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DEVELOPMENT OF EXPERIMENTAL MULTI-POINT, SIMULTANEOUSLY-INITIATED, UNDERWATER LINE CHARGES (U)

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1 MARCH 1962

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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DEVELOPMENT OF EXPERIMENTAL MULTI-POINT, SIMULTANEOUSLY-INITIATED, UNDERWATER LINE CHARGES (U)

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ABSTRACT: This report describes the development of two line charges and the initiators for them. The charges were made for a research program on explosive echo ranging. The two line charges consisted of: (a) primacord initiated at a number of points simultaneously by a "T" detonator and (b) a commercial plastic explosive in the form of a rod also initiated simultaneously at a number of points by the central initiation of strands of mild detonating fuse. Simultaneity of initiation between points was about ±1.5 microseconds for both systems. The practical construction details for the charges and the initiators are described.

Explosions Research Department
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 62-5 1 March 1962

This report describes the design, development, and construction of experimental charges used in explosive echo ranging tests. The work was performed in the Explosion Dynamics Division of the Explosions Research Department under Task RUME-3E-023/212 1/F001-13-006.

Although the charges were designed for a specific application, it is believed the tests and methods of fabrication will be of interest to others engaged in the design and construction of underwater and other type charges.

The identification of commercial materials implies no criticism or indorsement of these products by the Naval Ordnance Laboratory.

W. D. COLEMAN
Captain, USN
Commander

C. J. ARONSON
By direction

CONTENTS

Page

1. Introduction 1
2. Primacord Line Charges 1
   - 2.1 Requirements 1
   - 2.2 Design of Detonator. 2
   - 2.3 Loading and Assembly of Detonator. 2
   - 2.4 Functioning Tests. 2
   - 2.5 Simultaneity Testing by a Modified Dautriche Method. . 3
   - 2.6 Simultaneity Testing by the Camera Method. 3
   - 2.7 Simultaneity Testing of Multiple Detonators by a Modified Dautriche Method. 3
   - 2.8 Collision of Primacord Shock Fronts. 4
   - 2.9 Waterproofing of Primacord Charges 4
     - 2.9.1 Primacord-Detonator Junction 4
     - 2.9.2 End Seals 5
   - 2.10 Primacord Line Charge Configurations. 5
3. Line Charges for Sea Trials 5
   - 3.1 Requirements 5
   - 3.2 Methods for Obtaining Simultaneity 6
   - 3.3 Mild Detonating Fuse 6
     - 3.3.1 MDF Spacing. 6
     - 3.3.2 Simultaneity 7
   - 3.4 Line Charge Design 7
     - 3.4.1 Initiation 7
     - 3.4.2 Placement of Initiator Unit. 8
     - 3.4.3 Spiral Take-up Forms 8
     - 3.4.4 MDF Selection. 8
   - 3.5 Waterproofing. 8
     - 3.5.1 System Test. 9
     - 3.5.2 Initiator Block. 9
   - 3.6 Assembly 9
     - 3.6.1 Double-end Initiated 10
     - 3.6.2 Multi-point Initiated. 10
4. Discussion 10
5. Conclusions. 11

ILLUSTRATIONS

Figure	Title	Page
1	General Arrangement of Model "T" Test Detonator . . .	13
2	Simultaneity Test Setup for Individual Detonator (Modified Dautriche Method) . . .	14
3	Framing Camera Sequence for Simultaneity Testing . .	15

ILLUSTRATIONS (Con't)

Figure	Title	Page
4	Simultaneity Test Setup for Detonators Fired in Parallel (Modified Dautriche Method).	16
5	Framing Camera Sequence of Underwater Detonation Front Collision.	17
6	Method of Making Water Resistant Seal.	18
7	Types of Water Resistant Seals Used in Fabrication of Primacord Line Charges.	19
8	Primacord Line Charge Configurations Fabricated for Testing.	20
9	Mild Detonating Fuse Spacing Tests	21
10	Construction Details of Breadboard Setup to Determine Simultaneity.	22
11	Breadboard Setup to Determine Simultaneity	23
11	Smear Camera Record of Simultaneity.	23
12	Terminating Detonator Test System.	24
13	Testing of Spiral Forms.	25
14	Location of Spiral Forms	26
15	Final Terminating Detonator Design	27
16	General Arrangement of EX-7 Mod 0 Detonator. . . .	28
17	Potted Detonator Housing Ready for Insertion into Initiator Unit	29
18	Construction Details of Double-End Initiated Line Charges.	30
19	Construction Details of Multi-Point Initiated Line Charges	31

TABLES

Table 1	Mild Detonating Fuse (MDF) Spacing Tests	12

DEVELOPMENT OF EXPERIMENTAL MULTI-POINT, SIMULTANEOUSLY-INITIATED, UNDERWATER LINE CHARGES

1. Introduction

1.1 This report describes the design and development of experimental line charges for underwater use. There is very little in the literature describing the practical construction of such charges, consequently it was necessary to conduct many background tests before the charges could be prepared. It is hoped that the methods and techniques described for the specific charges built will assist future designers in the preparation of similar or more advanced charges.

1.2 The line charges constructed were used as explosive sound sources in an explosive echo ranging research program. Two main types of line charges were constructed to meet the demands of the program.

a. Primacord Charge. The first type of line charge constructed during the program was used as an interim charge to determine the location and number of initiation points necessary to generate a pressure field having a maximum value along the perpendicular bisector of the charge. These interim charges were made of primacord approximately five feet in length and had a total explosive load of 0.1 pound. The maximum spacing of initiation points that would achieve the desired pressure pattern was determined from these charges.

b. Sea Trial Charge. The second main type of line charge constructed was used in the actual sea trials to determine the effectiveness of the directional pressure pattern. These charges had a total explosive weight of two pounds and were either ten or twenty feet in length. The location and number of initiation points were based on the test results from the primacord charges.

2. Primacord Line Charges

2.1 Requirements. The first type of line charge tested was primacord (120 grains/foot) initiated at a selected number of points. Requirements for the initiating system were:

a. Provide initiation at a number of points with a simultaneity within ±1.5 microsecond.

b. Be capable of initiating the primacord line reliably.

c. Contain a minimum of explosive outside of the primacord so as to minimize interference with the pressure pattern.

d. The initiating system and primacord assembly to be water resistant for at least two hours at a fifteen-foot depth.

2.2 <u>Design of Detonator</u>. In order to obtain the simultaneity desired, a detonator of uniform functioning time was necessary. A very fast acting detonator appeared desirable. Previous investigators (1) have shown that wire bridge detonators with a milled dextrinated lead azide flash charge and a PETN base charge can be made to have a simultaneity within 1 microsecond when fired in parallel by capacitor discharge at a high voltage. Using this information, an experimental detonator was designed containing lead azide spot and flash charges and a PETN base charge. (See Figure 1.) This detonator was designated the Model "T" because of its configuration.

2.3 <u>Loading and Assembly of Detonator</u>. A 0.750-inch diameter by 1.200-inch long aluminum housing was used as the containing body. A copper tube, with an inside diameter that would permit a slip fit of primacord into it was bonded to the aluminum housing with epoxy resin. Care was taken to avoid resin entering the explosive cavity. PETN was loaded into the central portion of the copper tube and a 0.025-inch thick cardboard disc was cemented at each end of the PETN column. The aluminum housing was then loaded with PETN and an initiator plug and charge holder containing lead azide inserted. The remainder of the housing cavity was filled with epoxy resin to provide a water resistant seal.

2.4 <u>Functioning Tests</u>. Tests were conducted to determine if the Model "T" detonator could consistently initiate primacord. A control test was run by placing a length of primacord on a steel block, initiating it with an Engineer's Special blasting cap, and measuring the dent produced in the block. Primacord was then initiated with a Model "T" detonator and the dent it produced was compared to that of the control test. Through these tests it was found necessary to increase the PETN charge in the housing to 125 mg in order to obtain consistent high order initiation of the primacord.

(1) R. H. Stresau and J. Savitt, "Detonators for Multiple Point Simultaneous Initiation of Explosive Charges", NavOrd Report 2114, May 1953, Confidential.

2.5 Simultaneity Testing by a Modified Dautriche Method. Simultaneity of initiation of primacord from both arms of the Model "T" detonator was determined by means of a modified Dautriche (2) test. The free ends of a single length of primacord were crimped into the arms of the Model "T" detonator forming a loop. A lead plate was placed under the primacord and a scratch mark made on the plate to indicate the exact center of the loop (see Figure 2). If both arms are initiated simultaneously, a dent should appear in the lead plate exactly over the scratch where the shock waves collide. If initiation is not simultaneous and if the detonation velocity of the primacord is assumed to be constant at 6000 meters/second, a 0.125-inch shift of the dent with respect to the scratch should occur for each microsecond of non-simultaneity. Initial tests showed a scatter of 1 to 2 microseconds between the two arms. Some of this scatter was believed due to the method of crimping the primacord into the copper tube of the detonator. The crimping was thought to disturb the PETN core. When the crimping operation was eliminated and the primacord held in place with tape, the scatter dropped to 0 to 1 microsecond.

2.6 Simultaneity Testing by the Camera Method. The simultaneity of breakout from the arms of a single detonator was also checked using a Beckman-Whitley Model 189 Framing Camera. Four inches of primacord were inserted into each arm of the detonator. The detonator and primacord were fired and photographed at a framing rate of 1,000,000 frames/second. Of three shots made, two showed a simultaneity of better than 1 microsecond and the third showed a simultaneity within 1 microsecond but less than 2 microseconds. Selected frames from one of the explosion sequences are shown in Figure 3. The elapsed time from the moment of input of the electrical pulse to complete detonation of the primacord ranged from 20 to 22 microseconds for the three shots.

2.7 Simultaneity Testing of Multiple Detonators by a Modified Dautriche Method. A uniform firing time for detonators fired singly does not assure simultaneity of firing for multiple detonators fired in series or parallel. Since a number of initiation points were to be used in the final line charge it was necessary to determine the simultaneity of firing for a number of detonators. Parallel firing was chosen to keep a high firing voltage across each detonator. To determine the simultaneity of detonators fired in parallel, another modified Dautriche test was run. Three detonators were used in the test. (See Figure 4.) For this test arrangement the shock waves

(2) J. Taylor, "Detonation in Condensed Explosives", Oxford at the Clarendon Press, 1952.

which met at A and B were exactly on the halfway distance marks of the primacord while the shock waves which met at C were 1/16 inch from the center point giving a time differential of 0.5 microsecond. For the arrangement described and all subsequent line charges of this type fabricated, the bridge resistance of all the detonators on each line charge were matched to within 0.05 ohms. This was done so that each detonator would draw approximately the same current. A capacitor discharge with a more than ample energy content to fire all the detonators was used as the firing pulse. A much higher voltage than necessary for initiation was used to insure simultaneity of firing.

2.8 Collision of Primacord Shock Fronts. An underwater camera sequence was made to observe what would happen when the primacord detonation fronts, which started from adjacent detonators collided. The shot was made in a small glass aquarium using a Beckman-Whitley Model 189 Framing Camera. (See Figure 5.) Four inches of primacord were used between the detonators. Calculations of the shock front intersection showed that in the first 10 m.m. of travel the average Mach bridge velocity is 2840 meters/second giving a pressure value on the order of 12 kilobars. At 40 m.m. out the Mach bridge velocity has decayed to 1740 meters/second giving a pressure value in the order of 2 kilobars.

2.9 Waterproofing of Primacord Charges. The primacord line charges were designed to withstand four hours immersion in fifteen feet of water. 120 grain/foot rubberized primacord was used as the main charge. The initiator plug cavity and copper tube joints of the Model "T" detonators were sealed with epoxy resin to prevent any ingress of water. Since to fire the detonators a high voltage source was to be used and since the water at the firing location would have a slight salinity, "pitch and tape" joints were used to make the electrical connections waterproof against the expected ambient conditions at firing. This type of joint is made by alternating layers of electrical tape and pitch or other water repellant material until a sufficient water resistant thickness is built up.

2.9.1 Primacord-Detonator Junction. The primacord-detonator junction (without a crimp) was the most difficult connection to prepare. A joint with a large quantity of material such as a "pitch and tape" joint was not desirable. A satisfactory joint was developed (see Figure 6) after a few cut and try experiments. The exterior of the primacord at the end was coated with epoxy resin and inserted into the copper tube of the detonator. A 1.5-inch length of polyethylene tubing having an inner diameter slightly smaller than the outer diameter of the primacord was soaked in butyl acetate until it became flaccid.

This tubing which had been placed on the primacord before insertion into the detonator was then slipped over the junction. As the butyl acetate evaporates, the polyethylene tubing shrinks back into shape squeezing the still pliable epoxy resin into any crevices and forming a good water resistant seal.

2.9.2 End Seals. The unused copper arm of a detonator located directly on the end of the primacord line charge, was filled with epoxy resin to prevent water entry. When the end of the line charge was terminated by primacord, a copper cup was used and the water resistant junction completed in the same manner as the attachment to the detonator. (See Figure 7 for details.)

2.10 Primacord Line Charge Configurations. Experimental line charges of the type described were fabricated containing from one to ten detonators. Figure 8 shows some of the line charge configurations that were built and tested. Results of testing these charges indicated that the double-end detonated line charge and the line charges having three or more detonation points gave the desired pressure pattern. Since the line charges were five feet long, this indicated that a maximum spacing of twenty inches between initiation points could be used when the detonators are equally spaced along the line charge.

3. Line Charges for Sea Trials

3.1 Requirements. Three variations of a "prototype" line charge were designed for sea trials based on test results from the primacord line charges. The three types decided upon for sea trials were:

a. Double-end initiated -- 10 feet long.

b. Double-end initiated -- 20 feet long.

c. Multi-point initiated (7 point) -- 10 feet long.

Requirements for these line charges were that each charge was to:

a. Contain 2 pounds of high explosive.

b. Be simultaneously initiated at each point within $\pm$ 1.5 microseconds.

c. Be water resistant for at least two hours at a 1,000-foot depth.

3.2 Methods for Obtaining Simultaneity. The Model "T" detonators previously employed did not appear practical for the sea trial charges due to size and safety considerations. Methods for obtaining the simultaneity needed for these larger charges were surveyed and studied. Initially, insensitive detonators containing PETN which could be initiated by a high energy pulse resulting in an exploding bridgewire appeared most feasible. To attain this, the following methods were considered:

a. A high voltage surface signal.

b. High voltage capacitor discharge by a power supply attached to the charge.

c. High voltage pulse produced by explosively shocking a transducer.

The great depth (1,000 feet) ruled out the use of a high voltage firing signal from the ocean surface. An individual power supply for each charge was considered too expensive as it would be destroyed with the charge. As for explosive to electric transducers the state of the art was not considered advanced enough for the number of initiation points required and the large amount of explosive needed in the transducer system could interfere with the desired pressure pattern.

3.3 Mild Detonating Fuse. The disadvantages associated with exploding bridgewire detonators led to the consideration and finally the adoption of a mild detonating fuse system. MDF is a small diameter, continuous metal tubing (usually lead), containing a PETN core. The smaller sizes can be used to transmit detonation with very slight damage in the vicinity of the fuse. The ends of a number of equal lengths of MDF can be made to initiate simultaneously at different points when the opposite ends are simultaneously initiated from a common source.

3.3.1 MDF Spacing. At the time this phase of the development work was undertaken, very meager information was available on the use of MDF for this purpose. The first tests were conducted to determine the minimum allowable spacing between strands of adjacent MDF to prevent cut-offs, i.e., the minimum distance between strands for which the detonation of one strand does not interfere with the detonation of another. Two tests were run using the lowest core loadings of MDF available:

a. Type A-1 MDF containing 1 grain PETN/foot.

b. Type A-2 MDF containing 2 grains PETN/foot.

The strands of MDF in each test were of the same strength. Figure 9 shows the test setup. The center length of MDF was initiated with an electric primer and the effect on smaller lengths placed at varying distances adjacent to the center length observed. Table 1 summarizes the observed effects. It appears that a spacing of at least 0.250 inch is needed for the Type A-1 MDF and at least 0.500 inch for the Type A-2 MDF to prevent injury of the PETN core in adjacent strands.

3.3.2 Simultaneity. Breadboard setups were prepared to determine the simultaneity that could be obtained using an MDF initiation system. Eight five-foot long strands of MDF were initiated simultaneously from a central pellet of PETN in an aluminum block. Figure 10 shows some of the construction details of the setup. First, the eight strands of MDF were potted in the aluminum block. The MDF ends in the block terminated on the periphery of the central cavity. PETN was then pressed into the central cavity to insure intimate contact with the PETN core of the MDF. The other end of each MDF strand terminated in an explosive receptor. The receptor was made by potting an MDF strand flush with the bottom of a central cavity in a lucite cylinder. PETN was then pressed into the central cavity. Figure 11a is a photograph of the setup before firing. Figure 11b shows the smear camera record from which the simultaneity was determined. The spread between detonation of the first and last receptor using 1 grain MDF was 1.42 microseconds and 1.21 microseconds for 2 grain MDF. Both spreads were well within the time limits desired (±1.5 microseconds).

3.4 Line Charge Design. The explosive chosen for the line charge was EL-506D (3). It is composed of PETN combined with rubber and other materials. Upon request, the explosive was extruded as ten and twenty foot rods by the manufacturer. In order to meet the requirement of 2 lb. ±5%, the ten-foot long explosive rods were a nominal 0.625 inch in diameter, and the twenty-foot long ones were 0.437-inch in diameter. The material is not permeable nor affected by water making the use of a protective casing unnecessary. It can be safely cut with a knife facilitating the assembly of the initiator system.

3.4.1 Initiation. The manufacturer recommended an Engineer's Special Electric Blasting Cap, containing 13.5 grains (0.875 grams) of PETN, for initiation of the EL-506 explosive. It was found that consistent high order initiation of the EL-506 could be obtained when MDF was used to initiate terminating detonators (see Figure 12) containing 0.210 gram of PETN set in the EL-506. An electric initiator was used to initiate the MDF. Figure 12 shows the terminating detonator and test system employed.

(3) Manufactured by E. I. duPont deNemours & Co., Wilmington, Del.

3.4.2 Placement of Initiator Unit. When an initiator unit similar to the one used for simultaneity testing is placed at the middle of the ten-foot length EL-506 rod, two five-foot lengths of MDF with terminating detonators would be required for double-end initiation. When the initiator unit is placed at one end of the ten-foot line charge, two ten-foot lengths of MDF with terminating detonators would be required because equal lengths of MDF from the initiator unit to the terminal detonators are necessary for simultaneity. Therefore, it was decided to place the initiation unit in the center of the line charge to decrease the amount of MDF used.

3.4.3 Spiral Take-up Forms. In the fabrication of double-end initiated line charges, single strands of MDF are run directly from the centrally located initiator unit to each terminal detonator. No provision was necessary to take up excess lengths of MDF. For the seven-point initiated charge, it was necessary to provide a method for take-up of the MDF lengths which lead to detonation points near the initiation unit. The take-up was accomplished by winding the MDF on spiraled rods. A test was run as illustrated in Figure 13. The test demonstrated that detonation could be transmitted down the spiral without danger of cut-off. Figure 14 shows how the spiral forms were placed around the initiator block on a brass plate in one of the preliminary test units. It was found that the MDF tended to slacken on the spiral forms after assembly. To overcome this the whole central initiator unit was placed in a cylindrical pint cardboard container and potted with Epoxylite #2151 (4). This potting was chosen because it cures at a low temperature, has low shrinkage so as not to damage the MDF, and a high clarity so that the potted unit could be inspected.

3.4.4 MDF Selection. In the case of the seven-point line charge the spacing between the MDF lines was critical. To minimize the effect of spacing, it was decided to use the lowest strength MDF available. The lowest strength MDF type A-1 has a tensile strength of 5 pounds and is quite fragile. For added strength it was obtained plastic coated. The plastic covered MDF is the same as the plain material except that it also has a 0.010 to 0.015 inch polyethylene covering. This thin sleeve of plastic considerably increases the strength and resistance to abuse and does not make the MDF too cumbersome to use.

3.5 Waterproofing. With the general details of the line charge and initiation system worked out, methods of keeping the system water resistant were examined. Tests with EL-506D showed that it was water resistant as claimed by the manufacturer.

(4) Manufactured by the Epoxylite Corp., El Monte, California

Five pieces of EL-506D were subjected to 750 psi hydrostatic pressure (equivalent to 1700-foot depth) for two hours. One piece was sectioned with a knife and no evidence of internal wetting was found. The other four pieces initiated high order when tested immediately after removal from the pressure chamber using the system illustrated in Figure 12.

3.5.1 System Test. Because the EL-506D had excellent water resistance it was unnecessary to waterproof it. However, a waterproof initiating system was necessary. A test was made of the initiation system in which a central initiator, strands of MDF, and terminating detonators were subjected to a hydrostatic pressure of 750 psi for two hours and then fired. All MDF strands from the initiator block went high order, but three out of six terminating detonators failed to initiate high order. Damp PETN was found in the remains of those detonators which failed to go high order. The terminating detonator previously had been sealed with epoxy resin. It was now redesigned to contain an "O" ring and two roll pins to hold the detonator cup in place. Figure 15 illustrates the redesign. An initiating unit containing the redesigned terminal detonator was exposed to 750 psi hydrostatic pressure for sixteen hours. Upon removal and test all detonators initiated high order.

3.5.2 Initiator Block. The initiation system was designed to be initiated by an electric signal from a surface ship. An insensitive electric detonator, the EX-7 Mod 0, containing a lead azide flash charge, was chosen as the initiator for the PETN pellet in the initiator block. Figure 16 is a cross-section of this detonator. The EX-7 Mod 0 Detonator was potted into a brass housing which could be easily inserted into the initiator block just before the charge was lowered over the side of the ship for firing. An "O" ring seal on the brass housing was used to prevent water entry into the initiator block. (See Figure 17.) Tests of initiator units containing the potted EX-7 Mod 0 unit with an "O" ring seal successfully passed a two hour hydrostatic pressure test at 750 psi. Hydrostatic or other type fuzes could be substituted for the EX-7 Mod 0 Detonator by changing the dimensions of the initiator block cavity to accommodate the desired fuze.

3.6 Assembly. Since the EL-506D used for the main charge has low mechanical strength, some method of supporting the explosive was necessary. Two methods considered for supporting the charges were to tie the explosive rod to a metal rod or to place it in a metal tube. The latter method was chosen. Thin wall (0.022-inch), 1-inch O.D. aluminum tubing was used as it was thought it would interfere less with the pressure pattern on explosion. The tubing was selected as thin as possible but with enough strength to survive the rough handling it would encounter.

Couplings were placed on each end of the tubing to permit attachment of an anchor at one end and an eyelet for the lowering cable at the other. The tubing was not watertight and would fill with water when the charge was lowered for firing.

3.6.1 Double-end Initiated. The initiator unit was fastened to the midpoint of the tubing with a clamp. For the double-end initiated charges the MDF leads from the initiator unit were taped to the outside of the aluminum tubing and led into the EL-506D through slots cut in the tubing next to each end couple. Figure 18 illustrates some of the construction details. Two ten-foot lengths of tubing were coupled together to support the twenty-foot long, double-end initiated charges and the initiator unit was attached in the same manner as above.

3.6.2 Multi-point Initiated. For the multi-point initiated line charges, the MDF leads were led into the EL-506D through two slots in the tubing immediately adjacent to the centrally attached initiator unit. The MDF leads were taped to the explosive keeping suitable spacing between the leads to prevent cut-offs where two or three leads run parallel. The danger of the MDF initiating the EL-506D is nil except where terminated by a detonator. The explosive output of the MDF is insufficient to cause initiation of the EL-506D. Only a scarring of the surface of the EL-506D was produced in tests where MDF was detonated on the explosive. For assembly of the multi-point charges, the aluminum support tubing was cut in half, lengthwise. After the initiator system was attached to the line charge the aluminum tubing was placed over the line charge and taped together. Holes were made in the EL-506D with a cork borer for placement of the terminating detonators. Figure 19 illustrates the construction details for the multi-point line charge.

4. Discussion

4.1 The line charges described were developed for specific experimental field tests. Therefore the developmental effort did not include rough handling or environmental testing. For ordnance application, these designs would require further extensive developmental effort. Strict safety precautions were observed at all times in the handling of the charges since the safety and arming mechanism was omitted.

4.2 Both types of line charges performed satisfactorily in the field tests in which they were employed. One failure was encountered out of approximately thirty primacord line charges fired, and this failure was attributed to leakage into a detonator.

The sea trial charges were actually fired at 300 and 800 ft. depths during the field tests. Sixty-six out of seventy-one sea trial charges fired properly giving a 93% functioning percentage which is considered good for underwater charges. On one of the failures, the detonators fired but the main charge failed to initiate. One failure was due to improper use of the electric pulser and was not attributable to the charge construction. The cause of the other three failures was unknown.

5. Conclusions

5.1 Two types of multiple-point, simultaneously-initiated underwater line charges have been developed for use in an experimental program.

5.2 The simultaneity of the detonation points for the two initiation systems described is within ±1.5 microseconds.

5.3 Methods for making water resistant connections and construction details used in the fabrication of the line charges are described.

5.4 The line charges were successfully completed on schedule.

5.5 The line charges functioned properly despite adverse handling conditions during field tests.

Table 1

Mild Detonating Fuse (MDF) Spacing Tests

Type A-1 (1 grain/foot)		Type A-2 (2 grains/foot)	
Spacing (inches)	Result	Spacing (inches)	Result
0.000	PETN apparently went low order in section adjacent to initiated strand.	0.000	PETN went low order in adjacent section.
0.063	Severe pitting of lead sheath, PETN exposed.	0.063	PETN went low order in adjacent section.
0.125	Severe pitting of lead sheath, PETN exposed.	0.125	Severe pitting of lead sheath, PETN exposed.
0.250	Severe pitting of lead sheath.	0.250	Severe pitting of lead sheath, PETN exposed.
0.500	Severe pitting of lead sheath.	0.500	Severe pitting of lead sheath.
0.750	Very slight pitting of lead sheath.	0.750	Slight pitting of lead sheath.

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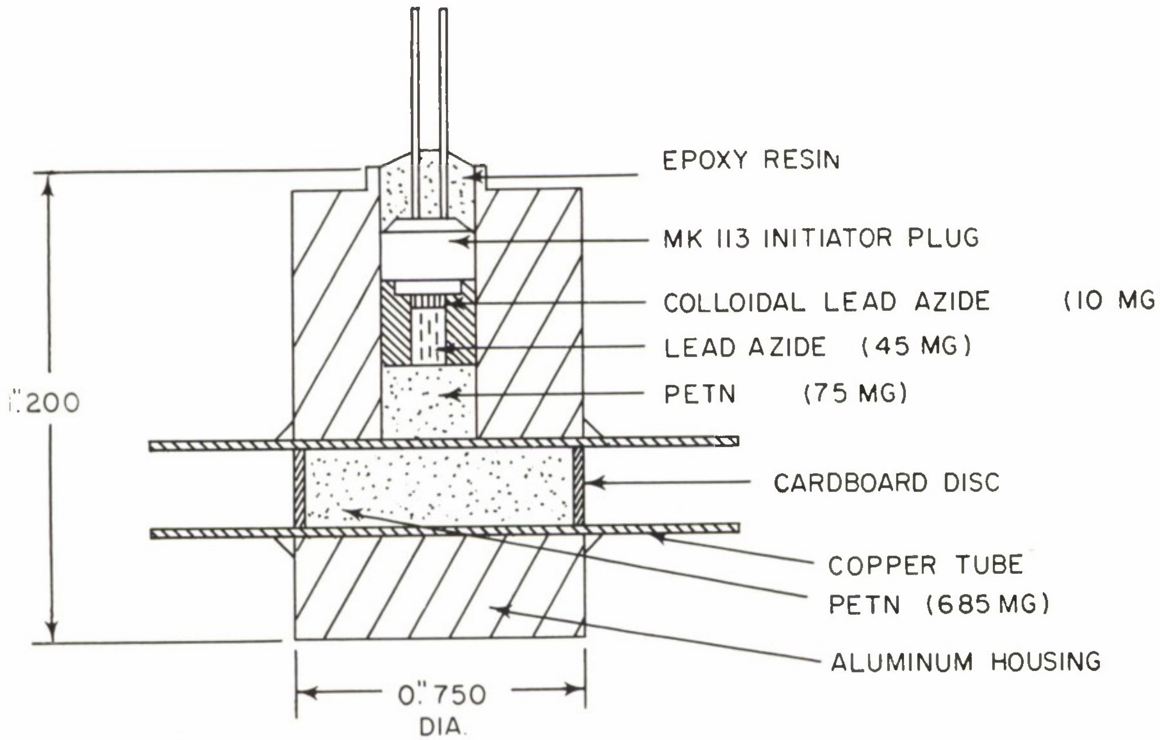


FIG. 1. GENERAL ARRANGEMENT OF MODEL "T" DETONATOR

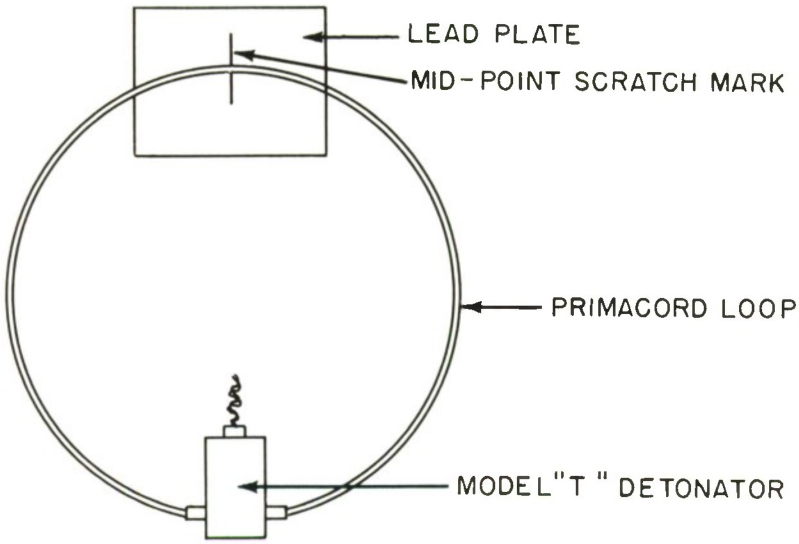


FIG. 2 SIMULTANEITY TEST SET-UP FOR INDIVIDUAL DETONATOR
(MODIFIED DAUTRICHE METHOD)

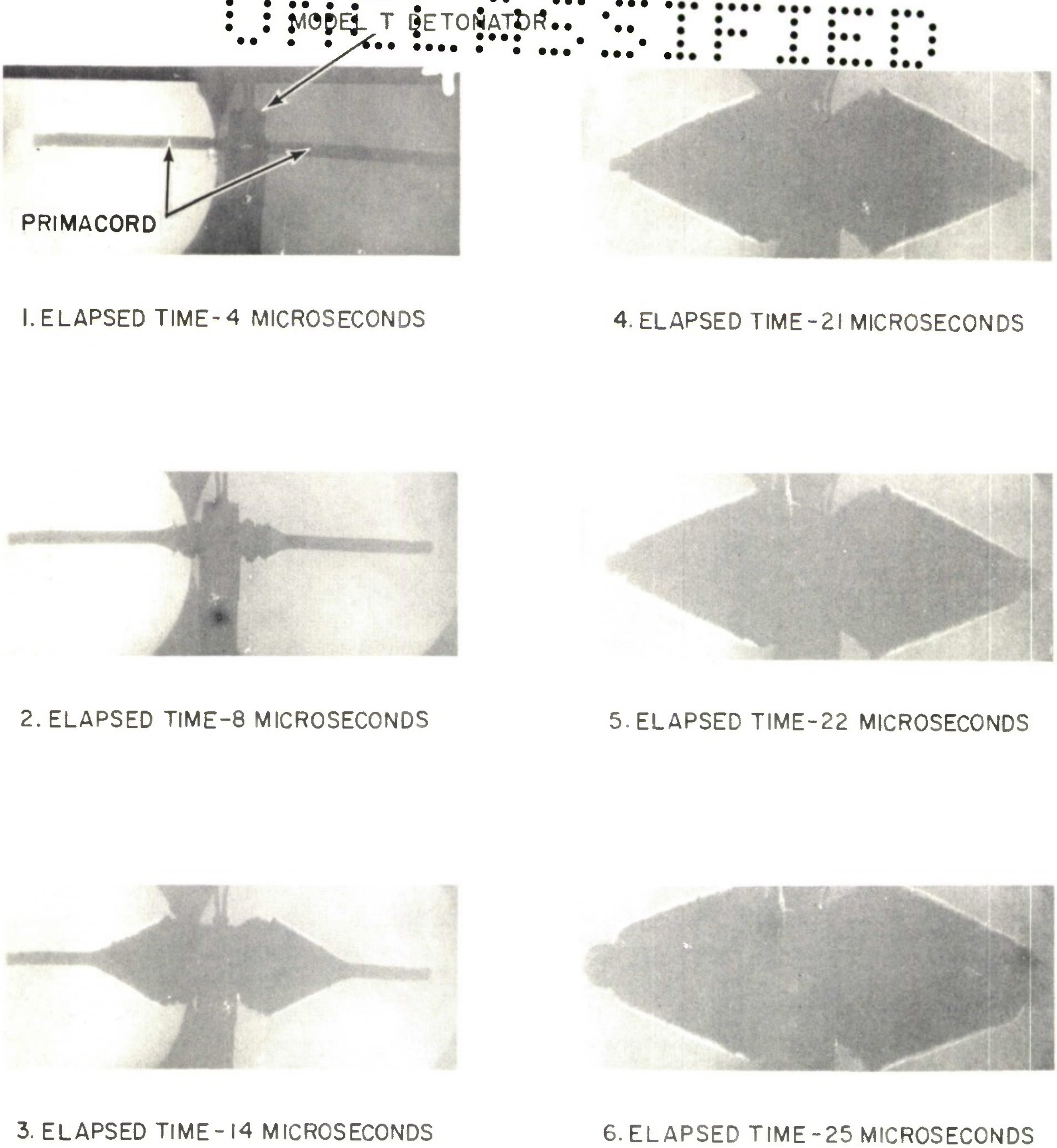


FIG. 3 FRAMING CAMERA SEQUENCE FOR SIMULTANEITY TESTING

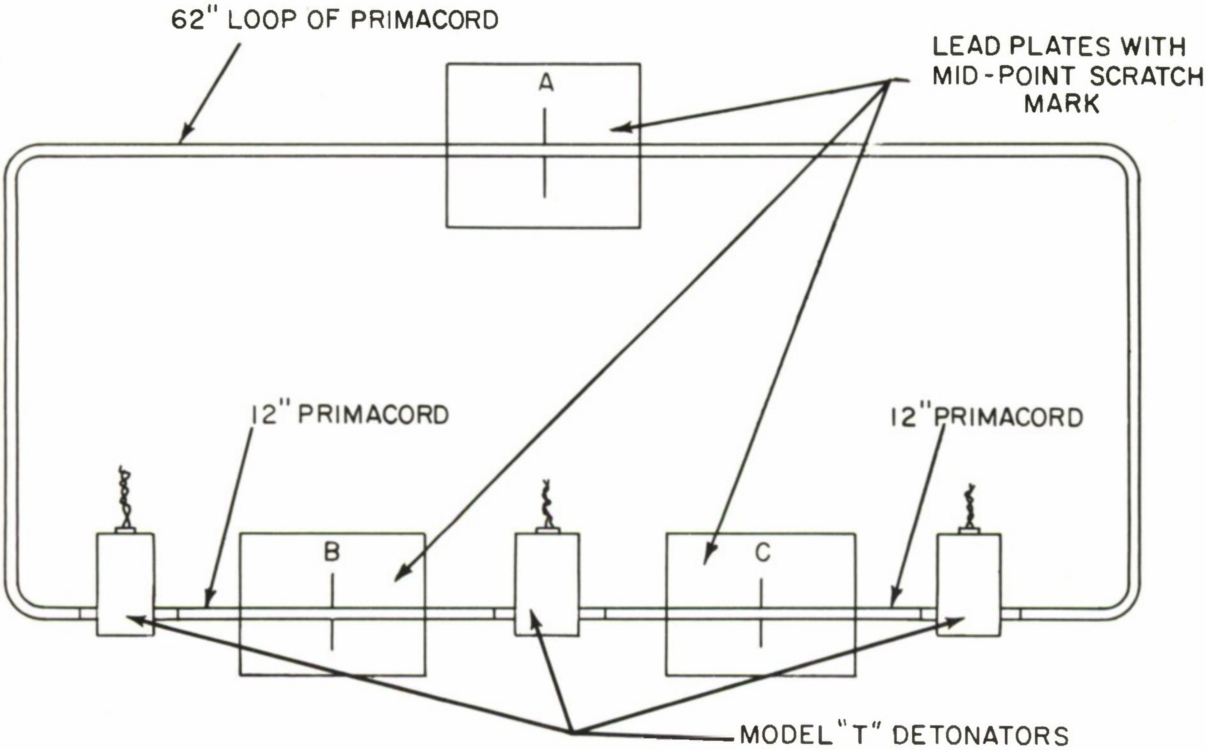
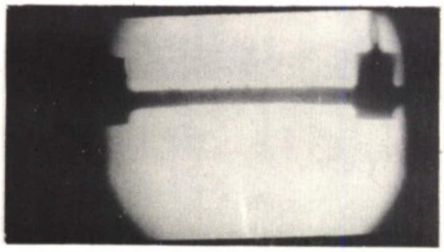
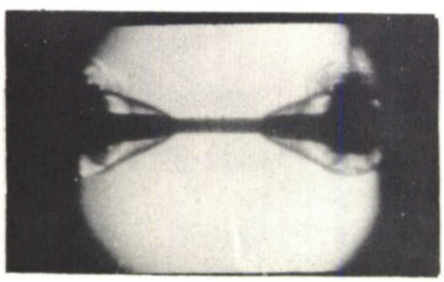


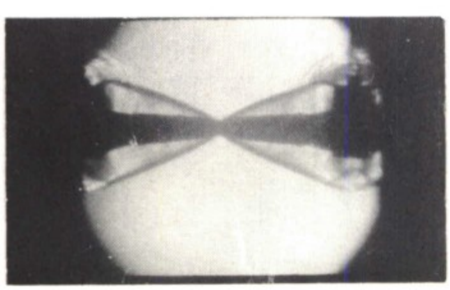
FIG. 4 SIMULTANEITY TEST SET-UP FOR DETONATORS FIRED IN PARALLEL (MODIFIED DAUTRICHE METHOD)



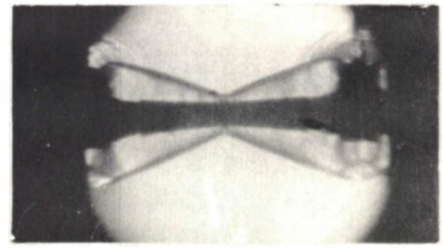
1. ELAPSED TIME-3.2 MICROSECONDS



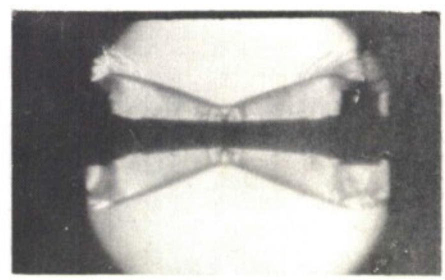
2. ELAPSED TIME-11.2 MICROSECONDS



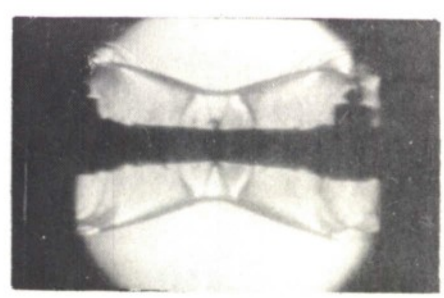
3. ELAPSED TIME- 14.4 MICROSECONDS



4. ELAPSED TIME-16.0 MICROSECONDS

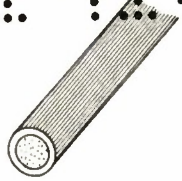


5. ELAPSED TIME-17.6 MICROSECONDS



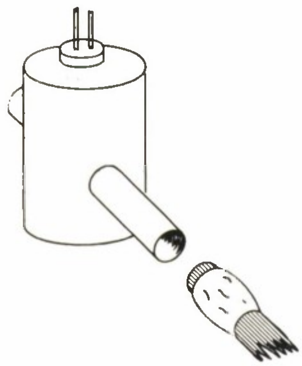
6. ELAPSED TIME-22.4 MICROSECONDS

FIG.5 FRAMING CAMERA SEQUENCE OF UNDERWATER DETONATION FRONT COLLISION

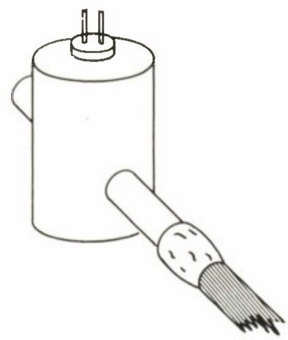


FRESH CUT SECTION
OF PRIMACORD

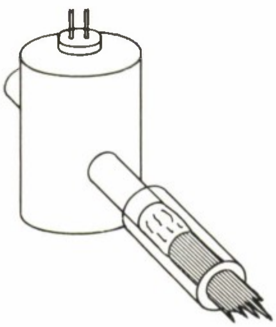
IS COATED WITH
EPOXY RESIN



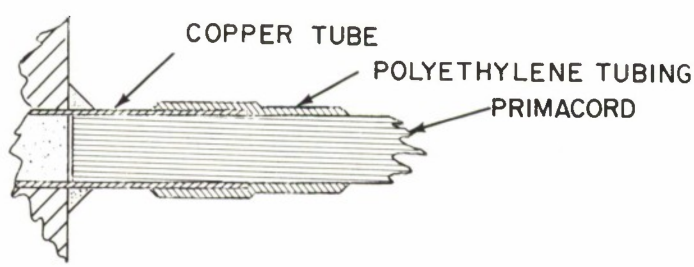
AND INSERTED INTO
AN ARM OF THE
"T" DETONATOR



THE EPOXY RESIN IS
SMEARED OVER THE
CONNECTION



AND A LENGTH OF POLYETHYLENE TUBING WHICH HAS BEEN SOAKED IN BUTYL ACETATE IS SLIPPED OVER THE EPOXY RESIN



THE POLYETHYLENE TUBING SHRINKS INTO
PLACE COMPLETING THE WATER RESISTANT
SEAL

FIG. 6 METHOD OF MAKING WATER RESISTANT SEAL

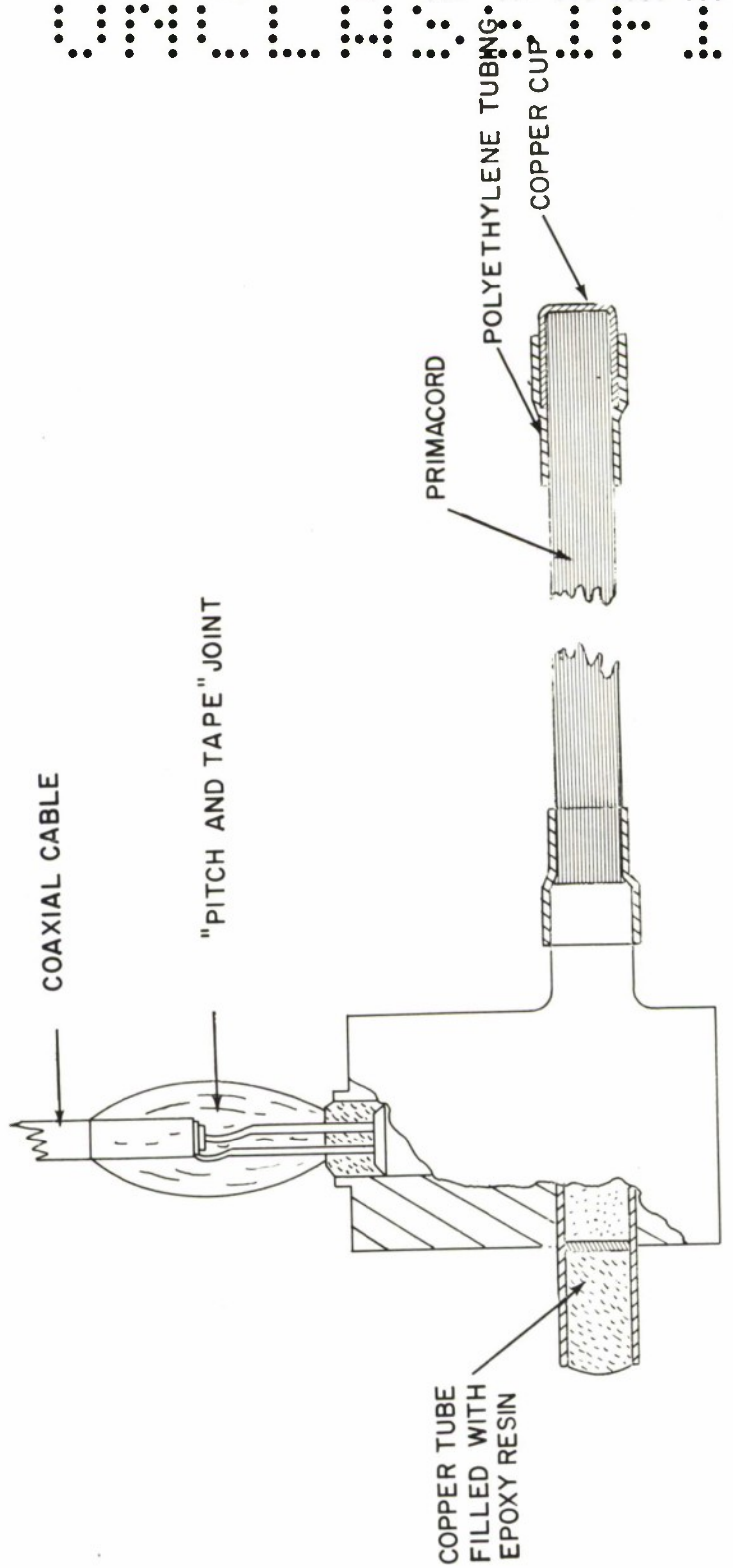
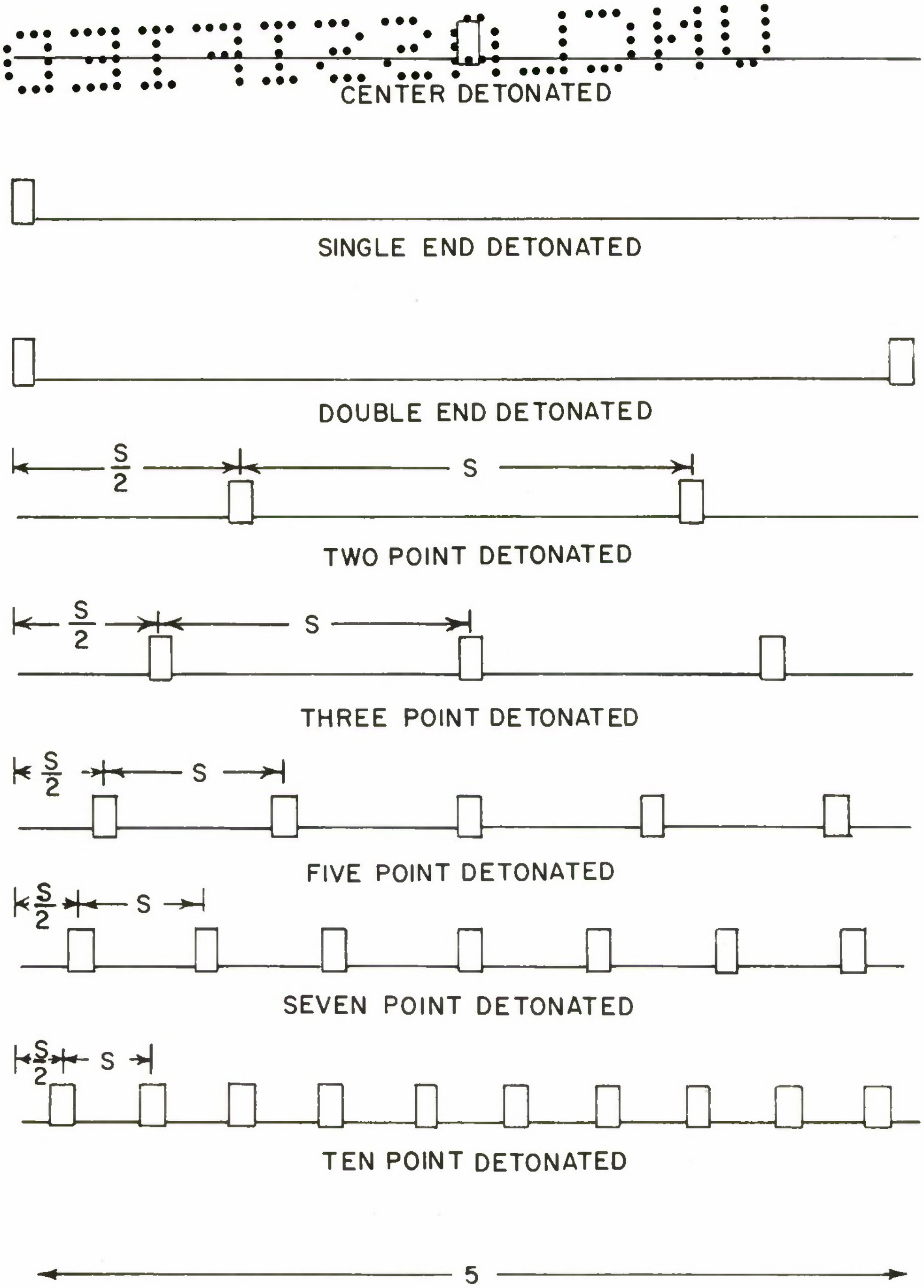


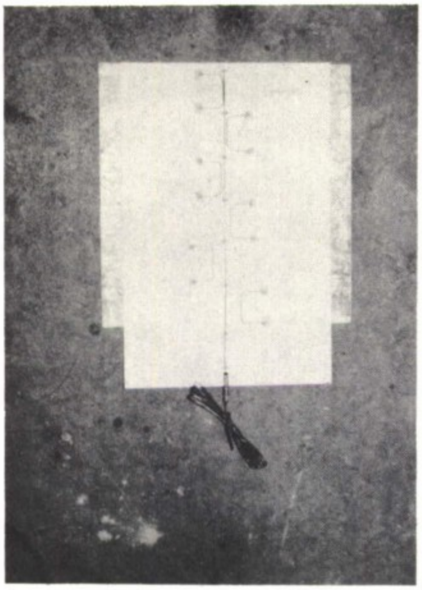
FIG. 7 TYPES OF WATER RESISTANT SEALS USED IN FABRICATION OF PRIMACORD LINE CHARGES



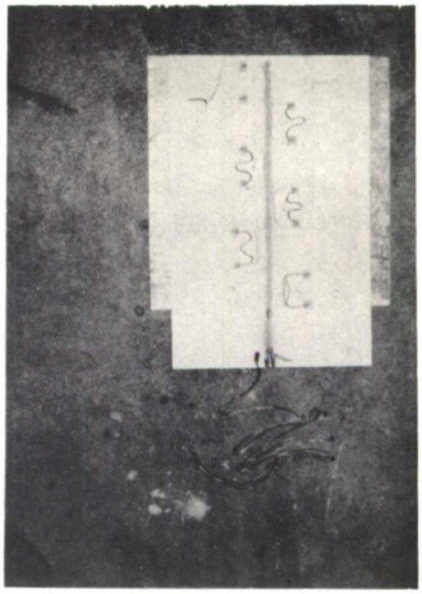
□ = LOCATION OF MODEL "T" DETONATOR

S = SPACING PROPORTION USED FOR DETONATOR

FIG. 8 PRIMACORD LINE CHARGE CONFIGURATIONS FABRICATED FOR TESTING

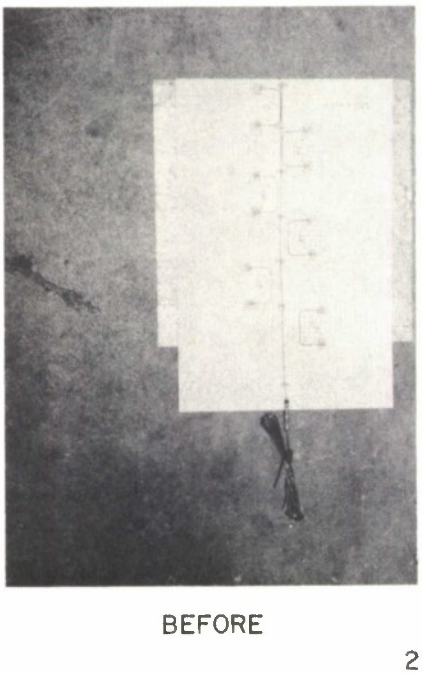


BEFORE

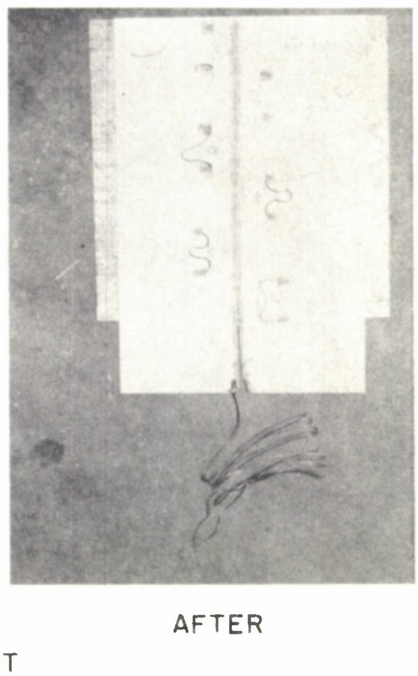


AFTER

1 GRAIN/FOOT



BEFORE



AFTER

2 GRAINS/FOOT

FIG. 9 MILD DETONATING FUSE SPACING TESTS

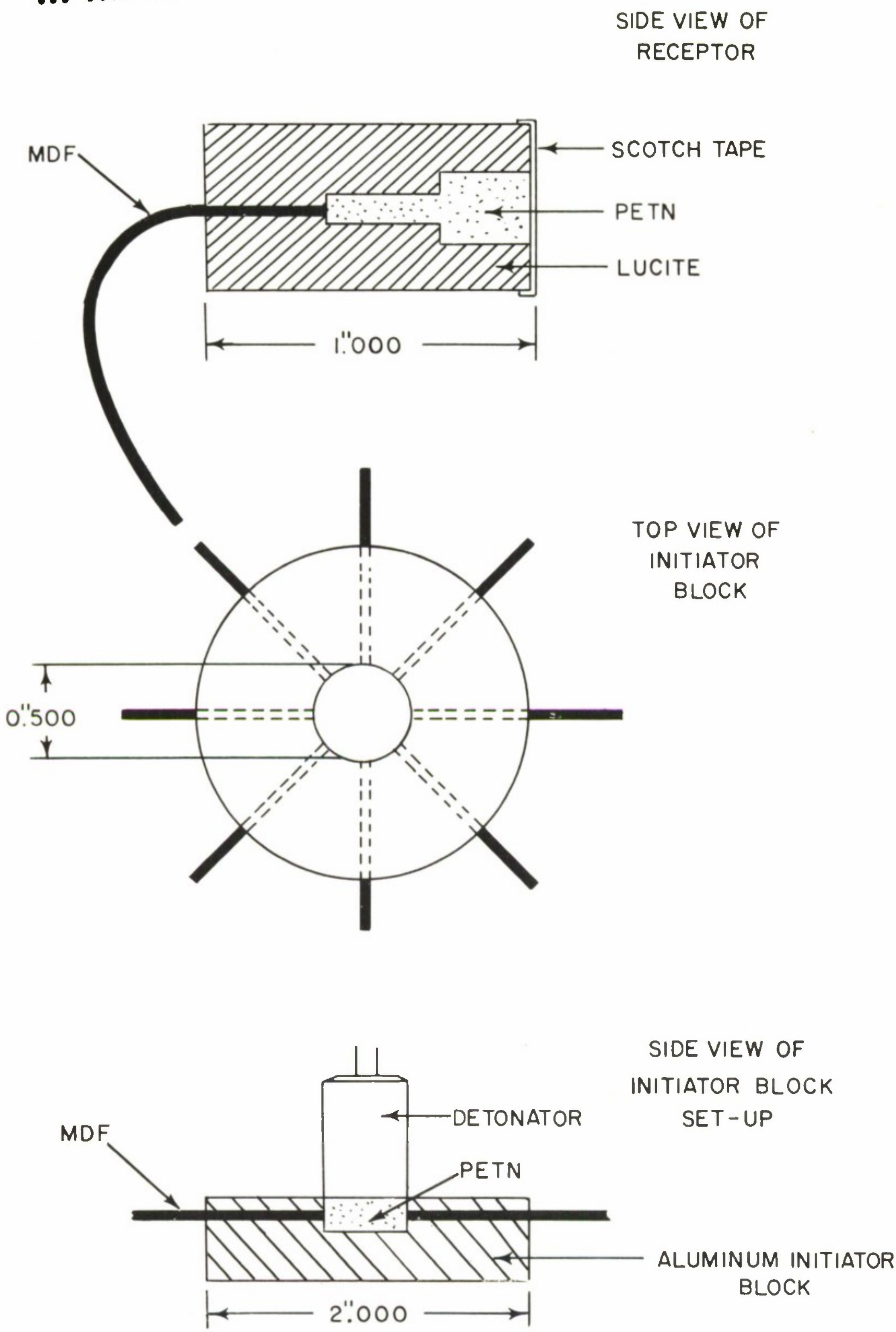


FIG. 10 CONSTRUCTION DETAILS OF BREADBOARD SET-UP
TO DETERMINE SIMULTANEITY

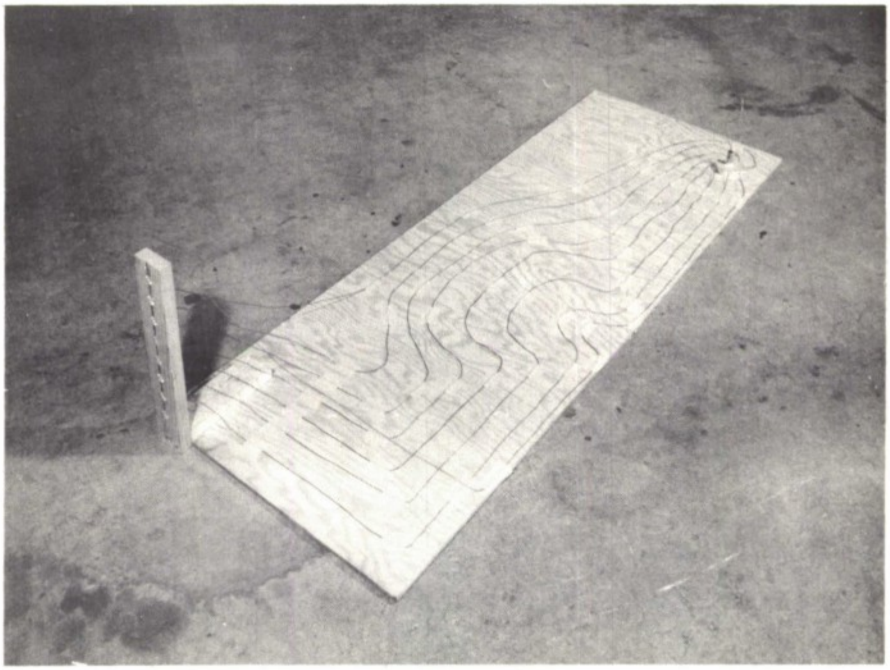
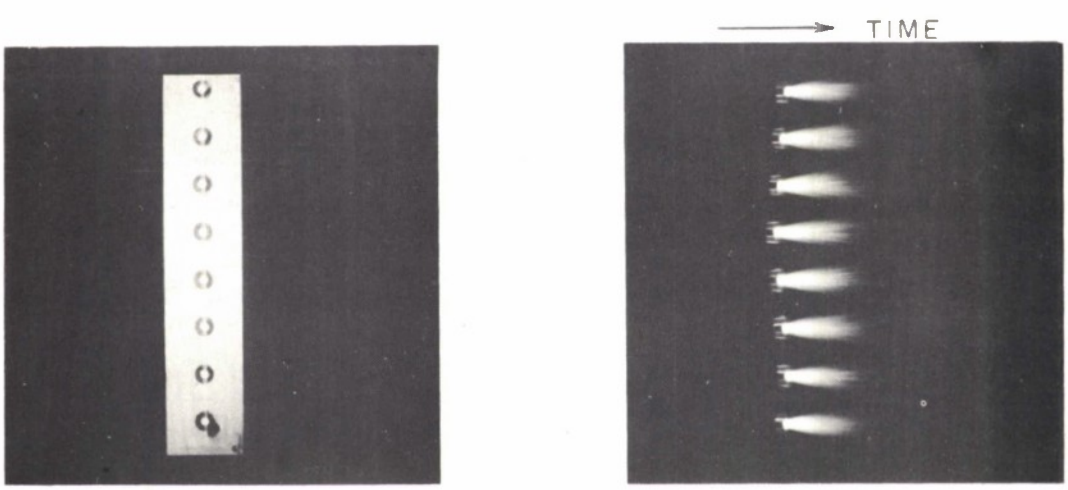


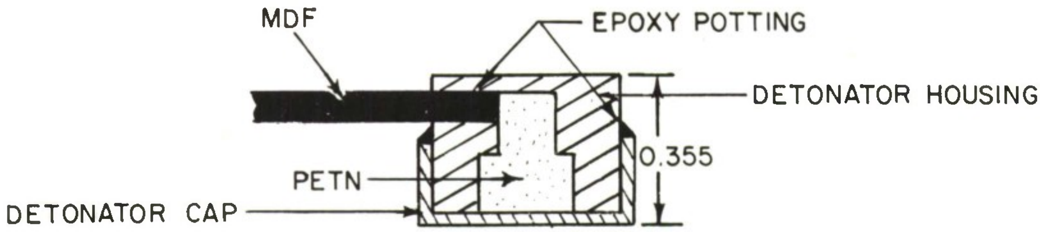
FIG. 11A BREADBOARD SET-UP TO DETERMINE SIMULTANEITY



STILL PHOTOGRAPH

→| |← 2 MICROSECONDS
DYNAMIC PHOTOGRAPH

FIG. 11B SMEAR CAMERA RECORD OF SIMULTANEITY



CROSS SECTION OF
TERMINATING DETONATOR

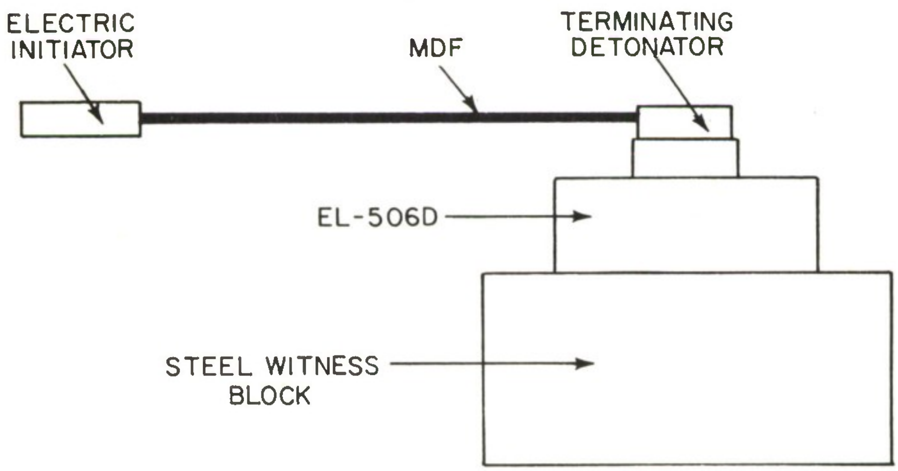


FIG.12 TERMINATING DETONATOR TEST SYSTEM

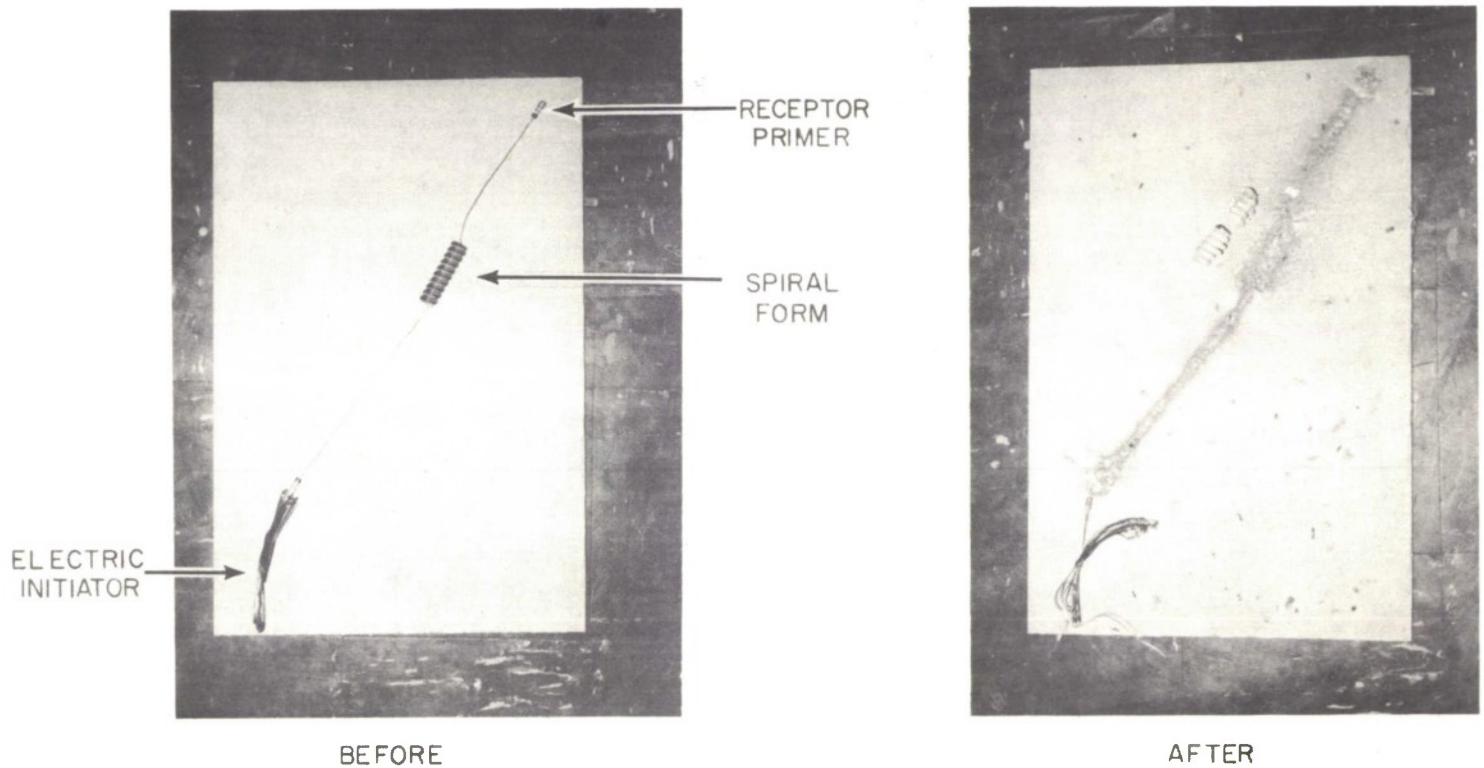


FIG. 13 TESTING OF SPIRAL FORMS

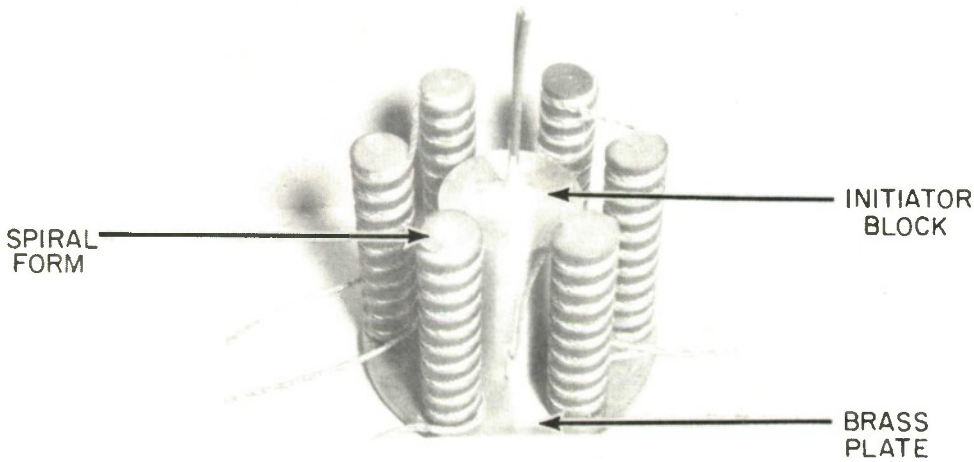


FIG. 14 LOCATION OF SPIRAL FORMS

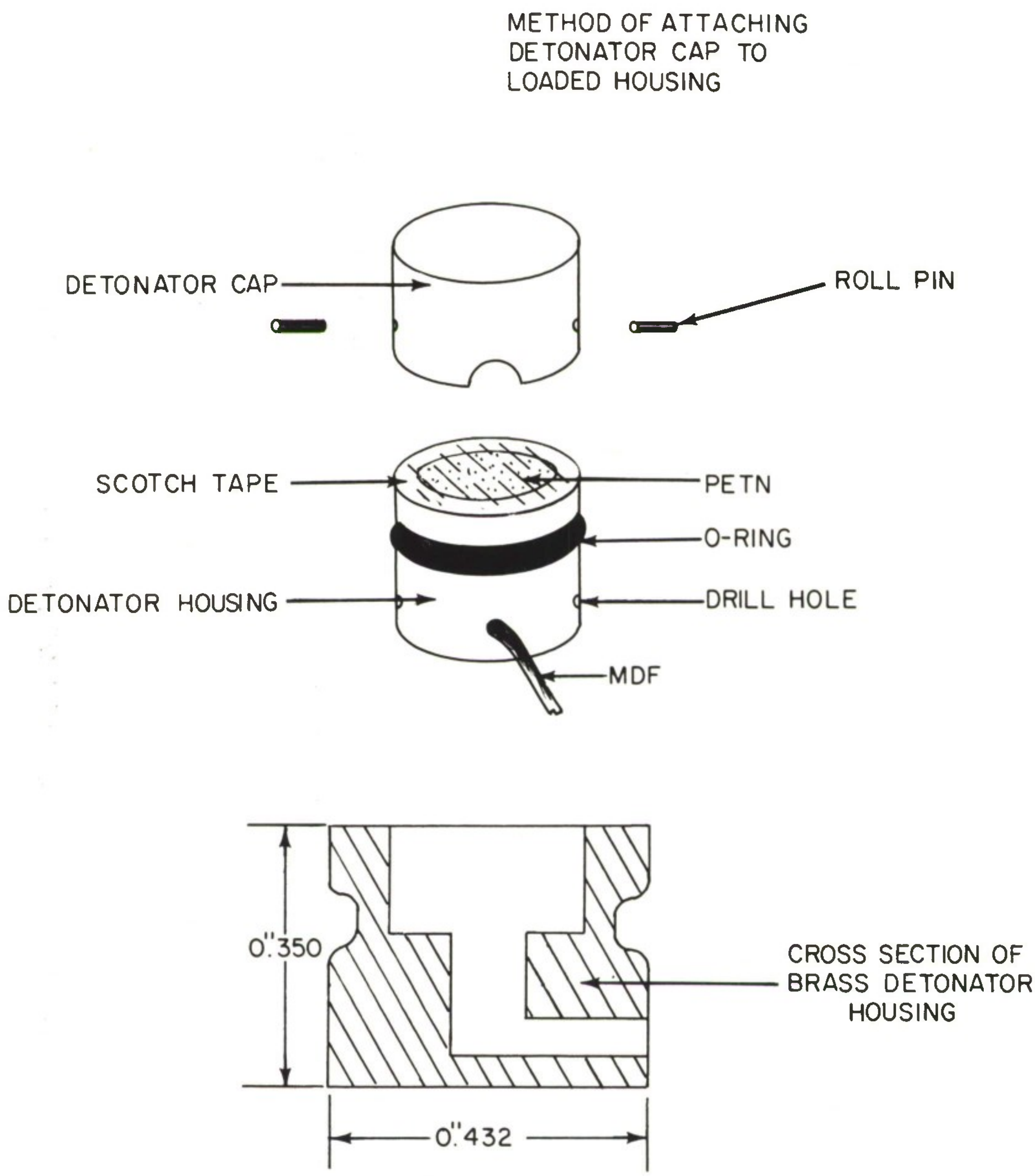


FIG.15 FINAL TERMINATING DETONATOR DESIGN

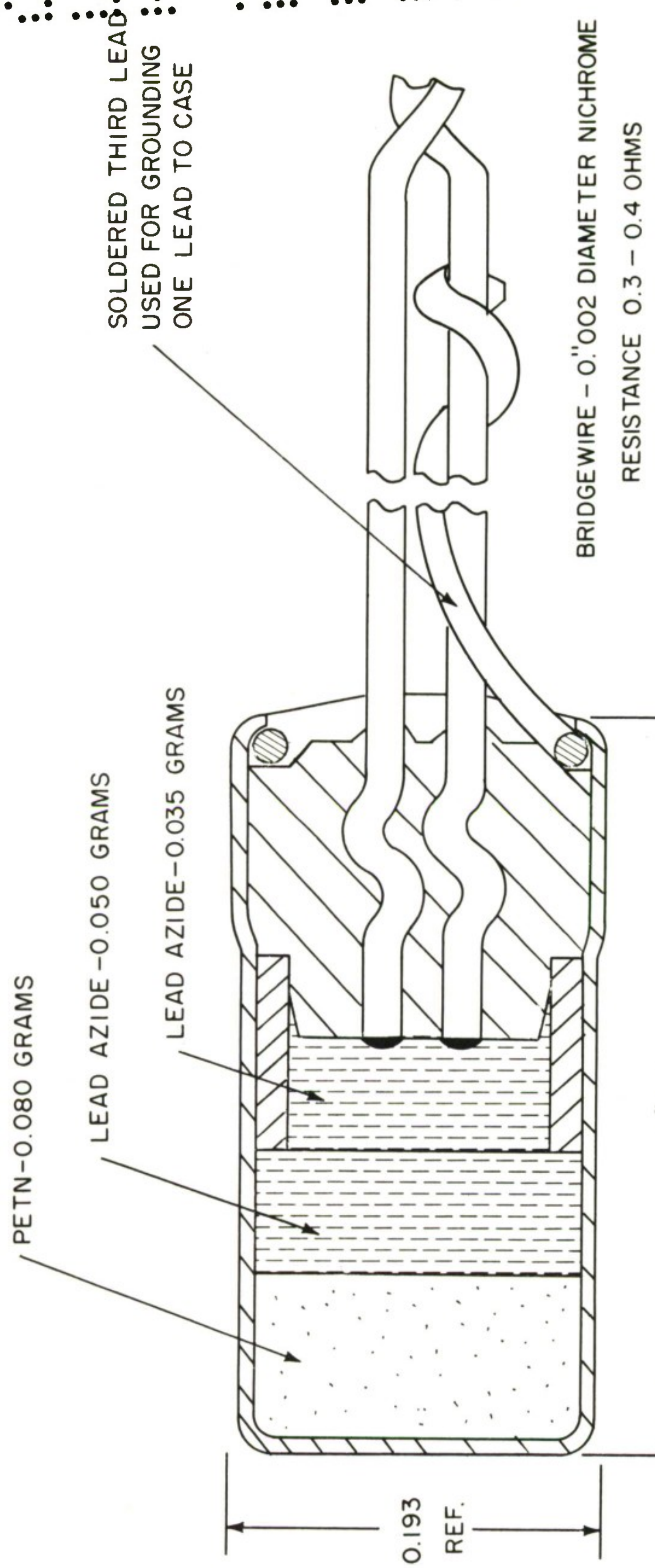


FIG. 16 GENERAL ARRANGEMENT OF EX7 MOD 0 DETONATOR

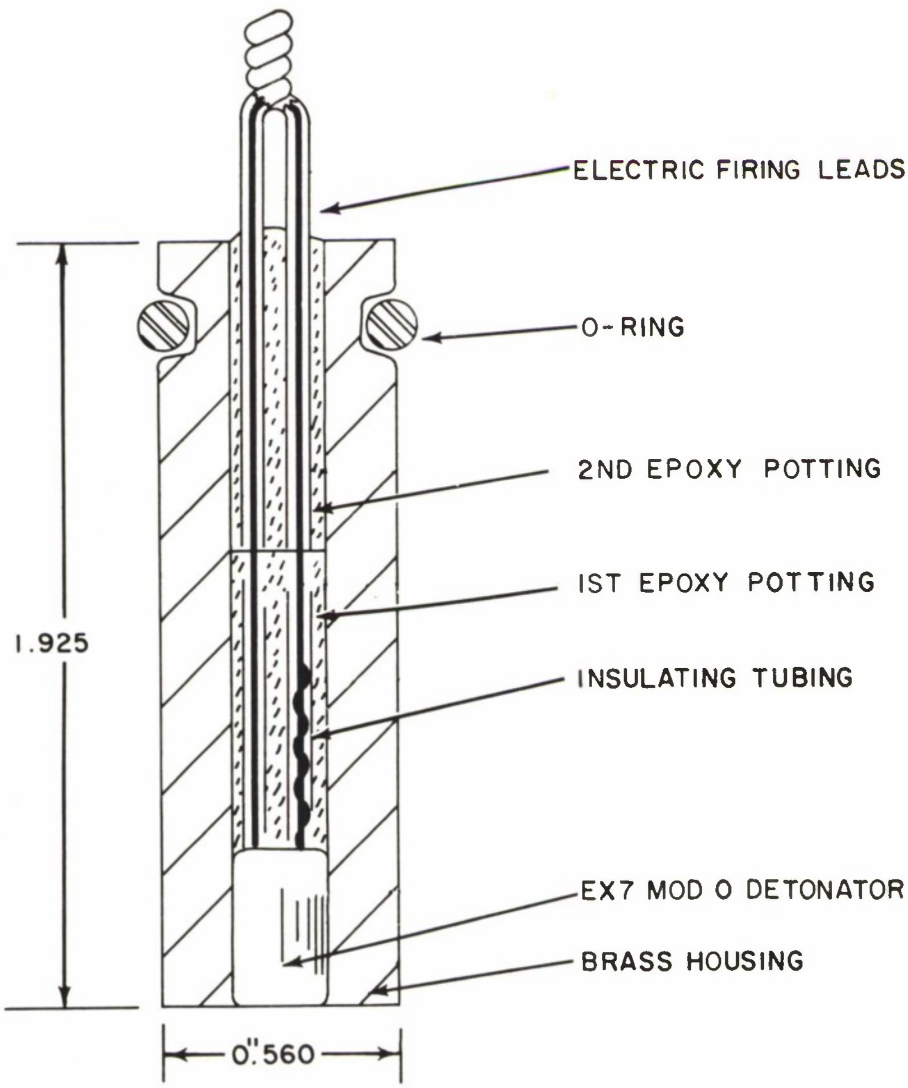


FIG. 17 POTTED DETONATOR HOUSING READY FOR INSERTION INTO INITIATOR UNIT

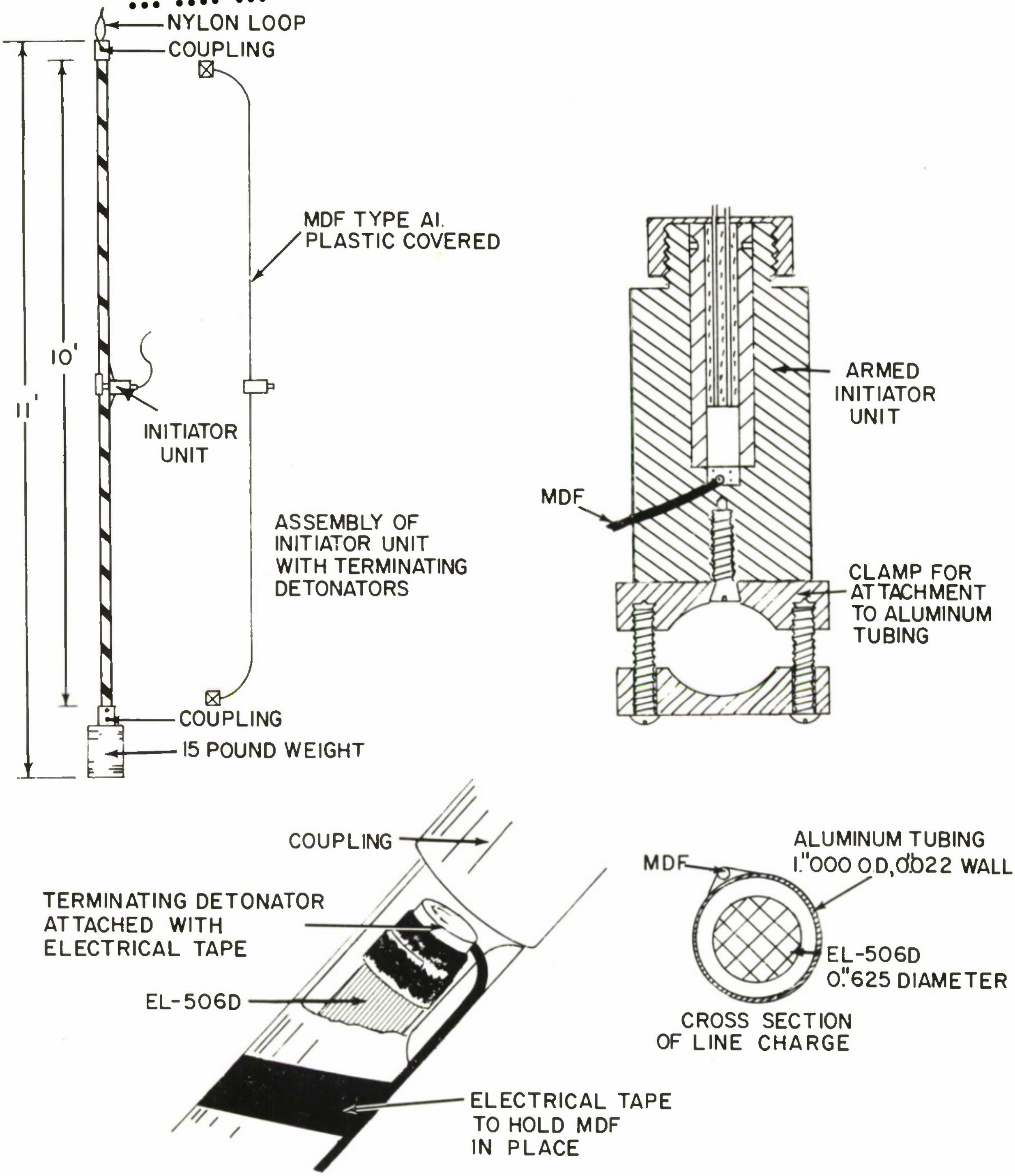


FIG. 18 CONSTRUCTION DETAILS OF DOUBLE END INITIATOR LINE CHARGE

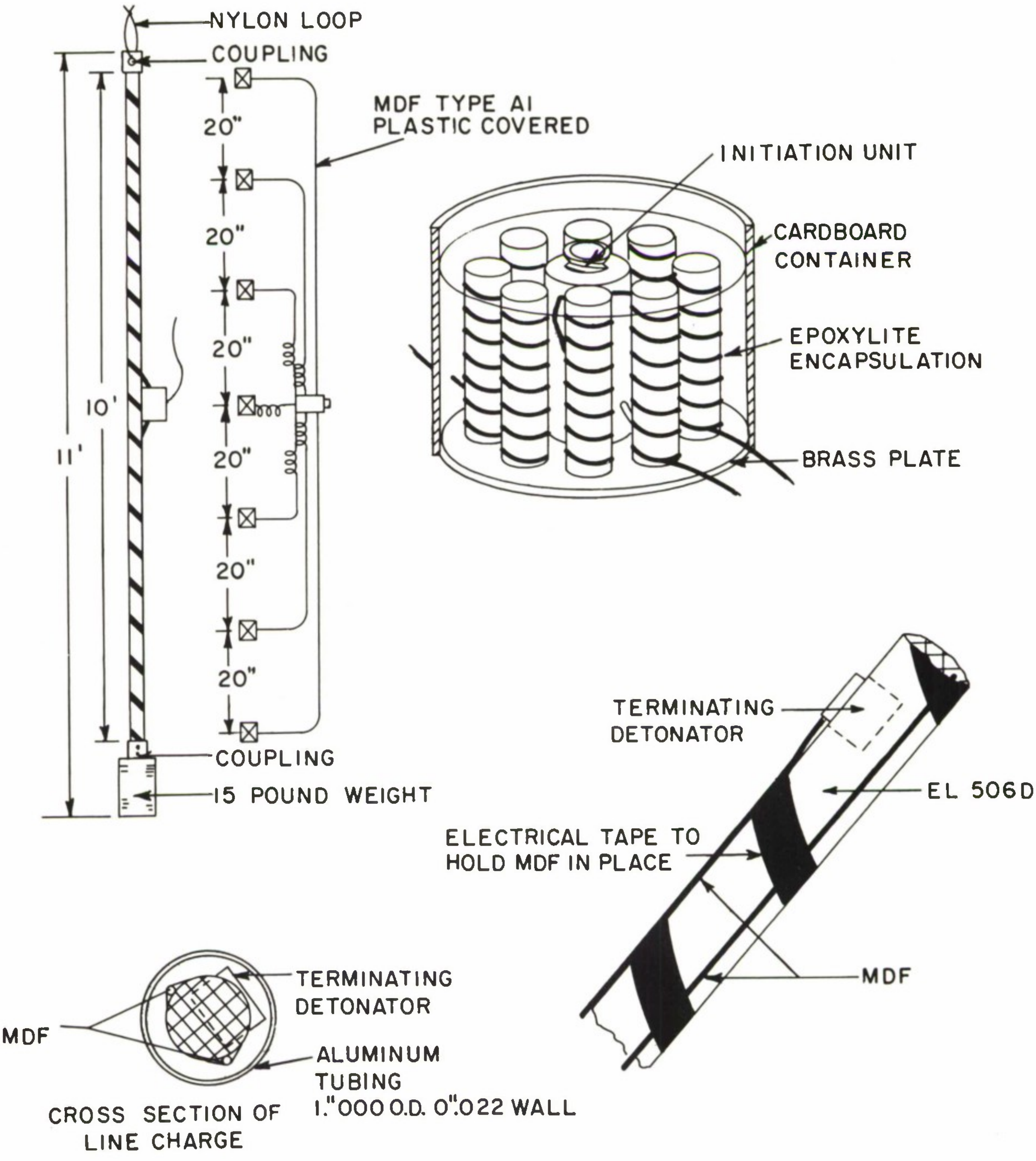


FIG. 19 CONSTRUCTION DETAILS OF MULTI-POINT INITIATED LINE CHARGE

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This report describes the development of two line charges and the initiators for them. The charges were made for a research program on explosive echo ranging. The two line charges consisted of: (a) primacord initiated at a number of points simultaneously by a "T" detonator and (b) a commercial plastic explosive in the form of a rod also initiated simultaneously at a number of points by central initiation of strands of mild detonating fuse. Simultaneity of initiation between points was about ±1.5 microseconds for both systems.

1. Charges, Line
2. Initiators
3. Detonators - Model T
4. Primacord
5. Explosive echo ranging

I. Title
II. Leopold, Howard S.
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