Woods Hole Oceanographic Institution
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LONG RANGE SOUND TRANSMISSION
Interim Report No. 2

SOFAR BOMBS AND DETONATORS

by

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PREFACE

The purpose of this report is to describe the problems affecting the design of a suitable sound source for use in connection with long range sound transmission (SOFAR), and to describe the bombs and detonators developed for that purpose.

The report was prepared under the supervision of Dr. G. P. Woollard and covers an extensive research program on the development of suitable ordnance for SOFAR investigations. The work was carried out primarily by Mr. J.-Lamar Worzel, Mr. Harry Robinson, and the writer.

TABLE OF CONTENTS

	Page No.
Introduction	1
Testing of Bombs and Detonators	3
Laboratory Tests	4
Field Tests	5
Description and Performance of Bombs	8
Explosion Bombs and Detonators (General Discussion)	9
Factors Affecting Bomb Design	9
Energy Available	9
Frequency Requirements	10
Effective Frequencies Obtained	10
Factors Affecting Detonator Design	11
Safety	11
Explosion Bombs and Detonators (Specific Descriptions and Performance Figures)	12
Bourdon Bomb, Model A	13
Bourdon Bomb, Model B	14
Douglas Percussion Bomb	15
Rockwell Bomb	16
Multiple Shot Bomb	18
"Bottle Cap" Bomb	19
Woods Hole Percussion Detonator	20
Woods Hole Pressure Detonator	22
History	22
Design	23
Derivation of Semi-Empirical Equation	25
Manufacture and Loading	27
Safety	28
Use	28
Performance	29
Adjustable Depth Woods Hole Detonators	30
Uncased Bomb	34
Sheet Metal Case Bomb	36
Research Model Bombs	37
MK 34 AA Bomb Case	37
4.5 inch Barrage Rocket	37
Research Model Bomb Type A	38
Research Model Bomb Type B	40
Research Model Bomb Type C	41
Sofar Interim Bomb (Self Arming)	42
Loading	43
Fin Area	43
Performance	44
Implosion Bombs	46
Energy Available	46
Types of Implosion Bombs	46
Performance	46

LIST OF TABLES

Table No.		Page No.
I	Types of Bombs and Detonators Tested	3
II	Cruises on Which Bombs were Tested	6
III	Effect of Weight of Charge on Sound Intensity	9
IV	Relative Energy from Explosives	10
V	Tests on Cylindrical Shells	24
VI	Wall Thickness of Test Specimens in Inches	27
VII	Observed Firing Depths	27
VIII	Woods Hole Pressure Detonators Performance	29
IX	Adjustable Depth Woods Hole Detonators .0051 Wall Thickness	31
X	Adjustable Depth Woods Hole Detonators .0079 Wall Thickness	32
XI	Effect of Age on Detonators	38
XII	Effect of Minor Variations on Sinking Times	38
XIII	General Performance of Type B Bombs	39
XIV	Free Fall Tests on Interim Bombs	45

LIST OF ILLUSTRATIONS

Figure

- 1 Equipment for Pressure Testing (Photograph)
- 2 Pressure Testing Apparatus
- 3 Determination of Firing Depth
- 4 Block Diagram - Monitoring Equipment
- 5 Shipboard Monitoring Installation, USS MUIR (Photograph)
- 6 Bourdon Bomb, Model A
- 7 Bourdon Bomb, Model B
- 8 Douglas Percussion Bomb
- 9 Rockwell Bomb
- 10 Rockwell Bomb (Photograph)
- 11 Multiple Shot Bomb, Assembled (Photograph)
- 12 Multiple Shot Bomb, Timer (Photograph)
- 13 Multiple Shot Bomb, Unit Bomb (Photograph)
- 14 "Bottle Cap" Bomb
- 15 Woods Hole Percussion Detonator
- 16 Woods Hole Pressure Detonator
- 17 Development of Woods Hole Sofar Bombs (Photograph)
- 18 Test Specimens Before and After Collapse (Photograph)
- 19 Woods Hole Adjustable Depth Detonators (Photograph)
- 20 Uncased Bomb
- 21 Sheet Metal Case Bomb
- 22 Research Model Bomb, Type A
- 23 Research Model Bomb, Type A (Photograph)
- 24 Research Model Bomb, Type B
- 25 Research Model Bomb, Type C

LIST OF ILLUSTRATIONS (continued)

Figure

26	Sofar Interim Bomb, Arming Mechanism
27	Modified Arming Mechanism, Sofar Interim Bomb
28	Sofar Interim Bomb, Alternate Design (Photograph)
29	Sofar Interim Bomb
30	Sofar Interim Bomb (Photograph)
31	Sofar Interim Bomb (Photograph)
32	Cover Hook and Spring Lock (Photograph)
33	Modified Interim Bomb (Photograph)
34	Modified Interim Bomb (Photograph)
35	Modified Interim Bombs (Photograph)
36	Modified Interim Bombs (Photograph)
37	Implosion Bomb, Flask Type
38	Implosion Bomb, Tubing Type

LIST OF GRAPHS

No.

- 1 Spectrum of Sound From TNT Explosions
- 2 Rockwell Bomb, Sinking Time to 670 Fathoms
- 3 4000 Foot "Bottle Cap" Bomb, Sinking Time
- 4 1500 Feet "Bottle Cap" Bomb, Sinking Time
- 5-30 Woods Hole Pressure Detonators, Failing Pressure Distribution Plot
- 31 Collapsing Pressure vs Free Length for Various Wall Thicknesses
- 32 Woods Hole Pressure Detonators, Probable Firing Depth, Live Detonators .0079" wall thickness
- 33 Woods Hole Pressure Detonators, Probable Firing Depth, Live Detonators .0094" wall thickness
- 34 Standard Woods Hole Detonators, Firing depth vs Wall Thickness
- 35 Firing Depths, Woods Hole Adjustable Depth Detonators
- 36 Research Model Bomb, Type A, Sinking Time to 660 Fathoms
- 37 Research Model Bomb, Type A (No Marlin), Sinking Time to 660 Fathoms
- 38 Research Model Bomb, Type A (With Marlin), Sinking Time to 660 Fathoms
- 39 Research Model Bomb, Type C, Sinking Time to 660 Fathoms

ABSTRACT

The use of the natural sound channel in the oceans in transmitting sound signals over distances as great as 3000 miles is known as SOFAR. The sound signal is initiated at the axis of the sound channel by some sort of bomb and the signal so generated is picked up at great distance by a hydrophone lying at or near the axis of the channel. It is the purpose of this paper to discuss the design and performance of the bombs developed to date for use in SOFAR.

The bombs fall into two general classes, namely explosion bombs and implosion bombs. Explosion bombs consist of a detonator which by means of a booster fires a main charge usually of TNT or other high explosive. The only practical method of actuating the detonator at the present time is on the basis of pressure, the detonator being designed to fire at a pressure corresponding to that at the sound channel axis. As the depth of the axis varies with the geographical location it is necessary that the detonator be replaceable or that it be adjustable to meet the requirements of a given area. Typical firing depth requirements to be met are 700 fathoms in the temperate latitudes in the Atlantic and 350 fathoms in corresponding latitudes in the Pacific. Explosion bombs have varied in design from uncased demolition blocks fired by a simple detonator to a cast charge of TNT in a pressure proof case fired by an intricate mechanism with elaborate safety devices. Detonators have been principally of three types; (1) the Woods Hole pressure detonator, (2) the diaphragm-percussion pin, and (3) the bourdon-electric.

Implosion bombs consist of empty containers designed to collapse at or near the axis of the sound channel and thus to release sound energy. It is not known how efficient this sound source is as development work on it has been somewhat limited. The advantages of this device is that it is perfectly safe to use under all conditions, and that it is simple to manufacture. The main disadvantage is that it is rather bulky.

INTRODUCTION

The development of a satisfactory sound source for use in long range sound transmission (3000 miles or more maximum range) is one of the primary research problems connected with the development of SOFAR. The general requirements of the sound source are that it generate relatively large amounts of sound energy particularly in the lower frequencies (below 1000 c.p.s.) at or near the sound channel axis¹ in the ocean, be simple in operation, involve no complicated installation; be highly reliable, and preferably be inexpensive, easily obtained, compact, and easily transported on both ships and planes. The most obvious type of sound source meeting these requirements is some type of explosive bomb.

The problem thus simplified reduces to first, the development of a cheap, light, and safe bomb containing sufficient explosive to send a signal to all parts of an area being monitored, and second, the development of a reliable detonator which will fire the bomb at or near the axis of the sound channel. An alternate type of sound source is an implosion bomb. Such a bomb contains no explosive and requires no detonator and consists of an empty container designed to collapse suddenly at the pressures encountered at the depth of the axis of the sound channel.

For preliminary scientific investigations of SOFAR in which a great many signals must be sent, large quantities of signal bombs are needed and the primary consideration of the bombs are reliability, simplicity, availability, safety, and low cost.

For the applied uses of SOFAR the primary considerations of a bomb signal are safety and high reliability. Such bombs should also be compact, light, have a short sinking time to the axis of the sound channel, and be automatic in operation. As such bombs may be used from aircraft it is necessary that they be capable of withstanding the severe vibrations encountered in aircraft, have an arming mechanism that will keep the bombs safe until they are in the water, have good air flight characteristics when dropped, be able to withstand the shock of impact at the ocean surface without detonating or damaging the automatic arming mechanism.

To meet the above requirements several types of signal bombs have been developed for use in connection with SOFAR. This report is devoted primarily to a description of these bombs and their performance.

¹ For a discussion of the sound channel and the fundamentals of SOFAR see WHOI Interim Report No. 1, Long Range Sound Transmission by Ewing and Worzel, August 25, 1945 or WHOI Memo for File, A Manual for SOFAR Observers by G. P. Woollard, July 1, 1947.

Work and experiments on the development of bombs for use in connection with SOFAR were started at the Woods Hole Oceanographic Institution in 1943. During the period from 1943 to 1946 the work was conducted under the direction of Dr. Maurice Ewing by Mr. J. Lamar Worzel and Mr. Harry Robinson. During the period from 1946 through 1947 the development work has been carried on under the direction of Dr. George P. Woollard by the writer. The present report covers all of the development work to date.

TESTING OF BOMBS AND DETONATORS

Performance tests on various bombs and detonators are made both in the laboratory and in the field. The laboratory tests are conducted for the purpose of studying the pressures required to fire detonators, to actuate arming mechanisms, and to collapse implosion bombs. Field tests are carried out in order to evaluate the overall performance of detonators, of complete explosion bomb and detonator units, and of implosion bombs. Table I lists the various types of bombs and detonators tested and the firing record of each.

TABLE I
Types of Bombs and Detonators Tested

Bomb	Detonator	No. Tested	% Known to Have Fired
Bourdon, Model A	Electric	11	91
Bourdon, Model B	Electric	9	56
Douglas Percussion	Percussion	8	0
Rockwell	Electric	96	73
USNUSL Multiple Shot	Fuse	Performance data not available	
NOL "Bottle Cap"	Percussion	26	100
-----	Woods Hole		
-----	Percussion Mechanical unit only tested		
	Woods Hole		
	Pressure	575	97
Uncased	Woods Hole		
	Pressure	83	67
Sheet Metal Case	Woods Hole		
	Pressure	117	79
Research, Type A	Woods Hole		
	Pressure	250	93
Research, Type B	Woods Hole		
	Pressure	9	67
Research, Type C	Woods Hole		
	Pressure	75	88
SOFAR Interim	Woods Hole		
	Pressure	24	100

IMPLOSION BOMBS

Bomb	Detonator	No. Tested	% Known to Have Fired
Tubing Type	None	4	0
Flask Type	None	2	50
Glass Vessels	None	4	0

Laboratory Tests. Pressure testing in the laboratory is performed with the equipment shown in Figures 1 and 2. This equipment consists of a piston pump which may be operated either by hand or by electric motor, a pressure vessel and a separator which by means of a simple gravity arrangement separates the oil at the pump end of the system from the water at the pressure vessel end of the system. A means of tapping the separator is provided so that the oil-water balance of the system may be maintained. Three pressure vessels made from 8, 14, and 16 inch high explosive shells are used at Woods Hole. All may be used safely with internal pressures up to 10,000 pounds per square inch. The smallest vessel is sufficient for the majority of the pressure tests on SOFAR ordnance. The 14 inch vessel is used for testing objects too large to fit in the 8 inch vessel and for other miscellaneous testing. The 16 inch vessel is used in testing "live" detonators as it is felt that the energy released could better be absorbed by the large volume.

The pressure in the system is determined approximately from a heavy duty pressure gage connected directly to the pump. (See Figures 1 and 2). A more precise determination of pressure is obtained either with a special 3000 pound hydraulic gage supplied by the Heise Bourdon Tube Company or with a standard 5000 pound hydraulic pressure gage. Both these gages are shown in Figure 1. For tests involving pressures above 3000 pounds per square inch and for all tests of explosive specimens the standard 5000 pound gage is used. For all other tests the Heise gage is used. In tests involving the collapse or explosion of test specimens in which considerable shock is experienced, a choke coil consisting of 50 feet of 1/8 inch copper tubing and 50 feet of 3/16 inch copper tubing in series is used between the pressure vessel and the gage to reduce the possibility of damage to the instrument.

The Heise gage has an accuracy of $\frac{1}{2}\%$ of the reading from 600 pounds per square inch to 3000 pounds per square inch. Below 600 pounds per square inch readings are accurate to within 3 pounds per square inch. Calibration is made with 500 pound Crosby and 10,000 pound American Instrument Company gage testers. The readings from the 5000 pound gage are limited in accuracy largely by the difficulty in reading the pressure scale accurately particularly when sudden changes in pressure are involved. Readings are probably accurate to within ± 20 pounds per square inch.

The pump is connected to the top of the separator and the pressure vessels to the bottom of the separator by means of copper tubing. However, the leads from the pressure vessels first pass through a manifold so that the vessel to be used may be selected merely by turning a valve. City water is also connected to the system through the manifold. Before a series of tests is run it is desirable to vent any residual air that may have accumulated in the top of the separator by opening the bleed valve and forcing the air out under city water pressure.

The procedure for testing is as follows (refer to Figure 2):

1. The most suitable pressure vessel is selected on the basis of the size and nature of the unit to be tested. A suitable pressure gage is attached to the lead from the pressure vessel using a choke coil if shock to the system is expected. All valves in the system are closed except the air bleed valve in the cover of the vessel. The unit to be tested is placed in the vessel and the cover of the vessel screwed tightly in place.
2. The manifold-vessel valve and the manifold-city water valve are opened admitting water to the vessel and expelling any air in the vessel through the bleed valve. When water begins to flow from the valve, the valve is closed.
3. The manifold-separator valve is opened thus applying city water pressure to the remainder of the system. The manifold-city water valve is then closed making a closed system from the pump through the separator to the vessel.
4. The pump which may be operated either by hand or electric motor gradually increases the pressure in the system. The failure of the device being tested in the vessel is usually audible and the pressure recorded on the precision gage noted at that time. In testing the functioning of arming devices and similar equipment it is not always possible to detect the instant of operation by ear in which case cut and try methods are required.
5. The pump valve is opened and the pressure released from the system.

Field Tests. More comprehensive data on bomb and detonator performance are obtained from field tests. Factors that can be evaluated in the field are: (1) reliability, (2) firing depth, (3) sinking time, (4) flight characteristics in air (if dropped from aircraft) and (5) range of audibility (under certain conditions)¹.

Reliability may be determined from tests at sea without any special equipment as bomb explosions are easily heard by ear aboard ship if the bombs are dropped when the ship is not under way. The approximate sinking time may be determined with a stop watch. However special recording equipment usually is used for monitoring from the ship dropping the bombs. The advantages of such a procedure are (1) monitoring may be done with the ship under way, (2) partial firing of the bomb (detonator failing to fire the main charge) may be detected (3) echos from the surface and bottom may be detected and accurately timed to determine firing depth and depth of water.

¹ Range of audibility is regarded as a special phase of bomb performance and is discussed in detail in a report on sound intensities being prepared concurrently with this report.

Firing depth is computed from the time interval between reflected signal arrivals as shown in Figure 3. From this diagram it is seen that the difference between the time of the second and third arrivals at a shoal hydrophone or fathometer head is very nearly equal to the travel time for twice the firing depth. The depth may then be computed from the mean vertical sound velocity in the area. Displacement of the ship from a position directly over the bomb introduces an error in depth determination but the error is usually very small.

A schematic diagram of a successful monitoring system suitable for shipboard use is shown in Figure 4. A photograph of another successful set up is shown in Figure 5. The monitoring equipment may be used in conjunction with the fathometer head of the ship or with a hydrophone. The former is preferable as it works well regardless of whether the ship is under way or not. The basic principle of operation is as follows: signals from an explosion are picked up by the fathometer head or hydrophone and fed to an amplifier. The amplified signal is then fed to a loud speaker or headset for audio-monitoring and to a power level recorder or other device for graphically recording the arrival times and amplitudes of the signals. On the same tape time ticks are recorded simultaneously with the signal arrivals. With these data reliability and sinking time can be determined directly.

Table II lists the various cruises on which bombs and detonators were tested in the field.

TABLE II
Cruises on which Bombs were Tested

<u>Vessel</u>	<u>Date</u>
DE-51	April 2-5, 1944
USCGR VALOR (CGR 3080)	January 10-29, 1945
USS SCOTT (DE-214)	February 8-23, 1945
RV PHYSALIA	April 2, 1945
Flight (Airplane)	May 7, 1945
USCGR VALOR (CGR 3080)	May 21-30, 1945
Flight (Airplane)	June 14-15, 1945
USCGR VALOR (CGR 3080)	June 16-22, 1945
RV ATLANTIS	June 25-July 2, 1945
USS SARDONYX (PYC 12)	July 1, 1945
USCGR VALOR (CGR 3080)	July 26-August 3, 1945
Triangulation Cruises (ATLANTIS, USCGR VALOR, USS MASON, PLANE)	August 20-September 5, 1945
USS MUIR (DE-770)	November 17-December 15, 1945
PCE(R) 849	April 30-May 2, 1946
RV ATLANTIS	September 16-November 17, 1946
RV ATLANTIS	April 10, 1947

The flight characteristics for the bomb are important if the bomb is designed for use from aircraft. Field testing for flight characteristics consists of visual observations and movie recordings of the flight behaviour of a falling bomb released from a plane at different elevations when travelling at normal flying speeds. An integral part of this test is the subsequent performance of the bomb after it hits the water. The details of flight tests are described in connection with the Woods Hole arming type Interim bomb.

DESCRIPTION AND PERFORMANCE OF BOMBS

In the following section is given (1) a general discussion of explosion bombs and detonators, (2) specific descriptions and performance summaries on various explosion bombs and detonators, and (3) discussion of implosion bombs followed by specific descriptions and performance summaries of implosion bombs.

Implosion bombs have been less extensively tested than explosion bombs and hence the general discussion, specific descriptions and performance summaries are given together.

Explosion Bombs and Detonators General Discussion

Factors Affecting Bomb Design. The thickness of casing or lack of casing, the shape of charge, the type of explosive, and the location of the detonator may affect the amount and directional characteristics of sound energy released by a bomb. Although the magnitudes of all these effects are not known, it is known that the total energy released by a specific type of explosive is not, as a rule, affected by external variables more than 10 to 15%. Although the relation between total energy and sound energy is not definitely known, it is reasonable to suppose the variations in one are similar to those in the other. Since 10 or 15% difference in sound energy is less than 1 decibel (Db), the effect of external variables may be considered as negligible. Incomplete detonation, or failure of the main charge to explode completely are the primary causes of marked changes in the amount of energy released.

Energy Available. Although the amount of sound energy released by a given weight of explosive is not definitely known, extensive experiments in the Atlantic indicated that one pound charges of TNT fired at or near the axis of the sound channel were heard at distances up to 1194 miles, and six and one-half pound charges of TNT were heard up to 3270 miles. Although the above data do not represent the extreme ranges obtainable for the sizes of charge indicated, they do permit an estimate to be made of the energy relations.

The general relationship between signal intensity and size of charge based on the experiments in the Atlantic are expressed by the approximate relation:

$$\Delta Db = 16 \log W_1/W_2 \quad (1)$$

In which ΔDb = the change in peak sound intensity expressed in decibels for a corresponding change in the weight of charge from W_1 to W_2 for charges fired at the same distance from the hydrophone.

Values computed from equation 1 for charges of varying weights of explosive of the same composition and at the same distance from the hydrophone are given in Table III.

TABLE III
Effect of Weight of Charge on Sound Intensity

Weight of Charge (Pounds)	Db Charge with Respect to 1 Pound Charge
.5	-5
1	0
2	5
4	10
8	14

The effect of composition of charge on intensity of signal as determined from field measurements is given in Table IV.

TABLE IV
Relative Energy from Explosives

	<u>TNT</u>	<u>Pentolite</u>	<u>Tetrytol</u>	<u>HBX</u>
Shock Wave Energy from WHOI Observations at Short Ranges (less than 100 yds.)	100%	126%	121%	137%
Sound Energy from WHOI Observations at Long Ranges (greater than 100 miles)	100%	130%	130%	Not Observed

Frequency Requirements for Long Range Sound Transmission

Experiments at the Eleuthera SOFAR monitoring station showed that the lower frequencies are most effective in long range sound transmission. The effect of frequency on audibility was studied by dividing the incoming signals into three frequency bands of about two octaves spread and peaking at 33, 140, and 550 cycles per second. The 33 cycle band was the most effective over long distances although impaired by a reduction in hydrophone efficiency at these frequencies. The 140 cycles band was nearly as effective. The 550 cycle band, although in a region of higher hydrophone efficiency, was least effective. Thus for the hydrophone in question (an USNUSL type AX-58C) the most effective frequency band for long distance sound transmission appears to be from about 15 to 200 cycles per second. The effectiveness of the lower frequencies is the direct result of the low scattering and absorption losses at these frequencies.

Effective Frequencies Obtained from Explosives. To the author's knowledge there is no published data on the direct measurement of the sound energy frequency distribution from explosions. However, indirect determinations have been made by H. B. McCurdy¹ in which Fourier analyses of the shock waves from the explosion of various weights of TNT were made using an approximate method. The results of these analyses expressed in Db are plotted on Graph 1. From this plot it may be seen that the weight of charge does not affect materially the frequency distribution of sound energy. Sound energy falls off with decrease in frequency below 100 cycles per second, but at 15 cycles the reduction below the peak value is not more than 7 Db.

¹ McCurdy, H. B. Frequency Analysis of an Underwater Explosion. Bachelor of Science Thesis at Massachusetts Institute of Technology, 1944.

These values should be regarded as a rough indication only of the sound spectrum of a SOFAR signal as the data on which McCurdy based his analysis were taken from explosion at depths of about 40 feet, whereas sound sources for SOFAR are designed to explode at depths of from 350 to 700 fathoms.

Factors Affecting Detonator Design. For effective long range sound transmission, detonators must fire charges at or near the sound channel axis. Investigation of hydrographic data shows that the axis of the sound channel in some parts of the Pacific is at a depth of about 350 fathoms while at corresponding latitudes in the Atlantic the axis is at about 700 fathoms. In polar latitudes the axis is much shallower and may be at depths of less than 100 fathoms.

Because of this variation in depth of the axis, the ideal detonator would be one that would fire on the basis of the reversal in sound velocity gradient encountered at the axis of the sound channel. Methods which have been considered as a means of securing detonation at the axis of the sound channel involve detonation on the basis of (1) sound velocity (2) sound velocity gradient (3) temperature (4) temperature gradient (5) pressure (6) depth (as determined by sinking rate) (7) any combination of salinity, temperature, and pressure or the gradient of the combination.

The only practical method developed to date uses detonators set to fire at a pressure corresponding to a specific depth. Although such detonators are reliable, they are subject to the disadvantage that they do not fire selectively at the axis of the sound channel. Because of the variation in the depth of the axis with area of operation a special detonator is necessary for each area involving a major change in axis depth. To overcome this difficulty a detonator with a variable depth setting is being developed.

Safety. Bombs suitable for scientific work which are to be used by personnel experienced in handling explosives may be armed manually by placing the detonator in contact with the booster just before the bomb is dropped. Bombs to be used by personnel inexperienced in the handling of explosives should arm automatically by water pressure after the bomb is dropped. The latter type has been approved for use in aircraft.

Explosion Bombs and Detonators
(Specific Descriptions and Performance Figures)

Explosion bombs and detonators are so diversified in design and manufacture that the descriptions of various types are presented in the following order:

1. Bombs with detonators or firing mechanisms unique to the particular bomb.
2. Woods Hole Percussion Detonator.
3. Woods Hole Pressure Detonator.
4. Woods Hole Adjustable Depth Detonator.
5. Bombs Using Woods Hole Pressure Detonators.

In addition to the performance summaries given in the text for both the explosion bombs and implosion bombs, a record of the performance of each unit of a given design is tabulated in the appendix.

Bourdon Bomb, Model A

The first bombs used in long range sound transmission experiments have been designated the Bourdon, Model A Bomb. These were designed and built by the Woods Hole Oceanographic Institution. The firing was accomplished as follows (See Figure 6): A Bourdon tube open to the sea water closes an electrical switch at a predetermined pressure (2000 pounds per square inch was used), completing the circuit from the enclosed flashlight batteries to an electric detonator. The detonator fires a tetryl booster which in turn fires a 4 pound charge of cast TNT. An external safety switch in the electrical circuit was closed by means of a lanyard after the charge was safely overboard. The whole charge was enclosed in a pressure proofed case.

Performance. Eleven of these bombs were tested at sea from April 2 to April 5, 1944 of which ten fired satisfactorily and one did not.

<u>No.</u>	<u>No.</u>			<u>Sinking Time to 700 fms.</u>	
<u>Tested</u>	<u>Fired</u>	<u>Det. only</u>	<u>Duds</u>	<u>Max.</u>	<u>Min.</u>
11	10	--	1	No Data	

Remarks. Because of the possibility of the firing circuit being accidentally closed, this bomb was considered too hazardous for extensive use. As a result the Bourdon Bomb, Model B was developed.

Bourdon Bomb, Model B

The Bourdon Bomb, Model B is similar to the Bourdon Bomb, Model A except that (See Figure 7) an outboard sea cell is used as both a battery and safety switch. On immersion of the bomb the sea cell is activated by sea water which serves as the electrolite. These bombs were designed by the Woods Hole Oceanographic Institution and manufactured by the Douglas Engineering Company.

Performance. Nine bombs were tested at sea with the following results./

<u>No.</u> <u>Tested</u>	<u>No.</u> <u>Fired</u>	<u>Det. Only</u>	<u>Duds</u>	<u>Sinking Time to 700 fms.</u>			
				<u>Maximum</u>		<u>Minimum</u>	
				<u>Min.</u>	<u>Sec.</u>	<u>Min.</u>	<u>Sec.</u>
9	5	1	3	13	09	4	51

Remarks. Because the sea cell served as a safety switch, this bomb was considered to be considerably safer to use than the Model A bomb. The Model B bomb did not fire as reliably as the Model A bomb, possibly because a special switch, used on some of the bombs and actuated by the Bourdon element, may not have been reliable.

Douglas Percussion Bomb

The Douglas Percussion Bomb was designed and built by the Douglas Engineering Company. The operation of the bomb (shown in Figure 8) was as follows: A diaphragm exposed to the sea water ruptures at about 2000 pounds per square inch forcing a piston which contained a percussion cap to shear off a series of discs on the firing pin. The fire from the cap caused a powder train of PETN in the side of the piston to burn. This train was aligned with a similar train of PETN because of the advanced position of the piston. The latter train ignited a 25 gram tetryl booster which fired a 4 pound charge of cast TNT. The whole charge was enclosed in a steel pressure proofed case.

Performance. Eight of these bombs were dropped by the USCGR VALOR. After the first three were thrown overboard and failed to explode various adjustments and tests were made. Attempts to improve the firing mechanism by filing away three of the four shear washers on the firing pin were unsuccessful. The firing mechanism of another bomb was removed, and the tetryl booster and shear diaphragm removed. A piece of welding rod was driven down on the piston, firing the cap and two PETN trains, and thus showing the mechanical action not to be the cause of failure. A modification to prevent possible leakage around the piston was also tried without success. Cause of failure was not determined.

<u>No.</u>				<u>Sinking Time</u>	
<u>Tested</u>	<u>Fired</u>	<u>Det. Only</u>	<u>Duds</u>	<u>Max.</u>	<u>Min.</u>
8	0	0	8	--	--

Rockwell Bomb

This bomb was developed by G. O. Rockwell at the U. S. Navy Underwater Sound Laboratory at New London, Connecticut.

The following description is from OSRD Report No. 6.lsr1128, 1937¹.

"The unit consists of a body, fuse, and tail." (Figure 9 shows a schematic drawing of the bomb and Figure 10 a photograph of the bomb). "The entire unit, when assembled, is 21½ inches long and weighs approximately 12½ pounds. The exploder will withstand pressures of 3000 pounds per square inch without damage.

"The unit is designed to arm at approximately 2000 feet and to detonate at approximately 4000 feet ($\pm$ 250 feet). The fuze is attached to the body of the exploder by engaging six 10/32 inch socket-headed Allen screws. The fact that the fuze is detachable facilitates shipping and permits insertion of the booster at the final point of assembly. The tail section is fastened to the opposite end of the body by a coarse-threaded plug which forms a part of the tail section.

"Body. The body of the exploder is 11½ inches long and is filled with four pounds of TNT. One end is recessed to accommodate the booster end of the fuze and also incorporates a water-tight cell between fuze and body. The other end of the body has a threaded hole to accommodate the tail section and to permit loading of the body with molten explosive.

"Fuze. The fuze is armed and fired by hydrostatic pressure. Removal of the safety wire permits operation of the arming mechanism when external pressure is applied to the copper bellows. This bellows is attached to a yoke supported by two helical coil springs. The springs are brought under compression as the bellows are elongated by increasing pressures. Compression of the two springs and elongation of the bellows require approximately 1000 pounds per square inch to permit sufficient compression of the combination to release the safety shutter. This shutter contains the detonating cap, electrical closing contact, and locking detent for the armed position. The travel of the shutter is approximately 1/2 inch. When locked in the armed position the detonating cap is in line with the detonating train.

"The detonating sequence is performed at a pressure of approximately 2000 pounds per square inch ($\pm$ 10 per cent). This pressure shears one of the two special alloy diaphragms which

¹ Rockwell, G. O. Hydrostatically Detonated Exploder OSRD Report No. 6.lsr1128, 1937, March 6, 1945. Columbia University - Division of War Research at the U. S. Navy Underwater Sound Laboratory, New London, Connecticut.

are placed over the metering orifices. The size of the metering orifice, 0.224 inch, causes shearing of the diaphragms when they are stressed to approximately 2000 pounds per square inch. Two diaphragms and two separate metering orifices are used to insure more accurate control of the detonating depth as any damage to the shearing surface of the metering orifice will increase the detonating depth an appreciable amount. Similar applications of this type of diaphragm and metering orifice can be found in the safety control mechanisms of all commercial gas cylinders and fire extinguishers.

"Battery. The sea water-activated battery is sealed in a pressure-proof chamber. When the exploder has reached a depth of approximately 4000 feet, the pressure shears the special diaphragms and admits sea water to the sea cell. Thus activated, the sea cell fired the electric cap and detonates the main charge of the exploder.

"Operation. The exploder can be expended from airships, aircraft, and surface vessels, or can be ejected from flare tube of underwater craft. The safety wire is removed just before launching and can be reinserted if the exploder is not expended. The exploder will arm at approximately 2000 feet and detonate at approximately 4000 feet. The detonating time is approximately 6 1/2 minutes after entering at the water surface."

Performance. 96 bombs were tested of which 1 fired detonator only and 25 were not heard. Of those not heard 17 may have fired. They were dropped from planes (monitoring at the source not possible) and the receiving station may have been shadowed.

No. Tested	Fired	Det. Only	Not Heard	Sinking Time (4000 ft. Det.)		
				Lower Quartile	Median	Upper Quartile
96	70	1	25	5 ^m 06 ^s	5 ^m 31 ^s	5 ^m 57 ^s

Sinking time values were determined from distribution plot on Graph 2.

Multiple Shot Bomb

The multiple shot bomb was designed by G. O. Rockwell and built by the United States Navy Underwater Sound Laboratory of New London, Connecticut. It is intended for use in sending coded messages in the sound channel. The following description of the multiple shot bomb is based on information furnished through the courtesy of the Director, U. S. Navy Underwater Sound Laboratory.

The bomb consists of five units: a timing unit and four firing units. Each firing unit contains approximately four pounds of TNT. Figure 11 shows an assembled bomb, Figure 12 the timing unit mechanism and Figure 13 the firing unit mechanism. The timing unit can be preset to give any firing interval between the four bombs within a total elapsed time of 90 seconds. Operation of the bomb is as follows:

Before reaching firing depth, water pressure expands a bellows in each of the individual bombs which in turn unlocks the safety devices. When the bomb reaches a depth corresponding to the axis of the sound channel a diaphragm in the timing unit ruptures allowing sea water to flood the sea-cell compartment and expand a bellows which in turn unlocks a safety pin and releases the timing mechanism. Electric current developed by the timing unit sea-cell fires a separation charge which releases each unit bomb at intervals determined by the timer setting. The unit bomb farthest from the timer is released first and is followed by the next farthest, and so on. At the time the unit bomb is released the fuse cap is fired, the fuse ignited, and a wing extended to retard the descent of the unit. The exploding of the released unit bomb is retarded by the time required for the previously ignited fuze to reach the cartridge.

Performance. No data is available at present on the performance of the bomb.

"Bottle Cap" Bomb

The Frederick Hart Company in collaboration with the Naval Ordnance Laboratory has developed the so-called "Bottle Cap" bomb. This bomb is provided with a means of selecting one of six firing depths ranging from 1500 to 4000 feet in increments of 500 feet. A schematic diagram of the bomb at its present state of development is shown in Figure 14. The following description is based on an article by R. C. Mack¹ and on drawings of the most recent model of the bomb.

As shown in the figure, five orifices are arranged around the periphery of the bomb and are equipped with diaphragms designed to fail at pressures corresponding to depths of from 1500 to 3500 feet. Each orifice is sealed with a bottle cap, and the corresponding firing depth is stamped on the bomb near the cap. Removing the bottle cap for a given depth setting determines the firing depth. The sixth orifice, for the 4000 foot setting, is located at the end of the bomb and is uncapped. Thus the bomb will fire at 4000 feet if released with no cap removed.

When the appropriate setting has been made and the bomb dropped, the pressure increases as the bomb sinks until the exposed diaphragm ruptures, permitting water to enter the interior chamber of the bomb. A snap diaphragm is then actuated driving home a firing pin which fires a percussion cap leading through a firing train and booster to the main charge.

The bomb has a safety device which holds the percussion cap and part of the firing train in misalignment with the rest of the firing mechanism. At a moderate depth the pressure springs a snap diaphragm attached to the arming slide and moves the slide (which contains the percussion cap and train) to a position of alignment.

The complete bomb has a total weight of approximately 13.4 pounds, an overall length of 28 inches and a maximum diameter of 3 inches. The main charge consists of approximately four pounds of TNT.

Performance. On April 10, 1947, 26 of these bombs were tested on board the R. V. Atlantis. All fired successfully. Tabulated results are given below:

¹ Mack, R. C. NOL and Frederick Hart Company are Developing Bombs for Sea Survivors to Signal Whereabouts. "Report" Naval Ordnance Laboratory, December 1946, p. 2.

<u>Design Firing Depth (feet)</u>	<u>Number of Observations</u>	<u>Sinking Time Distribution Plot Graph No.</u>	<u>Median Value Sinking Time</u>	<u>Sinking Time Range</u>	<u>Firing Depth Range (feet)</u>
4000	9	3	4:27	3:36-5:04	3770-3980
3500	2			3:50-4:10	3225
3000	2			3:52-4:00	3350-3405
2500	3			2:47-3:34	2695-2830
2000	1			2:15	1895
1500	9	4	1:40	1:25-1:58	1370-1530

Woods Hole Percussion Detonator

The Woods Hole percussion detonator was designed at the Woods Hole Oceanographic Institution as a possible alternate to the Woods Hole pressure detonator. As the latter proved to be highly successful the development of the percussion detonator was suspended after preliminary laboratory investigations were made.

Figure 15 is a schematic diagram of the percussion detonator. Essentially the detonator consists of a diaphragm to which is attached a plunger and firing pin, a percussion cap, and a housing. Water pressure causes the diaphragm to fail at a depth determined by its thickness and material. The sharpness of the edge of the diaphragm seat and the diameter of the seat also are variables affecting firing depth. The piston then advances under pressure causing the firing pin to set off the percussion cap.

Performance. Results of tests in the pressure vessel on this detonator are given in the appendix.

Woods Hole Pressure Detonator

Work on the Woods Hole pressure detonator was started by Mr. J. Lamar Worzel and Dr. M. Ewing of the Woods Hole Oceanographic Institution in March 1945. In its present form the detonator consists of a brass tube plugged at both ends as shown in Figure 16 and loaded with a detonating charge at one end and toy cap pistol ammunition at the other. Detonation is initiated by the collapse of the tube under external pressure. The collapse of the tube sets off the toy repeating paper caps which ignite the main detonator charge. These detonators are suitable for use with many different bombs and charges as shown in Figure 17. Firing depth is determined by wall thickness and other factors as will be described later. At the present time detonators for firing at approximately 100, 350, and 700 fathoms are available.

History. The chronology of the Woods Hole detonator is as follows:

- March 1945 - Development work initiated by Dr. Maurice Ewing and Mr. J. Lamar Worzel.
- May 8, 1945 - Steel tubing detonator (unloaded) tested for collapsing depth.
- May 9, 1945 - Two empty steel tubes and two containing explosives tested. No difference in collapsing depth. No explosion.
- May 11, 1945 - PETN mixed with various amounts of sand was tried. No explosion.
- May 22, 1945 - First successful Woods Hole detonator. Collapse of steel tube set off match heads which ignited non-electric detonating cap.
- May 23, 1945 - Round edged or sharp edged plugs showed no difference in collapsing depth of tubing.
- May 24, 1945 - Toy paper caps first used successfully. Collapse of steel tube set off caps which fired a non-electric detonating cap.
- May 27, 1945 - Woods Hole detonator first fired TNT demolition block (PETN booster) successfully.
- June 2, 1945 - Detonators loaded by du Pont tested. Those with explosive "A" did not fire on three tests. Explosive "B" fired two out of three tests. It is believed that the explosives were loosely packed mercury fulminate and lead azide but which was "A" and which was "B" was not designated. The main detonator charge in these tests was the same as that in a standard engineers special detonator.

- June 4, 1945 - Energy requirements to fire toy caps investigated. Average value was about .25 foot pounds.
- June 5, 1945 - Tests conducted to determine if the explosion of one toy paper cap in a strip of five in a small tube will set off remaining caps. In fifteen attempts all five caps fired in only two instances.
- June 21, 1945 - Four detonators containing explosive "A" (du Pont) fired successfully.
- July 1, 1945 - The USS SARDONYX conducted tests at sea with various modifications of the detonator. (See Appendix).
- July 19, 1945 - du Pont loaded 100 detonators with standard charge and paper cap pistol ammunition.

Miscellaneous results of the development work are as follows:

Liquid latex and glyptal lacquer may be used for a seal. It was felt that latex might deteriorate with age or temperature conditions and that glyptal lacquer would be preferable.

Du Pont demonstrated that tubes could be successfully sealed by crimping the tube into a rubber plug similar to that used in commercial electric detonators. This would be suitable for quantity manufacture only.

Glyptal lacquer deteriorates with age. After long storage glyptal sealed tubes should be re-lacquered around the seam.

A slight lead or taper is necessary for seating the flat top plugs in the tubes.

A force fit of the end plug is necessary for sealing with glyptal and for withstanding the vibration experienced in aircraft. Punched out caps have not been satisfactory with a glyptal sealed end in this respect because of the difficulty in holding tolerances.

No wires or tapes should be wrapped around the detonator body since the effective free length and thus the firing depth may be radically changed.

Design. Preliminary calculations and tests showed that the collapse of the detonator tube (which initiates the firing of the detonator) takes place under conditions of elastic instability. However, theoretical equations for determining failing pressures under such conditions are extremely complex and do not give values consistent with observed results. It was therefore necessary to develop an empirical or semi-empirical formula for the design of these detonators.

Under conditions of elastic instability the variables which determine the failing pressure of a thin cylindrical shell (such as the Woods Hole pressure detonator tube) are free length, wall thickness, the diameter of the neutral axis, Poisson's ratio, and the modulus of elasticity. The diameter of the Woods Hole pressure detonator is limited in practice to one-quarter inch in order that it may fit the detonator wells of standard demolition blocks. As a result, the diameter of the neutral axis may be regarded as being fixed at substantially one-quarter inch. The material from which the detonators are made has been standardized, and all are now made from high brass tubing drawn to .003 hard temper. Hence Poisson's ratio and the modulus of elasticity have fixed values.

To study the effects of the remaining two variables (free length and wall thickness) extensive tests have been conducted in the pressure vessel. Two hundred and fifty-eight specimens were made with nominal wall thicknesses of .005, .006, .0075, .008, .0095, and .0125 inch. Overall lengths used were $1\frac{1}{2}$, $2\frac{1}{2}$, 3 and $3\frac{1}{2}$ inches. The ends of the tubes were closed with a flat top brass cap at each end and sealed with glyptal lacquer as used on the standard Woods Hole pressure detonator (See Figure 16). The specimens of .0075 inch nominal wall thickness (except those of $1\frac{1}{2}$ inch free length) were made from standard detonator bodies and therefore had hollow top caps soldered in at one end. The testing procedure used is described in detail in the section on Testing Bombs and Detonators (pages 4 and 5.) Figure 18 shows a series of specimens of varying free lengths before and after collapse in the pressure vessel.

Table V indicates the number and type of specimen tested and Graphs 5 to 30 are distribution plots of the results of the tests.

TABLE V
Tests on Cylindrical Shells

Wall Thickness	Overall Tube Length in Inches				
	$1\frac{1}{2}$ "	2"	$2\frac{1}{2}$ "	3"	$3\frac{1}{2}$ "
	Number tested				
.005"	12	12	12	8	8
.006"	8	8	8	8	8
.0075"	12	12	8	8	-
.008"	12	12	12	8	8
.0095"	12	12	12	8	8
.0125"	2	2	2	8	8

The median values of failure determined from graphs 5 to 30 are plotted on graph 31. For the shorter .0125 wall thickness specimens, observed values only were plotted in graph 31 as tests were too few to warrant establishing median values.

Derivation of Semi-Empirical Equation. The points on graph 31 plus the theoretical relations of von Mises¹ serve to determine a semi-empirical equation relating failing pressure to free length and wall thickness. In this graph it will be noted that the free length plotted is .12 inches shorter than the overall length of the tube because the end plugs are inserted .06 inches in each end.

The general relations derived by von Mises¹ for the collapse from elastic instability of cylinders subject to radial and axial external pressure may be written:

$$p = \left[\frac{1}{3} \left\{ L^2 + \left(\frac{\pi D}{2L} \right)^2 \right\}^2 - 2\mu_1 n^2 + \mu_2 \right] \frac{2E}{1-\mu^2} \left(\frac{t}{D} \right)^3 \quad (2)$$

$$+ \frac{2E \left(\frac{t}{D} \right)}{\left[n^2 \left(\frac{2L}{\pi D} \right)^2 + 1 \right]^2} \times \frac{1}{n^2 - 1 + \frac{1}{2} \left(\frac{\pi D}{2L} \right)^2}$$

$$2\mu_1 = [1 - (1+\mu)\rho] [2 + (1-\mu)\rho]$$

$$\mu_2 = (1+\mu\rho) [1 + (1+2\mu)\rho - (1-\mu^2)(1 + \frac{1+\mu}{1-\mu}\rho)\rho^2]$$

$$\rho = \frac{1}{n^2 \left(\frac{2L}{\pi D} \right)^2 + 1}$$

where

p = failing pressure
n = number of nodes in which tube fails
D = diameter to neutral axis
L = free length
t = wall thickness
μ = Poisson's ratio
E = Young's modulus

The number of lobes, n, in which the specimens will fail may be determined by trial from equation 2. n is established as the integer giving a minimum value of p. For values of t/D greater than .010 and L/D greater than 5, n has a value of 2. In these experiments the minimum value of t/D was .020 and the minimum value of L/D was 5.52 which is well within the range for n equal to 2. All test specimens were observed to fail in two lobes confirming the theoretical prediction.

Because of the relatively large values of L/D, certain approximations can be made in equation 2. With a value of n equal to 2, the resulting approximate relation is:

$$p = \frac{2E}{1-\mu^2} \left(\frac{t}{D} \right)^3 + .253 E \frac{tD^3}{L^4} \quad (3)$$

It may be noted that the first term of equation (3) is the same as the value of "p" in the equation for cylinders

¹ R. von Mises, Der kritische Aussendruck für allseits belastete zylindrische Rohre, Fest. zum 70. Geburtstag von Prof. Dr. A. Stodola, Zurich, 1929, pp. 418-430.

of infinite length given by Bressel¹ and Bryan² as follows:

$$p = \frac{2E}{1-\nu^2} \left(\frac{t^3}{D} \right) \quad (4)$$

For hard, high brass tubing as used in these experiments probable constants are $E = 14 \times 10^6$ lbs/in² and $\nu = .333$. The inside diameter of the tubing was in all cases .250 inches and this is assumed to be equal to the diameter of the neutral axis. Hence, for this particular study equation 2 becomes:

$$p = 2.01 \times 10^6 \times t^3 + 55,400 \frac{t}{L^4} \quad (5)$$

In attempting to correlate values from equation 4 with values for appropriate wall thicknesses and free lengths as plotted on graph 31, it is found that the effective free length differs from the measured free length by approximately .27 inch so that the semi-empirical relation for failing pressure becomes:

$$p = 2.01 \times 10^6 \times t^3 + 55,400 \frac{t}{(L-.27)^4} \quad (6)$$

It is probable that the brass plugs inserted 1/16 inch into the ends of the tubes offer a restraint that reduces the effective free length. No particular difference is to be detected in the effect of soldered in plugs as compared with lacquer sealed plugs although the solder was well "sweated" into the joint and the lacquer applied only to the external seam.

It will be noted on graph 31 that the best values of wall thickness (t) to fit the points plotted for failing pressures differ from the nominal values of wall thickness originally called for by a few ten thousandths of an inch. The wall thickness of each test specimen was checked before testing by measuring the outside diameter with micrometers and then computing the wall thickness on the basis of an inside diameter of .2500 inches. However this method of measurement at best is accurate to not better than .005 inches and therefore serves only to identify the nominal thickness of the tubing and not to detect small departures from nominal thickness. To determine the wall thickness to a greater degree of accuracy representative samples were taken. These were sawed along the axis into quarters. Each quarter was then measured on a super-micrometer using a .15605 diameter ball to contact the concave surface. The contact pressure was two and one-half pounds. Results were checked with an electro limit gage and the readings by either method were found to agree within .00005 inch. The measurements were made by Mr. Arthur Cox of Pratt and Whitney Aircraft, Division, United Aircraft Corporation as tabulated in Table VI, show good agreement between the best values from graph 31 and measured values.

¹ Bresse, M. (1859) Cours de Mécanique Appliquée, Paris 1859, pp. 323-338.

² Bryan, G.H. (1888) Application of the Energy Test to the Collapse of a Long Thin Pipe Under External Pressure, Cambridge Phil. Soc. Proc. Vol. 6, pp. 287-292.

TABLE VI
Wall Thickness of Test Specimens in Inches

Nominal Value t	Best Value from Graph 31 t	Measured Values of t
.0050	.0051	.0049 - .0050 - .0051 - .0052
.0060	.0065	
.0075	.0079	.0077 - .0077 - .0080 - .0080
.0080	.0081	
.0095	.0094	.0096 - .0097 - .0098 - .0098
.0120	.0121	.0120 - .0123 - .0130 - .0131

To use equation 6 in the determination of the firing depth of standard Woods Hole Pressure Detonators (Figure 16), the standard detonator's free length of 2.06 inches is applied and a simple conversion from pressure in pounds per square inch to firing depth in fathoms is made, giving:

$$\text{Firing Depth (Fathoms)} = .754 \times 10^9 \times t^3 + 2020t \quad (\S)$$

Results obtained using "live" detonators in sea trials and pressure vessel tests are given in Table VII

TABLE VII
Observed Firing Depths, Woods Hole Pressure Detonators

Wall Thickness Inches	Number of Observations		Distribution Plot Graph No.	Firing Depth (Fathoms)
	Pressure Vessel	Atlantis		
.0051	4	--	--	118 (Average)
.0079	4	3	32	402 (Median)
.0094	3	75	33	656 (Median)

The agreement of the semi-empirical equation § with actual results is indicated in graph 34. It may be concluded from this graph that the pressed in detonator charge offers the same restraint to the collapse of the tube as the brass plug and that equation § is suitable for predicting firing depths from wall thickness.

Manufacture and Loading. The Woods Hole detonators in their present form are made by the Woods Hole Oceanographic Institution from high brass tubing, .003 hard, furnished by the Union Plate and Wire Company. A hollow top cap (.002 force fit) is pressed into one end of the tube and soldered in place. The tube is cleaned out thoroughly first with water, then dilute sulphuric acid, then water again, then alcohol. The soldered joint is then tested for leaks under 50 pounds air pressure. Tubes thus

prepared together with a flat top cap are sent to the E. I. du Pont de Nemours Company for loading. Working drawings for construction of the detonators is attached at the rear of the report.

The detonator tubes are loaded first by putting a charge of PETN at the bottom. This is followed by powdered lead azide (3 to 4 grains) and then a mixture of 55% tetryl and 45% lead styphnate (1 grain). The complete charge is pressed in under a static load of 200 pounds (about 4000 pounds per square inch). On the .005 wall thickness detonators it is necessary to reduce the load to 75 pounds in order to avoid deforming the walls of the tube. As the density of PETN is variable the weight used may vary from 22 to 28 grains. It is necessary that the amount of PETN used be selected on the basis of its density so that the complete pressed in charge fills the tube to within 2 1/8 inches of the top (see working drawings). The remaining space in the tube is used to hold 10 rounds of repeating paper caps trimmed of excess paper and folded in the middle. The top end of the tube is closed with a force fitted flat top cap and sealed with glyptal lacquer.

The hollow top cap serves to identify the end of the detonator containing the main charge. On some of the .005 wall thickness detonators (120 fathom) a shortage of hollow top caps necessitated the use of flat top caps at both ends. However the charge end of all detonators is identified by a painted color code band. The color code band also serves to indicate the firing depth of the detonator: a red band indicating a firing depth of 660 fathoms; green, 400 fathoms; and yellow, 120 fathoms.

A modification of the above method of loading involved the use of a somewhat different main detonator charge consisting of a pentolite pellet (5.7 grains) and an engineers special non-electric blasting cap (13.5 grains of PETN, 3 to 4 grains of lead azide and 1 grain of 55% tetryl and 45% lead styphnate). These have been loaded without special equipment at the Woods Hole Oceanographic Institution.

Safety. Ten Woods Hole detonators were dropped 20 feet to a concrete slab without firing. The test was repeated with a 50 foot drop and again none fired. All the detonators then were tested in a pressure vessel and all fired successfully.

Use. Woods Hole detonators have been used as detonators in the following bombs: Uncased, Sheet Metal Case, Research Models A, B. and C, and the Arming Type Interim. See Figure 12 for the above types of bombs. The performance of the detonator is best illustrated by the performance of these bombs which are described immediately following this section.

As with most detonators the Woods Hole pressure detonator requires a booster to fire safe explosives. Tests at sea showed that:

1. Woods Hole detonators fire Mark 4 (TNT tetryl) and tetrytol demolition blocks. These blocks have cast tetryl boosters.

2. Woods Hole detonators will not fire cast TNT, HBX, or Mark 4 demolition blocks when merely butted against them.

3. Woods Hole detonators fire plastic explosive C-2 when inserted about 1/2 inch into the explosive.

4. Woods Hole detonators will not fire straight TNT demolition blocks reliably.

Performance. The performance of the Woods Hole pressure detonator in laboratory tests in pressure vessels and in field tests at sea is given in Table VIII. In sea trials conducted by the Woods Hole Oceanographic Institution 575 detonators have been used of which 97% are known to have fired.

TABLE VIII
Woods Hole Pressure Detonator Performance

<u>Color Code</u>	<u>Number of Depth Observations</u>	<u>Firing Depth¹</u>	<u>Spread in Firing Depth between Quartiles</u>	<u>No. Tested for firing Lab. At Sea</u>	<u>Firing Reliability</u>
Yellow	4	118 fms.	---	4	100%
Green	7	402 "	26 fms.	4 3	100%
Red	78	656 "	44 fms.	3 575	97%

¹ Average value for yellow code; median value for green and red code.

Adjustable Depth Woods Hole Detonators

At the suggestion of Dr. Maurice Ewing of the Woods Hole Oceanographic Institution slip rings were fitted to standard Woods Hole Pressure Detonators to see if the firing depth could be varied by changing the free length of the collapsible part of the detonator. Experiments have recently been conducted which show this method of adjustment to be effective. Figure 19 is a photograph showing adjustable depth detonators with adjusting rings in various positions.

Rings for adjusting the firing depth were made from brass tubing $1/4$ inch long and reamed to give approximately .001 inch loose fit on the detonator bodies. Ring thicknesses of .012, .025, and .060 were tried in order to determine roughly what minimum thickness is required to support adequately the detonator body. The adjusting ring divides the maximum available "free" length into two cells, the longer of which determines the firing depth of the detonator. Some of the specimens had an extra ring at a position corresponding to the inner end of the charge.

Tests were carried out both on "live" detonators and on detonators having "dummy" charge. The "live" detonators use the regular DuPont SOFAR charge. The "dummy" charge consisted of an equal volume of compressed bicarbonate of soda. Both the "live" and "dummy" charges filled the tubes to a level which left a free length of 2.06 inches as shown in Figure 16. All specimens were tested in pressure vessels and the failing pressures determined from pressure gages as described in the previous section.

The observed failing pressures converted for convenience to firing depths in fathoms are given in Table IX for .0051 inch wall thickness detonators both "live" and "dummy" loaded.

TABLE IX
Adjustable Depth Woods Hole Detonators
.0051 Wall Thicknesses

Free Lengths (inches)		Firing Depth in Fathoms			
To Lacquered End	To Charge End	"Dummy" Load		"Live" Load	
		One Ring	Extra Ring	One Ring	Extra Ring
2.06		100		112	
		102		116	
		102		118	
		104		127	
		106			
		106			
		107			
		108			
		111			
		112			
.5	1.56	131	157	---	---
		133	166		
.75	1.31	127	180	---	---
		154	193		
1.0	1.06	130	236	180*	244
		181	244	210	
				225	
				240	
				244	
1.25	.81	199	199	---	---
		204	203		
1.5	.56	147*	156		
		162	157		

The two values marked * were obtained from specimens having an adjusting ring of .012 inch thickness. All other rings had a thickness of .025. An examination of the ring on the "dummy" loaded specimen after testing showed that it had partly collapsed which may explain the low values of firing depths obtained with the thinner rings. The .025 wall rings showed no signs of collapse and were in fact used over again in some cases. Other types and combinations of rings or collars were used including tightly wrapped wire, brass collars one inch wide, and three to five 1/4 inch rings in combination. No particular difference in performance was found using the above special rings.

The "dummy" loaded specimens with one adjusting ring showed wide variations in firing depth. An extra ring at the edge of the charge gave more consistent results. The "live" loaded specimens with one adjusting ring compared closely in performance with the "dummy" loaded specimens having an extra ring. An extra ring on a "live" loaded specimen did not show an increase in firing depth over that obtained with one ring. On the basis of the above results it was concluded that the "dummy" charge does not have the same crushing strength as the regular detonator charge.

On tests conducted on detonators with .0079 wall thickness and a maximum free length of 2.06 inches the increase in effective firing depth was approximately 50%. To obtain a greater increase in firing depth a 3/8 inch slug of brass was inserted in the lacquered end of test specimens, reducing the maximum free length to 1.68 inches. Results of these tests are given in Table X.

TABLE X
Adjustable Depth Woods Hole Detonators
.0079 Wall Thicknesses

Free Length (inches) To Lacquered End	To Charge End	Max. Free Length (inches)	Firing Depth (fathoms)
2.06 (ring removed from "free" end)		2.06	386, 409, 412, 430
1.0	1.06	2.06	588, 588, 635, 600** 612**
1.62 (ring removed from "free" end)		1.62	428***
.87	.75	1.62	750*** 790***

The value marked ** applies to a specimen having two rings .060 inch thick, one of which was located at the edge of the charge. The four values marked *** were obtained for specimens having an adjusting ring of .060 inch thickness. All other rings were .025 thick. It is evident that the .025 inch ring is of adequate thickness as no increase in firing depth was obtained by using heavier rings. Using an extra ring at the edge of the charge proved to be of no advantage. Reducing the maximum free length from 2.06 to 1.68 inches by means of a brass slug increased the range obtainable from 50% of the initial firing depth to nearly 100%. The decrease in maximum free length did not increase the initial firing depth appreciably.

Curves of firing depth against ring setting based on observed values are shown on graph 35. From these curves it may be concluded that:

1. 100% increase from an initial firing depth is obtainable with a single adjusting ring.
2. The spread in firing depth at a given setting is relatively small, i.e. 13% with no ring, (four observations); 15% with ring at maximum setting, (four observations).
3. The sensitivity to the position of the ring is low; i.e. maximum change in firing depth for $1/8$ inch movement of the ring is indicated as 14% of the initial setting.
4. A 100% increase from any desired initial setting is obtainable with the proper selection of wall thickness and maximum free length.
5. At the expense of increased sensitivity to ring position, greater than 100% increase from the initial setting could be obtained if desired.

The above results indicate that an adjustable depth detonator of this type is practical.

Uncased Bomb
(With Woods Hole Pressure Detonator)

Uncased bombs are, as the name implies, a group of miscellaneous bombs with no bomb casing. The simplest of these bombs consists of a Woods Hole pressure detonator inserted in the detonator well of a half pound demolition block and the two held together with friction tape as shown in Fig. 20. Somewhat more complicated combinations of several demolition blocks with one or more detonators have also been used.

NOTE: In order to insure reliable firing of this type of bomb, past experience has shown that:

1. Wire or other material must not be wrapped around the body of the detonator.
2. The charge end of the detonator must be inserted in the detonator well. The charge end is identified on all detonators by the color code painted near the charge end.
3. A suitable booster must be used when the main charge in the bomb is a safe explosive. Straight TNT demolition blocks cannot be expected to fire reliably. If demolition blocks are to be used a suitable type is the Mark IV TNT TETRYL $\frac{1}{2}$ pound block having a main charge of TNT and cast in TETRYL booster at the bottom of the detonator well.
4. It is essential that the detonator be exposed to sea water and not sandwiched between two demolition blocks since the bomb may fail to fire under such conditions.

Four special bombs of this classification were used in early work at sea as follows:

The first special type of bomb consisted of a charge of cast TNT or torpex into which projected a booster chimney designed for 45 gm. tetryl pellets. This chimney was packed with about 100 gm. of C-3, a plastic explosive. Two Woods Hole pressure detonators, and two special deep water type Engineers Special Electric detonators (all four taped together), were buried in the C-3. Two of each kind were used to lessen the possibility of misfires.

The second special type of bomb consisted of a cast pentolite charge provided with a detonator well about 2 inches deep with a Woods Hole pressure detonator in it.

The third special type of bomb consisted of two tetryl pellet charges which had been previously waterproofed with

five coats of Tygon. Two Woods Hole pressure detonators, and two of the Engineers Special detonators were attached.

The fourth special type of bomb consisted of two $\frac{1}{2}$ pound TNT-Tetryl demolition blocks taped with their butt ends together. A Woods Hole pressure detonator was inserted in each block.

Performance. Because of the variety of charges and arrangements, a summary of performance will not be given here. The performance of each bomb will be found in the Appendix.

Sheet Metal Case Bomb
(With Woods Hole Pressure Detonator)

The sheet metal case bombs have the charge encased in a galvanized sheet metal container. No attempt is made to protect the charge from water. Figure 21 may be regarded as representative of this type.

Charges usually consist of two or more $\frac{1}{2}$ pound demolition blocks with a Woods Hole pressure detonator inserted in the end one. A cast lead weight the same size as the demolition block is usually inserted in the nose of the bomb to serve as a sinker.

NOTE: In order to insure reliable firing of this type of bomb, the precautions outlined for the uncased bomb must be observed.

Performance. Because of the variety of charges and arrangements, a summary of performance will be given in the Appendix rather than here.

Research Model Bombs

Large numbers of surplus Mk 34 AA bomb cases and $4\frac{1}{2}$ inch rocket casings were available and as these cases were of convenient size and shape, various adaptions were made of them in making bombs to be used in long range sound transmission. The main advantage to be gained through the use of standard bomb cases, outside of convenience, is that sinking times can be standardized and also materially decreased through the use of a uniform streamlined container.

The specifications¹ of the Mk 34 AA bomb case are as follows:

5 pound AA	Mk 34
Overall length	15.0 inches
Body length	12.0 "
Body diameter	3.0 "
Wall thickness	.05 "
Tail length	3.0 "
Tail width	3.0 "
Weight empty	3.6 pounds

Body Construction. Reinforced steel nose and conical tail section welded to cylindrical steel body.

Tail Construction. Eight sheet steel vanes welded to tail cone which, in turn, is welded to the body. Vanes are welded on the cone at a ten degree angle from the longitudinal axis.

The specifications² of the $4\frac{1}{2}$ inch Barrage Rocket are as follows:

4.5 inch Barrage Rocket	
Mk 3 body	
Overall length	30.0 inches
Empty weight	22.1 pounds
Body length	13.0 inches
Body diameter	4.5 inches
Body weight	19.9 pounds
Motor length	15.5 inches
Motor diameter	2.25 inches

Body Construction. The body and motor are coupled by means of a threaded adapter. The fuze screws into the nose of the body. The body is cylindrical, the forward end hemispherical and the rear end reduced. The explosive is loaded through a $2\frac{3}{4}$ inch hole in the rear which is later sealed with the motor adapter. The motor consists of a seamless steel tube fitted with a nozzle at the aft end and sealed with the adapter to the body at the front.

Tail Assembly. Two circular shrouds, the same diameter as the body, are attached to supporting fins at the rear of the motor."

¹ United States Bombs and Fuzes, Pyrotechnics, Land Mines;

Firing Devices, U. S. Navy Bomb Disposal School, June 1, 1944.

² U.S. Rockets and Fuzes, U.S. Navy Bomb Disposal School, June 10, 1944

Research Model Bomb
Type A
(With Woods Hole Pressure Detonator)

The Mark 34 Case was adapted for use in experimental work as shown in Figure 22 and 23. When the inner flange is sawed off the case will accomodate 2 half-pound demolition blocks. The case will also hold 2.8 pounds of cast TNT (a little over 800 cc.).

NOTE: As with the other bombs using Woods Hole Detonators the precautions outlined on page 34 (Uncased Bomb) should be observed in order to insure reliable firing.

Performance. The probable effect of age on the glyptal seal of the Woods Hole detonator is illustrated in the performance of the one pound bombs as given in Table XI.

TABLE XI
Effect of Age on Detonators

<u>Cruise</u>	<u>Fired</u>	<u>Duds</u>	<u>Age of Detonators</u>	<u>Det. Only.</u>
Triangulation	103	1	Up to 3 months	1
ATLANTIS-46 ¹	106	11	Over 6 months	-

One series of 65 bombs was released from the ship by a special technique in which the bombs were held over the side by means of 4 to 6 feet of marlin tied to their tails. It was found that these bombs took approximately one minute longer than bombs without marlin to sink to firing depth. Table XII gives the sinking times of bombs with and without marlin and serves to emphasize the marked effect of apparently minor variations in bomb design on sinking time. Distribution plots on sinking times are given on graphs 36, 37 and 38.

TABLE XII
Effect of Minor Variation on Sinking Time

<u>Cruise</u>	<u>Marlin</u>	<u>No. Shots</u>	<u>Sinking Time</u> (660 Fathom Detonators)		
			<u>Lower</u> <u>Quartile</u>	<u>Median</u> <u>Value</u>	<u>Upper</u> <u>Quartile</u>
Triangulation	No	104	3m31 ^s	3m39 ^s	3m47 ^s
ATLANTIS-46	No	48	3m29 ^s	3m37 ^s	3m44 ^s
ATLANTIS-46	Yes	58	4m22 ^s	4m33 ^s	4m44 ^s

¹ In the ATLANTIS-46 Cruise the detonator ends were not re-lacquered although long storage indicated that such was in order.

The performance of the experimental bombs with different explosives in Mark 34 cases is given in Table XIII.

TABLE XIII
General Performance of Type A Bombs

<u>Charge</u>	<u>Fired</u>	<u>Dud</u>	<u>Sinking Times</u> (Minutes and Seconds)	
			<u>Maximum</u>	<u>Minimum</u>
2½ lbs. C-2	14	3	4:29	3:16
2.9 lbs. HBX	3	1	3:14	2:56
½ lb. TNT Teteryl	3	-	4:10	3:50
2½ lbs. Tetryptol	4	-	3:54	3:15

Research Model Bomb
Type B
(With Woods Hole Pressure Detonator)

The Research Model Bomb, Type B was designed by Mr. J. Lamar Worzel of the Woods Hole Oceanographic Institution to fill the need for a bomb that would be simple and cheap to manufacture and yet safe for use in aircraft.

Figure 24 shows that this bomb is detonated by a Woods Hole pressure detonator in the tail and that the main charge is 2.8 pounds of cast TNT. In the unarmed condition an arming pin holds the detonator in a position away from the main charge and booster. To arm the bomb, the arming pin is removed allowing the detonator to drop into the detonator well in the charge. The arming pin is then reinserted in the upper hole to retain the detonator in this position. The bomb is then ready for use.

NOTE: In order to insure reliable firing of this type of bomb it is necessary that the inside diameter of the detonator housing in the bomb proper be large enough to allow the detonators to collapse completely. Otherwise failure to fire may result. It is also necessary that the precautions outlined on page 34 (Uncased Bomb) be observed.

Performance. Of 9 bombs dropped by plane 3 were not heard.

Research Model Bomb
Type C
(With Woods Hole Pressure Detonator)

The research model bomb type C is an adaption of the 4½ inch barrage rocket previously described. For use as a sound source the Mark III body is cast full of TNT. A well large enough to accomodate a ½ pound demolition block is bored in the TNT using a copper bit. After boring the cast charge amounts to about six pounds. To arm the bomb the demolition block is inserted in the well and a Woods Hole Pressure Detonator is inserted in the block. The assembly is held in position by screwing the rocket motor (containing no charge) in place. A sketch of the assembled bomb is shown in Figure 25.

NOTE: As with other bombs using Woods Hole Pressure Detonators the precautions outlined on page 34 (Uncased Bomb) should be observed in order to insure reliable firing.

Performance: Of 75 bombs dropped, 1 was dropped in shoal water and did not fire, 8 were duds and 66 fired. The 8 duds were observed in the early part of the tests of this bomb. It was found that when the detonators were loaded the glyptal seal had been wiped off the outside. The breaking of the glyptal seal made a large percentage of the detonators leak. After the detonators were resealed with shellac, no more duds were observed.

No. Tested	Fired	Duds	Sinking Time to 660 Fathoms (See (Minutes and Seconds) Graph #39)		
			Lower	Median	Upper
75	66	9 ¹	2:28	2:34	2:40

¹ Of the 9 duds, 1 was dropped in shoal water and did not fire. The remaining 8 occurred during the early part of the tests. It was found that when the detonators were loaded the glyptal seal had been wiped off the outside. The breaking of the glyptal seal made a large percentage of the detonators leak. When this was determined as the cause the detonators were shellaced. No more duds were observed.

SOFAR Interim Bomb (Self-Arming)
(With Woods Hole Pressure Detonator)

The development of a self-arming device for use with the Woods Hole pressure detonator was started by Mr. J. Lamar Worzel of the Woods Hole Oceanographic Institution in March 1946. Test models were made using a modified Mark 34 casing to hold the charge with the arming device installed in the tail assembly.

The mechanism of the arming device consists essentially of a brass slide, one inch thick, which separates the Woods Hole pressure detonator from the booster; a spring which forces the detonator against the slide; and a bellows. (See Figure 26). The bellows serves to hold the slide in the unarmed position until the bomb is in the water and has reached a depth of about 90 fathoms. At that depth the bellows is completely collapsed by water pressure and the slide is in the armed position. In the armed position a hole in the slide is aligned with the detonator permitting the detonator to pass through the hole under the action of the spring and to come in contact with the booster. The bomb is then armed and will fire when the detonator fires.

As an additional safety feature the slide is locked in the unarmed position with a safety pin. Before the bomb is dropped, the safety pin must be pulled out using the attached pull ring provided for that purpose.

Dr. G. P. Woollard of the Woods Hole Oceanographic Institution has proposed a modification of the above mechanism in which a shear pin of soft copper wire is used in place of the safety pin and pull ring. This obviates the possibility of the bomb's failing to fire because of human error. Figure 27 shows the modified design.

As the SOFAR interim bomb is intended for air-sea rescue as well as scientific work, certain requirements as to range have to be met. On the basis of experiments in 1945, it is felt that a charge of four pounds of TNT will give adequate range for general use (about 3000 miles) with a large margin of safety.

Figure 28 shows the arming mechanism installed in an otherwise unmodified Mark 34 bomb case. As the unmodified case holds only 2.8 pounds of cast TNT it does not meet the arbitrary standard requiring 4 pounds of TNT. The unmodified case has the advantages of being cheap and compact, and of having a stable flight path without further modification when dropped from aircraft. Therefore it has been proposed that HBX be used as an explosive in place of TNT. HBX has about the same density as TNT, is acceptable as being safe explosive, and has approximately 40% more energy in the shock wave as an equivalent weight

of TNT. It is not known if the sound energy developed is also 40% greater in the effective frequency range since it has not been possible to conduct sea tests with this bomb. The total weight of such a bomb including 2.8 pounds of HBX would be approximately 6 pounds and the overall length 15 inches.

For current use TNT is being employed and the Mark 34 bomb case extended to accomodate 4 pounds. In the following discussions the extended case model will be called the SOFAR interim bomb and the unmodified case model, the SOFAR interim bomb, alternate design.

Drawings and photographs of the interim bomb in its present form are shown on Figures 29, 30 and 31. The approximate weight of the bomb with a four pound charge of TNT is 9 pounds and the overall length 18.5 inches. Working drawings showing the construction of the bomb are enclosed at the back of this report.

Loading. Detailed instructions for loading the bomb are given on the working drawing. As an alternate to the cast in booster (100 grams of Pentolite) a precast booster of the same weight may be used. It has been found that with Pentolite as a booster reliable firing is obtained without a detonator well when the detonator is butted against the booster. Therefore no detonator well is called for on the working drawing to simplify manufacture. A well may be provided if desired however.

To insert the Woods Hole pressure detonator in the arming mechanism a cover hook and a spring fork (See Figure 32) are used as follows:

Insert the hook in the small hole in the detonator cover. Draw the cover and collar to a position outside the tail cone of the bomb by means of the cover hook. Secure the cover and collar in this position by inserting the spring fork under the collar. Loosen the cover screws, slide open the cover, and insert the detonator. Close the cover and refasten the screws. Lift the cover and collar slightly with the cover hook and remove the spring fork. Guide the cover and collar back into the tail cone with the hook and remove the hook.

Fin Area. Preliminary tests by the Naval Ordnance Laboratory showed that the SOFAR Interim Bomb without added fin area did not have a stable fall through air. As the bombs are intended to be dropped from aircraft in flight, it is necessary that the bombs have stable flight characteristics so that they will strike the water nose first. Tail first entry or a flat fall into the water at high speed might injure the arming mechanism.

A series of tests were therefore conducted to determine the effect of nose weights and increased tail area. Various

bombs were dropped from an altitude of 500 feet at an air speed of from 60 to 90 m.p.h. The results are given in Table XIV (on the next page).

All bombs but the last five were dropped on land. The last five were dropped into seven to nine feet of water over a sand flat and were retrieved at low water. Of these five some injury to the tail fins was noted on recovery of the bombs, but the arming mechanisms were unaffected. All were tested in a pressure vessel after the drop tests and all armed satisfactorily.

On the basis of the above tests it was decided to increase the fin area and eliminate the nose piece. Tests at Dahlgren and Key West by the NOL confirmed the stability in flight of the final design of these bombs, and also demonstrated that bombs with added fin area have a much lower and more uniform sinking time.

Performance. Original tests were conducted by the Woods Hole Oceanographic Institution early in 1946. At that time 17 bombs were tried of which two were manually armed. Old detonators were used and 4 of them failed to fire. The remaining 13 detonators fired the main charge. 12 of these were on self arming bombs. This indicated that out of 12 possibilities 12 arming bombs fired, and that the arming device was 100% reliable. In April 1947, 12 of the bombs were tested at Key West by the Naval Ordnance Laboratory. All fired satisfactorily. Six were dropped from aircraft at air speed of 120 to 190 m.p.h. and altitudes of from 100 to 3000 feet.

<u>Interim Bomb</u>	<u>Approx. Firing Depth (Fathoms)</u>	<u>Number Tested</u>	<u>Firing Reliability</u>	<u>Sinking Time</u>		
				<u>High</u>	<u>Average</u>	<u>Low</u>
Fins Added	660	6	100%	3 ^m 28 ^s	3 ^m 56 ^s	5 ^m 22 ^s
" "	400	6	100%	1 ^m 58 ^s	2 ^m 08 ^s	2 ^m 13 ^s
Fins Not Added	660	12	100%	10 ^m 26 ^s	8 ^m 54 ^s	6 ^m 54 ^s

TABLE XIV
Free Fall Tests on Interim Bombs

<u>Figure</u>	<u>Extended Case</u>	<u>Load</u>	<u>Nose Weight</u>	<u>Extra Fin</u>	<u>Dropped</u>	<u>Flight</u>
17 Type A	No	None	None	No	Tail ahead	Good
17 (Interim Model)	Yes	None	None	No	Tail ahead	Very Poor (tumbled)
None	Yes	None	5# lead block	No	Tail ahead	Very Poor (flat spin)
33	Yes	4# sand	5# 9 oz. lead	No	Tail ahead	Poor (heavy oscillations)
17 (Interim Model)	Yes	4# sand	None	No	Tail ahead	Very Poor (very irregular)
17 Type A	No	None	None	No	Tail ahead	Good
34	Yes	4# sand	None	Can	Tail ahead	Very Poor (tumbled)
35	Yes	4# sand	None	Yes	Tail ahead	Good
35	Yes	4# sand	5# 9 oz. lead	Yes	Tail ahead	Fair (slight flat spin)
36	Yes	4# sand	None	Narrow	Tail ahead	Poor (irregular)
36	Yes	4# sand	None	Wide	Tail ahead	Good
29 and 30	Yes	4# sand	None	Yes	Nose down	Good
29 and 30	Yes	4# sand	None	Yes	Nose down	Good
29 and 30	Yes	4# sand	None	Yes	Nose down	Good
29 and 30	Yes	4# sand	None	Yes	Tail down	Good
29 and 30	Yes	4# sand	None	Yes	Tail ahead	Fair (considerable weave)

Implosion "Bombs"

A container designed to collapse suddenly at or near the axis of the sound channel was first suggested as a sound source by Mr. J. Lamar Worzel of the Woods Hole Oceanographic Institution on January 1, 1945 and was first tested on May 8, 1945. These containers are commonly referred to as implosion bombs.

The advantages of such a device are first, greater safety and second, simplicity. It is not known what amount or what frequencies of sound are given out by the implosion bomb and it may be that a practical bomb would be prohibitively bulky. Tests at sea were not extensive enough to establish range of audibility.

However, an estimate of energy available serves as a rough basis of comparison between the implosion bomb and the explosion bomb. Roberts and Garner¹ give the heat of explosion of TNT as 925 kilocal./kg. This is equal to 129,500 foot pounds per pound.

Energy Available. The energy released by the sea water in the collapse of the container (neglecting work on container and enclosed air) = pressure x volume. At the sound channel axis depth in the Atlantic near Bermuda the pressure is approximately 1850 pounds/square inch. Using the above values the volume required in an implosion bomb to be equivalent to 1 pound of TNT would be 841 cubic inches or .486 cubic feet. A bomb of such a volume would be relatively compact and easily handled.

Types of Implosion Bombs. Several types of implosion bombs were made or improvised. Figure 37 shows how an ordinary round bottom glass flask was modified for this use. Figure 38 shows a bomb specifically made for the purpose. It consisted of a steel tube about 3 inches in diameter, 30 inches long, and .110 inch wall thickness. The ends were sealed with steel caps and rubber gaskets.

Performance. The first bombs as tested on May 8th were made of cold rolled steel tubing, $\frac{1}{4}$ inch inside diameter, .007 inch wall, and 2 inches long. The ends were sealed with metal plugs. When the tubes were tested in a pressure vessel a dull thud was heard as the tubes collapsed. On May 14, 1945, 3 round bottom flasks and a gallon jug were collapsed in a pressure vessel with the same effect. While the pressure vessel gives an accurate determination of firing depth of implosion bombs such tests do not duplicate ocean conditions insofar as sound energy is concerned, the reason being that the pressure in the vessel falls off sharply as the implosion bomb collapses.

¹ Robertson, Robert and W. E. Garner, Proceedings of the Royal Society of London, Vol. 103A, 1923, p. 539.

Three glass flasks (as shown in Figure 30) were dropped at sea. The first imploded after a sinking time of 32 minutes and 21 seconds using an eight pound sinker. The second after a sinking time of 9 minutes 21 seconds (weight of sinker unknown), was heard aboard ship and was also picked up by the Eleuthera hydrophone 17.1 miles away. The other did not implode. Three photoflash bulbs were dropped 2 of which were not heard and one was not monitored. A glass seine float was also tried, but not heard.

Four tubing type bombs (as shown in Figure 31) were dropped. None were heard, but as they were monitored for only 20 minutes and bombs of similar shape have been known to take 40 minutes or more to sink, the bombs may have imploded.

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8 INCH PRESSURE VESSEL

14 INCH AND 16 INCH PRESSURE VESSELS

PISTON PUMP AND DRIVE MECHANISM

5000 POUND
HYDRAULIC GAGE

3000 POUND
PRECISION HYDRAULIC GAGE

PRESSURE GAGES

EQUIPMENT
FOR
PRESSURE TESTING

FIG. 2
50

LEVEL RECORDER TAPE

TIME BETWEEN 2ND. AND 3RD. ARRIVALS

$$= T_{2-3}$$

$$\frac{T_{2-3}}{2} \times \text{MEAN SOUND VEL.} = \text{DEPTH OF SHOT}$$

DETERMINATION OF
FIRING DEPTH

FIG.4

FIGURE 5

SHIPBOARD MONITORING
INSTALLATION, USS MUIR.

BOURDON BOMB
MODEL A
(SCHEMATIC DIAGRAM)

BOURDON BOMB
MODEL B
(SCHEMATIC DIAGRAM)

FIG. 8

DOUGLAS PERCUSSION
BOMB
(SCHEMATIC DIAGRAM)

ROCKWELL BOMB
SCHEMATIC DIAGRAMS

FIG. 10

ROCKWELL BOMB

USNUSL MULTI - SHOT BOMB

SAFETY PINS

ASSEMBLED BOMB

USNUSL MULTI - SHOT BOMB

TIMER ASSEMBLY

USNUSL MULTI - SHOT BOMB

"BOTTLE CAP"
BOMB
SCHEMATIC DIAGRAM

WOODS HOLE
PERCUSSION
DETONATOR
(SCHEMATIC DIAGRAM)

DEVELOPMENT OF WOODS HOLE SOFAR BOMBS

SCALE

"TYPE B"

"TYPE A"

PIPE FITTING

SHEET METAL

NO CASE

MK IV

INTERIM MODEL

RESEARCH MODELS

EARLY TYPES

↑ ADJUSTING RING
 SET FOR MINIMUM
 FIRING DEPTH

↑ ADJUSTING RING
 SET FOR INTERMEDIATE
 FIRING DEPTH

↑ ADJUSTING RING
 SET FOR MAXIMUM
 FIRING DEPTH

WOODS HOLE
 ADJUSTABLE DEPTH
 DETONATORS

UNCASED BOMB
(SCHEMATIC DIAGRAM)

SHEET METAL CASE
BOMB

RESEARCH MODEL BOMB
TYPE A
(SCHEMATIC DIAGRAM)

RESEARCH MODEL BOMB

TYPE A

FIG. 23

RESEARCH MODEL BOMB
TYPE B
(SCHEMATIC DIAGRAM)

RESEARCH
MODEL
BOMB
TYPE C

ENLARGED VIEW
UN — ARMED

ENLARGED VIEW
ARMED

SOFAR INTERIM BOMB
(SELF ARMING)
ARMING MECHANISM DETAILS

MODIFIED
ARMING MECHANISM
SOFAR INTERIM BOMB

FIG. 28

SO FAR ARMING TYPE INTERIM
BOMB (ALTERNATE DESIGN)

SOFAR INTERIM BOMB
(SELF ARMING)
(SCHEMATIC DIAGRAM)

SOFAR INTERIM BOMB
(MOST RECENT MODEL)

FIG. 31

FIGURE 32

SPRING FORK

COVER HOOK

IMPLOSION BOMB
FLASK TYPE
(SCHEMATIC DIAGRAM)

IMPLOSION BOMB
TUBING TYPE
(SCHEMATIC DIAGRAM)

GRAPH 2

FREQUENCY, PER CENT.

SINKING TIME (MINUTES)

NO. 3127. ARITHMETIC PROBABILITY. DESIGNED BY HAZEN, WHIPPLE & FULLER.
 CODEX BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

GRAPH 6

GRAPH 8

2

0

0

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

GRAPH 12

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

GRAPH 17¹⁰⁰

GRAPH 18

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

GRAPH 19

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01

0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99

FREQUENCY, PER CENT

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

GRAPH 22

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

COLLAPSING PRESSURE (POUNDS PER SQUARE INCH)

FREQUENCY, PER CENT

GRAPH 25

108

FREQUENCY, PER CENT

EUGENE DIETZGEN CO.
MADE IN U.S.A.

NO. 340-L210 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FAILING PRESSURE
(POUNDS/IN²)

NO. 2-1C-6 SEMCO SEMI-LOGARITHMIC PAPER
1 10 INCH CYCLE X 6 DIV. PER UNIT (60 DIV.)
GUARANTEED "ALL RAG PAPER"
SPALDING-MOSS COMPANY
BOSTON, MASS.
PRINTED IN U. S. A.

CODER BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS

NO. 3127. ARITHMETIC PROBABILITY. DESIGNED BY HAZEN, WHIPPLE & FULLER.

APPENDIX

Tests on Bombs and Detonators
at Sea and in Pressure Vessels.

BOURDON BOMB, MODEL A

Dropped by the DE-51 April 2 - April 5, 1944. Eleven were used, of which ten fired and one did not.

BOURDON BOMB, MODEL B

Dropped by the USCGR VALOR, January and February 1945.

Eleuthera Shot No.	Fired	Sinking Time	
		Min.	Sec.
36	Yes	12	10.0
40	Yes	13	09.2
42	Yes	05	13.0
46	Yes	09	10.0
48	Yes	04	51.0

3 duds and one on which the detonator only fired were also dropped.

DOUGLAS PERCUSSION BOMB

Dropped by USCGR VALOR, February 1945

Eight were used all of which were duds.

ROCKWELL BOMB

January '45 to September '45

P before Shot No. indicates that bomb was expended from aircraft.

Eleuthera Shot No.	Fired	Sinking Min.	Time Sec.
7	Yes	5	45.0
9	Yes	9	11.1
11	Yes	5	17.4
14	Yes	5	36.5
17	Yes	5	10.0
19	Yes	5	27.5
22	Yes	6	04.0
47	Yes	5	21.0
51	Yes	5	12.0
54	No		
56	No		
Two were duds. No numbers were given.			
57	Yes	5	07.0
58	Yes	5	31.0
Four good ones. No numbers were given.			
49	Yes	5	45.0
50	Yes	5	41.0
52	Yes	5	16.5
Two were duds. No numbers were given.			
53	Yes	4	49.5
55	Yes	5	16.0
P67	Yes		
P68	Yes		

ROCKWELL BOMB (continued)

Eleuthera Shot No.	Fired	Sinking Time	
		Min.	Sec.
P69	Yes		
P70	Yes		
P71	Yes		
P72	Yes		
P73	Yes		
P74	Yes		
P Two not heard. No numbers given.			
77	Yes	5	00.0
78	Yes	5	57.0
79	Yes	5	41.0
83	Yes	4	38.0
85	Yes	4	48.0
87	Detonator only	13	56.0
88	Yes	6	31.0
91	Yes	5	53.0
93	Yes	6	01.0
P95	Not Heard		
P96	Not Heard		
P97	Yes		
P98	Not Heard		
P99	Yes		
P100	Yes		
P101	Yes		
P102	Yes		
P103	Yes		

ROCKWELL BOMB (Continued)

Eleuthera Shot No.	Fired	Sinking Time	
		Min.	Sec.
P104	Not Heard		
P105	Yes		
P106	Yes		
P107	Not Heard		
P108	Not Heard		
P109	Not Heard		
113	Yes	7	12.0
118	Yes	6	03.0
119	Yes	7	42.0
Two were duds. No numbers were given.			
121	Yes	9	33.0
P350	Not Heard		
P352	Yes		
PP354	Yes		
P356	Yes		
P358	Not Heard		
P360	Yes		
P362	Yes		
P364	Not Heard		
P366	Yes		
P368	Not Heard		
P381	Yes		
P382	Yes		
P383	Yes		
P384A	Not Heard		

ROCKWELL BOMB (continued)

Eleuthera Shot No.	Fired	Sinking Time	
		Min.	Sec.
P384	Yes		
P385	Yes		
P386	Yes		
P387	Yes		
P388	Not Heard		
P389	Yes		
P390	Yes		
P391	Yes		
P392	Yes		
P393	Not Heard		
P394	Not Heard		
P395	Yes		
P396	Yes		
P397	Yes		
P398	Yes		
P399	Yes		

"BOTTLE CAP" BOMB

R/V ATLANTIS - April 10, 1947

P before Shot No. indicates that bomb was expended from aircraft

Atlantis Shot No.	Design Firing Depth (feet)	Altitude Dropped (feet)	Air Speed (m.p.h.)	Fired	Depth Fired (feet)	Sinking Min.	Time Sec.
2	4000	From Atlantis	----	Yes		3	36
P8	1500	2000	135	Yes	1350	1	37
P9	4000	2000	145	Yes	2000	4	32
P10	1500	2000		Yes	2000	1	25
P11	4000	2100	175	Yes	3770	4	25
P12	1500	100	175	Yes	1450	1	43
P13	4000	100	175	Yes	3980	4	39
14	1500	From Atlantis	----	Yes	1530	1	58
15	2500	From Atlantis	----	Yes		2	58
16	3500	From Atlantis	----	Yes	3225	3	50
P17	1500	100	175	Yes	1370	1	36
P18	4000	100	190	Yes	3830	4	39
P19	1500	3000	175	Yes	1440	1	40
P20	1500	3000	190	Yes		1	51
P21	4000	2800	185	Yes		4	23
P22	4000	2800	185	Yes		4	22
P23	1500	1000	190	Yes		1	39
P24	2500	1000	190	Yes	2695	3	34
P25	4000	1000	195	Yes		5	04
26	2000	From Atlantis	----	Yes	1895	2	15
27	2500	From Atlantis	----	Yes	2380	2	47
28	4000	From Atlantis	----	Yes	3810	4	23
29	3000	From Atlantis	----	Yes	3405	4	00
30	3000	From Atlantis	----	Yes	3350	3	53
31	3500	From Atlantis	----	Yes		4	10

WOODS HOLE PERCUSSION DETONATORS

May 16 - May 21, 1945

Diaphragm Thickness	Failing Pressure #/sq in	Diaphragm Attached to Plunger	Shearing Edge	Gasket
.012*	2000	integral	sharp	rubber
.008*	No failure up to 2800	"	"	"
.010*	No failure up to 3000	"	"	"
.0025	800	screw	"	
.010	2900	solder	"	
.005	2300	screw	"	
.005	2600	"	"	
.005	2200	"	"	
.010**	leaked	"	"	
.010**	case collapsed	"	"	
.010**	" "	"	"	
.010**	3900	"	radius	
.005**	1750	"	"	
.005	leaked	no plunger	sharp	film
.005	1875	" "	"	"
.005	1800	solder	"	rubber
.005	2000	"	"	"
.005	1200	screw	radius	
.005	1400	"	"	
.005	1475	"	"	
.005	1400	"	"	

I

WOODS HOLE PERCUSSION DETONATORS (cont.)

Diaphragm Thickness	Failing Pressure #/in ²	Diaphragm Attached to Plunger	Shearing Edge	Gasket
.005	1200	screw	radius	
.010	4700	"	"	
.005	1400	"	"	tracing cloth

* These diaphragms were machined from brass bar stock and were integral with the plungers. All other diaphragms were cut from brass shim stock.

** These detonators contained explosive charges, the last two of which exploded on collapse of the diaphragm.

STANDARD WOODS HOLE PRESSURE DETONATORS
Test at Sea Without Bombs or Charges

<u>Eleuthera Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>		<u>Remarks</u>
		<u>Min.</u>	<u>Sec.</u>	
July 2 to July 27, 1945				
-	Yes	6	04	Mk I Mousetrap* Weighted
-	Yes	5	20	" " "
-	Yes			" " "
-	Yes			" " "
167	Yes			
168	Yes	3		
177	Yes		01	" " "
180	Yes	3	05	" " "
183	Yes	3	09	" " "
187	Yes	3	13	" " "
190	Yes	3	07	" " "
192	Yes	3	01	" " "
195	Yes	3	35	" " "
197	Yes	3	57	" " "
199	Yes	3	49	" " "
201	Yes	4	03	" " "
203	Yes	3	37	" " "
205	Yes	3	08	" " "
207	Yes	3	08	" " "
209	Yes	3	29	" " "
210	Yes	3	47	" " "

* Mk I Mousetrap refers to the Subcaliber Mark I Mousetrap practise rocket used as a sinker.

STANDARD WOODS HOLE PRESSURE DETONATORS (cont.)

	Fired	Sinking Time		Remarks
		Min.	Sec.	
<u>USS GALAXY</u>				
<u>Shot No.</u>	July 10, 1945			
24	No			
32	Yes	8	00	Attached to 3.9 lead weight
<u>R/V PHYSALIA</u>				
<u>Shot No.</u>	August 2, 1945			<u>Loaded by</u>
37	Yes			WHOI
38	Yes			WHOI
57	Yes	35		du Pont
58	Yes	36		du Pont
59	Yes	45		" "
60	Yes	48		" "
61	Yes	66		" "
62	Yes	68		" "
63	Yes	69		" "
64	Yes	70		" "
65	Yes	71		" "
66	Yes	72		" "
67	Yes	73		" "
68	Yes	73		" "
69	Yes	34		" "
56	Yes	33	30	" "
<u>PCE(R) 849</u>				
<u>Shot No.</u>	April 30 to May 2, 1946			
1	Yes	8	27	Attached to Sashweight
2	Yes	8	28	" " "
3	Yes	10	00	" " "

STANDARD WOODS HOLE PRESSURE DETONATORS (cont.)
Tests in Pressure Vessels
May 26 to June 4, 1947

Wall thickness	Firing Depth
.0051 inch	127 fathoms
.0051 "	116 "
.0051 "	118 "
.0051 "	112 "
.0079 "	409 "
.0079 "	386 "
.0079 "	413 "
.0079 "	430 "
.0094 "	676 "
.0094 "	683 "
.0094 "	688 "

WOODS HOLE PRESSURE DETONATORS
 USS SARDONYX (PYC 12) TESTS WITH VARIOUS MODIFIED DETONATORS
 ON TNT-TETRYL DEMOLITION BLOCKS
 July 1, 1945

Number of Tests	Cap	Amount	Material	Tube End	Fired
2	sp**	--	----	thin	block
10	sp	--	----	thick	block
2*	sp	--	----	thick	no
1	sp	--	----	thick	det. only
4	sp	1 pellet	pentolite	thin	block
1	sp	1 pellet	pentolite	thick	block
1	sp	1 pellet	pentolite	thick	block
1	sp	1 pellet	Comp. A	thin	block
1	sp	1 pellet	Tetryl	thin	block
1	sp	1 pellet	Tetryl	thick	block
1	sp	1/8 tsp.	PETN	thin	det. only
1	sp	1/4 tsp.	PETN	thin	unknown
1	sp	3/16 tsp.	PETN	thin	unknown
1	6***	3 pellets	Comp. A	thin	block
1	6	2 pellets	Comp. A	thin	det. only
1	6	3 pellets	pentolite	thin	block
1	6	3 pellets	pentolite	thin	unknown
1	6	2 pellets	pentolite	thin	unknown
1	6	3 pellets	Tetryl	thin	unknown
2	6	4 pellets	Tetryl	thin	block
1	6	4 pellets	Tetryl	thick	block

* Loaded and used within 20 minutes. Water proofing not dry.

** sp = engineers special non-electric blasting cap.

*** 6 = Hercules non-electric blasting cap.

WOODS HOLE PRESSURE DETONATORS (continued)

Number of Tests	Cap	Charge Amount	Material	Tube End	Fired
1	6	3/16 tsp.	Tetryl	thin	det. only
4	6	3/16 tsp.	PETN	thin	unknown
3	6	3/16 tsp.	PETN	thin	block
1	6	3/16 tsp.	PETN	thin	det. only
3	6	3/16 tsp.	PETN	thin	det. only
1	6	3/16 tsp.	PETN	thick	unknown
3	6	3/16 tsp.	PETN	thick	det. only
1	6	3/16 tsp.	PETN	thick	det. only
1	6	1/4 tsp.	PETN	thin	unknown
1	6	1/4 tsp.	PETN	thin	block
1	6	1/4 tsp.	PETN	thin	det. only
1	6	3/8 tsp.	PETN	thin	det. only
1 ^x	6	3/16 tsp.	PETN	thin	det. only
1 ^x	6	1/4 tsp.	PETN	thin	unheard
1 ^x	6	3/8 tsp.	PETN	thin	unheard
1 ^x	6	4½ pellets	pentolite	thin	unheard
1 ^{xx}	6	5 pellets	pentolite	thin	unheard
1 ^{xxx}	6	3/8 tsp.	PETN	thin	det. only
^x TNT block. ^{xx} cast TNT. ^{xxx} comp. C-2.					

Thick tube end refers to a flat top brass cap used to seal the charge end of the detonator. This cap is normally used on the non-firing end of the standard detonator. Thin tube end refers to a hollow top cap used to seal the charge end of the detonator as is the practice on the standard detonator.

The pellets used were approximately ¼ inch long and slightly less than ¼ inch in diameter.

UNCASED BOMBS
With Woods Hole Pressure Detonators

Eleuthera shots 84 through 166, PHYSALIA Shot 35, and all GALAXY shots were made with detonators which had less than the present standard charge.

Eleuthera Shot No.	Fired	Sinking Time		Remarks
		Min.	Sec.	
May 21, to September 3, 1945				
1/2 lb. TNT (no booster) weighted with lead pipe				
84	Yes	24	30	
89	Yes	22	45	
90	Yes	22	43	
1/2 lb. TNT (no booster) weighted with Mk I subcaliber mousetrap (practise rocket)				
110	det. only	2	49	
114	det. only	7	07	
115	det. only	6	46	
120	det. only	7	57	in balloon
122	Yes	4	30	
123	det. only	6	47	
124	det. only	5	10	
----	det. only	7	23	
----	det. only	7	09	
4 lbs. TNT (no booster) weighted with Mk I mousetrap				
111	det. only	12	13	
112	det. only	10	11	
213	No			central detonator
217	Yes	8	39	

UNCASED BOMBS (continued)

ELEUTHERA Shot No.	Fired	Sinking Time		Remarks
		Min.	Sec.	
May 21, to September 3, 1945				
First special type (see text)				
125	No			250 gm TNT
126	No			" " "
127	No			" " "
128	Yes	32		" " "
130	Yes	37		" " "
131	Yes	41		" " "
132	Yes	44		" " "
141	Yes	36		" " "
134	Yes	31		250 gm TPX
137	Yes	12		" " "
153	Yes	44		" " "
160	Yes	35		250 gm TNT, 250 gm TPX
162	No			" " " " " "
129	Yes	35		200 gm TNT
158	Yes	37		500 gm TNT
155	Yes	15		400 gm TNT
156	No			" " "
164	No			" " "
166	No			" " "
139	Yes	36		800 gm TNT
Second special type (see text)				
135	Yes	26		371 gm pentolite
138	Yes	12		373 gm pentolite
136	Yes	24		406 gm pentolite

UNCASED BOMBS (continued)

<u>ELEUTHERA</u> <u>Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>		<u>Remarks</u>
		<u>Min.</u>	<u>Sec.</u>	
140	Yes	24		408 gm pentolite
154	Yes	24		424 gm pentolite
141J	Yes	8		400 gm pentolite
Third special type (see text)				
133	Yes	38		609 gm tetryl
Fourth special type (see text)				
141A	Yes	11		$\frac{1}{2}$ lb. Tetrytol
141B	Yes	45		" " "
141C	Yes	42		" " "
141D	Yes	47		" " "
141E	Yes	48		" " "
141F	Yes	47		" " "
141G	Yes	43		" " "
141H	Yes	39		" " "
143	Yes	61		1 lb. Tetrytol
144	Yes	54		1 " "
145	Yes	53		1 " "
146	Yes			1 " "
147	Yes			1 " "
148	Yes			1 " "
149	Yes	58		1 " "
150	Yes	62		1 " "

UNCASED BOMBS (continued)

	Fired	Sinking Time		Remarks
		Min.	Sec.	
<u>R/V PHYSALIA</u>				
<u>Shot No.</u>	April 2, 1945			
35	Yes	43		Tetrytol Block
72	Yes	50		" "
73	Yes	50		" "
74	Yes	50		" "
75	Yes			" "
76	Yes	50		" "
<u>USS GALAXY</u>				
<u>Shot No.</u>	July 10, 1945			
TNT (no booster) 5.2 lbs. lead weight				
39	Det. only	10		$\frac{1}{2}$ lb. charge
TNT (teteryl booster) 5.2 lbs. lead weight				
38	Yes	12	5 5	$\frac{1}{2}$ lb. charge
36	No			1 " "
40	Yes	12	5	1 " "
41	No			1 " "
35	Yes	11	5	3 " "
37	No			3 " "

SHEET METAL CASE BOMBS
With Woods Hole Pressure Detonators

<u>ELEUTHERA</u> <u>Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>		<u>Remarks</u>
		<u>Min.</u>	<u>Sec.</u>	
July 30 to September 2, 1945				
TNT (teteryl booster) 5.2 [#] lead weight				
221	Yes	5	39	1 lb. charge
215	Yes	5	42	1 lb. charge
230	det. only	5	57	" " "
211	Yes	6	07	" " "
---	Yes	6	12	" " "
227	Yes	6	26	" " "
216	Yes	6	33	" " "
212	Yes	6	40	" " "
---	Yes	6	41	" " "
232	Yes	6	52	" " "
---	Yes	6	53	" " "
214	No			" " "
229	No			" " "
231	No			" " "
219	Yes	4	29	2 lb. charge
220	Yes	4	49	2 " "
224	Det. only	6	07	2 " " central det.
218	No			2 " " " "
222	No			2 " " " "
223	No			2 " " " "
225	No			2 " " " "
226	No			2 " " " "
228	No			2 " " " "

SHEET METAL CASE BOMBS (cont.)

	<u>Fired</u>	<u>Sinking Time</u>		<u>Remarks</u>
		<u>Min.</u>	<u>Sec.</u>	
<u>ELEUTHERA</u>				
<u>Shot No.</u>	July 30 to September 2, 1945			
407	Yes	4	41	1 lb. charge
420	Yes	4	51	1 " "
<u>R/V PHYSALIA</u>				
<u>Shot No.</u>	August 2, 1945			
1	Yes	12		standard detonator
2	Yes	12		" "
3	Yes	43		" "
4	Yes	43		" "
5	Yes	44		" "
6	Yes	42		" "
7	Yes	42		" "
8	Yes	41		" "
9	Yes	42		" "
10	Yes	41		" "
11	Yes	32		" "
12	Yes	45		" "
13	Yes	44		" "
14	Yes	44		" "
15	Yes	45		" "
16	Yes	45		" "
17	Yes	47		" "
18	Yes	48		" "
19	Yes	49		" "
20	Yes	45		" "
21	Yes	43		" "

SHEET METAL CASE BOMBS (cont.)

R/V PHYSALIA Shot No.	Fired	Sinking Time		Remarks
		Min.	Sec.	
August 2, 1945				
22	Yes	45		standard detonator
23	Yes	45		" "
24	Yes	44		" "
25	Yes	42		" "
26	Yes	40		" "
27	Yes	44		" "
28	Yes	43		" "
34	Yes	40		detonator contains less than the present standard charge
36	Yes	43		same as remarks for 34
1½ lbs. TNT (no booster)				
31	Yes	44		standard detonator
32	Yes	45		" "
33	Yes	47		" "
39	Yes	43		" "
40	Yes	43		" "
41	Yes	42		" "
43	Yes	38		" "
44	Yes	35		" "
45	Yes	34		" "
46	Yes	32		" "
47	Yes	30		" "
48	Yes	29		" "
49	Yes	29		" "
50	Yes	31		" "

SHEET METAL CASE BOMBS (cont.)

	Fired	Sinking Time		Remarks
		Min.	Sec.	
R/V PHYSALIA				
<u>Shot No.</u>	August 2, 1945			
51	Yes	31		standard detonator
52	Yes	31		" "
53	Yes	32		" "
54	Yes	34		" "
55	Yes	33		" "
USS GALAXY				
<u>Shot No.</u>	July 10, 1945			
1 lb. TNT (teteryl booster) detonators contain less than the present standard charge				
1	Yes	5	30	5.2 lbs. lead weight
2	Yes	6		" " " "
3	Yes	10		1.9 lbs. lead weight
5	No			3.9 lbs. lead weight
6	No			1.9 lbs. lead weight
7	Yes	7	15	5.2 lbs. lead weight
8	Yes	5	30	" " " "
9	Yes	9	15	1.9 lbs. lead weight
10	No			5.2 lbs. lead weight
11	Yes	8	30	3.9 lbs. lead weight
13	Yes	7		" " " "
14	Yes	8	30	1.9 lbs. lead weight
15	Yes	7		5.2 lbs. lead weight
16	Yes	7	15	" " " "
17	Yes	11		1.9 lbs. lead weight
18	Yes	10	15	3.9 lbs. lead weight

SHEET METAL CASE BOMBS (cont.)

USS GALAXY Shot No.	Fired	Sinking Time		Remarks
		Min.	Sec.	
19	Yes	7	30	5.2 lbs. lead weight
20	Yes	6	30	" " " "
22	Yes	10	30	1.9 lbs. lead weight
23	No			3.9 lbs. lead weight
25	Yes	7		5.2 lbs. lead weight
26	Yes	6		" " " "
27	Yes	6		" " " "
28	Yes	5	30	5.2 lbs. lead weight
29	Yes	6	30	" " " "
30	No			" " " "
31	Yes	6		" " " "
33	Yes	7		3.9 lbs. lead weight
34	Yes	6	45	5.2 lbs. lead weight
1 lb. TNT (no booster)				
4	det. only	6		5.2 lbs. lead weight
12	det. only	6		" " " "
21	det. only	7		" " " "
PCE(R) 849 Shot No. April 30 to May 2, 1946				
23	det. only	7	8	2.6 lbs. TNT (no booster)
24	det. only	8	22	" " " " "
25	det. only	8		" " " " "
29	det. only	10 approx.		" " " " "
30	det. only	24	47	" " " " "
31	No			" " " " "

SHEET METAL CASE BOMBS (cont.)

PCE(R) 849 Shot No.	Fired	Sinking Time		Remarks							
		Min.	Sec.								
	April 30 to May 2, 1946										
46	Yes	8	36	1 1/2"	C-2 on top of 2.6 lbs. TNT						
47	Yes	10	23	"	"	"	"	"	"	"	"
48	Yes	8	41	"	"	"	"	"	"	"	"
49	Yes	9	38	"	"	"	"	"	"	"	"

RESEARCH MODEL BOMB, TYPE A
1 lb. TNT (tetryl booster)
With Standard Woods Hole Pressure Detonators

<u>ELFUTHERA</u> <u>Shot No.</u>		Fired	Sinking Time	
			Min.	Sec.
Triangulation Cruise August 20 to September 4, 1945				
320		Yes	3	34
321		Yes	3	47
322		Yes	3	45
323		Yes	3	31
324		Yes	3	28
325		Yes	3	20
327		No		
328		Yes	3	30
329		Yes	3	35
330		Det. only	3	28
331		Yes	4	07
332		Yes	3	58
333		Yes	3	38
334		Yes	3	43
335		Yes	3	50
336		Yes	4	48
337		Yes	3	31
338		Yes	3	59
339		Yes	3	50
340		Yes		
341		Yes	3	52
342		Yes	3	38
343		Yes	3	49

RESEARCH MODEL BOMB, TYPE A (cont.)

<u>ELEUTHERA</u> <u>Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>	
		<u>Min.</u>	<u>Sec.</u>
344	Yes	3	49
345	Yes	4	20
346	Yes	3	39
347	Yes	3	53
348	Yes	3	58
349	Yes	3	46
372	Yes	3	44
373	Yes	3	55
374	Yes	3	48
375	Yes	3	43
376	Yes	3	51
377	Yes	3	46
401	Yes		
402	Yes		
403	Yes		
404	Yes		
405	Yes	3	55
406	Yes	3	44
408	Yes	3	49
409	Yes	3	31
411	Yes	3	47
412	Yes	3	30
413	Yes	3	44
414	Yes	3	35

RESEARCH MODEL BOMB, TYPE A (cont.)

<u>ELEUTHERA</u> <u>Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>	
		<u>Min.</u>	<u>Sec.</u>
415	Yes	3	47
416	Yes	3	39
417	Yes	4	05
418	Yes	4	20
424	Yes	3	52
425	Yes	3	48
426	Yes	3	48
427	Yes	3	34
428	Yes		
429	Yes		
436	Yes	3	52
437	Yes	3	47
438	Yes	3	45
439	Yes	3	35
440	Yes	3	40
441	Yes	3	46
442	Yes	4	03
443	Yes	3	50
444	Yes	3	48
445	Yes	3	43
446	Yes		
447	Yes		
448	Yes	3	49

RESEARCH MODEL BOMB, TYPE A (cont.)

<u>ELEUTHERA</u> <u>Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>	
		<u>Min.</u>	<u>Sec.</u>
449	Yes	3	47
450	Yes	3	49
1000	Yes		
1001	Yes		
1002	Yes		
1003	Yes		
1004	Yes		
1005	Yes		
1006	Yes		
1007	Yes		
1008	Yes		
1009	Yes		
1010	Yes		
1011	Yes		
1012	Yes		
1013	Yes		
1014	Yes		
1015	Yes		
1016	Yes		
1017	Yes		
1019	Yes		
1020	Yes		
1021	Yes		
1022	Yes		

xxx

RESEARCH MODEL BOMB, TYPE A (Cont.)

<u>ELEUTHERA</u> <u>Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>	
		<u>Min.</u>	<u>Sec.</u>
1023	Yes		
1024	Yes		
1025	Yes		
1026	Yes		
1027	Yes		
1028	Yes		
1029	Yes		
1030	Yes		
1031	Yes		
1032	Yes		

RESEARCH MODEL BOMB, TYPE A (continued)

Miscellaneous Charges
With Standard Woods Hole Pressure Detonators

PCE(R) 849 Shot No.	Fired	Sinking Time	
		Min.	Sec.
April 30 to May 2, 1946			
Composition C-2 2½ lbs. (block)			
26	Yes	3	35
27	No		
28	Yes	4	29
32	Yes	3	36
33	Yes	3	26
34	Yes	3	52
35	Yes	3	27
36	Yes	3	26
37	Yes	3	22
38	Yes	3	29
39	Yes	3	16
40	Yes	3	53
41	Yes	3	31
42	Yes	3	40
43	Yes	3	44
44	No		
45	No		
½ lb. Mark IV TNT (tetryl booster) block			
50	Yes	4	10
51	Yes	3	64
61	Yes	3	64

RESEARCH MODEL BOMB, TYPE A (continued)

<u>PCE(R) 849</u> <u>Shot No.</u>	<u>Fired</u>	<u>Sinking Time</u>	
		<u>Min.</u>	<u>Sec.</u>
HBX 2.9 lbs.			
52	Yes	2	56
53	Yes	3	03
55	Yes	3	14
56	No		
2½ lbs. Tetrytol block			
58	Yes	3	20
59	Yes	3	43
63	Yes	3	15
66	Yes	3	54

RESEARCH MODEL BOMB, TYPE A (continued)
 1 pound TNT (teteryl booster)
 ATLANTIS Bottom Reflectivity Cruise
 Sept. 16 to Nov. 17, 1946
 With Woods Hole Pressure Detonators

1946 Date	Fired	Fathoms Firing Depth	Sinking Time Min.	Sec.	Marlin
Sept. 17	Yes		6	30	Yes
" 18	Yes		4	45	Yes
" 18	Yes		4	40	Yes
" 19	Yes		5	06	Yes
" 19	Yes		4	50	Yes
" 19	No				Yes
" 21	Yes		5	52	Yes
" 22	Yes		4	30	Yes
" 22	Yes		4	25	Yes
" 22	Yes		4	20	Yes
" 22	No				Yes
" 22	Yes		4	17	Yes
" 23	Yes		4	22	Yes
" 23	Yes	665	4	29	Yes
" 23	Yes		4	29	Yes
" 23	No				Yes
" 23	Yes		4	31	Yes
" 25	Yes	681	4	30	Yes
" 26	Yes		5	00	Yes
Oct. 2	Yes	653	5	00	Yes
" 3	Yes	672	4	50	Yes
" 3	Yes	676	5	20	Yes
" 4	Yes	595	4	25	Yes
" 4	No				Yes

RESEARCH MODEL BOMB, TYPE A (continued)
1 pound TNT (tetryl booster)

1946 Date		Fired	Fathoms Firing Depth	Sinking Time Min.	Sec.	Marlin
Oct.	4	Yes		4	50	Yes
"	5	Yes		4	45	Yes
"	6	Yes		4	55	Yes
"	9	Yes		4	21	Yes
"	10	Yes		4	55	Yes
"	10	No				Yes
"	10	Yes	713	4	45	Yes
"	11	No				Yes
"	11	Yes	627	4	50	Yes
"	11	No				Yes
"	11	Yes	671	4	53	Yes
"	12	Yes	693	4	50	Yes
"	12	Yes		4	43	Yes
"	13	Yes	620	4	23	Yes
"	13	Yes	664	4	32	Yes
"	14	Yes		5	15	Yes
"	14	Yes	721	4	45	Yes
"	15	Yes		4	35	Yes
"	16	Yes	668	4	31	Yes
"	16	Yes	693	4	42	Yes
"	17	Yes		4	00	Yes
"	17	Yes		3	50	Yes
"	17	Yes	665	4	33	Yes
"	17	Yes		4	57	Yes
"	18	Yes	613	4	09	Yes

RESEARCH MODEL BOMB, TYPE A (continued)
1 pound TNT (tetryl booster)

1946 Date	Fired	Fathoms Firing Depth	Sinking Time		Marlin
			Min.	Sec.	
Oct. 18	Yes		4	29	Yes
" 19	Yes	613	4	09	Yes
" 19	Yes	634	4	12	Yes
" 20	Yes	632	4	14	Yes
" 20	Yes		5	04	Yes
" 27	Yes	645	4	45	Yes
" 28	Yes		5	00	Yes
" 29	Yes	650	4	45	Yes
" 30	Yes	648	4	36	Yes
" 30	Yes	612	4	34	Yes
" 31	Yes	690	4	46	Yes
" 31	Yes	634	4	19	Yes
" 31	Yes		4	25	Yes
" 31	Yes	640	4	36	Yes
" 31	Yes	641	4	35	Yes
" 31	Yes	697	4	42	Yes
Nov. 1	Yes	689	3	40	No
" 1	Yes		3	46	No
" 2	Yes	636	3	35	No
" 2	Yes	690	3	55	No
" 2	Yes	668	3	50	No
" 2	Yes	690	3	41	No
" 2	Yes	638	3	42	No
" 2	Yes	668	4	01	No
" 2	Yes	595	3	35	No

RESEARCH MODEL BOMB, TYPE A (continued)
1 pound TNT (teteryl booster)

1946 Date		Fired	Fathoms Firing Depth	Sinking Time Min.	Sec.	Marlin
Nov.	4	Yes	693	3	50	No
"	5	Yes	640	3	35	No
"	5	Yes	648	3	40	No
"	5	No				No
"	5	Yes		unknown		No
"	5	Yes	652	3	36	No
"	6	Yes	668	3	46	No
"	6	No				No
"	6	Yes	655	3	48	No
"	6	Yes	642	3	34	No
"	6	Yes	604	3	33	No
"	6	Yes	685	3	53	No
"	6	Yes	655	3	36	No
"	6	Yes		3	23	No
"	6	Yes	668	3	42	No
"	6	Yes	688	3	56	No
"	6	Yes	620	3	45	No
"	6	Yes	653	3	45	No
"	7	No				No
"	7	Yes	656	3	39	No
"	7	Yes	605	3	23	No
"	8	Yes	640	3	32	No
"	8	Yes	680	3	58	No
"	9	Yes	644	3	35	No
"	9	Yes	700	3	57	No

RESEARCH MODEL BOMB, TYPE A (continued)
1 pound TNT (tetryl booster)

1946 Date	Fired	Fathoms Firing Depth	Sinking Time		Marlin
			Min.	Sec.	
Nov. 10	Yes	680	3	44	No
" 10	Yes	609	3	22	No
" 11	Yes		3	44	No
" 11	Yes	656	4	10	No
" 11	No				No
" 11	Yes	721	3	42	No
" 11	Yes	636	3	55	No
" 11	Yes	615	3	29	No
" 11	Yes	696	3	26	No
" 11	Yes	647	3	55	No
" 11	Yes	728	3	36	No
" 11	Yes	673	4	01	No
" 12	Yes	658	3	35	No
" 12	Yes	687	3	42	No
" 14	Yes	688	3	48	No
" 14	Yes	646	3	35	No
" 14	Yes	638	3	38	No
" 14	Yes	677	3	40	No

RESEARCH MODEL BOMB, TYPE B
2.2 lbs. TNT (tetryl booster)
With Standard Woods Hole Detonators

P before shot No. indicates bomb was expended from aircraft.

Shot No.	Fired	Sinking Time	
		Min.	Sec.
P351	Yes		
P353	Yes		
P355	Yes		
P357	Not heard		
P359	Yes		
P361	Not heard		
P363	Yes		
P365	Yes		
P367	Not heard		

RESEARCH MODEL BOMB, TYPE C
6½ lb. TNT (tetryl booster)
With Standard Woods Hole Pressure Detonators

Shot No.	Fired	Sinking Time	
		Min.	Sec.
500	No	(dropped in shoal water 580 fms)	
505	Yes	2	34
506	Yes	2	35
507	Yes	2	31
508	Yes	2	21
509	Yes	2	23
510	Yes	2	35
511	Yes	2	27
512	Yes	2	56
513	No		
514	Yes	2	42
515	Yes	2	47
516	Yes	2	28
517	Yes	2	40
518	Yes	2	43
519	Yes	2	48
520	Yes	2	48
521	Yes	2	44
522	No		
523	Yes	2	44
524	Yes	2	26
525	No		
526	Yes	2	32

RESEARCH MODEL BOMB, TYPE C (continued)

Shot No.	Fired	Sinking Time	
		Min.	Sec.
527	Yes	2	35
528	Yes	2	58
529	Yes	2	26
530	Yes	2	34
531	Yes	2	33
532	Yes	2	50
533	Yes	2	43
534	Yes	2	29
535	Yes	2	42
536	Yes	2	30
537	Yes	2	33
538	Yes	2	35
539	Yes	2	41
540	Yes	2	37
541	Yes	2	37
542	Yes	2	32
543	Yes	2	16
544	No		
545	No		
546	Yes	2	36
547	Yes	2	45
548	Yes	2	35
549	No		
550	Yes	2	42
551	Yes	2	30
552	Yes	2	44

RESEARCH MODEL BOMB, TYPE C (continued)

Shot No.	Fired	Sinking Time	
		Min.	Sec.
553	Yes	2	46
554	Yes	2	26
555	No		
556	Yes	2	31
557	No		
558	Yes	2	35
561	Yes	2	26
564	Yes	2	34
567	Yes	2	29
569	Yes	2	51
572	Yes	2	41
573	Yes	2	47
574	Yes	2	16
575	Yes	2	26
576	Yes	2	39
577	Yes	2	53
578	Yes	2	43
579	Yes	2	34
580	Yes	2	33
581	Yes	2	35
582	Yes	2	35
583	Yes	2	41
584	Yes	2	35
585	Yes	2	48
586	Yes	2	33

SOFAR INTERIM BOMB
4 lbs. TNT (pentolite booster)
With Standard Woods Hole Pressure Detonators

<u>PCE(R) 849</u> <u>Shot No.</u>	<u>Design</u> <u>Depth</u> <u>(fms)</u>	<u>Firing</u> <u>Depth</u> <u>(fms)</u>	<u>Fired</u>	<u>Sinking</u> <u>Time</u> <u>Min.</u>	<u>Time</u> <u>Sec.</u>	<u>Altitude</u> <u>Dropped</u> <u>(feet)</u>
4*	700	---	Yes	10	25	Over side
5*	700	---	No			Over side
6	700	---	Yes	6	54	Over side
7	700	---	Yes	8	51	Over side
8	700	---	Yes	8	23	Over side
9	700	---	Yes	9	03	Over side
10	700	---	Yes	9	10	Over side
11	700	---	No			Over side
12	700	---	Yes	9	24	Over side
13	700	---	No			Over side
14	700	---	Yes	9	16	Over side
15	700	---	Yes	9	18	Over side
16	700	---	Yes	8	30	Over side
17	700	---	Yes	8	43	Over side
18	700	---	No			Over side
19	700	---	Yes	10	26	Over side
20	700	---	Yes	8	56	Over side

ATLANTIS
Shot No.

April 1947

P before shot No. indicates bomb was
expended from aircraft

P1	350	---	Yes	--	--	Not known
P3	350	---	Yes	2	11	3000
P4	700	---	Yes	3	37	3000
P5	350	---	Yes	1	58	100

* Bombs 4 and 5 were manually armed.

SOFAR INTERIM BOMB (cont.)

<u>ATLANTIS</u> <u>Shot No.</u>	<u>Design</u> <u>Depth</u> <u>(fms)</u>	<u>Firing</u> <u>Depth</u> <u>(fms)</u>	<u>Fired</u>	<u>Sinking</u> <u>Time</u> <u>Min.</u>	<u>Time</u> <u>Sec.</u>	<u>Altitude</u> <u>Dropped</u> <u>(feet)</u>
P6	700	---	Yes	5	22	100
P7	700	673	Yes	3	36	100
32	350	400	Yes	2	12	Over side
33	700	664	Yes	3	28	Over side
34	350	383	Yes	2	04	Over side
35	350	419	Yes	2	13	Over side
36	700	715	Yes	3	48	Over side
37	700	718	Yes	3	49	Over side

IMPLOSION BOMBS

Shot No.	Fired	Sinking Time		Remarks
		Min.	Sec.	
---	Yes	32	21	Glass Flask Type #8 Sash Weight
188	Yes	9	21	Glass Flask Type (heard 17.1 miles away at Eleuthera) weight of sinker unknown
193	No			Glass Flask Type
501	No			Tubing Type monitored only 20 minutes
502	No			Tubing Type monitored only 20 minutes
503	No			Tubing Type monitored only 20 minutes
504	No			Tubing Type monitored only 20 minutes

Flash Bulbs GE Synchro press 3 dropped, 2 not heard, 1 no record.

Glass Float did not fire.

MK 34 BOMB CASE
MODIFY AS SHOWN

MAKE 1 - 1/16
PHOS. BRONZE WIRE (SPRING HARD)

HOUSING SUB-ASSEMBLY - 1 REQ.

ARMING MECHANISM ASSEMBLY

FIN
MAKE 4 - GALV.
#20 SHEET STEEL

END PIECE
MAKE 2 - BRASS

BELLOWS SUB-ASSEMBLY - 1 REQ.

ASSEMBLED SOFAR
INTERIM BOMB

INSTALLATION OF
ARMING MECHANISM
IN TAIL CONE

NOTE: EXPLOSIVE CAVITY OF BOMB
MUST BE SMOOTH AND FREE FROM
PROTRUDING SCREW HEADS.
ENTIRE CAVITY IS COATED WITH
PROJECTILE CAVITY PAINT. SEAM
AROUND BULKHEAD MUST BE COM-
PLETELY SEALED WITH CAVITY PAINT

LOADING:

1. STAND BOMB ON TAIL
2. UNSCREW NOSE
3. COVER BULKHEAD WITH CARDBOARD DISK.
4. POUR IN 100 GMS. MOLTEN PENTOLITE (BOOSTER)
5. COVER COOLED PENTOLITE WITH CARDBOARD DISK.
6. POUR IN MAIN CHARGE OF MOLTEN TNT (APPROX. 4 POUNDS)

ALL DIMENSIONS ± 1/32 EXCEPT AS NOTED

DETAILS AND ASSEMBLY SOFAR INTERIM BOMB

WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MASSACHUSETTS
DRAWN BY: V.M. APPROVED BY: S.C. DATE 9-23-47
PROJECT: B-17 (SOFAR) SCALE: FULL SIZE

ASSEMBLED WOODS HOLE
PRESSURE DETONATOR
SCALE: FULL SIZE

SECTION OF
ASSEMBLED DETONATOR
SCALE: 2X

FLAT TOP CAP
HIGH BRASS
FINISH ALL OVER
SCALE: 10X

HOLLOW TOP CAP
HIGH BRASS STAMPING
SCALE: 10X

DETAILS AND ASSEMBLY
WOODS HOLE PRESSURE DETONATOR
WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MASSACHUSETTS
DRAWN BY: VBM APPROVED BY: SC DATE: 8/28/47
PROJECT: B-17, (SOFAR) SCALE: AS INDICATED