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FAR-FIELD UNDERWATER-BLAST INJURIES PRODUCED BY SMALL CHARGES

Donald R. Richmond, et al

Lovelace Foundation for Medical Education and Research

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PREPARING AGENCY
Lovelace Foundation
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13. ABSTRACT

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Based on the results of this study, a safe impulse level of 2 to 3 psi·msec for unprotected swimmers, head above the surface, was proposed. This safe impulse level was discussed in relation to the underwater blast-wave parameters in the test pond and existing response data for personnel.

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FOREWORD

This report presents the results of tests run to determine the far-field underwater-blast injuries in large animals (mostly sheep). The tests were carried out in Lake Christian an artificial pond on Kirtland Air Force Base (East), Albuquerque, New Mexico.

The work was performed by the Lovelace Foundation for Medical Education and Research under contract with the Defense Nuclear Agency, Contract No. DASA-01-71-C-0013. The funds were provided by the U.S. Navy Bureau of Medicine and Surgery (BUMED 7111) and the work was under the direction of the U.S. Naval Ordnance Laboratory (NOL). The NOL representative was Miss Ermine A. Christian of the Explosions Research Department. Because of limited annual funding, the study spanned a 3-year period.

Twenty-one tests were run from September through November in 1970 involving 42 sheep, six monkeys, and six dogs exposed at 1-ft depths.

Fifteen tests were run from May through July in 1971 with 38 sheep and seven dogs exposed mostly at 2- and 10-ft depths. A preliminary data report was prepared in December 1971.

Nineteen tests were run in July and September of 1972 involving 21 sheep and 24 dogs exposed at depths of 1 ft or less.

The information gained in this study can be applied to estimating safe and deterrent ranges for swimmers in the environment of underwater explosions.

ACKNOWLEDGMENTS

The valuable assistance of the following Lovelace Foundation personnel in carrying out this study is gratefully acknowledged: Mr. Allie Shaw for animal handling and assisting in the postmortem examinations; Mr. William Jackson and Mr. Albert Trujillo for fabricating many items at the test pond; Mr. Jess Hunley for placing and firing the charges; Mr. Takeshi Minagawa for photographing organ specimens and illustrative materials; and Mrs. Berlinda S. Martinez for production of the report including preparing numerous figures and tables, editing, and typing the report.

The experimental work discussed in this manuscript was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences-National Research Council.

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INTRODUCTION

What is a safe distance from an underwater explosion for personnel in the water? The problem this question poses has existed for a long time. In particular, what is the closest range for no-effects from a given underwater explosion for unprotected swimmers? Although there is some information on the response of personnel clothed in diving gear, summarized in reference 1, data for unprotected swimmers are notably meager. Usually, volunteer swimmers were at such great distances from underwater explosions that the findings were not useful (references 1 through 3). The only safety criterion existing today for unprotected personnel in the water is--get out of the water during the explosion. The Naval Ordnance Laboratory (NOL)-Lovelace Test Facility provided an ideal opportunity to conduct systematic tests to determine the far-field underwater-blast effects in biological specimens. The tests could be run under carefully controlled conditions wherein the blast-wave parameters were measured precisely with the most up-to-date piezoelectric gages.

The purposes of this study were: (1) to determine how the biological effects of underwater blast fell off with range beyond the lethal zone from small charges, (2) to obtain some information on the response of ears to underwater explosions, and (3) to correlate the effects with the impulse of the underwater-blast wave so that the results could be scaled to other exposure conditions.

METHODS

The Test Pond

The test pond was 220 by 150 ft and was 30 ft deep over its 30- by 100-ft center portion, figures 1 and 2. The entire pond was lined with black polyvinyl plastic 20 mils thick. A 6-inch-deep layer of sand was located beneath the plastic in the 30-ft-deep portion of the bottom. The sides of the pond had a 2-to-1 slope. Two sets of rigging spanned the pond in a north-south direction. The main rigging, located 80 ft from the west end, consisted of a grid 14 by 24 ft which could be raised and lowered by an electric winch on the south bank. The other rigging was approximately 30 ft from the east end of the pond. Its center grid was 5 by 10 ft which could be raised and lowered by a hand winch on the south bank. The test pond contained approximately 3.2 million gallons of tap water.

The ambient air pressure at the pond was 12.0 psia.

General Procedures

In general, three animals were exposed per test. With few exceptions, they were all at the same range on a given shot. All the test subjects were mounted vertically in the water (long axis perpendicular to the surface). The depth of the sheep was measured from the water surface to their xiphisternum. Dogs and monkeys were submerged to about their glottis level, shoulders beneath the surface, but were designated at 1-ft depths. All animals were right-side-on to the charge.

Animals Vertical in the Water

The first tests were run by placing animals at increasing distances from the charges. The animals were at 1-ft depths, and the 1-, 3-, or 8-lb charges were detonated at 10-ft depths. Based on the initial results from the 1-lb charge firings, tentative biological endpoints (a given severity of injury) and corresponding impulse levels were chosen. These were to be evaluated with dogs and monkeys on the surface and with subjects beneath the surface. The endpoints were: threshold for lung injury (about 40 psi·msec), threshold for G.I. tract contusions (near 20 psi·msec), and no-effect level (approximately 10 psi·msec or less).

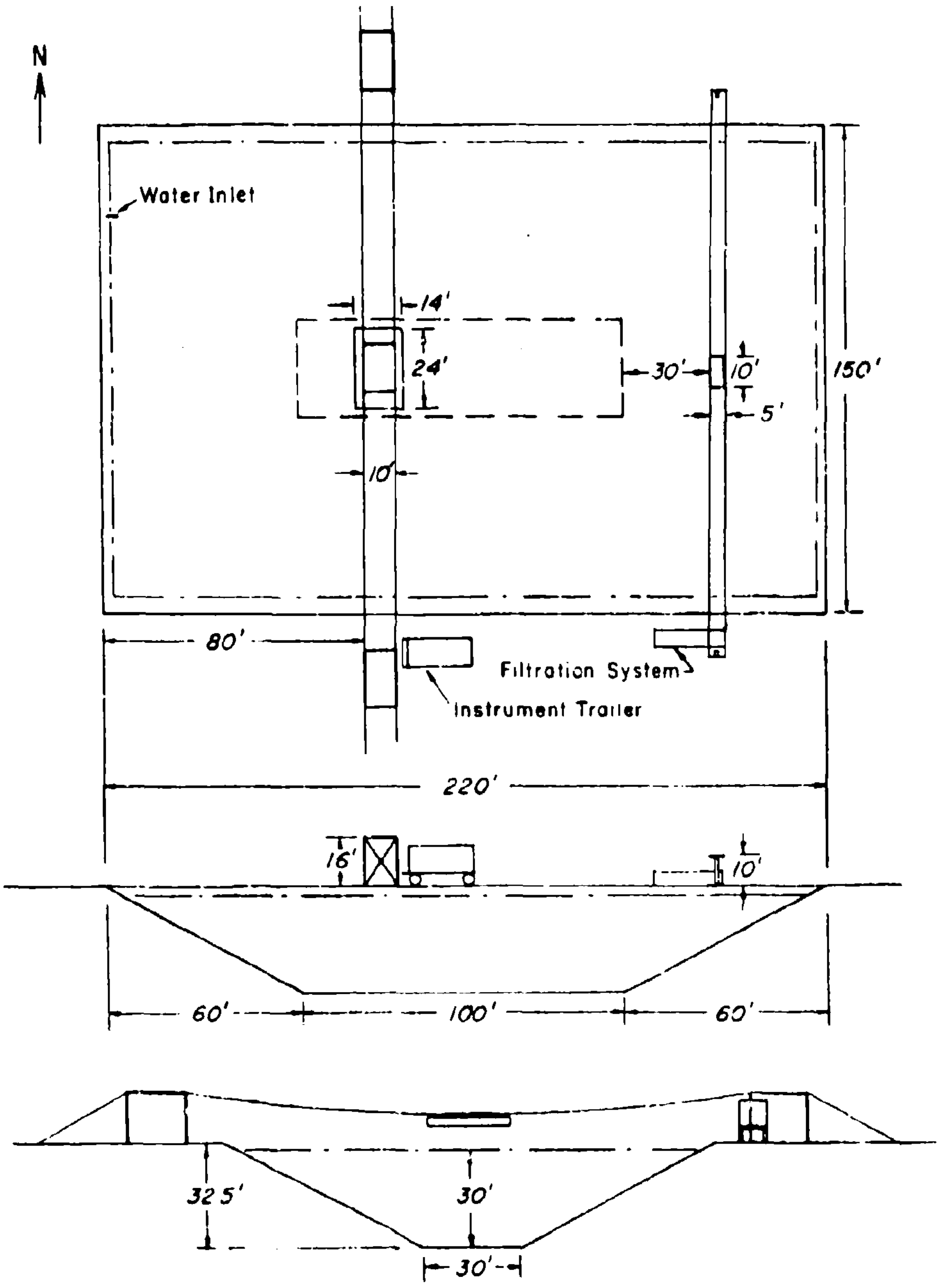


Figure 1.--Diagram of test pond facility.

Figure 2.--Test pond viewed from the southwest corner.

The 30-ft-deep portion of the pond was too small to confirm a no-effect range with 3- and 8-lb charges with animals at 1-ft depths. It was soon learned that even for the 1-lb charge it was necessary to work at ranges beyond 100 ft in order to obtain a certain no-effect range. A rigging was placed across the east end of the pond so that animals could be exposed at the 130-ft range. The charge was 60 ft from the west end of the pond, and the targets were in water 15-ft deep.

Later in the testing, animals were placed at 2- and 10-ft depths to confirm some of the endpoints in targets beneath the surface. It was necessary to use 0.5-lb charges to get impulses of 10 psi·msec or less for subjects at 10-ft depths.

The life-support system that supplied air to the sheep at 2- and 10-ft depths consisted of a face mask (made from polyethylene bottles) having an air inlet hose in the side and a one-way outlet valve in the front of the mask. It covered the animal's nose and mouth and was held in place by four strings tied to the back of the head. The compressed air was delivered to the mask via plastic tubing connected to a manifold of five pressure regulators fastened to two air bottles in series. When animals were exposed at 10-ft depths, 2 psi was applied to the system once the mask was attached to the animal. The pressure then was increased to 6 psi and the rigging lowered to place the animals at the 10-ft depth. Following the detonation, the animals were returned to the surface within 1 min, the delivery pressure reduced to 2 psi, and the face masks quickly removed and inspected for water.

A summary of the shots fired, the ranges used, and the animal numbers are given in tables 1 through 4 for each charge weight. In addition to those listed in the tables, four shots were taken to get additional bottom reflection data.

Animals Horizontal to the Surface

A series of four tests was run with the animals horizontal to the surface, table 5. On two of the tests, five animals were at 0.5 ft depths in the prone and supine positions, and one was in the upright orientation at a 1-ft depth. On the two tests with animals at 1-ft depths, they were all prone. The depths were measured from the water surface to the under surface of their trunks.

Eardrum Response Tests

Eight tests were run specifically for eardrum response data, table 6. Dogs were used because the size and geometry of the eardrum and middle ear

Table 1.--Ranges at which 0.5 lb charges were fired to subject targets vertical in the water to anticipated impulse levels of 10 psi·msec and less.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
181	110	1	Sheep Nos. 136, 129, 143
182	110	1	Sheep Nos. 138, 144, 130
178	93	2	Sheep Nos. 247, 120, 124
166	100	10	Sheep Nos. 237, 55, 49
169	100	10	Sheep Nos. 108, 121, 114
170	100	10	Sheep Nos. 123, 101, 122
180	100	10	Dogs Nos. 121, 122, 118

Table 2.--Ranges at which 1-lb charges were fired to subject targets vertical in the water to anticipated impulse levels of from 40 to 2 psi·msec.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
136	26	1	Sheep Nos. 156, 185, 189
152	26	1	Monkey No. 76; Dog No. 224
137	30	1	Sheep Nos. 118, 167, 169
151	34	1	Monkey No. 80; Dog No. 208
138	34	1	Sheep Nos. 115, 116, 171
139	38	1	Sheep Nos. 158, 177, NN
141	46	1	Sheep Nos. 188, 165, 191
151	46	1	Monkey No. 43; Dog No. 207
179	56	1	Dogs Nos. 213, 212, 161
153	56	1	Monkey No. 84; Dog No. 221
145	56	1	Sheep Nos. 211, 217, 212
203	56	1	Dogs Nos. 116, 200, 210
205[a]	56	1	Dogs Nos. 220, 110, 208
147	78	1	Sheep Nos. 162, 199, 228
154	78	1	Monkey No. 85; Dog No. 216
207[a]	78	1	Dogs Nos. 261, 102, 262
209[a]	78	1	Dogs Nos. 117, 263, 163
155	110	1	Monkey No. 33; Dog No. 00
156	110	1	Sheep Nos. 222, 172, 193
158	110	1	No animals. To get P-T at 110 ft for shots 155 and 156.
190	130	1	Sheep Nos. 66, 64, 65
191	130	1	Sheep Nos. 67, 68, 69
192	130	1	Sheep Nos. 71, 70, 72
193	130	1	Sheep Nos. 73, 74, 75
175	33	2	Sheep Nos. 102, 116, 104
176	54	2	Sheep Nos. 106, 107, 111
177	83	2	Sheep Nos. 118, 50, 119
168	48	10	Sheep Nos. 103, 115, 105
163	48	10	No animals.
167	84	10	Sheep Nos. 113, 148, 117
164	84	10	No animals.
171	84	10	Sheep Nos. 110, 125, 109

[a]Charge was TNT.

Table 3.--Ranges at which 3-lb charges[a] were fired to subject targets vertical in the water to anticipated impulse levels of 40, 20, 10, and 6 psi·msec.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
143	36	1	Sheep Nos. 179, 97, 173
144	61	1	Sheep Nos. 215, 225, 201
146	72	1	Sheep Nos. 229, 224, 214
148	97	1	Sheep Nos. 206, 184, 205
149	97	1	No animals. To get P-T for shot 148.

[a]Charge actually weighed 2.6-lb.

Table 4.--Ranges at which 8-lb charges were fired to subject targets vertical in the water to anticipated impulse levels of 40 and 20 psi·msec.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
140	52	1	Sheep Nos. 186, 194, 161
142	60	1	Sheep Nos. 114, 187, 85

Table 5.--Ranges at which 1-lb charges were fired with targets horizontal to the surface.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
187	13	0.5	Sheep Nos. 55[a], 56, 57
188	13	0.5	Sheep Nos. 58, 59, 60
189	16	1.0	Sheep Nos. 62, 61, 63
183	26	1.0	Sheep Nos. 141, 134; Dog No. 231

[a]Animal was oriented vertically in the water right-side-on to charge.

Table 6.--Ranges at which 1-lb charges[a] were fired with dog ears at 1-ft depths.

Shot No.	Slant Range, ft	Animal Numbers
194	20	Dogs Nos. 204, 217, 215
195	40	Dogs Nos. 1, 217', 218
204	40	Dogs Nos. 200, 116, 210
208	40	Dogs Nos. 261, 102, 262
210	40	Dogs Nos. 263, 117, 163'
200	45	Dogs Nos. 120, 253, 200'
206	45	Dogs Nos. 220, 100, 208
197	60	Dogs Nos. 205, 163, 202

[a]All charges were TNT.

approximate man's more so than other animals. The 24 dogs were oriented vertically in the water with their ears exactly at 1-ft depth. They were right-side-on to the charge with their right ear facing the charge. In order to maintain the exact position of the head, freshly sacrificed animals were used. After sacrifice, the pinna of the ear was clipped to approximate the size of the humans. Twelve of the 24 dogs used in this series had been exposed previously at 1-ft depths, head above the surface, in the first series of tests mentioned. To evaluate the extent of ear injury, the middle ear was dissected open from the brain side of the skull and then photographed.

Animals

One hundred and one Columbia-Rambouillet female sheep, 37 Dalmation dogs, and six rhesus monkeys were utilized on these tests. In addition, nine sheep and one dog were used as control animals to check out the effects, if any, that were due to handling of the animals, tethering them beneath the grid, and subjecting them to going beneath the surface using the life-support system. All the test subjects were autopsied 2 hours following the test. At postmortem, the entire length of the G.I. tract was examined carefully. It was slit open, its contents washed out, and the condition of the mucosal lining in the contused areas was recorded.

Explosive Charges

The explosive charges used in these experiments were bare spheres of cast Pentolite and 1-lb blocks of pressed TNT. The Pentolite spheres had 5/16-inch-diameter detonator wells. The charges were fired with electric blasting caps, DuPont No. E-99. The charge weights were designated at 0.5 lb, 1 lb, 3 lb, and 8 lb. The actual measured weights of these charges, mean and range, were as follows: 0.5 lb, 0.487 (0.485 to 0.492) lb; 1 lb, 1.052 (1.047 to 1.058) lb; 3 lb, 2.618 (2.608 to 2.626) lb; and 8 lb, 8.373 (8.369 to 8.377) lb. All the charges were detonated at 10-ft burst depths.

Pressure-Time Measurements

There were four channels of pressure-time measuring instrumentation. The methods and equipment used for measuring and recording the underwater-blast wave basically are those described in references 4 and 5. The pressure-time gages were a recent modification of the NOL gage Type B. Sensing elements of the gages consisted of four 1/4-inch-diameter tourmaline discs mounted in a Tygon[R] tube filled with silicone oil (Dow-Corning No. 200 dielectric oil). Signals from the gages were passed through a cathode-follower K amplifier unit and recorded on a dual-beam oscilloscope (Tektronix Model 555 with Type D pre-amplifier plug-in units). To ensure accurate time measurements, timing marks were placed on the oscilloscope with a time-marker generator.

On each trial, recording gages were placed at the same ranges and depths as were the animals. The only exception to this routine was on Shots 187 and 188 where targets were at 0.5-ft depths and the gages were 1 ft deep. Attempts were made to locate the gages away from the animals so that the subjects themselves would not alter the pressure-time pattern. Trigger gages were located just upstream from the recording gages so that their signals would initiate the sweep of the oscilloscope.

The system was calibrated by the voltage-step method. A voltage-step generator supplied a known voltage impulse to the system. The calibration voltage step and time markings were placed on separate oscillograph records immediately before each test.

Pressure recordings were enlarged photographically and semilogarithmic plots made for each one. Pressure values were obtained from the curves by the following equation:

$$P = \frac{C_s E_c}{KA} \frac{\Delta P}{\Delta V}$$

P = pressure, psi

C_s = standard capacitance, microfarads

E_c = calibration voltage, volts

ΔP = deflection on record due to pressure

ΔV = deflection on record due to calibration

KA = gage sensitivity, coulombs x 10^{-12}

The KA of the gages was determined at NOL.

A computer program was developed to extrapolate the pressure curve back to one-half the rise time on a particular record to obtain the peak pressure. This added area under the curve was included in the integration for the impulse.

The theta and energy parameters likewise were furnished by the computer. In determining the peak pressure in the bottom reflection records, the curves were not extrapolated back to one-half the rise time.

RESULTS

Animals Vertical in the Water

Nature and Severity of Underwater-Blast Injuries

In the main test series wherein animals were oriented vertically in the water, there were no deaths from blast injuries. As will be mentioned later, two of the subjects died as a result of an inadequate life-support system when they were located at the 10-ft depths. The only animals that from external signs appeared hurt were the three sheep from Shot 136 which were tested at a 1-ft depth and at a slant range of 26 ft from a 1-lb charge. They were docile and remained lying down after removal from their mounts but were on their feet at 5 minutes when the raft was docked. They did not run around the raft as the other sheep did when released from their mounts.

The immersion-blast injuries were, for the most part, confined to the lungs and G.I. tract. Some eardrums were ruptured in those animals tested beneath the surface at the shorter ranges. The injuries were similar to those repeatedly described in the literature (i.e., references 2, 6, and 7) but of minor severity. There were no instances of either ruptured lungs or ruptured G.I. tracts. At the shorter ranges, animals sustained slight amounts of lung hemorrhages as illustrated in figure 3 and multiple contusions of the G.I. tract, figures 4 and 5. The contusions were small in area and scattered throughout the small intestine, caecum, large intestine, including the spiralis, ansa terminalis, and rectum. There was only one case of contusions in the stomach. Some of these contusions, even though small in area (1/2 in or less), were of sufficient severity to ulcerate the mucosal layer of tissue that lines the lumen of these organs, figure 5. These ulcerations would account for small blood clots found in the feces of many of the animals. In no instance did the blood clots in the feces amount to more than a few drops of blood. This commonly would cause the animals to defecate soon after their removal from the water. In general, the number and size of these contused areas would decrease with distance from the charge. The most far-field lesions were a few petechia or small hyperemic

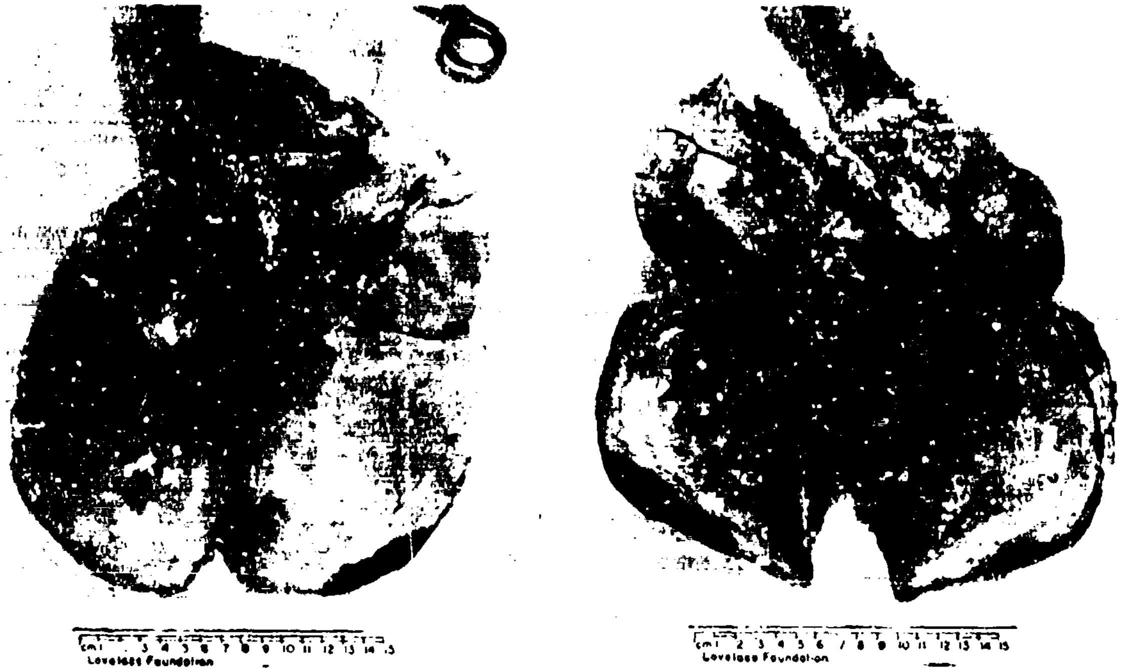


Figure 3.--Slight lung hemorrhage from Sheep No. 186, Shot No. 140. [Target at a 1-ft depth, 52 ft from an 8-lb charge detonated at a 10-ft depth. The peak pressure was 493 psi; the impulse was 36.5 psi·msec.]

Figure 4.--Lower portion of G.I. tract from Sheep No. 186, Shot No. 140. [Multiple contusions of spiralis, ansa terminalis, and rectum (lower left). Target at a 1-ft depth, 52 ft from an 8-lb charge detonated at a 10-ft depth.]

Figure 5.--Lower portion of G.I. tract from Sheep No. 161, Shot No. 140. [Large colon opened to show ulceration of mucosal lining (upper hemostat). Target at 1-ft depth, 52 ft from an 8-lb charge detonated at a 10-ft depth. The peak pressure was 493 psi; the impulse was 36.5 psi·msec.]

spots on the lower portion of the rectum near the anus. A more severe form of scattered multiple petechia lining the rectum is illustrated in figure 6.

The blast effects recorded in animals from the eight charge-target configurations are listed in tables A-1 through A-10, appendix A. Included in each table are the peak pressures, impulses, and durations (cutoff times) measured at the animals' designated depths. Also included are pressure-time values calculated at 2- and 3-ft depths in connection with the animals at 1- and 2-ft depths, respectively. Unless stated otherwise, pressure-time values pertain to those measured at the animals' designated depths. The contusions of the G.I. tract were termed as contusions if ulcerations of the mucosal lining were associated with any of them and were termed as mild contusions if there were no ulcerations of the mucosal lining. Exceptions to this scheme were noted; i.e., the subject had only mild contusions, yet there was a drop or two of clotted blood observed in its feces.

Underwater Blast Injuries in Relation to Distance From 1 lb-Charges for Animals at 1-ft Depths

Lung Hemorrhage

The incidence of lung hemorrhage in animals tested at 1-ft depths, in relation to range from 1-lb charges, appears in figure 7a. At the 26-ft slant range, slight lung hemorrhages occurred in the dog and monkey, and petechial hemorrhages were found in the lungs of one of the three sheep, table A-4 of appendix A. There were no lung lesions detected in animals at ranges beyond 26 ft.

Gastrointestinal Lesions

The general pattern of G.I. tract damage in animals at 1-ft depths, in relation to slant ranges from 1-lb charges, is given in figure 7b and table A-4 of appendix A. The general stepdown pattern of severity of G.I. tract lesions with range can be seen in figure 7b. Contusions of the more severe form extended out to 35 to 40 ft. Beyond the 60-ft range, the lesion found was a 1-in diameter mild contusion in the caecum of a sheep at the 78-ft range. All 12 sheep tested at the 130-ft range were entirely negative.

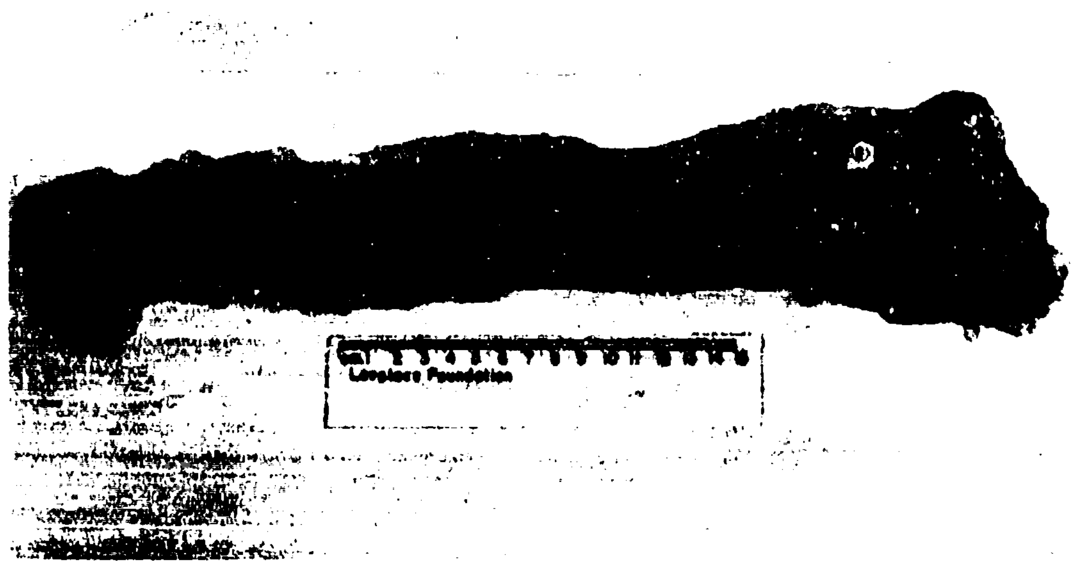


Figure 6.--The rectum of Sheep No. NN opened to show scattered petechiation and contusion, Shot No. 139. [The only other lesion was a 1/8-inch-diameter contusion in the caecum. Target at a 1-ft depth, 38 ft from a 1-lb charge detonated at a 10-ft depth. The peak pressure was 400 psi; the impulse was 25.8 psi·msec.]

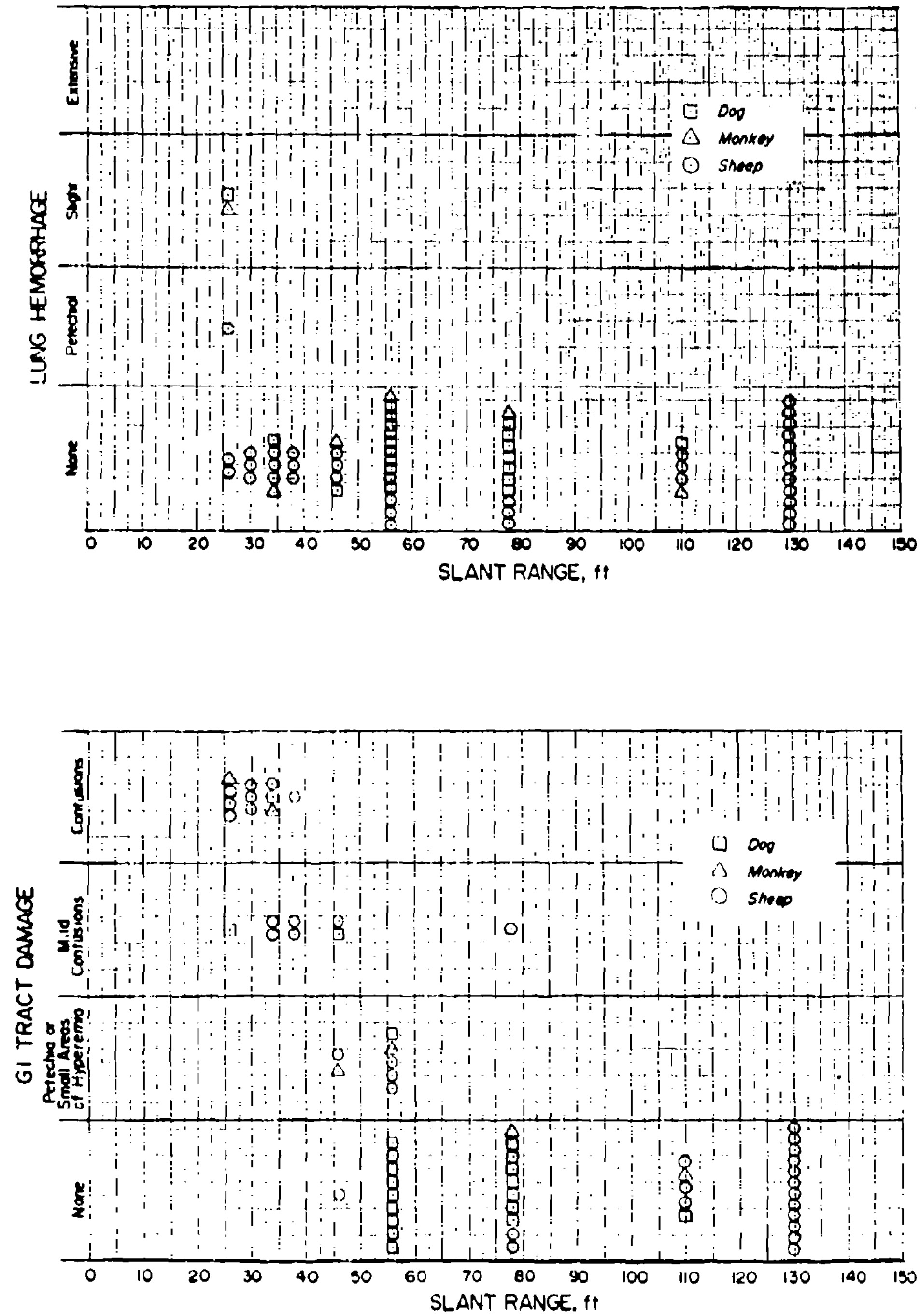


Figure 7.--The incidence of lung hemorrhage and G.I. tract injuries in animals at 1-ft depths in relation to slant range from 1-lb charges.

Underwater Blast Injuries as a Function of Impulse

The incidence of lung hemorrhages and G.I. tract lesions, along with the associated impulse values for all the animals exposed to the underwater blast in a vertical position, appear in figures 8a and 8b. The impulse values corresponding to each animal data point were those measured at the animals' designated depth, 1, 2, or 10 ft. As already mentioned, all these animals survived the underwater blast.

As seen in figure 8a, there was about a 50-percent incidence of slight lung hemorrhages at an impulse of 34 psi·msec. At an impulse on the order of 20 to 25 psi·msec, about half the animals sustained petechial hemorrhages. Below 20 psi·msec, there were no instances of slight lung hemorrhages. At impulses of 8 psi·msec and less, there was only one instance of petechial lung hemorrhage recorded in a sheep at 5.9 psi·msec. It is interesting to note that at the higher impulse levels some of the animals sustained no lung injury whatsoever. Lung lesions extended to lower impulse levels in those animals exposed to the underwater blast beneath the surface.

According to figure 7b, there was about a 50-percent incidence of G.I. tract contusions at impulse levels of 25 to 27 psi·msec. There were no contusions with ulcerations of the mucosal lining below an impulse level of about 15 psi·msec. About one-half of the animals subjected to an impulse of 21 to 23 psi·msec had either contusions or mild contusions in their G.I. tracts. The only lesions encountered below 10 psi·msec were two cases of animals with mild contusions at 6 to 7 psi·msec.

Animals Horizontal to Surface

Table A-9 of appendix A compares the severity of lung injury to that for the G.I. tract in six animals placed horizontal to the surface at 1-ft depths. The rationale was to expose the thorax and the abdomen of the animal at nearly the same depth and to the same impulse. Any air- or gas-containing organ, then, might be damaged to the same extent. The animals at the 26-ft range sustained slight lung hemorrhages and a few mild contusions of the G.I. tract. Those at the 16-ft range sustained slight to extensive lung hemorrhages and mild to multiple contusions with ulcerations into the lumen of the G.I. tract. As far as

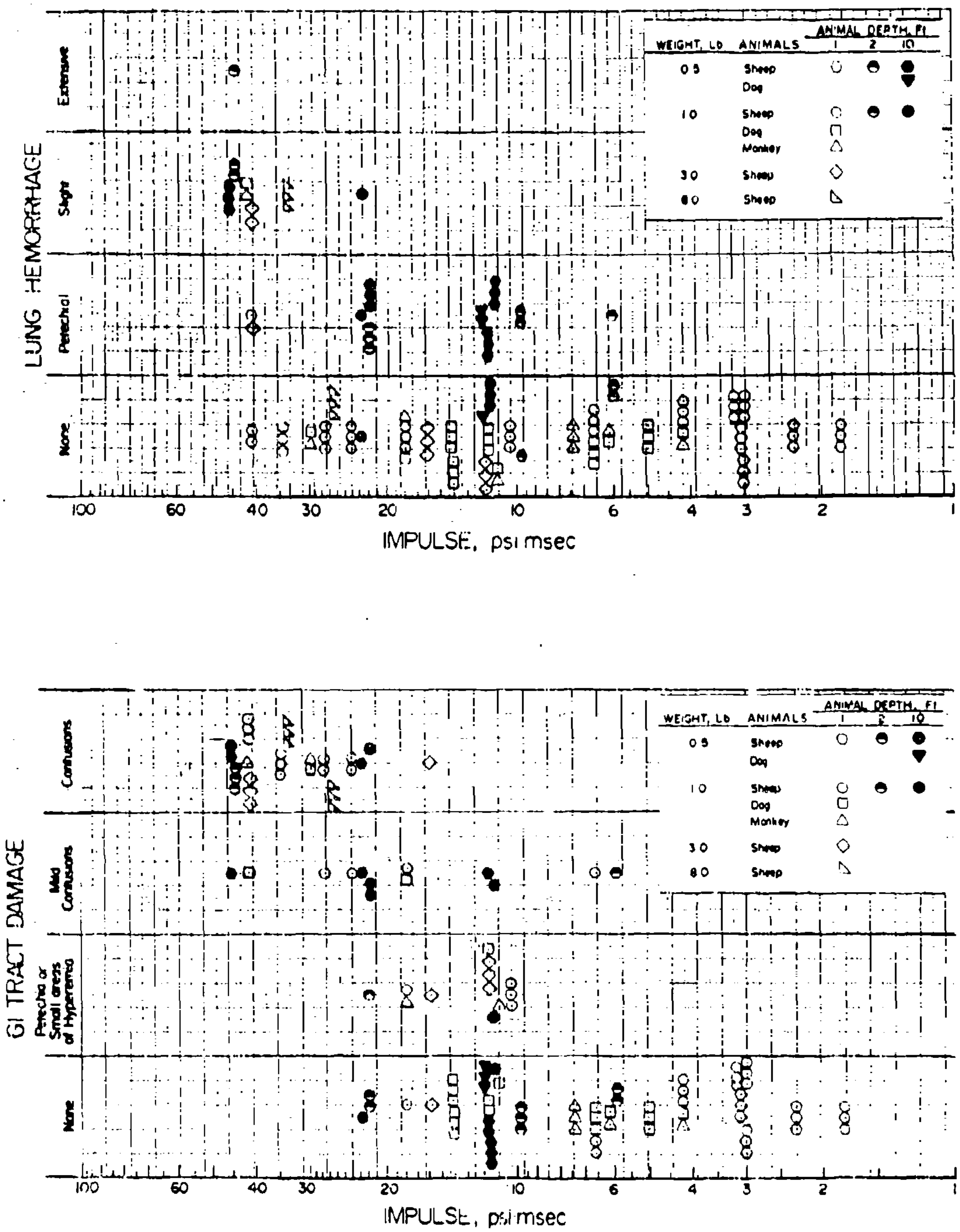


Figure 8.--The incidence of lung hemorrhage and G.I. tract injuries as a function of impulse, psi·msec.

one can go in comparing the severity of damage between two different organ systems, the results indicate the extent of damage to be about the same. Possibly the lungs were more damaged than the G.I. tract.

Table A-10 gives the results obtained with horizontal subjects at 0.5-ft depths in the prone and supine positions along with one animal that was vertical in the water at the usual 1-ft depth. The vertical animal received extensive lung hemorrhage and multiple ruptures of the small intestine. None of the animals at 0.5-ft depths received G.I. tract ruptures, and the extent of lung hemorrhage was less than that found in the upright animal. There was not a remarkable difference in the extent of injuries in the supine compared to the prone animals. The lung weights of the supine sheep (1.45 and 1.49 percent) were slightly higher than those from the prone ones (1.23 and 1.27 percent).

Ear Injury in Dogs

Table 7 gives the eardrum rupture data for dogs in terms of the percent of area destroyed and the corresponding range and pressure-time parameters. Photographs illustrating the different severities of ear injury are shown in figure 9. In general, the eardrums on the right side of the head (the heads were right-side-on) were more damaged than the left ones. The right ears from animals at the 20-ft range were more damaged than those at the 40-ft range in terms of the area of the tympanum destroyed and ossicular damage. In three cases, eardrum rupture was bilateral; the rest were unilateral.

Figure 10 gives the results of probit analysis that was run relating right eardrum rupture as a function of the log impulse. The data for animals at the 40-ft range were divided into two groups. The results predict that 50 percent of the right ears would be ruptured at an impulse of 22.6 psi·msec. The 85-percent confidence limits were 21.7 to 25.2 psi·msec. For both right and left ears there was a 36-percent incidence of eardrum rupture in dogs at the 40-ft range. The mean impulse measured on these four shots was 22.0 psi·msec; the mean peak pressure was 320 psi.

Control Animals

Table A-11 of appendix A lists the lesions recorded in control animals that were used. During the period of these tests, the life-support system appeared inadequate. Some of the control animals died when lowered to a 10-ft depth

Table 7.--Ear injury in dogs exposed right-side-on with their ears at 1-ft depths to underwater blasts from 1-lb TNT charges detonated at 10-ft depths.

Shot No.	Slant Range, ft	Peak Pressure, psi (Impulse, psi·msec) [Cut-Off Time, msec]	Dog No.	Eardrum Rupture, Percent Destroyed: Right Ruptured	Right Intact	Left Ruptured	Left Intact	Totals
194	20	676[a]	204	90%[b]			-	
		(68.2)	217	80%[b]			-	4/6
		[0.214]	215	100%[b]		60%		(66.7%)
195	40	319	1		N/A[c]		-	
		(23.5)	217'	60%			-	3/5
		[0.113]	218	60%		40%		
204	40	327	200	90%[b]		5%		
		(22.7)	116		-	50%		3/5
		[0.108]	210		-		N/A	
208	40	328	261		-		-	
		(21.5)	102		-		-	1/6
		[0.103]	262		-	30%		
210	40	307	263		-		-	
		(20.4)	117	30%			-	1/6
		[0.105]	163'		-		-	
								8/22 (36.4%)
200	45	292	120		-		-	
		(19.2)	253		-		-	0/6
		[0.099]	200'		-		-	
206	45	293	220		-		-	
		(19.0)	100		-	20%		1/5
		[0.092]	208		-		N/A	
								1/11 (9.1%)
197	60	215	205		-		-	
		(12.4)	163		-		-	0/6
		[0.078]	202		-		-	

[a]Pressure time was measured at 1-ft depths.

[b]Ossicles fractured or disrupted; otherwise intact.

[c]Not assessible.

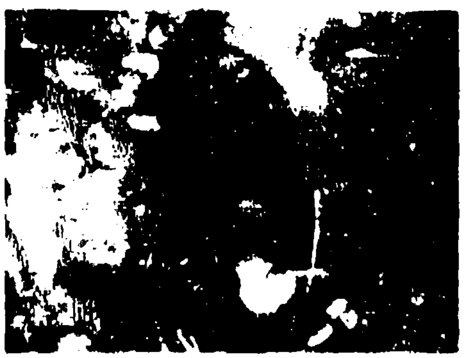
-Indicates eardrum intact.

Dog No. 205, Right Ear

Dog No. 253, Left Ear

Dog No. 218, Right Ear

Dog No. 218, Left Ear



Dog No. 215, Right Ear

Dog No. 215, Left Ear

Figure 9.--Dog eardrum and ossicular damage viewed from the middle ear.

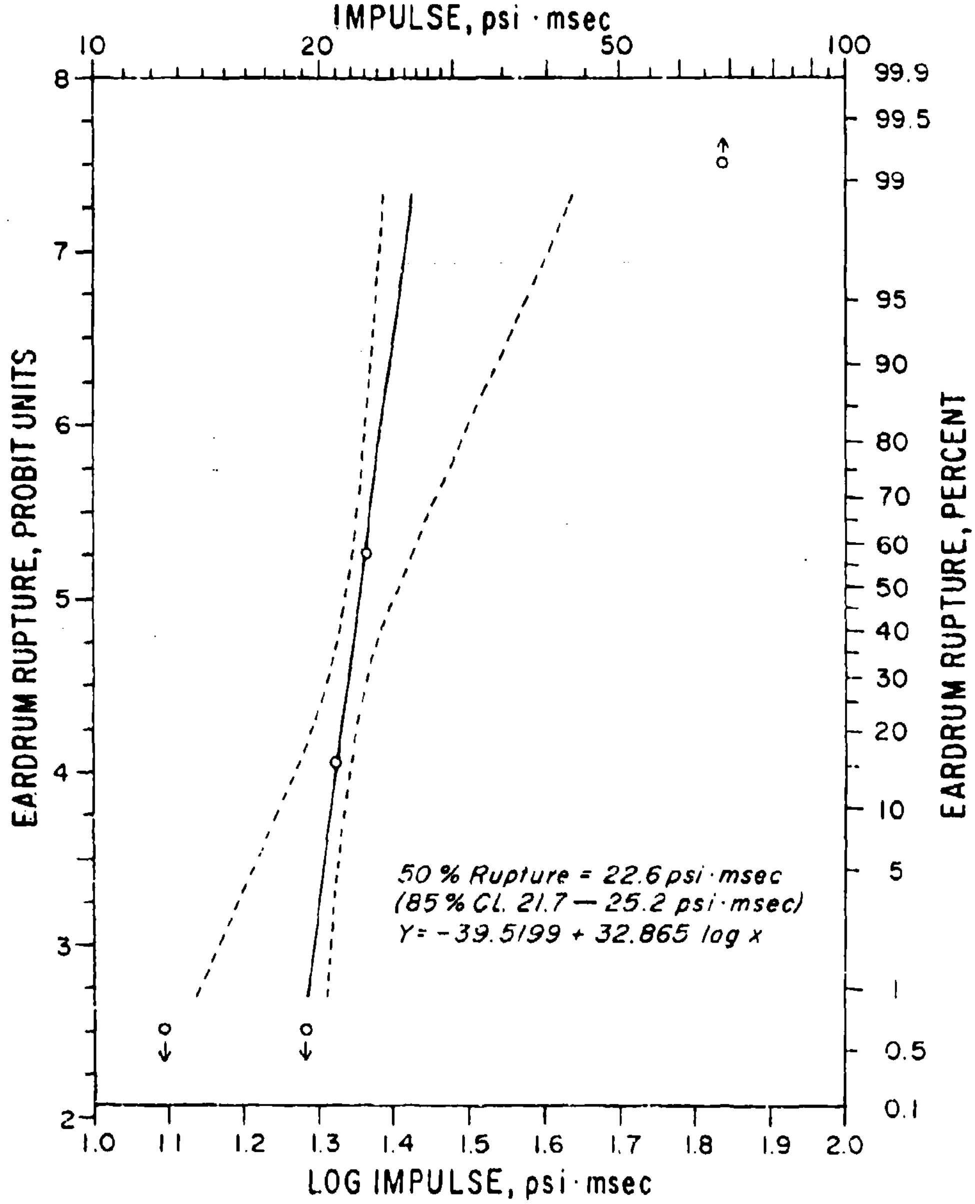


Figure 10.--Probit dose-response curve for the right ears of dogs.

for 4 minutes. No reason could be found for this malfunction. It was found that the life-support system could, in some instances, produce lung damage and hemorrhage in the lining of the middle ears and frontal sinuses. In addition, contusions of the endocardium were found in these subjects and in animals that received no blast. One of the animals placed at a 10-ft depth exhibited petechia about the anal sphincter. This lesion could be a result of placing the animal in a seated position. Hyperemic spots in the lining of the G.I. tract have been found in control sheep from other experiments in this facility. Histological examination revealed them to be caused by parasitic round worms. In some of the experimental sheep in the present study, hyperemic areas were assessed histologically and found to be associated with these parasitic round worms.

Pressure-Time Measurements

Incident Shock Waves

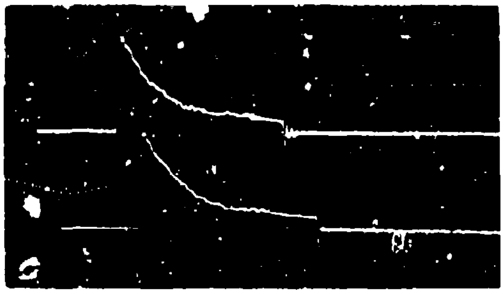
Pressure-time records showing the pattern of the incident shock waves, at selected ranges, are illustrated in figure 11. These records show that there is little to be desired from the NOL underwater-pressure gages which have the tourmaline crystals inside a Tygon® tube filled with silicone oil. The values for peak pressure, impulse, energy, theta, and cutoff time for each pressure-time record are listed in tables B-1 through B-10 of appendix B. As already mentioned, these values were calculated by a computer. The mean values for peak pressure, impulse, and cutoff time measured at 1-ft depths on the 1-lb charge firings are plotted in figure 12 in relation to slant range. The curves in figure 12 are those calculated from these empirically derived equations:

$$P_m = 18300 \left(W^{1/3}/R\right)^{1.10} \qquad (1)$$

$$\theta = 0.0603 \left(W^{1/3}/R\right)^{-0.168} W^{1/3} \qquad (2)$$

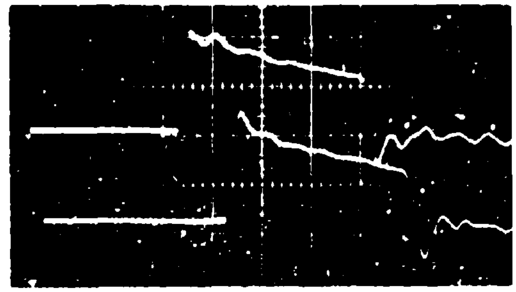
$$t_c = \left(R^2 + 4 D_w D_g - R\right) / C_o \qquad (3)$$

$$I = P_m \theta \left[\frac{9}{11} \left(1 - e^{-\frac{11 t_c}{10\theta}}\right) + 1 - e^{-\frac{t_c}{10\theta}} \right] \qquad (4)$$



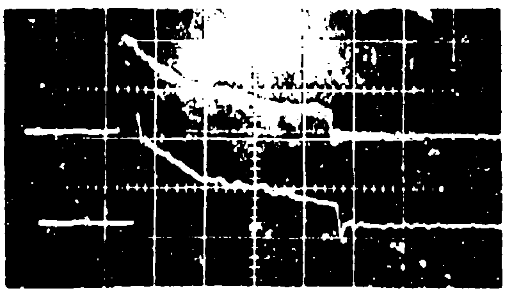
Shot No.: 188 Slant Range: 13 ft

Gage No.	Vertical Scale	Horiz. Scale
3257	565 psi/div	0.1 msec/div
3412	571 psi/div	0.1 msec/div



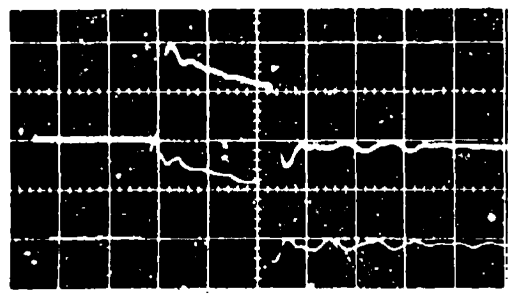
Shot No.: 199 Slant Range: 60 ft

Gage No.	Vertical Scale	Horiz. Scale
3414	100 psi/div	0.02 msec/div
3264	100 psi/div	0.02 msec/div



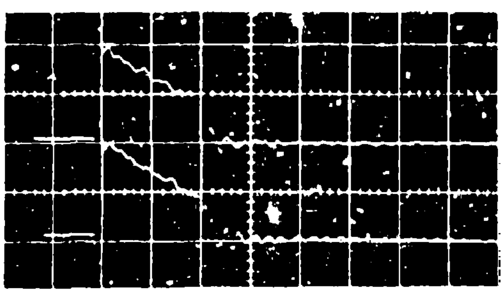
Shot No.: 191 Slant Range: 20 ft

Gage No.	Vertical Scale	Horiz. Scale
3414	329 psi/div	0.05 msec/div
3264	339 psi/div	0.05 msec/div



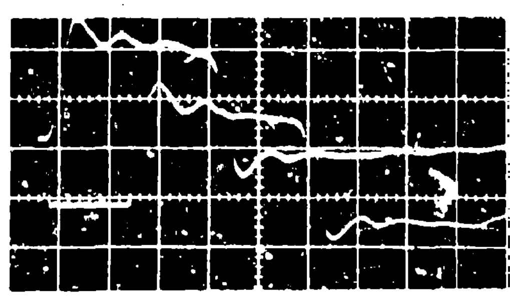
Shot No.: 207 Slant Range: 78 ft

Gage No.	Vertical Scale	Horiz. Scale
3257	75 psi/div	0.02 msec/div
3412	73 psi/div	0.02 msec/div



Shot No.: 204 Slant Range: 40 ft

Gage No.	Vertical Scale	Horiz. Scale
3257	153 psi/div	0.05 msec/div
3412	158 psi/div	0.05 msec/div



Shot No.: 193 Slant Range: 130 ft

Gage No.	Vertical Scale	Horiz. Scale
3257	45 psi/div	0.01 msec/div
3412	4[illegible] psi/div	0.01 msec/div

Figure 11. Oscillograms of incident shock waves from 1-lb charges at 10-ft depths recorded by gages at 1-ft depths.

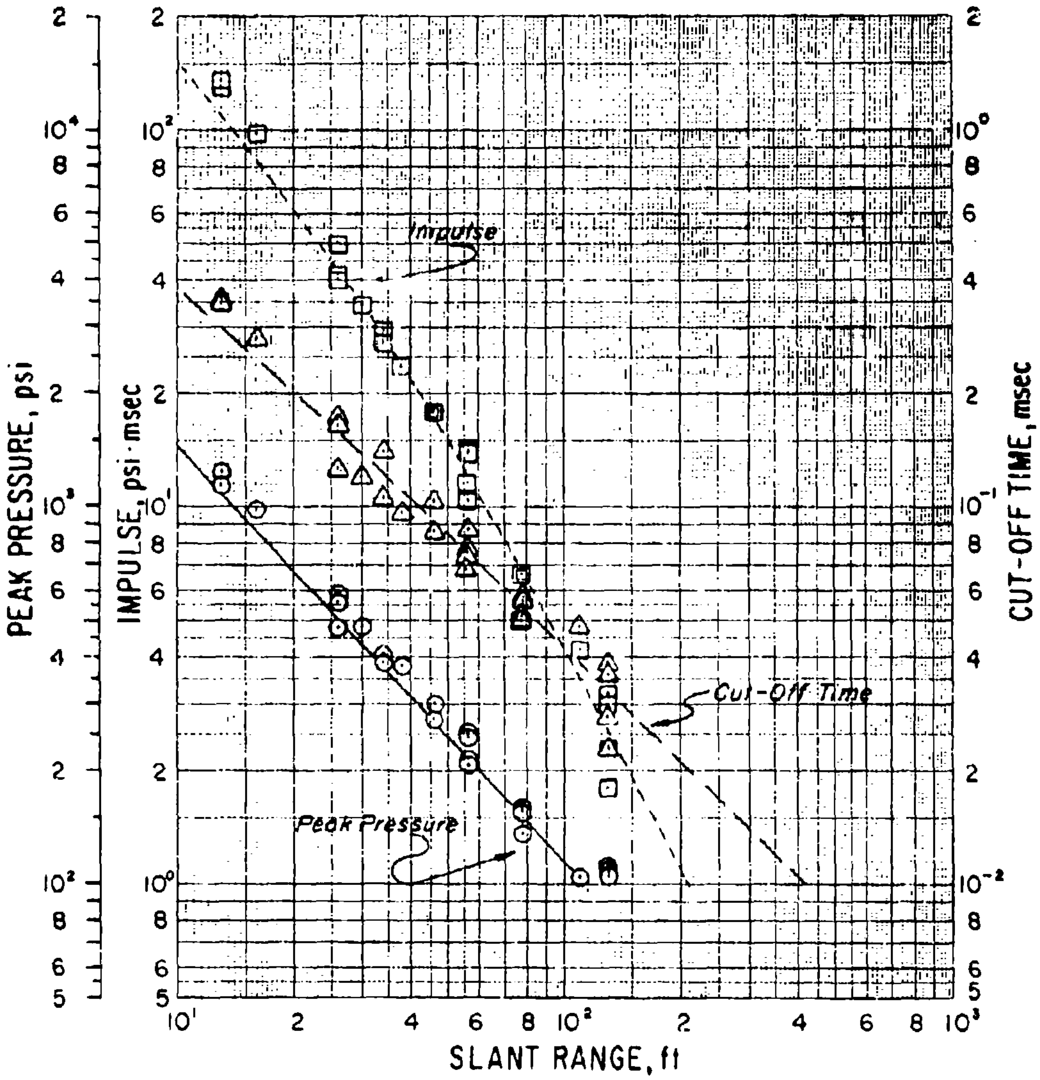


Figure 12.--Pressure-time parameters in the incident shock wave at 1-ft depths as a function of range from 1-lb charges detonated at 10-ft depths. [The data points were measured; the curves were computed.]

where W = charge mass, lb; R = slant range, ft; t_c = time of arrival of the surface cutoff wave, msec; θ = time constant, msec; P_m = peak overpressure, psi; I = impulse to cutoff time, psi·msec; D_w = depth of charge, ft; D_g = depth of gage, ft; and C_0 = speed of sound in water, 4.75 ft/msec.

As seen in figure 12 the measured data points for peak pressure, impulse, and cutoff time fall closely along the calculated curves. Moreover, there was little variation in the values measured by different gages, on a given shot, in regard to peak pressure, impulse, and cutoff times, tables B-1 through B-10 appendix B.

Negative Pressures

The peak negative pressures measured in the incident shock wave appear in tables B-1 through B-10 in appendix B. The peak negative pressures were read from the records from the preshock baseline to the maximum deflection the trace went below baseline. The mean peak negative pressures on each shot are plotted in figure 13 in relation to scaled slant range. The magnitude of the negative pressures decreased with increasing slant range. They ranged from 110 to 150 psi at scaled ranges of 13 and 16 ft to 20 to 25 psi at scaled ranges of 140 ft. The negative pressures were of short duration-on the order of 10 μsec, which, in terms of the frequency response of gages, could account for some of the scatter in these measurements. There was fair agreement between the points measured in this study and the curve for tap water from reference 8. The curves were obtained by measuring with piezoelectric gages the tension in the reflected wave in a vertical pipe filled with water. The bottom of the pipe contained a piston that was driven by a lead bullet fired at its center. The upper end of the pipe was open. The results showed that, the greater the pressure in the incident wave, the greater was the tension in the reflected wave, with maximum values in the tension wave leading off at 8.5 atmospheres for tap water and 15 atmospheres for boiled deionized water.

Bottom Reflections

A limited number of measurements were made of the waves that reflected from the bottom of the pond. The waveforms of these bottom reflections, recorded by gages at 1-ft depths on 1-lb charge firings, are illustrated in figure 14. As seen in the figure, the reflected waves recorded over the 13- to 45-ft

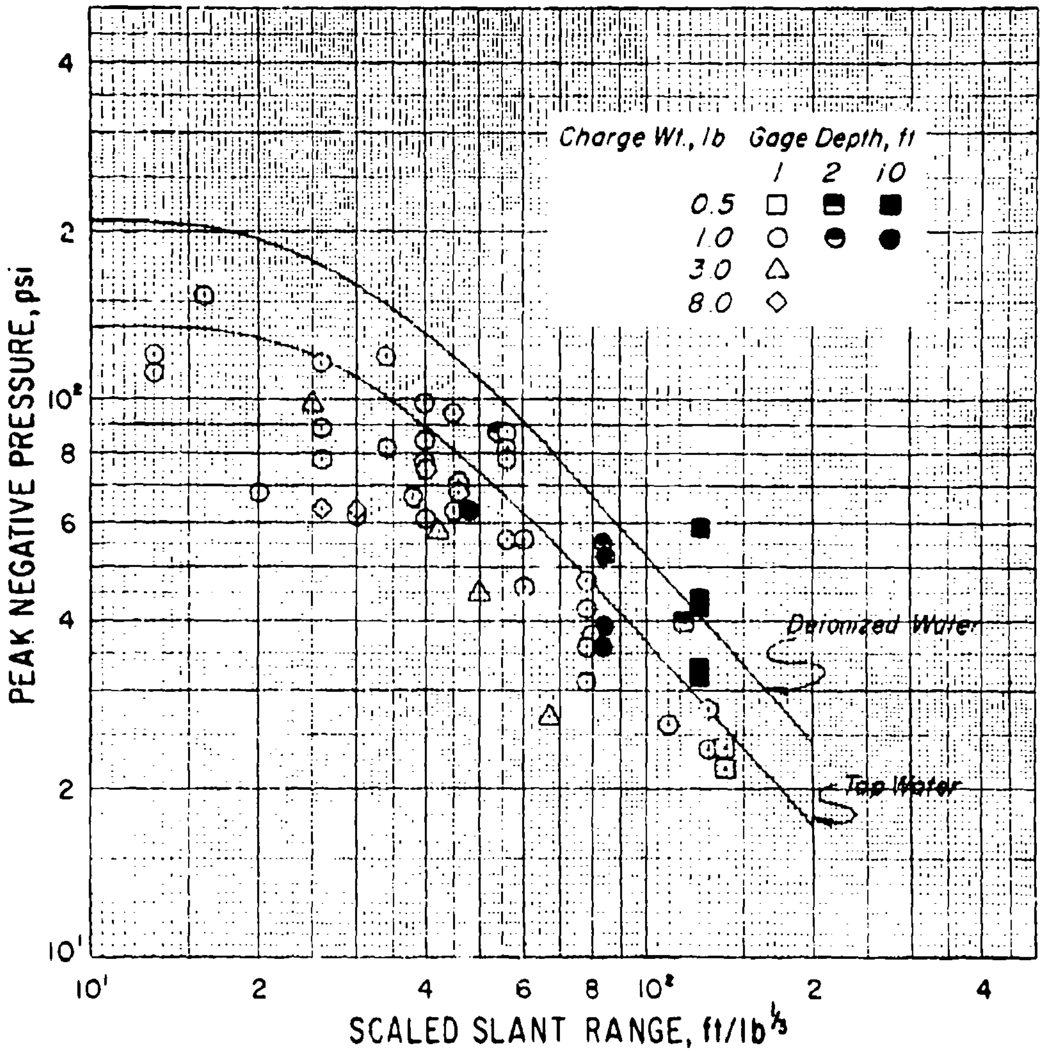
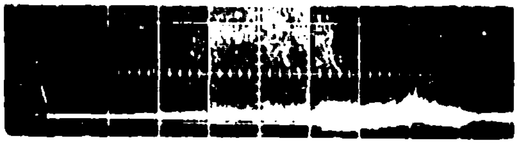
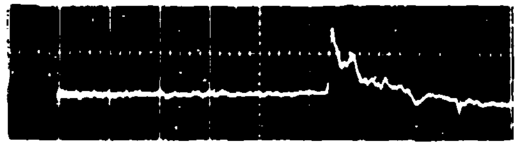


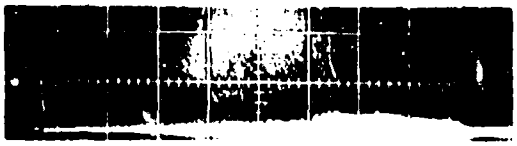
Figure 13.--Peak negative pressures as a function of scaled range from charges detonated at 10-ft depths. [The data points were measured; the curves were taken from reference 8.]



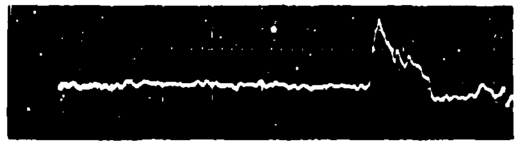
Shot No.: 188 Scale:
Gauge No.: 3414 Vertical: 583 psi/div
Slant Range: 13 ft Horiz.: 2.0 msec/div



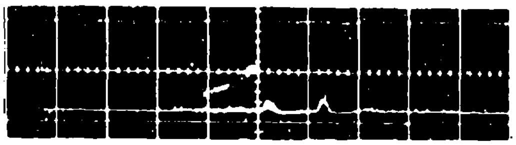
Shot No.: 205 Scale:
Gauge No.: 3264 Vertical: 124 psi/div
Slant Range: 56 ft Horiz.: 0.1 msec/div



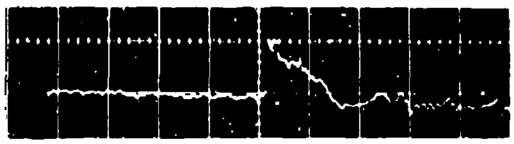
Shot No.: 189 Scale:
Gauge No.: 3414 Vertical: 450 psi/div
Slant Range: 16 ft Horiz.: 2.0 msec/div



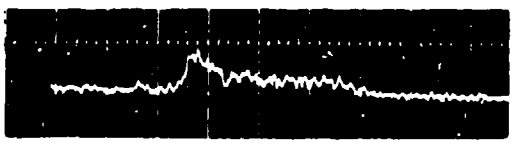
Shot No.: 199 Scale:
Gauge No.: 3264 Vertical: 92 psi/div
Slant Range: 66 ft Horiz.: 0.1 msec/div



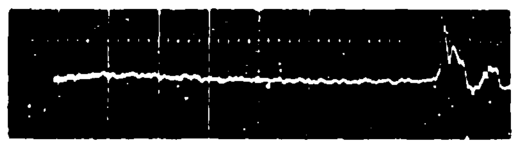
Shot No.: 194 Scale:
Gauge No.: 3257 Vertical: 243 psi/div
Slant Range: 20 ft Horiz.: 2.0 msec/div



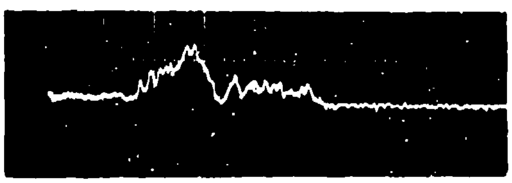
Shot No.: 199 Scale:
Gauge No.: 3412 Vertical: 89 psi/div
Slant Range: 66 ft Horiz.: 0.1 msec/div



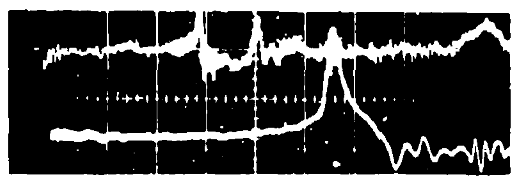
Shot No.: 196 Scale:
Gauge No.: 3264 Vertical: 145 psi/div
Slant Range: 40 ft Horiz.: 0.1 msec/div



Shot No.: 201 Scale:
Gauge No.: 3264 Vertical: 62 psi/div
Slant Range: 80 ft Horiz.: 0.1 msec/div



Shot No.: 200 Scale:
Gauge No.: 3264 Vertical: 109 psi/div
Slant Range: 45 ft Horiz.: 0.1 msec/div



Shot No.: 193 Scale:
Gauge No.: 3264 Vertical: 43 psi/div
Slant Range: 130 ft Horiz.: 0.05 msec/div

Figure 14.--Oscillograms of bottom reflected waves recorded by gages at 1-ft depths when 1-lb charges were detonated at 10-ft depths.

ranges were altered markedly from the ideal form that could be expected. The peak pressures were not on the leading portion of the waves. At and beyond the 60-ft range, the reflected waves appeared more normal in their pattern. Figure 15 gives the measured peak pressures and impulses in the bottom reflections along with the calculated curves. The peak pressure in the bottom reflected waves can be seen to be well below the calculated curves within the 45-ft range. Beyond 45 ft they were more near the curves. Measured impulses were an order of magnitude below the theoretical curve.

In contrast to peak pressure and impulse, the time between the incident and reflected shock waves and the cutoff times for the reflected wave were in fair agreement with the calculated curves, figure 16. The time between shocks ranged from near 10 msec at the closest range, down to 1.0 to 1.5 msec at the 130-ft range.

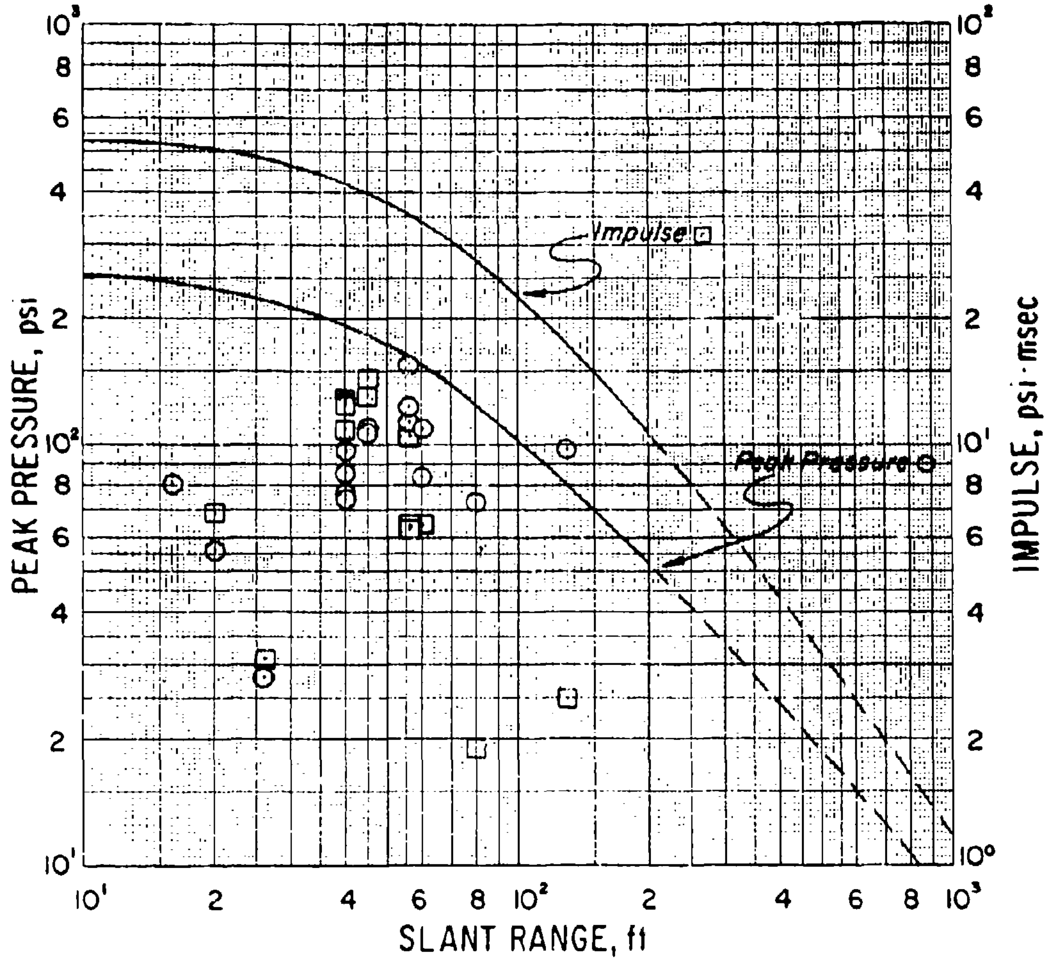


Figure 15.--Peak pressure and impulse in bottom reflected waves at 1-ft depths as a function of range from 1-lb charges detonated at 10-ft depths. [The data points were measured; the curves were computed.]

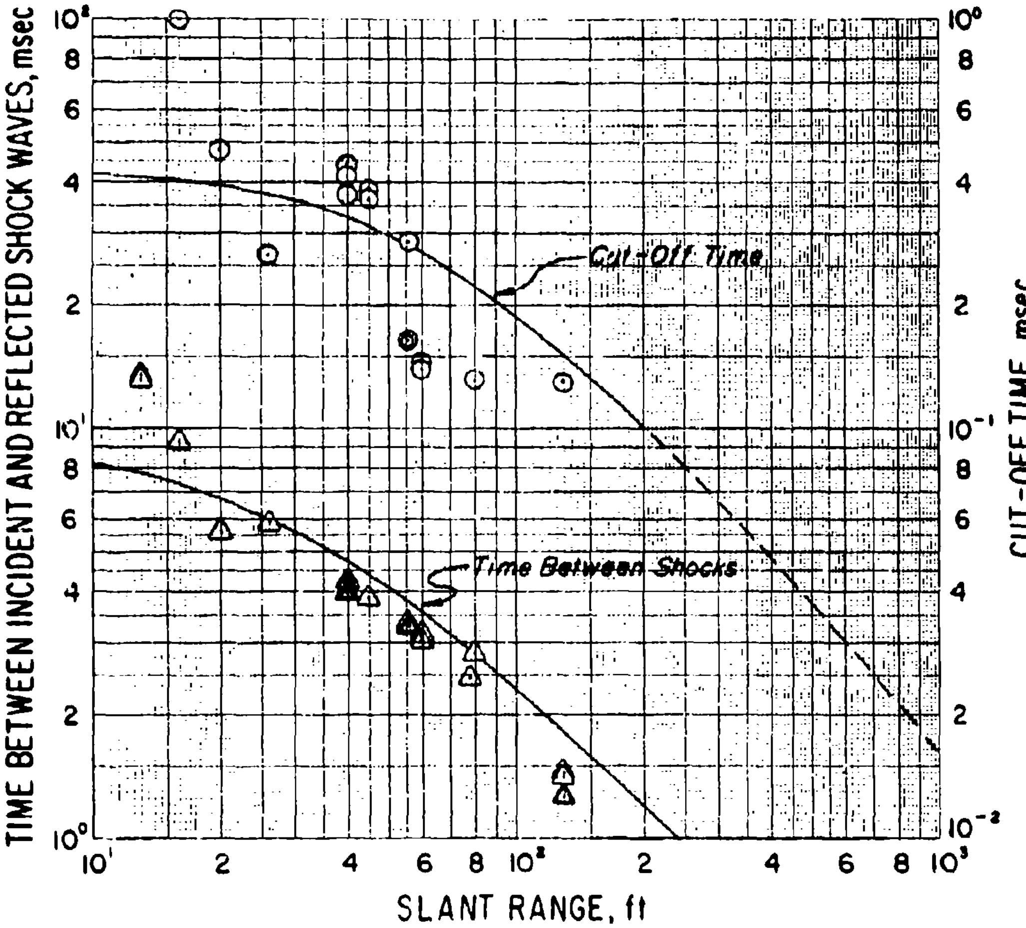


Figure 16.--Cutoff time for bottom reflected waves and time between the incident and reflected shock waves at 1-ft depths as a function of range from 1-lb charges detonated at 10-ft depths. [The data points were measured; the curves were computed.]

DISCUSSION

Safe Conditions From Underwater Explosions

This study has demonstrated how underwater-blast injuries fall off with range from small charges and has correlated these injuries and absence of injuries with the impulse parameter. This information well may be applied to establishing safe impulse levels (ranges) for swimmers in the environment of small underwater explosions. The results also may be applied to larger charge weights, provided swimmers are near the surface wherein the duration of the wave is governed more by the cutoff time than by charge weight. The results of this study also are helpful in establishing safe ranges because the results overlap animal data with volunteer swimmers.

According to the results of this study, large animal specimens did not receive any underwater-blast lesions at impulses of 1.8 to 3.0 psi·msec associated with peak pressures of 106 to 111 psi while at the 130-ft range from 1-lb charges with their heads out of the water. Thus, an impulse of 2 to 3 psi·msec, associated with a peak pressure on the order of 100 psi, apparently is a sure-safe underwater-blast dose for unprotected swimmers with their head out of the water. That these are a safe set of conditions for man, also, was confirmed by a volunteer swimmer, who was at the 130-ft range in the present study along with the sheep on Shot 193. The volunteer, clad only in swim trunks, was oriented vertically in the water immersed to his chin. He was face-on to the charge with arms outstretched to the side. The subject felt only one pulse in the form of some slight pressure over a 4- to 5-in diameter with a transient inward movement of the abdominal wall area around his navel which was approximately 1.5 ft beneath the water surface. Nothing was felt on other body regions. On the three preceding tests with 1-lb charges 60 ft from the west end of the pond, the volunteer was standing in the water at the southeast corner of the pond, a horizontal range of about 165 ft. The only sensation experienced from the underwater blast was a mild sting-like effect-like getting poked with the sharp end of a thumb tack. The effect was felt only at one point on the body: between the knees and ankles while in water 2.5-ft deep, between the hips and knees in water 3.5-ft deep, and at the lower abdomen while in water 5-ft deep (neck deep). Other pertinent information regarding unprotected swimmers is reported in reference 2. Volunteer swimmers wearing just swim trunks approached 110-lb charges at decreasing ranges where the calculated pressures were 22.5 psi to 69.2 psi and only experienced slight abdominal sensations with no feeling of impact on the thorax. The 110-lb charge was detonated at a 3-ft depth. The swimmers were in shallow water 5-ft deep with a soft mud bottom. On another occasion, with conditions paralleling the aforementioned ones, the volunteer was at 140 psi. The impulse levels were not given but were calculated to be 0.0128 psi·msec associated with 22 psi, 0.114 psi·msec for 69 psi, and 0.440 psi·msec for 140 psi. Unfortunately, the impulses were very low because the cutoff times were so short (0.58, 1.65, and 3.14 μsec) due to shallow burst depths and relatively long ranges.

Since blast lesions were rare in animals that received less than 10 psi·msec, the nondamaging impulse for man is probably higher than 2 to 3 psi·msec, but until more investigations are carried out, one would hesitate to predict the higher impulse levels that could be tolerated by unprotected swimmers. The underwater-blast impulse levels that humans could tolerate may depend on such factors as the amount, size, and distribution of metabolic gas bubbles in the G.I. tract. These factors could explain why the data suggest that the dog can tolerate higher impulse levels than the sheep without sustaining abdominal lesions.

Ear Injury

The authors are unaware of any information in the literature on eardrum rupture from underwater blast that could be compared with that from the present study. According to the results from the dogs, one would not expect eardrum rupture in swimmers with heads immersed at 2 to 3 psi·msec impulse levels. How obnoxious the sound intensity would be to a person at that impulse level can not be stated at this time.

The severity of ear injury encountered in the dogs tested at the 40-ft range could be important in terms of safety. At the 40-ft range (impulse 20.4 to 23.5 psi·msec), the ear injury was probably as serious an injury as the lung or G.I. tract injuries. At that range, half the dogs sustained eardrum rupture. When water enters the middle ear, especially unilaterally, it seriously disturbs man's sense of equilibrium. Obviously, this is a condition undesirable for someone swimming beneath the water's surface.

Bottom Reflections

There are several reasons why bottom reflections encountered in the test pond were not significant in regard to adding to the underwater-blast dose that the animals received.

First, based on the response of animals to air blasts having various waveforms (reference 9), the aberrant waveform of the bottom reflection over the ranges out to approximately 45 ft would not be expected to produce damage. Even though these impulses appear rather high in some instances, 10 to 15 psi·msec, the associated peak pressures were low, and the peak pressure was not at the leading edge of the wave. Beyond [illegible] ft, the waves are more ideal-like, but the peak pressures are low, and, more importantly, the pulses are of short duration so that the impulses are small.

Second, if the bottom reflections were to add to the incident blast-wave dose, one could expect to find a rise in the incidence of injuries at ranges that correspond to those where the reflected pressure waves are greater. That is, from 40 to 60 ft the pressure and impulse in the bottom reflections were the highest, yet the biological effects decreased over those ranges for targets at the 1-ft depths.

Third, some unpublished information exists in this laboratory that suggests that two pulses do not add to the damage effect unless they are delivered within a very short time--less than 2 msec. Furthermore, if these pulses are of low intensity, they are not additive even if delivered within the critical time. In order to have an additive effect from two pulses, they must be near lethal levels to begin with.

The reason that the bottom reflections are altered markedly from their classical waveforms cannot be given at this time. This effect is probably associated with the reflected wave having to travel through the bubble pulse and surrounding disturbed water, cavitation of the water, nature of the bottom, its angle of incident to the bottom, etc. Whatever the reason, it is beneficial not to have a strong reflection from the bottom in this test pond.

Negative Pressures

Although the biological effects correlated reasonably well with the impulse delivered by the underwater blast wave, the impulse may not necessarily be the exact damage parameter. It is not clear at this time whether or not the negative pressure could have something to do with the damage mechanism. If the negative pressure plays a part, one would expect the biological effects to correlate with some parameter(s) of the negative part of the pressure-time curve. This study was not designed to elucidate the damage mechanisms that must await future investigations.

Targets Horizontal to the Surface

The results of the tests run with animals horizontal to the surface suggest that the impulse necessary to inflict G.I. tract damage may not be much different from that necessary to cause lung hemorrhage. It has been stated repeatedly in the literature, for instance reference 10, that for personnel near the surface the impulse delivered to the deeper portions of the body is greater than that received by those closer to the surface. Consequently, for targets upright in the water at a given range from an underwater explosion, one would expect the abdominal lesions to be more severe than those in the thorax. However, for animals horizontal to the surface, there is little difference in the damage to these body regions. In this connection, the information obtained on the tests run with animals at 0.5-ft depths demonstrates well that a swimmer in the vicinity of an underwater explosion is far safer if he is attempting to get horizontal to the surface and as far out of the water as possible than if he is treading water; the difference in orientation could mean the difference between lethal and nonlethal blast injuries. One could not conclude from the limited amount of data whether or not the prone or supine orientation affords more protection from the underwater blast.

RECOMMENDATIONS

1. Perform tests to determine the effect of bubble size and distribution of metabolic gas on injury to the G.I. tract from underwater explosions.
2. Obtain pressure-time measurements inside animals during underwater-blast exposure. This should aid in understanding the mechanisms of underwater-blast damage and in developing a general damage model.
3. Investigate the possibility of using special clothing and ear protectors to reduce the severity of minor immersion-blast injuries.
4. Evaluate the sound effects produced by underwater explosions from small charges in the very far-field with animals and/or volunteer swimmers.

REFERENCES

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APPENDIX A

PATHOLOGY TABLES

Table A-1.--Effects of 0.5-lb charge fired at 10-ft depths on sheep at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
181	110 (110)	89 [a] (3.1) [0.047]	136 (41)	No lung hemorrhage, (lung weight, 0.9[illegible]%). No GI tract lesions; no blood clots in feces.
		81 [b] (4.5) [0.076]	143 (47)	No lung hemorrhage, (lung weight, 0.90%). No GI tract lesions; no blood clots in feces.
			129 (42)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions; no feces.
182		88 [a] (3.0) [0.044]	138 (36)	No lung hemorrhage, (lung weight, 1.04%). No GI tract lesions; no feces.
		81 [b] (4.5) [0.076]	144 (33)	No lung hemorrhage, (lung weight, 1.22%). No GI tract lesions; no feces.
			130 (36)	No lung hemorrhage, (lung weight, 1.06%). No GI tract lesions, no feces.

[a] Pressure time measured at 1-ft depths.

[b] Pressure time calculated for 2-ft depths.

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Table A-2.--Effects of 0.5-lb charge fired at 10-ft depths on sheep at 2-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
178	93 (93)	103 [a] (5.9) [0.091]	120 (40)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions. Both eardrums intact.
		97 [b] (7.6) [0.135]	124 (32)	No lung hemorrhage, (lung weight, 1.04%). No GI tract lesions. Both eardrums intact.
			247 (36)	Petechial lung hemorrhage, (lung weight, 0.86%). Mild contusions of GI tract. Both eardrums intact.

[a] Pressure time measured at 2-ft depths.

[b] Pressure time calculated for 2-ft depths.

Table A-3.--Effects of 0.5-lb charge fired at 10-ft depths on targets at 10-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
180	100 (100)	93 [a] (12.1) [0.454]	D-121 (19)	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions. Both eardrums intact.
			D-122 (18)	Petechial lung hemorrhages, (lung weight, 0.86%). No GI tract lesions. Both eardrums intact.
			D-118 (20)	Petechial lung hemorrhages, (lung weight, 0.82%). No GI tract lesions. Both eardrums intact.
170		111 [a] (11.7) [0.372]	S-123 (34)	Petechial lung hemorrhages, (lung weight, 1.05%). Mild contusions. Both eardrums intact. No blood in feces.
			S-101 (37)	Petechial lung hemorrhage, (lung weight, 1.18%). No GI tract lesions. No blood in feces. Both eardrums intact.
			S-122 (36)	Petechial lung hemorrhage, (lung weight, 1.00%). No GI tract lesions. Left eardrum ruptured, right eardrum intact.
169		92 [a] (11.5) [0.400]	S-108 (38)	No lung hemorrhage, (lung weight, 0.86%). No GI tract lesions; no feces. Right eardrum ruptured, left eardrum intact.
(continued)				

Table A-3.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
169 (con.)			S-121 (41)	Lungs discolored,[b] (lung weight, 1.30%). No GI tract lesions. Both eardrums intact.
			S-114 (40)	Lungs discolored,[b] (lung weight, 1.32%). No GI tract lesions. Both eardrums intact.
166	100 (100)	97 [a] (11.2) [0.382]	S-237 (50)	Petechial lung hemorrhage, (lung weight, 0.82%). Hyperemic spot in rectum; no feces. Both eardrums intact.
			S-55 (50)	Petechial lung hemorrhages, (lung weight, 0.83%). No GI tract lesions; no feces. Both eardrums intact.
			S-49 (48)	Petechial lung hemorrhages, (lung weight, 1.05%). Mild contusions of G. I. tract. No feces. Both eardrums intact.

[a] P.essure time measured at 10-ft depths.

[b] Sheep died-drowned or asphyxiated.

Table A-4.--Effects of 1-lb charge fired at 10-ft depths on targets at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
152	26 (24)	478[a] (41.5) [0.166]	D-224 (20)	Slight lung hemorrhage, (lung weight, 0.76%). Mild contusions of GI tract; no blood in feces.
		508[b] (55.6) [0.315]	M-76 (6)	Slight lung hemorrhage, (lung weight, 0.68%). Contusions of GI tract; blood clots in feces.
136		563[a] (40.6) [0.127]	S-156 (41)	Petechial lung hemorrhage, (lung weight, 1.02%). Contusions of GI tract; blood clots in feces.
		508[b] (55.6) [0.315]	S-185 (37)	No lung hemorrhage, (lung weight, 1.04%). Contusions of GI tract; blood clots in feces.
			S-189 (42)	No lung hemorrhage, (lung weight, 0.78%). Contusions of GI tract; blood clots in feces.
137	30 (29)	481[a] (34.7) [0.121]	S-169 (38)	No lung hemorrhage, (lung weight, 1.16%). Contusions of GI tract; blood clots in feces.
		434[b] (46.2) [0.275]	S-118 (38)	No lung hemorrhage, (lung weight, 0.94%). Contusions of GI tract; blood clots in feces.
			S-167 (41)	No lung hemorrhage, (lung weight, 0.89%). Contusions of GI tract; blood clots in feces.

(continued)

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
151	34 (33)	389[a] (29.7) [0.140]	M-80 (5.6)	No lung hemorrhage, (lung weight. 0.57%). Contusions of GI tract; blood clots in feces.
		378[b] (39.1) [0.244]	D-208 (21)	No lung hemorrhage, (lung weight, 0.72%). Contusions of GI tract; no feces.
138		407[a] (27.5) [0.107]	S-171 (41)	No lung hemorrhage, (lung weight, 0.94%). Contusions of GI tract; blood clots in feces.
		378[b] (39.1) [0.244]	S-115 (36)	No lung hemorrhage, (lung weight, 0.91%). Mild contusions of GI tract; no feces.
			S-116 (37)	No lung hemorrhage, (lung weight, 0.97%). Mild contusions of GI tract; no feces.
139	38 (37)	381[a] (23.9) [0.219]	S-NN (38)	No lung hemorrhage, (lung weight, 0.99%). Mild contusions of large intestine, contusions and petechia in rectum; blood clots in feces.
		335[b] (33.6) [0.219]		
			S-158 (39)	No lung hemorrhage, (lung weight, 1.27%). Mild contusions of GI tract; no feces.
			S-177 (37)	No lung hemorrhage, (lung weight, 1.05%). Contusions of GI tract; no feces.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
141	46 (45)	306[a] (18.2) [0.086] 271[b] (25.5) [0.181]	S-165 (40)	No lung hemorrhage, (lung weight, 0.87%). Mild contusions on large intestine and "hyperemic" spot in rectum; no feces.
			S-191 (36)	No lung hemorrhage, (lung weight, 0.81%). Petechia in rectum; no feces.
			S-188 (37)	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions; no feces.
151		274[a] (18.2) [0.104] 271[b] (25.5) [0.181]	D-207 (18)	No lung hemorrhage, (lung weight, 0.83%). Mild contusions of GI tract; no feces.
			M-43 (4)	No lung hemorrhage, (lung weight, 0.64%). Petechia in GI tract; no feces.
179	56 (55)	246[a] (14.2) [0.087]	D-213 (21)	No lung hemorrhage, (lung weight, 0.79%). No GI tract lesions.
		218[b] ([illegible]9.0) [0.149]	D-212 (2[illegible])	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions.
			D-164 (24)	No lung hemorrhage, (lung weight, 1.02%). No GI tract lesions.

(continued)

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
203	56 (55)	253[a] (14.0) [0.078]	D-116 (20)	No lung hemorrhage, (lung weight, 0.82%). No GI tract lesions.
		218[b] (19.0) [0.149]	D-200 (19)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions.
			D-210 (20)	No lung hemorrhage, (lung weight, 0.84%). No GI tract lesions.
205		218[a] (11.7) [0.077]	D-220 (14)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions.
		218[b] (19.0) [0.149]	D-210 (14)	No lung hemorrhage, (lung weight, 0.81%). No GI tract lesions.
			D-208 (14)	No lung hemorrhage, (lung weight, 0.98%). Focal mucosal hemorrhage in area of ileo-cecal valve.
153		200[a] (11.0) [0.080]	D-221 (21)	No lung hemorrhage, (lung weight, 0.84%). No GI tract lesions; no feces.
		218[b] (19.0) [0.149]	M-84 (5.9)	No lung hemorrhage, (lung weight, 0.48%). Hyperemic spots near anus; no feces.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
145	56 (55)	207[a] (10.4) [0.068]	S-212 (46)	No lung hemorrhage, (lung weight, 0.85%). Few petechia at anus; no feces.
		218[b] (19.0) [0.149]	S-217 (46)	No lung hemorrhage, (lung weight, 0.91%). Small hyperemic area in rectum; blood clots in feces.
			S-211 (43)	No lung hemorrhage, (lung weight, 0.89%). Few petechia at anus; no blood clots in feces.
207	78 (78)	160[a] (6.6) [0.057]	D-261 (20)	No lung hemorrhage, (lung weight, 0.87%). No GI tract lesions.
		152[b] (11.1) [0.108]	D-102 (15)	No lung hemorrhage, (lung weight, 1.22%). No GI tract lesions.
			D-262 (19)	No lung hemorrhage, (lung weight, 0.87%). No GI tract lesions.
147		156[a] (6.6) [0.053]	S-228 (36)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions; no blood clots in feces.
		152[b] (11.1) [0.108]	S-162 (37)	No lung hemorrhage, (lung weight, 0.99%). No GI tract lesions; no blood clots in feces.
			S-199 (39)	No lung hemorrhage, (lung weight, 0.77%). Mild contusion in caecum; no blood in feces.

(continued)

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
154	78 (78)	157[a] (6.2) [0.055]	D-216 (21)	No lung hemorrhage, (lung weight, 0.75%). No GI tract lesions; no feces.
		152[b] (11.1) [0.108]	M-85 (4.6)	No lung hemorrhage, (lung weight, 0.56%). No GI tract lesions; no feces.
209		136[a] (5.0) [0.050]	D-263 (19)	No lung hemorrhage, (lung weight, 1.05%). No GI tract lesions.
		152[b] (11.1) [0.108]	D-117 (14)	No lung hemorrhage, (lung weight, 1.41%). No GI tract lesions except for few pin-head size spots in rectum.
			D-163 (14)	No lung hemorrhage, (lung weight, 1.62%). No GI tract lesions.
155[a,c]	110 (110)	104[a] (4.2) [0.048]	D-0 (16)	No lung hemorrhage, (lung weight, 0.89%). No GI tract lesions.
		104[b] (6.1) [0.076]	M-33 (3.4)	No lung hemorrhage; (lung weight, 0.63%). No GI tract lesions.
156[a,c]		104[a] (4.2) [0.048]	S-193 (36)	No lung hemorrhage; (lung weight, 0.85%). No GI tract lesions.
		104[b] (6.1) [0.076]	S-172 (39)	No lung hemorrhage; (lung weight, 0.92%). No GI tract lesions.
			S-222 (36)	No lung hemorrhage; (lung weight, 0.90%). No GI tract lesions.

(continued)

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
192	130 (130)	111[a] (3.2) [0.038]	S-71 (46)	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions; no feces.
		87[b] (4.5) [0.065]	S-70 (45)	No lung hemorrhage, (lung weight, 0.89%). No GI tract lesions; no feces.
			S-72 (47)	No lung hemorrhage, (lung weight, 0.97%). No GI tract lesions; no feces.
193		108[a] (3.0) [0.036]	S-73 (46)	No lung hemorrhage, (lung weight, 0.85%). No GI tract lesions; no feces.
		87[b] (4.5) [0.065]	S-74 (45)	No lung hemorrhage, (lung weight, 0.86%). No GI tract lesions; no feces.
			S-75 (45)	No lung hemorrhage, (lung weight, 0.70%). No GI tract lesions; no feces.
190		106[a] (2.3) [0.028]	S-66 (49)	No lung hemorrhage, (lung weight, 0.76%). No GI tract lesions; no feces.
		87[b] (4.5) [0.065]	S-64 (45)	No lung hemorrhage, (lung weight, 0.80%). No GI tract lesions; no feces.
			S-65 (50)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions; no feces.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
191	130 (130)	110[a] (1.8) [0.023]	S-67 (50)	No lung hemorrhage, (lung weight, 0.87%). No GI tract lesions; no feces.
		87[b] (4.5) [0.065]	S-68 (50)	No lung hemorrhage, (lung weight, 0.76%). No GI tract lesions; no feces.
			S-69 (47)	No lung hemorrhage, (lung weight, 0.85%). No GI tract lesions; no feces.

[a] Pressure time measured at 1-ft depths.

[b] Pressure time calculated for 2-ft depths.

[c] Pressure-time values taken from shot no. 158.

Table A-5.--Effects of 1-lb charge fired at 10-ft depths on sheep at 2-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
175	33 (32)	436 [a] (44.4) [0.236] 391 [b] (46.2) [0.373]	S-102 (37)	Slight lung hemorrhage, (lung weight, 1.27%). Contusions of GI tract, petechia in rectum; blood clots in feces. Both eardrums ruptured.
			S-116 (41)	Slight lung hemorrhage, (lung weight, 0.97%). Contusions of GI tract; no feces. Right eardrum ruptured, left eardrum not readable.
			S-104 (34)	Extensive lung hemorrhage, (lung weight, 1.45%). Contusions of GI tract, no ulceration; blood clots in feces. Right eardrum intact, left eardrum not readable.
176	54 (53)	259[a] (21.9) [0.160] 227[b] (24.2) [0.232]	S-106 (36)	Pe[illegible]hial lung hemorrh[illegible], (lung weight, 0.94%). No GI tract lesions. Eardrums intact.
			S-107 (34)	Petechial lung hemorrhage (lung weight, 1.03%). No GI tract lesions. Eardrums intact.
			S-111 (34)	Petechial lung hemorrhage, (lung weight, 1.10%). Few petechia in rectum. Right eardrum intact, left eardrum not readable.

(continued)

Table A-5.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
177	83 (83)	150[a] (9.7) [0.101]	S-118 (43)	Petechial lung hemorrhage, (lung weight, 0.90%). No GI tract lesions. Both eardrums intact.
		142[b] (12.8) [0.152]	S-50 (40)	Petechial lung hemorrhage, (lung weight, 0.74%). No GI tract lesions. Both eardrums intact.
			S-119 (33)	No lung hemorrhage, (lung weight, 0.91%). No GI tract lesions. Both eardrums intact.

[a] Pressure time measured at 2-ft depths.
[b] Pressure time calculated for 3-ft depths.

Table A-6.--Effects of 1-lb charge fired at 10-ft depths on sheep at 10-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
168	48 (48)	269 [a] (45.5) [0.809]	S-103 (42)	Slight lung hemorrhage, (lung weight, 0.80%). Mild contusions and petechia in GI tract; no feces. Both eardrums intact.
			S-115 (41)	Slight lung hemorrhage, (lung weight, 0.90%). Mild contusions of GI tract; trace of blood in feces. Both eardrums intact.
			S-105 (40)	Slight lung hemorrhage, (lung weight, 1.26%). Mild contusions of stomach and small intestine; scatt[illegible]d contusions of lar[illegible] [illegible]testine and rectum, no feces. Both eardrums intact.
167	84 (84)	153 [a] (22.8) [0.516]	S-113 (41)	Few petechial lung hemorrhage, (lung weight, 0.83%). No GI tract lesions. Both eardrums intact.
			S-148 (42)	Slight lung hemorrhage, (lung weight, 0.73%). Contusions of rectum; no feces. Both eardrums intact.
			S-117 (44)	No lung hemorrhage, (lung weight, 0.81%). Mild contusions of GI tract; no feces. Both eardrums intact.

(continued)

Table A-6.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
171	84 (84)	166[a] (21.7) [0.429]	S-110 (43)	Petechial lung hemorrhage, (lung weight, 0.89%). Mild contusions of GI tract; no feces. Both eardrums intact.
			S-125 (41)	Petechial lung hemorrhage, (lung weight, 0.90%). One contusion of caecum; no feces. Both eardrums intact.
			S-109 (37)	Petechial lung hemorrhage, (lung weight, 1.13%). Mild contusions of large intestine, no ulcerations; no feces. Eardrums not readable.

[a] Pressure time measured at 10-ft depths.

Table A-7.--Effects of 3-lb charge fired at 10-ft depths on sheep at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
143	36 (35)	538 [a] (40.3) [0.106] 532 [b] (64.4) [0.230]	S-179 (36)	Slight lung hemorrhage, (lung weight, 1.25%). Contusions of large intestine; blood clots in feces.
			S-173 (34)	Slight lung hemorrhage, (lung weight, 1.09%). Contusions of GI tract; no feces.
			S-97 (36)	Petechial lung hemorrhages, (lung weight, 1.02%). Contusions of GI tract; no feces.
144	61 (60)	299 [a] (15.9) [0.066] 298 [b] (27.9) [0.137]	S-201 (41)	No lung hemorrhage, (lung weight, 0.84%). No GI tract lesions; no feces.
			S-215 (45)	No lung hemorrhage, (lung weight, 0.88%). Single contusion of large intestine and rectum; no blood clots in feces.
			S-225 (43)	No lung hemorrhage, (lung weight, 0.84%). Scattered petechia in rectum; blot clots in feces.
146	72 (71)	248 [a] (11.8) [0.059] 248 [b] (21.0) [0.116]	S-214 (39)	No lung hemorrhage, (lung weight, 0.86%). Scattered petechia in rectum, no blood clots in feces.

(continued)

Table A-7.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body) Wt., kg)	Effects
146 (con.)			S-229 (42)	No lung hemorrhage, (lung weight, 0.94%). Scattered petechia in rectum; no blood in feces.
			S-224 (41)	No lung hemorrhage, (lung weight, 0.78%). Scattered petechia in rectum; blood clots in feces.
148	97 (97)	191 [c] (7.4) [0.047]	S-206 (39)	No lung hemorrhage, (lung weight, 0.99%). No GI tract lesions; no blood clots in feces.
		179 [b] (12.3) [0.087]	S-184 (39)	No lung hemorrhage, (lung weight, 1.04%). No GI tract lesions; no blood clots in feces.
			S-205 (39)	No lung hemorrhage, (lung weight, 0.87%). Few petechia in anus, no blood clots in feces.

[a] Pressure time measured at 1-ft depths.

[b] Pressure time calculated for 2-ft depths.

[c] Pressure-time values taken from shot no. 150.

Table A-8.--Effects of 8-lb charge fired at 10-ft depths on sheep at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
140	52 (51)	556[a] (33.2) [0.074]	S-186 (36)	Slight lung hemorrhage, (lung weight, 1.07%). Contusions of GI tract; blood clots in feces.
		508[b] (57.4) [0.161]	S-194 (37)	Slight lung hemorrhage, (lung weight, 0.91%). Contusions of GI tract; no feces.
			S-161 (36)	Slight lung hemorrhage, (lung weight, 0.92%). Contusions of GI tract; blood clots in feces.
142	60 (59)	477[a] (26.4) [0.067]	S-187 (34)	No lung hemorrhage, (lung weight, 1.08%). Mild contusions of rectum; blood clots in feces.
		434[b] (44.7) [0.140]	S-114 (34)	No lung hemorrhage, (lung weight, 1.11%). Contusions of GI tract; blood clots in feces.
			S-85 (37)	No lung hemorrhage, (lung weight, 0.73%). Contusions of GI tract; blood clots in feces.

[a] Pressure time measured at 1-ft depths.

[b] Pressure time calculated for 2-ft depths.

Table A-9.--Effects of 1-lb charge fired at 10-ft depth on targets at 1-ft depths horizontal to surface.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
189	16 (13.2)	987[a] (99.6) [0.281]	S-62 (43)	Extensive lung hemorrhage, (lung weight, 2.38%). Bloody froth at nares. Scattered light contusions with slight ulcerations of mucosa; feces, no blood clots. Hemorrhage in tracheal wall.
			S-61 (46)	Slight lung hemorrhage, (lung weight, 0.87%). Sub-serosal extravasation in the caecum; no feces. Extensive hemorrhage in tracheal wall.
			S-63 (45)	Extensive lung hemorrhage, (lung weight, 1.34%). Bloody froth at nares. Multiple contusions with ulcerations of G.I. tract; no feces. Hemorrhage in tracheal wall.
183	26 (24)	588[a] (50.6) [0.173]	S-141 (36)	Respiration normal. Petechial lung hemorrhage, (lung weight, 0.95%). A few small (1/8-1/4-in.) hyperemic areas in the ansa terminalis. No feces.
			S-134 (34)	Respiration normal. Slight lung hemorrhage, (lung weight, 1.08%). Several mild contusions in the ansa terminalis. No feces.
			D-231 (16)	Respiration normal. Slight lung hemorrhage (lung weight, 0.91%). One small (1/8-in.) mild contusion in rectum. No feces.

[a] Pressure time measured at 1-ft depths.

All animals were oriented prone in the water.

Table A-10.--Effects of 1-lb charge fired at 10-ft depths on targets at 0.5-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
187	13 (10)	1147[a] (132.6) [0.354] 1089[b] (85.7) [0.157]	S-55 (43) VRSO[c]	Extensive lung hemorrhage, (lung weight, 1.60%). Down; grunting respiration. Six ruptures of small intestine. Multiple large areas of submucosal contusions with ulcerations of mucosal lining throughout stomach, large and small intestine, and rectum. Frank blood from anus.
			S-56 (49) Prone[c]	Slight lung hemorrhage (lung weight, 1.27%). Four one-inch segments of submucosal mild contusions in ansa terminalis and rectum. Feces; no hemorrhage.
			S-57 (43) Supine[c]	Extensive lung hemorrhage, (lung weight, 1.45%). Few half inch subserosal contusions and hyperemic areas in ansa terminalis. No ulcerations of mucosal lining. No feces.
188	13 (10)	1224[a] (135.4) [0.358] 1089[b] (85.7) [0.157]	S-58 (48) Supine	Extensive lung hemorrhage, (lung weight, 1.49%). Two submucosal contusions with ulceration of mucosal lining and one small mild contusion in caecum. Petechia surrounding fecal pellets in ansa spiralis. Feces; no blood clots.

(continued)

Table A-10.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
188	(continued)		S-59[c] (50) Prone[c]	Extensive lung hemorrhage, (lung weight, 1.27%). Slight amount of bloody froth from nares. Small contusion on stomach, four 1/8-1/4-inch submucosal contusions on small intestine and scattered small areas of submucosal contusions throughout spiralis and ansa terminalis with pin-head size clots of blood in lumen.
			S-60 (49) Prone[c]	Extensive lung hemorrhage, (lung weight, 1.23%). Respiration slightly labored; slight amount of bloody froth from nares. Multiple small areas of subserosal contusions in small intestine. A 2-inch submucosal contusion in large colon and a few 1-inch submucosal contusions in ansa terminalis. No feces.

[a] Pressure time measured at 1-ft depths.

[b] Pressure time calculated for 0.5-ft depths.

[c] Animal Orientations: VRSO - Animal mounted vertically in the water right-side-on (long axis perpendicular to surface). Supine = Animal mounted horizontally in the water, supine. Prone = Animal mounted horizontally in the water, prone.

Table A-11.--Lesions recorded in control animals.

Treatment	Animal No.[a]	Effects
None	S-250	All organs negative. Lung weight, 0.85%.
	S-112	Lungs negative; lung weight, 0.83%. 1/8-in^2 hemorrhagic spot on mitral valve.
Placed on animal mounts on the grid and held at 1-ft depth.	S-190	All organs negative. Lung weight, 1.20%.
	S-112	All organs negative. Lung weight, 1.28%.
Placed on animal mounts on the grid and held at 10-ft depth for 4-min, no blast.	S-127	Died, water in face mask. Lungs discolored, many petechia. Lung weight, 2.02%. Hemorrhages beneath lining of middle ears.
	S-126	Died, no water in face mask. Lungs discolored. Lung weight, 1.75%. Middle ears negative.
	D-00	Sacrificed at 1 hr. Lungs negative. Lung weight, 0.94%. Two small subcapsular contusions in spleen. Hemorrhages beneath lining of middle ears.
	S-141	Air hungry. Many scattered petechia throughout lungs. Lung weight, 0.92%. Mild contusions in endocardium. Petechia at the anus. Petechia lining middle ears.
	S-228	Died. Lungs discolored, light colored hemorrhages. Lung weight, 2.07%. Petechia lining middle ears.
	S-69	Air hungry. Scattered petechia throughout lungs. Lung weight, 0.89%. Hemorrhages beneath lining of middle ears and frontal sinus. Contusions of endocardium.

[a] S = sheep; D = dog.

APPENDIX B

PRESSURE-TIME PARAMETER TABLES

Table B-1.--Pressure-time parameters measured at 1-ft depths when 0.5-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
181	3257	110	109.6	91	3.1	0.04	0.046	0.087	29	-
	3412			94	3.3	0.04	0.054	0.075	NR[b]	-
	3414			83	2.8	0.04	0.042	0.133	19	-
Mean				89	3.1	0.04	0.047	0.098	24	-
	3264[a]			20	1.0	0.003	0.122	-	-	2.000
182	3257	110	109.6	95	3.2	0.04	0.045	0.076	29	-
	3412			94	3.2	0.04	0.047	0.064	18	-
	3414			74	2.6	0.03	0.040	-	20	-
Mean				88	3.0	0.04	0.044	0.070	22	-
	3264[a]			7	0.7	0.001	0.356	-	-	1.967

a Bottom reflection parameters.

b Not readable.

Table B-2. --Pressure-time parameters measured at 2-ft depths when 0.5-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
178	3257	93	92.7	105	6.0	0.08	0.091	0.090	43	-
	3412			111	6.5	0.09	0.097	0.092	42	-
	3414			94	5.2	0.07	0.085	0.097	34	-
Mean				103	5.9	0.08	0.091	0.093	40	-
	3264[a]			33	0.5	0.002	0.054	-	-	2.174

[a] Bottom reflection parameters.

Table B-3. --Pressure-time parameters measured at 10-ft depths when 0.5-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
180	3257	100	100	100	11.6	0.10	0.445	0.096	58	-
	3412			86	12.8	0.10	0.455	0.129	58	-
	3414			93	12.0	0.10	0.463	0.109	62	-
Mean				93	12.1	0.10	0.454	0.111	59	-
	3264[a]			36	1.2	0.003	0.247	-	-	0.685
170	3257	100	100	113	11.4	0.12	0.370	0.093	32	-
	3412			109	12.0	0.12	0.374	0.099	31	-
Mean				111	11.7	0.12	0.372	0.096	32	-
	3264[a]			------------NR[b]------------						
169	3257	100	100	94	11.9	0.10	0.416	0.112	48	-
	3412			91	11.4	0.09	0.414	0.112	NR	-
	3414			90	11.3	0.10	0.371	-	41	-
Mean				92	11.5	0.10	0.400	0.112	44	-
	3264[a]			47	0.7	0.004	0.055	-	-	1.429

Table B-3.--(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
165	3257	100	100	92	10.7	0.09	0.385	0.092	34	-
	3412			103	11.5	0.10	0.380	0.086	30	-
	3414			95	11.3	0.10	0.381	0.106	35	-
Mean				97	11.2	0.10	0.382	0.095	33	-
	3264[a]			72	0.7	0.003	0.055	-	-	1.475
155	3257	100	100	96	10.3	0.09	0.339	0.069	42	-
	3264			96	11.7	0.10	0.351	0.104	45	-
	3414			94	11.4	0.10	0.354	0.103	43	-
Mean				95	11.1	0.10	0.348	0.092	43	-
	3412[b]			60	1.2	0.008	0.030	-	-	1.407

[a] Bottom reflection parameters.

[b] Not readable.

Table B-4.--Pressure-time parameters measured at 1-ft depths when 1-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft Slant	Range, ft Horiz.	Peak Pressure, psi	Impulse, psi-msec	Energy, in.-lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
[illegible]	3257	13	[illegible]	1227	132.[illegible]	14.07	0.355	0.097	122	-
	3412			1220	138.4	14.65	0.361	0.102	120	-
Mean				1224	135.4	14.36	0.[illegible]58	0.100	121	-
	3414[a]			-	-	-	-	-	-	13.662
[illegible]	3257	13	[illegible]	1165	129.6	13.55	0.353	0.103	122	-
	3412			1129	135.5	13.94	0.354	0.113	103	-
Mean				1147	132.6	13.74	0.354	0.108	112	-
	3414[a]			-	-	-	-	-	-	13.364
[illegible]	3257	16	13.2	970	96.5	8.82	0.277	0.103	149	-
	3412			1003	102.7	9.54	0.285	0.102	157	-
Mean				987	99.6	9.18	0.281	0.102	153	-
	3414[a]			[illegible]	-	-	1.021	-	-	9.415

Table B-4. --(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
133	3257	26	24.4	596	50.2	3.29	0.173	0.098	151	-
	3412			597	51.0	3.34	0.174	0.098	126	-
	3414			570	50.6	3.31	0.173	0.111	72	-
Mean				588	50.6	3.33	0.173	0.102	116	-
	3264[a]			28	3.1	0.01	0.267	-	-	5.94
152	3257	26	24.4	478	41.1	2.27	0.167	-	58	-
	3412			477	41.9	2.36	0.164	-	97	-
Mean				478	41.5	2.32	0.166	-	78	-
136	3257	26	24.4	568	42.4	3.02	0.124	0.111	91	-
	3412			540	38.5	2.48	0.130	0.096	83	-
	3264			563	46.2	3.18	0.142	0.117	83	-
	3414			579	35.3	2.45	0.113	0.081	99	-
Mean				562	40.6	2.78	0.127	0.101	89	-

Table B-4.--(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
137	3257	30	28.6	467	34.0	2.01	0.121	0.109	65	-
	3412			482	34.7	2.05	0.128	0.102	76	-
	3264			489	37.0	2.30	0.123	0.116	42	-
	3414			487	33.1	2.02	0.113	0.103	62	-
Mean				481	34.7	2.10	0.121	0.108	61	-
151	3412	34	32.8	389	29.7	1.35	0.140	0.110	119	-
134	3257	34	32.8	416	27.4	1.47	0.106	0.102	68	-
	3412			415	26.9	1.45	0.105	0.101	96	-
	3264			393	27.9	1.45	0.110	0.119	80	-
	3414			404	27.7	1.47	0.106	0.112	82	-
Mean				407	27.5	1.46	0.107	0.108	82	-
134	3257	38	36.9	386	24.6	1.24	0.101	0.104	56	-
	3412			384	24.2	1.21	0.099	0.103	77	-
	3264			378	23.4	1.16	0.096	0.105	63	-
	3414			375	23.4	1.19	0.093	0.111	73	-
Mean				381	23.9	1.20	0.097	0.106	67	-

Table B-4.--(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi-msec	Energy, in.-lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
141	3257	46	45.1	310	18.1	0.77	0.087	0.102	64	-
	3412			314	18.2	0.77	0.089	0.105	64	-
	3264			301	18.4	0.79	0.086	0.128	67	-
	3414			297	18.2	0.77	0.084	0.132	78	-
Mean				306	18.2	0.78	0.086	0.117	68	-
151	3257	46	45.1	274	18.2	0.65	0.104	0.110	71	-
179	3257	56	55.3	256	14.3	0.49	0.084	0.097	95	-
	3412			259	14.5	0.49	0.092	0.062	90	-
	3414			223	13.9	0.48	0.084	-	57	-
Mean				246	14.2	0.49	0.087	0.080	81	-
	3264a			124	6.3	0.09	0.165	-	-	3.359

Table B-4.--(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
203	3257	56	55.3	254	13.6	0.47	0.079	0.104	105	-
	3412			26[illegible]	13.[illegible]	0.49	0.079	0.094	NR[b]	-
	3414			241	14.[illegible]	0.53	0.079	0.156	64	-
	3264			252	13.[illegible]	0.50	0.076	0.126	93	-
Mean				253	14.[illegible]	0.50	0.078	0.120	87	-
	3414[a]			-	-	-	-	-	-	3.322
	3264[a]			114	10.[illegible]	0.11	0.289	-	-	-
20[illegible]	3257	56	55.3	21[illegible]	11.3	0.34	0.077	0.102	90	-
	3412			22[illegible]	11.4	0.34	0.076	0.088	81	-
	3414			213	12.3	0.35	0.079	0.12[illegible]	64	-
Mean				21[illegible]	11.7	0.35	0.077	0.106	78	-
	3414[a]			-	-	-	-	-	-	3.311
	3264a			15[illegible]	[illegible].4	0.08	0.166	-	-	-
1[illegible]5	3257	56	55.3	202	[illegible].7	0.31	0.061	0.156	60	-
	3412			212	11.1	0.35	0.074	0.136	52	-
Mean				207	10.4	0.33	0.068	0.146	56	-

Table B-4.--(Continued).

Shot No.	Gauge No.	Range, ft Slant	Range, ft Horiz.	Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
207	3257	78	77.5	171	6.7	0.16	0.057	0.065	52	-
	3412			178	7.0	0.17	0.058	0.064	61	-
	3414			143	6.2	0.14	0.056	0.108	26	-
	3264			149	6.5	0.14	0.057	0.106	49	-
Mean				160	6.6	0.15	0.057	0.086	47	-
147	3257	78	77.5	155	6.6	0.16	0.052	0.138	36	-
	3412			150	6.4	0.15	0.054	0.152	30	-
	3254			156	6.6	0.17	0.052	0.172	34	-
	3414			161	7.0	0.18	0.054	0.135	42	-
Mean				156	6.6	0.16	0.053	0.149	36	-
154	3412	78	77.5	157	6.2	0.14	0.055	0.102	42	-
209	3257	78	77.5	139	5.0	0.10	0.049	0.076	36	-
	3412			136	4.7	0.09	0.048	0.069	35	-
	3414			131	5.2	0.10	0.050	0.109	19	-
	3264			139	5.0	0.10	0.051	0.058	34	-
Mean				136	5.0	0.10	0.050	0.078	31	-
	3414[a]			-	-	-	-	-	-	2.458

Table B-4.--(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks msec
		Slant	Horiz.							
158	3257	110	109.6	105	4.3	0.08	0.048	0.175	26	-
	3412			104	4.2	0.07	0.047	0.169	27	-
Mean				104	4.2	0.08	0.048	0.172	26	-
192	3257	130	129.6	113	3.1	0.05	0.036	0.061	33	-
	3412			109	3.2	0.05	0.040	0.062	34	-
Mean				111	3.2	0.05	0.038	0.062	34	-
	3414[a]			-	-	-	-	-	-	1.461
193	3257	130	129.6	107	3.0	0.05	0.036	0.061	28	-
	3412			109	2.9	0.05	0.035	0.063	29	-
Mean				108	3.0	0.05	0.036	0.062	28	-
	3414[a]			-	-	-	-	-	-	1.442
	3264[a]			95	2.5	0.02	0.130	-	-	-

Table B-4.--(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.-lb/in.²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
190	3257	130	129.6	106	2.3	0.04	0.029	0.060	25	-
	3412			105	2.3	0.04	0.028	0.067	31	-
Mean				106	2.3	0.04	0.028	0.064	28	-
	3414[a]			-	-	-	-	-	-	1.271
191	3257	130	129.6	107	1.8	0.03	0.023	0.053	25	-
	3412			112	1.8	0.03	0.023	0.044	23	-
Mean				110	1.8	0.03	0.023	0.048	24	-
	3414[a]			-	-	-	-	-	-	1.271

[a] Bottom reflection parameters.

[b] Not readable.

Table B-5. --Pressure-time parameters measured at 2-ft depths when 1-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi-msec	Energy, in.-lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
175	3257	33	32.6	427	44.7	1.96	0.249	0.114	NR[b]	-
	3412			449	42.9	1.95	0.228	0.099	NR	-
	3414			432	45.5	2.11	0.231	0.121	NR	-
Mean				436	44.4	2.01	0.236	0.111	NR	-
	3264[a]			NR						
176	3257	54	53.4	272	21.8	0.64	0.161	0.070	103	-
	3412			240	20.9	0.60	0.154	0.097	81	-
	3414			266	23.1	0.71	0.159	0.112	77	-
Mean				256	21.9	0.65	0.160	0.093	87	-
	3264[a]			108	7.8	0.10	0.167	-	-	3.370
177	3257	53	52.6	147	9.4	0.18	0.095	0.116	60	-
	3412			153	9.7	0.19	0.108	0.107	60	-
	3414			151	9.9	0.20	0.099	0.113	45	-
Mean				150	9.7	0.19	0.101	0.112	55	-
	3264[a]			48	0.7	0.003	0.055	-	-	2.391

[a] Bottom reflection parameters.

[b] Not readable.

Table B-6.--Pressure-time parameters measured at 10-ft depths when 1-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
168	3257	48	49	260	45.0	1.03	0.748	0.124	64	-
	3412			259	44.5	0.91	0.849	0.132	69	-
	3414			[illegible]	47.1	0.98	0.831	0.129	57	-
Mean				269	45.5	0.97	0.809	0.128	63	-
	3264[a]			145	10.0	0.18	0.136	0.089	-	2.545
163	3257	[illegible]	[illegible]	252	46.2	0.90	0.807	0.139	NR[b]	-
	3412			[illegible]	[illegible]	1.12	0.763	0.119	NR	-
	3414			267	47.4	0.97	0.808	0.127	NR	-
Mean				272	47.6	1.00	0.793	0.128	NR	-
	3264[a]			186	18.9	0.45	0.221	-	-	2.593
167	3257	84	84	150	23.1	0.29	0.512	0.116	37	-
	3412			154	19.4	0.23	0.517	0.094	NR	-
	3414			154	25.8	0.34	0.518	0.134	34	-
Mean				153	22.8	0.29	0.516	0.115	36	-
	3264[a]			154	[illegible]	0.05	0.098	-	-	1.594

Table B-6. --(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
164	3257	84	84	157	22.9	0.31	0.484	0.124	44	-
	3412			168	23.5	0.33	0.491	0.114	59	-
	3264			155	22.8	0.31	0.478	0.122	56	-
	[illegible]			145	21.5	0.27	0.463	0.118	47	-
Mean				157	22.7	0.30	0.479	0.120	52	-
171	3257	84	84	176	19.4	0.30	0.585	0.099	41	-
	3412			157	22.3	0.31	0.455	0.131	39	-
	3414			164	23.4	0.35	0.448	0.129	36	-
Mean				166	21.7	0.32	0.429	0.120	59	-
	32e4[a]			46	0.8	0.004	0.060	-	-	1.664

[a] Bottom reflection parameters.

[b] Not readable.

Table B-7.--Pressure-time parameters measured at 1-ft depths when 1-lb TNT charges were detonated at 10-ft depths (dog eardrum tests).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
194	3414	20.0	17.9	655	69.5	4.83	0.220	0.105	62	-
	3264			696	67.0	4.77	0.208	0.089	75	-
Mean				676	68.2	4.80	0.214	0.097	68	-
	3257[a]			56	6.9	0.04	0.480	-	-	5.569
	3414[a]			-	-	-	-	-	-	5.705
Mean				56	6.9	0.04	0.480	-	-	5.637
195	3414	40.0	39.0	319	23.5	0.97	0.113	0.106	75	-
	3257[a]			-	-	-	-	-	-	4.244
	3414[a]			-	-	-	-	-	-	4.222
Mean				-	-	-	-	-	-	4.233
204	3412	40.0	39.0	335	22.1	0.95	0.105	0.105	100	-
	3414			321	23.5	1.01	0.110	0.123	56	-
	3264			326	22.6	0.97	0.108	0.124	96	-
Mean				327	22.7	0.98	0.108	0.117	84	-
	3264[a]			86	12.5	0.10	0.443	-	-	-
	3414[a]			-	-	-	-	-	-	4.043

Table B-7.--(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
208	3257	[illegible]	34.0	324	20.3	0.84	0.099	0.101	118	-
	3412			330	21.9	0.92	0.107	0.103	110	-
	3414			324	22.7	[illegible]	0.104	0.108	66	-
	3264			333	21.1	0.90	0.101	0.094	100	
Mean				328	21.5	[illegible]	0.103	0.102	98	-
	3264^a			76	12.8	[illegible]	0.414	-	-	--
	3414^a			-	-	-	-	-	-	4.021
210	3257	40.9	34.6	324	[illegible]	0.82	0.104	0.081	98	-
	3412			[illegible]	21.0	0.84	0.107	0.109	99	-
	3414			267	[illegible]	0.77	0.103	0.119	32	-
	3264			[illegible]	[illegible]	0.77	0.105	0.065	80	--
Mean				[illegible]	20.4	0.80	0.105	0.098	77	-
	3264^a			77	12.9	[illegible]	0.437	-	-	--
	3414^a			-	-	-	-	-	-	4.021
[illegible]	3414	45.0	44.1	[illegible]	19.6	[illegible]	0.099	0.192	61	-
	3264			[illegible]	18.8	0.73	[illegible]	0.077	65	--
Mean				292	[illegible]	0.76	0.099	0.134	63	-
	3257^a			-	-	-	-	-	-	3.977
	3412^a			106	13.2	0.13	0.345	-	-	-
	3414^a			-	-	-	-	-	-	[illegible]
	3264^a			112	15.8	[illegible]	0.391	-	-	--
Mean				[illegible]	14.5	[illegible]	[illegible]	-	-	[illegible]

Table B-7. --(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
206	3257	45.0	44.1	287	17.7	0.70	0.088	0.122	102	-
	3412			305	19.3	0.79	0.094	0.114	111	-
	3414			282	19.2	0.79	0.092	0.150	72	-
	3264			297	19.6	0.82	0.095	0.142	92	-
Mean				293	19.0	0.78	0.092	0.132	94	-
	3264[a]			107	13.3	0.14	0.389	-	-	-
	3414[a]			.	-	-	-	-	-	3.857
197	3414	60.0	59.3	200	12.4	0.38	0.078	0.211	43	-
	3264			230	12.4	0.40	0.077	0.082	49	-
Mean				215	12.4	0.39	0.078	0.146	46	-
	3257[a]			80	-	-	0.122	-	-	3.122
	3414[a]			89	-	-	0.170	-	-	3.000
Mean				84	-	-	0.146	-	-	3.061

[a] Bottom reflection parameters.

Table B-8.--Pressure-time parameters measured at 1-ft depths when 3-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi
		Slant	Horiz.						
143	3257	36	34.9	527	38.4	2.84	0.103	0.144	90
	3412			534	40.3	2.98	0.110	0.145	101
	3264			544	42.9	3.32	0.110	0.166	104
	3414			536	39.7	3.05	0.102	0.157	97
Mean				538	40.3	3.05	0.106	0.153	98
144	3257	51	60.3	303	16.4	0.77	0.069	0.160	60
	3412			297	15.4	0.72	0.065	0.176	44
	3264			297	16.4	0.78	0.066	0.202	68
	3414			300	15.3	0.73	0.063	0.176	59
Mean				299	15.9	0.75	0.066	0.178	58
146	3257	72	71.4	246	12.4	0.49	0.063	0.208	49
	3412			238	11.6	0.44	0.061	0.202	44
	3264			255	11.0	0.45	0.054	0.158	41
	3414			253	12.0	0.49	0.058	0.188	45
Mean				248	11.8	0.47	0.059	0.189	45
150	3257	97	96.6	189	7.0	0.21	0.047	-	31
	3412			186	6.7	0.20	0.044	-	23
	3414			197	8.4	0.27	0.051	-	26
Mean				191	7.4	0.23	0.047	-	27

Table B-9.--Pressure-time parameters measured at 1-ft depths when 8-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi
		Slant	Horiz.						
140	3257	52	51.2	557	34.4	3.02	0.076	0.199	67
	3412			558	31.9	2.77	0.072	0.179	70
	3264			553	33.2	2.93	0.074	0.218	66
	3414			556	33.2	2.94	0.073	0.206	53
Mean				556	33.2	2.92	0.074	0.200	64
142	3257	60	59.3	477	26.3	2.02	0.067	0.212	67
	3412			480	27.7	2.12	0.071	0.210	59
	3264			474	26.0	2.00	0.066	0.223	59
	3414			478	25.6	1.99	0.064	0.216	66
Mean				477	26.4	2.03	0.067	0.215	63

Table B-10.--Pressure-time parameters measured at 1-ft depths when 1-lb TNT charges were detonated at 10-ft depths (tests to measure bottom reflections, no targets).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
196	3414	40	39.0	313	23.0	0.96	0.112	0.126	[illegible]	-
	3257[a]			-	-	-	-	-	-	4.244
	3412[a]			84	10.5	0.06	0.346	-	-	-
	3414[a]			-	-	-	-	-	-	4.222
	3264[a]			110	11.3	0.09	0.403	-	-	-
Mean				97	10.9	0.08	[illegible]	-	-	4.233
199	3414	60	59.3	216	11.5	0.35	0.075	0.096	52	-
	3264			23[illegible]	10.5	[illegible].31	0.071	0.048	61	-
Mean				226	11.0	0.33	0.073	0.072	56	-
	3257[a]			-	-	-	-	-	-	3.200
	3412[a]			98	6.7	0.08	0.145	-	-	—
	3414[a]			-	-	-	-	-	-	3.043
	3264[a]			120	6.3	0.08	0.136	-	-	-
Mean				109	6.5	0.08	0.140	-	-	3.122

Table B-10. --(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.^{2}	Cut-Off Time, msec	Theta, msec	Negative, Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
201	3414	80	79.5	183	8.1	0.22	0.058	0.112	39	-
	3264			178	7.8	0.22	0.056	0.089	38	-
Mean				180	8.0	0.22	0.057	0.100	38	-
	3257[a]			-	-	-	-	-	-	2.922
	3412[a]			78	-	-	-	-	-	2.750
	3264[a]			68	1.9	0.01	0.133	-	-	-
Mean				73	1.9	0.01	0.133	-	-	2.836

[a] Bottom reflection parameters.