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MEASUREMENTS OF EXPLOSION-INDUCED SHOCK
WAVES IN ICE AND SNOW, GREENLAND, 1957
AND 1958

L. F. Ingram, et al

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

June 1960

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MISCELLANEOUS PAPER NO. 2-399

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**U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi**

ARMY-MRC VICKSBURG, MISS.

Preface

This report describes the instrumentation and presents the results of blast-pressure measurements made in and above ice and snow on the Greenland Icecap during the summers of 1957 (ice) and 1958 (snow). The work was performed in conjunction with Task No. 4.2, "Weapons Effects in Arctic Terrain," as a part of R&D Project 8-12-10-001 (subsequently changed to R&D Subproject 8-12-95-420), sponsored by the Office, Chief of Engineers, U. S. Army.

The explosives effects project, of which these measurements were a part, was conducted under the supervision of the U. S. Army Snow Ice and Permafrost Research Establishment (SIPRE) and its contractor, Barodynamics, Inc., with instrumentation support (personnel and equipment) provided by the U. S. Army Engineer Waterways Experiment Station (WES) and the Engineer Research and Development Laboratories (ERDL).

The 1957 field party consisted of Messrs. L. F. Ingram, F. P. Hanes, L. T. Watson, Jr., E. W. Flowers, and W. C. Fortner, Jr., of WES and Messrs. F. A. Pieper, A. Tieman, and F. Stevens of ERDL. Mr. Watson was in charge of operating the equipment and was assisted by Messrs. Flowers and Fortner during the entire 1957 test series. The 1958 field party consisted of Messrs. Hanes, Flowers, C. M. Wright, and E. L. Sadler of WES and Mr. Stevens of ERDL. Mr. Flowers operated the equipment for most of the 1958 tests.

This report was prepared by Messrs. Ingram and S. H. Halper of the Hydrodynamics Branch, Hydraulics Division, WES, under the supervision of Messrs. G. L. Arbuthnot and F. R. Brown. Col. A. P. Rollins, Jr., CE, and Col. Edmund H. Lang, CE, were Directors of the WES during the course

of these tests and preparation of this report. Mr. J. B. Tiffany was Technical Director, and Mr. E. P. Fortson, Jr., was Chief of the Hydraulics Division.

The cooperation and assistance of personnel from the First Engineer Arctic Task Force, U. S. Army; Barodynamics, Inc.; SIPRE; and ERDL are gratefully acknowledged.

Contents

	<u>Page</u>
Preface	iii
Abbreviations and Symbols	vii
Summary	ix
Purpose and Scope	1
Objectives	1
Tests in Ice, 1957	1
Test site and characteristics of test medium	1
Test program	2
Instrumentation	2
Test conditions and results	4
Discussion of test results	4
Tests in Snow, 1958	6
Test site and characteristics of test medium	6
Instrumentation	7
Test conditions and results	8
Discussion of test results	9
Tables 1-2	
Plates 1-5	

Abbreviations and Symbols

d_c	Charge depth,* ft
I	Positive impulse of pressure wave, lb-msec/in. ²
msec	Millisecond
P_m	Maximum pressure, psi
R_s	Slant range, charge to gage, ft
t_a	Arrival time of initial pressure front, msec
W	Charge weight, lb
x	Horizontal distance, gage to ground zero,** ft
y	Depth of gage referred to ground zero,* ft
λ_c	Reduced charge depth,* = $d_c/W^{1/3}$, ft/lb ^{1/3}
λ_s	Reduced slant range, charge to gage = $\frac{R_s}{W^{1/3}}$, ft/lb ^{1/3}
\bar{v}	Average velocity of initial pressure front, charge to gage, fps
τ	Positive duration of pressure wave, msec
A-60	Atlas 60 explosive
C-4	Composition 4 explosive
5-S	Coalite 5-S explosive
7-S	Coalite 7-S explosive

* Negative values refer to below-surface positions.

** Negative values refer to distances left of ground zero.

Summary

Pressure-time histories of shock waves, both above and below the surface, were obtained in the proximity of high-explosive charges detonated in ice and snow. Measurements with piezoelectric gages were obtained from 15 explosions in glacial ice and 36 explosions in deep snow. Four different charge types, with weights ranging from 2.5 to 160 lb, were fired. Charge positions ranged from above the surface to a depth of 23.10 ft below the surface. The resulting pressure, impulse, and shock-velocity data exhibited considerable scatter when plotted as a function of reduced distance. At distances of 2 to 20 ft from the charge, the mean shock velocities were 11,500 fps in ice and 4200 fps in snow. Peak pressure values measured in ice were much lower than those that would be expected at comparable distances in water. Pressure waves resulting from charges detonated in snow were severely attenuated as compared with those resulting from free-air bursts. Complete tabulations of the data are presented.

1

MEASUREMENTS OF EXPLOSION-INDUCED SHOCK WAVES
IN ICE AND SNOW, GREENLAND
1957 AND 1958

Purpose and Scope

1. The test programs, from which the measurements described herein were obtained, were conducted primarily to determine the cratering effects of high explosives detonated in ice and snow. However, since the cratering tests afforded an opportunity to study the characteristics of blast-induced shock waves transmitted through ice and snow, plans were made to instrument a number of shots in both the 1957 (ice) and 1958 (snow) programs.

2. This report concerns only the pressure-measuring phase of the test programs. Instrumentation, test conditions, and procedures are described together with some of the problems encountered. Test conditions and results are presented in tabular form, and representative plots of the data obtained from these tests, showing typical pressure-wave forms and peak pressure-distance relations, are included.

Objectives

3. The objectives of the measurements were to obtain pressure-time histories of shock waves, both above and below the surface of the medium, in the proximity of high-explosive charges fired in ice and snow, and from these data to: (a) determine the nature of explosive-generated pressure-wave transmission in snow and ice, and (b) obtain information pertinent to an understanding of the mechanics of crater formation in these media.

Tests in Ice, 1957

Test site and characteristics of test medium

4. The 1957 tests were conducted on the western slope of the Greenland Icecap approximately three miles east of Camp TUTO in an area just south of the Ramp Road. Camp TUTO is located at the edge of the glacier about 12 miles east of Thule Air Base. Because of the relatively warm

daytime temperatures at the time of these tests, the top few inches of snow overlying the ice was subject to considerable melting. The melt water presented a problem in placement of charges, sounding of craters, and operations in general. To minimize this problem, all testing was done between the hours of 6:00 PM and 6:00 AM.

5. The physical properties of the ice including crushing strength, modulus of elasticity, and density were determined by SIPRE.* The ice was not homogeneous in that slush and water layers existed in the top few feet, and it was filled with voids or air pockets as large as 7 mm in diameter. It was understood that the ice had an average density of approximately 0.89 g per cu cm.

Test program

6. Prior to departure of the test teams for Greenland a test program had been planned by Barodynamics, Inc., but this program was not adhered to in the field because estimates of the quantities being measured proved too uncertain. Instead, the test conditions (gage geometries) were planned by Mr. C. W. Livingston of Barodynamics, Inc., on a shot-to-shot basis. The majority of the shots were fired to obtain cratering information, and only a small number (15) of the total shots fired were instrumented with pressure gages.

Instrumentation

7. Tourmaline gages were used to measure both ice shock and air blast. Air-blast measurements were made only for shallow-buried and above-surface charge positions; baffle-mounted gages with nominal sensitivities of 25, 40, and 80 picocoulombs per psi were used for these measurements. In addition to measurements with the tourmaline gages, a few measurements were made at large standoff distances with quartz piezoelectric gages made by the Road Research Laboratory of England. Gages 1/4 and 1/2 in. in diameter with nominal charge sensitivities of 2.0 and 8.0 picocoulombs per psi, respectively, were used for the shock measurements in the ice. These gages were installed by inserting them in 1-in.-diameter holes drilled in

* U. S. Army Snow Ice and Permafrost Research Establishment, CE, Some Physical Properties of Ice from the TUTO Tunnel and Ramp, Thule, Greenland, by T. R. Butkovitch. Research Report 47 (Wilmette, Illinois, May 1959).

the ice and allowing the melt water (which immediately filled the holes) to refreeze. At depths of more than 3 ft the gages would freeze in place rapidly. When positioning gages in the upper 3-ft layer some question always existed as to the degree of solidity of the ice, especially since water was visible in the holes; however, a light tug on the gage cable would confirm that the gage was frozen in place.

8. Shock-wave and pressure data were recorded on a William Miller, Model CR-1A, Cathode-Ray Recorder. This unit is a compact package containing eight dual-beam oscilloscopes whose beams are focused on a continuous photosensitive paper strip. The unit contains all the required amplifiers, power supplies, optical system, paper-transport mechanism, etc. Recording-paper speeds up to 800 in. per sec were available. Auxiliary equipment included cathode-follower preamplifiers, a calibration-step generator, a detonator-firing supply, and a sequence timer for controlling events. The electronic recording equipment was housed in a skid-mounted wanigan 8 ft wide and 22 ft long. Power was supplied by two 5-kw, gasoline-engine-driven generators, which were not sheltered in any way. The Miller unit had exclusive use of one generator, and all other equipment derived power from the other generator. A commercial record processor was used to develop and fix the records.

9. In addition to the pressure measurements, a zero-time mark was provided on the records for correlation purposes. This was done by allowing the charge detonation to break a wire, thus removing an electrical short, which produced a sudden break or departure in one of the record traces. Still another recording channel was used to indicate the time (with respect to zero) of gross upheaval of the ice surface above the detonation point. A circuit similar to the zero-time arrangement was used for this purpose. The sequence timer also provided switch closures for starting movie cameras and seismic recorders which were operated by members of another test group. The gage layout, hole drilling, charge preparation, crater sounding, and part of the gage recovery were performed by Barodynamics, Inc., personnel. Detonation of the instrumented charges was programmed by the sequence timer, which also controlled the calibration and recorder start-stop functions.

10. Recovery of gages was a real problem (especially the deeply

buried gages) during most of the operation. Finally, a steam generator was secured which was very effective in melting the ice around the gages. Previously, digging and blasting had been employed; the latter method resulted in appreciable damage to the gages. During the tests approximately 40 gages were in use, although only about 10 were required for any one shot. The large number of gages was necessary because of the time required for the gages to freeze in position and the subsequent recovery and repair operations. A major effort was required for gage maintenance and recalibration.

11. Initially the air-blast gages were mounted on iron pipes, but spurious vibrations attributed to shock through the mount necessitated substitution of wooden mounts. Fragments of ice impinging on the gages also tended to mar what would normally have been smooth records.

12. Aside from minor difficulty with the paper transport, the Miller unit performed very well. The main equipment trouble was with power generators. It was difficult to keep at least two units operating satisfactorily, and to accomplish this it was necessary to retain a mechanic full time. Protection against the elements would have contributed greatly to the reliability of the power plants. In inclement weather, the fine, wind-driven snow often completely filled all voids inside the generator housing; for this reason, several days of testing were lost.

Test conditions and results

13. Test conditions and results for charges detonated in and above the ice are presented in table 1. Charge positions ranged from 2.16 ft above to 12.50 ft below the ice surface. Four explosives, C-4, A-60, 7-S, and 5-S, with weights ranging from 10 to 40 lb, were used. Fig. 1 shows the general shapes of representative pressure-wave forms obtained from the shots detonated in ice. Plates 1 and 2 are plots of pressure versus reduced slant range for explosives A-60 and C-4, respectively. Data on the crater size, etc., will be contained in the comprehensive report of the 1957 tests which is being prepared for SIPRE by Barodynamics, Inc.

Discussion of test results

14. Shock-wave velocity in ice near the explosion was very nearly equal to seismic-wave velocity measured (by Barodynamics, Inc.) over a greater interval with conventional seismometers. Although there was

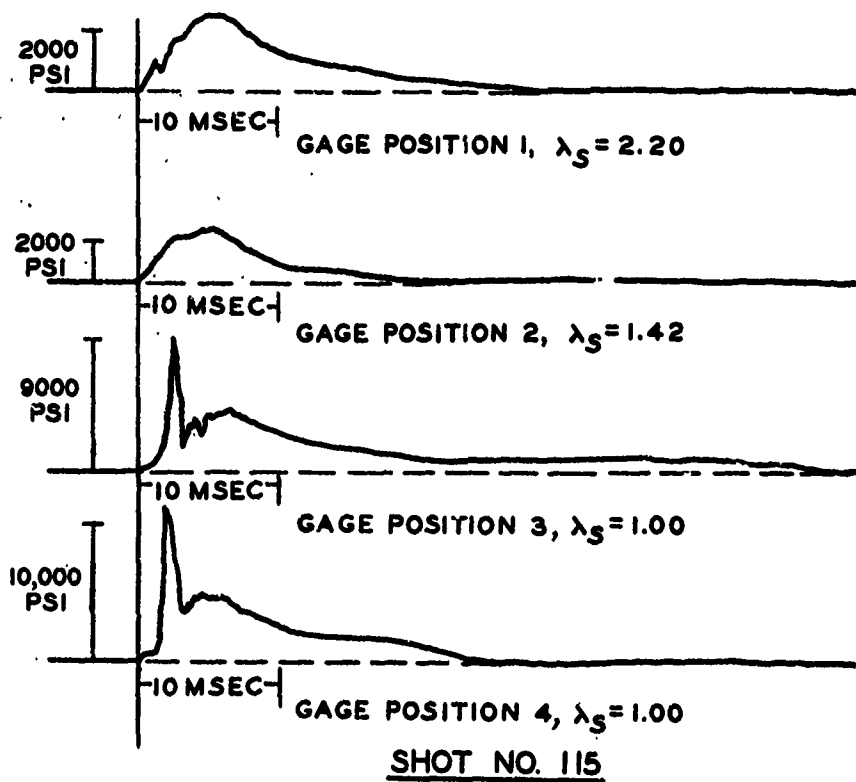
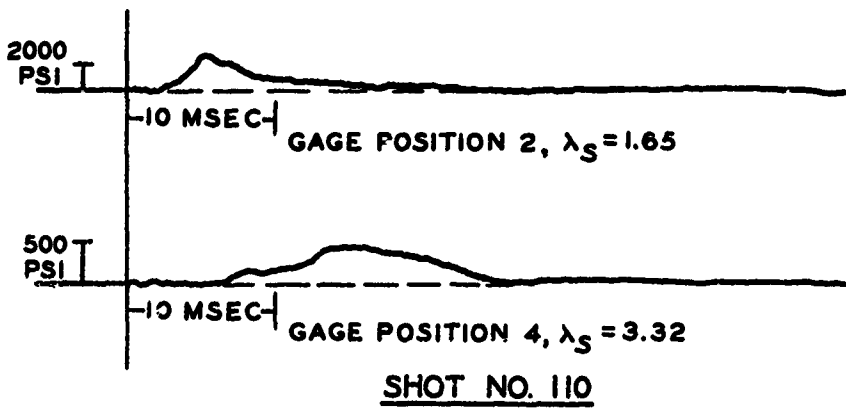
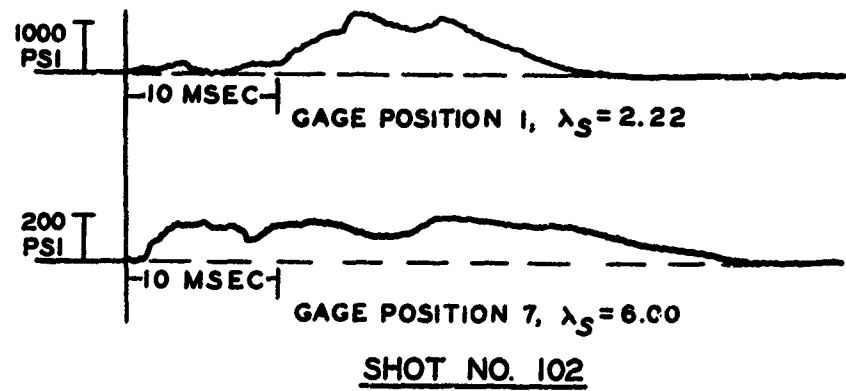


Fig. 1. Representative pressure-wave forms in ice

considerable scatter in the velocity data, they are reasonably consistent in that 85 per cent of the observations were in the range of 10,000 to 14,000 fps. At distances from 2 to 20 ft from the charge, the average shock-wave velocity was determined to be 11,500 fps. The considerable scatter exhibited by the velocity data is attributed to: errors in knowledge of slant range (gage-placement errors), record scaling and reading errors (particularly for close-in gages), errors in judgment in determining the exact instant of zero time, and variations in the physical characteristics of the ice.

15. The data on pressure and impulse presented in table 1 were derived from records which were quite erratic. Questions exist regarding the coupling of the ice stresses to the gages and the effect of the presence of a gage on the stress field. These uncertainties always exist in free-field measurements of this nature. The effects of the relative compressibility of the ice and the measuring gage are unknown but undoubtedly this factor affects the gage response. Considerable judgment had to be exercised in reduction of the data, particularly in determining the integration cutoff point for determination of impulse. The severity of test conditions undoubtedly caused damage to gages and cables that was reflected in the records in an unknown manner. Nevertheless, these data have value in that the order of magnitude of peak pressures and an indication of the rate of attenuation of the pressure wave in ice have been determined. Peak pressure values measured in ice were much lower than those that would be expected at comparable distances in water.

Tests in Snow, 1958

Test site and characteristics of test medium

16. The 1958 tests were conducted approximately one-half mile southeast of Camp Fist Clench (Site II), Greenland, located 200 miles east of Camp TUTO. This location is about 7000 ft above sea level, and the daily temperatures during the field operations averaged 23 F for a high and 8 F for a low. Consequently, there was essentially no melting of the snow.

17. The following tabulation presents snow densities measured in

the area of the instrumented shots. Additional properties of the snow have been described in a SIPRE report.*

<u>Depth, ft</u>	<u>Density, g per cu cm</u>	<u>Depth, ft</u>	<u>Density, g per cu cm</u>
0.65	0.325	8.53	0.420
1.31	0.360	9.19	0.425
1.97	0.400	9.48	0.370
2.62	0.350	10.50	0.430
3.28	0.380	11.15	0.415
3.93	0.365	11.81	0.445
4.59	0.365	12.47	0.450
5.25	0.410	13.12	0.440
5.91	0.430	13.78	0.410
6.56	0.440	14.44	0.455
7.22	0.430	15.09	0.440
7.87	0.430	15.75	0.450

Instrumentation

18. Piezoelectric gages, made of three different pressure-sensitive materials, were used for pressure measurements. Tourmaline gages made by Crystal Research, Inc., and ranging from 1/2 to 1-7/8 in. in diameter were used at the close-in positions. Pencil-type gages, made by the Atlantic Research Corp., were used at the remaining gage stations and employed both barium titanate and lead zirconate as the sensing elements. The zirconate gages were usually placed farthest from the charge because of their relatively higher sensitivities. Exploratory work by WES had shown the need for highly sensitive gages for making pressure measurements in snow.** The gages were connected to the recording instruments by 400-ft lengths of coaxial cable.

19. The recording and auxiliary equipment used in these tests was essentially the same as was used in the ice tests (described in paragraph 8). Because of the relatively slow rate of travel and long duration of the pressure waves, the recording paper was operated at a speed of 100 in. per sec. Zero-time reference marks and time-of-snow-surface-rise measurements

* U. S. Army Snow Ice and Permafrost Research Establishment, CE, Visco-Elastic Properties of Snow and Ice in the Greenland Ice Cap, by U. Nakaya. Research Report 46 (Wilmette, Illinois, May 1959).

** U. S. Army Engineer Waterways Experiment Station, CE, Blast-Pressure Measurements in Snow, Miscellaneous Paper 2-274 (Vicksburg, Mississippi, June 1958).

were recorded as described in paragraph 9. Gasoline-engine-driven generators were used for power.

20. Gages were placed in holes bored in the snow with hand augers. The holes were drilled to within a few inches above the desired gage locations. The gages were then gently forced into the undisturbed snow to the desired depth. The holes were backfilled and tamped to approximately undisturbed density conditions. In the more dense snow (at deeper depths) it was necessary to preform the tourmaline gage holes with wooden molds to avoid damage to the gages during installation. The gages were recovered manually by pick-and-shovel excavations.

Test conditions and results

21. Test conditions and results are shown in table 2. Thirty-six test shots were instrumented for these tests. The same four types of explosives were used as in the ice tests, but the charges were positioned deeper in the snow (to 23.10 ft below the surface), and charge weights varied from 2.5 to 160 lb.

22. Fig. 2 provides a good indication of the general form of the

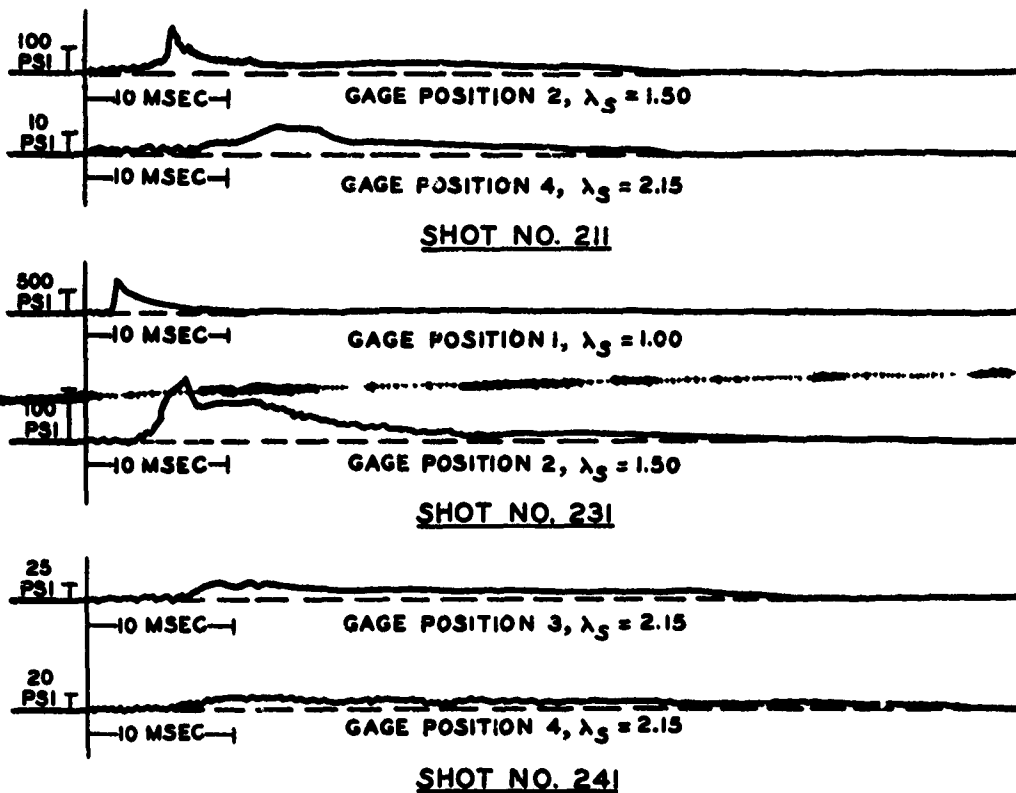


Fig. 2. Representative pressure-wave forms in snow

pressure wave in snow, although there were wide variations from these shapes. Plates 3, 4, and 5 are plots of pressure versus reduced slant range for explosives C-4, A-60, and 7-S, respectively. Because of scatter in the data only the individual points are shown, and no attempt has been made to fit a curve thereto. It should be noted that data points are shown only for the charges detonated at or below the surface. A small amount of data pertaining to above-surface charges (air-blast measurements) is given in table 2.

Discussion of test results

23. Plates 3-5 and table 2 reveal the drastic attenuation of the pressure wave afforded by snow. It appears that a shock-type wave was recorded only by gages very close to the charge, while at more remote gage locations, the pressure build-up was more gradual. Referring to fig. 2, it is seen that at a reduced slant range of 1.00 (shot 231, position 1) the wave front is quite steep; the slope of the wave front is reduced at greater distances. It is suspected that the flattening of the wave front is the result of successive delay (or slowing down) of the stress wave caused by compaction of the snow. Mean shock velocities at distances of 2 to 20 ft from the charge were in the range of 4200 fps.

24. Since the same instrumentation system was used for recording both ice and snow data, the snow data are subject to the same types of errors as described in paragraphs 14 and 15. The data tabulated herein were obtained primarily from measurements made with the tourmaline gages. The pencil-type-gage results were inconsistent and were, for the most part, discarded. The disadvantage of the latter gages for measurements of this type lies in their susceptibility to bending caused by shear planes in the snow. Bending moment causes a gage output or signal that could be interpreted erroneously as pressure.

25. An appreciation of the attenuation effect of the snow when compared with free-air blast can be obtained from plates 3-5. For example, in plate 3, the 1-psi level occurs at a reduced distance of λ_s = approximately 6. At this same reduced distance the pressure would be about 20 psi in free air.

26. In spite of the scatter in the data, sufficient measurements were made to establish fairly well the pressure-distance relation for

charges detonated in snow. A more extensive test program would be required to isolate the effects of depth of burial of charge and of gage.

Table 1
Results of Ice Shock and Air-Blast Measurements
Explosion Tests in Ice, 1957

Shot No.	Explosive		Charge Position		Gage Position No.	Gage Geometry		Blast Impact		Max Pressure P _m psi	Positive Impulse, I lb-sec/in. ²	Reduced Impulse I/P _m ^{1/3}	Positive Duration τ msec	Arrival Time t _a msec	Avg Shock Velocity V ft/sec
	lb	Type	d _c ft	r _c ft		x ft	y ft	r ₀ ft	r ₀ ft						
Ice Shock Measurements															
154-B	10	C-4	2.16	1.00	1	-3.00	-3.00	5.96	2.76	127	34	16	0.4	0.48	12,400
					2	0.00	-3.00	5.15	2.38	121	30	0.4	0.40	12,900	
					3	3.00	-3.00	5.96	2.76	132	33	0.4	0.48	12,400	
151	20	C-4	-0.72	-0.26	8	-3.50	-3.00	4.49	1.66	2,266	2500	919	2.9	0.34	13,800
					9	5.75	-3.00	6.36	2.35	376	405	149	2.1	0.49	13,000
					10	8.80	-3.00	9.24	3.40	82	46	17	0.8	0.72	12,800
					11	16.80	-3.00	17.04	6.26	376	615	226	1.1	1.10	15,500
152	20	C-4	-1.45	-0.53	7	-3.62	-2.90	4.08	1.50	---	---	---	2.3	0.34	12,000
					9	5.95	-2.90	6.12	2.25	---	---	---	7.7	0.53	11,600
					10	9.04	-2.90	9.16	3.37	317	297	94	1.7	0.77	11,900
					11	13.62	-2.90	13.70	5.04	132	126	46	3.6	1.13	12,100
153	20	C-4	-4.05	-1.49	1	-7.85	-6.75	8.30	3.05	156	---	---	0.3	---	---
					2	-5.00	-6.75	5.68	2.09	1,852	---	---	---	---	---
					3	-3.40	-6.75	4.34	1.60	2,411	1556	572	1.1	---	---
					4	2.90	-4.50	2.93	1.08	3,642	1800	662	1.8	---	---
154	20	C-4	-9.2	-3.38	1	-2.71	-9.20	2.71	1.00	---	---	---	1.7	0.18	15,000
					2	1.23	-6.90	4.61	1.00	6,061	---	---	---	0.25	10,400
					5	4.04	-9.20	4.04	1.50	3,463	2917	1072	2.7	0.40	10,100
					6	5.06	-6.90	6.05	2.22	735	597	330	2.8	0.88	6,900
154-C	10	A-60	2.16	1.00	1	-3.00	-3.00	5.96	2.76	129	20	9	0.4	0.65	9,200
					2	0.00	-3.00	5.15	2.38	62	17	8	0.4	0.50	10,300
					3	3.00	-3.00	5.96	2.76	63	18	8	0.4	0.55	10,800
					---	---	---	---	---	---	---	---	---	---	---
154-F	10	A-60	2.15	1.00	1	-3.00	-3.00	5.96	2.76	---	---	---	---	---	---
					2	0.00	-3.00	5.15	2.38	93	25	12	0.6	---	---
					3	3.00	-3.00	5.96	2.76	---	---	---	---	---	---
110	10	A-60	0.00	0.00	1	-6.50	-3.00	7.16	3.32	243	177	82	1.7	0.58	12,300
					2	-1.82	-3.00	3.56	1.65	2,630	1522	718	1.5	0.30	11,900
					3	3.72	-3.00	4.78	2.21	520	333	154	1.1	0.42	11,400
					4	6.50	-3.00	7.16	3.32	487	417	193	2.0	0.65	11,000
					5	10.27	-3.00	10.72	4.96	99	98	45	1.9	1.08	10,700
					6	15.90	-3.00	16.18	7.49	42	25	12	1.2	1.84	11,200
113	10	A-60	-1.15	-0.53	1	-6.90	-3.00	7.14	3.30	115	226	105	2.3	0.69	10,400
					2	2.55	-3.00	3.15	1.46	---	---	---	1.5	0.30	10,500
					3	4.55	-3.00	4.91	2.27	1,455	2320	1074	2.9	0.42	11,700
					4	6.90	-3.00	7.14	3.30	368	267	262	2.8	0.64	11,200
					5	10.55	-3.00	10.71	4.96	243	207	96	1.4	0.96	11,200
					6	16.10	-3.00	16.20	7.50	274	570	268	3.8	1.41	11,500
115	10	A-60	-4.70	-2.18	1	-4.45	-3.00	4.76	2.20	2,494	2333	1079	2.9	0.47	10,100
					2	-2.55	-3.00	3.06	1.42	2,847	2120	981	2.2	0.33	9,300
					3	-1.30	-3.00	2.14	1.00	9,450	3636	1683	2.3	0.21	10,200
					4	2.15	-4.70	2.15	1.00	10,452	4000	1852	2.1	0.29	7,400
					5	3.07	-4.70	3.07	1.42	2,610	2353	1009	2.2	0.36	8,500
					9	16.10	-3.00	16.19	7.49	155	113	52	1.3	1.57	10,300
					1	-6.82	-6.38	7.02	3.25	704	---	---	2.8	0.55	12,000
					2	-4.77	-8.50	4.75	2.20	2,312	---	---	3.0	0.42	11,400
					4	-2.15	-8.50	2.16	1.00	6,220	---	---	2.0	0.15	14,300
102	40	A-60	-12.50	-3.66	1	-7.85	-6.75	8.30	3.05	163	226	105	3.7	---	---
					2	9.15	-3.00	10.70	4.94	172	179	83	1.9	0.83	12,900
					3	9.82	-4.25	10.70	4.94	358	701	324	3.4	0.82	13,000
					11	15.18	-3.00	16.14	7.47	152	327	151	3.4	1.26	12,800
154-D	10	7-8	2.16	1.00	1	4.33	-6.25	7.60	2.22	1,238	1565	457	3.1	0.67	11,300
					2	6.42	-3.00	11.46	3.35	291	379	111	2.3	0.95	12,100
					3	6.88	-9.35	7.57	2.21	569	150	44	5.3	0.70	10,800
					4	9.65	-6.25	11.42	3.34	532	1938	566	5.6	1.02	11,200
					5	14.35	-3.00	17.21	5.03	321	620	181	4.2	1.48	11,600
					6	16.10	-6.25	17.27	9.05	260	761	222	4.7	1.49	11,600
					7	18.18	-3.00	20.51	6.00	194	495	145	4.0	1.72	11,900
154-E	10	7-8	-7.80	-2.86	1	2.71	-7.80	2.71	1.00	---	---	---	6.5	0.26	10,600
					2	4.72	-3.90	6.12	2.25	262	1161	427	7.1	0.58	10,600
					3	5.78	-3.90	6.12	2.25	1,784	5125	1884	7.8	0.52	11,700
154-F	10	5-8	2.16	1.00	1	8.29	-3.90	9.16	3.37	---	---	---	3.9	0.82	11,400
					2	10.00	-3.90	10.73	3.94	---	---	---	6.4	0.95	11,300
					3	13.12	-3.90	13.69	5.03	---	---	---	---	1.16	11,800
					4	20.20	-3.90	20.57	7.56	---	---	---	---	1.74	11,800
154-G	10	7-8	2.16	1.00	1	-3.00	-3.00	5.96	2.76	94	25	12	0.4	0.60	9,900
					2	0.00	-3.00	5.15	2.38	---	---	---	---	---	---
					3	3.00	-3.00	5.96	2.76	108	19	9	0.3	0.60	9,900

(Continued)

Table 1 (Continued)

Shot No.	Explosive		Charge Position		Gage Position No.	Gage Country		Blast Range		Mm Pressure P _m psi	Positive Impulse, I lb-sec/in. ²	Reduced Impulse I _r lb ^{2/3} /in. ²	Positive Duration τ msec	Arrival Time t _a msec	Avg Shock Velocity v _s ft/sec
	lb	Type	d _c ft	λ _c ft		x	y	R _a ft	R _b ft						
Air-Blast Measurements															
154-B	10	C-A	2.16	1.00	4	6.46	2.16	6.46	3.00	120	64	30	1.8	0.90	7,800
					5	6.46	4.32	6.81	3.15	100	36	17	1.7	7.14	6,000
					6	6.46	6.46	7.77	3.60	60	36	17	1.5	1.55	5,000
					8	8.62	4.32	8.90	4.12	69	40	18	2.3	1.98	4,900
					9	8.62	6.46	9.63	4.46	---	---	---	2.1	2.41	4,000
110	10	A-60	0.00	0.00	7	6.46	2.16	6.81	3.15	48	23	11	1.7	1.66	4,100
					8	6.46	4.32	7.78	3.60	51	31	14	1.7	1.85	4,200
					9	6.46	6.46	9.14	4.23	40	31	14	? 1	2.34	3,900
					10	8.62	2.16	8.87	4.10	---	---	---	---	---	---
					11	8.62	4.32	9.64	4.46	24	12	6	1.8	3.01	3,200
					12	8.62	6.46	10.78	5.00	20	19	9	2.3	3.17	3,400
154-C	10	A-60	2.16	1.00	5	6.46	4.32	6.81	3.15	43	26	12	1.9	1.31	5,200
					6	6.46	6.46	7.77	3.60	26	19	9	2.6	1.34	5,800
					7	8.62	2.16	8.62	4.00	44	24	11	1.7	2.27	3,800
					8	8.62	4.32	8.90	4.12	17	8	4	1.9	2.12	4,200
					9	8.62	6.46	9.63	4.46	59	44	20	2.8	2.47	3,900
154-F	10	A-60	2.16	1.00	4	6.46	2.16	6.46	3.00	52	41	19	2.5	0.99	6,500
					5	6.46	4.32	6.81	3.15	54	75	35	4.1	1.15	5,900
					6	6.46	6.46	7.77	3.60	98	33	15	2.1	1.55	5,000
					7	8.62	2.16	8.62	4.00	74	33	15	2.2	2.00	4,300
					8	8.62	4.32	8.90	4.12	---	---	---	---	2.07	4,300
					9	8.62	6.46	9.63	4.46	32	43	20	2.4	2.14	4,500
154-D	10	7-8	2.16	1.00	4	6.46	2.16	6.46	3.00	46	29	13	1.8	1.34	4,800
					5	6.46	4.32	6.81	3.15	56	22	10	1.7	1.58	4,300
					6	6.46	6.46	7.77	3.60	34	13	6	1.0	2.10	3,700
					7	8.62	2.16	8.62	4.00	24	22	10	2.2	2.33	3,700
					9	8.62	4.32	8.90	4.12	42	30	14	2.8	3.21	3,000
154-E	10	5-8	2.16	1.00	4	6.46	2.16	6.46	3.00	32	28	13	1.8	1.47	4,400
					5	6.46	4.32	6.81	3.15	39	20	9	1.3	1.66	4,100
					6	6.46	6.46	7.77	3.60	21	20	9	1.7	2.16	3,600
					7	8.62	2.16	8.62	4.00	27	24	11	2.6	2.69	3,200
					9	8.62	4.32	8.90	4.12	34	23	11	1.8	3.32	2,900

Table 2
Results of Snow Shock and Air-Blast Measurements
Explosion Tests in Snow, 1958

Shot No.	Explosive		Charge Position		Charge Position No.	Gage Geometry				Max. Freez. °F	Positive Impulse, \int lb-sec/in. ²	Reduced Impulse $\int/\sqrt{r^3}$	Positive Duration τ msec	Arrival Time t_a msec	Avg. Shock Velocity \bar{v} ft/sec
	a	b	r_c	$r_e/\sqrt{r^3}$		r_c	r_e	r_e/r_c	$r_e/\sqrt{r^3}$						
Snow Shock Measurements															
210	2.5	C-4	-4.08	-3.0	1	1.36	-4.08	1.36	1.00	464	---	---	---	---	---
					2	2.04	-4.08	2.04	1.50	108	---	---	---	---	---
					4	2.92	-4.08	2.92	2.15	19	---	---	---	---	---
					6	3.54	-2.04	4.08	3.00	13	---	---	---	---	---
					9	5.03	-2.04	5.44	4.00	---	191	140	43.8	0.32	5,000
					10	8.57	-2.04	8.83	6.50	0.6	---	---	25.6	1.22	4,400
X-2	5	C-4	-3.42	-2.0	1	3.42	-1.71	3.83	2.24	---	8.3	6.1	31.3	2.35	3,800
					3	5.10	-1.71	5.39	3.15	5.8	160	94	16.6	0.92	4,100
					4	6.80	-1.71	7.13	4.17	1.4	---	---	---	---	---
					6	10.20	-1.71	10.37	6.06	1.0	18	10	---	2.04	3,500
					7	10.20	-1.71	10.37	6.06	0.8	---	---	---	2.65	3,900
X-3	5	C-4	-3.42	-2.0	1	1.71	-1.71	2.40	1.40	66	94	55	8.25	0.72	3,300
					4	5.10	-1.71	5.39	3.15	7.5	87	51	43.3	1.41	3,000
					5	5.10	-1.71	5.39	3.15	1.8	68	40	51.3	1.76	3,100
					6	5.10	-1.71	5.39	3.15	4.5	74	43	43.1	1.75	3,100
					7	5.10	-1.71	5.39	3.15	3.8	65	38	44.7	1.75	3,100
X-4	5	C-4	-1.71	-1.0	2	1.71	-1.71	1.71	1.00	246	---	---	3.12	0.52	3,300
					3	1.71	-1.71	1.71	1.00	168	---	---	---	0.52	3,300
					5	3.42	-1.71	3.42	2.00	19	60	35	22.6	1.14	3,000
					6	5.10	-1.71	5.13	3.00	9.6	64	37	21.7	1.88	2,700
					7	5.10	-1.71	5.13	3.00	4.1	71	42	35.4	1.88	2,700
					8	8.50	-1.71	8.55	5.00	1.7	43	25	27.7	3.54	2,400
					9	17.00	-1.71	17.10	10.00	1.0	20	12	54.3	3.95	4,300
293	5	C-4	-1.71	-1.0	1	1.71	-1.71	1.71	1.00	732	---	---	---	0.41	4,200
					2	2.96	-1.71	2.96	1.50	318	1200	385	16.1	0.51	5,000
					3	3.63	-1.71	3.68	2.15	87	---	---	---	---	---
					6	5.13	-1.71	5.13	3.00	7.4	104	61	36.6	---	3,000
					7	6.84	-1.71	6.84	4.00	1.6	42	24	---	---	2,800
					5	7.70	-1.71	7.70	4.50	1.0	24	14	71.2	3.06	2,300
					10	11.12	-1.71	11.10	6.50	0.4	13	7.6	71.2	3.37	2,600
												61.7	4.28	2,600	
211	10	C-4	-6.48	-3.0	2	3.24	-6.48	3.24	1.50	200	2000	986	39.6	1.95	3,400
					3	4.65	-6.48	4.65	2.15	40	---	---	---	1.58	2,900
					4	4.65	-6.48	4.65	2.15	13	101	47	40.6	1.35	3,400
					5	6.48	-6.48	6.48	3.00	6.4	188	59	50.6	1.88	3,400
					6	5.62	-3.24	6.48	3.00	---	---	---	---	---	---
					7	8.63	-6.48	8.63	4.00	6.8	71	33	28.5	1.88	3,400
					8	8.00	-3.24	8.63	4.00	---	---	---	---	2.71	3,200
					9	13.50	-3.24	14.05	6.50	---	---	---	---	2.58	3,400
					10					---	---	---	---	4.38	3,200
260	10	C-4	2.16	1.00	2	2.16	-4.95	5.40	2.50	8.5	264	122	53.0	0.70	7,700
					3	2.16	-4.95	5.40	2.50	12	167	77	31.0	---	---
					4	2.16	-6.09	6.50	3.00	6.4	155	72	41.0	1.1	5,900
					5	2.16	-6.09	6.50	3.00	---	---	---	---	1.20	5,400
					6	3.24	-6.83	7.55	3.50	3.8	89	41	60.0	1.40	5,400
					8	3.24	-6.83	7.55	3.50	2.7	---	---	---	1.40	5,400
					9	3.24	-8.00	8.65	4.00	---	---	---	---	1.60	5,400
										---	---	---	---	1.60	5,400
270-A	10	C-4	1.08	0.50	2	2.16	-4.95	5.40	2.50	21	922	427	90.0	0.60	9,000
					3	2.16	-4.95	5.40	2.50	14	329	152	39.0	0.60	9,000
					4	2.16	-6.10	6.50	3.00	8.4	143	66	38.0	---	---
					5	2.16	-6.10	6.50	3.00	---	---	---	---	---	---
					6	3.24	-6.83	7.55	3.50	---	---	---	---	1.00	6,500
					7	3.24	-6.83	7.55	3.50	12	121	56	65.0	1.50	5,000
					8	3.24	-7.80	8.65	4.00	2.8	64	30	23.2	1.50	5,000
					9	3.24	-7.80	8.65	4.00	1.7	---	---	---	1.60	4,700
										1.3	---	---	---	1.80	4,700
280	10	C-4	0.00	0.00	1	0.00	-3.22	3.24	1.50	191	---	---	---	0.49	6,600
					2	1.08	-5.27	2.40	2.50	32	1280	592	88.0	1.07	5,100
					4	2.15	-6.08	6.50	3.00	15	---	---	---	0.68	9,500
					5	4.82	-4.30	6.50	3.00	8.7	321	148	93.0	2.00	3,800
					6	2.15	-7.22	7.55	3.50	5.7	316	146	115	2.14	3,500
					7	6.17	-4.30	7.55	3.50	2.2	---	---	---	2.20	3,400
					9	3.24	-2.00	6.65	4.00	---	---	---	---	2.30	3,800
890	10	C-4	-2.16	-1.00	2	3.24	-2.16	3.24	1.50	98	---	---	---	---	---
					3	4.65	-2.16	4.65	2.15	12	---	---	---	---	---
					4	4.65	-2.16	4.65	2.15	22	---	---	16.9	---	---
					5	6.48	-2.16	6.50	3.00	2.1	286	132	37.6	1.50	3,100
					6	6.48	-2.16	6.50	3.00	---	---	---	---	---	---
					7	8.65	-2.16	8.65	4.00	---	---	---	---	---	---
					9	9.72	-2.16	9.72	4.50	1.6	23	11	34.0	---	---
					10	14.05	-2.16	14.05	6.50	0.3	---	---	---	---	---
212	40	C-4	-10.26	-3.00	2	5.13	-10.26	5.13	1.20	161	6050	1768	59.0	0.60	8,500
					3	7.35	-10.26	7.35	2.15	37	2122	680	125	1.40	5,800
					4	7.35	-10.26	7.35	2.15	27	1338	391	109	1.40	5,800
					5	10.26	-10.26	10.26	3.00	4.2	315	92	120	2.20	4,700
					6	8.90	-5.13	10.26	3.00	---	---	---	---	2.50	4,100
					7	13.68	-10.26	13.70	4.00	2.8	132	38	116	2.80	4,900
					9	12.65	-5.13	13.70	4.00	---	---	---	---	3.30	4,200
					10	21.55	-5.13	22.10	6.50	---	---	---	---	5.40	4,100

(Continued)

(1 of 4 sheets)

Table 2 (Continued)

Shot No.	Charge Position			Shot Range				Max Pressure P _m Psi	Positive Impulse, X lb-sec/ft ²	Reduced Impulse I _r /ft ³	Positive Duration τ sec	Arrival Time t _a msec	Avg Shock Velocity v ft/s							
	Explosive lb	Type	d ft	c ft	a ft	b ft	c ft							d ft						
See Shot Measurements (Continued)																				
296	40	C-4	-3.42	-3.00	2	5.13	-3.42	5.13	1.50	116	---	---	---	---						
					3	7.35	-3.42	7.35	2.15	21	417	122	51.4	1.47	5,000					
					4	7.35	-3.42	7.35	2.15	21	1107	384	110	1.67	4,400					
					5	10.26	-3.42	10.26	3.00	3.1	73	21	42.2	1.86	5,500					
					6	10.26	-3.42	10.26	3.00	---	---	---	---	2.45	4,800					
					7	13.68	-3.42	13.70	4.00	1.9	62	18	73.0	2.90	4,700					
					9	15.40	-3.42	15.40	4.50	2.6	73	21	91.0	4.70	3,900					
					10	22.23	-3.42	22.20	6.50	0.9	---	---	---	7.16	3,100					
					44.5	160	C-4	-19.50	-3.60	1	17.02	-9.75	19.60	3.60	5.4	---	---	---	3.67	5,200
										2	17.02	-9.75	19.60	3.60	6.6	---	---	---	4.10	4,800
3	17.02	-9.75	19.60	3.60						7.6	---	---	---	4.40	4,400					
4	17.02	-9.75	19.60	3.60						4.2	---	---	---	4.20	4,700					
200	2.5	A-60	-4.08	-3.00	1	1.36	-4.08	1.36	1.00	1500	---	---	1.5	---	---					
					2	2.20	-4.08	2.20	1.62	148	---	---	---	---	---					
					3	2.92	-4.08	2.92	2.15	120	550	404	20.0	---	---					
					4	2.92	-4.08	2.92	2.15	22	100	74	22.0	---	---					
					5	4.08	-4.08	4.08	3.00	3.8	17	12	35.0	---	---					
					6	3.54	-2.04	4.08	3.00	---	---	---	---	1.16	3,500					
					7	5.43	-4.08	5.43	4.00	2.3	74	54	51.0	1.27	4,270					
					9	5.03	-2.04	3.43	4.00	---	---	---	---	1.27	4,340					
					10	8.57	-2.04	8.65	6.50	0.9	24	18	39.8	2.84	3,120					
					230	2.5	A-60	-4.08	-3.00	1	1.36	-4.08	1.36	1.00	171	---	---	15.0	0.30	4,500
2	2.04	-4.08	2.04	1.50						74	1036	762	44.5	---	---					
3	2.92	-4.08	2.92	2.15						28	355	261	40.0	---	---					
4	2.92	-4.08	2.92	2.15						14	---	---	---	---	---					
5	4.08	-4.08	4.08	3.00						6.5	104	76	56.0	0.70	5,800					
6	3.53	-2.04	4.08	3.00						---	---	---	---	0.80	5,100					
7	5.43	-4.08	5.43	4.00						7.3	71	52	24.0	1.00	5,400					
9	5.02	-2.04	3.43	4.00						---	---	---	---	0.90	6,000					
10	8.55	-2.04	8.65	6.50						---	---	---	---	1.70	5,200					
295	5.0	A-60	-1.71	-1.00						1	1.71	-1.71	1.71	1.00	1161	---	---	---	---	
					2	2.56	-1.71	2.56	1.50	440	---	---	---	---	---					
					3	3.68	-1.71	3.68	2.15	14	132	77	29.0	---	---					
					4	3.68	-1.71	3.68	2.15	13	308	180	61.0	---	---					
					5	5.13	-1.71	5.13	3.00	5.7	---	---	---	2.08	2,500					
					6	5.13	-1.71	5.13	3.00	---	---	---	---	2.08	2,500					
					7	6.84	-1.71	6.84	4.00	3.2	140	82	86.0	2.08	3,300					
					9	7.70	-1.71	7.70	4.50	1.0	95	96	61.0	2.92	2,600					
					10	11.12	-1.71	11.10	6.50	0.6	8	4.7	28.0	3.54	3,140					
					201	10	A-60	-6.48	-3.00	1	2.15	-6.48	2.16	1.00	425	667	309	8.0	0.41	5,200
2	3.22	-6.48	3.24	1.50						245	3500	1620	59.0	0.51	6,300					
3	4.62	-6.48	4.65	2.15						103	2300	1065	62.0	---	---					
4	4.62	-6.48	4.65	2.15						21	220	102	33.0	1.63	2,800					
5	6.45	-6.48	6.50	3.00						5.8	229	106	67.0	2.10	3,100					
6	5.59	-3.24	6.50	3.00						---	---	---	---	2.20	2,900					
7	8.70	-6.48	8.65	4.00						3.5	80	37	65.0	2.76	3,100					
9	7.96	-3.24	8.65	4.00						---	---	---	---	2.65	3,200					
10	13.54	-3.24	14.05	6.50						2.4	33	15	40.0	4.18	3,300					
231	10	A-60	-6.48	-3.00						1	2.15	-6.48	2.16	1.00	751	333	154	7.3	---	
					2	3.22	-6.48	3.24	1.50	121	1258	582	58.0	0.73	4,400					
					3	4.62	-6.48	4.65	2.15	59	1620	750	78.0	0.83	5,600					
					4	4.62	-6.48	4.65	2.15	20	533	247	73.0	0.94	4,900					
					5	6.45	-6.48	6.50	3.00	3.8	31	14	38.0	1.25	5,200					
					6	5.59	-3.24	6.50	3.00	---	---	---	---	1.35	4,800					
					7	8.60	-6.48	8.65	4.00	12	100	46	25.0	1.67	5,100					
					9	7.96	-3.24	8.65	4.00	---	---	---	---	1.67	5,100					
					10	13.54	-3.24	14.05	6.50	---	---	---	---	2.71	5,100					
					201	10	A-60	-6.48	-3.00	3	2.15	-4.95	5.40	2.50	12	222	103	55.0	---	
4	2.15	-4.95	5.40	2.50						10	229	106	49.0	---						
7	2.15	-6.10	6.50	3.00						4.2	---	---	---	---						
8	3.24	-6.83	7.56	3.50						2.7	---	---	---	---						
9	3.24	-7.00	8.65	4.00						1.1	20	9	38.0	---						
201	10	A-60	0.0	0.0	2	2.15	-4.92	5.40	2.50	27	883	409	75.0	---						
					3	2.15	-4.92	5.40	2.50	16	284	131	47.0	---						
					6	2.15	-6.06	6.50	3.00	9.0	260	120	55.0	---						
					7	3.22	-6.79	7.56	3.50	2.4	44	20	48.0	---						
					8	3.22	-6.79	7.56	3.50	1.9	12	6	29.0	---						
292	10	A-60	-2.16	-1.00	2	3.24	-2.16	3.24	1.50	243	---	---	65.0	---						
					3	4.65	-2.16	4.65	2.15	24	791	360	60.0	---						
					4	4.65	-2.16	4.65	2.15	31	117	54	33.0	---						
					5	6.48	-2.16	6.50	3.00	4.1	167	77	63.0	---						
					6	6.48	-2.16	6.50	3.00	---	---	---	---	---						
					7	8.65	-2.16	8.65	4.00	1.5	---	---	---	2.00	3,200					
					9	9.72	-2.16	9.72	4.50	---	---	---	---	---	---					
					10	14.05	-2.16	14.05	6.50	1.3	37	17	58.0	3.20	3,000					
					X-6	10	A-60	-2.16	-1.00	1	8.65	-2.16	8.65	4.00	4.7	92	42	26.0	2.24	3,900
										2	8.65	-2.16	8.65	4.00	---	---	---	---	2.24	3,900
4	8.65	-2.16	8.65	4.00						2.1	40	18	33.0	2.24	3,900					

(Continued)

(2 of 4 sheets)

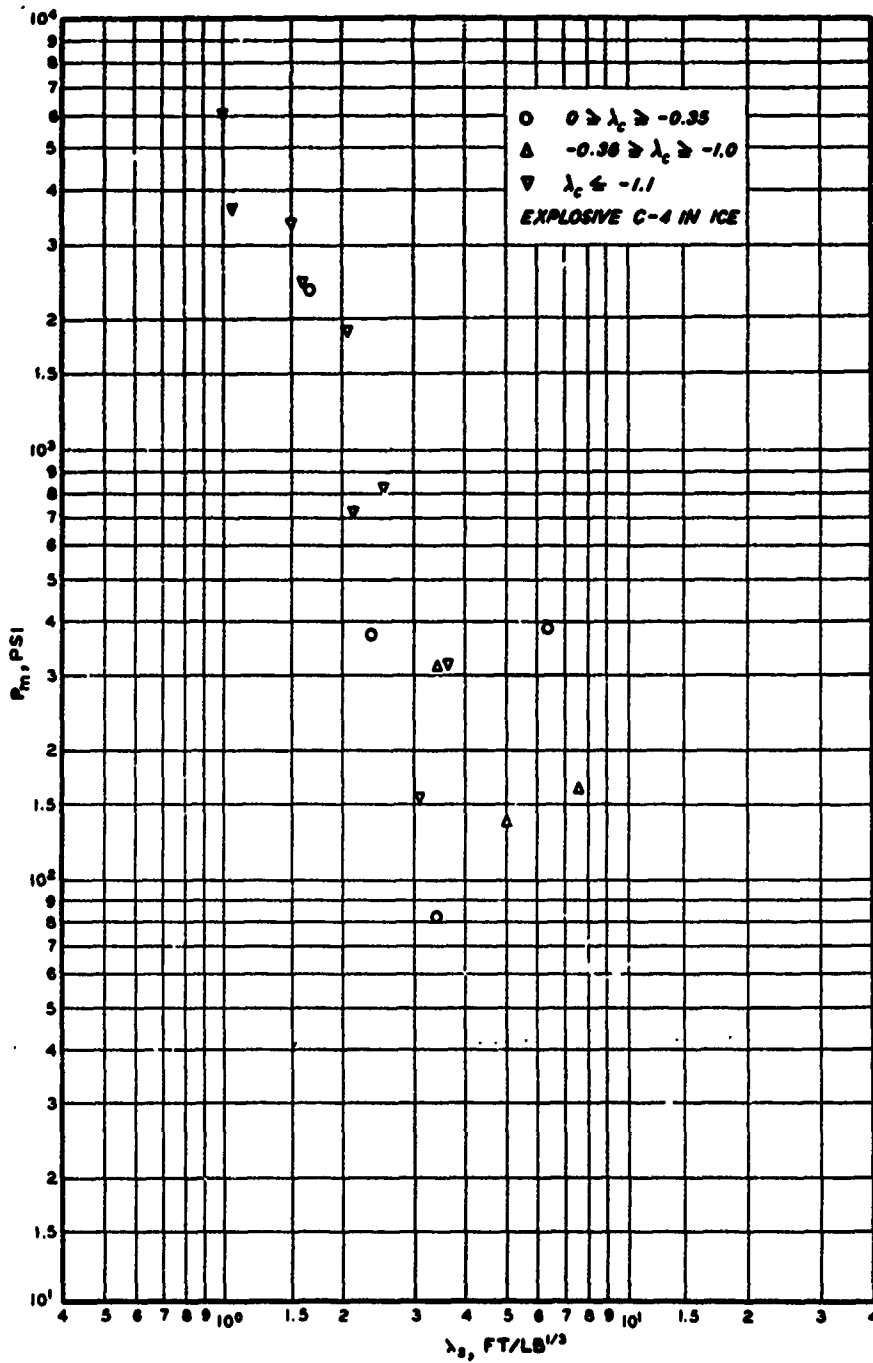
Table 2 (Continued)

Shot No.	Explosive	Type	Charge Position		Case Position No.	Shot Measurements				Max Pressure P _m psi	Positive Impulse I ₁₋₂ lb-sec/ft ²	Reduced Impulse I _{1/3} lb-sec/ft ²	Positive Duration τ msec	Arrival Time t _a msec	Avg Shock Velocity v _s ft/sec										
			c	e		W ₁ ft	W ₂ ft	R ₁ ft	R ₂ ft							R ₃ ft	R ₄ ft								
Shot Measurements (Continued)																									
E32	40	A-60	-10.26	-3.00	2	5.13	-10.26	5.13	1.90	285	---	---	---	---	1.18	4,300									
					3	7.35	-10.26	7.35	2.15	47	2080	117	1.76	4,200											
					4	7.35	-10.26	7.35	2.15	37	2197	630	117	1.76	4,200										
					5	10.26	-10.26	10.26	3.00	---	---	---	---	2.55	4,000										
					6	8.89	-5.13	10.26	3.00	---	---	---	---	2.65	3,900										
					7	13.68	-10.26	13.70	4.00	2.8	46	13	63.0	3.14	4,400										
					9	12.65	-5.13	13.70	4.00	---	---	---	---	3.53	3,900										
					10	21.95	-5.13	22.30	6.50	---	---	---	---	5.59	4,000										
					298	40	A-60	-3.42	-1.00	2	5.13	-3.42	5.13	1.90	185	595	162	16.0	---	---					
										3	7.35	-3.42	7.35	2.15	43	341	100	68.0	---	---					
4	7.35	-3.42	7.35	2.15						47	789	231	88.0	---	---										
6	10.26	-3.42	10.26	3.00						---	---	---	---	2.50	4,100										
9	15.40	-3.42	15.40	4.50						1.4	56	16	54.0	4.90	3,100										
10	22.23	-3.42	22.30	6.50						1.4	45	13	62.0	6.50	3,400										
23.5	160	A-60	-23.10	-4.26						2	19.8	-23.10	22.8	4.20	5.4	285	92	77.0	4.80	4,800					
										4	19.8	-23.10	22.8	4.20	7.5	---	---	---	---	---					
										220-P	2.5	7-8	-4.08	-3.00	2	2.20	-4.08	2.04	1.50	154	102	134	6.0	---	---
															3	2.92	-4.08	2.92	2.15	55	100	74	10.0	---	---
					4	2.92	-4.08	2.92	2.15						17	197	115	29.0	---	---					
					5	4.08	-4.08	4.08	3.00						2.0	---	---	---	36.0	---					
					7	5.43	-4.08	5.43	4.00						7.9	34	25	18.0	1.43	5,200					
					9	5.03	-2.04	5.43	4.00						---	---	---	---	1.63	4,400					
					10	8.57	-2.04	8.85	6.50						---	---	---	---	2.86	4,100					
					240	2.5	7-8	-4.08	-3.00						1	1.36	-4.08	1.36	1.00	437	333	245	5.0	0.30	4,500
2	2.04	-4.08	2.04	1.50											41	1091	802	35.0	---	---					
3	2.92	-4.08	2.92	2.15											7.6	162	119	25.0	---	---					
5	4.08	-4.08	4.08	3.00						2.4	---	---	---	---	0.85	4,800									
6	3.54	-2.04	4.08	3.00						---	---	---	---	0.96	4,200										
7	5.43	-4.08	5.43	4.00						2.3	65	48	35.0	1.17	4,600										
294	5.0	7-8	-1.71	-1.00						1	1.71	-1.71	1.71	1.00	327	667	390	8.8	1.67	1,000					
										2	2.56	-1.71	2.56	1.50	107	320	175	10.7	1.88	1,400					
										4	3.68	-1.71	3.68	2.15	8.7	111	65	23.0	1.56	2,400					
										6	5.13	-1.71	5.13	3.00	5.2	136	80	62.0	2.19	2,300					
					7	6.84	-1.71	6.84	4.00	2.4	---	---	---	2.81	2,400										
					9	7.70	-1.71	7.70	4.50	2.4	48	26	42.0	3.12	2,900										
					10	11.12	-1.71	11.10	6.50	1.1	21	12	41.0	4.38	2,500										
					202	10	7-8	-6.48	-3.00	1	2.16	-6.48	2.16	1.00	327	1667	722	5.1	---	---					
										2	3.24	-6.48	3.24	1.50	136	2000	926	27.0	---	---					
										3	4.65	-6.48	4.65	2.15	91	500	231	18.0	---	---					
5	6.48	-6.48	6.50	3.00						---	---	---	---	1.63	4,000										
6	5.60	-3.24	6.50	3.00						---	---	---	---	2.10	3,100										
7	8.65	-6.48	8.65	4.00						22	341	158	43.0	1.43	6,000										
9	8.00	-3.24	8.65	4.00						---	---	---	---	2.44	5,500										
10	13.60	-3.24	14.05	6.50						---	---	---	---	4.28	3,200										
241	10	7-8	-6.48	-3.00						1	2.16	-6.48	2.16	1.00	410	1290	579	13.0	---	---					
										2	3.24	-6.48	3.24	1.50	139	1538	712	20.0	0.91	3,600					
					3	4.65	-6.48	4.65	2.15	26	705	327	18.0	0.91	5,700										
					4	4.65	-6.48	4.65	2.15	16	496	211	63.0	0.71	6,500										
					5	6.48	-6.48	6.50	3.00	3	74	34	53.0	1.41	4,600										
					6	5.60	-3.24	6.50	3.00	---	---	---	---	1.52	4,200										
					7	8.65	-6.48	8.65	4.00	---	---	---	---	2.02	4,300										
					9	8.00	-3.24	8.65	4.00	10	545	452	107	2.02	4,200										
					10	13.60	-3.24	14.05	6.50	---	---	---	---	3.64	3,800										
					272	10	7-8	1.08	0.50	2	2.16	-3.87	5.40	2.50	5	---	---	2.0	0.71	7,600					
3	2.16	-3.87	5.40	2.50						3	---	---	---	2.1	0.71	7,600									
4	2.16	-5.02	6.50	3.00						1.4	---	---	---	2.4	1.53	4,200									
5	2.16	-5.02	6.50	3.00						---	---	---	---	---	1.73	3,900									
6	3.24	-5.75	7.57	3.50						---	---	---	---	---	1.0	3,900									
7	3.24	-5.75	7.57	3.50						---	---	---	---	---	6.6	4,700									
8	3.24	-6.95	8.65	4.00						---	---	---	---	---	7.8	1.84	4,700								
9	3.24	-6.95	8.65	4.00						1.4	---	---	---	---	---	---									
282	10	7-8	0.00	0.0						2	2.16	-4.93	5.40	2.50	13	214	99	39.0	---	---					
										3	2.16	-4.93	5.40	2.50	13	144	67	42.0	---	---					
					4	2.16	-6.06	6.50	3.00	2.1	---	---	---	20.0	1.80	3,600									
					5	2.16	-6.06	6.50	3.00	---	---	---	---	---	1.80	3,600									
					6	2.16	-6.80	7.57	3.50	1.1	---	---	---	24.0	2.00	3,800									
					7	2.16	-6.80	7.57	3.50	2.2	---	---	---	---	2.00	3,800									
					291	10	7-8	-2.16	-1.00	2	3.23	-2.16	3.24	1.50	68	---	---	3.0	---	---					
										4	4.64	-2.16	4.65	2.15	17	---	---	---	4.0	---					
										5	6.46	-2.16	6.50	3.00	9	---	---	---	11.0	---					
										10	14.00	-2.16	14.05	6.50	1.4	2	1	5.0	---	---					
222	40	7-8	-10.26	-3.00						2	5.13	-10.26	5.13	1.50	194	4833	1413	97.0	---	---					
										3	7.35	-10.26	7.35	2.15	28	1149	336	111	1.60	4,600					
										4	7.35	-10.26	7.35	2.15	22	1214	345	111	1.60	4,600					
										5	10.26	-10.26	10.26	3.00	3	---	---	---	2.40	4,300					
										6	8.89	-5.13	10.26	3.00	---	---	---	---	2.40	4,300					
										7	13.68	-10.26	13.70	4.00	2	18	5	33.0	2.90	4,700					
					9	12.65	-5.13	13.70	4.00	---	---	---	---	3.30	4,200										
					10	21.95	-5.13	22.20	6.50	---	---	---	---	5.40	4,100										

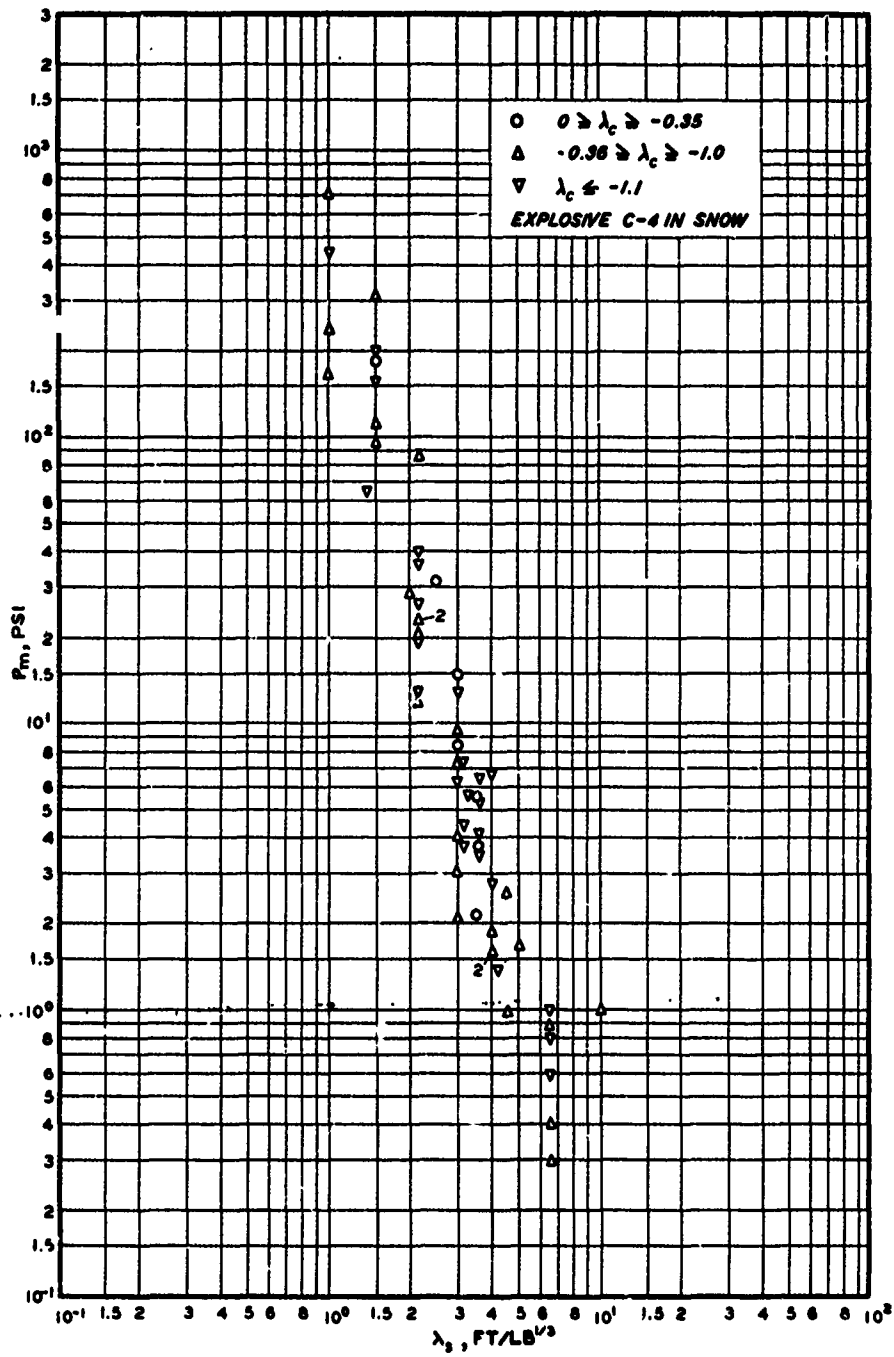
(Continued)

Table 2 (Continued)

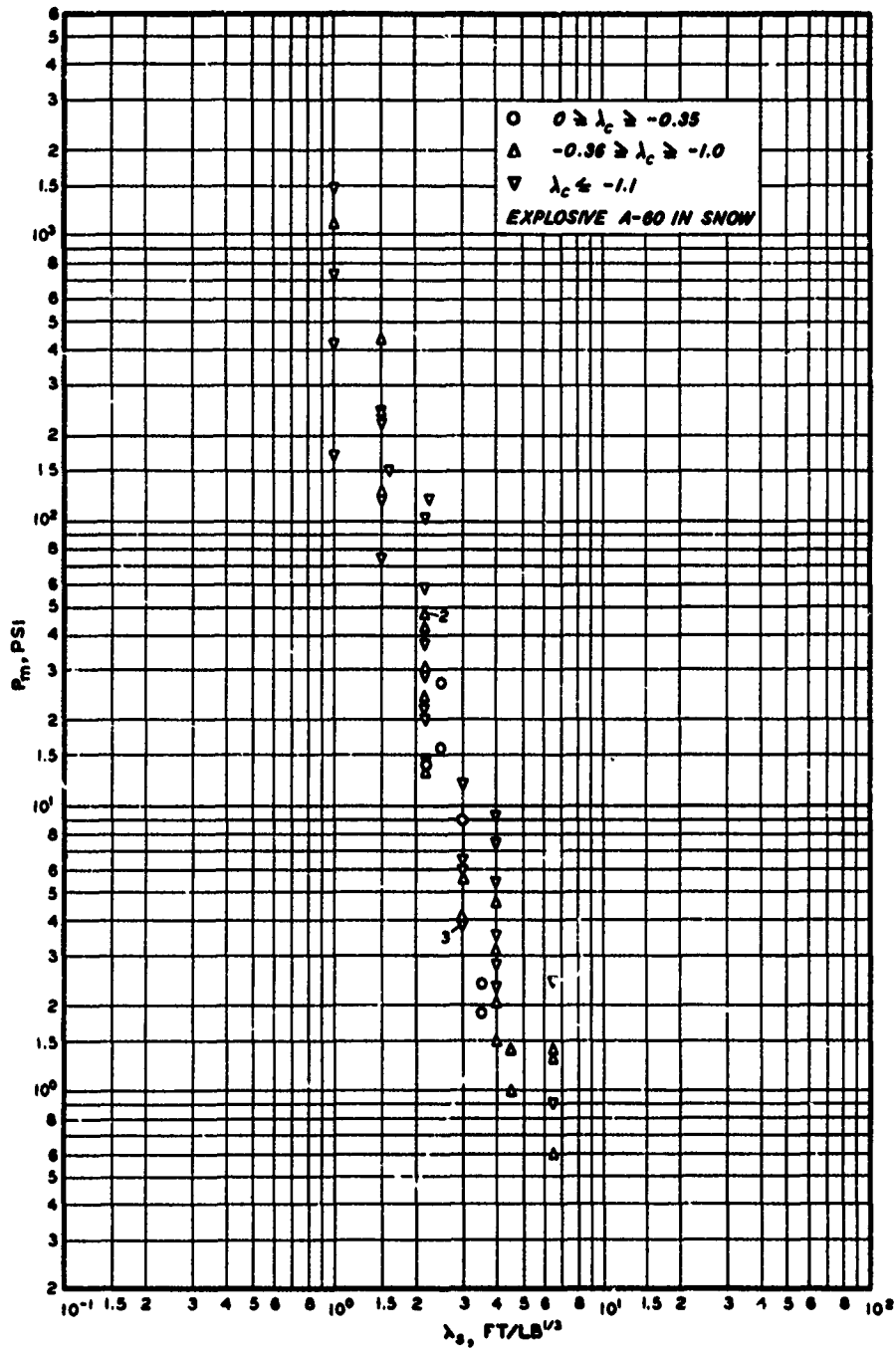
Shot No.	Explosive		Charge Position		Case Position No.	Blast Range				Max Pressure P psi	Positive Impulse, Z lb-sec/10.2	Reduced Impulse 1/ft ³	Positive Duration τ msec	Arrival Time t msec	Avg Shock Velocity v ft/s						
	lb	Type	c ft	c c ₀ /ft ^{1/3}		Gap Geometry x y ft ft	R ft	R R ₀ /ft ^{1/3}													
Shot Shock Measurements (Continued)																					
297	40	7-8	-3.42	-1.00	2	5.13	-3.42	5.13	1.50	137	600	---	175	13.5	---	---					
					3	7.35	-3.42	7.35	2.15	33	---	---	---	---	---						
					4	7.35	-3.42	7.35	2.15	17	---	---	---	---	---						
					5	10.26	-3.42	10.26	3.00	4	576	169	61.0	2.12	3,500						
					6	10.26	-3.42	10.26	3.00	---	---	26	24.0	3.08	3,300						
					7	13.68	-3.42	13.70	4.00	1	---	---	---	3.08	3,300						
					9	15.39	-3.42	15.40	4.50	2	---	---	7	52.0	4.23	3,200					
					10	22.23	-3.42	22.20	6.50	---	---	---	---	53.0	5.19	3,000					
					65.5	160	7-8	-18.50	-3.41	1	16.00	-9.25	18.50	3.41	2	---	---	---	189	3.60	5,100
										2	16.00	-9.25	18.50	3.41	2	---	---	---	---	4.00	4,600
3	16.00	-9.25	18.50	3.41						2	110	20	---	191	4.10	4,500					
4	16.00	-9.25	18.50	3.41						5	111	20	---	---	3.80	4,900					
Air-Blast Measurements																					
260	10	C-4	2.16	1.00	10	4.32	3.24	5.40	2.50	223	---	---	---	---	---	---					
					11	6.16	4.32	7.57	3.50	83	29	13	2.6	0.40	13,500						
					12	8.08	5.40	9.73	4.50	57	15	7	3.2	0.80	9,400						
270-A	10	C-4	1.08	0.50	10	4.95	2.16	5.40	2.50	180	---	---	---	---	---	---					
					11	6.83	3.24	7.57	3.50	---	6	---	1.1	0.60	9,000						
					12	8.70	4.32	9.73	4.50	57	71	2.8	1.7	1.00	7,600						
280	10	C-4	0.0	0.00	10	4.30	3.22	5.40	2.50	79	---	---	---	---	---	---					
					12	8.04	5.38	9.73	4.50	54	71	3.3	2.4	2.00	4,900						
271	10	A-60	1.08	0.50	10	4.95	2.16	5.40	2.50	75	---	---	---	---	---	---					
					11	6.83	3.24	7.57	3.50	16	---	---	6.0	---	---						
					12	8.70	4.32	9.73	4.50	35	50	23	13.0	---	---						
281	10	A-60	0.0	0.00	10	4.30	3.24	5.40	2.50	84	38	18	5.5	---	---	---					
					12	8.04	5.38	9.73	4.50	39	31	14	2.5	---	---						
					13	8.04	5.38	9.73	4.50	24	35	16	3.6	---	---						
272	10	7-8	1.08	0.50	11	6.83	3.24	7.57	3.50	30	---	---	---	---	---	---					
282	10	7-8	0.00	0.00	10	4.32	3.24	5.40	2.50	39	---	---	---	1.4	1.00	7,600					
					11	6.15	4.32	7.57	3.50	29	---	---	---	2.4	0.50	6,000					
					12	8.08	5.40	9.73	4.50	15	---	---	---	2.4	1.40	5,400					
					13	8.08	5.40	9.73	4.50	23	25	12	7.7	2.80	3,500						



PRESSURE VS REDUCED
 SLANT RANGE
 EXPLOSIVE C-4 IN ICE



PRESSURE VS REDUCED
 SLANT RANGE
 EXPLOSIVE C-4 IN SNOW



**PRESSURE VS REDUCED
 SLANT RANGE
 EXPLOSIVE A-60 IN SNOW**

