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MEMORANDUM REPORT NO. 2031

AN EMPIRICALLY BASED ANALYSIS ON THE RESPONSE
OF HE MUNITIONS TO IMPACT BY STEEL FRAGMENTS (U)

by

Harry J. Reeves

March 1970

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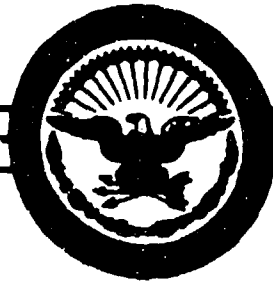
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MEMORANDUM REPORT NO. 2031

MARCH 1970

AN EMPIRICALLY BASED ANALYSIS ON THE RESPONSE
OF HE MUNITIONS TO IMPACT BY STEEL FRAGMENTS (U)

Harry J. Reeves

Vulnerability Laboratory

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MEMORANDUM REPORT NO. 2031

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Aberdeen Proving Ground, Md.
March 1970

AN EMPIRICALLY BASED ANALYSIS ON THE RESPONSE
OF HE MUNITIONS TO IMPACT BY STEEL FRAGMENTS (U)

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ABSTRACT

Efforts to derive a satisfactory measure of the vulnerability of High Explosive munitions to steel fragment impact have been hampered by a lack of experimental data. In an attempt to remedy this deficiency, a number of tests have been carried out.

This report presents the results of tests of firings of steel fragments against U.S. 90mm, 105mm, and 175mm HE (Comp. B) artillery projectiles, Soviet 57mm HE (RDX/Aluminum/wax) artillery projectiles, Soviet 122mm and 152mm HE (TNT) artillery projectiles, Soviet 140mm HE (TNT) rocket projectiles, U.S. 81mm and Soviet/CHICOM 82mm mortars (TNT), and a variety of U.S. Sub-Missile munitions.

These firing data were used to determine contributions of fragment striking mass and velocity required to initiate explosive reactions.

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TABLE OF CONTENTS

	Page
ABSTRACT	3
LIST OF ILLUSTRATIONS.	7
LIST OF TABLES	9
I. INTRODUCTION	11
II. DISCUSSION	12
A. Bare Charge Attack	12
B. Covered Charge Attack.	12
C. Explosive Reactions.	13
D. Application	13
III. SCOPE OF STUDY AND TEST PROCEDURES	16
A. Approach	16
B. Test Procedures.	18
IV. RESULTS AND OBSERVATIONS	21
A. U.S. Artillery Projectiles	21
B. Soviet Artillery and Rocket Projectiles.	25
C. U.S. 81mm and Soviet/CHICOM 82mm Mortar Projectiles (TNT)	25
D. Firings Against U.S. Sub-Missile Munitions	26
V. EXPLOSIVE REACTIONS	26
VI. ANALYSIS OF DATA	29
A. U.S. Artillery Projectiles	29
B. Soviet Artillery Projectiles	34
C. U.S. 81mm and Soviet/CHICOM 82mm Mortar Projectiles.	45
D. U.S. Sub-Missile Munitions	45

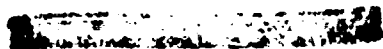


TABLE OF CONTENTS (Continued)

	Page
VII. CONCLUSIONS	50
A. Fragment Characteristics	50
B. Projectile Characteristics	50
C. HE Filler Characteristics	59
VIII. RECOMMENDATIONS FOR FUTURE WORK	60
REFERENCES	61
APPENDIX A	63
Steel Fragments Versus U.S. Artillery Projectiles . . .	63
APPENDIX B	75
Steel Fragments Versus Soviet Artillery and Rocket Projectiles	75
APPENDIX C	83
Steel Fragment Versus U.S. 81mm and Soviet/CHICOM Mortar Projectiles.	83
APPENDIX D	89
Steel Fragments Versus U. S. Sub-Missile Munitions	89
APPENDIX E	103
Engineering Drawings of U.S. Artillery Projectiles, Soviet Artillery and Rocket Projectiles, U.S. and Soviet/CHICOM Mortar Projectiles	103
DISTRIBUTION LIST	115

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LIST OF ILLUSTRATIONS

Figure		Page
1.	Projectile Orientation	19
2.	Characteristics of Steel Fragments	20
3.	Test Setup	22
4.	Firing Chamber	23
5.	Vulnerability of Bare Composition B to Cylindrical Fragment Impact.	35
6.	Vulnerability of the U.S. 90mm HE Projectile (Composition B) to Fragment Impact	37
7.	Vulnerability of the U.S. 105mm HE Projectile (Composition B) to Fragment Impact	38
8.	Vulnerability of the U.S. 155mm HE Projectile (Composition B) to Fragment Impact	39
9.	Vulnerability of the U.S. 175mm HE Projectile (Composition B) to Fragment Impact	40
10.	Cumulative Probability Distributions for the U.S. 90mm HE Projectile (Comp. B)	41
11.	Cumulative Probability Distributions for the U.S. 105mm HE Projectile (Comp. B).	42
12.	Cumulative Probability Distributions for the U.S. 155mm HE Projectile (Comp. B).	43
13.	Cumulative Probability Distributions for the U.S. 175mm HE Projectile (Comp. B).	44
14.	Vulnerability of the Soviet 57mm HE Projectile (RDX/aluminum) to Fragment Impact.	46
15.	Vulnerability of the Soviet 122mm HE Projectile (TNT) to Fragment Impact	47
16.	Vulnerability of the Soviet 140mm HE Rocket Projectile (TNT) to Fragment Impact.	48
17.	Vulnerability of the U.S. 81mm Mortar Projectile (TNT) to Fragment Impact.	49

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
18.	Vulnerability of Sub-Missile Munitions to Fragment Impact	58
E-1.	Shell for U.S. 90mm Artillery Projectile.	105
E-2.	Shell for U.S. 105mm Artillery Projectile	106
E-3.	Shell for U.S. 155mm Artillery Projectile	107
E-4.	Shell for U.S. 175mm Artillery Projectile	108
E-5.	Shell for Soviet 57mm Artillery Projectile.	109
E-6.	Shell for Soviet 122mm Artillery Projectile	110
E-7.	Shell for Soviet 152mm Artillery Projectile	111
E-8.	Shell for Soviet 140mm Rocket Projectile.	112
E-9.	Shell for U.S. 81mm Mortar Projectile	113
E-10.	Shell for CHICOM 82mm Mortar Projectile	114

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LIST OF TABLES

Table	Page
I. Summary Table - Total Number of Firings	17
II. Classification of Results - Impacting Mass-Velocity Combinations Required to Explosively Function U.S. Artillery Projectiles	33
III. Protection Coefficients for U.S. Artillery Projectiles	36
IV. Classification of Results - Fragments Versus Sub-Missile Munitions	51
V. Classification of Results - Fragments Versus Sub-Missile Munitions	54
VI. Impacting Mass-Velocity Combinations Required to Detonate High Order Sub-Missile Munitions 50% of the Time	57
A-I. Classification of Results - Fragments Versus 90mm HE Projectile (Empty)	65
A-II. Classification of Results - Fragments Versus 105mm HE Projectile (Empty and Wax Filled)	66
A-III. Classification of Results - Fragments Versus 155mm HE Projectile (Empty).	68
A-IV. Classification of Results - Fragments Versus 175mm HE Projectile (Empty).	69
A-V. Classification of Results - Fragments Versus 90mm HE Projectile (Composition B)	70
A-VI. Classification of Results - Fragments Versus 105mm HE Projectile (Composition B).	71
A-VII. Classification of Results - Fragments Versus 105mm HE Projectile (Composition B).	72
A-VIII. Classification of Results - Fragments Versus 155mm HE Projectile (Composition B).	73
A-IX. Classification of Results - Fragments Versus 175mm HE Projectile (Composition B).	74

LIST OF TABLES (Continued)

Table	Page
B-I. Classification of Results - Fragments Versus Soviet 57mm HE Projectile	77
B-II. Classification of Results - Fragments and Bullets Versus Soviet 122mm Artillery Projectile (TNT).	78
B-III. Classification of Results - Fragments Versus Soviet 140mm HE Rocket Projectiles (TNT).	80
B-IV. Classification of Results - Fragments and Bullets Versus Soviet 152mm Artillery Projectile (TNT)	82
C-I. Classification of Results - Fragments Versus U.S. 81mm Mortar Projectile (TNT)	85
C-II. Classification of Results - Fragments Versus Soviet/CHICOM 82mm Mortar Projectile (TNT)	88
D-I. Classification of Results - Fragments Versus Sub-Missile Munitions	91
D-II. Classification of Results - 30 Grain HD Fragments Versus Groups of XM-41 Sub-Missiles in Aluminum Containers	101

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I. INTRODUCTION

The Ballistic Research Laboratories are presently engaged in an analysis of the vulnerability of a wide variety of air and ground targets to fragment impact. To complete vulnerability studies on weapon systems such as field artillery, tank, aircraft and anti-aircraft systems, the vulnerability of the High Explosive (HE) munitions belonging to each system has to be determined.

A review of available data dealing with the vulnerability of explosives and explosive-filled munitions revealed that, with the exception of bomb vulnerability, only limited, empirically-based, vulnerability data have been generated for most types of HE munitions. The data that are available result from limited ad hoc testing. It is not possible to interpolate among and/or extrapolate from the results of these tests because of the wide variations in the testing and target parameters. A summary of the results of these investigations is discussed in parts A and B of Section II of this report.

This report presents vulnerability data on a wide variety of HE projectiles to steel fragment impact. Included are the results of extensive testing against Composition B (Comp. B)-loaded U.S. artillery projectiles and several types of Sub-Missile munitions and the results of limited testing against foreign artillery, rocket and mortar projectiles. The data from the limited testing against foreign munitions do not provide a sound basis for rigorous statistical analysis but are sufficient for a comparative analysis of the effects of steel fragment impacts versus U.S. and foreign munitions.

Threshold fragment mass-velocity combinations required for an explosive reaction with an associated probability of 0.5 have been established by fitting least squares polynomials to the data from the firing records for the U.S. artillery projectiles and Sub-Missile munitions. These data were used to generate cumulative-probability curves for the artillery projectiles. Assumptions upon which the cumulative probability curves are based are specified in the text.

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The vulnerability of the foreign munitions and the U.S. mortar projectiles were determined by plotting the median values for explosive reactions from their respective firing tables. In all cases, interpolations and extrapolations were required because of the limited number of data points.

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II. DISCUSSION

This section has been included to familiarize the reader with some of the data that are available on the vulnerability of explosives and with the way in which these data relate to the vulnerability of HE munitions.

A. Bare Charge Attack

Slade and Dewey^{1*}, in the abstract of their report, state that: "Firings of right cylinders against bare tetryl and Composition B show that the velocity for 50 percent initiation is a function of contact area but not of mass nor of the form of the projectiles behind the contacting surface." Brown, Steel and Whitbread², using different types of explosive targets, recorded results confirming these findings. Because extensive sensitivity data on Comp B. were already available, this explosive was selected as a filler for tests conducted against the U.S. artillery projectiles. Unfortunately, similar data are not available on other common HE fillers.

B. Covered Charge Attack

Most investigators^{1, 2, 3, 4, 5} have recorded data indicating that, for a given fragment, the striking velocity required to achieve a 50 percent probability of detonating a covered HE charge is directly proportional to the thickness of the cover plate. These results were observed when both the HE type and cover plate composition were varied and the attack angle was kept constant.

*References are listed on page 61.

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C. Explosive Reactions

No attempt was made during the tests discussed in this report to determine the mechanism responsible for the explosive reactions which occurred. In the consideration of fragment impacts on HE projectiles, one or more of the following mechanisms may affect the outcome.

1. Initiation by Single Shock. A compression wave is formed which reinforces the original shock wave and forms a detonation wave.
2. Initiation by Multiply-Reflected Shocks. A reflected shock wave from a boundary meets the oncoming projectile head-on.
3. Surface Initiation. The temperature of the surface layer of the explosive rises very quickly.
4. Initiation Caused by Hot Objects Embedded in the Explosive. Impacting fragments are heated as they perforate the projectile wall before they come to rest within the HE filler. The shape of the impacting fragment is critical if this is the mechanism involved.

Any attempt to determine which of these mechanisms causes or cause the explosive reaction requires the measurement of "induction times". The induction time is defined as the time between the moment an explosive is attacked and the moment reaction is initiated. Unfortunately, the techniques and instrumentation required to obtain such measurements are not conducive to large-scale, explosive, field testing. Such measurements are normally obtained in a laboratory using small charges.

D. Application

Attempts to extrapolate from basic explosive vulnerability data have been hampered by the sparseness of the basic data available. The number of impact parameters involved in an analysis of the vulnerability of explosives can be quite large, and the interactions between and among these parameters have not been quantitatively established or even considered in many cases.

Fragment attack against HE-filled projectiles can cause the projectiles to function explosively. The explosive reactions of these HE projectiles

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to fragment attack can be conveniently grouped into two categories: shock-initiated reactions and non-shock initiated reactions. This technique allows us to discuss in a qualitative manner those fragment and projectile characteristics that determine the probability of a successful attack.

1. Shock-Initiated Reactions. When a fragment strikes the wall of an HE-filled projectile a shock wave is transmitted to the filler. The ability of this shock wave to trigger an explosive reaction is dependent on the following:

a. Fragment Characteristics. Striking velocity, weight, fragment geometry (contact area), shock impedance*, and obliquity angle.

b. Projectile Characteristics. Wall thickness at the point of impact, shock impedance of the casing, protective coatings (paint or enamel applied to the interior surface of the projectile could provide protection via an impedance mismatch), HE filler sensitivity to shock initiation and HE filler shock impedance.

Shock-initiated reactions are characterized by the following:

a. The probability that a given HE projectile will react explosively to fragment impact will increase as the impact velocity, striking weight or the area of the fragment impinging on the target increases. The probability of reaction will also increase as the ratio of shock impedance of the fragment to that of the projectile approaches unity.

b. The probability that a given fragment striking any HE projectile will initiate an explosive reaction will increase as the HE sensitivity increases and as the projectile wall thickness decreases.⁶

*The shock impedance of a material is defined as the product of its density and velocity with which a shock wave propagates in it. The efficiency with which shock is transmitted from one material to another is a function of the impedance match of the two materials. The most efficient coupling will be realized when the impedances of the two materials are equal.

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The impedance matches between the fragment and projectile wall, projectile wall and any coating material and the interior surface of the projectile, and between any coating material and the HE filler will also affect the probability of initiation. The more efficient the coupling of the shock wave from the fragment to the projectile wall to any coating material to the HE filler, the greater will be the probability of an explosive reaction.

2. Non-Shock Initiated Reactions. Fragments often perforate the casing of HE projectiles without triggering any explosive or burning reactions. However, a perforation criterion appears to be an effective means of predicting an explosive or burning reaction. If a fragment must first perforate the casing of a projectile before any explosive or burning reactions are observed, and shock is not the mechanism of initiation, then embedded hot fragments within the HE filler appear to be likely candidates for initiating an explosive or burning reaction.

While a fragment perforates the casing of an HE projectile, the fragment experiences a temperature rise. The magnitude of the rise is a function of both fragment and casing characteristics, and is directly proportional to the thickness of the casing material.

The probability that a hot fragment embedded in the HE filler will initiate an explosive reaction is determined by the temperature of the fragment and the sensitivity of the HE filler to heat. The fact that a fragment perforates the casing of an HE projectile before any explosive reaction is observed, does not necessarily imply that the hot fragment is the initiating mechanism. It may well be that the shock from the striking fragment would have been sufficient in itself to initiate the reaction.

The foregoing discussion is provided to point up some of the difficulties one has in trying to predict exactly what caused a particular reaction in the explosive in terms of meaningful parameters. The British Ordnance Board report by Ledsham⁶ treats this problem in considerable detail.

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(UNCL) III. SCOPE OF STUDY AND TEST PROCEDURES

This report presents data on the vulnerability of a wide variety of HE munitions to steel fragment and bullet impact. Firings were carried out against U.S. 90mm, 105mm, 155mm, and 175mm HE (Comp. B) artillery projectiles, Soviet 57mm HE (RDX/aluminum/wax) artillery projectiles, Soviet 122mm and 152mm HE (TNT) artillery projectiles, Soviet 140mm HE (TNT) rocket projectiles, U.S. 81mm and Soviet/CHICOM 82mm mortar projectiles (TNT), and five types of U.S. Sub-Missile munitions.

Over 800 firings were conducted in this program. A breakdown of these firings by fragment and munition type is presented in Table I. A physical description of the artillery, rocket and mortar projectiles can be found in Appendix E. A physical description of the Sub-Missile munitions is available from the Warhead and Special Projects Laboratory at Picatinny Arsenal.

A. Approach

U.S. projectiles were selected for large-scale testing because of their availability in suitable quantities. The 105mm, in particular, was subjected to extensive testing because it has a thinner wall than the other U.S. projectiles identified above. It was anticipated before testing, that because of fragment striking velocity requirements, vulnerability data could be more easily generated against the thinner-walled projectiles.

Because the sensitivity of bare Comp. B to steel fragment impact had already been established, it was selected as a filler for the U.S. artillery projectiles.

Prior to explosive testing, steel fragments were fired against empty U.S. projectiles to establish the fragment mass-velocity combinations required for perforation. The impact location was defined as a circular area, one inch in diameter, centered over the aim point, see Figure 1. Impacts registered outside this area that did not result in explosive

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TABLE I. SUMMARY TABLE
Total Number of Firings
Steel Fragments Versus HE Munitions

Target Type	Fragment Weight (Grains)					
	30-HD ^a	30	60	120	240	480
U.S. Artillery Projectiles						
90mm			29	18	27	
105mm		52	34	56	46	
155mm			4	31	28	
175mm			4	40	35	
Soviet Artillery Projectiles						
57mm			1	4	5	
122mm			10	5	7	
140mm					9	6
152mm			1	6	2	
U.S. 81mm and Soviet/CHICOM 82mm Mortars						
81mm			1	12	4	
82mm			1	1	3	
U.S. Sub-Missile Munitions						
M-32	51					
M-40	33		20	31	36	
M-43E1		7	6	9	9	
XM-41	13		4	5	4	
XM-42	25		32	27	17	

^a 30 HD = 30 Grain High Density Steel (Mallory 3000). Remaining fragments were case-hardened to Rockwell C-30.

reactions were assessed as poor hits. The rationale behind these preliminary tests was twofold: (1) the tests could be conducted inexpensively at an indoor test facility with experimental errors kept to a minimum, and (2) the data obtained would provide the Test Director, who conducts the explosive testing in the field, with a priority of the impact conditions to be considered.

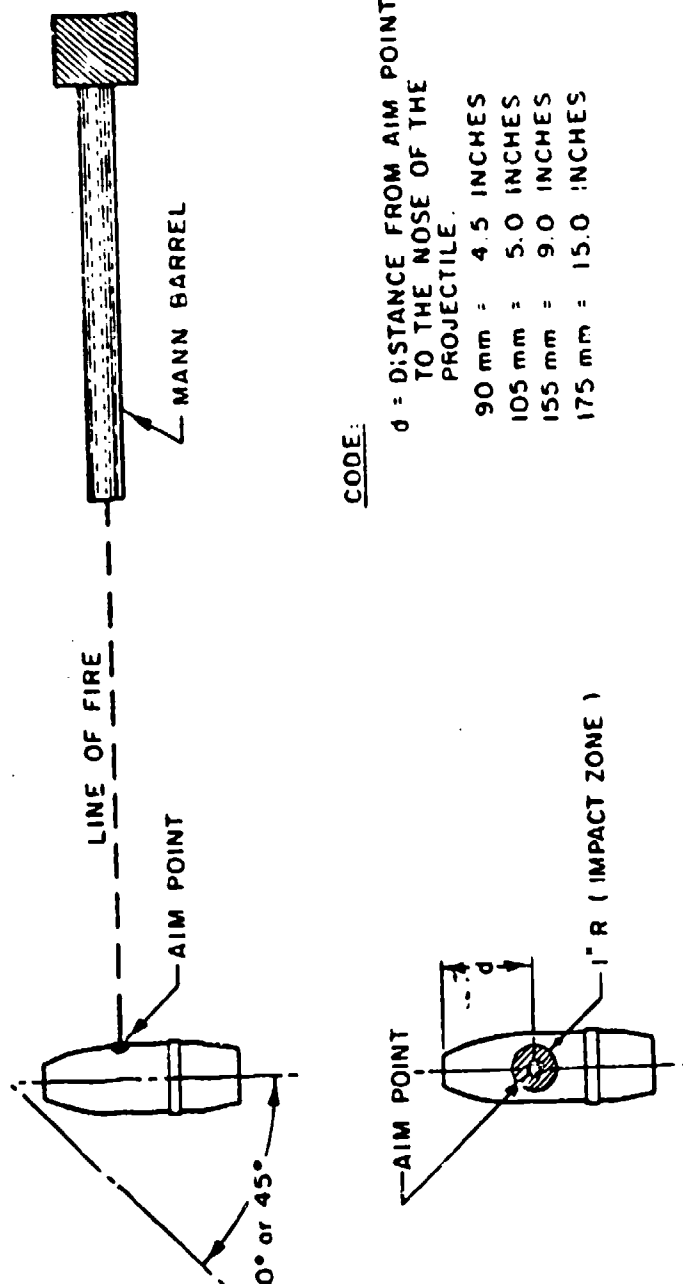
During the explosive-testing phase, fragments were again fired to impact close to and above the bourrelet. However, in this phase, effects of fragment impacts at angles of both zero and forty-five degrees were considered (see Figure 1). Observations made during this test phase indicate that for a given fragment mass, the impact velocity required for perforation of the wall of an HE filled projectile is greater than that required to perforate the wall of an empty projectile. The magnitude of this velocity increase was determined by conducting fragment impact tests against projectiles containing wax of the same density as Comp. B.

The data obtained on the vulnerability of the foreign artillery, mortar and rocket projectiles and the U.S. mortar rounds are the result of several ad hoc tests. The results of these tests have been included only for comparative purposes, since they were based on small samples of data.

Extensive firings were conducted against five different types of Sub-Missile munitions. Target configurations were varied to include firings against bare rounds and rounds shielded by thin aluminum plate. In some cases, the target configurations simulated to a high degree a missile warhead employing these rounds as a payload. In addition to the mild steel fragments, 30 grain High Density (HD) fragments were fired against these rounds to satisfy an additional requirement.

B. Test Procedures

In all the fragment impact phases of the tests, compact, cylindrically shaped, steel fragments weighing 30, 60, 120, 240 and 480 grains were used (see Figure 2).

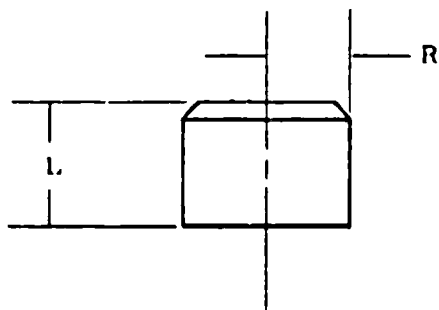


CODE:

d = DISTANCE FROM AIM POINT
TO THE NOSE OF THE
PROJECTILE.

90 mm = 4.5 INCHES
105 mm = 5.0 INCHES
155 mm = 9.0 INCHES
175 mm = 15.0 INCHES

Figure 1. Projectile Orientation



WEIGHT (GRAINS)	RADIUS R (INCHES)	LENGTH L (INCHES)	AVERAGE PRESENTED AREA (SQ. INCHES)
30HD	0.117	0.163	0.0500
30	0.15	0.225	0.0884
60	0.20	0.248	0.1533
120	0.249	0.315	0.2210
240	0.2985	0.451	0.3511
480	0.3435	0.660	0.5425

NOTE: 30 HD = 30 Grain High Density Steel (Mallory 3000). Remaining fragments were case-hardened to Rockwell C-30.

Figure 2. Characteristics of Steel Fragments

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Smoothbore Mann barrels mounted on a "Frankford Mount" were used for propelling fragments at velocities up to approximately 2050 meters per second. For higher velocities a light gas gun was used. A chronograph and "break screens" provided the means for obtaining velocity measurements.

An overall schematic of the field test set-up and firing chamber is shown in Figures 3 and 4. The muzzle-to-target distance illustrated was used for firing against the smaller caliber projectiles. It was necessary to increase the muzzle-to-target distance when firing against the larger caliber projectiles to protect the firing chamber.

(CONFIDENTIAL) IV. RESULTS AND OBSERVATIONS

The results of over 800 individual firings have been grouped into four categories: (1) U.S. artillery projectiles, (2) Soviet artillery and rocket projectiles, (3) U.S. and Soviet/CHICOM mortar projectiles, and (4) U.S. Sub-Missile munitions. The results are presented in tabular form in Appendices A through D of this report.

Considerable data were generated on U.S. artillery and Sub-Missile munitions. Consequently, those firings against the U.S. artillery and Sub-Missile munitions which resulted in poor hits were deliberately omitted from Appendices A and D. Those test results associated with poor hits were considered outside the range of interest of this study. Because data generated on the remaining munitions were limited, all available results, including some which may have very limited value, for these munitions, were included in Appendices B and C.

Observations based on these firing records are discussed below. In the discussion, tables identified by a letter hyphenated to a Roman numeral will be found in the appendix associated with the letter.

A. U. S. Artillery Projectiles

Tables A-I through A-IV present the results of firings conducted with empty and wax-filled artillery projectiles. In general, as would

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Figure 3. (U) Test Setup

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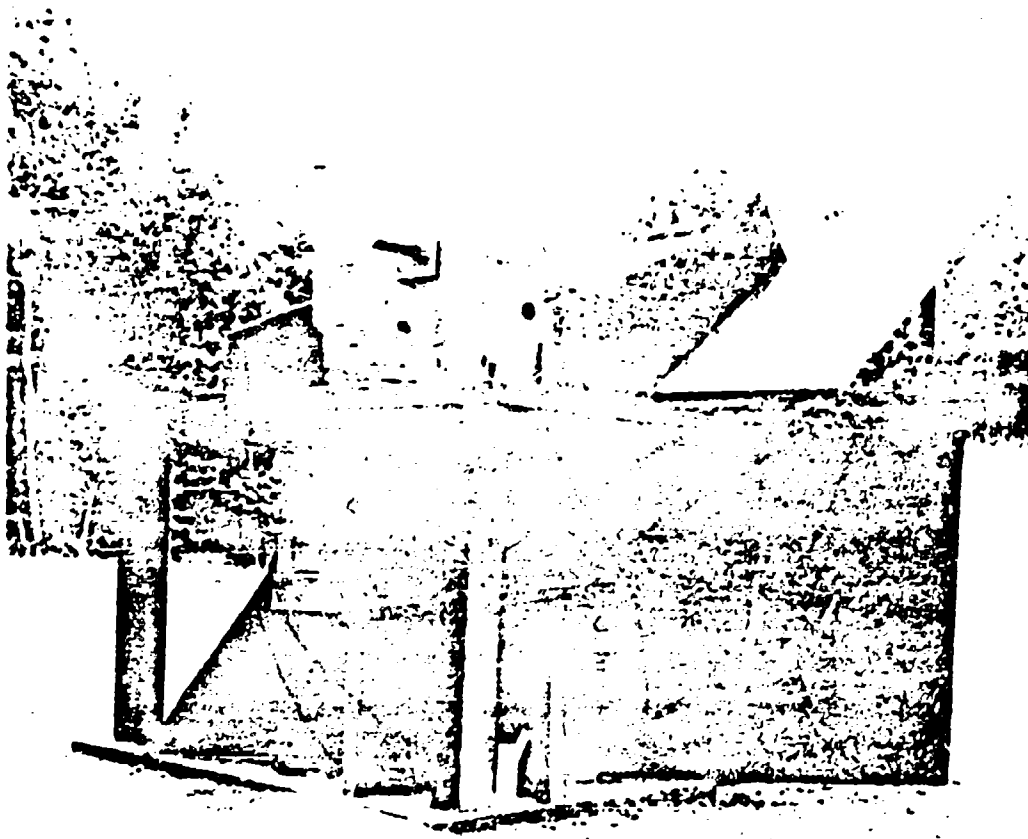


Figure 4. (U) Firing Chamber

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be expected, it is observed that the impact velocity required by a given fragment to perforate the wall of an empty projectile increases as the wall thickness of the projectile increases. These laboratories believe that observed departures from this general trend are due to small variations in the average wall thickness of the four types of projectiles tested and to variations in the wall thickness of individual projectiles.

Table A-II presents the results of tests conducted against wax-filled projectiles. Test results suggest that if some given fragment requires some minimum impact velocity to perforate the wall of an empty projectile, then an increase of approximately 100 meters per second in the impact velocity is needed for the fragment to perforate the wall of the same projectile when it is filled with wax.

The results of the firings conducted against U.S. Comp. B-loaded 90, 105, 155 and 175mm projectiles are presented in Tables A-V through A-IX. It is observed that:

1. For a given fragment, the impact velocity required to initiate an explosive or burning reaction increases as projectile wall thickness increases. However, it is noted that the 155mm projectiles used in this test were originally issued with a TNT filler. The TNT was "steamed" out and replaced with Comp. B at the Aberdeen Proving Ground. During the steaming-out process, the asphalt-based paint coating on the interior of the projectile was washed out. This changes the impedance match between the projectile and the filler and could have influenced the sensitivity of the round to shock initiation.

2. High Order, Low Order, and Burning Reactions resulted from similar impact mass and velocity combinations. The minimum impact velocities, for a given mass producing these reactions, were essentially the same.

3. Fragments, impacting Comp. B-filled projectiles, can initiate explosive reactions at velocities below that required for perforation of the projectile wall. This trend was noticed particularly when testing the thicker-walled projectiles.

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4. For a given fragment impact mass (velocity), a greater velocity (mass) is required to initiate an explosive reaction for an impact at forty-five degrees obliquity than for an impact at zero degrees obliquity. This observation is based on a limited amount of data and may not be valid for all mass-velocity combinations.

B. Soviet Artillery and Rocket Projectiles

Because of a shortage of projectiles, only a few tests were conducted against the Soviet 57mm, 122mm, 140mm, and 152mm HE projectiles. The test results, presented in Tables B-I through B-IV, indicate that:

1. The Soviet projectiles tested are less vulnerable than U.S. Comp. B-filled projectiles of similar caliber. This may be attributed to both the thicker wall and the less sensitive HE filler of the Soviet projectiles.

2. Fragments, impacting either a 57mm, 122mm, or a 140mm HE projectile, did not initiate any explosive reactions at velocities below that required for perforation of the projectile wall. No wall perforations or explosive reactions were observed when fragment firings were conducted against the thicker-walled 152mm HE projectiles.

C. U. S. 81mm and Soviet/CHICOM 82mm Mortar Projectiles (TNT)

The Ballistic Research Laboratories have conducted tests to determine the vulnerability of both in-flight and stacked mortar ammunition to fragment attack. The results of these tests are presented in Tables C-I and C-II.

Both the 81mm and 82mm projectiles have a wall thickness of approximately 0.32 inches throughout most of their length. The major difference between the two projectiles is in the type of metal used in their manufacture. The domestic 81mm projectile casings are made of steel while the foreign 82mm projectile casings are made of cast iron.

Test results show that if an explosive or burning reaction is the objective of a fragment attack, the steel-cased projectiles are more vulnerable than those with cast iron casings. However, if the only purpose of attacking the projectile is to defeat it as an offensive weapon,

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(dud the round) then the cast iron cased projectile is more vulnerable as it fractures more readily.

Although the fuze sections of projectiles contain the most sensitive elements, impacts on or near the fuzes in this test did not result in High Order reactions.

D. Firings against U.S. Sub-Missile Munitions

Table D-I presents the results of over 300 firings against five types of Sub-Missile munitions. It is observed that:

1. The five types of munitions tested are considered equally vulnerable to fragment impact.
2. Masking the rounds with a 0.63 inch aluminum sleeve and/or a 0.125 inch aluminum plate with or without a standoff, does not provide sufficient protection to significantly reduce round vulnerability to fragment impact.

A limited number of tests were conducted wherein 2.0 inches of polyurethane was placed between a 0.125 inch aluminum plate and a round with a 0.063 inch sleeve. No reduction in round vulnerability was observed.

Tests were also conducted against grouped XM-41 rounds in aluminum containers. The results of these tests, presented in Table D-II, show that if one round in the group detonates High Order, the remaining rounds will also detonate High Order.

(CONFIDENTIAL) V. EXPLOSIVE REACTIONS

The "Military Standard"⁷ definition of a detonation is: "An exothermic chemical reaction that propagates with such rapidity that the rate of advance of the reaction zone into the unreacted material exceeds the velocity of sound in the unreacted material, that is, the advancing reaction zone is preceded by a shock wave. A detonation is classed as an explosion. The rate of advance of the reaction zone is termed detonation rate or detonation velocity. When this rate of

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advance attains such a value that it will continue without diminution through the unreacted material, it is termed the stable detonation velocity. The exact value of this term is dependent upon a number of factors, principally the chemical and physical properties of the material. When the detonation rate is equal to or greater than the stable detonation velocity of the explosive, the reaction is termed a high order detonation. When the detonation rate is lower than the stable detonation velocity of the explosive, the reaction is termed a low order detonation."

Detonation rate measurements can be obtained in the laboratory when testing small quantities of bare explosive. Because of the elaborate instrumentation required to obtain detonation rate velocities, it is not feasible to collect such data in the field when testing HE-filled munitions.

When HE munitions are subjected to steel fragment impact, the results are usually classified as either High Order (HO), Low Order (LO), Burning (B), or No Reaction (NR). Some investigators have subdivided the Low Order and Burning reactions and labeled them High Low Order, Mild Low Order, Low Low Order, Prolonged Burning, etc. Test results are usually classified by personnel in the field on the basis of some predetermined criteria and are subjective in many cases.

The classifications of the results presented in this report are qualitative. No photographic, electronic or mechanical equipment was used to quantitatively measure the response. The Test Director in the field was required to classify the results as No Reaction (with or without perforation), Burning, Low Order or High Order.

Classification of results as No Reaction or Burning is straightforward and presents no problems. However, the rationale used for assessing results as High Order or Low Order requires some explanation.

It was observed, during the tests, that impacting steel fragments could perforate the wall of a steel-cased projectile leaving a well-defined hole. A visual inspection did not reveal any additional degradation

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in the structural integrity of the projectile. When comparable projectiles, under similar impact conditions, fractured into two or more pieces, it was assumed that it was the result of an explosive reaction.

It was further assumed that the number and size of the projectile pieces were, in some sense, indicative of the magnitude of the explosive reaction. Explosive reactions were classified High Order if there was no evidence of large fragments and of unconsumed HE filler in the impact area. If any large pieces of the projectile or unconsumed HE were observed in the impact area, the test result was classified Low Order.

If a detonation rate criterion is the only accurate method of classifying test results as either High Order or Low Order, then it is possible that some of the explosive reactions classified High Order, in this report, should be reclassified Low Order.

These Laboratories have conducted tests⁸ to determine the vulnerability of 30mm and 40mm HE gun systems to small arms attack. It was observed that 0.30, 0.50, and 0.60 caliber bullets, impacting at service velocity on the base of 30mm rounds, could detonate the 30mm projectile High Order. The criterion for a High Order reaction was complete fragmentation of the projectile and the complete consumption of all the HE filler. Additional tests were conducted wherein groups of rounds were taped together and one round was subjected to bullet impact. Test results indicated that some of the remaining rounds could sympathetically function Low Order. However, when one round in a group of rounds was statically detonated, all rounds in the group detonated High Order.

If we assume that statically detonated projectiles always detonate High Order, and that when one projectile in a group of projectiles detonates High Order the remaining projectiles will always sympathetically detonate High Order, then all the test results classified High Order in reference 8 as a result of bullet impact are suspect.

Using the response of witness rounds as a criterion for classifying explosive reactions as High Order or Low Order could prove to be a valid

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technique. Unfortunately, range facility limitations and safety restrictions would limit the use of this technique to those tests involving the smaller caliber HE projectiles.

Until personnel in the field have the means of quantitatively assessing the magnitude of explosive reactions, at a reasonable cost, these test results classified High Order, in fragment or bullet impact tests conducted against HE munitions, are questionable and could easily be Low Order.

(CONFIDENTIAL) VI. ANALYSIS OF DATA.

Test results were analyzed using several different methods. For a given projectile, the number of parameters investigated and the number of data points available for each parameter determined the method to be used. The methodology reflects both the utility and validity of analysis as a predictive tool.

The methods used in analyzing the vulnerability of each group of munitions are discussed in the following sections.

A. U. S. Artillery Projectiles

In this analysis, those test results classified High Order and Low Order were combined and treated as one phenomenon. This approach is justified on the bases that, for the area of primary interest, (i.e., thresholds for High Order and Low Order reactions), the impacting mass-velocity combinations were observed to be the same.

For each type of shell, the data is of the form (m_i, v_{ij}, d_{ij}) , where

m_i is the mass of the fragment fired, $i = 1, 2, \dots, M$.

v_{ij} is the corresponding velocity for each i , $j = 1, 2, \dots, N$.

d_{ij} is the corresponding result of the test, $d_{ij} = 0$ or 1 ,

that is, $d_{ij} = 0$ when a fragment of mass m_i , fired at a velocity v_{ij} resulted in no detonation, and $d_{ij} = 1$ when the fragment impact resulted in a detonation.

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An adequate model for this type of experiment is described by Golub and Grubbs⁹. The assumptions and techniques are described in reference 9 and will not be repeated here. With this method, for each shell and each fragment of mass m_i , (v_{ij} , d_{ij}) are used to obtain $\bar{V}_i$, $\hat{\sigma}_i^2$, $\hat{\sigma}_{\bar{V}_i}^2$, $\hat{\sigma}_{\sigma_i}^2$

where

- $\bar{V}_i$ (commonly called V_5) is an estimate of the mean velocity u_i corresponding to m_i with the property that a projectile of mass m_i fired at the given shell with a velocity of u_i will detonate the shell 50% of the time.
- $\hat{\sigma}_i^2$ is an estimate of the variance σ_i^2 .
- $\hat{\sigma}_{\bar{V}_i}^2$ is the approximate variance of the estimate $\bar{V}_i$.
- $\hat{\sigma}_{\sigma_i}^2$ is the approximate variance of the estimate s_i^2 .

One assumption of the model is that the probability of detonation p is given by

$$(1) \quad p = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^t \exp(-t^2/2) dt$$

where

$$t = \frac{V - u}{\sigma}$$

Since, for each shell and each fragment mass m_i , $\bar{V}_i$ and $\hat{\sigma}_i^2$ are maximum likelihood estimates of u and σ^2 , one can construct a probability function based on the assumption of normality and the estimates.

Preliminary analysis of the data using median velocity values (see Table A-V through A-IX) for each type of shell indicate that mass versus velocity plots for each shell would be hyperbolic. Therefore, a curve of the form $\bar{V}^h = K/m$ was fit to the data corresponding to each shell,

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namely, h and K were to be estimated for each shell. Because of the small number of data points used to fit each curve, it was decided that only one parameter should be estimated. Since $h = 3$ was a good representative value for the power of $\bar{V}$ over all fits, we fixed the value of h at 3 and estimated K only.

For each shell, a curve

$$(2) \quad \bar{V}^3 = K/m$$

was fit using the method of Least Squares and the Data points $(m_i, \bar{V}_i)$, $i = 1, \dots, n$. K was chosen so that

$$(3) \quad \sum_{i=1}^n (\bar{V}_i - (K/m)^{1/3})^2$$

was a minimum. The solution is

$$(4) \quad K = \frac{\left[\sum_{i=1}^n \bar{V}_i m_i^{-1/3} \right]^3}{\sum_{i=1}^n m_i^{-2/3}}$$

For each shell, eq. (2) gives an estimate of $\bar{V}$ (V.5) as a function of the mass of the projectile.

For each shell and each $\bar{V}_i$ corresponding to m_i , $\frac{\hat{\sigma}^2}{\bar{V}_i}$, an approximate variance of the estimate $\bar{V}_i$, was used as a weighting factor in a second fit of the curve $\bar{V}^3 = K'$ so that

$$\sum_{i=1}^n w_i (\bar{V}_i - (K'/m)^{1/3})^2$$

is a minimum, where

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$w_i = 1/\sigma_i^2$. The minimizing value of K' is

$$K' = \frac{\left[\sum_{i=1}^n w_i \bar{V}_i m_i^{-1/3} \right]^3}{\sum_{i=1}^n w_i m_i^{-2/3}}$$

The second fit of the data, using the weights, would appear to be a reasonable criterion. For a data point $(m_i, \bar{V}_i)$ where the σ_i^2 is small,

indicative of a more reliable estimate, the weight is large, thus forcing the curve close to the point. Similarly, for data point $(m_i, \bar{V}_i)$ where the σ_i^2 is large, indicative of a less reliable estimate, the weight is

small, thus permitting the curve to miss the data point by more. Thus the estimates for the fits using the weighted criterion will be closer to the points which have lower confidence than the corresponding estimates for the fits using equation (4). These data are presented in tabular form in Table II.

The results of this analysis were used to establish a protection coefficient "K" for Comp. B-1c led artillery projectiles. This technique developed by F. C. Ledsham is discussed in detail in the British Ordnance Board report.⁶

The protection coefficient is defined as:

$$(5) \quad K = \frac{(V - V_0) d}{V_0 x}$$

where

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TABLE II (C). CLASSIFICATION OF RESULTS
Impacting Mass-Velocity Combinations Required to
Explosively Function U.S. Artillery Projectiles
(Composition B) 50% of the Time (U)

Projectile Type	Impacting Mass (grains)	Impacting Velocity (mps)							Median Values from Firing Record
		Golub and Grubbs					Weighted Least Squares		
		$\bar{V}$	σ	$\frac{\sigma}{\bar{V}}$	σ_0	Least Squares			
90mm	30	2147	100	40	49	2582*	2558*	2126	
	60	1552	52	28	36	2049	2030	1570	
	120	1267	43	19	18	1626	1611	1334	
	240					1291	1271		
105mm	30	3054	674	427	569	2650	2630	2666	
	60	1808	90	29	43	2103	1873	1743	
	120	1479	117	46	90	1669	1486	1453	
	240	1224	48	20	39	1325	1180	1228	
155mm	30					2586*	2560*		
	60					2053*	2063*		
	120	1598	85	31	34	1629	1638	1697	
	240	1333	72	25	33	1293	1300	1372	
175mm	30					3003*	2837*		
	60					2383*	2252*		
	120	1968	332	113	226	1892	1788	1878	
	240	1405	92	28	29	1501	1418	1423	

* Extrapolated values.

NOTE: This Table was generated by combining data from High Order and Low Order reactions.

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V = striking velocity (mps) that a cylindrical steel fragment, impacting face-on, required to detonate a Comp. B-loaded artillery projectile 50 percent of the time.

V_0 = the striking velocity (mps) that the same fragment, impacting face-on, required to detonate High Order bare Comp. B 50 percent of the time. These data were taken from a report by Slade and Dewey (see Figure 5).

d = the diameter of the fragment in inches.

x = projectile wall thickness in inches at the point of impact.

Protection coefficients were generated for all the U.S. projectiles using eq. (5) and are presented in Table III.

To arrive at a generalized solution for these projectiles, the weighted least squares data was averaged and found to be 0.740. Setting $K = 0.740$ and solving

$$(6) \quad V = \frac{V_0 (Kx + d)}{d}$$

predictive curves were generated for each projectile. Figures 6 through 9 show these predictive curves together with the weighted least squares curves for High Order and Low Order reactions and least squares curves for perforation of the projectile wall.

Assuming normality of data and using the $V_{.5}$ and σ values generated via the Golub and Grubbs Analysis, it was possible to construct cumulative probability distributions in most cases. These distributions are illustrated in Figures 10 through 13 and provide some guidance in predicting the changes in striking velocity required to detonate a projectile for probabilities of detonation other than 0.5.

B. Soviet Artillery Projectiles

Because of the limited data available, estimates of the vulnerability of the 57mm, 122mm and 140mm projectiles were made using a residual velocity criterion. An analysis of all the data for these rounds shows that no explosive reactions, High or Low Order, were observed until the striking velocity of the fragment exceeded that required for perforation. Using

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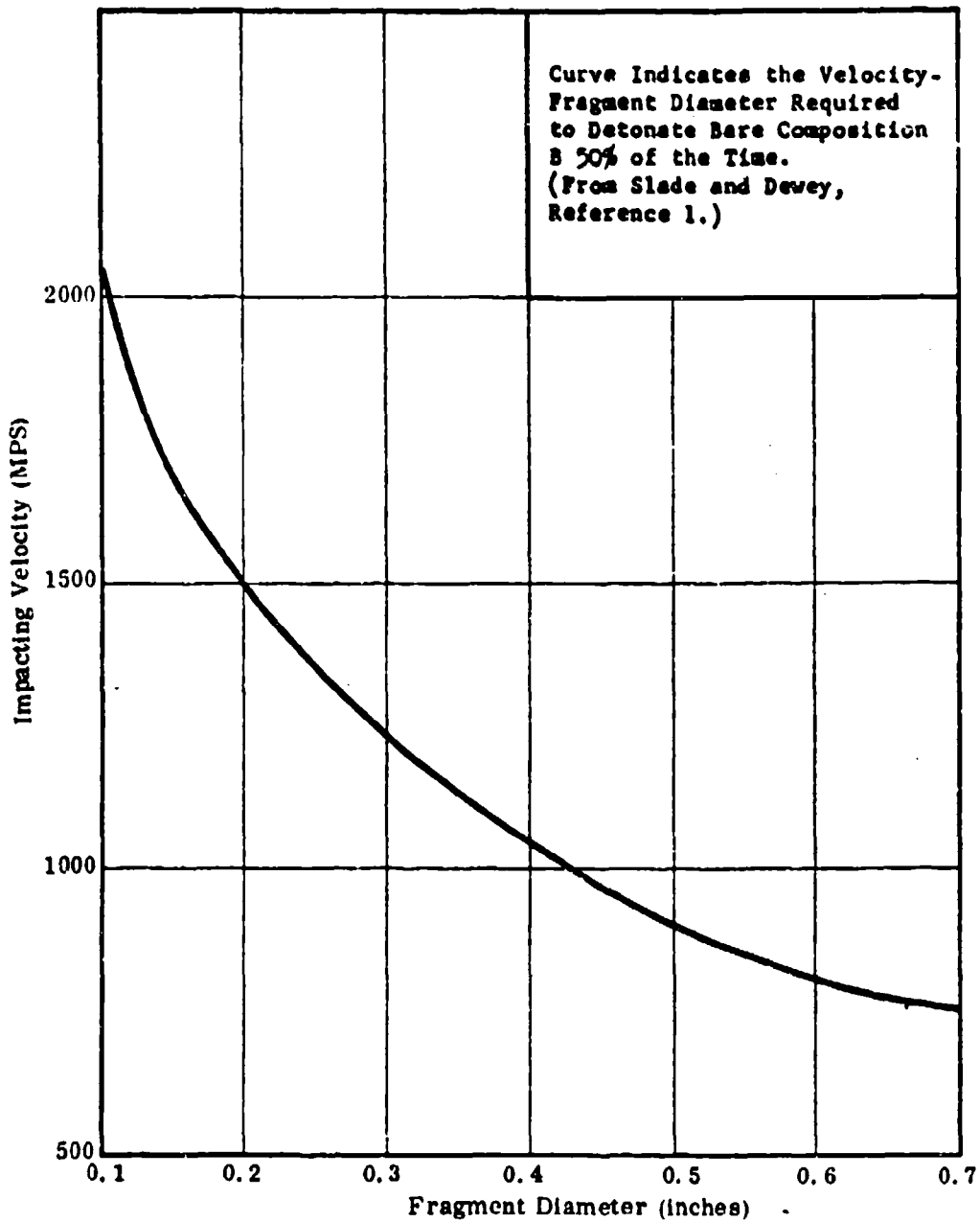


Figure 5 (C). Vulnerability of Bare Composition B to Cylindrical Fragment Impact (U)

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TABLE III (C). Protection Coefficients for U.S. Artillery Projectiles (Comp 2) (U)

Projectile Type	Striking Mass Grains	Median Values	Golub and Grubbs	Least Squares	Weighted Least Squares
90mm	30	no data	no data	.708*	.695*
	60	.843	.859	.782	.757
	120	.736	.683	.799	.782
	240	.764	.665	.700	.682
105mm	30	.904	1.144	.894	.715
	60	.766	.714	.992	.775
	120	.728	.763	1.020	.773
	240	.729	.723	.903	.642
155mm	30	no data	no data	.615*	.662*
	60	no data	no data	.681*	.626*
	120	.712	.664	.696	.706
	240	.761	.661	.632	.645
175mm	30	no data	no data	.854*	.775*
	60	no data	no data	.955*	.879*
	120	1.000	1.093	1.014	.906
	240	.829	.804	.937	.823

* Coefficients were generated from extrapolated data.

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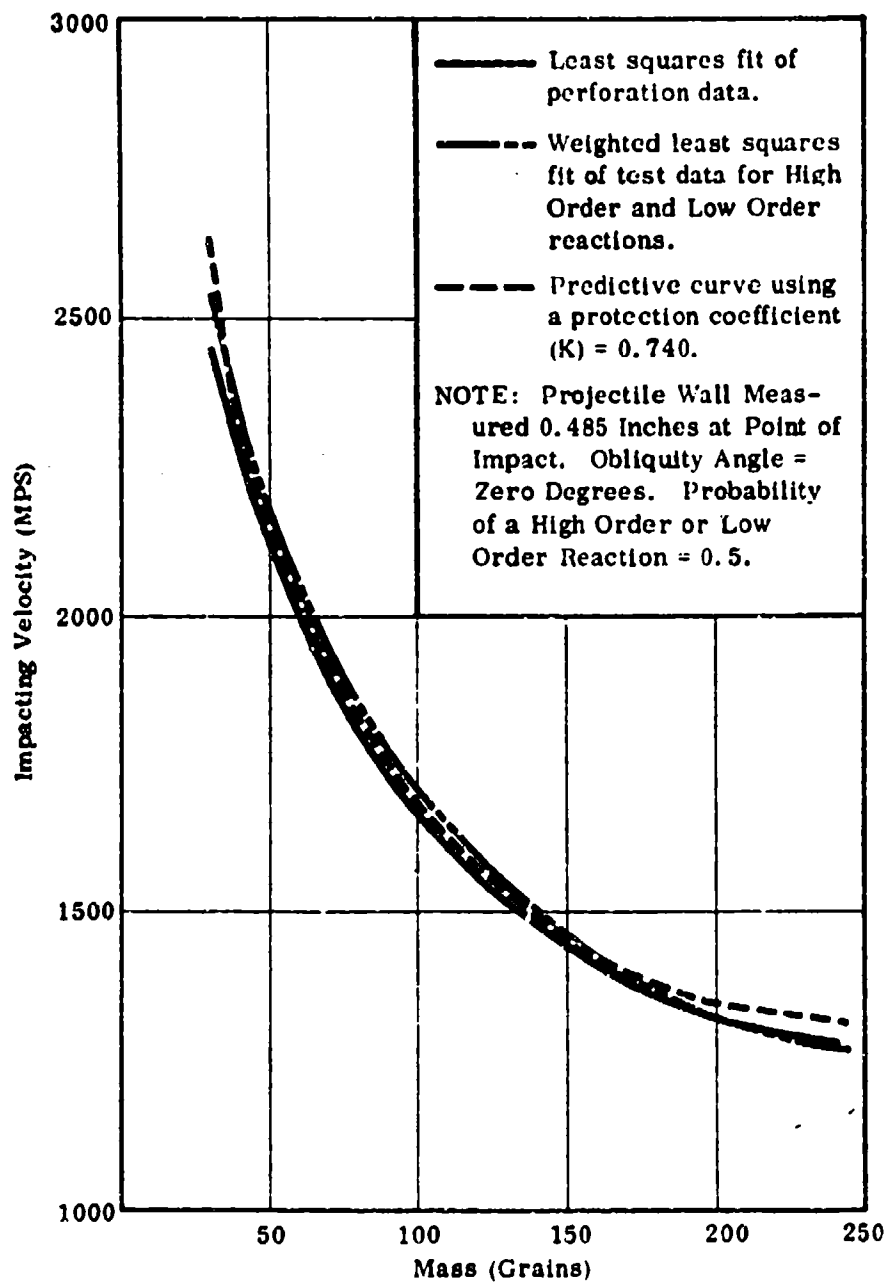


Figure 6 (C). Vulnerability of the U.S. 90mm HE Projectile (Composition B) to Fragment Impact (U)

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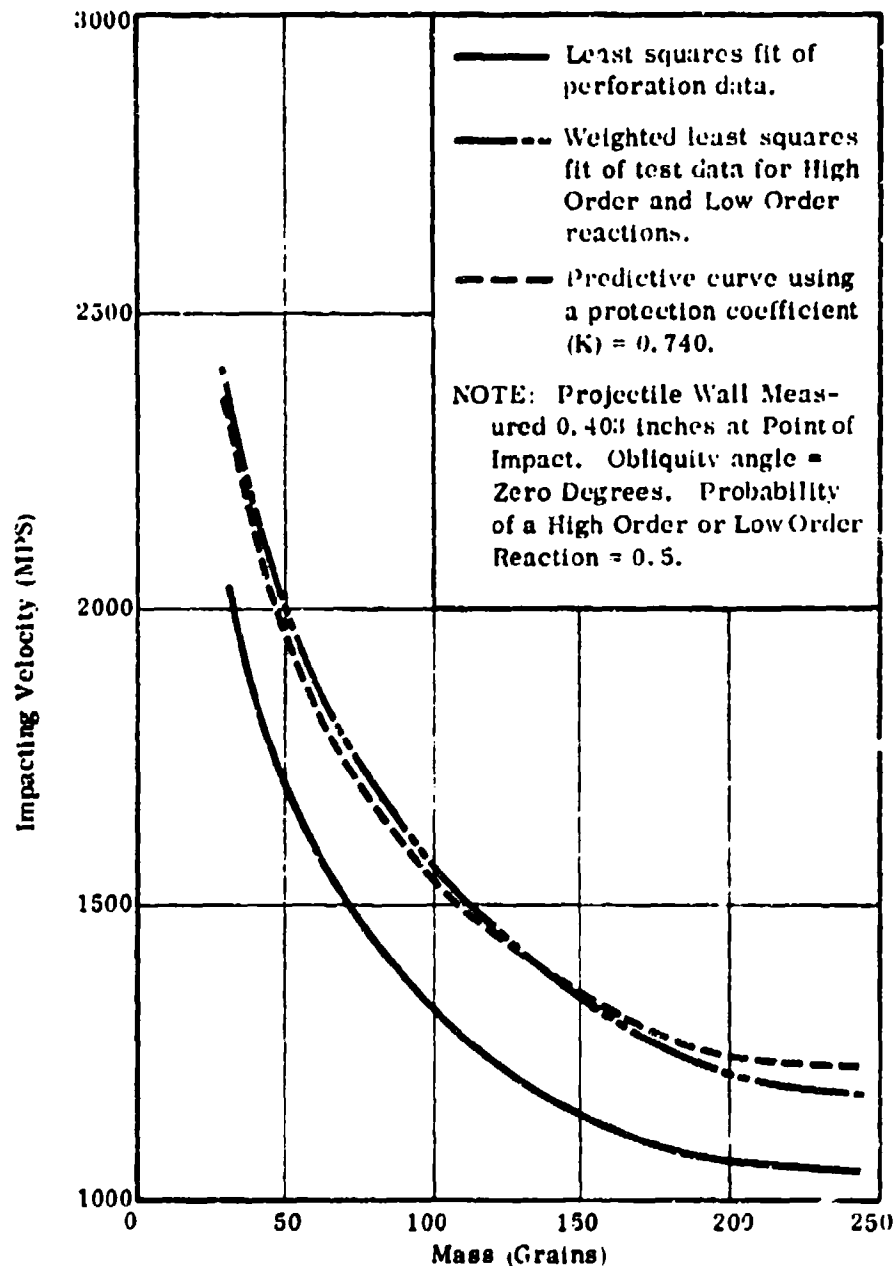


Figure 7 (C). Vulnerability of the U.S. 105mm HE Projectile (Composition B) to Fragment Impact (U)

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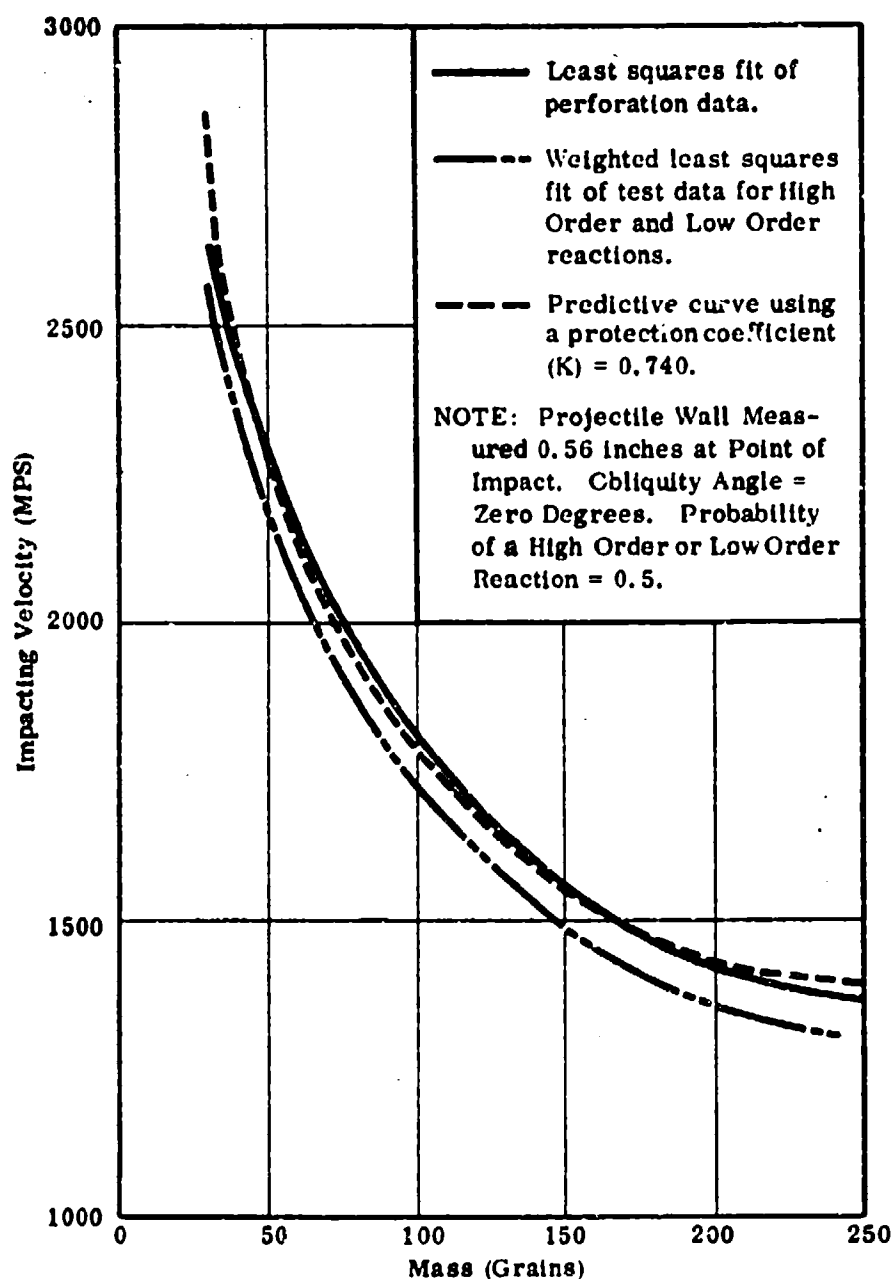


Figure 8 (C). Vulnerability of the U.S. 155mm HE Projectile (Composition B) to Fragment Impact (U)

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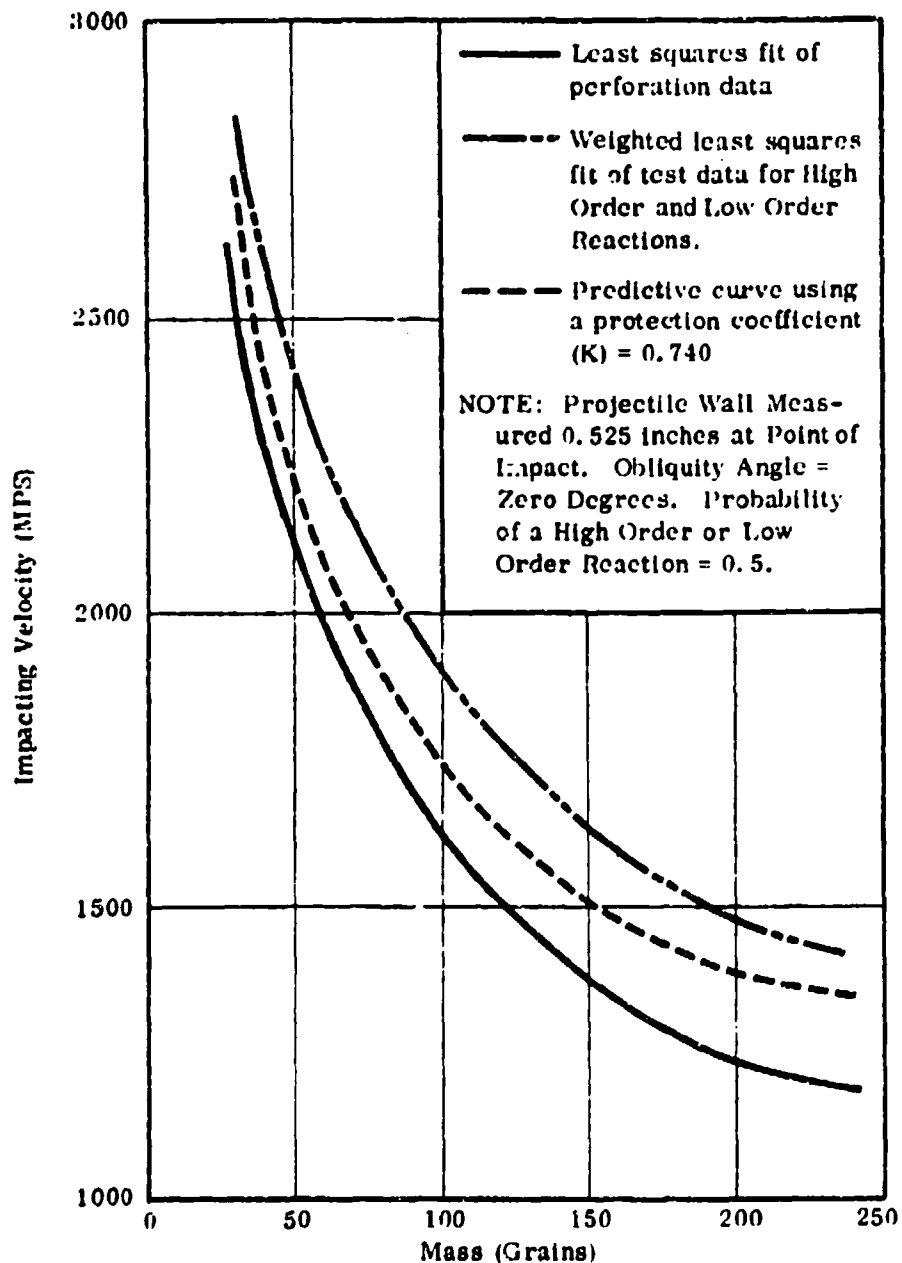


Figure 9 (C). Vulnerability of the U.S. 175mm HE Projectile (Composition B) to Fragment Impact (U)

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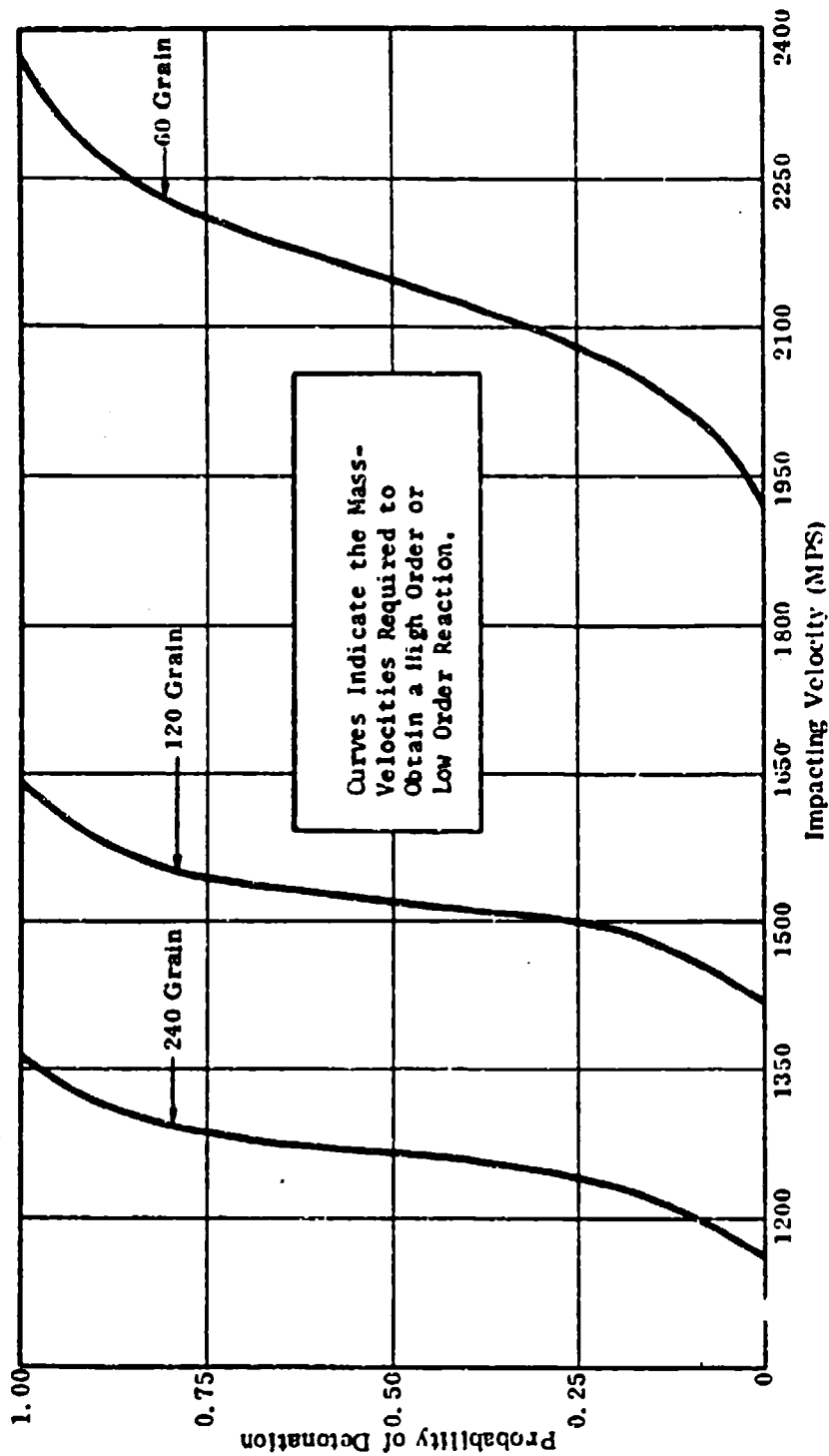


Figure 10 (C). Cumulative Probability Distributions for the U.S. 90mm HE Projectile (Comp. B) (U)

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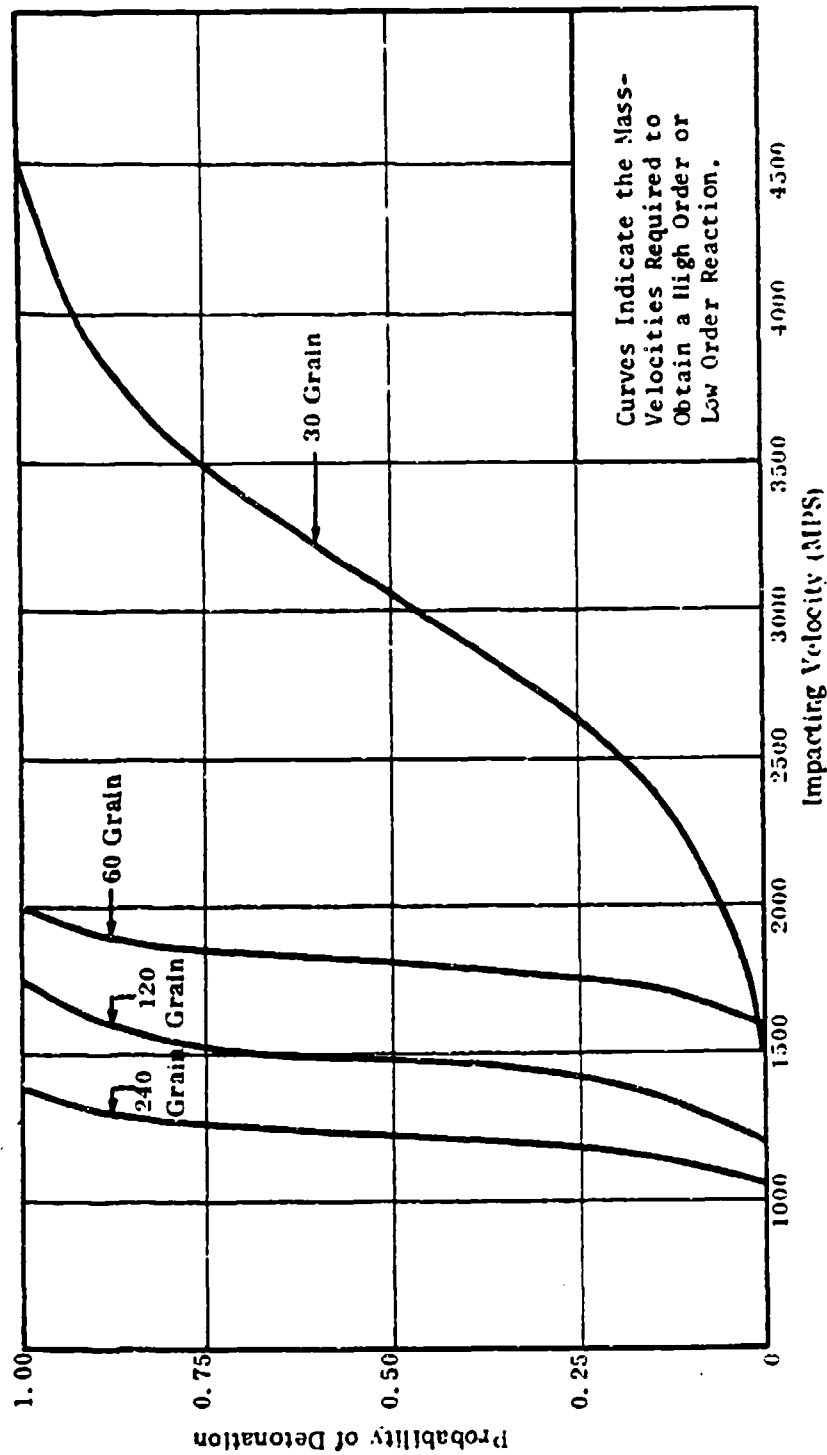


Figure 11 (C). Cumulative Probability Distributions for the U.S. 105mm HE Projectile (Comp. B) (U)

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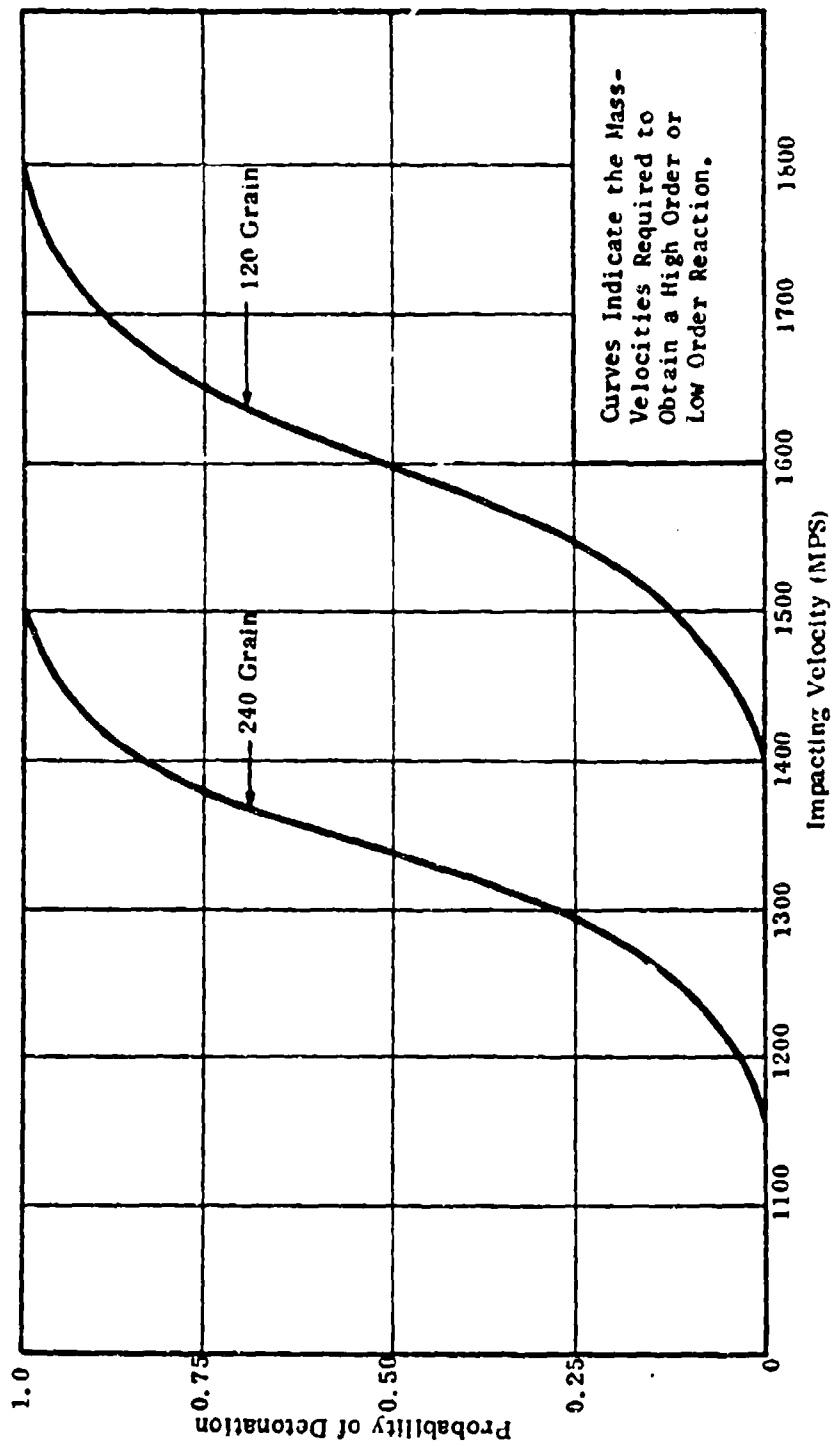


Figure 12 (C). Cumulative Probability Distributions for the U.S. 155mm HE Projectile (Comp. B) (U)

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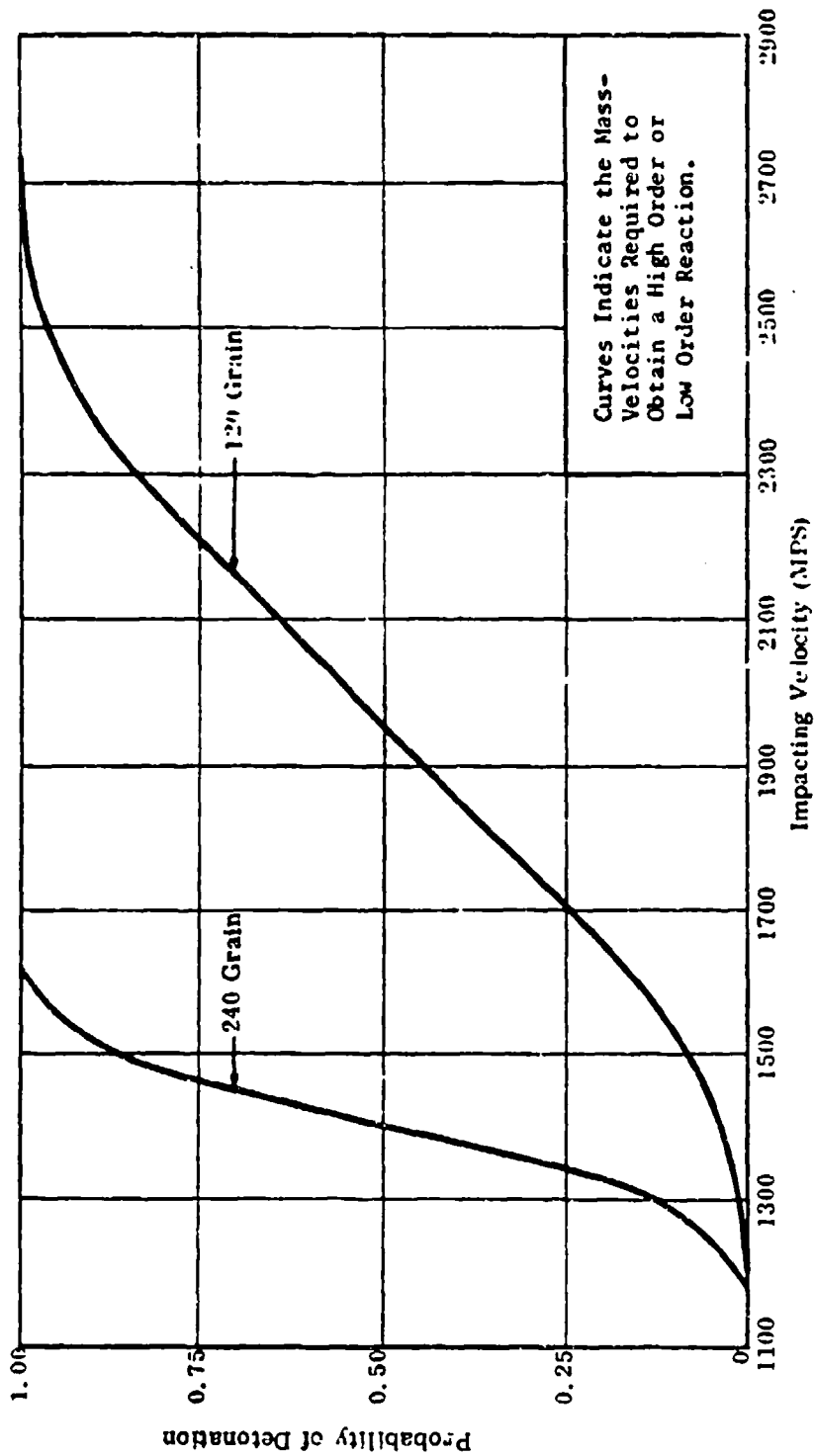


Figure 13 (C). Cumulative Probability Distributions for the U.S. 175mm HE Projectile (Comp. B) (U)

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all the projectile perforation data available and the firing records for these rounds, the following velocity criterion was established for each round

	60 gr	120 gr	240 gr
57mm	750 mps	600 mps	500 mps
122mm	400 mps	500 mps	275 mps
140mm	1000 mps	800 mps	700 mps

These velocities are estimates of the minimum velocities required by the fragments, after perforating the projectile wall, to initiate a Low-Order reaction 50% of the time. The predictive curves for these rounds are presented in Figures 14, 15, and 16.

It was not possible to make any predictions on the vulnerability of the 152mm projectile. None of the fragments fired against this round were able to perforate the projectile wall. The .50 cal bullet impacting at service velocity (869 mps) initiated a Low Order reaction.

C. U.S. 81mm and Soviet/CHICOM 82mm Mortar Projectiles

The experimental data for these two mortar projectiles result from two ad hoc tests conducted at these Laboratories and are included in this report for comparative purposes. The objective of the first test was to determine the vulnerability of stacked mortar ammunition in wooden boxes to fragment impact. The second test was conducted to establish the in-flight vulnerability of the round. Both tests were limited and it was not possible to generate a predictive curve for the Soviet/CHICOM 82mm round. An estimated vulnerability curve for the U.S. 81mm mortar projectile based on the two data points available is presented in Figure 17.

D. U.S. Sub-Missile Munitions

Considerable data were generated during this series of tests. The 30 grain high density fragments were used to satisfy an additional requirement and the data are included for comparative purposes only.

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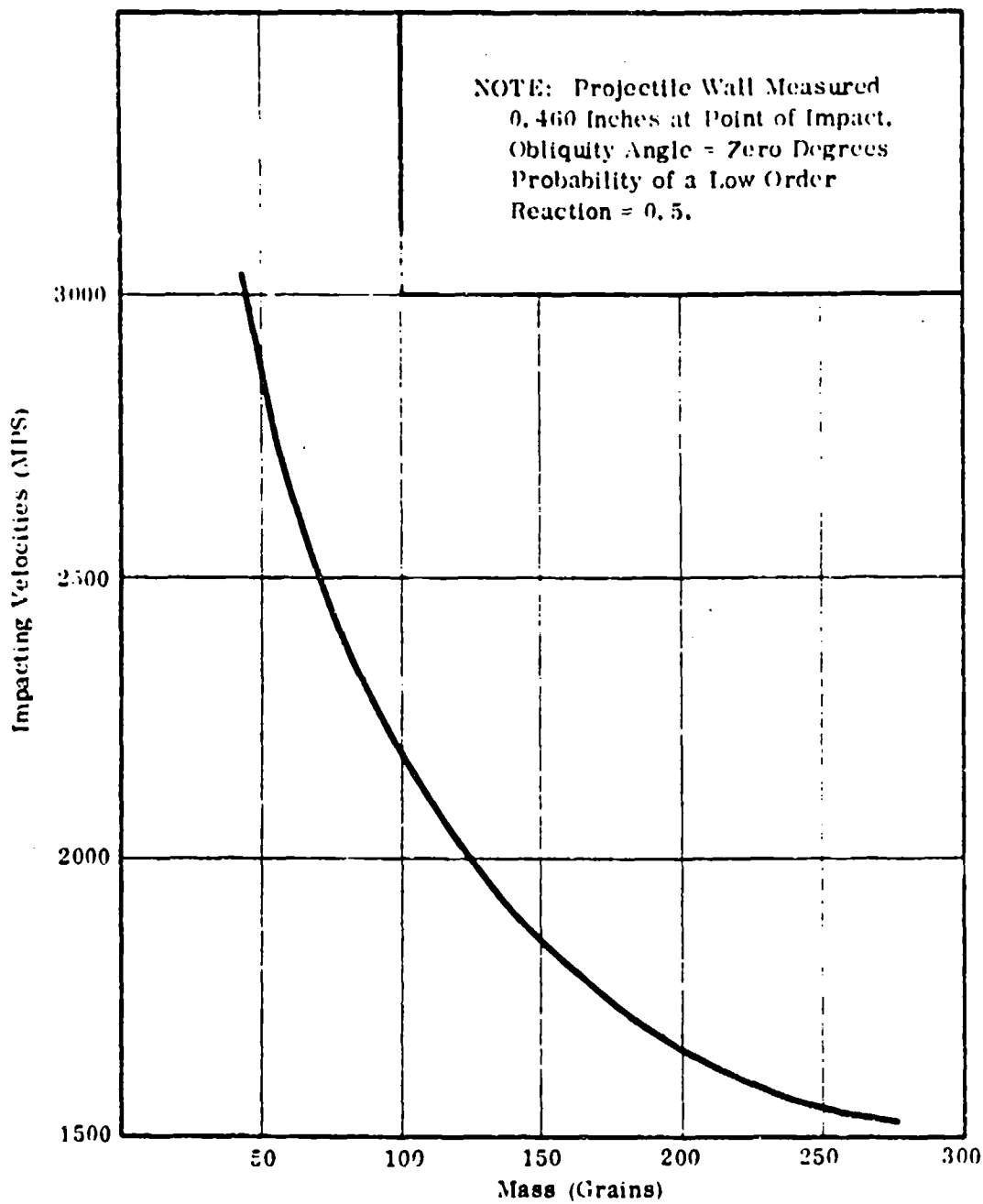


Figure 14 (C). Vulnerability of the Soviet 57mm HE Projectile (RDX/aluminum) to Fragment Impact (U)

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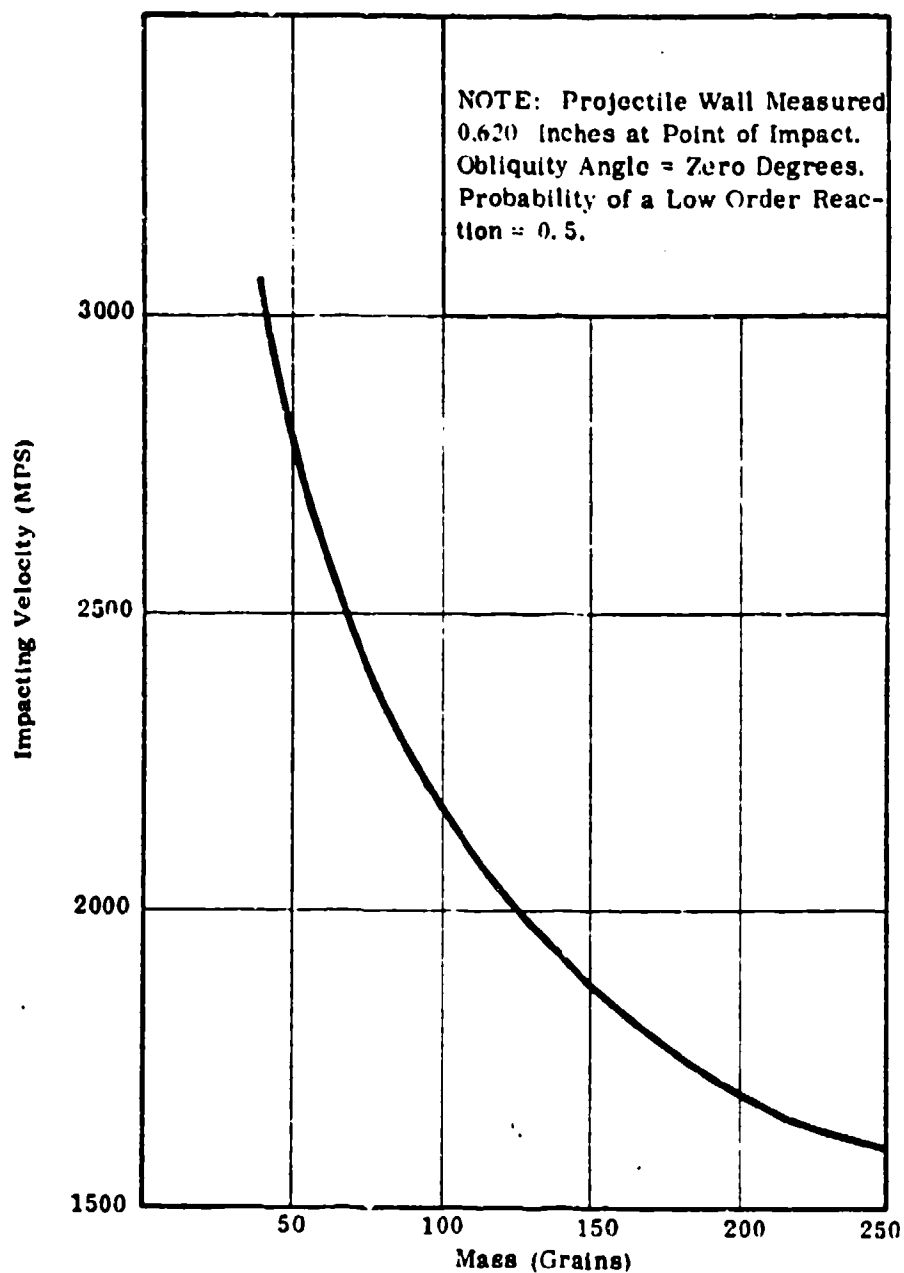


Figure 15 (C). Vulnerability of the Soviet 122mm HE Projectile (TNT) to Fragment Impact (U)

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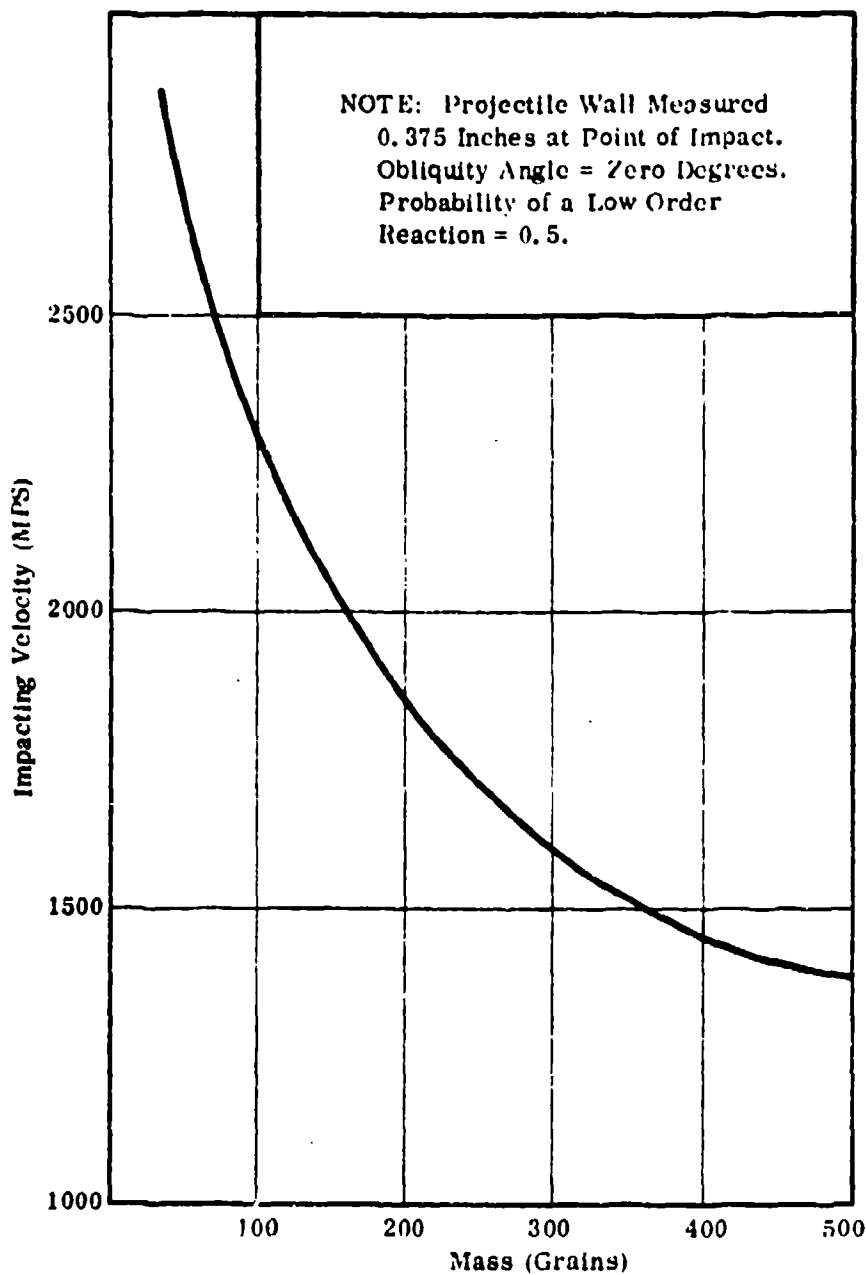


Figure 16 (C). Vulnerability of the Soviet 140mm HE Rocket Projectile (TNT) to Fragment Impact (U)

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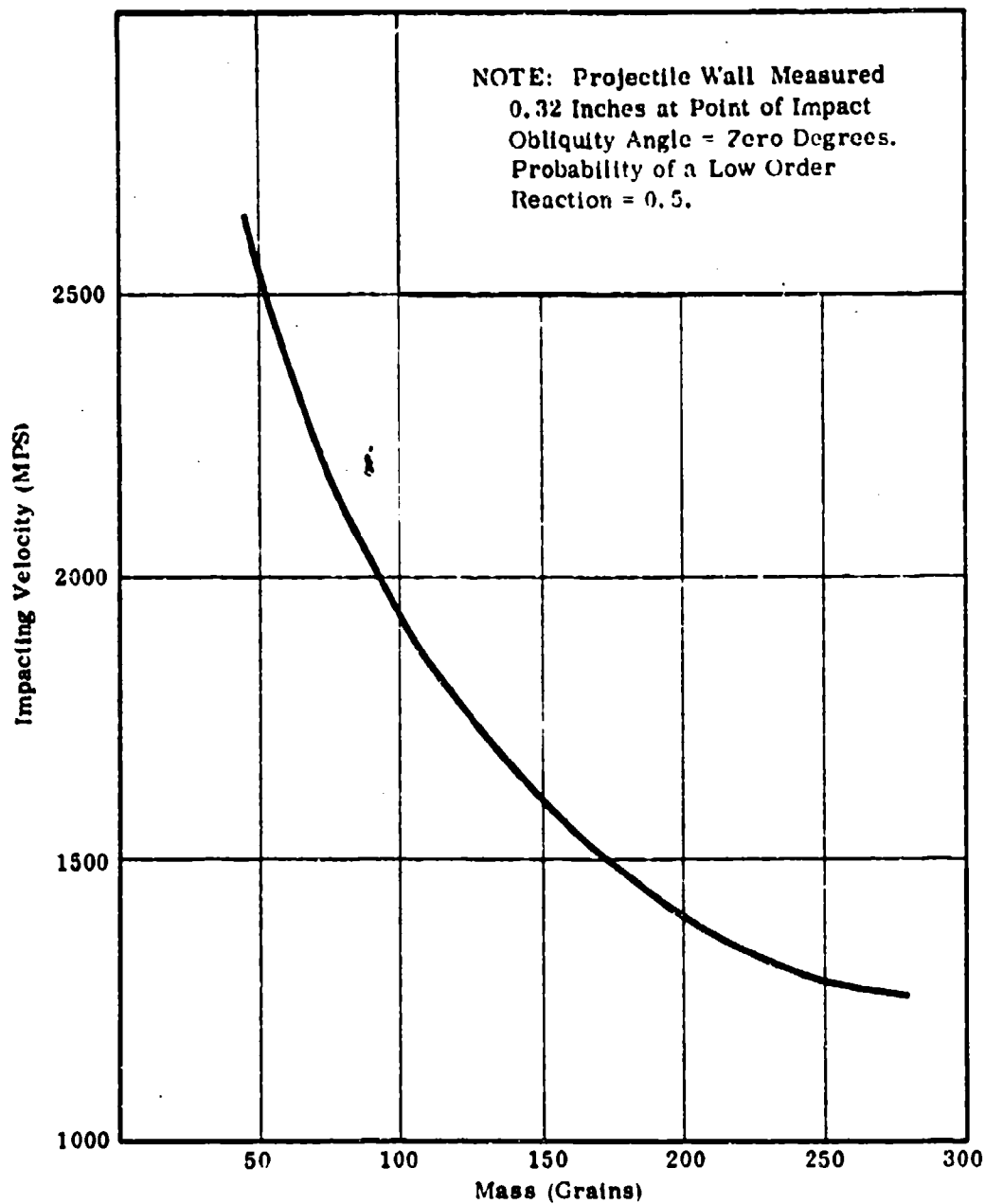


Figure 17 (C). Vulnerability of the U.S. 81mm Mortar
Projectile (TNT) to Fragment Impact (U)

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The median value, of the impacting velocities, each fragment required for each type of reaction is grouped by munition type for all impact conditions in Table IV. The same median value data are grouped by impact conditions for all munition types in Table V. The number in parentheses following the median values in both Tables IV and V is the number of observations used in arriving at the median values.

An examination of the data in Table V indicates that the five types of munitions tested can be considered equally vulnerable to fragment impact. Therefore, the data were combined and an analysis was made independent of munition type.

The median values presented in Table VI were reduced from these combined data using High Order values only. The $\bar{V}_{.5}$ and σ values were computed using the Golub and Grubbs technique and classifying both the Low Order and ruptured case results as the no detonation case, i.e., $d_{ij} = 0$. Curves were fit to the median value data for all three impact conditions, see Figure 18.

Because of the physical size and shape of these rounds, these Laboratories believe that the vulnerability curves in Figure 18 are valid for all obliquity angles up to ricochet.

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VII. CONCLUSIONS

All types of conventional HE-filled munitions are vulnerable to steel fragment impact. The response of a particular round to fragment impact is a function of the following parameters.

A. Fragment Characteristics

The impacting mass, velocity and shape all influence the way in which a round will respond. However, it is not known which of these three parameters is predominant.

B. Projectile Characteristics

There is a steady decrease in the vulnerability of steel HE projectiles as the wall thickness increases. Limited tests indicate

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TABLE IV (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Target Type (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC ^a	LO ^b	HO ^c
M-32	0	0	30HD ^d	2583(1) ^e	2503(6)	2671(5)
M-32	0	0.125 ^f	30HD	2354(1)	2474(6)	2643(5)
M-32	1.875	0.125	30HD		2153(3)	
M-32	2.000	0.125	30HD	2655(2)	2520(17)	2679(3)
M-40	0	0	30HD	1688(1)	2283(2)	2476(3)
M-40	0	0.125	30HD	2697(1)	2534(7)	2628(5)
M-40	1.875	0.125	30HD	2038(4)	2503(10)	
M-40	0	0	60			2012(4)
M-40	0	0.125	60		1850(2)	2033(4)
M-40	1.750	0.125	60		1850(2)	2245(2)
M-40	1.875	0.125	60		2234(4)	2340(2)
M-40	0	0	120			1222(3)
M-40	0	0.125	120		1509(7)	1702(9)
M-40	1.750	0.125	120		930(1)	1880(1)
M-40	1.875	0.125	120		1657(4)	1632(6)
M-40	0	0	240		960(5)	1109(5)
M-40	0	0.125	240		917(7)	1126(3)
M-40	1.875	0.125	240		925(5)	1372(11)

a. RC = Ruptured Case

b. LO = Low Order Reaction

c. HO = High Order Reaction

d. 30 HD = 30 grain high density steel, remainder of fragments are mild steel.

e. The number of data points used in generating the median value.

f. 0.125 plate, 0.03 sleeve, 2.0 inch polyurethane or combinations of all three.

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TABLE IV (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Target Type (Continued) (H)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				PC ^a	LO ^b	HO ^c
M-42E1	0	0.125	30			2350(4)
M-42E1	1.570	0.125	30			2460(3)
M-42E1	0	0.125	60			1852(3)
M-42E1	1.570	0.125	60		2052(2)	1905(1)
M-42E1	0	0	120			1208(6)
M-42E1	1.570	0.125	120			1630(3)
M-42E1	0	0	240			1031(6)
M-42E1	1.570	0.125	240		977(3)	
XM-41	0	0.125	30HD			2505(4)
XM-41	0	2.188	30HD			2530(1)
XM-41	0	0.125	60		1926(2)	2002(2)
XM-41	0	2.188	120		1817(1)	1967(4)
XM-41	0	2.188	240			1911(4)
XM-42	0	0	30HD	1553(1)	2243(5)	2350(10)
XM-42	0	0.125	30HD		2306(1)	2448(7)
XM-42	0	2.188	30HD			2554(1)
XM-42	0	0	60		1372(4)	1554(8)
XM-42	0	0.125	60		1557(2)	1807(2)
XM-42	0	0.188	60		2001(5)	2202(4)
XM-42	1.570	0.188	60	2264(2)	2250(2)	2458(5)

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TABLE IV (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Target Type (Continued) (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (Grains)	Median Velocities (mps)	
				RC ^b	LC ^c
XM-42	0	0.063	120		1203(4)
XM-42	0	0.188	120		1362(6)
XM-42	1.570	0.188	120		1652(4)
					1833(3)
					1923(4)
XM-42	0	0	240		1049(2)
XM-42	0	0.125	240		1088(4)
XM-42	1.570	0.125	240		975(3)
					692(3)
					1064(2)
					1160(3)

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TABLE V (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Impact Conditions (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC ^a	LO ^b	HO ^c
N-32	0	0	30HD ^d	2583(1) ^e	2583(6)	2671(5)
N-40	0	0	30HD	1688(1)	2283(2)	2476(3)
M-42	0	0	30HD	1553(1)	2243(5)	2360(10)
N-32	0	0.125 ^f	30HD	2354(1)	2474(1)	2643(6)
M-40	0	0.125	30HD	2697(1)	2931(1)	2628(5)
XM-41	0	0.125	30HD			2989(4)
XM-42	0	0.125	30HD		2304(1)	2418(7)
XM-41	0	2.186	30HD			2630(1)
XM-42	0	2.188	30HD			2634(1)
M-32	1.875	0.125	30HD		2163(3)	
M-40	2.875	0.125	30HD	2038(1)	2603(1)	

a. RC = Ruptured Case

b. LO = Low Order Reaction

c. HO = High Order Reaction

d. 30HD = 30 Grain high density steel, remainder of fragments are mild steel

e. The number in parentheses following the median value indicates the number of data points used in generating the median value.

f. 0.125 = An aluminum plate 0.125 inches thick

0.063 = An aluminum sleeve 0.063 inches thick.

0.125 = Combination of 0.063 sleeve and 0.125 plate

2.188 = Combination of 0.063 sleeve, 0.125 plate and 2.0 inches Polyurethane

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TABLE V (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Impact Conditions (Continued) (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC ^a	LO ^b	HO ^c
M-32	2.0	0.125	30HD	265(2)	2629(17)	2679(3)
M-42E1	0	0.125	30			2350(4)
M-42E1	1.570	0.125	30			2469(3)
M-40	0	0	60		1372(4)	2016(4)
XM-42	0	0	60		1372(4)	1584(8)
M-40	0	0.125	60		1869(2)	2033(4)
X-42E1	0	0.125	60			1882(3)
XM-41	0	0.125	60		1926(2)	2008(2)
XM-42	0	0.125	60		1887(2)	1898(2)
XM-42	0	0.188	60		2091(5)	2292(4)
M-42E1	1.570	0.125	60		2056(2)	1968(1)
M-40	1.750	0.125	60		1860(2)	2245(2)
M-40	1.875	0.125	60		2204(4)	2340(2)
XM-42	1.570	0.188	60	2264(2)	2288(2)	2498(5)
M-40	0	0	120			1222(3)
M-42E1	0	0	120			1298(6)
XM-42	0	0.063	120		1203(4)	1362(8)
M-40	0	0.125	120		1509(7)	1702(9)
XM-42	0	0.188	120		1682(4)	1809(3)
XM-41	0	2.188	120		1817(1)	1965(4)

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TABLE V (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Impact Conditions (Continued) (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC ^a	LO ^b	HO ^c
M-42E	1.570	0.125	120			1630(3)
M-40	1.750	0.125	120		980(1)	1889(1)
M-40	1.875	0.125	120		1657(4)	1632(6)
XM-42	1.570	0.188	120		1823(4)	1908(4)
M-40	0	0	240		980(5)	1109(5)
M-42E1	0	0	240			1031(6)
XM-42	0	0	240		849(2)	1106(4)
M-40	0	0.125	240		917(7)	1126(3)
XM-42	0	0.125	240		975(3)	1068(2)
XM-41	0	2.188	240			1911(4)
M-42E1	1.570	0.125	240		977(3)	1160(3)
XM-42	1.570	0.125	240		992(3)	
M-40	1.875	0.125	240		925(5)	1372(11)

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TABLE VI (C). Impacting Mass-Velocity Combinations
Required to Detonate High Order
Sub-Missile Munitions 90% of the Time (U)

Mass (grains)	Median Values (mps)	$\bar{V}_{.5}$ (mps)	σ (mps)	Shielding ^a Aluminum	Spacing ^b
30HD	2430 ^c	2247	549	No	No
30	2106 ^c			No	No
60	1405	1405	68	No	No
120	1222			No	No
240	1052	800	194	No	No
30HD	2414	2430	375	Yes	No
30	2350			Yes	No
60	2027	1929	302	Yes	No
120	1777	1379	93	Yes	No
240	1792 ^d	1075	20	Yes	No
30HD	2720	3647	792	Yes	Yes
30	2450			Yes	Yes
60	2408	2256	346	Yes	Yes
120	1760	1502	274	Yes	Yes
240	1200	1074	150	Yes	Yes

- a. Shielding was either a 0.063 inch sleeve, a 0.125 inch plate or a combination of both plate and sleeve.
- b. Spacing varied between 1.570 inches to 2.000 inches
- c. Estimated. No data available.
- d. Poor data point. XM-41 data used in the analysis adversely affected the median value. Use $\bar{V}_{.5}$ data.

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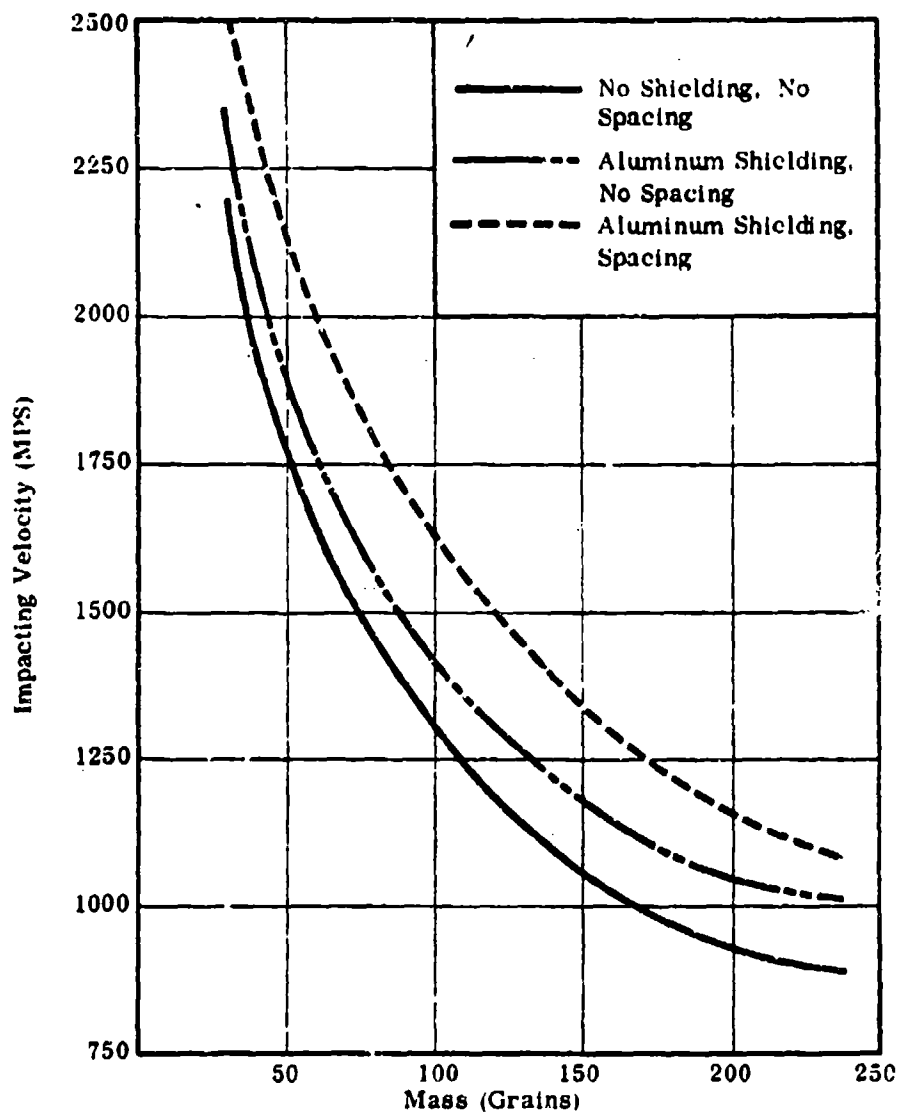


Fig. 18 (C). Vulnerability of Sub-Missile Munitions to Fragment Impact (U)

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that cast iron projectiles fracture when subjected to fragment impact at mass-velocity combinations well below those required to initiate an explosive reaction. The shock attenuation properties of cast iron probably provide some degree of protection against shock-initiated explosive reactions.

C. HE Filler Characteristics

Comp. B-filled artillery projectiles are more vulnerable to fragment impact than comparable rounds filled with TNT.

There does not appear to be any difference in the minimum impacting mass-velocity combinations required to initiate High Order and Low Order reactions for Comp. B-filled projectiles.

It is possible to explosively initiate a Comp. B-filled projectile, via fragment impact, at velocities below that required for perforation of the projectile wall. However, the mass-velocity combinations required to perforate the wall of TNT-filled projectiles was always exceeded, in this series of tests, before any explosive reactions were initiated. A residual mass-velocity criterion appears to be the only method available in making reasonable estimates on the vulnerability of the HE munitions tested utilizing a filler other than Comp. B.

The Sub-Missile munitions tested are equally vulnerable to fragment impact. It is reasonable to assume that other munitions in this class will respond similarly.

Because data were available on the vulnerability of bare Comp. B to fragment impact, it was possible to generate protection coefficients for Comp. B-filled munitions. These coefficients can be used in making reliable estimates on the vulnerability of Comp. B-filled munitions.

The results of this series of tests should prove useful to analysts in assessing the vulnerability of a wide range of HE ammunition to fragment impact. They should also be of value to those engaged in the design of new munitions. Attention has been focused on those parameters which influence the vulnerability of HE munitions. It appears likely that the vulnerability of conventional HE munitions can be significantly reduced.

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(UNCL) VIII. RECOMMENDATIONS FOR FUTURE WORK

To provide those engaged in assessing and predicting the vulnerability of HE munitions to fragment or other type projectile impact with the information they require, the following recommendations are made.

A. Using instrumentation, establish an "absolute standard" for determining the response characteristics for High Order and Low Order reactions. This would provide test personnel in the field with a method for making quantitative assessments for all explosive reactions and assist the analyst in the application of the results.

B. Conduct firings against TNT-filled U.S. artillery projectiles. TNT is one of the least sensitive of the more common HE fillers while Comp. B. is one of the most sensitive.

C. Conduct additional firings against Comp. B and TNT-filled munitions and determine their vulnerability as a function of impact angle.

D. Determine the vulnerability of bare TNT to steel fragment impact. It may be that a relationship exists between the vulnerability of bare TNT and TNT-filled munitions. If a relationship does exist, it could provide the means for developing a predictive technique similar to that now available to analysts assessing the vulnerability of Comp. B-filled artillery munitions.

E. Through live firings, quantitatively assess the desensitizing effect, if any, of the more common and experimental materials that could be used as either a coating on the interior surface of the projectile or as an additive to the HE filler.

It is recognized that these additional investigations will not satisfy the requirements of all researchers. However, they should provide the vulnerability analyst with a data bank from which valid predictions can be made on the vulnerability of a wide variety of HE munitions to steel fragment impact.

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(CONFIDENTIAL) APPENDIX A

Steel Fragments Versus
U.S. Artillery Projectiles (U)

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1. A-1 (C). 176857112 1 1 137112 -

Fragment's mass, velocity, impact velocity, impact velocity

Fragment Mass (grains)	Impact Velocity (mps)	Fragment Penetration	Fragment Penetration
10	1000	X	
	1000		X
120	1280	X	
	1347	X	
	1375	X	
	1389		X
240	761	X	
	823	X	
	1047	X	
	1064	X	
	1082	X	
	1160		X
	1252		X
	1399		X

NOTE: All fragments were aimed to impact at a point where the projectile wall measured 0.485 ± 0.013 inches and at an obliquity angle of zero degrees.

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TABLE A-II (c).

CLASSIFICATION OF RESULTS -
Fragments Versus Thickness of Target Plate
(Empty and Wax Filled)

Fragment Mass (grains)	Impact Velocity (mps)	Projectile Filler	Wall Thickness (inches)	Results Partial Penetra- tion	Perfore- tion
30	1407	Empty	0.403 $\pm$.012	X	
	1559	"	"	X	
	1721	"	"	X	
	1769	"	"	X	
	1885	"	"	X	
	1899	"	"	X	
	1923	"	"	X	
	1943	"	"		X
60	2098	"	"		X
	1389	Empty	0.403 $\pm$.012	X	
	1407	"	"	X	
	1492	"	"	X	
	1533	"	"		X
	1525	Wax	"	X	
	1579	"	"	X	
	1670	"	"		X
	1780	"	"		X
	1986	"	"		X
120	979	Empty	0.403 $\pm$.012	X	
	994	"	"	X	
	1124	"	"	X	
	1134	"	"		X
	1172	"	"		X
	1216	"	"		X
	1252	"	"		X
	1255	"	"		X
240	691	Empty	0.403 $\pm$.012	X	
	788	"	"	X	
	802	"	"	X	
	941	"	"	X	
	955	"	"		X
	997	"	"		X
	1006	"	"		X
	1022	Wax	"	X	
	1096	"	"		X
	1272	"	"		X

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A-II

TESTING OF 1.5 IN. F - SUITS -
 Fragments 1.5 in. F - Projectile
 (Empty and 1/2 Filled)

Fragment Mass (grains)	Impact Velocity	Projectile Filler	Wall Thickness (inches)	Results Partial Penetration	Perforation
30	1803	Empty	0.40 ± .012	X	
	2041	"	"	X	
	2063	"	"	X	
60	1804	Empty	0.40 ± .012	X	
	1817	"	"	X	
	1851	"	"	X	
	1883	"	"		X
	1846	"	"		X
	1863	"	"		X
120	1176	Empty	0.40 ± .012	X	
	1207	"	"	X	
	1258	"	"	X	
	1308	"	"	X	
	1337	"	"		X
240	1073	Empty	0.40 ± .012	X	
	1063	"	"	X	
	1062	"	"		X

NOTE: All fragments were aimed to impact at a point where the projectile wall measured 0.403 or 0.50 ± 0.030 inches and at an obliquity angle of zero degrees.

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TABLE A-III(C). CLASSIFICATION OF RESULTS -
Fragments Versus 155mm HE Projectile (Empty) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results	
		Partial Penetration	Perforation
60	1970	X	
	1975	X	
	2012	X	
	2059		X
120	1476	X	
	1519	X	
	1531		X
	1551		X
	1612	X	
	1617	X	
	1629		X
	1676		X
	1708		X
	1815		X
240	1282	X	
	1378		X
	1386		X

NOTE: All fragments were aimed to impact at a point where the projectile wall measured 0.56 ± 0.030 inches and at an obliquity angle of zero degrees.

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TABLE A-IV (C). CLASSIFICATION OF RESULTS -
Fragments Versus 17mm HE Projectile (Empty) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results	
		Partial Penetration	Perforation
60	1784	X	
	1890		X
	2020		X
	2044		X
120	1317	X	
	1327	X	
	1341	X	
	1360	X	
	1429	X	
	1459		X
	1472		X
	1476		X
	1479		X
	1505		X
	1622		X
	1627		X
240	1035	X	
	1096		X
	1160		X
	1190		X

NOTE: All fragments were aimed to impact at a point where the projectile wall measured 0.525 ± 0.030 inches and at an obliquity angle of zero degrees.

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TABLE A-V (C). CLASSIFICATION OF RESULTS -
Fragments Versus 90mm HE Projectile (Composition 6) (U)

Fragment Mass (grains)	Impact Velocities (mps)				
	High Order	Low Order	Burn	No Reaction	
60	2187	2060 2038 2104 2117 2126 2151 2154 2328	2111*	1847 1893 1882 1952 2020 2033 2059 2066 2066	2074 2085 2101 2131 2131 2146 2146 2162 2171
120	1525 1568 1571 1571 1580	- 1552 1553 1554 1568 1586		1463 1529 1554 1585	
240	1319 1342 1362 1386	1228 1228 1334	1204* 1319*	1179 1191 1202 1205 1223	1239 1243 1253 1254 1260*

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

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TABLE A-VI (C). CLASSIFICATION OF RESULTS -
Fragments Versus 105mm M1 Projectile
(Composition -) (U)

Fragment Mass (grams)	Impact Velocities (mms)			
	High Order	Low Order	Burn	No Reaction
30	2311 2350 2431 2500 2600 2620 2700 2714 2894		2104* 2711*	2171* 2459 2675 2190 2482* 2687* 2227 2513 2687 2313 2585* 2725* 2355 2609 2726* 2357 2621 2745 2387 2623 2867* 2409 2635 2454 2638
60	1720 1783 1835 1854 1876 1876 1876	1847 1871 1879		1689 1775 1717 1785 1739 1863 1754* 1886 1754
120	1444 1446 1449 1477 1494	1456	1456* 1524*	1175 1420* 1211* 1449* 1271* 1467* 1412* 1495* 1417* 1531* 1417
240	1205 1228 1232 1251	1202	1279*	925* 1171* 1007* 1207* 1022 1207* 1089* 1210* 1092* 1238* 1131* 1237*

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

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TABLE A-VII (C). CLASSIFICATION OF RESULTS -
Fragments Versus 105mm HE Projectile
(Composition B) (U)

Fragment Mass (grains)	Impact Velocities (mps)			
	High Order	Low Order	Burn	No Reaction
120	1629 1668 1752 1805 1840			1525 1544* 1548* 1553 1564 1585 1587 1605 1614* 1658
240	1690 1692		1620*	1579* 1565* 1568* 1571* 1572 1575*

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of forty-five degrees.

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TABLE A-VIII (c). CLASSIFICATION OF RESULTS -
Fragments Versus 155mm HE Projectile
Composition A (U)

Fragment Mass (grains)	Impact Velocities (mps)			
	High Order	Low Order	Burn	No Reaction
120	1524 1543 1526 1547 1575 1718 1761 1797 1799 1815			1379 1397 1483 1486 1518 1521 1525 1556 1557 1559 1536
240	1319 1332 1337 1358 1372 1375 - 1378 1410 1462			998 1219 971 1242 974 1266 1019 1291 1046 1294 1072 1292 1085 1378 1089* 1421

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

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TABLE A-IX(C). CLASSIFICATION OF RESULTS -
Fragments Versus 175mm HE Projectile
(Composition B) (II)

Fragment Mass (grains)	Impact Velocities (mps)				
	High Order	Low Order	Burn	No Reaction	
120	1747	1936		1745	1871
	1757	1868		1510	1871*
	1876	1879		1607	1905
	1955	1884		1695	1923
		1952		1723	1931
		2072		1749	1940
				1770	1945
				1786	1965
				1817	1971
240	1288	1326		1066	1272
	1405	1413		1162	1287
	1432			1167	1308*
	1455			1196	1334
	1464			1198	1339
	1566			1235	1344
				1237	1365
				1242	1369
				1243	1434
				1250	1440
				1258	1463
				1260	

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

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(CONFIDENTIAL) APPENDIX B

Steel Fragments Versus Soviet
Artillery and Rocket Projectiles (U)

75

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TABLE B-1 (C). CLASSIFICATION OF RESULTS
Fragments Versus Soviet HE Projectile (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
100	1513	Projectile wall perforated. Slight burning.
120	1511	Low hit. Fragment impacted on rotating band. No perforation.
100	1510	Projectile wall perforated. No burning or explosive reaction observed.
120	1507	Projectile wall perforated. Slight burning.
120	1535	Projectile wall perforated. Slight burning.
140	1280	Projectile wall perforated. No burning or explosive reaction observed.
240	1521	Low order reaction.
240	1524	Projectile wall perforated. No burning or explosive reaction observed.
240	1630	Low order reaction.
240	1632	Low order reaction.

*The sim point was mid-way between the bourrelet and the rotating bands. The obliquity angle was zero degrees. The wall thickness at this point is 0.460 inches. The HE filler is RDX 73%; aluminum 23%; wax 4%.

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TABLE B-II (C). CLASSIFICATION OF RESULTS
Fragments and Bullets Versus Soviet
122mm HE Artillery Projectile (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
60	2330	Fragment hit two inches low of intended point of impact. No perforation or explosive reaction.
60	2345	Fragment hit one inch low of intended point of impact. No perforation or explosive reaction.
60	2502	Projectile wall perforated. Slight burning.
60	2540	Fragment hit one half inch to the right of the intended point of impact. No perforation or explosive reaction.
60	2536	Projectile wall perforated. Slight burning.
60	2574	Fragment hit one half inch to the right of the intended point of impact. No perforation or explosive reaction.
60	2605	Low Order Reaction.
60	2610	Low Order Reaction.
60	2641	Fragment hit one half inch low and one half inch to the left of the intended point of impact. Projectile wall perforated. Slight burning.
60	2669	Projectile wall perforated. Slight burning.
120	1679	No perforation or explosive reaction.
120	1752	No perforation or explosive reaction.
120	1939	Fragment hit one inch high of the intended point of impact. Projectile wall perforated. Slight burning.

*The aim point was one inch below the bourrelet. The obliquity angle was zero degrees. The wall thickness at this point is 0.620 inches.

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TABLE B-II (C). CLASSIFICATION OF RESULTS
Fragments and Bullets Versus Soviet
100mm High Velocity Projectile (M) (Continued) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
110	1301	Projectile wall perforated. Explosive burned for 40 minutes.
120	1303	Fragment hit one inch low of the in- tended impact point. Projectile wall perforated. Slight burning.
240	1300	No perforation or explosive reaction.
240	1401	Fragment hit one inch high of the intended point of impact. Projectile wall perforated. Slight burning.
240	1400	Fragment hit one inch low of the intended point of impact. Projectile wall perforated. Slight burning.
240	1628	Low order reaction.
240	1688	Low order reaction.
240	1760	Low order reaction.
240	1804	Low order reaction.
240	800	A .50 cal. ball bullet was used in this test resulting in a low order reaction.

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TABLE B-III (C). CLASSIFICATION OF RESULTS --
Fragments Versus Soviet 140mm HE Rocket
Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Wall Thickness (inches)	Obliquity Angle (degrees)	Results
240	1830*	0.375	0	Low Order.
240	1678*	0.375	0	Wall perforated. No explosive reaction.
240	1678*	0.375	0	Fragment impacted 1-inch to the right of desired impact point. Wall perforated. No explosive reaction.
240	1531	0.375	0	Wall perforated. Slight burning.
240	1824	0.375	0	High Order.
240	1835	0.375	45	Wall perforated. Explosive burned for 50-minutes.
240	1844	0.50	0	High Order.
240	1794	0.60	0	Wall perforated. No explosive reaction.
240	1779	0.60	0	Wall perforated. No explosive reaction.
480	1120	0.375	0	Fragment impacted 1-inch to the right of desired impact point. Wall perforated. No explosive reaction.
480	1115	0.375	0	Wall perforated. No explosive reaction.
480	1085	0.375	0	Wall perforated. No explosive reaction.

* Estimated Velocities

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TABLE B-III (C). CLASSIFICATION OF RESULTS -
Fragments Versus Soviet Polm 91 Rocket
Projectiles (RT) (continued) (U)

Fragment Weight (lb)	Impact Velocity (fps)	Wall Thickness (inches)	Obliquity Angle (degrees)	Results
1.1	1131	0.00	0	Fragment impacted 1-inch to the right of desired impact point. No explosive reaction.
1.1	1132	0.00	0	Wall perforated. No explo- sive reaction.
1.1	1133	0.00	0	No wall perforation. No explosive reaction.

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TABLE B-IV (C). CLASSIFICATION OF RESULTS
Fragments and Bullets Versus Soviet
152mm HE Artillery Projectile (151) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
120	2604	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2281	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2316	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2316	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2345	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2352	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2377	Fragment failed to perforate projectile wall. No burning or explosive reaction.
240	1795	Fragment failed to perforate projectile wall. No burning or explosive reaction.
240	1944	Fragment failed to perforate projectile wall. No burning or explosive reaction.
180	869	A .50 cal. ball bullet was impacted at an obliquity angle of zero degrees resulting in a low order reaction.
180	869	A .50 cal. ball bullet was impacted at an obliquity angle of 45 degrees resulting in a low order reaction.

*The aim point was one inch below the bourrelet. The wall thickness at this point is 0.790 in. All fragments were aimed to impact at an obliquity angle of zero degrees.

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(CONFIDENTIAL) APPENDIX C

Steel Fragments Versus U.S. 81mm
and Soviet/CHICOM Mortar Projectiles (U)

83 The following page is blank.

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TABLE C-I (c).

CLASSIFICATION OF RESULTS -
Fragments Versus U.S. 81mm Mortar
Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Masking	Fuze	Results
60	1800	0	3/4" Pine	No	Perforation. Small amount of HE burned. Impacted 2" below gas check bands.
120	1647	0	"	No	Small amount of HE burned. Part of the plastic nose cap broken. Impacted 2" below gas check bands.
120	1647	0	None	No	Some HE burned. Nose cap knocked off. Unburned HE scattered around. Impact below gas check bands.
120	1891	0	None	No	Mild low order reaction. Round broke up into a few large pieces. Impact below gas check bands.
120	2135	0	3/4" Pine	No	A flash observed as the HE burned. No breakup of the projectile. Nose plug knocked off. Impact below gas check bands.
120	1891	0	"	No	Some of the HE burned. Nose plug knocked off. Impact below gas check bands.
120	1890	0	"	No	Same as previous round.
120	2130	0	"	No	Same as previous round.
120	2135	0	"	No	Impacted on gas check bands. Some HE burned.

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TABLE C-1 (C). (Continued)

CLASSIFICATION OF RESULTS -
Fragments Versus U.S. 81mm Mortar
Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Masking	Fuze	Results
120	2135	0	3/4" Pine	Yes	Fuze armed with safety devices attached. Mild low order. Projectile casing opened completely. Impacted one inch below gas check bands.
120	2135	45	"	No	Perforation, no burning. Impact on gas check bands.
120	2135	45	"	No	Same as previous round.
240	1830	0	"	No	Mild low order, projectile fractured into three pieces. Sustaining wood fire started in packing box below the round. Impact on gas check bands.
240	1594	0	"	No	Some HE burned. Impact on gas check bands.
240	1427	0	"	No	Some HE burned. Unburned HE scattered about. Impact on gas check bands.
240	1830	0	"	No	Three rounds placed in a six-round Soviet type container. A weighted wooden box placed above. Fragment impacted on gas check band. Low order reaction of the impacted round. Other rounds slightly damaged.

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TABLE C-I (C) (Continued)

CLASSIFICATION OF RESULTS -
Fragments Versus U.S. 81mm Mortar
Projectiles (PNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Masking	Fuze	Results
120	2135	0	None	Nc	Impacted one inch below gas check rings. Mild low order reaction. Pro- jectile broke into three sections.

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TABLE C-II(c).

CLASSIFICATION OF RESULTS -
Fragments Versus Soviet/CHICOM 82mm HE
Mortar Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Fuze (Unarmed)	Results
30	946	0	Yes	Fragment impacted at 0° on the unarmed fuze. The plastic fuze was shattered. No explosive or burning reaction observed.
120	1891	0	No	Fragment impacted on gas check rings. The cast iron projectile fractured into ten pieces. No explosive reaction or burning observed.
240	946	20	Yes	Fragment impacted one inch below the fuze, 20° off the nose. Top section of the projectile fractured into several pieces. Fuzes, undamaged, thrown about ten feet. No explosive or burning reaction observed.
240	1586	0	No	Projectile, impacted on gas check rings, fractured into twelve pieces. No explosive or burning reaction observed.
240	1830	0	Yes	Projectile, impacted one inch below gas check rings, fractured into 26 pieces. No explosive or burning reaction observed.

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(CONFIDENTIAL) APPENDIX D

Steel Fragments Versus
U.S. Sub-Missile Munitions (U)

89

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TABLE D-1 (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC ^a	LO ^b	HO ^c
M-32	30HD ^d	0	0	2583	1793	2562
					2072	2671
					2540	2671
					2626	2768
					2628	2802
M-32	30HD	0	0.125 ^e	2354	2674	2540
					1732	2573
					2316	2643
					2325	2650
					2471	2727
M-32	30HD	1.875	0.125		2478	2559
					2603	2668
					1860	
					.63	
					2682	

- a. RC = Ruptured Case
b. LO = Low Order Reaction
c. HO = High Order Reaction
d. 30HD = 30 Grain high density steel, remainder of fragments are mild steel
e. 0.125 = An aluminum plate 0.125 inches thick
0.063 = An aluminum plate 0.125 inches thick
0.188 = Combination of 0.063 sleeve and 0.125 plate
2.188 = Combination of 0.063 sleeve, 0.125 plate and v.0 inches polyurethane

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TABLE D-1(C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC ^a	IO ^b	HC ^c
M-32	30HD	2.000	0.125	2000	1845	2448
				2009	2191	2679
					2340	2753
					2571	
					2586	
					2600	
					2614	
					2628	
					2633	
					2639	
M-40	30HD	0	0		2650	
					2711	
					2731	
					2746	
					2758	
M-40	30HD	0	0.125	1686	2239	2429
					2327	2475
						2507
					1797	2591
					2326	2605
M-40	30HD	0	0.125		2372	2628
					2534	2639
					2543	2674
					2636	
					2662	

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TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC ^a	LO ^b	HO ^c
M-40	30HD	1.875	0.125	1539 1997 2080 2561	2233 2372 2537 2572 2577 2630 2645 2647 2751 2842	
M-40	60	0	0			1964 2011 2021 2044
M-40	60	0	0.125		1854 1873	1948 2032 2034 2279
M-40	60	1.750	0.125		1846 1873	2225 2266
M-40	60	1.875	0.125		2133 2202 2205 2237	2340 2340

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TABLE D-1(C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC ^a	LO ^b	HC ^c
M-40	120	0	0			1102 1222 1256
M-40	120	0	0.125		1408 1487 1492 1509 1704 1795 1864	1326 1526 1540 1651 1702 1869 1874 1879 1920
M-40	120	1.750	0.125		980	1389
M-40	120	1.875	0.125		1526 1654 1680 1637	1476 1524 1617 1646 1660 1854
M-40	240	0	0		639 828 980 1010 1023	1102 1107 1107 1121 1563

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TABLE D-1 (C). CLASSIFICATION OF FRAGMENT
Fragments Versus Sub-Missile Particles (Continued)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				10°	0°	90°
M-40	240	0	0.125		80	1107
					800	1126
					848	1790
					914	
					917	
M-40	240	1.875	0.125		985	
					1146	
					811	754
					856	1184
					925	1191
					1051	1201
					1098	1217
						1372
M-42E1	30	0	0.125			1376
						1400
						1503
						1787
M-42E1	30	1.570	0.125			1794
						2345
						2347
						2353
M-42E1	30	1.570	0.125			2560
						2455
						2469
						2476

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TABLE D-1 (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (fps)		
				50°	10°	HO°
M-42E1	60	0	0.125			1874 1822 1886
M-42E1	60	1.570	0.125		2051 2062	1966
M-42E1	120	0	0			1103 1116 1121 1104 1124 1131
M-42E1	120	1.570	0.125			1593 1630 1643
M-42E1	240	0	0			768 777 1029 1033 1052 1245
M-42E1	240	1.570	0.125		976 977 1097	

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TABLE D-1 (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				PC ^a	LC ^b	HC ^c
XM-41	30HD	0	0.125			2284
						2256
						2014
						2130
XM-41	30HD	0	2.185			2630
XM-41	60	0	0.125		1878	1909
					1974	2027
XM-41	120	0	2.186		1817	1954
						1955
						1974
						1980
XM-41	240	0	2.186			1829
						1834
						1838
						1848
XM-42	30HD	0	C	1553	1576	1864
					1739	2149
					2243	2249
					2252	2310
					2234	2354
						2376
						2370
						2372
						2473
						2485

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TABLE D-1 (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Penetration (Continued) (C)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shattering (inches)	Impact Velocities (mps)		
				R ¹	L ¹	H ²
X ¹ -42	30HD	0	0.125		25.0	2209
						2372
						2409
						2447
						2467
X ¹ -42	30HD	0	0.125			2516
						2550
						2674
	60	0	0	1326		1337
				1365		1475
X ¹ -42	60	0	0	1380		1522
				1398		1539
						1627
						1639
						1670
X ¹ -42	60	0	0.125		1704	1713
					1920	1923
X ¹ -42	60	0	0.187		1715	2119
					1737	2249
					2091	2336
					2120	2377

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TABLE D-1 (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC ^a	LO ^b	HO ^c
XM-42	60	1.570	0.153	2455	2255	2176
				2473	2292	2494
XM-42	120	0	0.063			2491
					1191	2501
					1202	2506
					1204	
					1204	
XM-42	120	0	0.193			1279
					1457	1277
					1659	1289
					1704	1291
XM-42	120	1.570	0.188		1742	1368
					1754	1433
					1809	1503
					1836	1658
XM-42	240	0	0		1875	1828
					1909	1809
					1935	1926
					826	1935
XM-42	240	0	0		872	971
						992
						1030
XM-42	240	0	0			1033

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TABLE D-1 (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC ^a	LO ^b	HO ^c
X-42	240	0	0.125		972	1035
					975	1037
					1054	
X-42	240	1.570	0.125		963	1155
					992	1160
					1046	1166

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TABLE D-II (C). CLASSIFICATION OF RESULTS
30 Grain HD Fragments Versus Groups of XM-41
Sub-Missiles in Aluminum Containers (U)

Number of Rounds in Container	Container Size (Inches)			Configuration	Impact velocity (mps)	Results
	Length	Diameter	Wall Thickness			
6	5.70	3.44	0.125	Two layers of three each	2550	All rounds functioning high order
6	5.70	3.44	0.125	Two layers of three each	2488	All rounds functioning high order
14	5.70	8.75	0.125	Two layers of seven each	2040	All units functioning high order
14	5.70	8.75	0.125	Two layers of seven each	2577	All units functioning high order
14	5.70	8.75	0.125	Two layers of seven each	2583	All units functioning high order
14	5.70	8.75	0.125	Two layers of seven each	2608	All units functioning high order
14	5.70	8.75	0.125	Two layers of seven each	2079	All units functioning high order
14	5.70	8.75	0.125	Two layers of seven each	2691	All units functioning high order

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(CONFIDENTIAL) APPENDIX E

**Engineering Drawings of U.S. Artillery Projectiles,
Soviet Artillery and Rocket Projectiles,
U.S. and Soviet/CHICOM Mortar Projectiles (U)**

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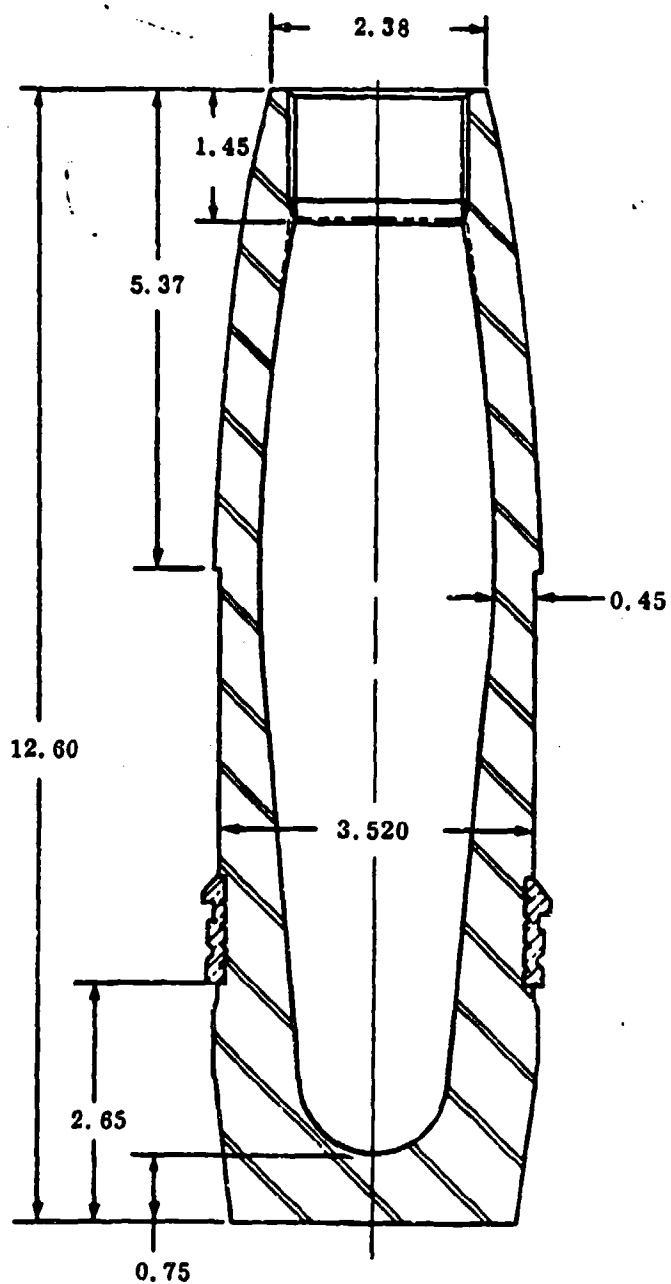


Figure E-1. Shell for U.S. 90mm Artillery Projectile

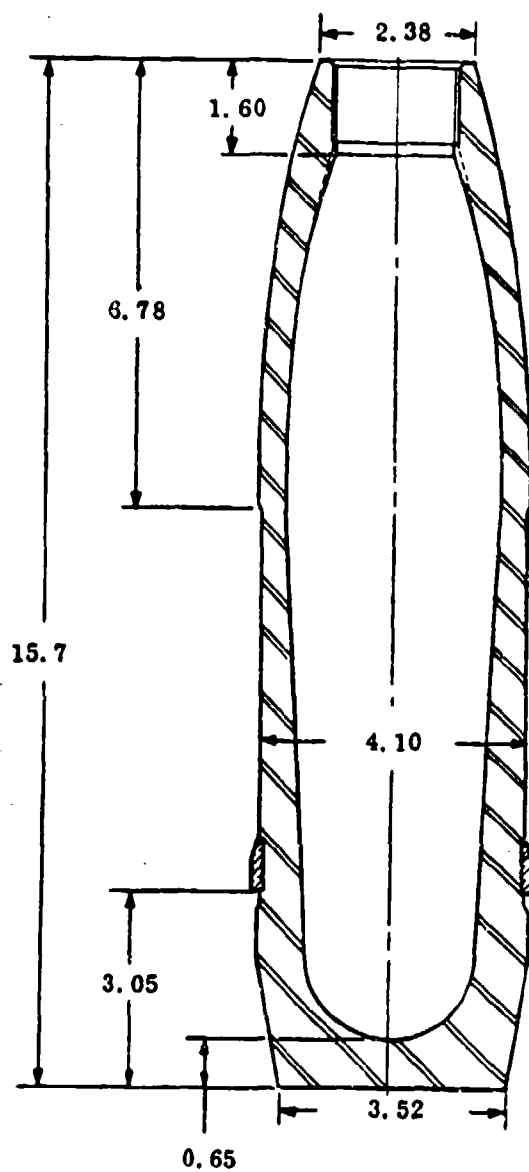


Figure E-2. Shell for U.S. 105mm Artillery Projectile

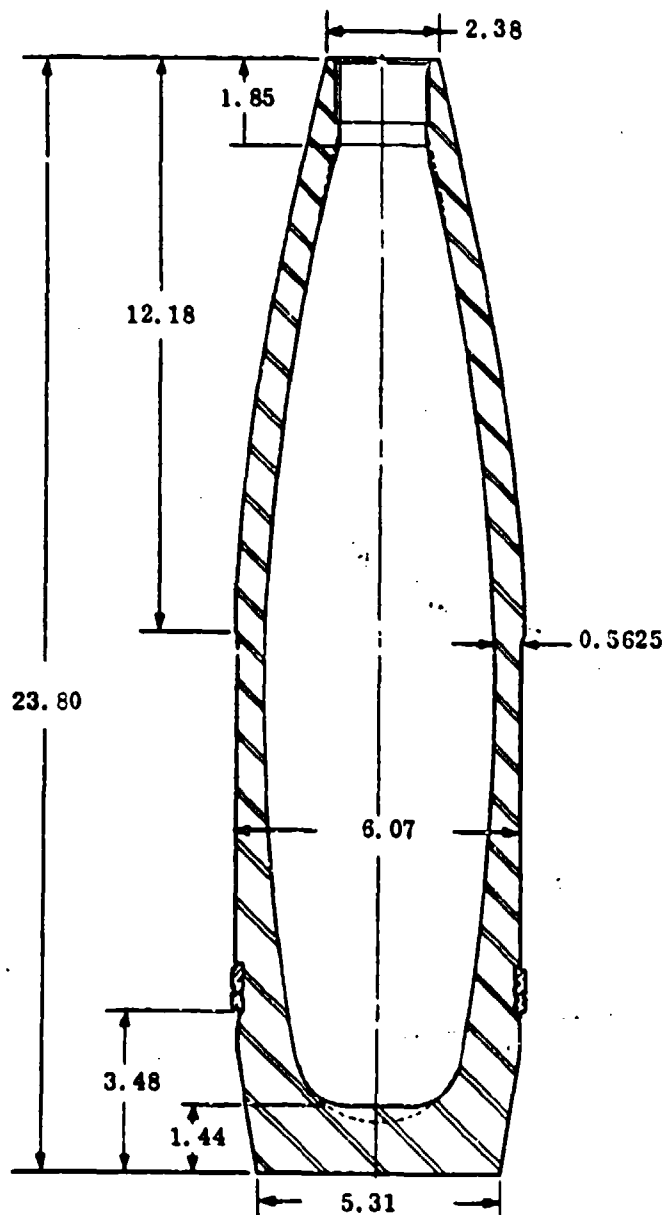


Figure E-3. Shell for U.S. 155mm Artillery Projectile

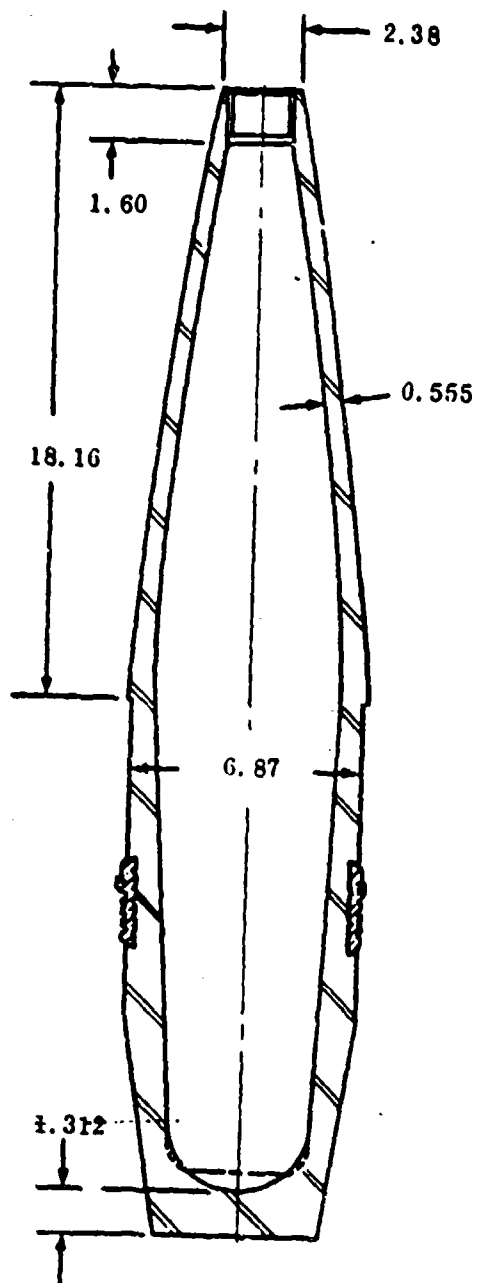


Figure E-4. Shell for U.S. 175mm Artillery Projectile

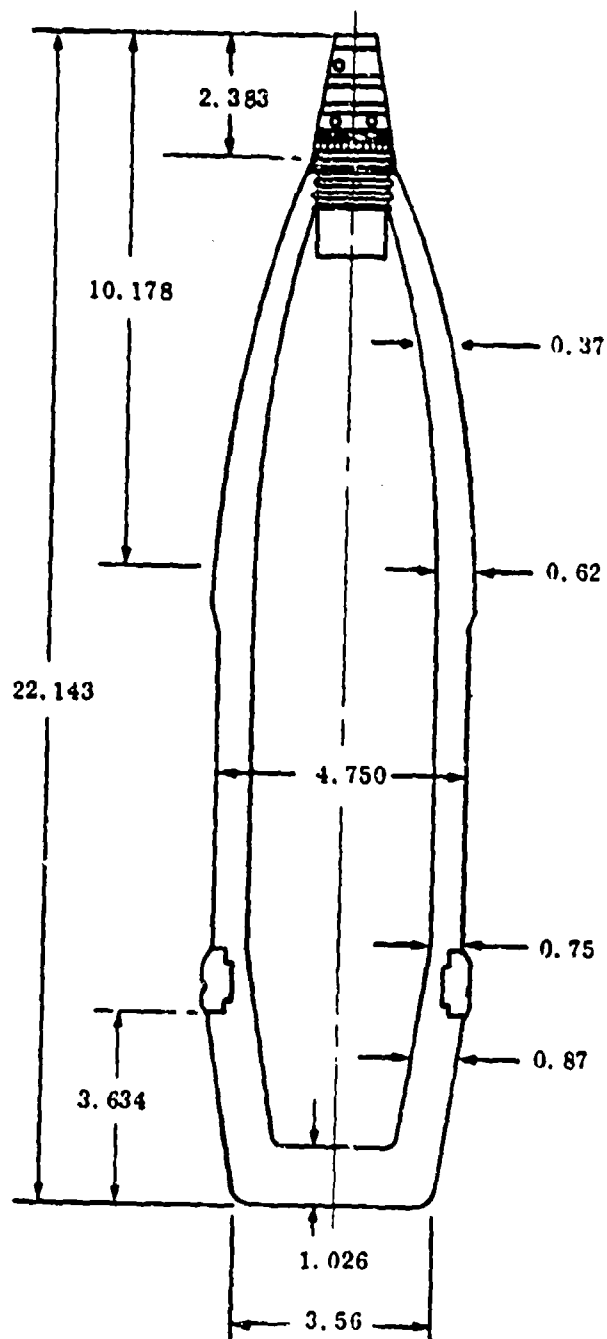


Figure E-6 (C). Shell for Soviet 122mm Artillery Projectile (U)

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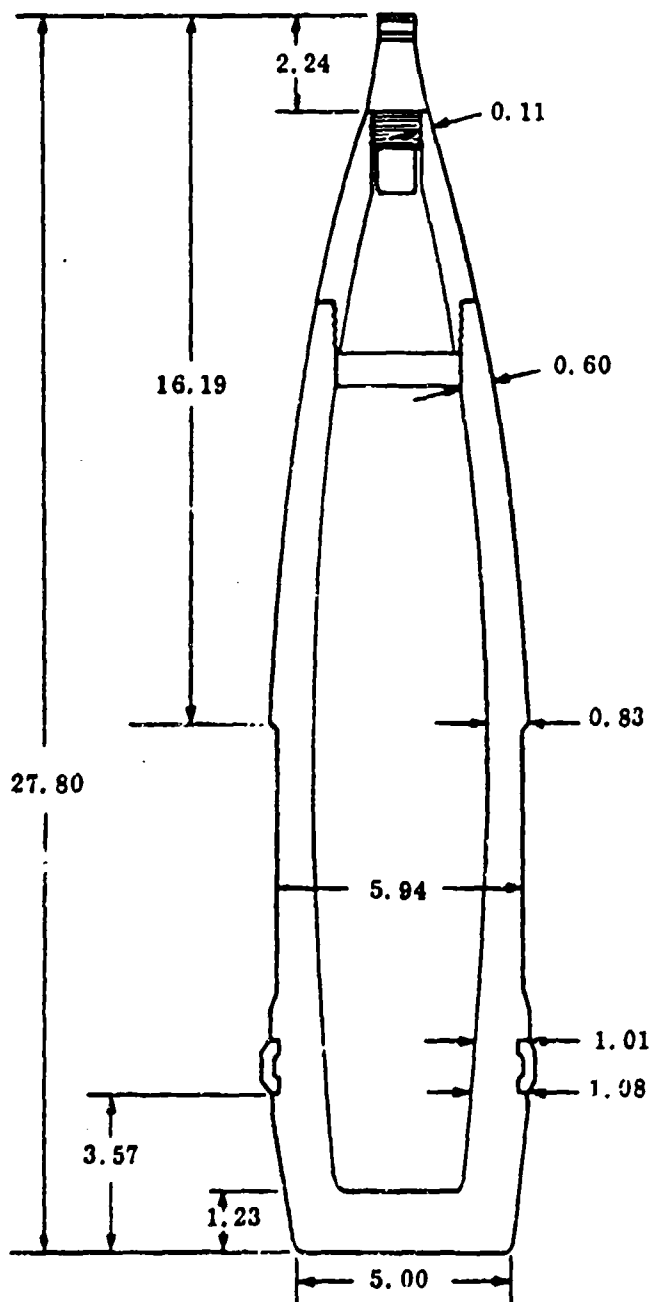


Figure E-7 (C). Shell for Soviet 152mm Artillery Projectile (U)

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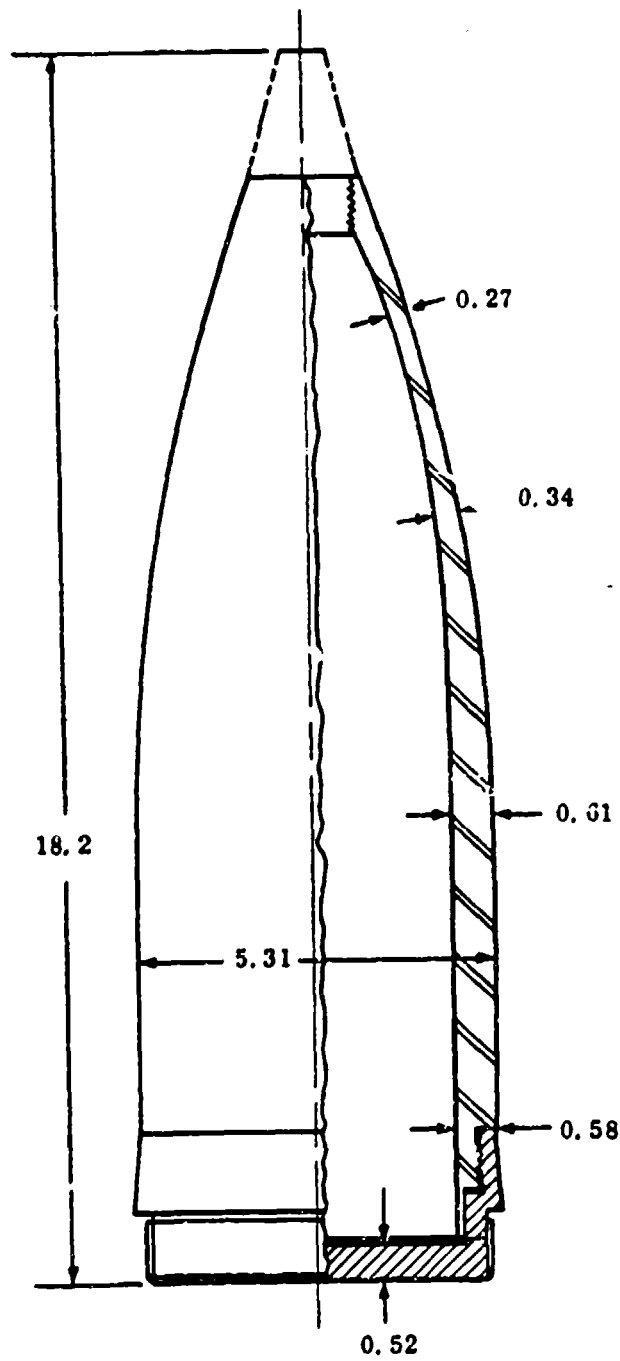


Figure E-8 (C). Shell for Soviet 140mm Rocket Projectile (U)

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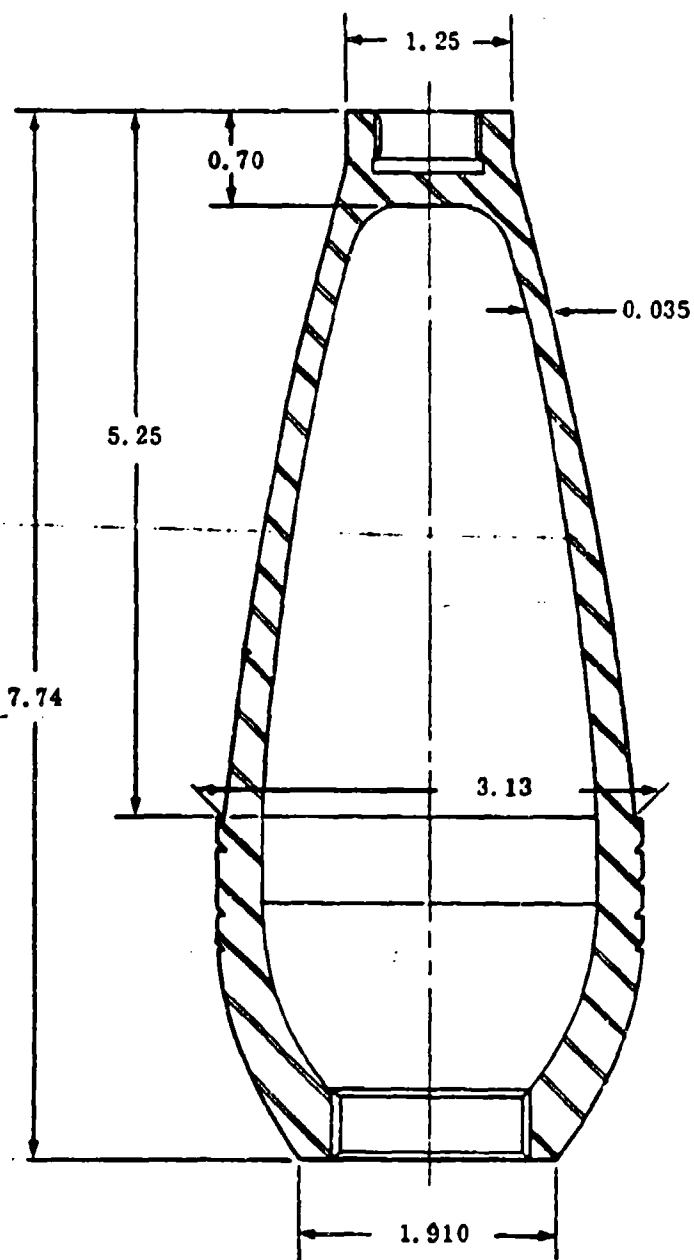


Figure E-9. (U) Shell for U.S. 81mm Mortar Projectile

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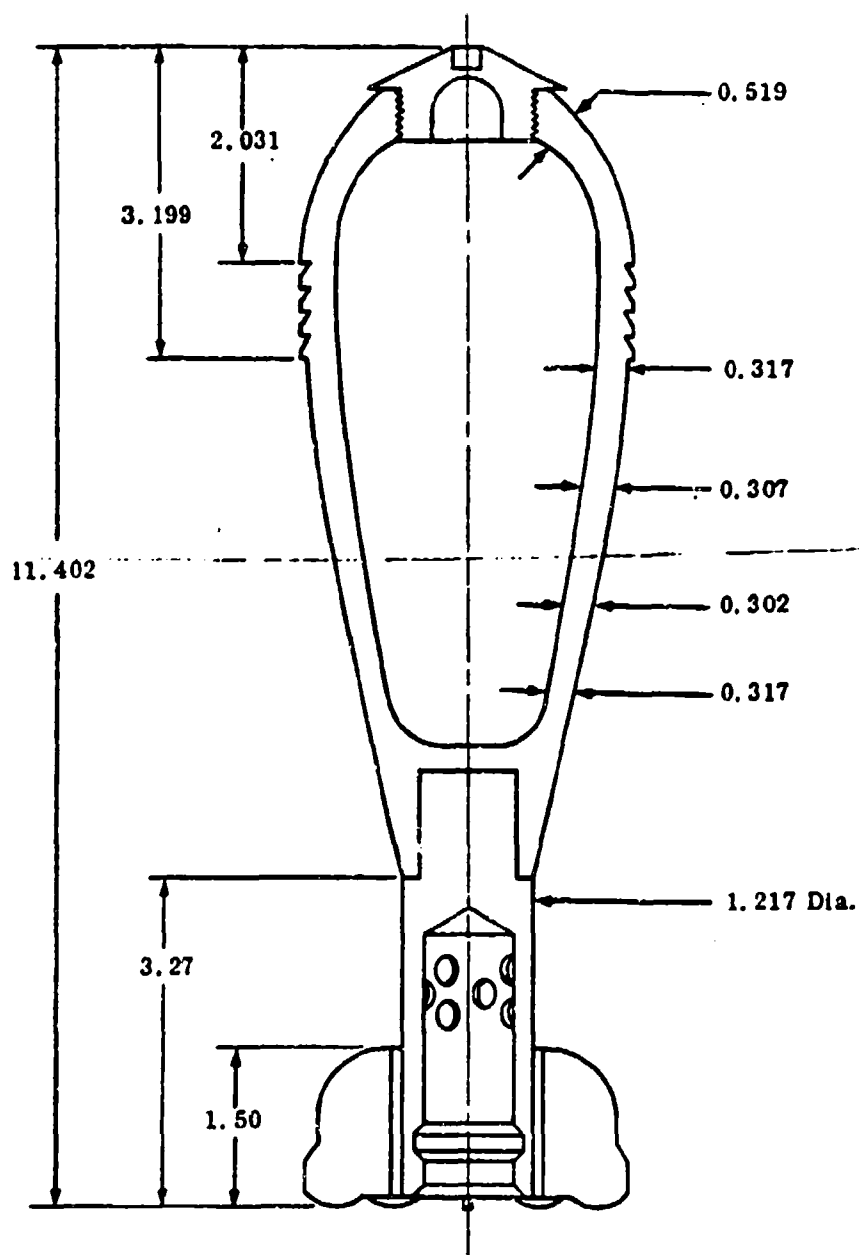


Figure E-10 (C). Shell for CHICOM 82mm Mortar Projectile (U)

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Security Classification

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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13. ABSTRACT Efforts to derive a satisfactory measure of the vulnerability of High Explosive munitions to steel fragment impact have been hampered by a lack of experimental data. In an attempt to remedy this deficiency, a number of tests have been carried out. (U) This report presents the results of tests of firings of steel fragments against U.S. 90mm, 105mm, and 175mm HE (Comp. B) artillery projectiles, Soviet 57mm HE (RDX/aluminum/wax) artillery projectiles, Soviet 122mm and 152mm HE (TNT) artillery projectiles, Soviet 140mm HE (TNT) rocket projectiles, U.S. 81mm and Soviet/CHICOM 82mm mortars (TNT), and a variety of U.S. Sub-Missile munitions. (U) These firing data were used to determine contributions of fragment striking mass and velocity required to initiate explosive reactions. (U)			

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