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UNDERWATER EXPLOSION TESTS OF TWO STEAM PRODUCING EXPLOSIVES I. SMALL CHARGE TESTS

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UNDERWATER EXPLOSION TESTS OF TWO STEAM PRODUCING EXPLOSIVES
I. SMALL CHARGE TESTS

by

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ABSTRACT: Eight and sixteen-lb charges of $LiClO_4 \cdot 3H_2O/Al$ and H_2O_2/Al steam-producing explosives were fired under water to obtain values of shock wave and bubble parameters. Both showed lower shock wave peak pressures than equivalent nuclear explosions; bubble radius and period coefficients for both compositions were higher. The $LiClO_4 \cdot 3H_2O/Al$ composition showed less scatter in both shock wave and bubble measurements than did the H_2O_2/Al composition.

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UNDERWATER EXPLOSION TESTS OF TWO STEAM PRODUCING EXPLOSIVES
I. SMALL CHARGE TESTS

This report discusses the initial tests conducted with two steam generating compositions being developed for use as nuclear bubble simulants. This development is part of a continuing program to improve knowledge of bubble phenomena resulting from the underwater detonation of both nuclear and conventional explosives. This work was supported by WEPTASK No. RRRE 51001/212-8/F008-21-03 (005) (DASA NWER 14.086), Nuclear Underwater Explosion Bubble Phenomena.

Mention of commercially available products does not constitute an endorsement or criticism by the Laboratory.

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By direction

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The successful completion of the two experimental programs discussed in this report represents the combined efforts of several people and groups within the Laboratory. While it is impossible to recognize each person individually, it is appropriate to mention those who contributed significantly to the programs and subsequent analysis of data.

The authors wish to acknowledge the guidance given by H. G. Snay, who originally recognized the need for charges of the type discussed in this report.

Personnel in the Chemical Engineering Division designed and fabricated the experimental charges. The efforts of L. E. Starr and Rolf Cederstad of this Division deserve particular recognition in solving the many and varied problems which arose in working with the unfamiliar materials associated with these charges.

The authors also wish to acknowledge the cooperation shown by personnel of the NOL Test Facility, Solomons, Md., particularly the crew of the YSD-72, from which the second experimental program was fired.

NOL personnel who participated in the experimental programs and analysis of the resulting data included B. W. Scott, R. L. Willey, J. E. Morgan, W. W. Hammack, H. G. Thomas, R. L. Marbury, D. L. Marks, C. E. Hopkins, B. A. Robey, Jean H. Rowe, and Marjorie N. Coleman.

UNDERWATER EXPLOSION TESTS OF TWO STEAM PRODUCING EXPLOSIVES
I. SMALL CHARGE TESTS

1. INTRODUCTION

In the study of the effects of underwater nuclear explosions, one of the phenomena to be considered is the behavior of the explosion bubble. This bubble is formed by the extremely high temperatures of such an explosion and thus consists primarily of steam. As the bubble oscillates and migrates upward, condensation effects of this steam rapidly damp its energy.

It is because of these condensation effects that a study was initiated on the development of a conventional explosive which generates a steam bubble. Most conventional explosives generate permanent gases as a result of their chemical reaction. However, in order to study the migration and oscillation of a nuclear bubble with conventional charges, it is necessary to use an explosive which will reproduce the condensation effects. This report presents the results of the initial underwater tests of two compositions in which steam is the major reaction product.

2. BACKGROUND

When an explosive is detonated under water, energy is dissipated primarily in two ways - in the form of a shock wave which radiates outward from the charge, and in the formation of the bubble of explosion gases. Because of the high internal pressure of these gases, the surrounding water is pushed outward and, if the explosion takes place at a sufficient depth, a spherical bubble is formed. This expands rapidly past the equilibrium point and reaches a maximum size with the internal pressure lower than that of the surrounding water. The bubble then contracts, reaches a minimum size, and re-expands. During the time shortly before and after the minimum, the bubble migrates upward. A pressure pulse is emitted at the time of the bubble minimum. The expansion and contraction (referred to as pulsation or oscillation) and migration of the bubble continue until the bubble energy is dissipated or until it reaches the water surface.

The maximum radius attained by the bubble is given by (Cole, 1948*):

$$A_{max} = J \frac{W^{1/3}}{Z^{1/3}} \qquad (2.1)$$

where: A_{max} = maximum bubble radius, ft

J = radius coefficient characteristic of the particular explosive

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* See Bibliography, Page 22.

W = charge weight, lb
Z = hydrostatic pressure at charge depth, ft

The time after detonation at which the minimum is reached, referred to as the period, is given by (Cole, 1948):

$$T_1 = K \frac{W^{1/3}}{Z^{5/6}} \qquad (2.2)$$

where: T_1 = first bubble period, sec
K = period coefficient characteristic of the particular explosive.

For most conventional explosives, experimental measurements have indicated that the following relationship between the radius and period coefficients is valid (Snay, 1964):

$$\frac{J}{K} \cong 2.9 \qquad (2.3)$$

If the explosion takes place at a shallow depth, the bubble expands above the water surface and is momentarily contained by a seal of continuous water. Due to instabilities and continued thinning of this seal, it soon ruptures. If the seal ruptures with the internal pressure of the gases greater than atmospheric, an outflow, or blowout, of these gases will occur; if the pressure is lower than atmospheric, an inflow, or blowin, of ambient air will occur.

The radioactivity from a nuclear explosion is initially contained within the nuclear bubble. The pulsation of the bubble is turbulent near the minimum and because of mixing processes, radioactive contaminants are left in the water. When the bubble arrives at the water surface, radioactivity is distributed within the plumes, base surge, and foam patch. In the case of blowout, radioactive material is expelled directly into the atmosphere. Condensation of the steam when it meets the ambient atmosphere may modify the blowout phenomena from that observed with conventional high explosive charges.

Very little experimental information is currently available on the behavior of a nuclear bubble. Period measurements were obtained on only one nuclear test, Operation Wigwam. These measurements, together with scaling studies using electric sparks and theory based on HE results, have led to an approximate computational method for estimating the successive periods and migration of a nuclear bubble in free water (Snay, 1960).

Further information on the behavior of the nuclear bubble is required to improve these prediction techniques and to extend them to other than free water conditions; i.e., in proximity to the bottom or surface.

Because of the lack of currently available nuclear data, and in the absence of nuclear testing, it is necessary to use conventional charges and scaling techniques in order to obtain as much information as possible about the behavior of the nuclear bubble.

One of the techniques used in such studies is the use of 0.2 gm charges fired in tanks. Study of the bubble behavior using small charges has several advantages, among them being the ability to observe the entire bubble motion by means of high speed photography. Both static and accelerated test tanks are employed and scaling laws are developed for extrapolating these results up to nuclear conditions (Snay, 1964). In order to reproduce more realistically the behavior of the nuclear bubble, a small charge which produces a steam bubble has been developed and is currently being evaluated for use in the tanks. This explosive composition will be used extensively in scaled experiments to study nuclear bubble behavior.

It is necessary that the scaling laws derived from the tank work be checked experimentally. A direct comparison with nuclear explosions is the most desirable check; however, the lack of sufficient data precludes such a comparison to any extent. In order to provide a means for comparison, it is necessary to develop a chemical charge which also produces a steam bubble and which can safely be used in sizes up to many tons in order to provide a wide range in charge weight and possibly be in the nuclear range.

In certain scaling experiments, it is not necessary to use special tanks. Where geometric scaling is applicable, actual field tests can be conducted and the results scaled to the nuclear condition. Geometric (cube root) scaling can be used in studying certain events from a shallow underwater burst, among these being the shock waves produced in air. It has been shown (Goertner, 1965) that the column motion produced by the expanding bubble is a major contributor to this airblast. As mentioned previously, the phenomena of blowout may be modified by the condensation of steam within the bubble. This phenomenon can also be studied without the use of tanks. Steam charges therefore will be used extensively in the study of airblast and other phenomena from shallow underwater nuclear explosions.

In order to provide such a charge, work was initiated at NOL by the Chemical Engineering Division. In developing the charges, consideration was given only to the condensation effect. No attempt was made to reproduce the nuclear shock wave or to reproduce other aspects of the nuclear bubble, such as the temperature and density of the bubble contents and their variation in time and space. Several compositions were considered, two of which were recommended for testing purposes (Murphy, 1963). These compositions are a lithium perchlorate·trihydrate/aluminum mixture ($LiClO_4 \cdot 3H_2O/Al$), in a 69/31 percent ratio by weight, and a 98 percent concentrated hydrogen peroxide/aluminum mixture (H_2O_2/Al) in a 65/35 percent ratio by weight. The chemical reactions are:

$$3\ LiClO_4 \cdot 3H_2O + 8\ Al \rightarrow 3\ LiCl + 4\ Al_2O_3 + 9\ H_2O \qquad (2.4)$$

$$3\ H_2O_2 + 2\ Al \rightarrow Al_2O_3 + 3H_2O \qquad (2.5)$$

The products other than steam are either solid or are water soluble; no permanent gases are produced.

Initial tests of these compositions were made to determine the underwater shock wave and bubble parameters and to determine if they detonated properly. Two charge weights were fired, nominally 8 and 16 lb. The results of these tests are presented in this report.

3. CHARGES

3.1 $LiClO_4 \cdot 3H_2O/Al$

The lithium perchlorate composition is a granular explosive and is not easily cast, therefore it must be cased. The lithium perchlorate trihydrate is also water soluble, and a case is necessary to isolate it from the surrounding water. A spherical charge case was designed and fabricated; a drawing of this case is shown in Figure 1. A cased 112 gm pentolite booster was centrally located and was detonated by a U. S. Army Engineers' Special detonator. The lithium perchlorate was kiln dried before mixing with the aluminum as this explosive is hygroscopic and the material obtained by NOL contained considerable excess water. Dichromated aluminum was used. The density of this explosive composition was 1.22 gm/cm^3.

3.2 H_2O_2/Al

The specially constructed cases for these charges were packed with finely-divided aluminum; the addition of hydrogen peroxide was made at the firing site. In the initial attempt to test these charges, difficulties were encountered in the construction of the case and with the aluminum used in the charge.

Problems in case manufacture arose as the result of misleading and incomplete information available on the handling and storage of hydrogen peroxide, and by the lack of experience at NOL in working with this material. Ninety-eight percent concentrated hydrogen peroxide reacts with many metals and organic compounds. For some materials, this reaction is slow, for others it is quite rapid and violent. Thus, materials must be selected that have little or no reaction with the peroxide for a time period sufficient to allow the charge to be placed in the water and detonated. Available publications indicated that 1060 aluminum (99.6 percent pure) and stainless steel show no reaction with the peroxide if properly handled; however, the first cases constructed of these materials were quite reactive. It was subsequently discovered that only special production runs of these materials could be used because precautions must be taken in rolling the metal to insure that small bits of the steel

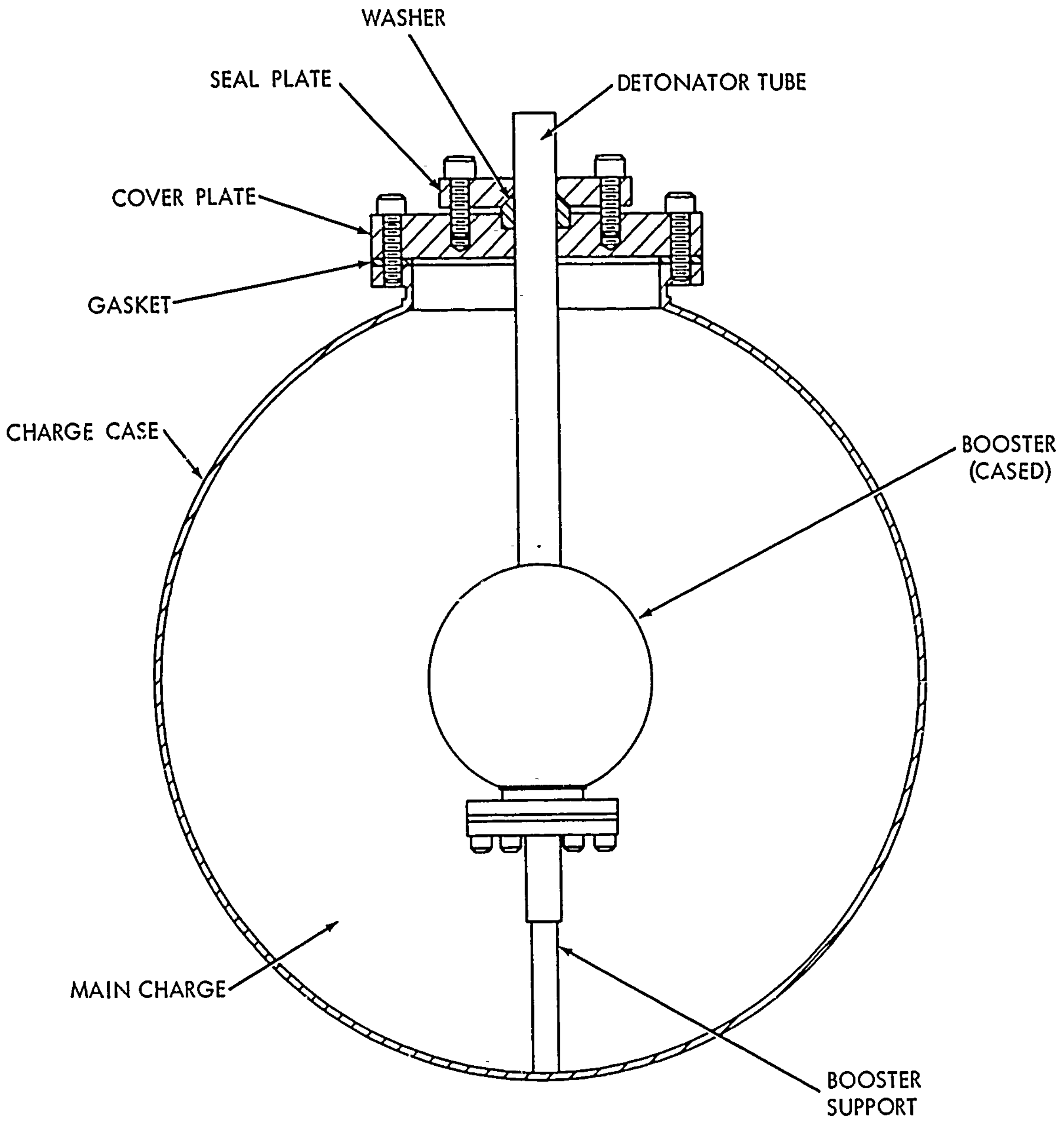

FIG. 1 $LiClO_4 \cdot 3H_2O/Al$ CHARGE CASE roller, which will react, are not imbedded in the otherwise acceptable metal. Extreme care must also be taken during fabrication to insure that no contamination occurs which cannot easily be removed; as, for example, in welding, where special techniques must be used. In order to insure that nonreactive cases were obtained, the charge and booster cases for the second series were fabricated by a contractor experienced in the fabrication of storage and handling equipment for concentrated hydrogen peroxide*.

In the initial tests, aluminum chaff was used to fill the cases as this form of aluminum is readily available and can be packed to the required density. However, considerable reaction occurred when the hydrogen peroxide was added. It was found that minute quantities of lubricating oil on the cutters had contaminated the chaff as it was being sheared. Aluminum wool was substituted for the chaff in the second series as no oil is used in the preparation of this product and no reaction problems were encountered. However, in order to reach the required density, the wool had to be considerably compressed. This was not possible to do in the spherical cases originally designed, so the cylindrical case shown in Figure 2 was used. The wool was compressed into discs and then packed into the case. These charges were centrally boostered with 100 gm of pentolite, which was detonated by an Engineers' Special detonator. The density of this explosive composition is nominally 1.88 gm/cm^3.

The hydrogen peroxide was added in the field just before placing the charge in the water for firing. Loading of an 8-lb charge is shown in Figure 3. The case is evacuated and the hydrogen peroxide allowed to flow into the case through rubber tubing. When peroxide is pulled out of the case into traps located in the vacuum line, the case is considered loaded. Bottles containing the peroxide were weighed before and after loading to obtain the amount loaded into each case.

Safety precautions were taken to minimize the hazards entailed in handling the hydrogen peroxide. The greatest danger is fire, as the reduction of this material produces considerable heat. As can be seen in Figure 3, an inert plastic sheet was placed underneath the loading operation to prevent any spilled hydrogen peroxide from reaching the deck paint, with which it would react violently. Protective clothing (gloves, face masks, disposable coveralls, and boots) was provided to all personnel working with the charges.

The easiest and quickest way to slow down dangerous reactions is to dilute the hydrogen peroxide with large quantities of water. Provision for doing this included a fire hose for flooding any large volumes of peroxide which might be spilled; a safety shower for personnel who might be splashed; and a pail of water for diluting small areas of contamination. Some burns were experienced by people handling the hydrogen peroxide, and small amounts of peroxide were spilled in the course of handling and

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* Contract NOLWO 39674, awarded to G. Schwabel Manufacturing Co., 349 Sawyer Avenue, Tonawanda, New York.

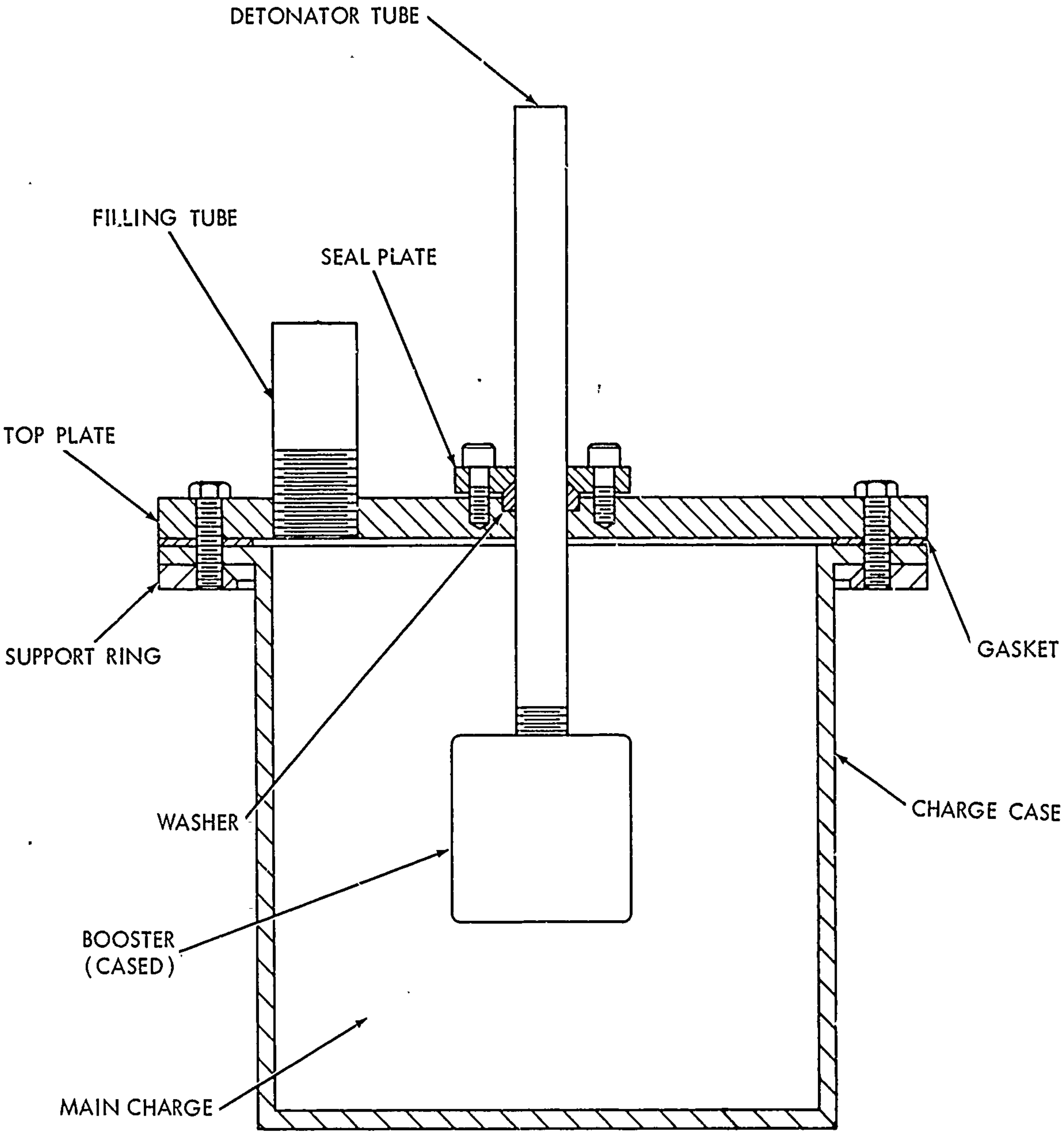

FIG. 2 H_2O_2/Al CHARGE CASE

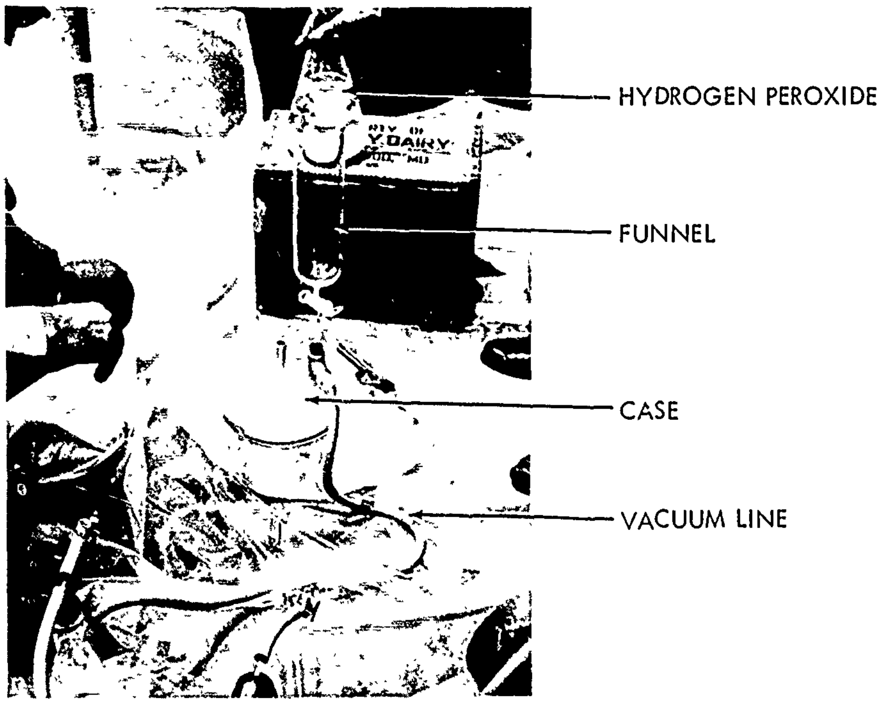

FIG. 3 LOADING OF A HYDROGEN PEROXIDE CHARGE

loading the charges. However, no serious contamination problems were experienced.

The liquid hydrogen peroxide is added to the cases just before the charges are fired and cannot be continuously monitored to assure that the proper amount is added. Therefore, the exact composition is not known until after the charge is loaded for firing. The actual compositions of the eleven charges fired in this series are given in Table 1.

TABLE 1

Actual Composition of H_2O_2/Al Charges

Shot No.	Weight Al (gm)	Weight H_2O_2 (gm)	Total Weight[1] (gm)	Percent	
				H_2O_2	Al
98% H_2O_2/Al					
1217	1271	2070	3341	62.0	38.0
1218	1271	2020	3291	61.4	38.6
1243	1114	2150	3264	65.9	34.1
1247	1052	2010	3062	65.6	34.4
1220	2542	4244	6786	62.5	37.5
1222	2460	4308	6768	63.7	36.3
1250	2405	3855	6260	61.6	38.4
1251	2402	3796	6198	61.3	38.7
Mean				63.0	37.0[2]
90% H_2O_2/Al					
1244	1068	2028	3096	65.5	34.5
1246	1057	1980	3037	65.1	34.9
1248	1054	2005	3059	65.5	34.5
Mean				65.4	34.6[3]

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1. Total weight does not include weight of booster.

2. Desired percentage composition of 98 percent H_2O_2/Al charges is 65/35.

3. Desired percentage composition of 90 percent H_2O_2/Al charges is 67.8/32.2.

As indicated in this table, the mean percentage composition is about two percent different from that required for the 98 percent charges, and 2.4 percent different from that required for the 90 percent charges. The difficulty in obtaining the correct composition was due in part to the lack of precise knowledge of the volume of the containers. This was calculated from measured dimensions of the cases; this method subsequently proved inadequate. Adjustments were made in the amount of wool loaded in the cases after the first two 8-lb and first 16-lb charges had been fired. In most cases this improved the percentage composition; however, in the case of the 16-lb charges, this was accompanied (for shots 1250 and 1251) by a decrease in the amount of H_2O_2 loaded, rather than the expected increase.

Very little gassing was experienced with these charges. A balloon was placed over the filler pipe after the charge had been loaded to allow for expansion due to such gassing. This generally contained very little hydrogen peroxide when the charge was placed in the water. The time interval between completion of loading and placing the rig in the water was of the order of 15 minutes. Firing of the charge usually took place about 35 minutes after it had been loaded.

4. EXPERIMENTAL PROGRAM

The experimental program was designed to provide information on the shock wave parameters (peak pressure, impulse, energy, and decay) and on the bubble parameters(maximum radius and period). Because of the difficulty encountered in initially fabricating the hydrogen peroxide charges, the program was fired in two phases. The first portion evaluated the performance of the lithium perchlorate composition and was fired during the late winter and spring of 1964 in the Potomac River at Indian Head, Md. The second phase, evaluating the hydrogen peroxide composition, was fired during the early summer of 1965 in the Patuxent River from the YSD-72, operating out of NOLTF, Solomons, Md. Instrumentation and rigging arrangements for both programs were essentially the same.

4.1 Instrumentation

Shock wave pressure-time records were obtained by twelve piezoelectric gages located at nominal scaled distances ($W^{1/3}/R$) varying from 0.600 to 0.125 $lb^{1/3}/ft$. Two gages were located at each position; the actual distance of each gage relative to the charge was measured before each shot. One-quarter inch tourmaline gages were used and the voltages generated were displayed as vertical deflections on Tektronix oscilloscopes and recorded on 35mm film on rotating drum cameras operating at 4500 rpm. The bubble period was measured with a one-half inch tourmaline gage; the output of this gage was also displayed on an oscilloscope and photographed by a rotating drum camera operating at 60 rpm. One thousand cps timing marks were placed on the shock wave records, 100 cps timing was placed on the bubble period record. The positions of the PE gages were interchanged at regular intervals and in a random manner to minimize any systematic error due to the gages.

Two bubble probes were used to determine the maximum radius of the bubble. These probes are of a continuous resistance type and detect a change in current due to the non-conducting bubble gases which displace the conductive water (Phillips and Scott, 1965). The probes were each about two feet long and were located so that the bubble would reach to about their midpoint. For the lithium perchlorate series, the probes were located about 30 degrees above the horizontal and were pointed directly at the center of the charge. For the hydrogen peroxide series, the probes were located about 10 degrees above the horizontal and also pointed at the center of the charge.

In addition to the two compositions being evaluated, pentolite charges were fired as standards to provide a basis for comparison and to provide a check on the instrumentation. High explosive charges have shown a scatter of about six percent from series to series; thus, a meaningful evaluation with a small number of shots requires the firing of a standard for which sufficient data has already been obtained. Pentolite was selected because it is considered to be the most reproducible of available common high explosives and because it requires no boostering.

The rig used to support the charge, gages, and probes consisted of a 17-foot diameter ring with a 20-foot, approximately rectangular, extension. The ring was constructed of 1.75-inch solid circular steel rod, the extension was constructed of 1.5-inch extra strong steel tubing and was welded to the ring. The charge was located in the center of the ring, the PE gages were located at varying distances from the charge and were usually located slightly above or below the plane formed by the ring and extension. The ring was supported horizontally at the firing depth using six 55-gallon drums as floats. All charges were fired at a depth of 20 feet. Total water depth for the charges fired in the Potomac River was approximately 40 feet. Water depth for those fired in the Patuxent River varied from 42 to 79 feet, with most of the shots being fired in about 60 feet of water. The actual water depths are given in Tables 3 and 4.

5. RESULTS

5.1 $LiClO_4 \cdot 3H_2O/Al$

Six 8-lb and five 16.3-lb lithium perchlorate charges were fired in this program. Seven pentolite standards were also fired.

5.1.1 Shock Wave Measurements. Shock wave pressure-time records were analyzed to obtain values of peak pressure, energy, impulse, and decay. The initial portion of an underwater shock wave is generally assumed to be an exponential of the form:

$$P = P_m e^{-t/\theta} \qquad (5.1)$$

where: P = pressure
P_m = peak pressure
t = time
θ = decay constant of the shock wave

The shock wave energy, E, is defined as (Cole, 1948):

$$E = \frac{1-(1.7\times10^{-6}\ P_m)}{\rho_o\ c_o}\int_o^t P^2dt \qquad (5.2)$$

where: ρ_o = ambient density of the medium
c_o = ambient sound speed of the medium

The shock wave impulse, I, is defined as (Cole, 1948):

$$I = \int_o^t Pdt \qquad (5.3)$$

The decay constant, θ, is defined as the time at which the pressure has reached a value of P_m/e. Pressure-time records are generally integrated to some value of θ, usually either 5 or 6.7 times the decay constant.

Fits of previous experimental shock wave data have indicated that equations of the following form are obtained:

$$P_m = C_P\left(\frac{W^{1/3}}{R}\right)^{\alpha_P} \qquad (5.4)$$

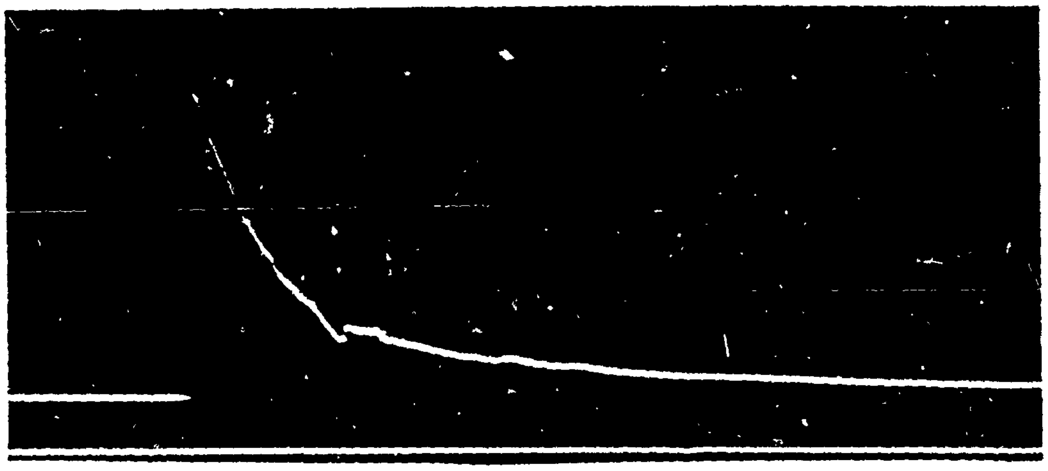
$$\frac{E}{W^{1/3}} = C_E\left(\frac{W^{1/3}}{R}\right)^{\alpha_E} \qquad (5.5)$$

$$\frac{I}{W^{1/3}} = C_I\left(\frac{W^{1/3}}{R}\right)^{\alpha_I} \qquad (5.6)$$

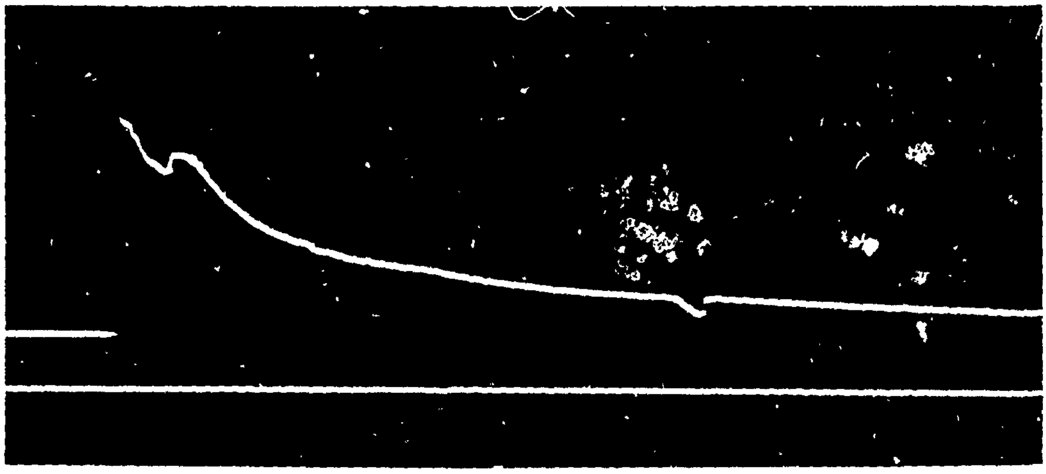
$$\frac{\theta}{W^{1/3}} = C_\theta\left(\frac{W^{1/3}}{R}\right)^{\alpha_\theta} \qquad (5.7)$$

where: C = coefficient associated with the particular parameter
α = exponent associated with the particular parameter
Subscripts P, E, I, θ refer to the particular parameter.

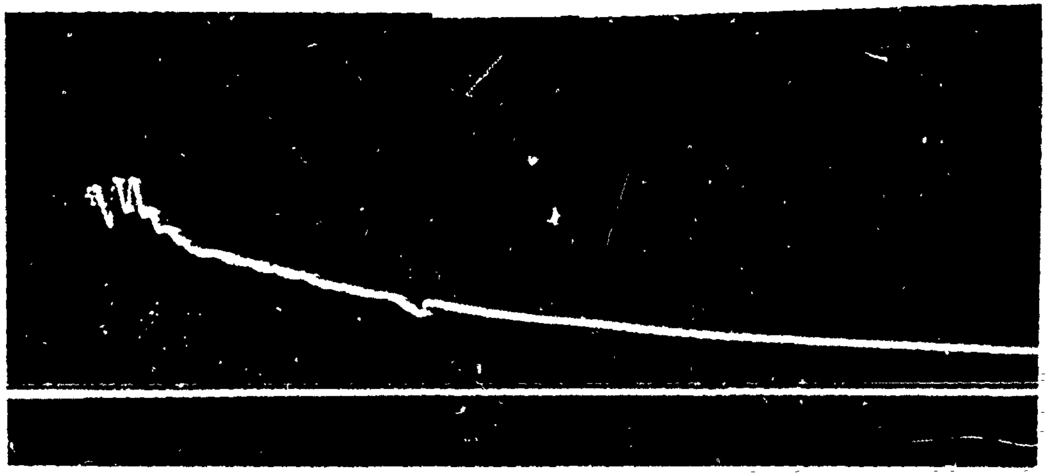
A typical shock wave pressure-time record for a $LiClO_4 \cdot 3H_2O/Al$ charge is shown in Figure 4. For comparison purposes, a pentolite shock wave record obtained at the same gage position is also shown.



PENTOLITE



$LiClO_4 \cdot 3H_2O/Al$



H_2O_2/Al

FIG. 4 TYPICAL SHOCK WAVE RECORDS

On these records, the horizontal scale is the same. However, the vertical gain was changed on the lithium perchlorate record because of the expected lower pressure, thus the pressure per unit length of deflection is about 1.3 times that of the pentolite record. The "hump" which appears on the lithium perchlorate record apparently results from the reflection of the initial detonation wave by the charge case as the time of the first rise of this hump agrees to an acceptable degree with the calculated time difference between the primary and such a reflected wave.

The records were converted to digital form using a Telereadex X-Y film reader. The digitized records were then analyzed on an IBM 7090 computer to obtain values of pressure, impulse, and energy as functions of time. The initial pressure read on these records was taken as the peak pressure, P_m. Because of the hump which occurred on the lithium perchlorate records, it was not possible to obtain meaningful values of the decay constant. Therefore, impulse and energy were obtained by integrating these records to a point where the pressure-time trace had essentially returned to the baseline.

Values of C and α as expressed in Equation (5.4) through (5.7) for the lithium perchlorate composition and pentolite standards are given in Table 2.

TABLE 2

MEASURED SHOCK WAVE PARAMETERS

Explosive	P_m		$E/W^{1/3}$		$I/W^{1/3}$	
	C_P	α_P	C_E	α_E	C_I	α_I
Pentolite (reported)[1]	2.35×10^4	1.14	2.66×10^3	2.04	1.48	0.91
Pentolite (1964 series)	2.47×10^4	1.14	3.00×10^3	2.00	1.77	0.90
	$\sigma = 5.7\%$		$\sigma = 16.8\%$		$\sigma = 15.9\%$	
Pentolite (1965 series)	2.54×10^4	1.21	2.64×10^3	2.12	1.32	0.90
	$\sigma = 8.3\%$		$\sigma = 23.0\%$		$\sigma = 13.2\%$	
$LiClO_4 \cdot 3H_2O/Al$	1.16×10^4	1.03	1.56×10^3	1.86	1.86	0.88
	$\sigma = 9.0\%$		$\sigma = 18.6\%$		$\sigma = 13.8\%$	
H_2O_2/Al (98%)	8.68×10^3	1.09	1.45×10^3	2.15	2.16	1.05
	$\sigma = 23.8\%$		$\sigma = 42.9\%$		$\sigma = 26.2\%$	
H_2O_2/Al (90%)	5.94×10^3	0.98	7.36×10^2	1.88	1.64	0.90
	$\sigma = 22.4\%$		$\sigma = 39.7\%$		$\sigma = 21.4\%$	

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[1] From NavWeps 7380 (Thiel, 1961).

Standard deviations (σ), expressed in terms of percentage difference because of the exponential form of the curves, are also included. The pentolite standards show somewhat higher values than those previously reported (Thiel, 1961). The lithium perchlorate composition has a lower peak pressure and energy than does pentolite and a somewhat higher impulse. While the value of the decay constant could not be determined precisely, it was roughly double that of pentolite. As expected, the lithium perchlorate results show somewhat greater scatter than do the pentolite results.

5.1.2 Bubble Measurements. The measured bubble periods and maximum radii are given in Table 3.

TABLE 3

BUBBLE MEASUREMENTS: $LiClO_4 \cdot 3H_2O/Al$ AND PENTOLITE CHARGES FIRED AT 20-FT DEPTH

Shot No.	Total Weight (lb)[1]	Water Depth (ft)	A_{max} (ft)	J	T_1 (sec)	K
Pentolite						
986	8.0	44	--	--	0.306	4.37
987	8.0	42	--	--	0.304	4.34
1002	8.0	45	6.96	12.86	0.308	4.41
1015	8.0	46	--	--	0.304	4.35
993	16.0	45	8.55	12.76	0.375	4.42
1007	16.0	41	8.56	12.76	0.371	4.35
1012	16.0	46	8.47	12.64	0.374	4.41
Mean				12.76		4.38
$LiClO_4 \cdot 3H_2O/Al$						
995	8.0	41	8.15	15.32	0.359	5.31
996	8.0	40	8.22	15.45	0.364	5.38
1000	8.0	44	--	--	0.360	5.35
1001	8.0	40	--	--	0.366	5.42
1003	8.0	45	8.43	15.85	0.363	5.40
1005	8.0	45	8.28	15.57	0.365	5.43
1008	16.3	42	9.95	14.78	0.444	5.28
1009	16.3	42	9.92	14.74	0.445	5.30
1010	16.3	45	--	--	0.447	5.35
1011	16.3	44	10.14	15.07	0.446	5.33
1013	16.3	45	--	--	0.449	5.37
Mean				15.25		5.36

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[1] No booster used for pentolite charges. $LiClO_4$ charge weight includes a 0.25-lb booster.

Because the bubble probes were in the early stages of development, maximum radii were not measured on all tests. In computing values of J and K from these measurements, corrections were applied for surface and bottom effects on the period (Niffenegger, 1953). No correction for these effects were made on the radius measurements.

The resulting values of J and K are also given in Table 3. For pentolite, the percentage deviation in J was 0.7 percent; for K, it was 0.8 percent. The average values of J and K (12.76 and 4.38) are in good agreement with the accepted values for this explosive (12.6 and 4.36).

For the lithium perchlorate composition, a correction to K for the booster was also included* (Niffenegger, 1953). A similar relationship was used for correcting J. The value of J obtained for this composition is 15.2 and for K, it is 5.36. The percentage deviation of J was 3.1 percent; for K it was 0.9 percent. This relatively large deviation in J is misleading as it is believed to be the result of increased motion of the probe on the larger shots. In Table 3, it can be seen that the value of J for the 8-lb charges is slightly larger than the value obtained with the 16.3-lb charges. The available data for pentolite also indicates this same trend. Since J is calculated from the measured radius, movement of the probe away from the burst due to water flow from the expanding bubble would produce an apparently smaller bubble and thus a smaller value of J. A more accurate indication of variability is probably obtained by calculating the percentage deviation separately for each charge weight. Percentage deviations of 1.6 and 1.2 percent are obtained for the 8- and 16.3-lb charges, respectively, which is in better agreement with the deviation obtained with pentolite.

The ratio of J/K for this composition is 2.85. This is slightly lower than that given in Equation (2.3), a trend which was postulated by H. G. Snay (1960) of this Laboratory for highly aluminized explosives.

5.2 H_2O_2/Al

A total of eleven H_2O_2/Al charges were fired. Of these, eight contained 98 percent concentrated hydrogen peroxide and three contained

---

*

$$K = \left[K^3_t - \frac{\frac{W_b K^3_b}{W_t}}{1 - \frac{W_b}{W_t}} \right]^{1/3}$$

where: K = period coefficient for lithium perchlorate composition

K_t = measured period coefficient for total charge

K_b = period coefficient of booster

W_b = weight of booster, lb

W_t = total weight of charge, lb

90 percent concentrated hydrogen peroxide. Nine pentolite standards were also fired. The 98 percent concentration had been recommended for use in these charges (Murphy, 1963); the 90 percent concentration was tested to see if a reduction in concentration would affect the energy partition between the shock wave and bubble. Four of the 98 percent were nominal 8-lb charges and four were nominal 16-lb charges; all the 90 percent were nominal 8-lb charges.

5.2.1 Shock Wave Measurements. A typical shock wave pressure-time record is also shown in Figure 4 for the H_2O_2/Al charges. In this case, the pressure per unit deflection is approximately 1.6 times that of the pentolite record. The values of C and α and the standard deviations (σ) for the shock wave parameters obtained on this program are given in Table 2.

The peak pressure was determined by plotting the pressure-vs-time record on semi-logarithmic paper and drawing a smooth line through the initial portion of the shock wave, ignoring the "overshoot". The value of this line at zero time was taken as the peak pressure, P_m; the time at which the pressure reached a value 1/e of the peak pressure was taken as θ. This method of determining P_m is generally used in underwater shock wave analysis and is described in detail in the report by Slifko and Farley (1959).

The results of the shock wave analysis for this program are also given in Table 2. The pentolite results show good agreement with previous work, although the scatter is somewhat greater than that observed for the pentolite standards fired in the lithium perchlorate program. The hydrogen peroxide charges show considerably lower shock wave parameters than pentolite. In addition, the standard deviation for the shock wave parameters is considerably greater than those of the pentolite standards and is also greater than those obtained with the lithium perchlorate composition. This large scatter, combined with the low pressures and generally ragged shape of the shock wave pulse, indicates that these charges did not detonate properly. Murphy (1963) has stated that strong boostering and heavy confinement of the hydrogen peroxide composition are required to obtain high order detonation. However, exactly what sufficient boostering is and how adequate the confinement is cannot be determined prior to testing.

5.2.2 Bubble Measurements. Measured values of the maximum bubble radius and period, and values of J and K computed from these values, are given in Table 4. The maximum radius was measured by at least two probes on each shot, and an average value of these measurements used to compute J. Corrections for surface and bottom effects and for the booster, similar to those applied to the lithium perchlorate bubble data, were also applied to these data.

Good internal consistency of the bubble parameters for the pentolite standards was also obtained in this series. The percentage deviation in J was 1.0 percent; for K, it was 0.8 percent. However, the average value of J is about six percent larger than the value of 12.6 generally accepted

TABLE 4

BUBBLE MEASUREMENTS: H_2O_2/Al AND PENTOLITE CHARGES FIRED AT 20-FT DEPTH

Shot No.	Total Weight (lb)[1]	Water Depth (ft)	A_{max} (ft)	J	T_1 (sec)	K
Pentolite						
1214	7.99	60	7.14	13.40	0.304	4.44
1215	8.01	55	7.12	13.38	0.303	4.43
1223	8.01	79	7.09	13.33	0.301	4.36
1226	8.01	48	6.97	13.10	0.300	4.38
1241	8.01	43	--	--	0.299	4.35
1245	8.03	62	7.04	13.24	0.304	4.43
1219	15.96	60	8.97	13.38	0.374	4.41
1221	16.04	43	9.08	13.55	0.373	4.38
1249	16.02	75	8.90	13.28	0.373	4.36
Mean				13.33		4.39
98% H_2O_2/Al						
1217	7.59	55	9.02	17.22	0.372	5.66
1218	7.48	54	8.74	16.77	0.374	5.72
1243	7.42	63	8.63	16.64	0.378	5.79
1247	6.97	60	8.72	17.17	0.388	6.10
1220	15.18	59	11.00	16.68	0.473	5.85
1222	15.14	42	11.17	17.00	0.470	5.77
1250	14.02	70	11.19	17.45	0.470	5.92
1251	13.88	69	10.92	17.11	0.468	5.92
Mean				17.00		5.84
90% H_2O_2/Al						
1244	7.05	62	<8.12[2]	--	0.304	5.21
1246	6.92	62	>8.20[3]	--	0.375	5.88
1248	6.96	60	7.92	15.59	0.346	5.37
Mean				15.59		5.49

1/ No booster used for pentolite charges. H_2O_2/Al charge weight includes a 0.22-lb booster.

2/ Bubble did not reach probe.

3/ Bubble over probe.

for this explosive. It is believed this increase in J is the result of the non-spherical shape of the bubble caused by the proximity of the water surface and bottom. It is also larger than J obtained for the pentolite standards on the lithium perchlorate program, probably because the support used on the lithium perchlorate program was not sufficiently rigid and some movement of the probe took place. It also could result from the fact that the probes for the two series were mounted at different angles above the horizontal. For these reasons, it is believed that the previous value of J for pentolite is preferable, and it is likely that the value of J given here for the H_2O_2/Al charges is also high, probably by about the same percentage. It is therefore believed that a value of J of 16.1 for the free water coefficient for H_2O_2/Al is a better value than the one given in Table 4.

For the 98 percent concentrated hydrogen peroxide charges, the percentage deviation in J was 2.0 percent; for K, it was 2.4 percent. This composition shows greater scatter than does the lithium perchlorate composition, probably because of the varying composition of these charges and the difficulty in properly detonating them. The ratio of J/K for this composition is 2.76 which, like the value for the lithium perchlorate composition, is lower than that observed for most conventional explosives.

As indicated in Table 4, a large variation was obtained in the bubble measurements for the charges using 90 percent concentrated hydrogen peroxide. A measurement of the maximum radius was obtained on only one shot because of this large variation. The period was measured on all three shots; the percentage deviation in K was 6.4 percent. Because of the lack of data, and the large scatter where such data was obtained, no further corrections have been applied.

5.3 Comparison with Nuclear Shock Wave and Bubble Parameters

If the shock wave parameters for a nuclear explosion given in the report by Snay and Butler (1957) are converted to pounds of explosive ($1 \text{ kt} = 2 \times 10^6$ lb), the following expressions are obtained:

$$P_m = 1.86 \times 10^4 \left(\frac{W^{1/3}}{R}\right)^{1.13} \qquad (5.8)$$

$$E = 1.64 \times 10^3 \, W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{2.04} \qquad (5.9)$$

$$I = 1.16 \, W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{0.91} \qquad (5.10)$$

In order to properly compare these parameters with the steam charge results, it is necessary that the exponent of the particular parameter for both explosives be the same. For each parameter, the exponent of the steam charge equations was adjusted to the exponent of the nuclear equation; the coefficient C was then adjusted by fitting the experimental data, using this new exponent, to a value where a minimum percentage difference between measured and calculated values was obtained. The resulting values of C are compared with the nuclear values in Table 5.

TABLE 5

COMPARISON OF NUCLEAR AND STEAM CHARGE
SHOCK WAVE AND BUBBLE PARAMETERS

	Shock Wave[1]			Bubble	
	C_P	C_E	C_I	J	K
Nuclear	1.86×10^4	1.64×10^3	1.16	11.9	4.09
$LiClO_4 \cdot 3H_2O/Al$	1.32×10^4	2.04×10^3	1.94	15.2	5.36
H_2O_2/Al	9.40×10^3	1.30×10^3	1.82	16.1	5.84
HBX-1[2]	2.38×10^4	2.96×10^3	1.57	14.4	5.00

---

[1] Coefficients for two steam charge compositions obtained after adjusting exponents of steam charge data to those of nuclear as given in Equation 5.8 through 5.10.

[2] Shock wave parameters from Thiel, 1961. No correction of the coefficients has been made. The difference in these coefficients from nuclear, however, is minor. Bubble parameters from NAVORD 2986.

Shock wave values for HBX-1 (Thiel, 1961) are also shown, as this explosive has been used extensively in the study of nuclear phenomena. It can be seen from this table that both compositions exhibit lower shock wave peak pressures than a nuclear explosion. The lithium perchlorate composition shows a higher shock wave energy than nuclear, the hydrogen peroxide is lower. Both compositions have a higher impulse than does the nuclear shock wave.

Converting the nuclear bubble parameters given in the report by Snay (1960) to pounds of explosive, the following equations are obtained:

$$A_{max} = 11.9 \frac{W^{1/3}}{Z^{1/3}} \qquad (5.11)$$

$$T_1 = 4.09 \frac{W^{1/3}}{Z^{5/6}} \qquad (5.12)$$

Values of J and K for the two steam charges are also compared with the nuclear and HBX-1 values in Table 5. Both steam compositions have larger values of these parameters, thus they produce a larger bubble having a longer period than would a nuclear explosion of the same energy fired at the same depth. In terms of energy partition, neither composition shows the desired ratio of shock wave to bubble energy (assuming that J^3 or K^3 is indicative of bubble energy).

6. SUMMARY

To summarize, tests of the lithium perchlorate and hydrogen peroxide compositions have shown the following results:

1) Both compositions showed a reduction in the ratio of J/K as a result of their high aluminum content.

2) The lithium perchlorate composition showed good reproducibility in both shock wave and bubble parameters, although the scatter was greater than that of the pentolite standards.

3) The low pressure and irregular shape of the shock wave pulse, and the large scatter in the shock wave parameters from the hydrogen peroxide charges, indicate that charges of this composition did not detonate properly. No improvement was noted when less concentrated hydrogen peroxide was used.

4) Both compositions produced a larger bubble than would a nuclear explosion of the same yield fired under the same conditions.

7. CONCLUSIONS

Based on the results of these tests, the lithium perchlorate composition seems to be the better of the two. It detonates well with a 100 gm booster in the charge sizes tested and shows good reproducibility of both shock wave and bubble parameters. It is also a much easier and simpler explosive with which to work in the field.

It must be emphasized, however, that the above conclusion is based only on the results of the two test series reported here and is not a final evaluation of the superiority of one composition over the other. Further tests still must be conducted with larger charges to see if there is a charge size effect and to investigate handling of such charges in larger sizes. Only after such information has been obtained and evaluated can a final recommendation be made.

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UNDERWATER EXPLOSION TESTS OF TWO STEAM PRODUCING EXPLOSIVES, by D. E. Phillips and T. B. Heathcote. 23 May 1966. 22p. illus., charts. BuWeps task RRRE 51001/212-8/F008-21-03.

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Eight and sixteen-lb charges of $LiClO_4 \cdot 3H_2O/Al$ and H_2O_2/Al steam-producing explosives were fired under water to obtain values of shock wave and bubble parameters. Both showed lower shock wave peak pressures than equivalent nuclear explosions; bubble radius and period coefficients for both compositions were higher. The $LiClO_4 \cdot 3H_2O/Al$ composition showed less scatter in both shock wave and bubble measurements than did the H_2O_2/Al composition.

Abstract card is unclassified.

1. Explosions, Underwater
2. Explosives, Underwater - Effects
3. Lithium perchlorate
4. Hydrogen peroxide
5. Aluminum

I. Title
II. Phillips, Donald E.
III. Heathcote, Thomas B., jt. author
IV. Project

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