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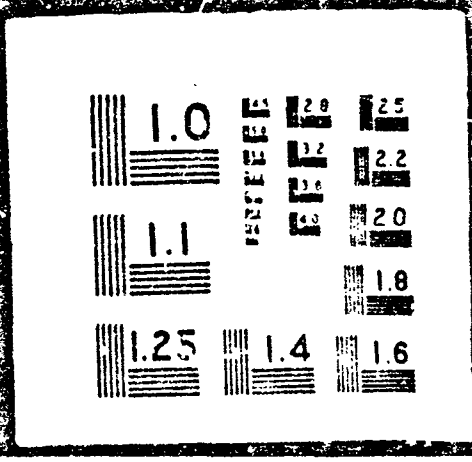

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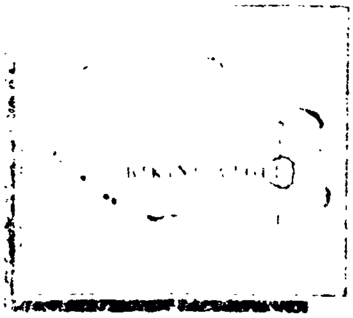
Operation CASTLE

PACIFIC PROVING GROUNDS

March – May 1954

Project 1.3

DYNAMIC PRESSURE INVESTIGATION



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WT--911

OPERATION CASTLE—PROJECT 1.8

Report to the Scientific Director

DYNAMIC PRESSURE INVESTIGATION

Edward J. Bryant

Explosion Kinetics Branch
Terminal Ballistic Laboratory
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

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March 1957

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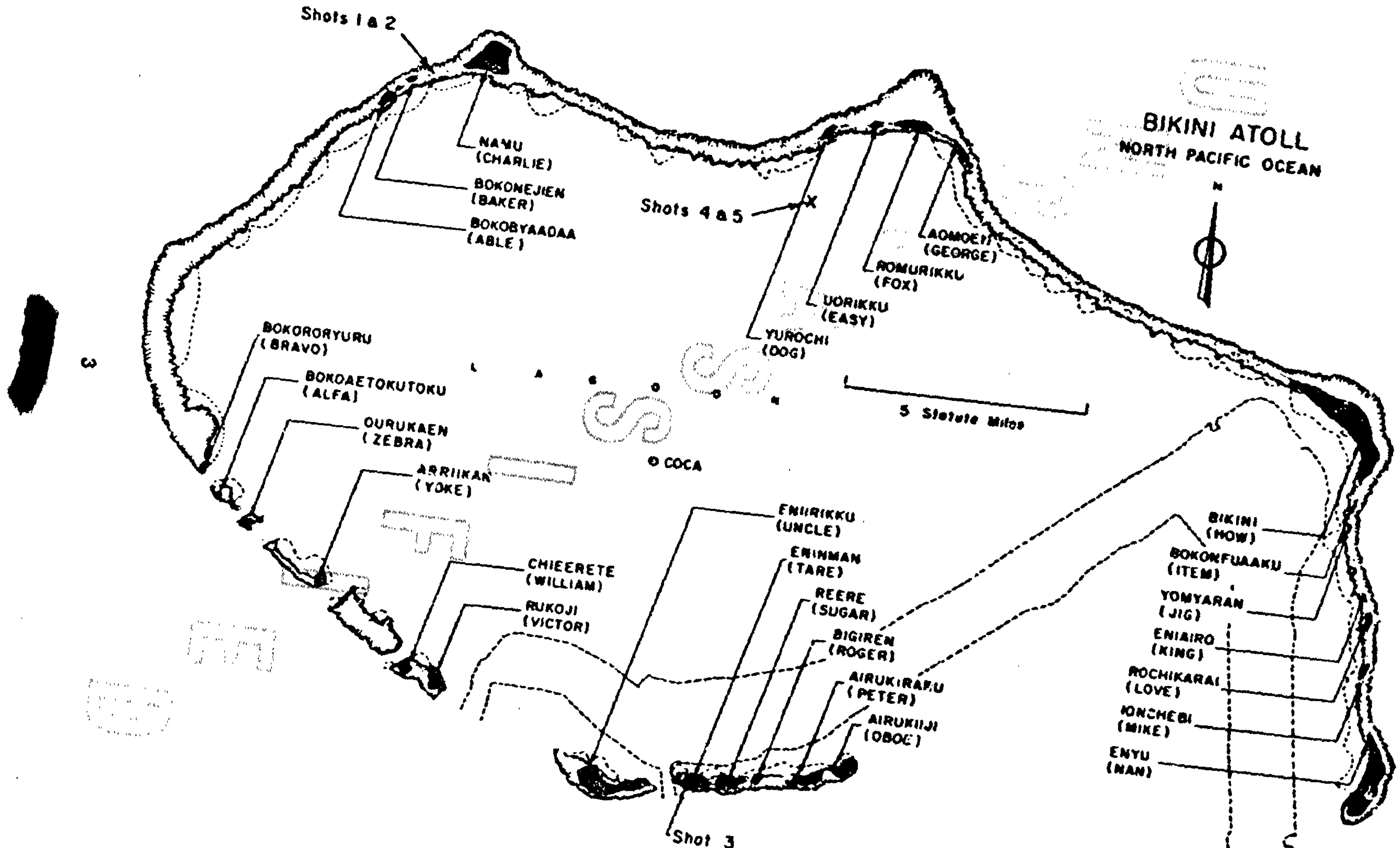
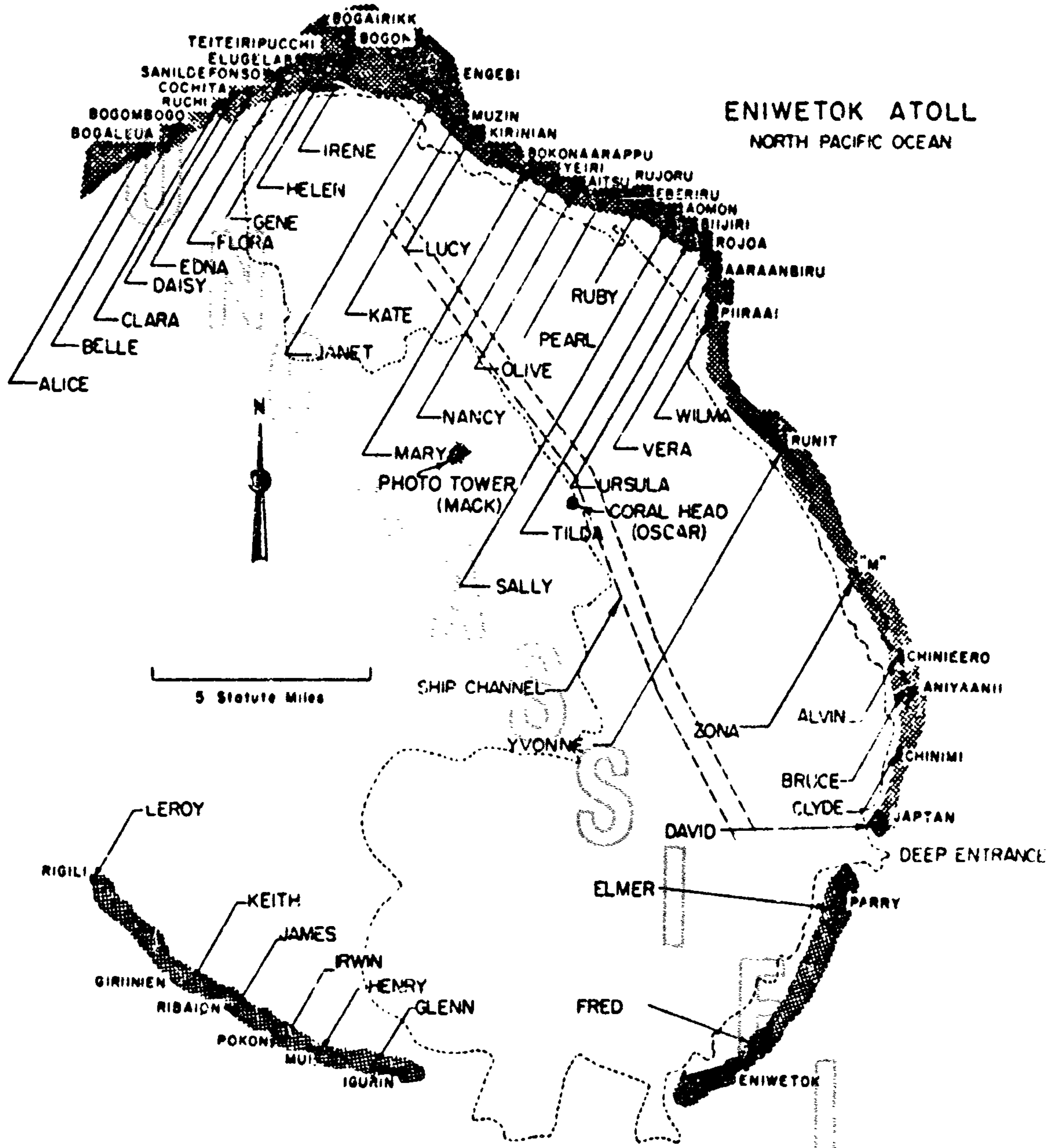
TISIA E

GENERAL SHOT INFORMATION

	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
DATE	1 March	27 March	7 April	26 April	5 May	14 May
CODE NAME (Unclassified)	Bravo	Romeo	Koon	Union	Yankee	Nectar
TIME*	06:40	06:25	06:15	06:05	06:05	06:15
LOCATION	Bikini, West of Charlie (Namu) on Reef	Bikini, Shot 1 Crater	Bikini, Tare (Eninman)	Bikini, on Barge at Intersection of Arcs with Radii of 6900' from Dog (Yurochi) and 3 Statute Miles from Fox (Aomoen).		Eniwetok, IVY Mike Crater, Flora (Elugelab)
TYPE	Land	Barge	Land	Barge	Barge	Barge
HOLMES & NARVER COORDINATES	N 170,617.17 E 76,163.98	N 170,635.05 E 75,950.46	N 100,154.50 E 109,799.00	N 161,698.83 E 116,800.27	N 161,424.43 E 116,683.15	N 147,750.00 E 67,790.00

* APPROXIMATE


BIKINI ATOLL
NORTH PACIFIC OCEAN
N
Shots 1 & 2
NAMU (CHARLIE)
BOKONEJIEN (BAKER)
BOKOBYAADAA (ABLE)
Shots 4 & 5
AOMOEN (GEORGE)
ROMURIKKU (FOX)
UORIKKU (EASY)
YUROCHI (DOG)
BOKORORYURU (BRAVO)
BOKOAETOKUTOKU (ALFA)
OURUKAEN (ZEBRA)
ARRIIKAN (YOKE)
CHIEERETE (WILLIAM)
RUKOJI (VICTOR)
L A G O O N
5 Statute Miles
COCA
ENIIRIKKU (UNCLE)
ENINMAN (TARE)
REERE (SUGAR)
BIGIREN (ROGER)
AIRUKIRAIRU (PETER)
AIRUKIIJI (OBOE)
Shot 3
BIKINI (HOW)
BOKONFUAAKU (ITEM)
YOMYARAN (JIG)
ENIAIRO (KING)
ROCHIKARAI (LOVE)
IONCHEBI (MIKE)
ENYU (NAN)


ENIWETOK ATOLL
NORTH PACIFIC OCEAN
BOGAIRIKK
TEITEIRIPUCCHI
BOGON
ELUGELAB
SANILDEFONSO
ENGEBI
COCHITA
RUCHI
BOGOMBOGO
BOGALLUA
MUZIN
KIRINIAN
BOKONAARAPPU
YEIRI
AITSU
RUJORU
EBERIRU
AOMON
BIIJIRI
ROJOA
AARAANBIRU
PIIRAAI
RUNIT
"M"
CHINIEERO
ANIYAANII
CHINIMI
JAPTAN
DEEP ENTRANCE
PARRY
ENIWETOK
IRENE
HELEN
GENE
FLORA
EDNA
DAISY
CLARA
BELLE
ALICE
LUCY
KATE
JANET
RUBY
PEARL
OLIVE
NANCY
WILMA
VERA
MARY
PHOTO TOWER
(MACK)
URSULA
CORAL HEAD
(OSCAR)
TILDA
SALLY
N
5 Statute Miles
SHIP CHANNEL
YVONNE
ZONA
ALVIN
BRUCE
CLYDE
DAVID
ELMER
FRED
LEROY
RIGILI
KEITH
JAMES
IRWIN
HENRY
GLENN
GIRIINIEN
RIBAION
POKON
MUI
IGURIN

ABSTRACT

The primary objective of Project 1.8 was to evaluate dynamic pressure as a damage parameter. In addition an attempt was made to determine the damage effect of the long positive phase duration.

A total of 27 1/4-ton trucks were exposed in Shots 3 and 6 of Operation CASTLE. The ground ranges were selected to obtain dynamic pressures comparable to those acting upon jeeps experiencing light to severe damage on Shot 10 of Operation UPSHOT-KNOTHOLE.

The yield value realized on Shot 3 was too low to give any significant results. For each degree of damage sustained by the jeeps in Shot 6 dynamic pressures were recorded which are related to measured overpressure by use of the Rankine-Hugoniot equation. The damage results of Shot 6, CASTLE, compare favorably with that of Shot 10, UPSHOT-KNOTHOLE. Although valuable data were obtained in Operation CASTLE, it was not enough to conduct a meaningful analysis of the effect of the long positive phase on damage.

The data obtained from Operation CASTLE were sufficient to evaluate dynamic pressure as a damage parameter and also to determine the magnitude of dynamic pressures required for specific damage to 1/4-ton trucks for the set of conditions as realized in Operation CASTLE. For reasonable estimates of ground range for damage to jeeps for various weapon yields the scaling can be as $W^{1/3}$ where W is the yield of weapon.

[redacted]

FOREWORD

This report is one of the reports presenting the results of the 34 projects participating in the military-effect test program of Operation CASTLE, which included six test detonations. For readers interested in other pertinent test information, reference is made to WT-934, Summary of Weapons Effects Tests, Military Effects Program. This summary report includes the following information of possible general interest: (1) An overall description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the six shots. (2) Discussion of all project results. (3) A summary of each project including objectives and results. (4) A complete listing of all reports covering the military-effect test program.

[redacted]

PREFACE

The purpose of this report is to present the damage to 1/4-ton trucks (jeeps) as a function of dynamic pressure obtained from Shots 3 and 6 of Operation CASTLE. A comparison of the results is made with damage sustained in Shot 10 of Operation UPSHOT-KNOTHOLE and with analytical studies conducted at Ballistic Research Laboratories.

The project plans in Operation CASTLE were flexible so that participation could be accomplished in any of the shots in which the conditions were determined to be suitable to meet the requirements of the test. The factors influencing participation were sufficient land area and water-wave action. Because of the revisions in shot schedules and cancellation of one shot, active participation was accomplished in Shots 3 and 6 only.

Self-recording mechanical-type gages were used for measuring dynamic pressure and static overpressure within the vehicle stations vicinity. These gages were supplied by Project 1.2b. A joint effort was made by both projects to utilize these gages in the most efficient manner in order that both projects could achieve the desired objectives. For description of the gages and details of instrumentation, reference should be made to report prepared by Project 1.2b, WT-905.

The following individuals were active participants in Project 1.8 during Operation CASTLE in the capacities noted: E. J. Bryant, project officer; Captain J. L. McCoy, deputy project officer; H. D. Duppstadt, damage evaluation and consultant; Corporal A. W. Garrard, field work and gage installation; Pfc. J. R. Michalak, field work and gage installation; and A/2C K. L. McCoy, field work and gage installation.

Grateful acknowledgement is made to C. W. Lampson and E. E. Minor of Ballistic Research Laboratories for providing technical assistance throughout the various stages of the project. To Lt Col B Jones and Major J. Brandenburg, of Armed Forces Special Weapons Project, special appreciation is expressed for suggesting and indicating the requirements for this project.

Particular and grateful acknowledgement is made to N. H. Ethridge of Ballistic Research Laboratories for the calculations performed concerning the effect of positive duration on damage.

Grateful appreciation is expressed for the technical assistance rendered by LCDR W. L. Carlson, USN, Director of Program 1, at the test site.

Appreciation is expressed to personnel of Task Unit 8 and Task Unit 9 for the technical and documentary photography they provided.

Also, grateful appreciation is expressed to the many support divisions, without which very little of project work could have been accomplished.

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CONTENTS

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FIGURES

[redacted]

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Chapter I

INTRODUCTION

1.1 OBJECTIVES

The primary objective was to evaluate the magnitude of dynamic pressure as a damage parameter for one type of target. In addition, an attempt was made to determine the damage effect of the long positive phase duration of the shock wave.

Further information was required to determine whether or not the damage curves devised after Operation UPSHOT-KNOTHOLE (see Reference 1) are valid and also to extend the present knowledge of the effects of atomic weapons on ordnance equipment.

1.2 BACKGROUND

The exposure of equipment in Operation CASTLE was a consequence of the anomalous results obtained in UPSHOT-KNOTHOLE, specifically, Shot 10 (see Reference 1). On most of the equipment exposure tests in the past, the damage effects have been influenced by the presence of varying amounts of dust behind the shock and on some by the presence of both, a precursor shock wave and dust behind the precursor wave.

Prior to UPSHOT-KNOTHOLE, static overpressure was the parameter associated with damage. The assumption was made that other blast-wave parameters were uniquely related to the static overpressure. The data obtained in Shot 10 indicated that dynamic pressures measured were higher by factors of three to four times and possibly more than the dynamic pressures computed from measured overpressures using the Rankine-Hugoniot relation (See Reference 2). Furthermore, the damage to ordnance equipment on Shots 9 and 10, UPSHOT-KNOTHOLE did not correlate with measured overpressures. Damage within the precursor zone (Shot 10) was excessive as compared to damage on Shot 9 at corresponding overpressure levels. Studies of damage sustained indicated that dynamic pressure is the significant parameter to be associated with damage. The magnitudes of dynamic pressure for specific type damage are uncertain.

The observed values of dynamic pressure (see Reference 2) and subsequent investigations suggested that the damage sustained on Shot 10 may be attributed to dynamic pressures computed from an ideal over-pressure-distance curve (see Reference 3) using the normal Rankine-Hugoniot relation. These assumed values of dynamic pressure were used in the ensuing statistical analysis. The test in Operation CASTLE was to prove or disprove the validity of the assumption made and to

[redacted]

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ascertain whether or not the precursor will enhance damage.

In view of the development of high-yield weapons, it is desirable to know the effect on damage of the positive duration so that the present damage criteria can be extended for range of weapons approximately from 0.1 KT up to and including 10 MT. There is no experimental data available beyond a yield of approximately 60 KT or below 1 KT. The study undertaken at Ballistic Research Laboratories indicated that as the yield of weapon increases the pressure level for specific damage decreases for drag sensitive targets.

[redacted]

Chapter 2
EXPERIMENT DESIGN

2.1 GENERAL

To understand better the blast-wave parameters associated with the damage noted on Shot 10 of UPSHOT-KNOTHOLE, a total of 27 1/4-ton trucks were used for exposure on Shots 3 and 6 of CASTLE in a pressure-time field expected to be that of a classical shock wave. The ground ranges were selected to obtain dynamic pressures comparable to those acting upon jeeps experiencing light to severe damage on Shot 10. In terms of values of side-on or static pressures, the region of interest for exposure of jeeps was 6 to 25 psi, based on the ideal pressure-distance curve. Within the vicinity of each station, static and dynamic pressures were measured. Dynamic pressures were also calculated from measured static pressures using the following relation:

$$P_d = \frac{2.5\,(P_s)^2}{P_s + 7P_o} \qquad (2.1)$$

where: P_o = atmospheric pressure, psi

P_s = static overpressure, psi

P_d = dynamic pressure, psi

The study of the effect of positive duration (see Appendix A) indicated a lowering of pressure for specific damage to drag-type targets for the large yield of weapons. Further insight into this effect was to be obtained from results of these tests.

Damage evaluation of vehicles was in accordance with the procedures for UPSHOT-KNOTHOLE. That is, damaged items were classified in terms of echelon of maintenance and time to restore to combat use.

2.2 FIELD LAYOUT

A total of 12 1/4-ton trucks were exposed on Shot 3. Table 2.1 presents the vehicle stations and the pressures expected from the estimated average yield and the estimated maximum yield. Within the pressure range indicated in Table 2.1, damage to vehicles was expected to be between moderate and severe for any value of yield from the estimated average to the estimated maximum. Placement of vehicles in

[redacted]

TABLE 2.1 - Field Layout, Shot 3

STATION NUMBER	DISTANCE	ORIENTATION*		PREDICTED P_s AVG YIELD (1.5 MT)	PREDICTED P_s MAX YIELD (4 MT)	INSTRUMENTATION P_t GAGE RANGE (psi)	INSTRUMENTATION q GAGE RANGE (psi)
180.09	6,500	2-SO	1-FO	35.0	70.0	50	50-50
180.10	6,[illegible]00	2-SO	1-FO	20.0	44.0	25	15-15
180.08	10,900	2-SO	1-FO	11.5	24.0	15	15-15
180.07	13,800	3-SO		7.6	13.5	--	15-15
	Total:	12					

NOTE: *SO refers to side-on
FO refers to face-on

pressure regions of interest corresponding to the estimated minimum yield was not considered. It was felt that if vehicles were placed in pressure regions corresponding to the minimum yield and the actual yield exceeded the maximum limit, (this possibility existed since the yield values of the preceding shots were above the estimated average) vehicles would be demolished and no information would be gained. On the other hand, if the lower limit of yield were realized, the vehicles would not be damaged and, therefore, could be used for exposure in a subsequent shot. The field layout for Shot 3 is shown in Fig. 2.1.

Because the shot that most suited the requirements of this project was cancelled, participation in Shot 6 was a move of desperation for gathering some useful data. Shot 6 was the only remaining shot with enough land area available whereby vehicles could be exposed within the pressure regions of interest.

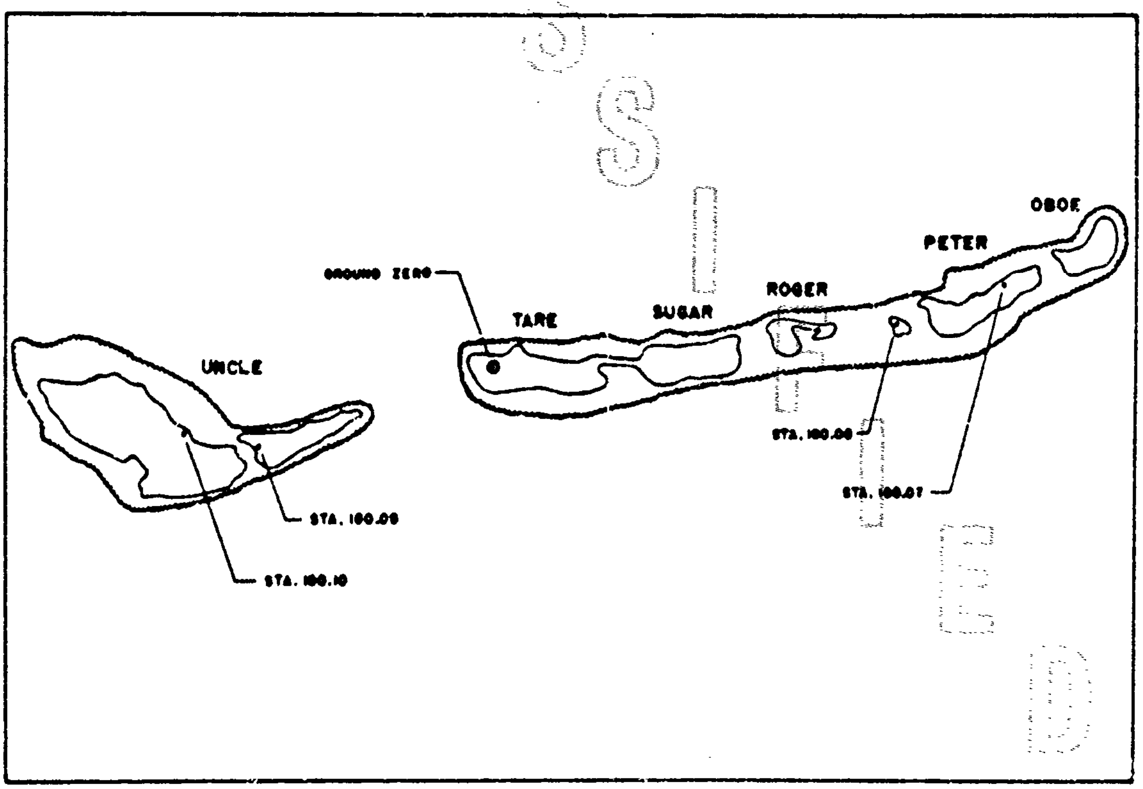

Fig. 2.1 - Field layout, Shot 3

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TABLE 2.2 - Field Layout, Shot

STATION NUMBER	DISTANCE	ORIENTATION*		PREDICTED P_s (Min Yield) 1 MT	(Avg Yield) 1.8 MT	(Max Yield) 2.5 MT	INSTRUMENTATION P_t GAGE RANGE (psi)	q GAGE RANGE (psi)
180.13	5,200	1-SO	1-FO	43	67	87	50	
180.14	5,900	1-SO	1-FO	32	50	65	50	150-150
180.15	6,750	1-SO	1-FO	23	37	47	50	50-50
180.16	7,250	1-SO	1-FO	19.5	32	41	25	
180.17	7,600	1-SO	1-FO	17.5	27.7	36	25	50-50
180.18	7,900	1-SO	1-FO	16.0	25.0	33	25	50-50
180.19	8,500	1-SO	1-FO	14.0	21.0	27.0	25	25-25
180.20	9,000	1-SO	1-FO	12.5	18.5	24.0	25	25-25
180.21	9,580	1-SO	1-FO	11.2	16.5	21.0	15	15-15
180.22	13,090	1-SO	1-FO	6.7	9.2	15	15	
	Total:	20						

NOTE: * SO refers to side-on
FO refers to face-on

In order to be assured of some data in Shot 6 the vehicle locations ranged from 5200 feet to 13,100 feet. Severe and moderate damage could be expected from the estimated minimum yield to the estimated maximum yield. A total of 20 vehicles were exposed; six of these vehicles were recovered from Shot 3, the other six were too contaminated to be transported. Two vehicles, one side-on and one face-on, were placed at each station, instead of three per station, to be certain there were sufficient stations for complete coverage. The vehicle stations for Shot 6 are presented in Table 2.2 and the field layout is shown in Fig. 2.2.

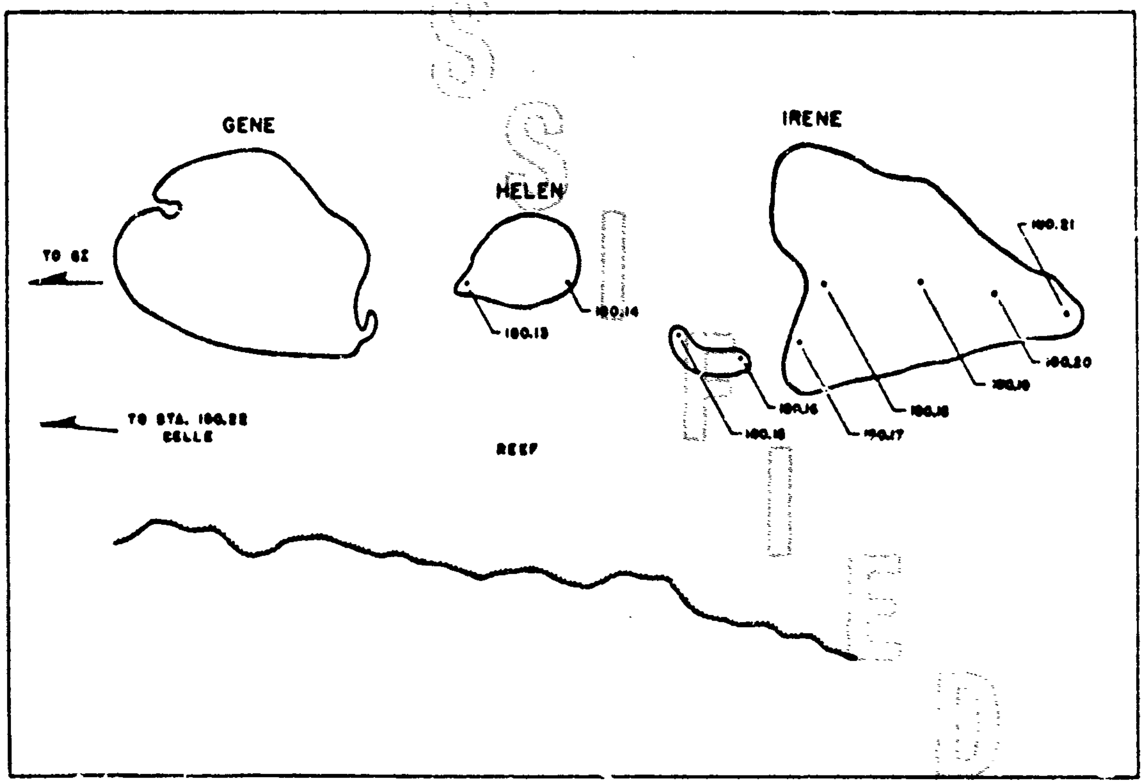

Fig. 2.2 - Field layout, Shot 6

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Chapter 3
RESULTS

3.1 SHOT 3

The yield value realized in Shot 3 was too low to give any significant results. The highest pressure region in which vehicles were located was 7.48 psi. At this pressure level damage to vehicles was light. The damage and the displacements are tabulated in Table B.1. The pressure values measured at each vehicle station are shown in Table 3.1. Two of the "q" gages at 10,900 feet and 13,800 feet did not function.

3.2 SHOT 6

The pressure region to which vehicles were subjected ranged from 8.3 psi to 58 psi. Within this range, damage varied from light to severe. Most of the vehicles were completely demolished.

As in previous shots, vehicles in side-on orientation sustained more damage than the vehicles in face-on orientation. In the region of over-kill, where vehicles are totally dismembered, the vehicles placed face-on were not damaged to the extent of the vehicles placed side-on (note difference in photographs in Appendix C). An observation of unusual damage was made at Station 180.20. The vehicle in face-on position was displaced 200 feet; yet the only damage incurred was to the two front wheels. The body and steering column were intact, so it may be assumed that this vehicle did not roll. However, it is not certain whether the vehicle was picked up and hurled through the air, landing on its two front wheels, or whether the vehicle slid.

Two vehicles at Station 180.21 were blown into the lagoon, and damage could not be evaluated. If the damage could be evaluated, this result would not be valid, since damage would certainly be different if the vehicles were hurled against a ground surface.

Water waves did wash over the nearer positions to ground zero and possibly inflicted additional damage to vehicles at these stations. Beyond Station 180.19 there appeared to be no damage resulting from water-wave action. From the terrain features noted, it was reasonable to assume that water waves did not wash over beyond Station 180.19.

The damage evaluations and the displacements are listed in Appendix B, Table B.2. The static pressures and dynamic pressures as measured are shown in Table 3.2 and plotted in Figs. 3.1 and 3.2, respectively. The plot of static pressure data generally fits the predicted pressure-distance curve, if a yield value of 1.7 MT is used. The dynamic pressure curve of Fig. 3.2 was obtained from the predicted pressure-distance curve of Fig. 3.1 by the use of Equation 2.1.

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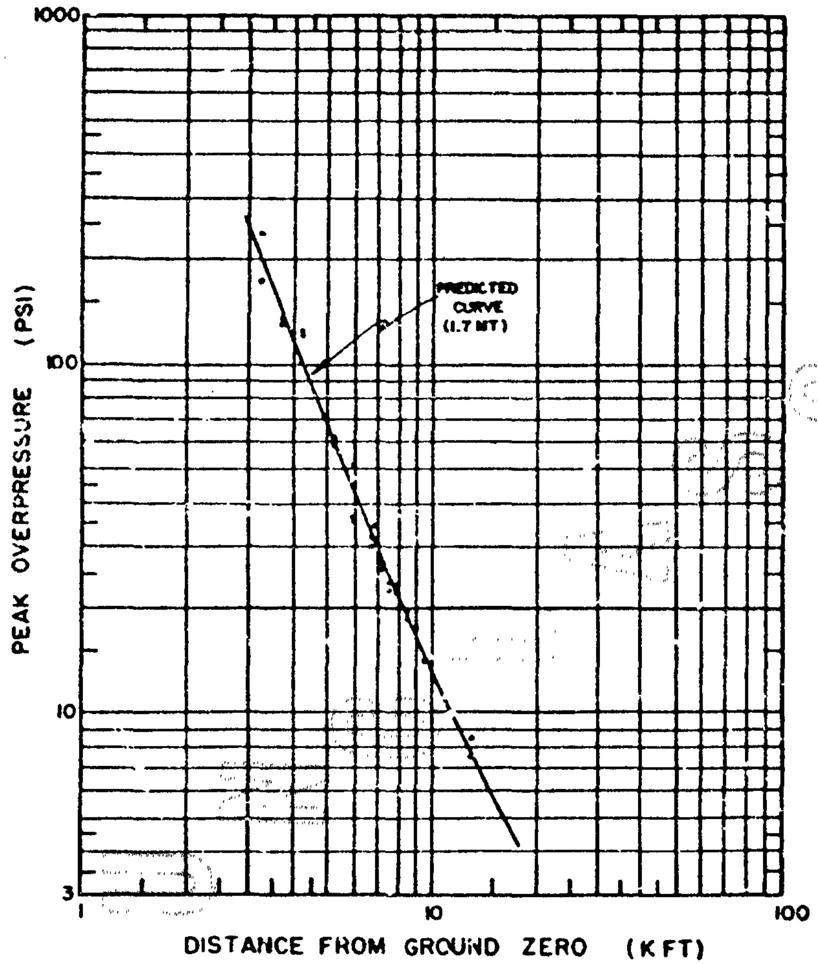

Fig. 3.1 Static pressure versus distance, Shot 6 (measured values).

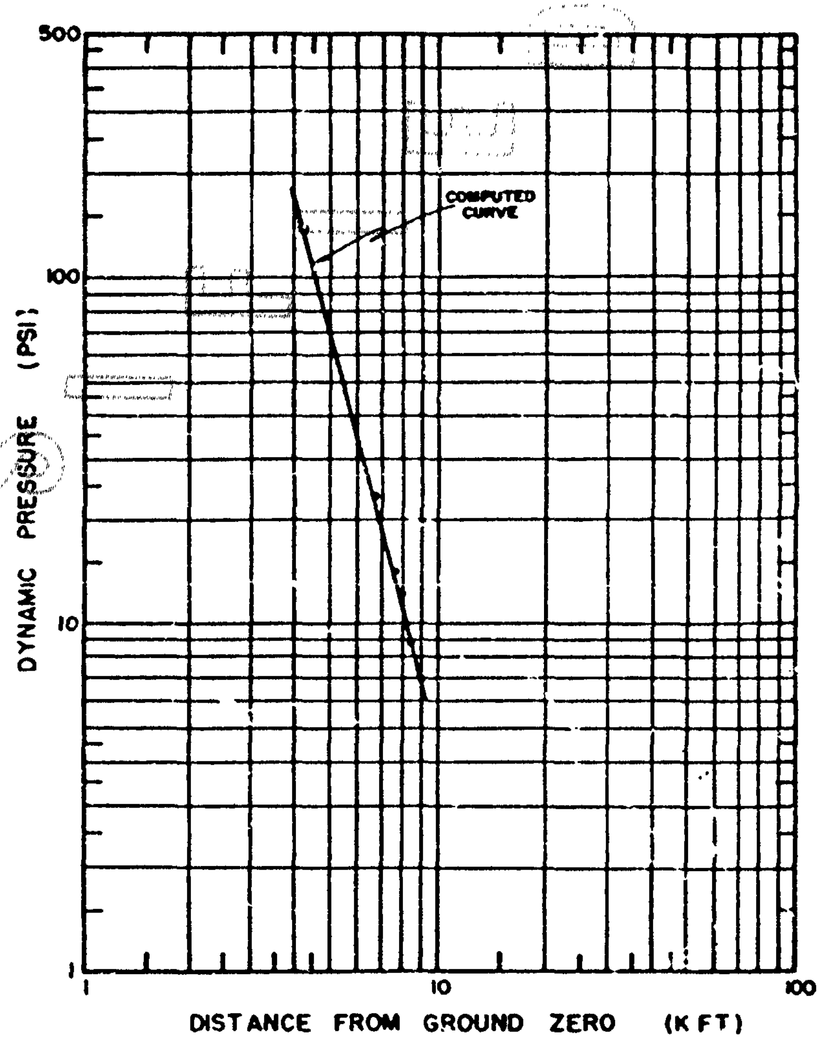

Fig. 3.2 Dynamic pressure versus distance, Shot 6 (measured values).

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TABLE 3.1 Pressure versus Distance, Shot 3

Station Number	Distance (ft)	P_s Meas.	P_d Meas.	P_d Calc.
180.09	6,500	7.48	1.10	1.26
180.10	8,200	4.50	0.47	0.46
180.08	10,900	2.30	--	--
180.07	13,800	1.40	--	--

TABLE 3.– Pressure versus Distance, Shot 6

Station Number	Distance (ft)	P_s Meas.	P_d Meas.	P_d Calc.
180.13	5,200	58.0	--	--
180.14	5,900	51.0	--	--
180.15	6,750	34.5	20.3	21.7
180.16	7,230	26.0	--	--
180.17	7,600	23.5	12.8	10.9
180.18	7,900	22.4	11.1	10.0
180.19	8,500	19.0	8.2	7.4
180.20	9,000	16.8	6.5	5.9
180.21	9,580	14.0	--	--
180.22	13,090	8.3	--	--

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Chapter 4
DISCUSSION

4.1 GENERAL

The wave forms of the pressures measured and the general agreement between the measured and calculated dynamic pressures indicated that the shock wave of Shot 6 was nearly a classical shock wave. Although there was sand in the blast wave, as evidenced by the vehicles being sandblasted, there was an insufficient amount of sand to alter appreciably the wave forms. It is believed that the contributions to damage of vehicles by dust was negligible.

A surprisingly larger value of dynamic pressure is required to cause the same degree of damage to vehicles placed face-on than for vehicles placed side-on. The value of dynamic pressure for lower limit of severe damage, (vehicle demolished) for face-on orientation was 12.1 psi. Unfortunately, data were not available at pressure levels less than 6.9 psi to establish the lower limit of severe damage for side-on orientation. A gap of 4000 feet existed between the last station for severe damage and the next station for moderate damage. Land area was not available for placement of vehicles within this gap.

4.2 COMPARISON OF DAMAGE AND DISPLACEMENTS OF SHOT 6, CASTLE WITH SHOT 10, UPSHOT-KNOTHOLE

A comparison of damage for Shots 6 (CASTLE) and 10 (UPSHOT-KNOTHOLE) is given in Table 4.1 and shown in Figs. 4.1 and 4.2. In both figures, Figs. 4.1 and 4.2, the symbols S, S-M, M, and L signify severe, severe-moderate, moderate and light damage, respectively sustained by the jeeps at the distances indicated. The damage noted is for side-on orientation. Severe-moderate classification indicates that item was still intact, but repairs for immediate combat use were such as to require depot maintenance. This classification makes a distinction from severe damage whereby item is completely dismembered.

Examination of the limited data indicates that, for similar damage to jeeps higher values of overpressure were recorded on Shot 6 (CASTLE) than on Shot 10 (UPSHOT-KNOTHOLE). The relative comparisons as shown in Fig. 4.1 indicates that damage to jeeps on Shot 10 (UPSHOT-KNOTHOLE) corresponds to the ideal overpressure-distance curve. However, since measurements of overpressure were taken on both shots and are reliable the damage to jeeps on Shot 10 as a function of the ideal overpressure is meaningless.

As mentioned in Section 1.2, damage to jeeps will be a function of dynamic pressure, but the magnitudes of dynamic pressure for specific damage were in question. On Shot 6, CASTLE, measurements of

[redacted]

dynamic pressure which are related to measured overpressure by use of the Rankine-Hugoniot relation, Equation 2.1 were recorded for each specific damaged sustained by the jeeps. Comparing damage of Shot 6 (CASTLE) with Shot 10 (UPSHOT-KNOTHOLE) as a function of dynamic pressure as shown in Fig. 4.2 indicates the damage to jeeps on Shot 10 correlate better with the ideal dynamic pressure than with the values measured by Sandia Corporation (see Reference 4). The measured values of dynamic pressure on Shot 10 are questionable. This comparison suggests that the probability curves for damage to jeeps (see Reference 1) are valid since ideal dynamic pressures were used for correlation with damage in the statistical analysis conducted.

Up to now no mention has been made of the effect of positive duration on damage to jeeps. Intuitively, it can be expected that if

TABLE 4.1 Damage Comparison Between Shot 10 (UPSHOT-KNOTHOLE) and Shot 6 (CASTLE) for 1/4-Ton Trucks, Side-on

Shot 10

Distance ft	Measured P-D Curve		Ideal P-D Curve		Degree of Damage	Displacement (ft)
	P_s	P_d*	P_s	P_d		
1422		9.6				
1600	12.0		26.5	14.8	Severe	-
1920	9.3	10.9	18.8	8.3	Severe	312
2415	8.5		11.7	3.3	Severe-Moderate	72
2770	7.8		8.8	2.0	Light	17.7

* see Reference 4

Shot 6

Station Number	Distance (ft)	Measured P-D Curve		Degree of Damage	Displacement (ft)
		P_s	P_d		
180.18	7,900	22.4	11.1	Severe	280
180.19	8,500	19.0	8.2	Severe	360
180.20	9,000	16.8	6.5	Severe	290
180.22	13,090	8.3	1.55	Moderate	75

a force of sufficient magnitude to cause motion acts on a target for a long period of time, the damage will be greater than for an equivalent force acting on the target for a shorter period of time. The treatment of the effect of positive duration is given in Appendix A. It is shown that as the yield of weapon increases the dynamic pressure for a given displacement decreases. Now, displacement and damage of a vehicle are related. It can be expected that the larger displacements of a vehicle will cause greater damage. Therefore, for the same level of damage the dynamic pressure will be higher from a low yield weapon than from a high yield weapon. In view of this, the dynamic pressure on Shot 10 could have been higher than the ideal dynamic pressure even though the comparison of the damage made between Shot 6 and Shot 10 implies that the ideal dynamic pressure was effective in causing damage to jeeps on Shot 10. Although the data obtained in Operation CASTLE was valuable, it was not enough to

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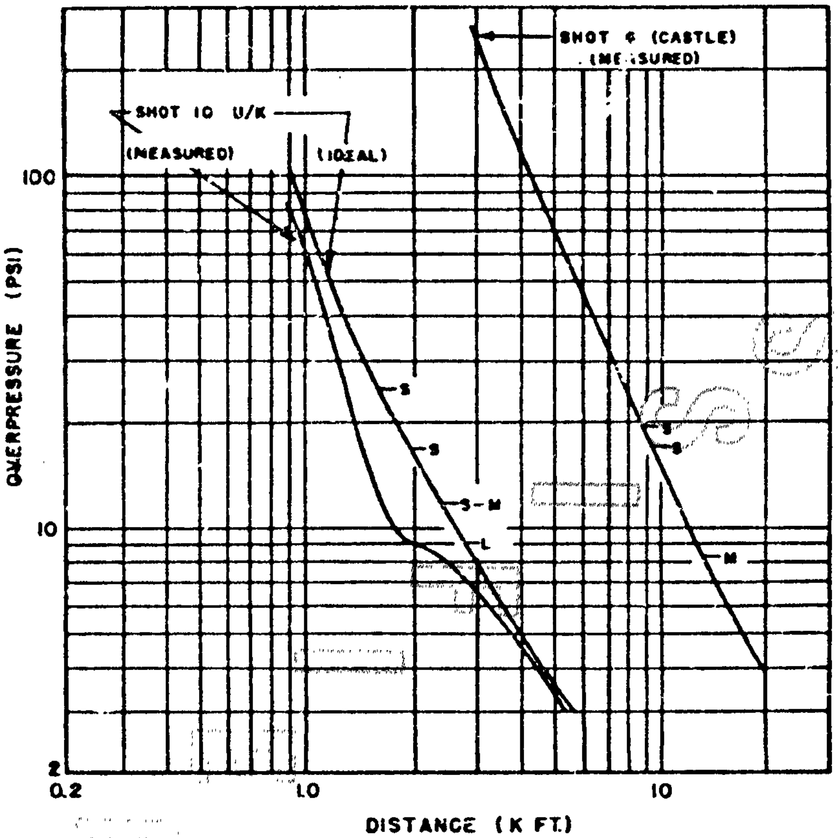

Fig. 4.1 - Comparison of damage, Shot 6 (CASTLE), with damage, Shot 10, (UPSHOT-KNOTHOLE), on static pressure versus distance.

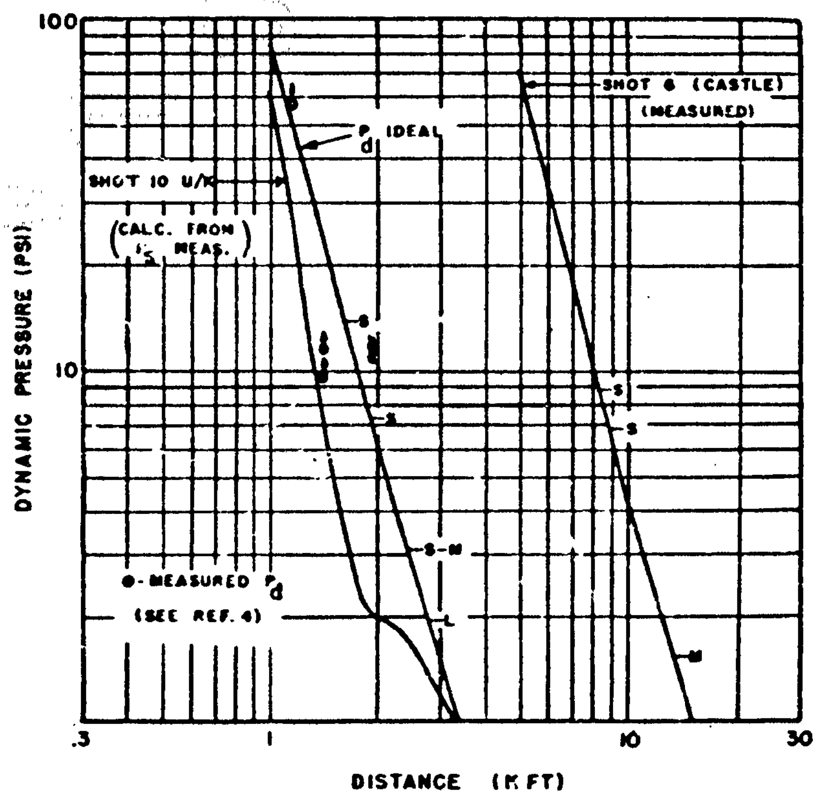

Fig. 4.2 - Comparison of damage, Shot 6 (CASTLE), with damage, Shot 10 (UPSHOT-KNOTHOLE), on dynamic pressure versus distance.

separate the effects of dynamic pressure on damage to vehicles from the effects of positive duration on damage to vehicles. It follows therefore that the effect on damage resulting from the long positive duration is still to be determined and that the validity of the probability curves for damage as a function of ideal dynamic pressure remain to be proven.

It is of interest to point out that if the damage to the jeep at 13,090 feet (Shot 6) was severe then a more favorable comparison would exist for displacement as well as damage between Shot 6 (CASTLE) and Shot 10 (UPSHOT-KNOTHOLE). The damage to the jeep at 13,090 feet could just as likely have been severe since during the transient time of the vehicle being displaced the manner of impact of the vehicle with the ground would itself be a probability function. The displacement and damage then would be approximately similar at 13,090 feet, Shot 6 and 2415 feet, Shot 10. In each case the vehicles were intact except that on Shot 10, the vehicle required depot maintenance to restore to combat use which is considered as severe-moderate damage and on Shot 6, the vehicle required field maintenance which is considered moderate damage.

If the comparison was as indicated above the scaling from Shot 6 conditions to Shot 10 conditions for displacement of jeep as well as the damage to jeep would be approximately $W^{1/3}$. At each of two locations on Shot 6 and Shot 10 the displacements were approximately equal. That is at 9,000 feet, Shot 6 and 1,920 feet, Shot 10, the displacements of jeeps were 290 feet and 310 feet, respectively. Also, at 13,090 feet, Shot 6 and 2,415 feet, Shot 10, the displacements were 75 feet and 72 feet respectively.

Hence, for W_2 = 1.7 MT, Shot 6 and W_1 = 15 KT, Shot 10

$$\frac{R_2}{R_1} = \left(\frac{W_2}{W_1}\right)^x = \frac{9000}{1920} = \left(\frac{1700}{15}\right)^x$$

or $x = 0.33$

and

$$\frac{R_2}{R_1} = \left(\frac{W_2}{W_1}\right)^x = \frac{13,090}{2,415} = \left(\frac{1700}{15}\right)^x$$

or $x = 0.36$

Therefore, for reasonable estimates of ground range for specific damage to 1/4 ton trucks, the scaling for various yield weapons can be as $W^{1/3}$ where W is the yield of weapon.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The data obtained in Operation CASTLE were sufficient to evaluate dynamic pressure as a damage parameter and also to determine the magnitude of dynamic pressure required for specific type damage to 1/4-ton trucks for a set of conditions as that in CASTLE. The limited data of CASTLE when compared to Shot 10 (UPSHOT-KNOTHOLE) suggests that the ideal dynamic pressures were effective in causing damage on Shot 10. However, because of the uncertainty as to what effect the long positive duration has on damage the values of dynamic pressure causing damage on Shot 10 remain questionable. In the CASTLE results, it was not possible to separate the effect of dynamic pressure on damage from the effect of the long positive duration on damage.

Reasonable estimates of ground ranges for specific type damage to 1/4-ton trucks can be made when the scaling is as $W^{1/3}$, where W is yield of weapon.

In view of the knowledge accumulated on damage to jeeps under varied blast conditions, the jeeps can be regarded as response gages to forces resulting from nuclear blasts. It is recommended that in future nuclear tests jeeps be exposed along with instrumentation for basic blast measurements to investigate any variations of the blast and its effects on damage to drag sensitive targets under various conditions of nuclear detonations.

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3. F. B. Porzel, Theoretical Blast Curves, Supplement to Memorandum T-17837, May 25, 1953, Theoretical Blast Curves, August 20, 1953.
4. C. D. Broyles, Dynamic Pressure vs Time and Supporting Air Blast Measurements, Project 1.1d, Operation UPSHOT-KNOTHOLE, WT-714, February 1954.
5. Armour Research Foundation, The Effects of Atomic Blasts on Military Field Equipment, ARF No. M041, Final Report, 28 February 1955.
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Appendix A
EFFECT OF POSITIVE DURATION ON DAMAGE

A.1 GENERAL

The study of the effects on damage of positive duration was undertaken prior to the test in Operation CASTLE and completed during the time the test was conducted at Pacific Proving Ground.

For drag targets, such as vehicles, much damage will result because of motion due to either high acceleration forces or impact with the ground. The easiest and simplest parameter selected from experimental data for correlation to forces of a blast wave was displacement. Displacement of the item is proportional to the dynamic pressure impulse of the blast wave.

Calculations were made for displacements of 1/4-ton trucks exposed to weapons of various yields. Furthermore, a statistical analysis was conducted to determine the relation of displacement of a vehicle to damage. From this procedure, the quantitative effect on damage of the positive duration was obtained.

A.2 CALCULATED DISPLACEMENTS FOR OPERATION CASTLE

In the calculations for displacements performed, the loading methods developed by Armour Research Foundation (see Reference 5) were used. These calculations are for linear displacements assuming a constant area and a constant frictional force for 1/4-ton truck exposed to the long durations expected in Operation CASTLE. The calculations involved the computation of the pressure-time decay curves for the pressures of interest, the integration of these curves and calculations of the displacements for various coefficients of friction. Three values of coefficient of sliding friction were used, 0.25, 0.5, and 1.0 and three values of yield, 0.125 MT, 1.0 MT and 10 MT burst at surface level.

The equations used to describe the decay of the pressure-time curve was the modified Friedrich's equation, and the duration for pressures of interest were obtained from Operation IVY. The durations are not considered to be precise. However, three significant figures were used so that the resulting displacement data would form smooth curves. The data used for the calculations are listed in Table A.1.

Fig. A.1 and Fig. A.2 present the normalized overpressure and dynamic pressure decay curves. Three pressures are plotted in each figure to indicate the decay changes as λ changes.

The calculated values of displacement obtained were plotted against dynamic pressure and are shown in Figs. A.3, A.4, A.5 and A.6.

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Shown also in Figs. A.3 and A.5 are the calculated displacements performed for Shot 9, UPSHOT-KNOTHOLE. This shot was a high air burst weapon and the calculated displacements were the values resulting from the horizontal component of dynamic pressure. The dynamic pressures for computation were obtained from the usual Rankine-Hugoniot relation, (Eq. A.1).

$$P_d = \frac{2.5\ (P_s)^2}{7\ P_o + P_s} \qquad \text{(A.1)}$$

with P_o = 14.7 psi.

The horizontal lines shown in Figs. A.3 through A.6 depict the damage that may be expected for the calculated displacements. The correlation of displacement with damage to 1/4-ton trucks was obtained from a statistical analysis of previous data. The treatment of the data involved the analysis of "sensitivity data" (see Reference 6). This correlation is shown in Fig. A.7, which gives the probability of damage to 1/4-ton trucks versus displacement and is for side-on orientation only. Since there was no overlap of data in the region of moderate and severe damage, neither the mean value μ nor the standard deviation σ could be calculated for the probability of severe damage. The mean value of displacement for 50 percent probability of light damage is μ = 27.1 feet and standard deviation is σ = 3.66 feet. The interval of displacement for 50 percent probability of severe damage is $40 < \mu < 72$ feet. The values of the horizontal lines shown in the figures mentioned above are 27.1 feet for 50 percent probability of light damage and 72 feet, above which is severe damage.

A study of the curves indicates that for drag targets that are damaged when moved, such as vehicles, an additional increase in lethal area may occur resulting from the longer duration of the large yields. The longer duration lowers the dynamic pressure for specific type damage and thus the radius of damage extends beyond the usual scaling value, i.e., using $W^{1/3}$ for scaling the distance from ground zero for a given value of dynamic pressure. To determine the exponent of the yield, W, for scaling the lethal radius for specific damage, a curve was drawn (see Fig. A.8) showing the distance from ground zero for which a given displacement can be expected from different size weapons burst at surface level. The values of displacement selected from Figs. A.3 and A.4 were for side-on orientation and for μ = 0.5, sliding coefficient of friction. The actual displacements of jeeps in Shot 9, UPSHOT-KNOTHOLE, for side-on orientation within the Mach region were scattered about the displacement curve calculated for a sliding coefficient of friction of μ = 0.5. Additional calculations for displacement were performed for yields other than those mentioned to cover the range of yields from 0.1 KT up to 10 MT. The slope of the curves varies from a minimum of 0.40 up to a maximum of 0.5 which suggests that the average value for scaling the yield, W, for damage should be as $W^{0.45}$.

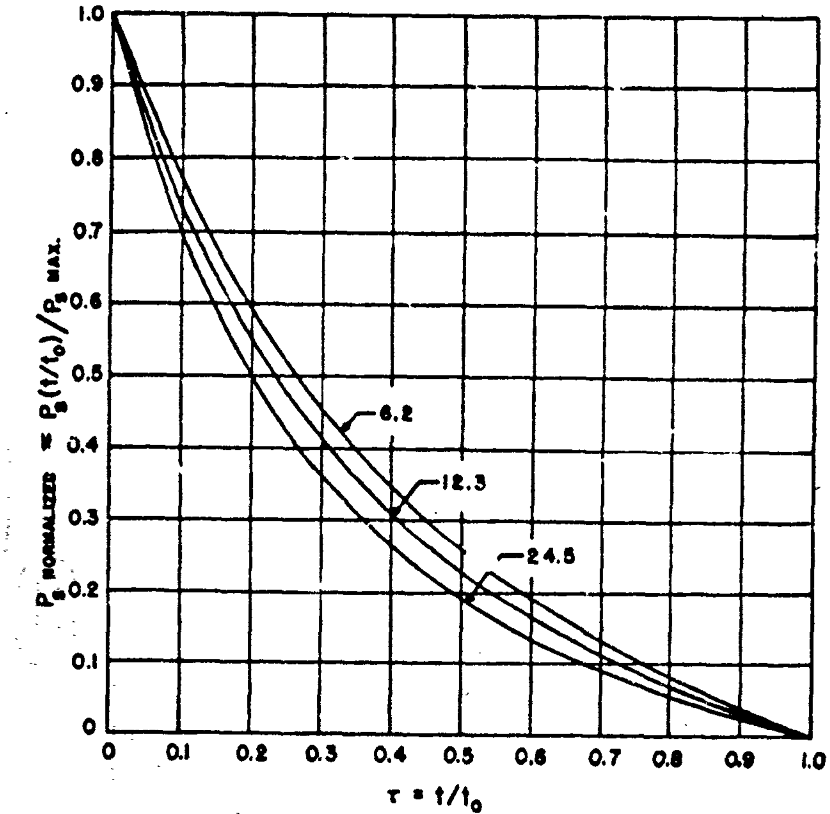

Fig. A.1 - Normalized overpressure versus time for pressure levels of 6.2, 12.3 and 24.5 psi overpressure (surface bursts).

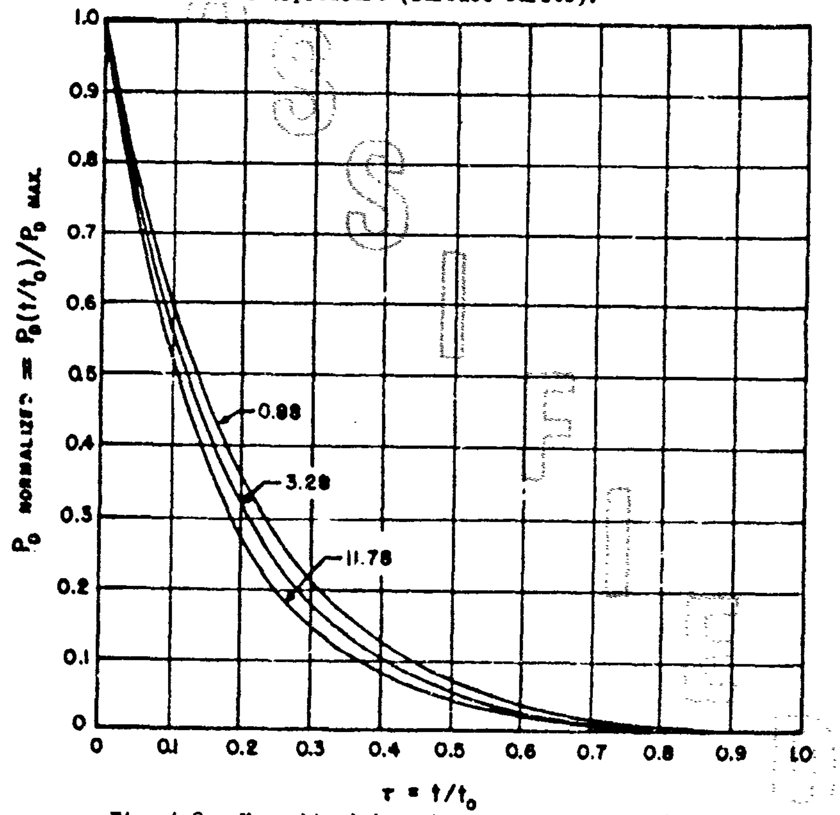

Fig. A.2 - Normalized dynamic pressure versus time for pressure levels of 0.83, 3.28 and 11.78 psi dynamic pressure (surface bursts).

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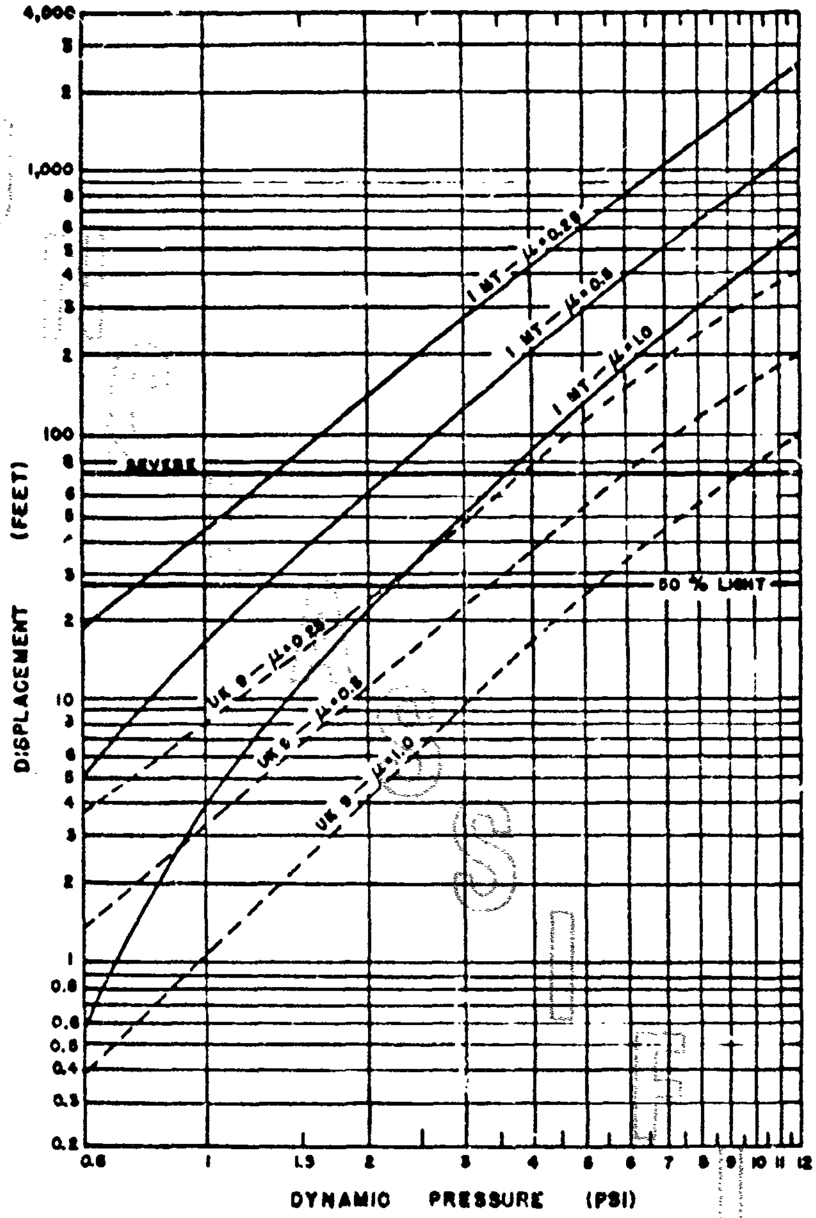

Fig. A.3 - Calculated displacements versus dynamic pressure of 1/4-ton trucks (side-on) for yields of weapon of 24 KT (UK-9) and 1 MT (surface burst)

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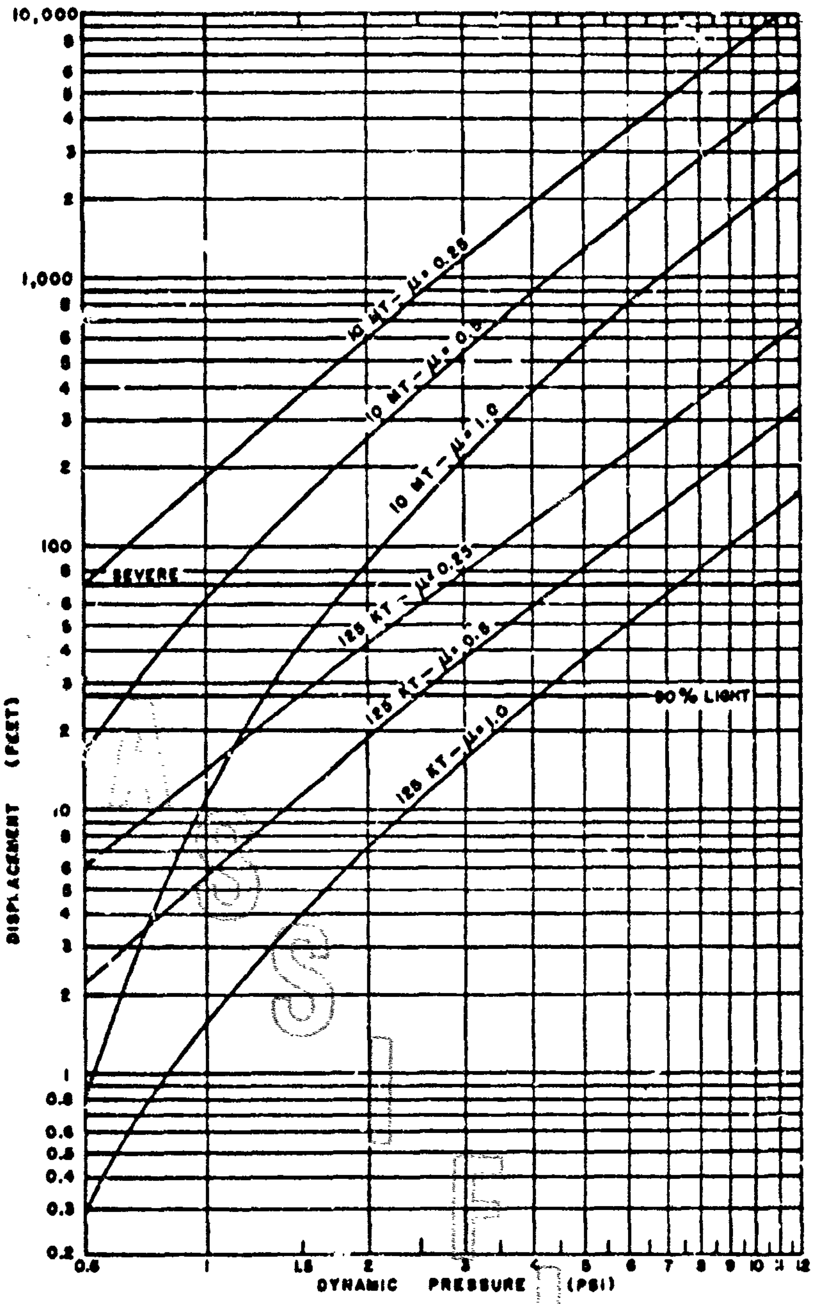

Fig. A.4 - Calculated displacements versus dynamic pressure of 1/4-ton trucks (side-on) for yields of weapon of 125 KT and 10 MT (surface bursts).

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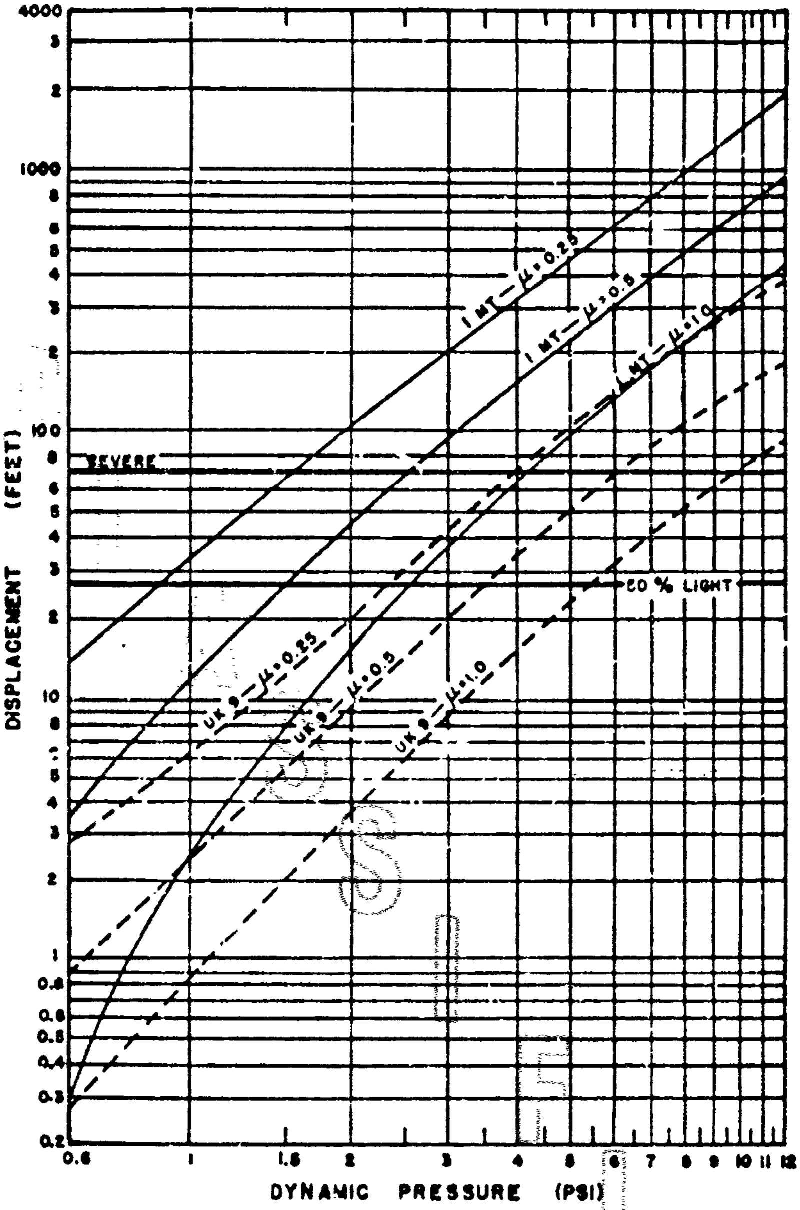

Fig. A.5 - Calculated displacements versus dynamic pressure of 1/4-ton truck (face-on) for yields of weapon of 24 KT (UK-9) and 1 MT (surface burst).

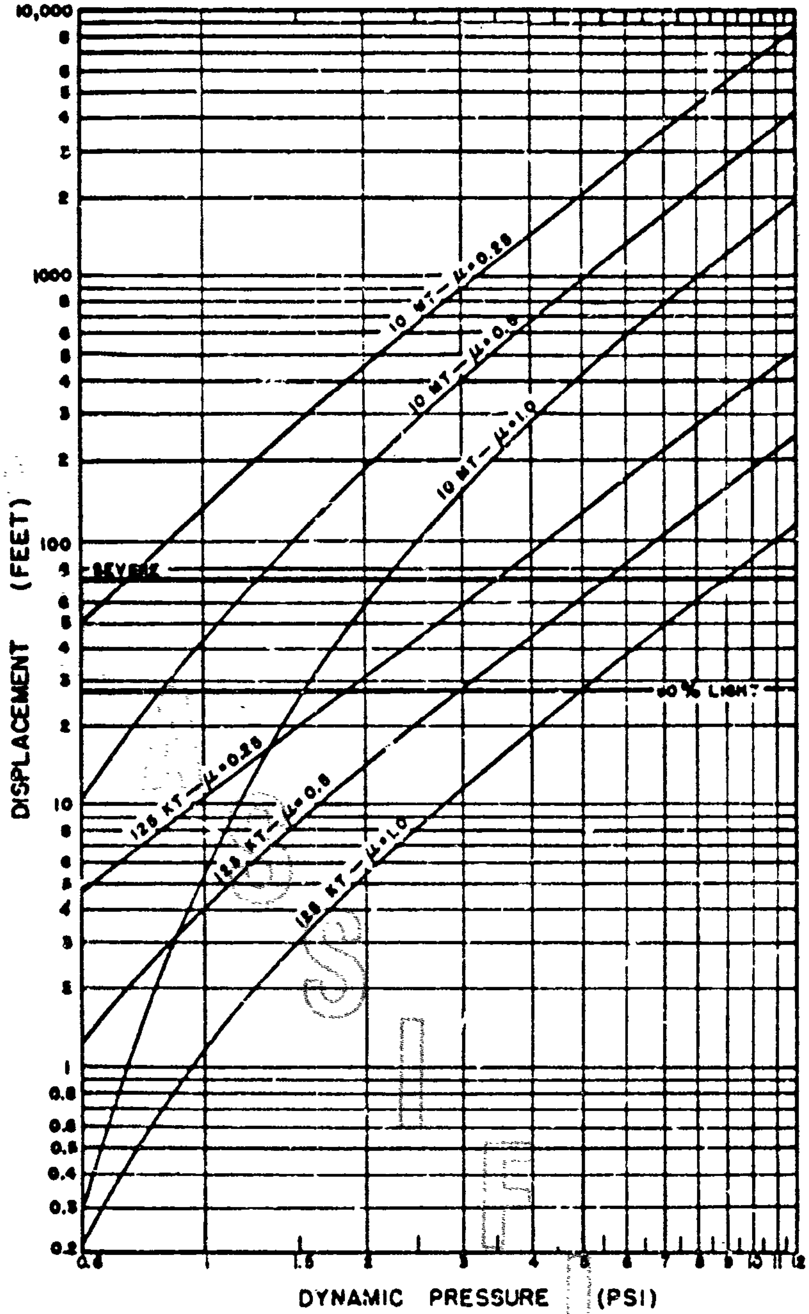

Fig. A.6 - Calculated displacements versus dynamic pressure of 1/4-ton truck (face-on) for yields of weapon of 125 KT and 10 MT (surface bursts).

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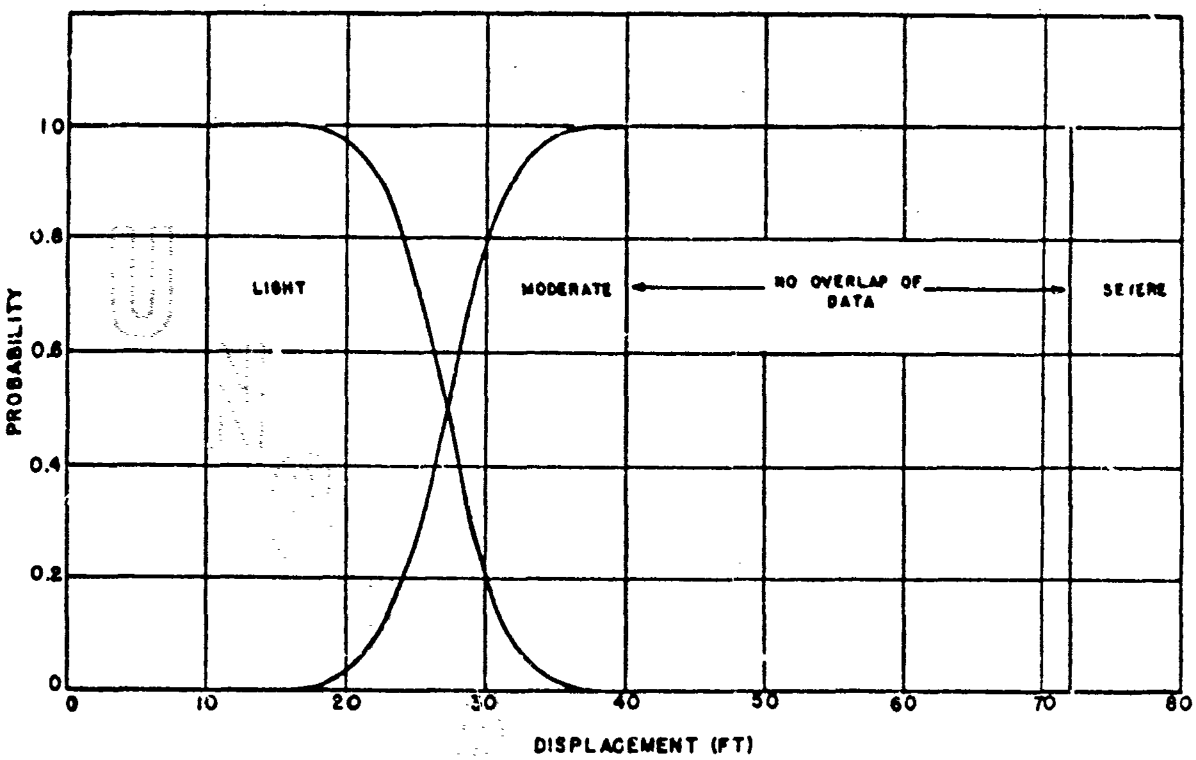

Fig. A.7 - Probability of damage versus displacement for 1/4-ton truck (side-on).

TABLE A.1 - Shock Wave Parameters Used in Calculations for Displacement of 1/4-Ton Trucks

P, psi	λ $R/W^{1/3}$	Duration t_o Sec. 0.125 MT	Duration t_o Sec. 1 MT	Duration t_o Sec. 10 MT
24.5	6.74	0.95	1.89	4.07
20.8	7.33	0.98	1.95	4.20
16.6	8.09	1.02	2.03	4.37
12.3	9.54	1.09	2.18	4.70
8.8	11.54	1.19	2.37	5.10
6.2	13.95	1.32	2.64	5.99

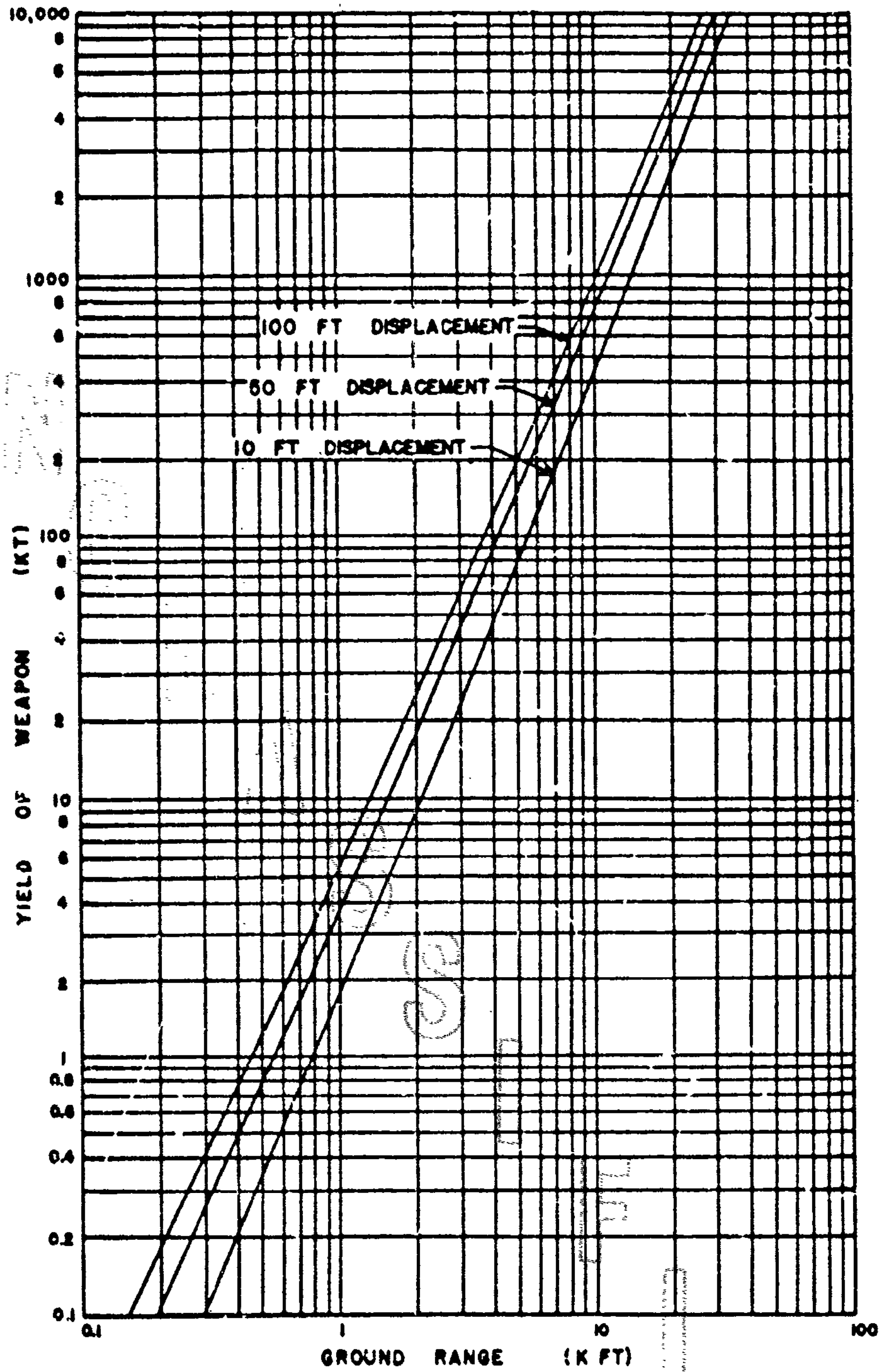

Fig. A.8 - Yield of weapon versus distance from ground zero for a given displacement of 1/4-ton truck (side-on). Surface bursts at sea level. (Coefficient of friction, $\mu = 0.5$)

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Appendix B
DAMAGE RESULTS

TABLE B.1 - Damage Results, Shot 5

Station Number	Distance	Pressure P_s psi	Pressure P_d psi	Orien.	Dis-placement	Degree of Damage	Damage Description	To Restore Combat Use: Man Hours	To Restore Combat Use: Main Echelon
180.09	6,500	7.48	1.10	FO	28 in.	L	Hood blown off - cowl torn windshield blown back over steering column. Vehicle upright and intact.	1/2	Organ
180.09	6,500	7.48	1.10	SO	15.1 ft	L	Turned over on back. Hood blown off. Steering column bent. vehicle intact.	1	Organ
180.09	6,500	7.48	1.10	SO	21 ft.	L	Turned over on back Vehicle intact. Hood blown off. Steering column bent.	1	Organ
180.10	8,200	4.50	0.47	FO	18 in.	L	Vehicle upright and intact. Hood blown off. Steering column bent by hood.	1/2	Organ
180.10	8,200	4.50	0.47	SO	9.0 ft.	L	Turned over on back Hood blown off. Steering column bent. Vehicle intact.	1	Organ
180.10	8,200	4.50	0.47	SO	7.5 ft.	L	Turned on side. Vehicle intact.	1	Organ
180.08	10,900	2.3					No damage to any of the vehicles.		
180.08	13,800	1.4					No damage to any of the vehicles.		

[redacted]

TABLE B.2 - Results · Shot 6

Station Number	Distance	Pressure P_s psi	P_d psi	Orien.	Dis-placement (ft)	Degree of Damage	Damage Description	To Restore Combat Use: Man Hours	Main Echelon
180.13	5,200	58.0	-	SO	- -	S	Demolished	- -	Salvage
180.13	5,200	58.0	-	FO	- -	S	Demolished	- -	Salvage
180.14	5,900	51.0	-	SO	- -	S	Demolished	- -	Salvage
180.14	5,900	51.0	-	FO	- -	S	Demolished	- -	Salvage
180.15	6,750	34.5	20.5	SO	- -	S	Demolished	- -	Salvage
180.15	6,750	34.5	20.5	FO	- -	S	Demolished	- -	Salvage
180.16	7,250	26.0	-	SO	Chassis 500	S	Demolished	- -	Salvage
180.16	7,250	26.0	-	FO	Chassis 500	S	Demolished	- -	Salvage
180.17	7,600	23.5	12.8	SO	Chassis 300	S	Demolished	- -	Salvage
180.17	7,600	23.5	12.8	FO	Chassis 260	S	Demolished	- -	Salvage
180.18	7,900	22.4	11.1	SO	Chassis 280	S	Demolished	- -	Salvage
180.18	7,900	22.4	11.1	FO	260	S	Chassis bent. Engine mounts broken, engine intact w/vehicle	- -	Salvage
180.19	8,500	19.0	8.2	SO	Chassis 360	S	Demolished	- -	Salvage
180.19	8,500	19.0	8.2	FO	180	S	Chassis intact, brake drum of left rear wheel bent, frame bent, engine torn loose at front mounts radiator and grill assembly bent, left front wheel bent.	15	Depot
180.20	9,000	16.8	6.5	SO	Chassis 290	S	Demolished	- -	Salvage
180.20	9,000	16.8	6.5	FO	200	M	Both front wheels damaged, one wheel bent, one wheel blown off, radiator pushed back slightly, steering column not bent	2	Organ
180.21	9,580	14.0	-	SO	- -	-	Vehicle blown into lagoon, damage could not be evaluated, appeared to be intact.		
180.21	9,580	14.0	-	FO	- -	-	Same as vehicle above.		
180.22	13,090	8.3	-	SO	75	M	Vehicle on its back, engine mounts torn loose, body bent	4	Field
180.22	13,090	8.3	-	FO	14	L	Body bent, windshield and hood blown off, vehicle upright.	-	- -

NOTE: FO - Face-on; SO - Side-on; Organ - Organization; S - Severe; L - Light; M - Medium

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Appendix C
PHOTOGRAPHY

Aerial and surface photographs were made of the vehicle stations before and after each shot. The photography included still and motion pictures. Aerial photography was for the purpose of evaluating damage from the pictures in the event radiological conditions were such as to preclude entry into the area after the shot.

Aerial photography after Shot 6 was unnecessary, since entry into the area was permissible one day after the shot. Only still pictures were taken.

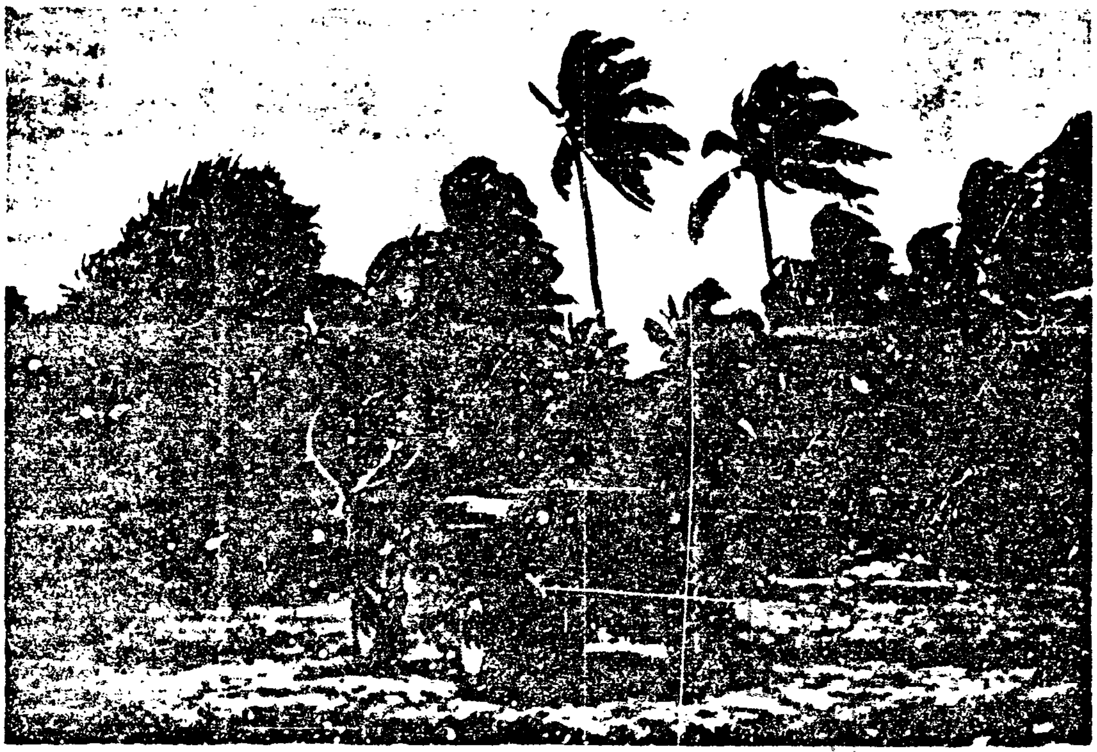

Fig. C.1 - Station 180.10, showing 1/4-ton truck, side-on and "q" gage before Shot 3 (surface view). Ground Range 8200 feet.

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Fig. C.2 - Station 180.10, before Shot 3, two 1/4-ton trucks, side-on, one 1/4-ton truck face-on. Ground range 8200 feet.

Fig. C.3 - Station 180.10 after Shot 3 P_s = 4.50 psi. Ground Range 8200 feet.

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Fig. C.4 - Station 180.09 before Shot 3, two 1/4-ton trucks side-on, one 1/4-ton truck face-on. Ground Range, 6500 feet.

Fig. C.5 - Station 180.09 after Shot 3, P_s = 7.48 psi. Ground Range, 6500 feet.

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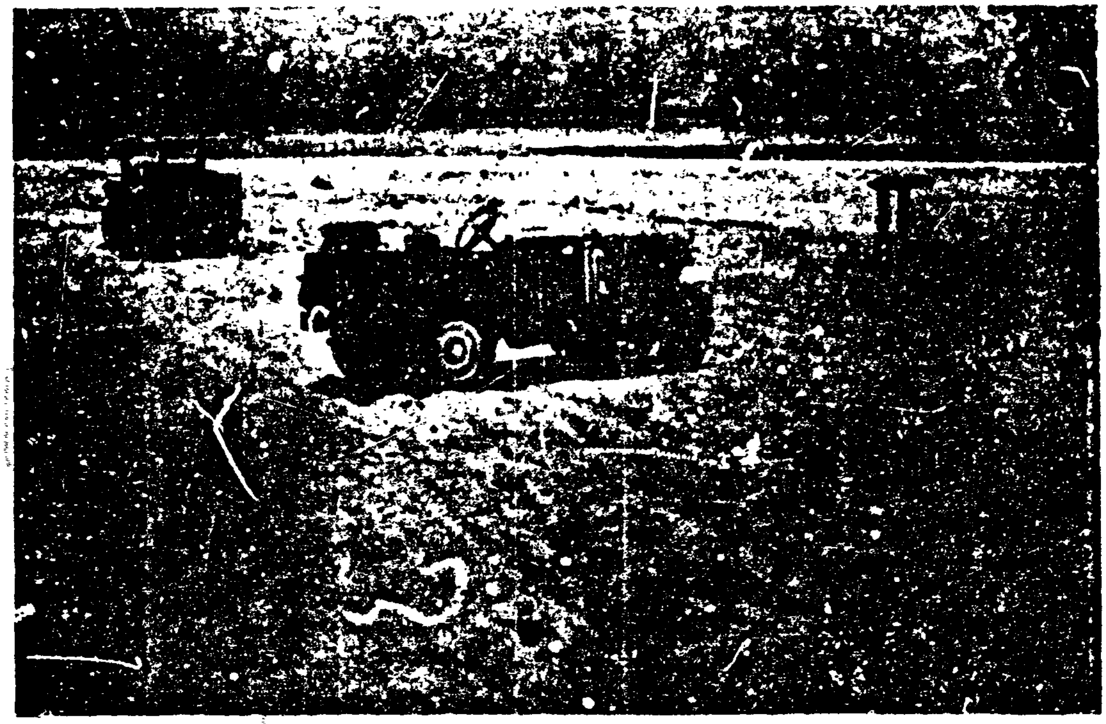

Fig. C.6 - Station 180.17 before Shot 6, Vehicle 10 face-on, Vehicle 11 side-on "q" gage to right of vehicles. Ground Range, 7600 feet.

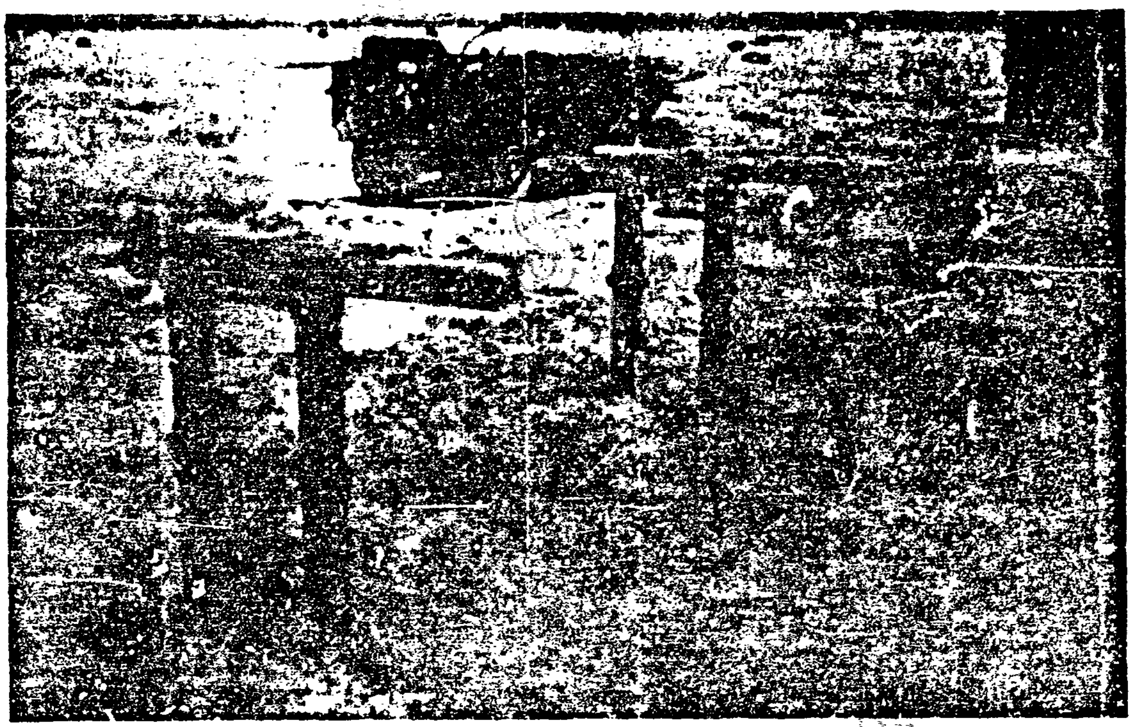

Fig. C.7 - Station 180.19 before Shot 6, Vehicle 14 face-on, Vehicle 8 side-on. Two "q" gages and two "P_t" gages in foreground. Ground Range, 8500 feet.

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Fig. C.8 - Station 180.17 after Shot 6, Vehicle 10 face-on, severe damage; P_s = 23.5 psi, P_d = 14.1 psi (compare with below). Ground Range, 7600 feet.

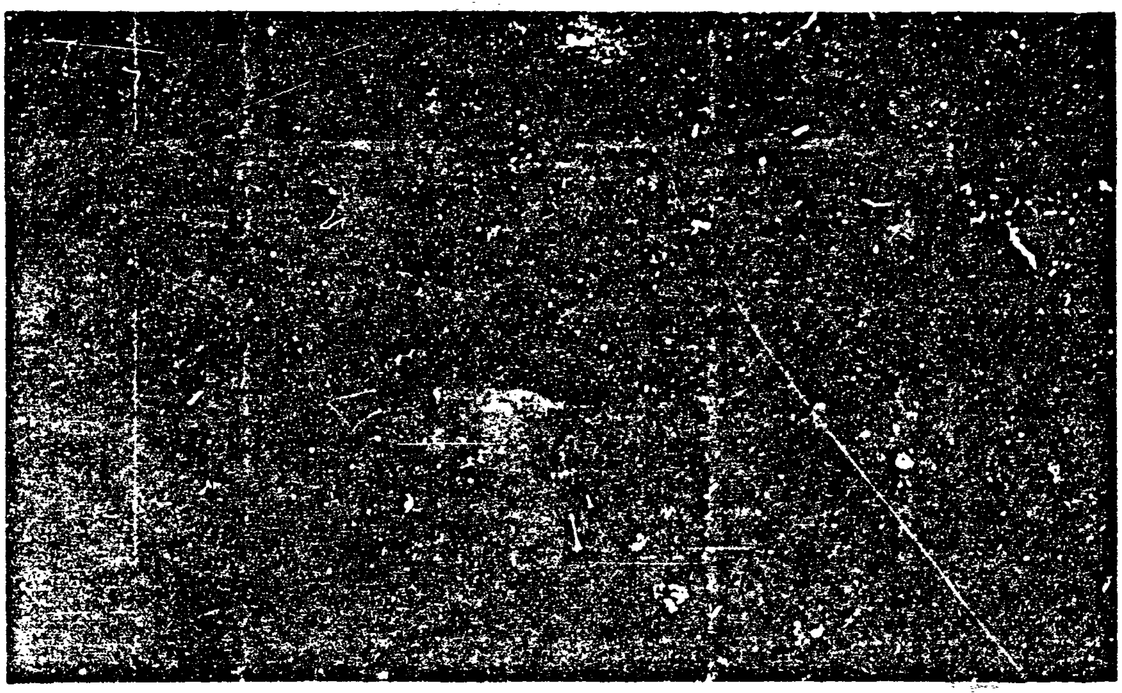

Fig. C.9 - Station 180.17 after Shot 6, Vehicle 11 side-on, demolished; P_s = 23.5 psi, P_d = 14.1 psi (compare with above). Ground Range, 7600 feet

Fig. C.10 - Station 180.18 after Shot 6, Vehicle 3 face-on, severe damage; P_s = 22.4 psi, P_d = 12.1 psi (compare with below). Ground Range, 7900 feet.

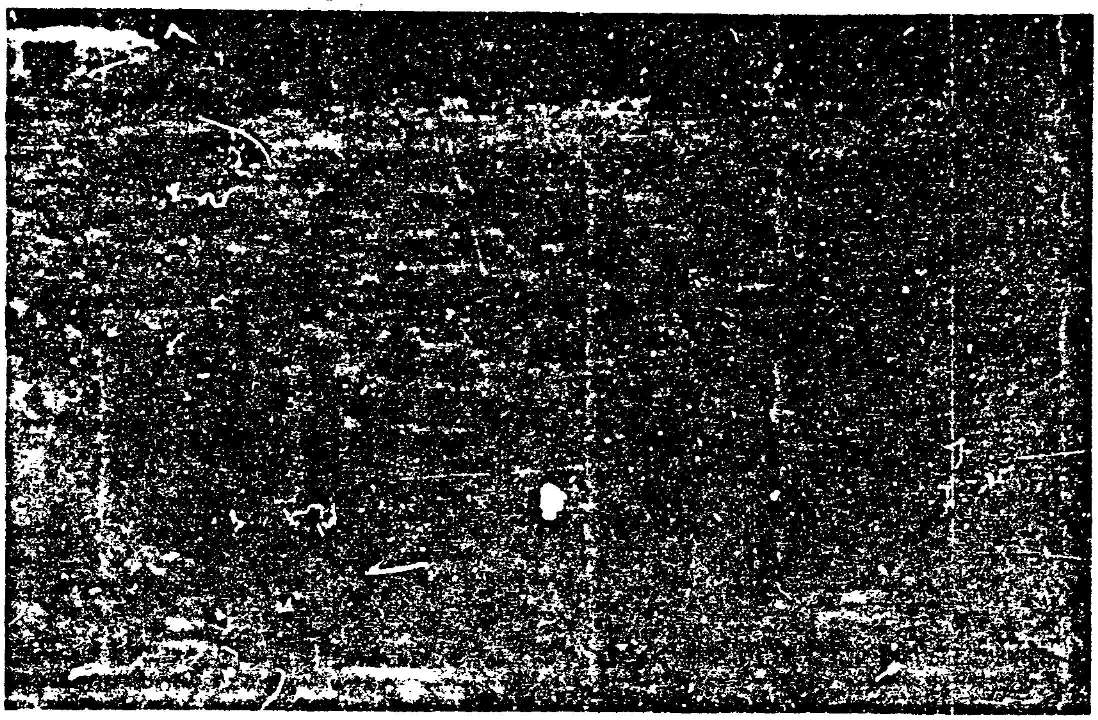

Fig. C.11 - Station 180.18 after Shot 6, Vehicle 1 side-on, demolished; P_s = 22.4 psi, P_d = 12.1 psi (compare with above). Ground Range, 7900 feet.

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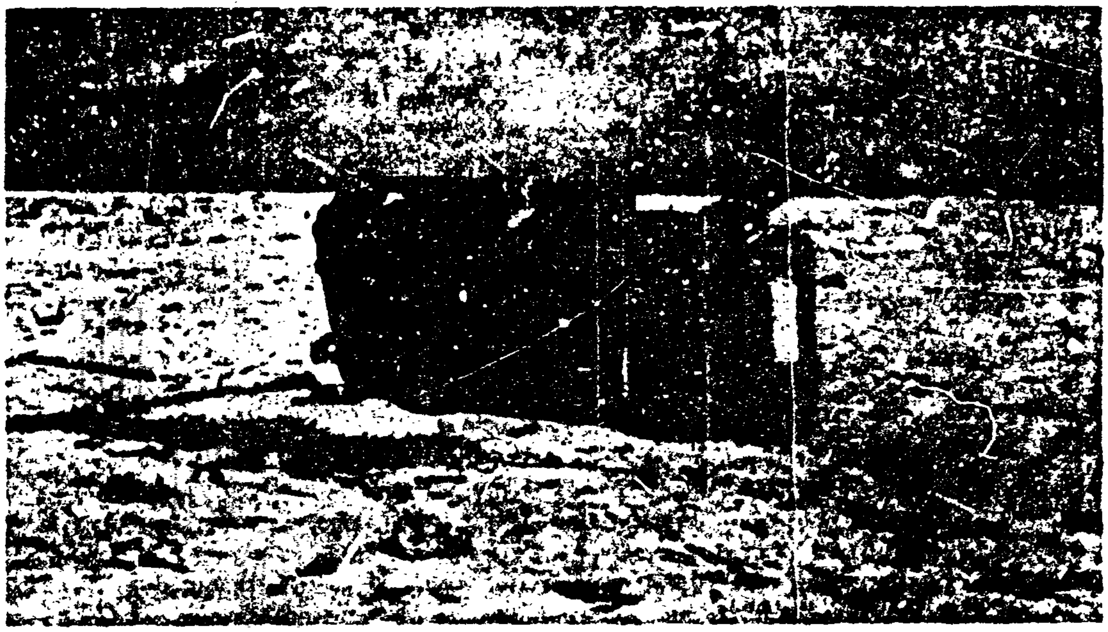

Fig. C.12 - Station 180.19 after Shot 6, Vehicle 14 face-on, severe damage; P_s = 19.0 psi, P_d = 8.8 psi (compare with below). Ground Range, 8500 feet.

Fig. C.13 - Station 180.19 after Shot 6, Vehicle 8 side-on, demolished; P_s = 19.0 psi, P_d = 8.8 psi (compare with above). Ground Range, 8500 feet.

[redacted]

Fig. C.14 - Station 180.20 after Shot 6, Vehicle 3 face-on, moderate damage; P_s = 16.8 psi, P_d = 6.9 psi, vehicle displaced 200 feet (compare with below). Ground Range, 9000 feet.

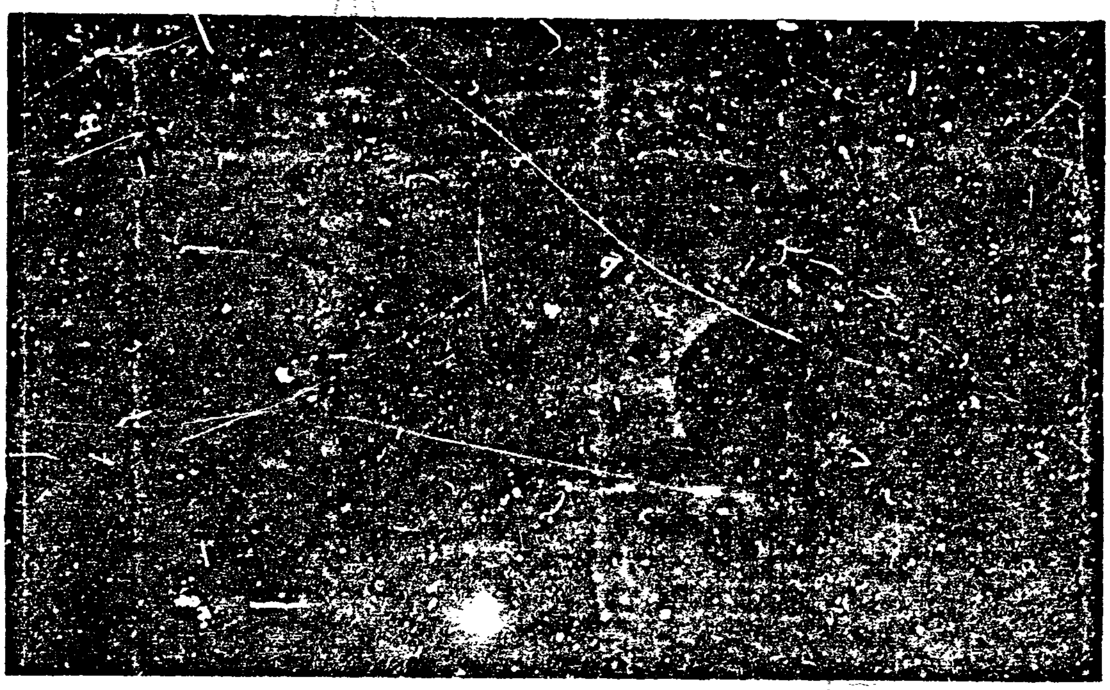

Fig. C.15 - Station 180.20 after Shot 6, Vehicle 12 side-on, demolished; P_s = 16.8 psi, P_d = 6.9 psi, chassis displaced 290 feet (compare with above and Fig. C.19). Ground Range, 9000 feet.

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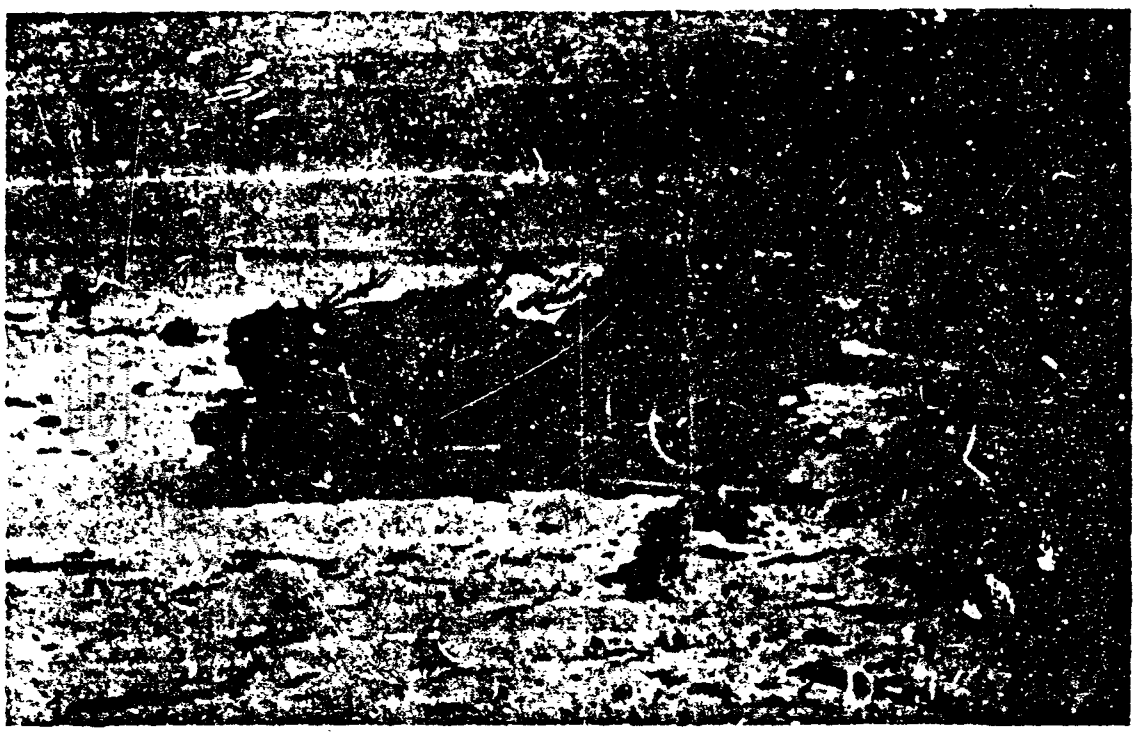

Fig. C.16 - Station 180.22 after Shot 6, Vehicle 2 face-on, light damage; P_s = 8.3 psi, $P_{d(comp)}$ = 1.55 psi (compare with below). Ground Range, 13,090 feet.

Fig. C.17 - Station 180.22 after Shot 6, Vehicle 6 side-on, moderate damage; P_s = 8.3 psi, $P_{d(comp)}$ = 1.55 psi, displaced 75 feet (compare with above and Fig. C.20) Ground Range, 13,090 feet.

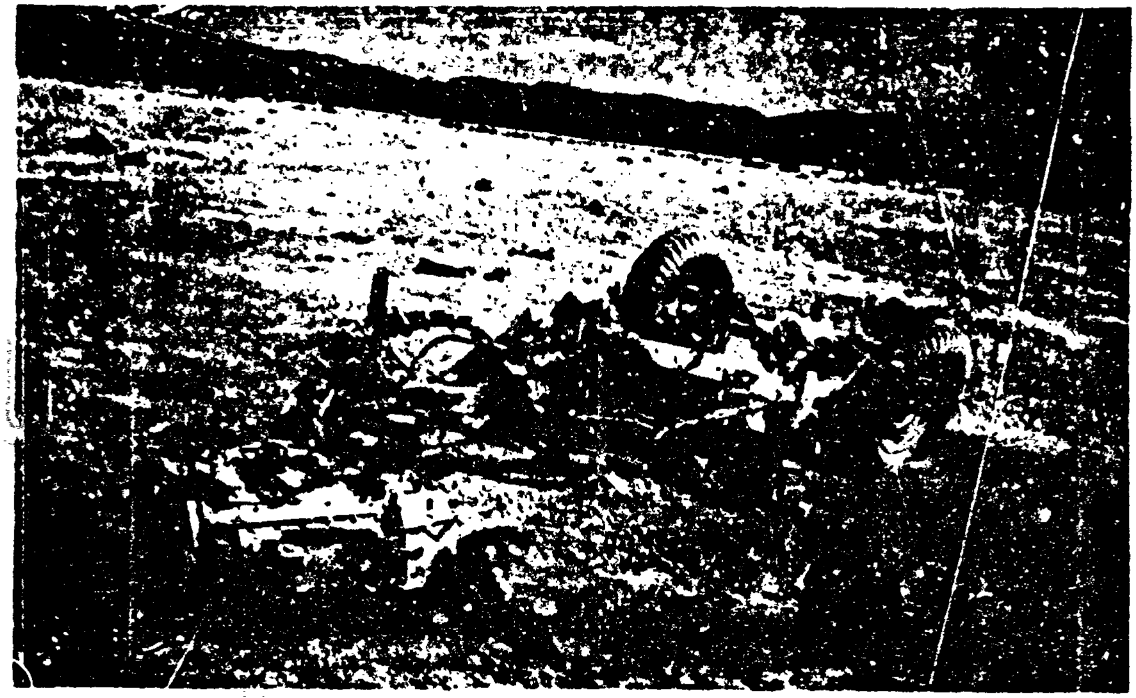

Fig. C.18 - Position 3.21 ad after Shot 10 (UPSHOT-KNOTHOLE), vehicle side-on, demolished; $P_{s(meas)}$ = 12.0 psi, $P_{d(ideal)}$ = 14.3 psi (compare with Fig. C.13).

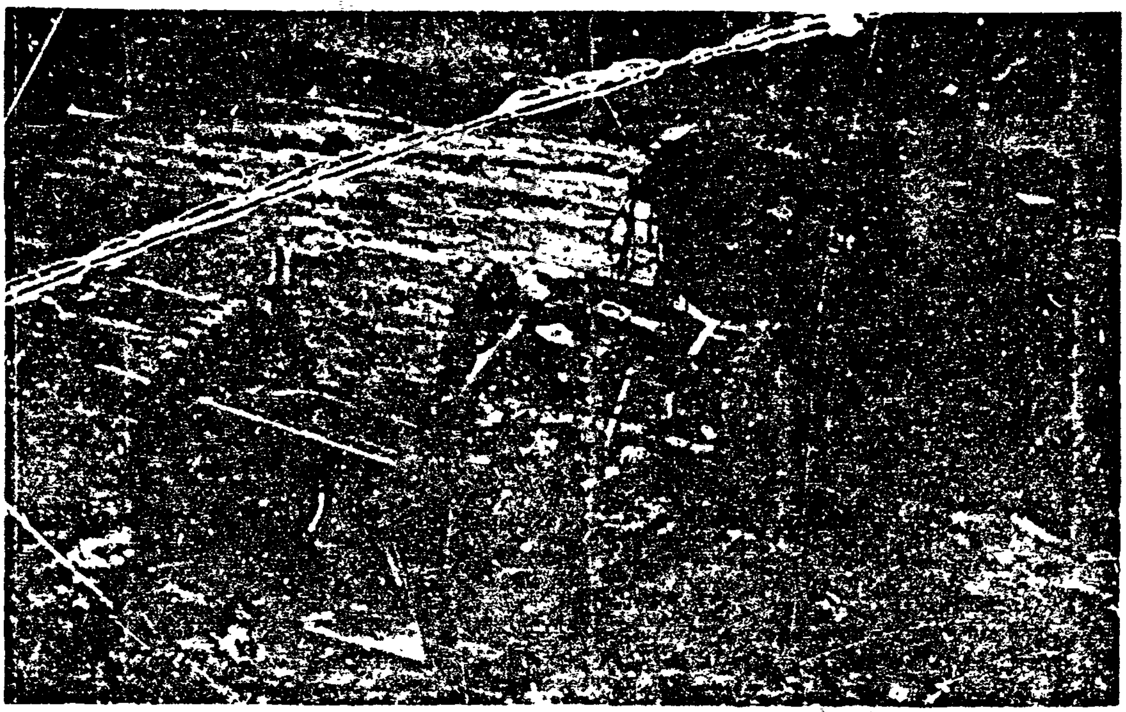

Fig. C.19 - Position 3.21 i after Shot 10 (UPSHOT-KNOTHOLE), vehicle side-on, demolished; $P_{s(meas)}$ = 9.3 psi, $P_{d(ideal)}$ = 8.3 psi chassis displaced 312 feet (compare with Fig. C.15).

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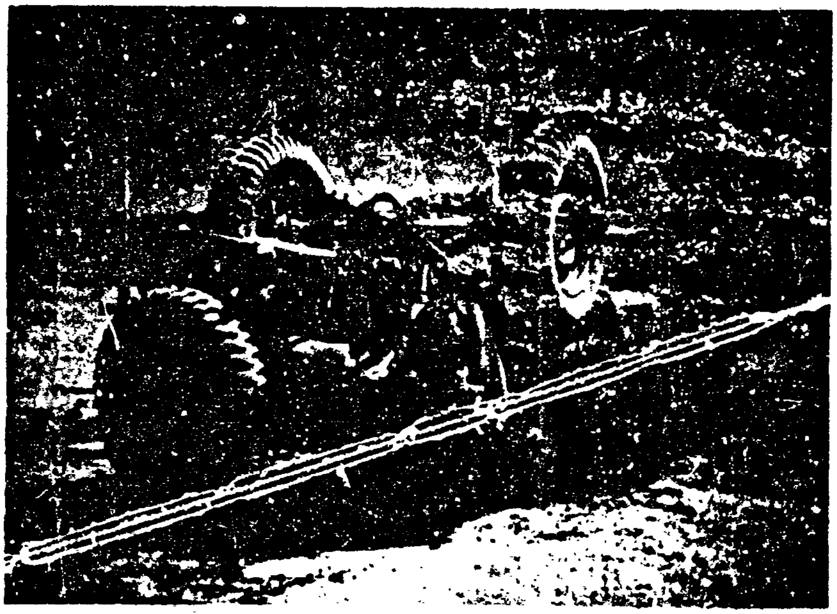

Fig. C.20 - Position 3.21 af after Shot 10 (UPSHOT-KNOTHOLE), vehicle side-on, severe-moderate damage; $P_{s(meas)} = 8.5$ psi, $P_{d(ideal)} = 3.3$ psi. Vehicle displaced 72 feet (compare with Fig. C.17).

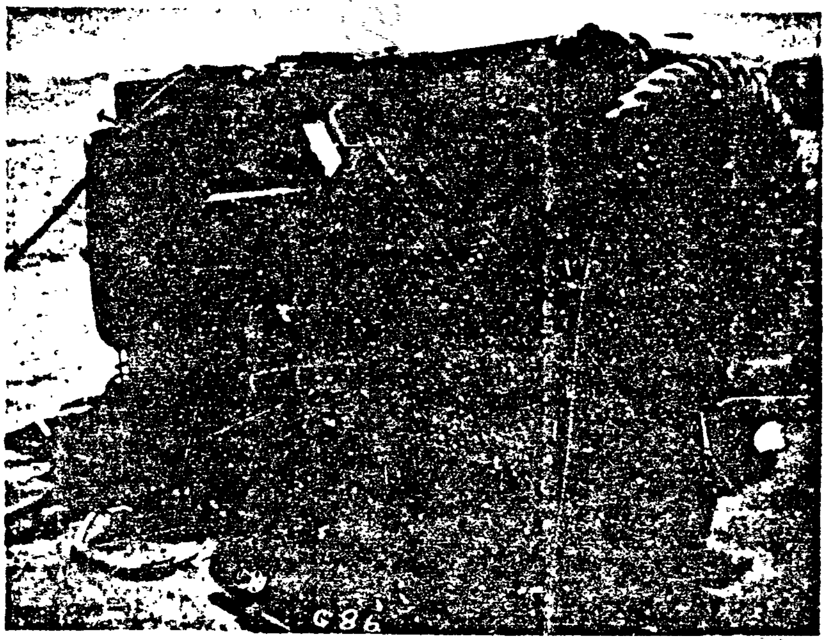

Fig. C.21 - Position 3.21 ag after Shot 10 (UPSHOT-KNOTHOLE), vehicle side-on, light damage; $P_{s(meas)} = 7.8$ psi, $P_{d(ideal)} = 2.0$ psi. Vehicle displaced 17.7 feet. (Photograph completes range of damage from severe to light on Shot 10).

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