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NOLTR 66-22

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IMPROVEMENTS IN UNDERWATER EXPLOSION SYSTEMS: FIELD TESTS, PHASE II (U)

10 JUNE 1966

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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IMPROVEMENTS IN UNDERWATER EXPLOSION SYSTEMS: FIELD TESTS, PHASE II (U)

by

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ABSTRACT: Underwater shock wave pressure-time recordings from imploded HBX-1 charges were compared with measurements from centrally exploded HBX-1 charges on an equal volume basis. The shock wave peak pressure was up to 16 percent greater for implosions initiated at 32 and 1536 points than for explosions. No enhancement of shock wave energy resulted from 32-point, simultaneously-initiated implosions because of the more rapid decay of the pressure. However, the shock wave energies from charges with dense cores (a 6.5 inch diameter, 22/78 Comp B/Lead sphere in a 3.25-inch thick HBX-1 shell) imploded by simultaneous initiation at 1536 points, were 7 to 14 percent higher than for the explosions. The first bubble periods were essentially the same for the explosions and implosions.

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NOLTR 66-22 10 June 1966

IMPROVEMENTS IN UNDERWATER EXPLOSIVE SYSTEM: FIELD TESTS, PHASE II (U)

The work described in this report is part of the Naval Ordnance Laboratory's continuing program to increase the damage capability of torpedoes by improved warhead design. This phase of the investigation tested the underwater performance of multi-point surface initiated implosion systems and was done under Task No. RMMO 62 058 F008 08 11 (Problem Assignment No. 1). formerly RUME 4E-000/212-1/F008-08-11 (Problem Assignment No. 002), Supporting Research in Underwater Explosives and Explosions.

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By direction

CONTENTS

ILLUSTRATIONS

TABLES

IMPROVEMENTS IN UNDERWATER EXPLOSIVE SYSTEM: FIELD TESTS, PHASE II (U)

1. INTRODUCTION

Measurements of the velocity of the underwater shock wave at ranges of 2.5 to 7 charge radii from 5-inch diameter, 4-pound, explosive spheres showed that higher peak pressures were obtained from charges initiated at 20 points simultaneously on the surface than from charges initiated at a single point centrally[1]*. The results generally were in good agreement with those predicted by theory[2]. Subsequent pressure-time records from the implosion of 70-pound, 13-inch diameter charges did not show as much enhancement of the peak pressure, and showed no improvement in shock wave energy[3].

Suspected reasons for the failure to observe a significant improvement in these tests included: (a) the inability to obtain reliable pressure-time data at distances within 7 charge radii where most improvement was expected, (b) the effect of the boostering system which comprised 20 percent by weight of the imploded charges, and (c), the use of an inadequate implosion system. However, a recent theoretical study[4] showed that while a large peak pressure increase could be gained by implosion, only a small shock wave energy increase would result because of a decrease in the time constant. This study also showed that the time constant could be increased if the imploded charge contained a dense core, i.e., a heavy metal, such as lead or tungsten, mixed with explosive to give a density of about $5 g/cm^3$. The shock wave energy resulting from the implosion of such charges would be about 35 percent greater than that of an exploded charge on a volume basis.

This report presents the results of a field test using the dense core concept and improved multi-point surface initiation systems. Pressure-time records were made of the underwater shock wave from the implosion of two types of HBX-1 charges:

a. 13-inch diameter HBX-1 spheres initiated at 32 points, and

b. 3.25-inch thick shells of HBX-1 containing 6.5-inch diameter spheres of 22/78 Comp B/Lead and initiated at 32 and 1536 points.

Pressure-time records also were made of the shock waves from the explosion of 13-inch diameter HBX-1 spheres. In this report, the shock wave peak pressure, time constant, impulse, energy, and bubble periods produced by the imploded and by the exploded charges are compared.

* References are on page 8.

2. EXPERIMENTAL DETAILS

2.1 Charges. The pertinent charge data are listed in Table 1. Three 13-inch diameter charges of each type* were detonated with the exception of the homogeneous spheres imploded from 32 initiation points; only two of these charges were fired.

Each exploded charge was boostered by a 1.5-pound, 3-inch diameter CH-6 sphere located at the charge center. A U. S. Army Engineers' Special Electric Detonator fired the CH-6 booster.

Each sphere imploded at 32 points was fitted with two hemispherical polyethylene shells, 0.375 inch-thick. CH-6 pellets, 0.375-inch diameter by 0.5-inch high and weighing 1.5 g each, were secured in contact with the HBX-1 through thirty-two symmetrically arranged holes drilled through the polyethylene shells. The 32-point implosions were initiated by thirty-two detonators within 0.15 microseconds of each other. The pulsing unit was similar to the unit used in the laboratory tests[2].

Each sphere imploded at 1536 points was fitted with a 0.63-inch thick outer shell containing labyrinth patterns of EL 506C-2 sheet explosive potted into an epoxy matrix; the total weight of sheet explosive was about 5.4 pounds. The detonation network was actuated at a single point by an EX-7 detonator embedded in a small quantity of RDX. From this common point of actuation, the paths to each of the 1536 initiation points in the system are made equal. More specifically, the 1536-point implosion system consists of six, 90-degree epoxy segments, each containing 0.086-inch thick explosive labyrinth patterns which are terminated at 256 points as shown in Figure 1. Three of these segments have peripheral EL 506C-2 strands which transfer detonation to a segment pair. When the segmented system is assembled and fired, detonation begins in an epoxy cap connector containing the EX-7 detonator, powdered RDX, and the three peripheral leads, and is transferred via the labyrinths of the six segments to 1536 EL 506C-2 terminal plugs distributed uniformly over the 13-inch diameter explosive sphere. The pulsing unit mentioned previously was used with this system, but the voltage requirement was substantially lower (about 3000v).

Figure 2 shows each of the three initiation systems assembled to charges for test firing.

The dense core used in these charges consisted of a 22% Comp B, 78% powdered lead mixture. It was cast in the form of a sphere 6.5 inches in diameter, and had an average density of 4.95 g/cc. Around this was cast an HBX-1 shell 3.25 inches thick, so that the over-all charge diameter was 13 inches. All of the charges fired in this program had the same diameter, and hence volume.

* Data from only two charges initiated at 1536 points were used. The results from the third charge were considered unreliable.

2.2 Rigging and Instrumentation. Tourmaline piezoelectric gages (1/4-in.) were used to record the shock wave signals. The signals were fed through low-noise coaxial cables, cable terminations, and cathode follower circuits into cathode ray oscilloscopes where the spot deflections of the signals were photographed on 35mm film strips in rotating-drum cameras. Each film record contained the pressure-time trace, simultaneously-recorded timing marks at some known interval, and a calibration step resulting from the application of a known voltage. In addition to the twelve shock wave recording channels, two channels were used to record the bubble periods from 1/2-inch piezoelectric gages.

Firing was done from the YSD-72 in the Patuxent River near Solomons, Md. Once the ship was anchored near the desired water depth of 60 feet or greater, the high-voltage pulser unit mounted on flotation drums was placed in the water alongside the ship. Detonator leads were connected to the grounding terminals of the pulser and the unit locked as a safety precaution. The charges were then mounted centrally in a fifteen-foot diameter steel ring and radial distances to the recording gages were adjusted to 5, 7.5, 10 and 13 charge radii*. Three shock wave recording gages were placed at each stand-off and were mounted on steel frames attached to the ring.

After the charge was armed, the ring was placed in the water and lowered to the 30-ft firing depth. Flotation drums supported the weight of the array. The detonator leads that had been grounded at the pulser were then moved to the fire position. A small boat was used to tow the complete array into the firing site; a second steel cable terminating at the YSD held the array taut. Figure 3 shows the approximate orientation at the time of firing of all units used in the tests.

When the array was in position, the voltage applied to the pulser was raised to the required level and the charge was detonated. Figure 4 is a block diagram showing the firing and recording network used in the implosion phase of this series. The only change in the firing and recording network for the explosions was the exclusion of the high voltage pulser from the circuit.

An Eastman High Speed camera was used to photograph the surface phenomena on all shots (Figure 4). Data from these films are not reported here; the films are available in the Underwater Explosions Division.

3. RESULTS

3.1 Data Reduction

3.1.1 Shock Wave Data. Pressure-time records of the shock waves were projected on the NOL Telereader; this instrument, and its associated equipment, was used to read the records and convert the pressure-time data

* Distances were recorded from the charge center to the gage center.

to IBM cards for use with computer programs. Log pressure versus time plots were obtained from the computer output using automatic plotting equipment. Lines were drawn by hand through the initial slope of the plot. Peak pressures, p_m, were obtained from extrapolations to zero time which was taken as being midway between the zero time on the base-line and the apparent peak[6]. All records had an apparent rise time of 8 microseconds ± 2 microseconds.

The time constants, θ, were read from lines drawn through the initial portion of the log pressure versus time plots. The impulse (psi-sec) and energy flux density (in.-lbs/in.^{2}) were computed by the IBM 7090, using the standard definitions:

Impulse:

$$I = \int_0^{5\theta} p(t)\,dt \tag{1}$$

Energy:

$$E = \frac{(1-1.7 \times 10^{-6} p_m)}{\rho_o c_o} \int_0^{5\theta} p^2(t)\,dt \tag{2}$$

where: ρ_o and c_o are the density and the sound velocity of the water, respectively. As indicated, integrations were carried out to 5θ. The extrapolated peak pressure and the smoothed curve just behind the peak were used in the integrations. This was done to minimize errors due to instrumentation.

Averaged values of the shock wave parameters are listed for each charge type and distance in Table 2. The standard deviation of the mean was computed and is shown beneath each value in the table.

The standard deviation of the mean, σ_m, is defined as:

$$\sigma_m = \frac{100\sigma}{\bar{x}\sqrt{n}} \tag{3}$$

where:

$$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$$

x = measured value

$\bar{x}$ = average value

n = number of observations

Ratios of the various parameters for the implosions relative to the explosions are shown in Table 3 on a volume basis.

3.1.2 Bubble Period Data. The intervals between the shock wave and the first bubble pulse were measured on pressure-time records obtained from the bubble recording channels. The bubble periods, T, are listed in Table 4 along with the relative bubble energies on a volume basis. The relative bubble energies for the implosions are within 4 percent of the values for the explosions, a difference which is not significant.

3.2 Comparison of Shock Wave Parameters of Various Charge Types

In Figure 5 the ratios of the various shock wave parameters for the implosions relative to those for the explosion on an equal volume basis, are plotted as a function of range. The results for each parameter are discussed below.

3.2.1 Shock Wave Peak Pressure. The peak pressures for the implosions are about 10 percent (16 percent for the 32-point homogeneous implosions) greater than those for the explosions at a range of 5 charge radii. The relative improvement decreases with increasing range. The decrease appears to be somewhat slower for the two 1536-point dense core implosions. At 13 charge radii, the peak pressures for the implosions are about equal to those for the explosions. In general, there are no large differences among the three types of imploded charges.

3.2.2 Shock Wave Time Constant. The time constants for the implosions are from 10 percent to 30 percent smaller than those for the explosions at a range of 5 charge radii. The relative values increase with increasing range out to a range of 10 charge radii. The values at 10 charge radii and 13 charge radii are essentially equal. As predicted by Sternberg et al (4), the time constants for the dense core implosions (32-point and 1536-point) are considerably larger than the corresponding values for the 32-point, homogeneous implosions.

3.2.3 Shock Wave Impulse. The impulses for the 32-point, homogeneous implosions are between 11 percent and 6 percent smaller than corresponding values for the explosions. The impulses for the 1536-point, dense core implosions are equal to or slightly larger than corresponding values for the explosions. The impulses for the 32-point, dense core implosions are between those for the 32-point, homogeneous implosions and the 1536-point, dense core implosions. There appears to be a slight increase in the relative values with increasing range; however, this change is small.

3.2.4 Shock Wave Energy Flux Density. The energies for the 32-point homogeneous implosions and the 32-point dense core implosions are within 6 percent of the corresponding values for the explosions. The energy of the 32-point homogeneous implosions are all less than for the explosion; two of the values (at 7.5 and 10 charge radii) for the 32-point dense core implosions are 4-6 percent greater than the explosion. The energies for the 1536-point dense core implosions are greater than those for the explosions at all four distances (13 or 14 percent at 5, 7.5, and 10 charge radii; and 7 percent at 13 charge radii). However, none of the values is as large as expected from theoretical calculations (4).

4. DISCUSSION

4.1 32-Point Implosions

With implosion systems like the 32-detonator system, no implosion effects occur until the detonation waves from the separate detonation sites meet and interact. The interactions begin after each detonation wave has traveled half the distance of minimum separation between initiation sites. Consequently, with the symmetrically distributed 32-detonator system, 68.5 percent of the explosive sphere detonates before any implosion effects occur. Thus only about 22 pounds of the 69.4 pound HBX-1 spheres and 39 pounds of the dense core charges were actually imploded by the 32-point system. In the dense core charges, only about half of the imploded material was explosive; the remainder was an inert, lead.

Even with somewhat less explosive being imploded in the dense core charges, there is a significant improvement in shock wave energy in the 32-point system. For example, the 32-point homogeneous implosions yielded energy values about 5 percent less than exploded HBX-1 beyond 5 charge radii. The 32-point, dense core implosion energy values were 4-6 percent greater than the explosions at 7.5 and 10 charge radii.

4.2 1536-Point Implosions

The performance of the 1536-point EL506C-2 boostering system in the dense core implosions can not be evaluated accurately. With perfect surface initiation by the 1536-point system, the imploded volume should be greater than the 32-point system by a factor of two (about 60 percent compared to about 31). However, the booster system did nct function well and only two of three shots fired gave usable data.

There were found to be small air gaps separating the booster segments from the sphere of HBX-1; these hindered the transfer of detonation. In addition, it is suspected that propagation failure in the explosive labyrinth may have prevented simultaneous initiation at all 1536 points.

Laboratory studies have shown that a controlled particle size distribution of PETN in the EL506 is critical for preventing detonation failures in the booster. This result required design changes in early prototypes of the booster and forced the use of EL506C-2 (0.08-inch thick) instead of the preferred thinner EL506C-1 (0.04-inch thick). In EL506C-2 sheet explosive, the PETN particle size distribution is satisfactory, but because of its greater weight per unit length, neighboring labyrinth strands are subjected to stronger shock-interactions through the epoxy matrix. Framing camera photographs of detonating EL506C-2 booster segments show that these interactions promote premature initiation at some points and prevent initiation by pre-compression at others.

Despite the above difficulties, the 1536-point implosions did give improvements over the 32-point dense core implosions. The largest increase in the shock wave parameters was about 10 percent in the energy flux.

When compared to the centrally detonated explosions, the improvement in shock wave energy values is even more significant, i.e. ranging up to 14 percent.

5. CONCLUSIONS AND RECOMMENDATIONS

Field tests conducted with 13-inch diameter spherical charges loaded with HBX-1 have shown that:

1. The shock wave peak pressures obtained with the 32-detonator and the 1536-point systems are about 10 percent greater than those from explosions at a range of 5 charge radii.

2. The shock wave time constants are smaller for an imploded, homogeneous charge than for an exploded charge.

3. The shock wave time constant for a dense core implosion is greater than that for a homogeneous implosion.

4. The underwater shock wave energy for a 1536-point, dense core implosion is up to 14 percent greater than that for an explosion.

Since completion of these tests, improvements were made in the fabrication of the labyrinth booster and laboratory lots of EL506C-1 with controlled PETN particle size have been obtained. Improved prototypes of the 1536-point system should be fabricated and additional firings made. These firings should include the implosion of HBX-1 and PBXW-100. In addition, HBX-3 or even more highly aluminized explosives of low shock wave peak pressure and large time constant might be imploded to see if the long-range shock wave energy is improved.

Explosives of low detonation velocity (e.g. baratol) could be used as the explosive core enclosed in octol booster shells. Propellant compositions, e.g. EJC, FFP, PAX, or other highly energetic but more slowly reacting materials also should be considered as core materials if these compositions give good results in small scale laboratory tests using a 96-point labyrinth booster.

Additional firings using the 32-detonator system are not recommended for implosion-explosion comparisons of shock wave parameters.

Eventually, damage tests against realistic models should be carried out when a reliable system with enhanced power has been developed.

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TABLE 1. CHARGE DATA*

Main Charge	Type of Initiation	HBX-1 Weight (lb)	Booster Weight (lb)	Core Weight (lb)	Total Explosive Weight (lb)	Total Charge Weight (lb)	Remarks
HBX-1	central 1 point	68.6	1.5	--	70.1	70.1	3-in. dia. CH-6 spherical booster at center.
HBX-1	implosion 32 points	69.4	0.1**	--	69.5	69.5	Type SE-1 detonators initiate 1.5g CH-6 pellets symmetrically placed on surface.
HBX-1 dense core	implosion 32 points	61.1	--	5.6***	66.7	86.3	Same initiation as above.
HBX-1 dense core	implosion 1536 points	60.9	5.4	5.6***	71.9	91.5	EL506C booster system. Weight of booster explosive 5.4 lbs.

* All weights nominal.
** Total weight of CH-6 pellets.
*** Weight of Comp B only. Total charge weight includes 19.6 lbs of lead.

TABLE 2

SHOCK WAVE PARAMETERS*

Reduced Range (Charge Radii)	P_m (psi)	θ (msec)	I (psi-sec)	E (in.-lbs/in.^{2})
			EXPLOSION	
5	50,500 ± 1.5	0.171 ± 1.0	10.1 ± 2.2	39,300 ± 3.3
7.5	28,700 ± 1.9	0.204 ± 1.2	7.14 ± 3.6	16,200 ± 4.5
10	19,100 ± 0.9	0.224 ± 0.5	5.37 ± 1.3	8,300 ± 1.3
13	13,500 ± 1.2	0.249 ± 1.0	4.10 ± 3.4	4,470 ± 4.9
			32-POINT HOMOGENEOUS IMPLOSION	
5	58,600 ± 1.3	0.120 ± 3.5	8.89 ± 3.0	39,000 ± 3.2
7.5	30,400 ± 1.4	0.167 ± 2.9	6.55 ± 2.7	15,300 ± 3.3
10	19,900 ± 2.7	0.203 ± 2.0	5.03 ± 5.8	8,000 ± 8.9
13	13,600 ± 1.5	0.225 ± 1.2	3.86 ± 2.9	4,220 ± 3.9

* The first number listed (50,500 for example) for a given condition is the average value of the parameter; the second (±1.5) is the standard deviation of the mean in percent.

TABLE 2 (continued)

32-POINT, DENSE CORE IMPLOSION

5	55,100 ± 0.9	0.143 ± 1.8	9.20 ± 1.1	38,400 ± 1.4
7.5	29,300 ± 1.7	0.196 ± 1.6	7.00 ± 1.3	16,800 ± 3.2
10	19,800 ± 1.2	0.224 ± 1.5	5.50 ± 1.5	8,830 ± 2.2
13	12,700 ± 3.3	0.246 ± 0.9	4.04 ± 3.2	4,530 ± 4.8

1536-POINT, DENSE CORE IMPLOSION

5	55,800 ± 1.6	0.151 ± 1.8	10.1 ± 2.0	44,400 ± 3.6
7.5	31,000 ± 1.5	0.196 ± 2.1	7.28 ± 3.4	18,500 ± 0.5
10	20,700 ± 2.1	0.229 ± 0.9	5.53 ± 2.3	9,380 ± 3.8
13	13,600 ± 1.8	0.264 ± 0.8	4.30 ± 2.2	4,790 ± 3.2

TABLE 3

RELATIVE PERFORMANCE OF IMPLODED CHARGES
(Compared to Equal Volume HBX-1 Explosion)

Reduced Range (Charge Radii)	P_m	θ	I	E
	32-POINT, HOMOGENEOUS IMPLOSION			
5	1.16	0.70	0.88	0.99
7.5	1.06	0.82	0.92	0.94
10	1.04	0.91	0.94	0.96
13	1.01	0.90	0.94	0.94
	32-POINT, DENSE CORE IMPLOSION			
5	1.09	0.84	0.92	0.98
7.5	1.02	0.96	0.98	1.04
10	1.04	1.00	1.02	1.06
13	0.94	0.99	0.99	1.01
	1536-POINT, DENSE CORE IMPLOSION			
5	1.11	0.88	1.00	1.13
7.5	1.08	0.96	1.02	1.14
10	1.08	1.02	1.03	1.13
13	1.01	1.06	1.05	1.07

TABLE 4

BUBBLE PERIOD DATA

Charge	Bubble Period (sec)	Relative Bubble Energy For Equal Volume*
Explosion	0.610 ± .005	1.00
32-Point Homogeneous Implosion	0.604 ± .003	0.97
32-Point Dense Core Implosion	0.608 ± .005	0.99
1536-Point Dense Core Implosion	0.619 ± .002	1.04

* Taken as the ratio of the bubble periods cubed. HBX-1 used as standard.

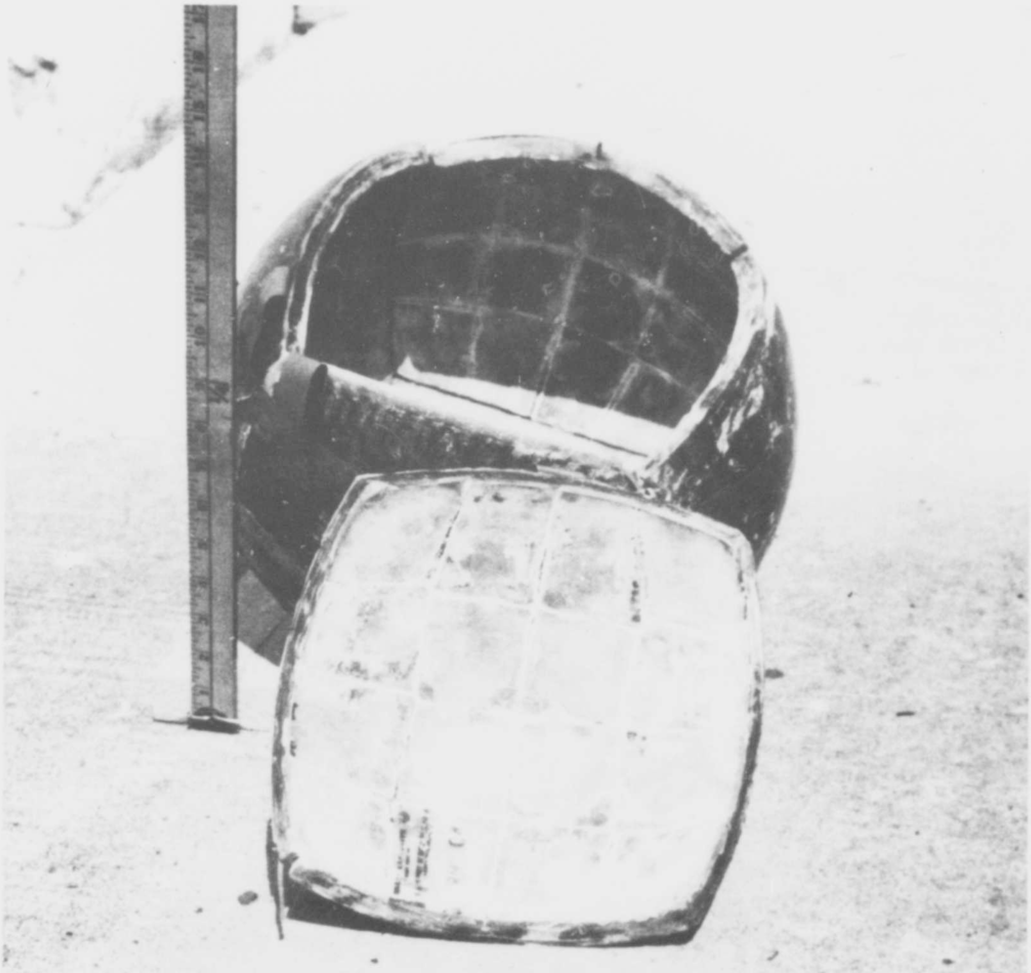


FIG. 1 THE 1536-POINT EL506C-2 LABYRINTH BOOSTER. A PERIPHERAL 256-POINT SEGMENT IS SHOWN BELOW. EACH CELL CONTAINS 16 INITIATION POINTS.

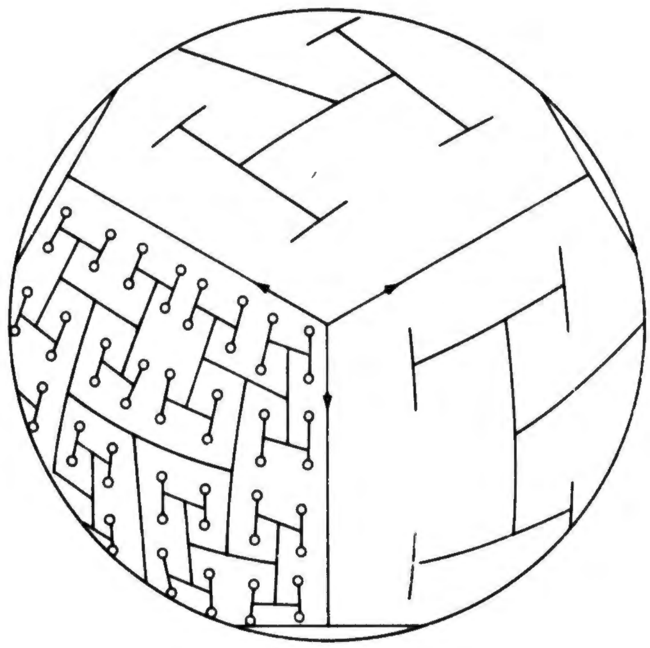
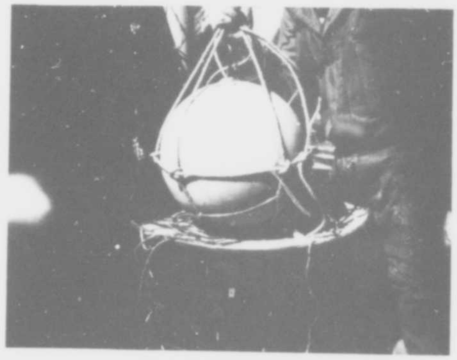
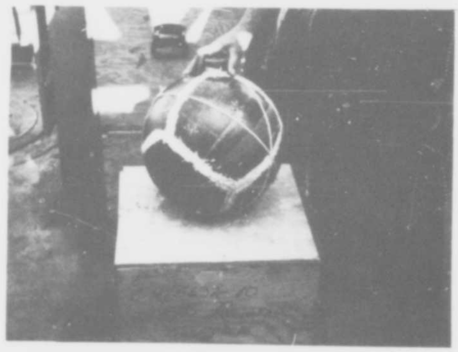


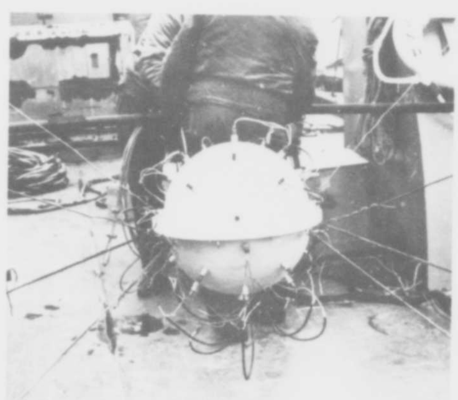
FIG. 1a SURFACE INITIATION SYSTEM ASSEMBLED (PARTIALLY DRAWN).
THE 1536-POINT BOOSTER CONSISTS OF SIX 90°, 256-POINT SEGMENTS



SINGLE - POINT CENTRAL EXPLOSION



1536 - POINT IMPLOSION



32 - POINT IMPLOSION

FIG. 2 ASSEMBLED CHARGES

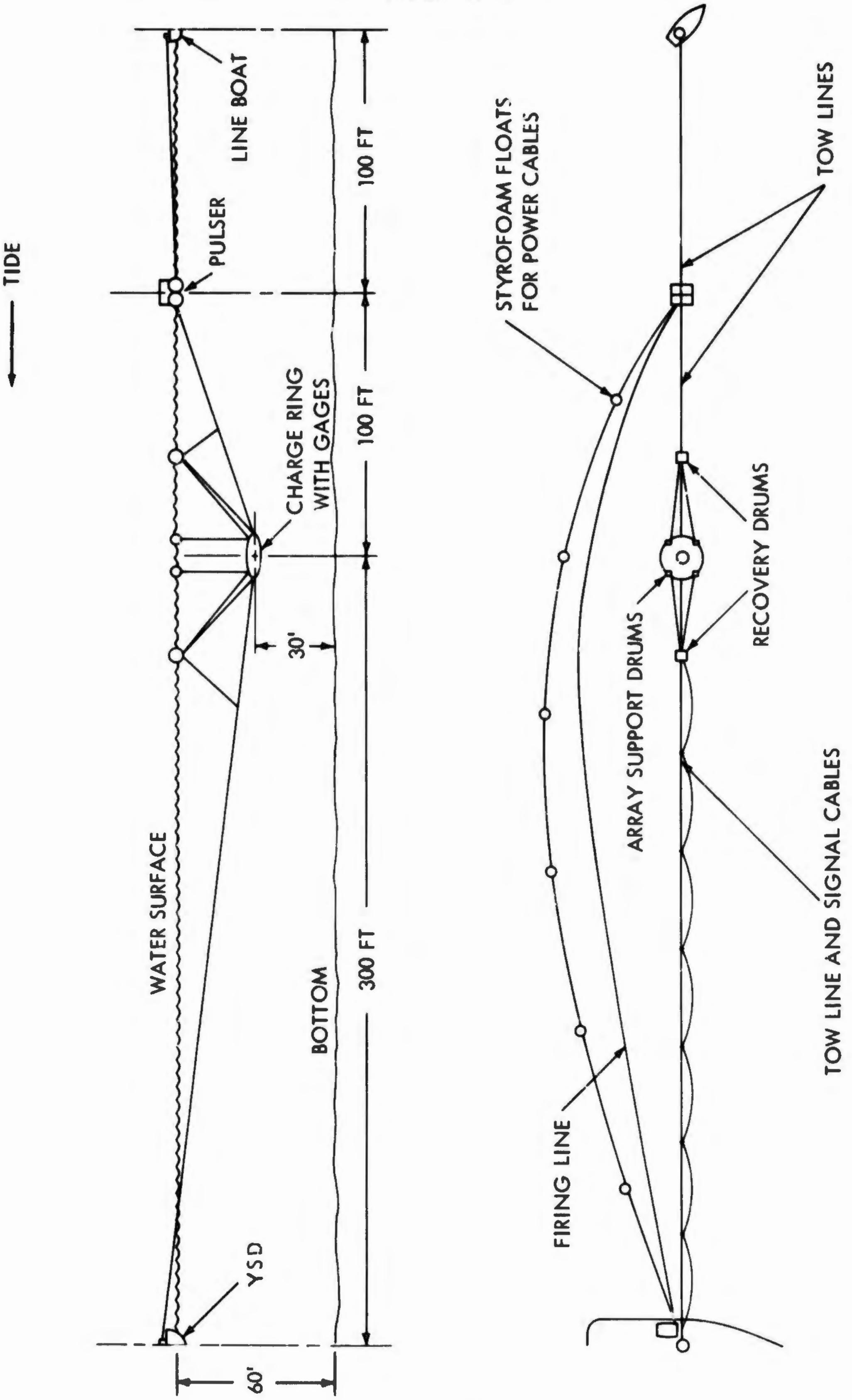


FIG. 3 EXPERIMENTAL LAYOUT

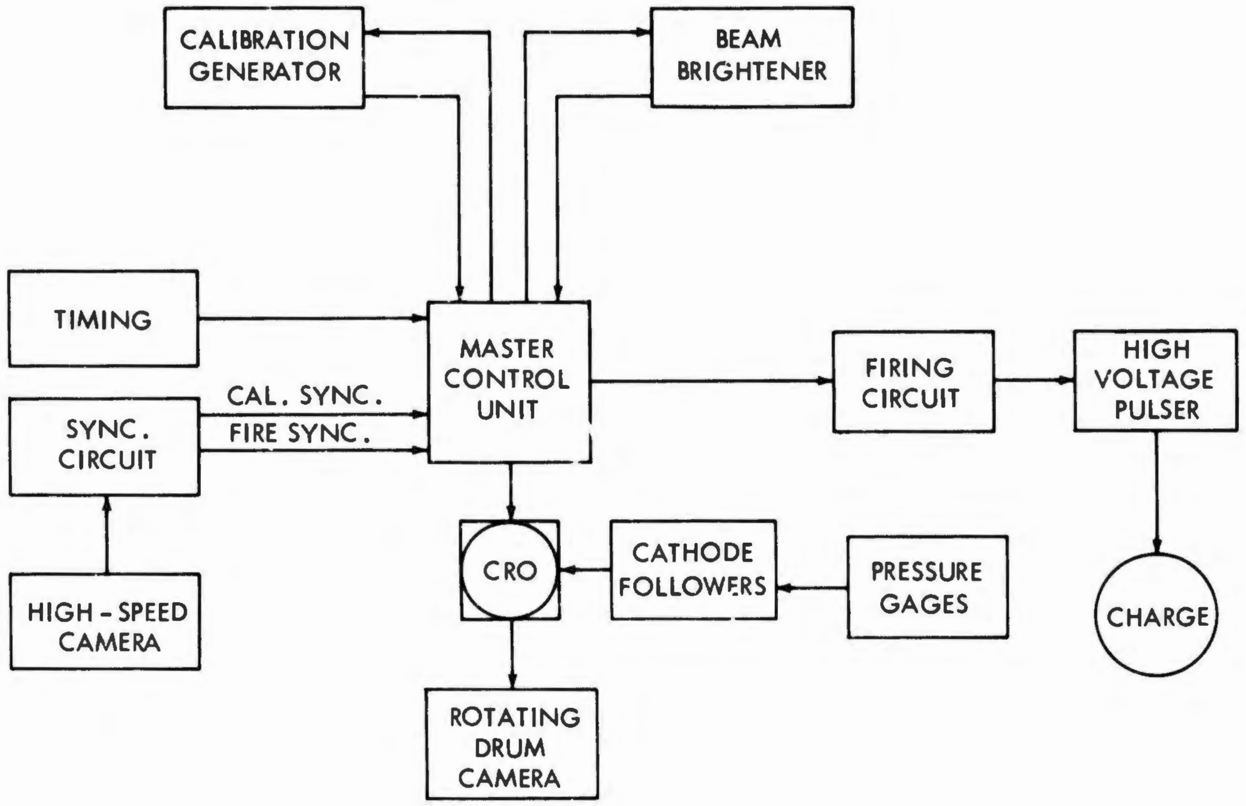


FIG. 4 FIRING AND RECORDING SYSTEM

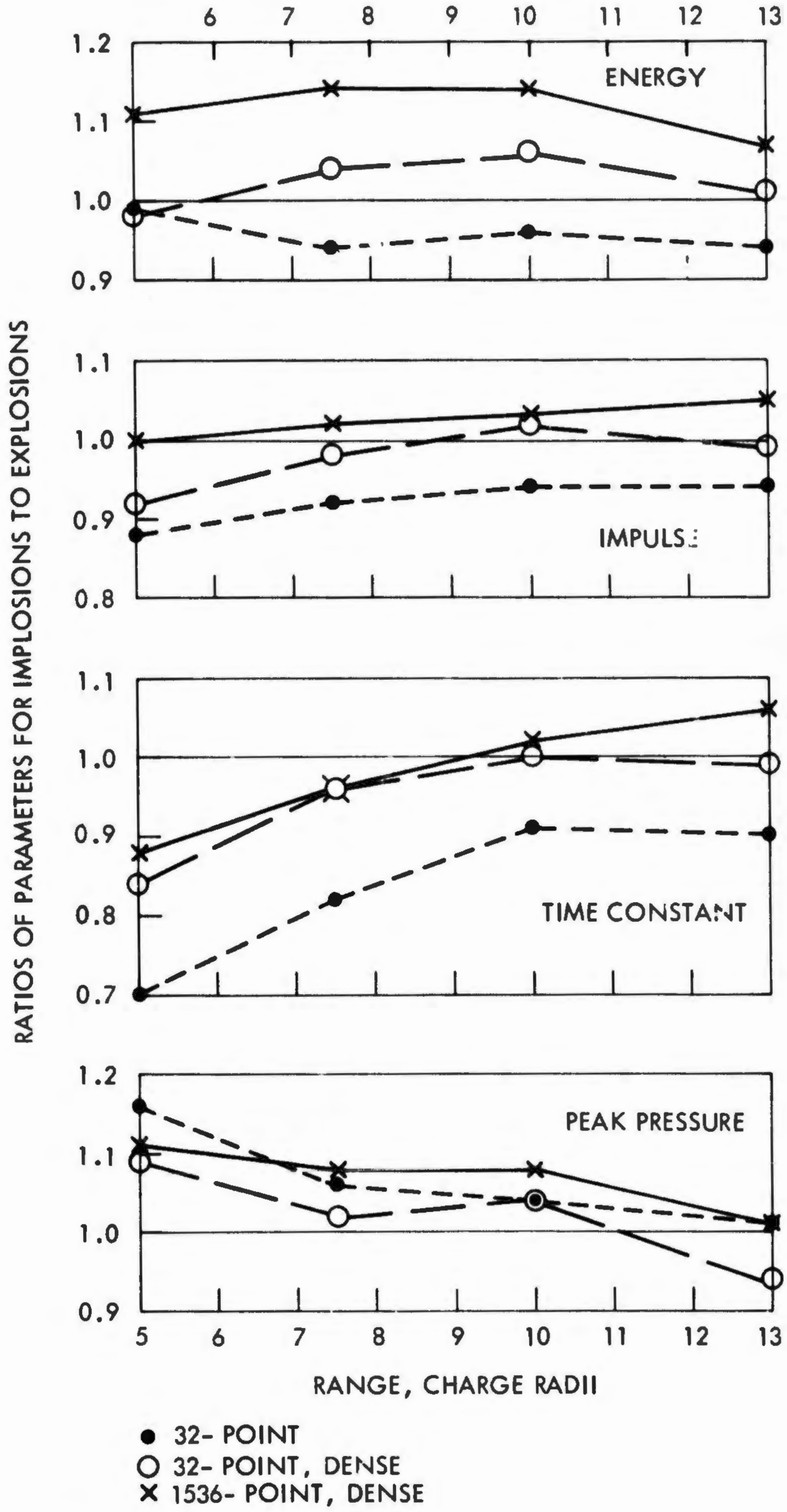


FIG. 5 COMPARISON OF IMPLOSIONS WITH EXPLOSIONS (CONSTANT VOLUME BASIS)

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U. S. Naval Ordnance Laboratory White Oak, Silver Spring, Maryland	2a. REPORT SECURITY CLASSIFICATION CONFIDENTIAL 2b. GROUP 4

3. REPORT TITLE
Improvements in Underwater Explosion Systems: Field Tests, Phase II(U)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*
N. L. Coleburn C. P. Niffenegger
L. A. Roslund
T. B. Heathcote

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
10 June 1966	19	6

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) NOLTR 66-22
b. PROJECT NO. RMMO 62 058 F008 08 11	
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13. ABSTRACT
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DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Abstract card is unclassified.

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2. Explosions, Underwater
3. Explosions, Underwater - Shock waves
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II. Coleburn, Nathaniel L.
III. Project

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