and
  Readiness Command
ATTN: DRCDE-E
  DRCPI
  DRCSG-S
5001 Eisenhower Avenue
Alexandria, VA 22333

Commander
US Army Armament Materiel
  Readiness Command
ATTN: DRSAR-SF
  DRSAR-IS
  DRSAR-LEP-L
Rock Island, IL 61201

Commander
US Army Materiel Command
ATTN: AMCRD-TC, Dr. Borum (3)
Washington, DC 20315

Commander
US Army Test & Evaluation Command
ATTN: AMSTE
Aberdeen Proving Ground, MD 21005

Commander
Harry Diamond Laboratories
ATTN: Library
Washington, DC 20436

Commander
US Army Ordnance Center & School
ATTN: AISO-SL
Library
Aberdeen Proving Ground, MD 21005

Commander
US Army Mobility Equipment R&D Center
ATTN: Technical Document Center (2)
Fort Belvoir, VA 2060

Defense Documentation Center (12)
Cameron Station
Alexandria, VA 22314

Commander
US Army Engineer Research &
Development Laboratories
ATTN: Mr. Abbott Jackson
Mr. James Dennis
Fort Belvoir, VA 22060

Chairman
DoD Armed Forces Explosives Safety Board (2)
Washington, DC 20315

University of California
Lawrence Livermore Laboratory
ATTN: Maj Briggs
Technical Information Dept
P.O. Box 808
Livermore, CA 94550

Commander
US Army Tank Automotive Command
ATTN: AMSTA
Warren, MI 48090

Commander
US Army Artillery & Missile School
ATTN: AKPSIGV-R&A Division
Fort Sill, OK 73503

Headquarters, US Army, Europe
Deputy Chief of Staff, Operation
ATTN: AEAGG-NAF
APO New York 09403

Redstone Scientific Information Center
US Army Missile Command
ATTN: Chief, Document Section (4)
Redstone Arsenal, AL 35809

Commander
US Army Foreign Science
& Technology Center
Building 220, 7th Street, N.E.
Charlottesville, VA 22901

Commander
Naval Ordnance Systems Command
Department of the Navy
Washington, DC 20360

Air Force Armament Laboratory
ATTN: DLOS
Eglin Air Force Base, FL 32542

US Army Missile Research and
Development Command
ATTN: DRCPM-RK
Redstone Arsenal, AL 55809

Office of the Project Manager for
Selected Ammunition
US Army Materiel Command
ATTN: DRCPM-SA
Dover, NJ 07801

Office of the Chief of Engineers
ATTN: ENG-SO, Mr. L. E. Dolton
Forrestal Building, Room GB268
Washington, DC 20314

US Army Cold Regions Research and
Engineering Laboratory
ATTN: CRREL-EA, Dr. M. Mellor (2)
PO Box 282
Hanover, NH 03755

Research Director
Explosives Research Center
4800 Forbes Avenue
Pittsburgh, PA 15213

Weapon System Concept Team/CSL
ATTN: DRDAR-ACW
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-CLJ-L
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21005

Technical Library
ATTN: DRDAR-LCB-TL
Benet Weapons Laboratory
Watervliet, NY 12189

Hqs, USACOMZEUR S&MA
ATTN: AEZSM-MM-S
Zweibrucken, Germany
APO New York 09052