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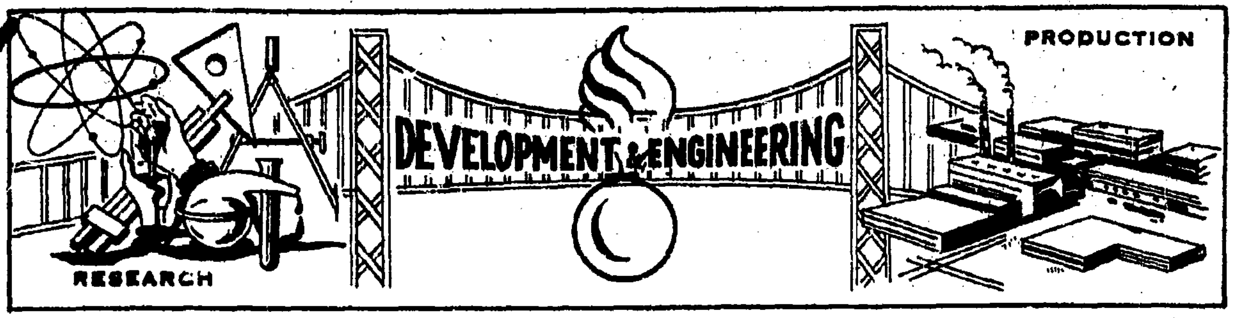

TECHNICAL REPORT
DB-TR: 6-60

SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT (U)

BY
RICHARD M. RINDNER
AND
STANLEY WACHTELL

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AMMUNITION GROUP
PICATINNY ARSENAL — DOVER, NEW JERSEY

SECRET

TECHNICAL REPORT

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BY
RICHARD M. RINDNER
AND
STANLEY WACHTELL

PROJECT NO. 70304231-19-46851-01

REPORT NO. DB-TR: 6-60

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SECTION I

INTRODUCTION

Two earlier reports on this overall program dealt with a consideration of transmission of detonation through blast effects (Reference 1) and through impact of fragments (Reference 2) resulting from the primary or subsequent secondary detonations. It was possible, on the basis of a large quantity of experimental and accident data amassed over the years, to establish a distance beyond which propagation would not occur assuming no missiles were produced by the donor explosion. It was also possible, on the basis of a good deal of experimental work done in Great Britain and in this country, to establish a basis on which we could calculate the gross mass-detonability characteristics of explosive systems (i. e., the possibility of mass detonation due to fragment impact occurring in cases of adjacent explosive systems made up of explosive-containing items) (Reference 3). In the large majority of the cases calculated, predictions based on the formulas presented in Reference 2 coincided with recommendations for handling given in the Ordnance Safety Manual (Reference 4) (these recommendations being based on experience or incidents which have occurred in manufacturing or loading plants, and storage depots).

Up to this point the studies relating to detonation by fragment impact were concerned primarily with development of what may be thought of as an initial screening procedure for determining whether or not a possibility of propagation of explosion due to fragment impact exists. For this purpose, the severest conditions were assumed, e.g., no consideration was given to the effects of distance of separation between the acceptor and donor, nor to shielding other than that which the acceptor supplies by virtue of its own minimum casing thickness. It is the intent of this third interim report to extend the fragment impact relationships to incorporate factors indicating the effects of (1) distance between donor and acceptor (2) probability of propagation and (3) supplementary acceptor shielding.

SECTION II

SUMMARY

Relationships are presented which permit the calculation of safe distances for prevention of propagation of detonation due to fragment impact between adjacent potentially mass-detonating systems for any assumed degree of risk and degree of acceptor shielding. These relationships permit prediction of probability of propagation in an existing situation, as well as calculation of necessary changes in acceptor shielding and/or separation distances for any other degree of tolerable risk. All that is necessary to develop the specific relationships for a given situation is knowledge of (1) properties of the explosives involved, and (2) geometry of the explosive system.

A simple method for graphically representing the relationships is presented, together with illustrative examples.

SECTION III

CONCLUSION

A procedure has been developed whereby, knowing the overall geometry of adjacent explosive systems which are potentially mass-detonating, as well as characteristics of the explosives involved, a relationship can be derived which correlates probability of mass-detonation occurrence with separation distance and degree of acceptor shielding. The methods involved are simple and practical and should prove to be very useful in designing any degree of safety into explosive manufacture and storage facilities.

SECTION IV

RECOMMENDATION

With respect to designing for prevention of propagation of detonation due to fragment impact, it is recommended that the methods outlined in this report be adopted for the calculation of at least the approximate degree of risk of such propagation occurrence in an existing situation, as well as an estimate of the changes in shielding and/or separation distances required for the desired degree of risk when this differs from the existing one. It should be noted that as results of confirmatory testing (which is anticipated in subsequent phases of the overall program) become increasingly available the reliability of the proposed relationships, or resultant modifications thereof, will become correspondingly greater.

SECTION V

STUDY

A. Technical Approach

If it is assumed that the propagation of detonation by fragment impact is a function of mass and velocity of the fragment, then the effectiveness of any fragment will decrease with increasing distance because of loss in velocity due to air drag. Previous studies (References 5, 6) have shown that this velocity loss may be expressed by the relationship:

$$V_s = V_o e^{\left(\frac{-k'R}{m^{1/3}}\right)} \tag{1}$$

where:

V_s = velocity of the fragment at any distance R from the detonation (ft. /sec.)

V_o = initial velocity of the fragment (ft. /sec.)

R = distance from detonation (ft.)

m = mass of fragment (oz.)

$$k' = \text{constant} = \left(\frac{A}{m^{2/3}}\right)(\rho_A)(C_D) \tag{1a}$$

A = presented area of fragment (in^2)

ρ_A = air density (oz/in^3)

C_D = drag coefficient

The method of determining the initial velocity and mass of fragments resulting from a particular explosion of a bomb, shell, warhead or any other configuration was given in Reference 2. This velocity is essentially a function of casing to explosive weight ratio, type of casing and explosive used, and is independent of the mass of the fragments produced. The mass distribution of fragments is calculated according to the Mott equations also outlined in (Reference 2).

In the evaluation of k', the shape of the fragment is of major importance in determining the presented area/mass ratio $\frac{A}{m}$ since for thin walled and heavy walled casings these could be different. For a sphere, $\frac{A}{m} = \frac{0.445}{m^{1/3}}$ while for a cube, $\frac{A}{m} = \frac{0.59}{m^{1/3}}$. For irregular fragments that are generally formed during an explosion, this value must be determined experimentally. According to Reference 5 the spread in $\frac{A}{m}$ values for actual fragments produced by detonation of a cased charge is not appreciable and has been shown to have an average value of $\frac{0.78}{m^{1/3}}$ for irregular mild steel fragments from bombs. The value of k' can then be computed if the drag coefficient and the density of air (taken at sea level and room temperature) are known. Air density is taken as .00071 oz. / cu. in. The supersonic drag coefficient was found to be 0.6 (Reference 5).

Thus $$k' = (.6)(.00071)\left[\frac{(.78)(12)}{m^{1/3}}\right] = \frac{.0039}{m^{1/3}}$$

K. S. Jones, in his reports, (References 7, 8, 9) has suggested the use of $k' = \frac{.0039}{m^{1/3}}$ for heavy case bombs and shell, and $k' = \frac{.0048}{m^{1/3}}$ for G. P. bombs and thin case items. For the purpose of the work presented herein in order to be conservative and to simplify calculations we have used $k' = \frac{.004}{m^{1/3}}$ throughout.

Once the initial velocity and mass of the fragments produced are known, the distance at which there is no chance of propagation of detonation to a particular acceptor can be calculated. To do this the mass of the largest fragment produced by the donor and the boundary velocity, (velocity below which high order detonation will not occur) corresponding to this fragment are first calculated as described in (Reference 2). These values are then substituted into equation (1), and R is calculated.

In an actual storage or manufacturing situation, the separation of items according to the distances calculated by the method outlined above might well be unrealistic from the standpoint of the amounts of real estate which would be required especially where thick cased and thin cased items are stored in the same area. To avoid this it becomes necessary to find methods of reducing these distances appreciably. This can be done in two ways, namely:

1. By inserting a shield in front of the acceptor and donor.

2. By accepting a specified degree of risk and a corresponding probability level of propagation. A combination of these two methods can also be used and will be presented here:

Let us consider a storage configuration in which a donor and an acceptor are "R" feet apart. A shield "t" inches thick is placed in front of the acceptor. (We are assuming for the purpose of discussion that we know which is the donor and which is the acceptor charge). For the purpose of simplifying the calculation, we assume, conservatively, that the shield becomes part of the acceptor casing and that the thicknesses are additive. From information which is available in Reference 2, we can calculate the size and velocity of the largest fragment produced by the donor. We can also calculate the probable number of effective hits (i.e., hits capable of causing detonation) at an acceptor at some distance R from an explosion:

$$P = \frac{(N_x)(A')(g)}{R^2} \quad \text{(2)(Reference 10)}$$

or the probable number of hits per unit area:

$$\frac{P}{A'} = \frac{(N_x)(g)}{R^2} \quad \text{(2a)}$$

The chance of at least one hit at the acceptor is

$$E = 1 - e^{-P} \quad \text{(3)}$$

where:

N_x = number of effective fragments

R = distance between donor and acceptor (ft.)

A' = presented area of acceptor (ft.^{2})

g = factor governing the spatial distribution of fragments.

It was found experimentally by Mott (Reference 10) that variations in the solid angle swept by fragments are not too great and that for bombs exploded on the ground a value of 0.1 can be used for (g) while for those exploded just above the ground a value of 0.16 is correct. In this report, an average value of 0.1 for (g) is assumed (see Appendix E). We can then form equation 2a for any explosive system in a specific environment, and make a plot of distance versus the probable number of hits, provided that we correct the number of effective fragments for each change in distance, since N_x is a function of distance. The method for calculating this is given under the next section of this report.

The relationships discussed above supply us with a method for prediction of probability of detonation propagation in a particular situation for different values of (R) and (t) or if we wish to specify a particular degree of risk we can find the conditions of (t) and (R) to achieve it. Although the examples included in this report are for donor and acceptor of the same type, it is also possible to perform these calculations for systems where the donor and acceptor are of different types.

B. Results

Based on results contained in Reference 2 on the mass detonability of certain explosive systems, an extension of the relationships for the effects of distance and shielding on reducing the chance of propagation of detonation due to fragment impact was made. The method now proposed indicates the limiting distance, or a limiting distance-shielding combination beyond which no high order detonation due to fragment impact would occur, as well as a means of establishing distances and/or shielding between any two or more explosive systems for any assumed degree of risk that can be tolerated in a particular situation.

Graphs shown in Figures 1-10 (Appendix C) were drawn by the procedure outlined in Appendix A for the purpose of calculating the smallest effective fragment formed during a high order detonation of donor charge and striking or boundary velocities at any distance-shielding combination. These graphs relate the striking (or boundary) velocity of a fragment (V_s, V_B) with fragment mass (m) at various distances (R) and acceptor casing thickness (t). By equating the striking velocity to boundary velocity it becomes possible to find the effective fragment of minimum mass produced by the donor explosive at any distance from the donor (R) and/or shielding of the acceptor(t). Hence, according to equation 3 in Reference 2 it is possible to calculate the total number of effective fragments (fragments which upon striking the acceptor charge will cause a high order detonation occurrence) produced at any distance from the donor charge. The graphs were drawn for TNT with initial fragment velocities ranging from 2,500 - 10,000 ft./sec. and for Cyclotol 60/40 with velocities of 3,000 - 8,000 ft./sec. Each curve represents a single initial fragment velocity (V_o) and a particular explosive sensitivity (K_f) and covers a distance range of 25 - 400 feet and an acceptor shielding range of 0 - 1.0 inches. For initial fragment velocities other than those indicated on the graphs a linear interpolation may be used. Similar relationships can be drawn for any mass-detonating system provided the sensitivity of the explosive involved (expressed in terms of the sensitivity constant K_f) is known.

Sample calculations for two simple explosive systems which are potentially mass detonating are shown in Appendix D. The relationships presented on these graphs relate the distance between the donor and acceptor charges (R), shielding (including the casing of the item) (t), and probability (E). The zero probability curve (E_o) represents the limiting relationship between the distance and shielding, beyond which no high order detonation is possible. The other lines on the graphs represent various probability levels related to the distance-shielding combinations in each individual case. The relationships presented on these graphs were based on the calculation of the probability of detonation due to fragment impact as a function of the number of effective fragments (obtained according to equation 3, and graphs 1 - 10), distance from the donor charge, and exposed area. Each graph was drawn for a single item only, considering the total number of effective fragments produced by the donor explosive and the presented area of the acceptor charge.

C. Discussion of Results

In developing the relationships presented in the preceding section of this report, the following conservative assumptions were made:

a. The calculations concerning the probability of high order detonation occurrence were made assuming fragment impact at the thinnest portion of the acceptor casing.

b. Presented area of a cylindrical acceptor charge was taken as the projected cylindrical surface, despite the fact that fragment impact is not normal along all portions of this surface.

In reality the probability of detonation occurrence due to fragment impact, according to Reference 11, is most likely to be much less than predicted by equation 2.

The blast effects in propagation of detonation were not considered in these calculations. As was pointed out in previous reports (Reference 1, 2) the blast effect at these distances is small when compared with missile effects. The situation might differ in cases where two explosive items are stored (or processed) in close proximity within one explosive system. In this event the effects of blast will have to be considered in addition to missiles.

Other simplifying assumptions made in calculating the distance-shielding probability relationship were:

a. The use of average presented area of the impacting fragment (equation 1).

b. Use of single value for "g" in equation 2.

c. Use of mild steel only as a shielding of the acceptor. For other materials than mild steel a relative value in relation to mild steel could be obtained experimentally.

As indicated previously, the illustrative examples presented in this report deal with donor and acceptor charges consisting of single items. In order to determine the effect between two or more stacks, containing a number of explosive items, the total exposed area of the stack (i. e., area which is vulnerable for an effective hit) as well as the total number of effective fragments (i.e., fragments having minimum effective mass as well as velocity) must be known. This will depend on the manner in which the items are stored or processed and the orientation of the stacks relative to one another. Therefore each case must be treated individually, using the relationships presented, to predict the potential propagation characteristics of an explosive system, as well as to establish a design basis for prevention of propagation.

D. Future Plans

Utilizing the relationships so far developed in this report and References 1 and 2, as well as results of confirmatory testing now in progress, a recently initiated study is being aimed at establishing means for decreasing these distances through use of barricades, substantial dividing walls and other protective structures. This phase of the overall program will deal with the effectiveness of protective walls against the propagation of explosion due to blast and missile impact in terms of wall geometry, material of construction and reinforcement. For purposes of preventing propagation, the wall will be considered expendable; however, where personnel and/or costly equipment are to be protected, design criteria for barricades to withstand blast and missile effects will be established.

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APPENDICES

APPENDIX A

PROCEDURE FOR CALCULATING THE PROBABILITY OF H. O. DETONATION

Procedure for Calculating the Probability of High Order Detonation Occurrence as a Function of Distance and Shielding

The following formulas are used in the calculation procedure and sample calculation which follow in pages A-4 and A-5 and Appendix B, respectively.

1. Fragment Initial Velocity (see Reference 2).

$$V_0 = \left[\left(\frac{E_I}{C}\right)(k')(f)\right]^{1/2}$$ Equation 1, Reference 2.

where:

$\frac{E_I}{C}$ = explosive weight to casing weight ratio (lbs.)

k' = constant designating explosive output.

f = factor depending on $\frac{E_I}{C}$ ratio (see Reference 2).

2. Number of fragments (see Reference 2).

$$\ln N_x = \ln\left(C' M_A\right) - \frac{m^{1/2}}{M_A}$$ Equation 3, Reference 2.

N_x = number of fragments with mass greater than m.

C' = fragment distribution constant which is defined by the equation

$$C' = \frac{C}{2M_A^3}$$ Equation 3b, Reference 2.

where:

C = total weight of initial casing.

M_A = fragment distribution parameter which is defined by an equation

$$M_A = (B)\left(t_{AV}^{5/6}\right)\left(d_i^{1/3}\right)\left(1 + \frac{t_{AV}}{d_i}\right)$$ Equation 3a, Reference 2.

where:

B = constant depending on explosive output.

d_i = average inside diameter of the ammunition item (in.).

t_{av} = average thickness of casing (in.)

3. The largest fragment is produced when

$$N_x = 1, \text{ or } \ln N_x = 0$$

then

$$m^{1/2} = (M_A) \ln (C' M_A) \qquad \text{Equation 4, Reference 2.}$$

4. Minimum striking velocity of a fragment of mass (m) to cause a high order detonation in the acceptor charge is equal to V_B.

$$V_B^2 = \frac{K_f e^{\left(\frac{5.37t}{m^{1/3}}\right)}}{m^{2/3}\left(1 + \frac{3.3t}{m^{1/3}}\right)} \qquad \text{Equation 5, Reference 2.}$$

where:

K_f = explosive sensitivity constant to fragment impact

t = thickness of casing of acceptor (at its thinnest portion)

m = mass of fragment

V_B = boundary velocity of a fragment

5. The velocity of a fragment after traveling a distance R equals:

$$V_s = V_o e^{\left(\frac{-k'R}{m^{1/3}}\right)} \qquad \text{Equation 1, page 9.}$$

where:

V_o = initial velocity of the fragment

R = distance from the donor (ft.)

m = mass of fragment (oz.)

k' = constant depending on air drag and presented area/mass ratio

= .005 for thin cased items

= .004 for heavy cased items

6. The probable number of effective hits

$$P = \frac{(N_x)(A')(g)}{R^2}$$ Equation 2, page 12

where:

A' = acceptor exposed area (ft.^{2})

N_x = number of effective hits

R = distance between donor and acceptor

g = factor governing distribution of fragments, equal to 0.1

7. The chance of at least one hit at the acceptor is

$$E = 1 - e^{-P}$$ Equation 3, page 12

Step 1

a. Calculate the initial velocity of the fragments using equation 1, Reference 2. For this initial velocity, prepare a graph (see Figures 1-10) relating velocity at distance R, mass of particle and the thickness of shielding. This can be done by utilizing equation 1 and either equation 4 or the graphs presented in Reference 2. First plot velocity as a function of missile mass at constant values of R (use equation 1); then plot boundary velocity as a function of missile mass for constant values of shielding (t), (use equation 4 or the graphs in Reference 2).

Figures 1-10 are used as follows: Each graph represents an initial velocity of missiles and an acceptor containing a specific explosive of known sensitivity (K_f). These graphs can be used to determine the thickness of shielding (or casing and shielding) required at any distance from a donor when the initial missile velocity and minimum effective fragment mass are known.

Step 2

To determine the probability of propagation in a particular situation,

a. Determine the minimum size of fragment at distance R which will be effective against the acceptor having casing thickness t. (Use a prepared graph as described in Step 1).

b. Calculate the number of fragments of minimum size or greater produced by the explosion using equation 3, Reference 2.

c. Calculate the probable number of effective hits which will occur for the situation under consideration from equation 2.

d. Calculate the chance of at least one effective hit using equation 3, Page 12.

e. Plot a graph relating the probability of detonation occurrence (E) versus distance (R) for constant shielding (t) lines.

f. Re-plot from (e) this relationship as distance (R) versus acceptor shielding (t) for lines of constant probability.

g. Calculate and plot on graph (f) a zero probability line (P = 0). This line is obtained for any R and t combination that will result in $N_x = 1$. (i. e., the largest fragment produced by the donor charge). This is the line beyond which no detonation is expected to occur.

APPENDIX B

SAMPLES FOR CALCULATING THE PROBABILITY OF H. O. DETONATION

Sample Calculations

Warhead T2021 assumed to be filled with 60/40 Cyclotol

1. The initial velocity of the fragment V_o = 7,800 ft./sec.
2. The largest fragment produced m_{max} = 3.203 oz.
3. The smallest effective fragment (at zero distance) m_{min} = 0.150 oz.
4. Number of effective fragments (at zero distance) N_x = 800.

All these calculations above were based on formulas developed in Reference 2.

5. Finding the smallest effective fragment for various distances such as 25, 50, 75, 100, 200 and 300 ft. from the detonation source. The smallest effective fragment at any of these distances is obtained for 2 different values of V_o (Figure 9 and Figure 10), (Appendix C) (for V_o = 7000 ft./sec. and V_o = 8000 ft./sec.) and then a linear interpolation of a V_o = 7,800 ft./sec. follows. The smallest effective fragment (m_{min}) for R = 25 ft. (V_o = 7000 ft./sec. and t = .1875 in. which is the minimum thickness of the warhead as an acceptor) m = .2302 m_{min} (at R = 25 ft. & t = .1875 in.) for V_o = 8000 ft./sec., m_{min} = .1802. Interpolating between these 2 values.

For V_o = 7,800 ft./sec., m_{min} = 0.19 oz.

The same procedure is followed for the remaining distances R (50, 100, 150, 200 and 300 ft.) and finding m_{min} from the graph.

6. The number of effective fragments at R = 25 ft.

$$\ln N_x = \ln (C' M_A) - \frac{m^{1/2}}{M_A} = 8.7 - 2.1 = 6.6$$

N_x = 720 fragments

The probable number of hits per unit area $\frac{P}{A} = \frac{(720)(.1)}{625} = 0.115$

the exposed area of a warhead A = 7.5 ft.^{2} and P = (0.115) (7.5) = 0.875

Thus the chance of at least one hit E

$$E = 1 - e^{-P} = 1 - \frac{1}{e^{0.875}} = 0.6$$

7. Find the smallest effective fragment at a shielding Δt = .2 in. This value is added to the original t of .1875 thus making it a total effective thickness of t + Δt = .3875. At the distances of 25 ft. (Figures 9 and 10 in the same manner as before) the smallest fragment m_{min} = .45 oz. The total number of effective fragments under these conditions is;

$$\ln N_x = 8.7 - \frac{.675}{.206} = 5.42$$

Then N_x = 260. Proceed in the same manner for Δt = .4 and Δt = .6. The chance of at least one effective hit E (for 25 ft. distance and Δt = .2 in.)= 0.32

The complete results for this item for the conditions of R = 25 to 300 ft. and mild steel shielding for 0 - .6 in. are plotted on Figure 11 in the Appendix D of this report.

APPENDIX C

FIGURES 1-10

RELATING FRAGMENT MASS
WITH STRIKING VELOCITY

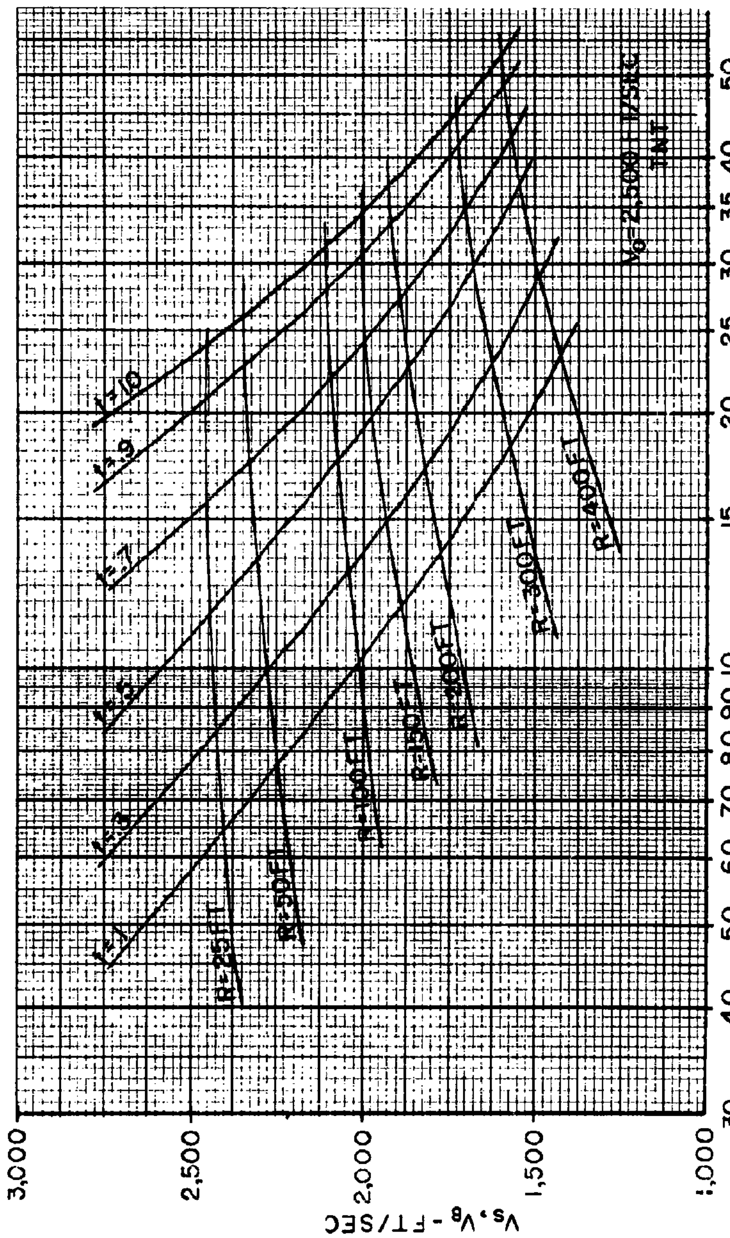


Figure 1. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

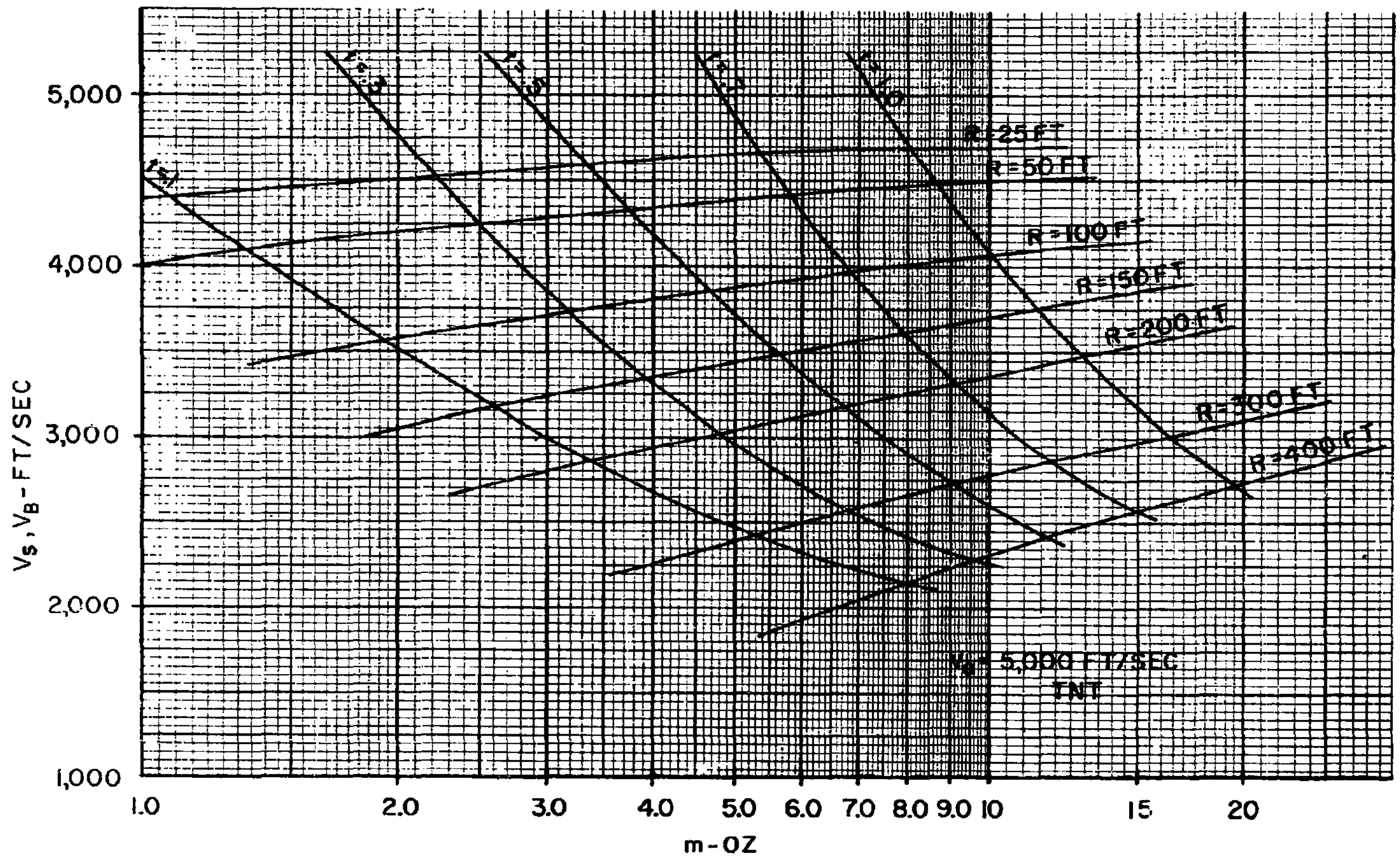


Figure 2. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

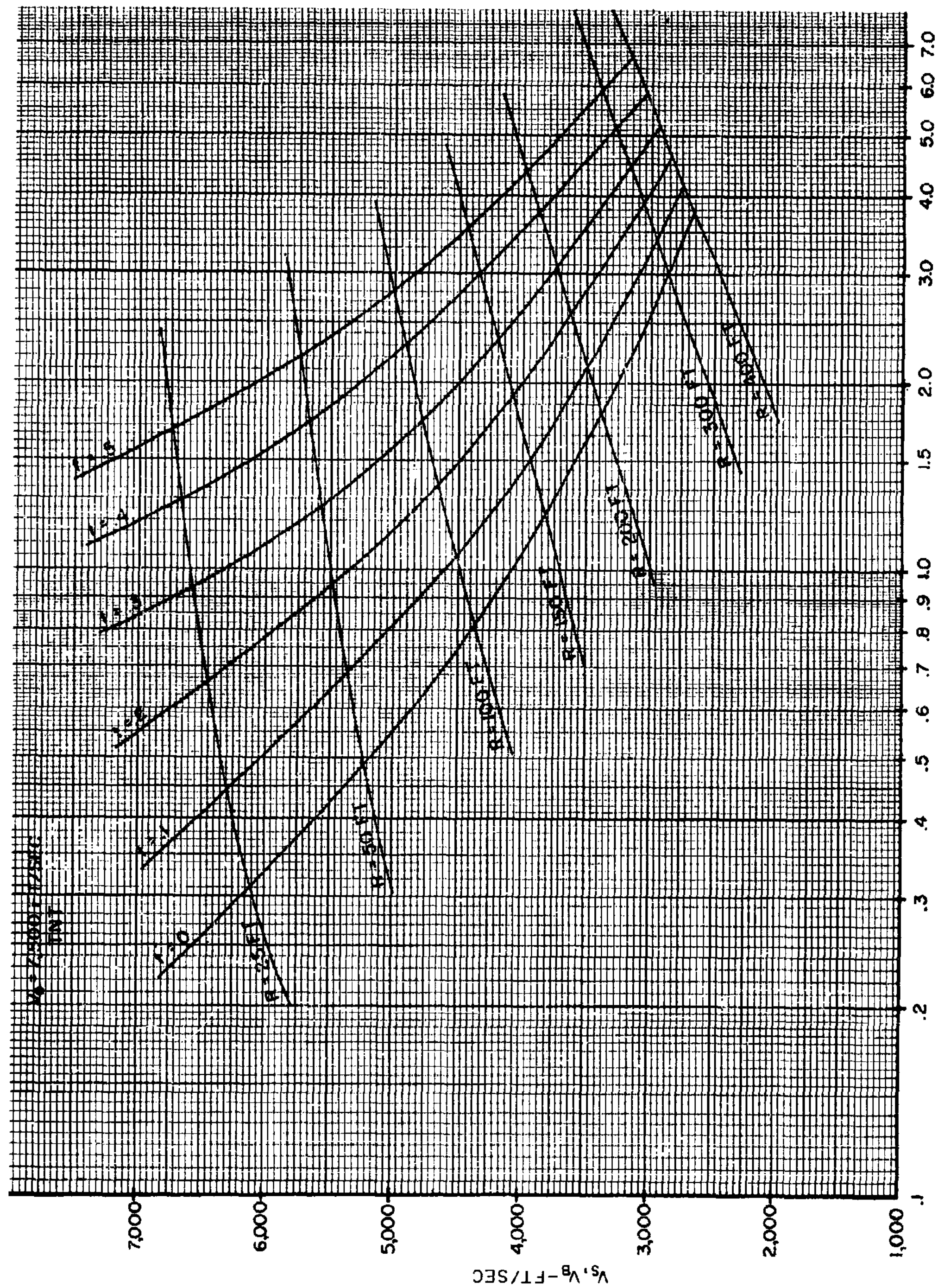


Figure 3. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

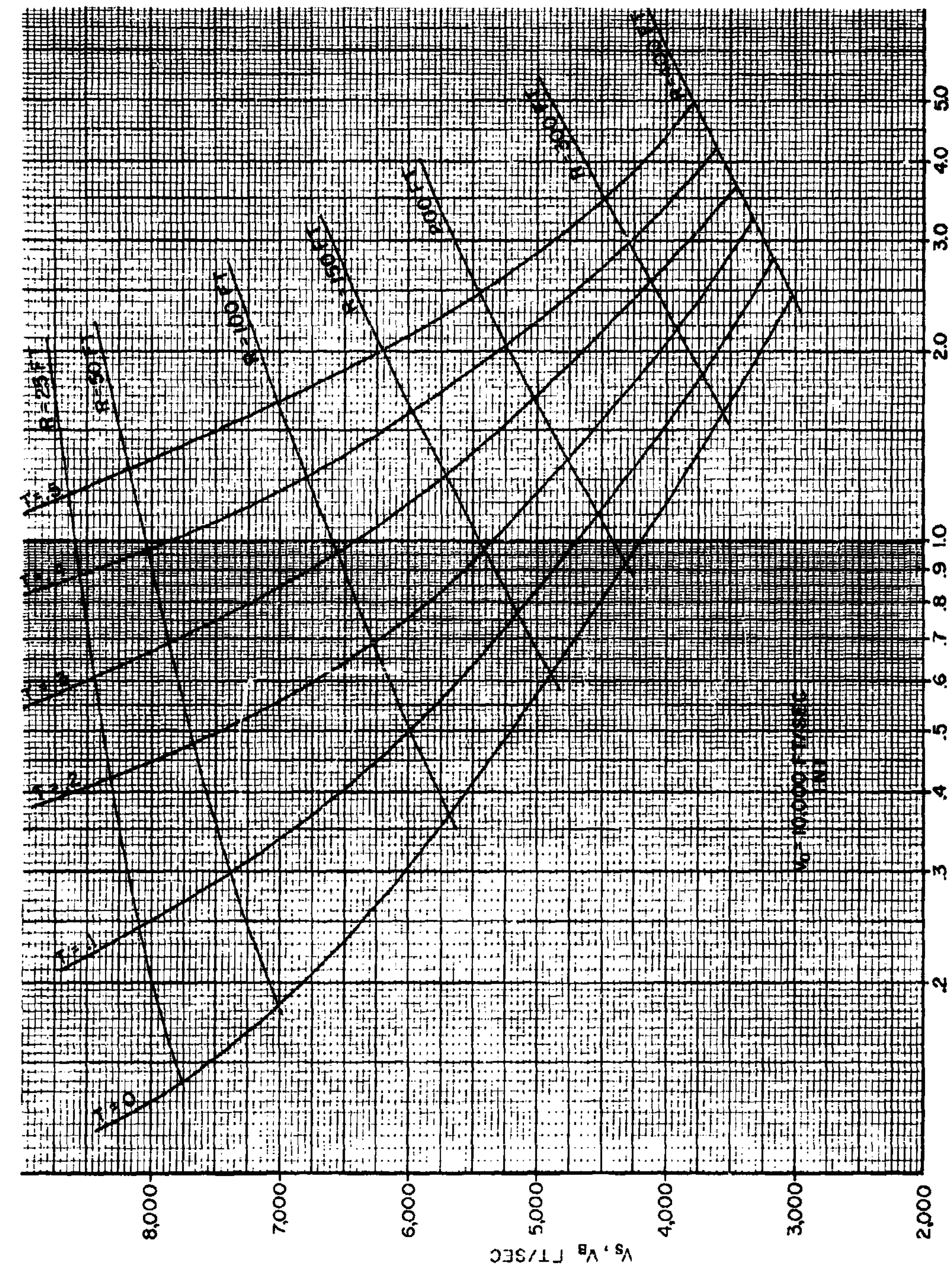


Figure 4. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

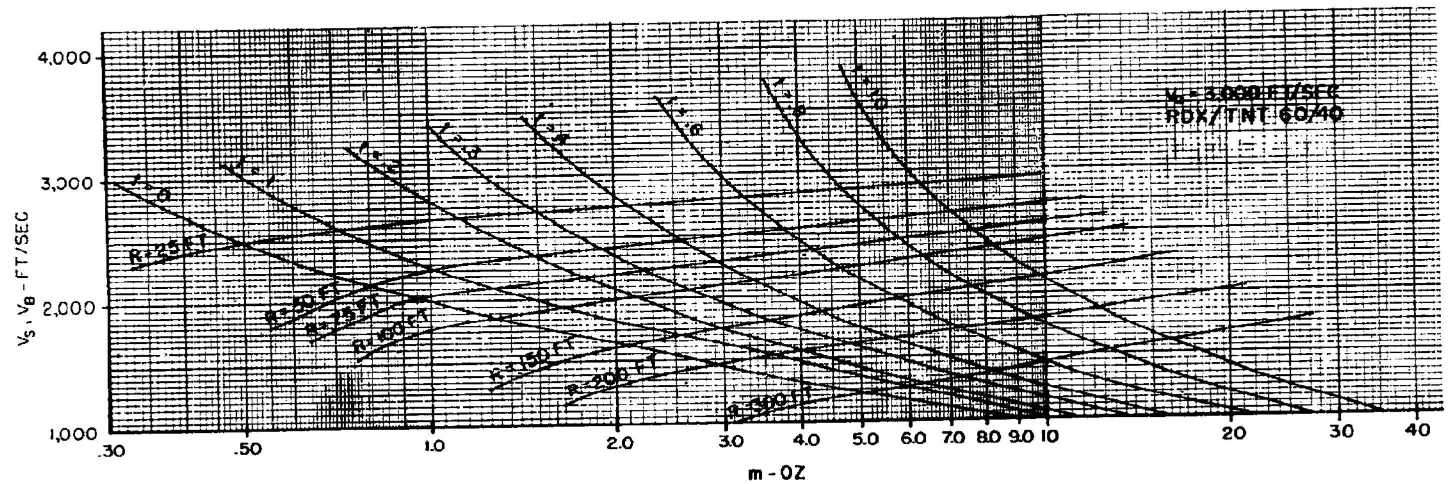


Figure 5. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

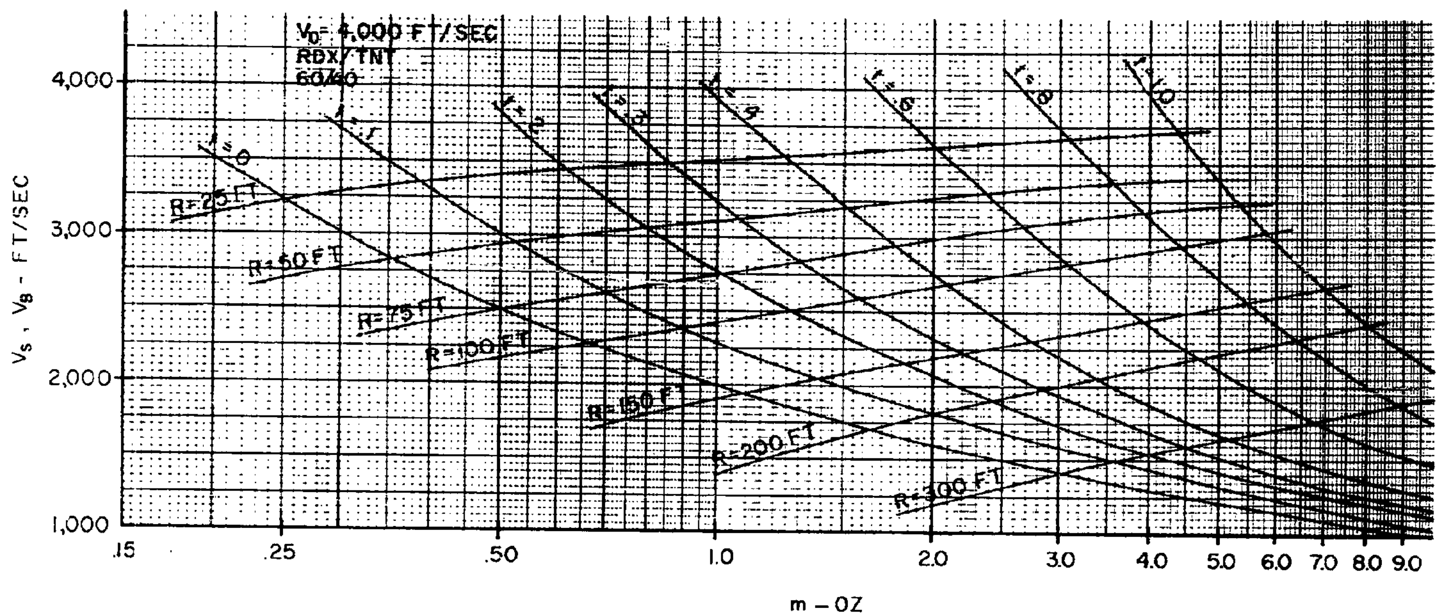


Figure 6. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

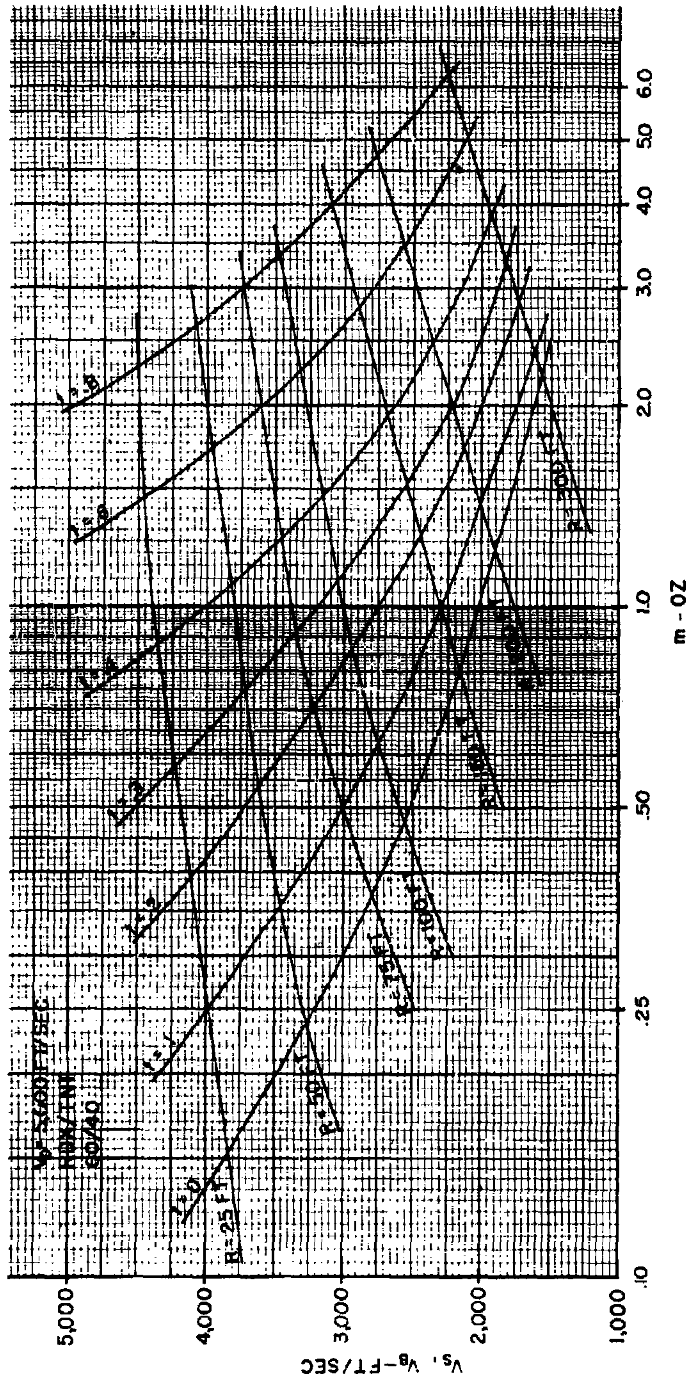


Figure 7. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

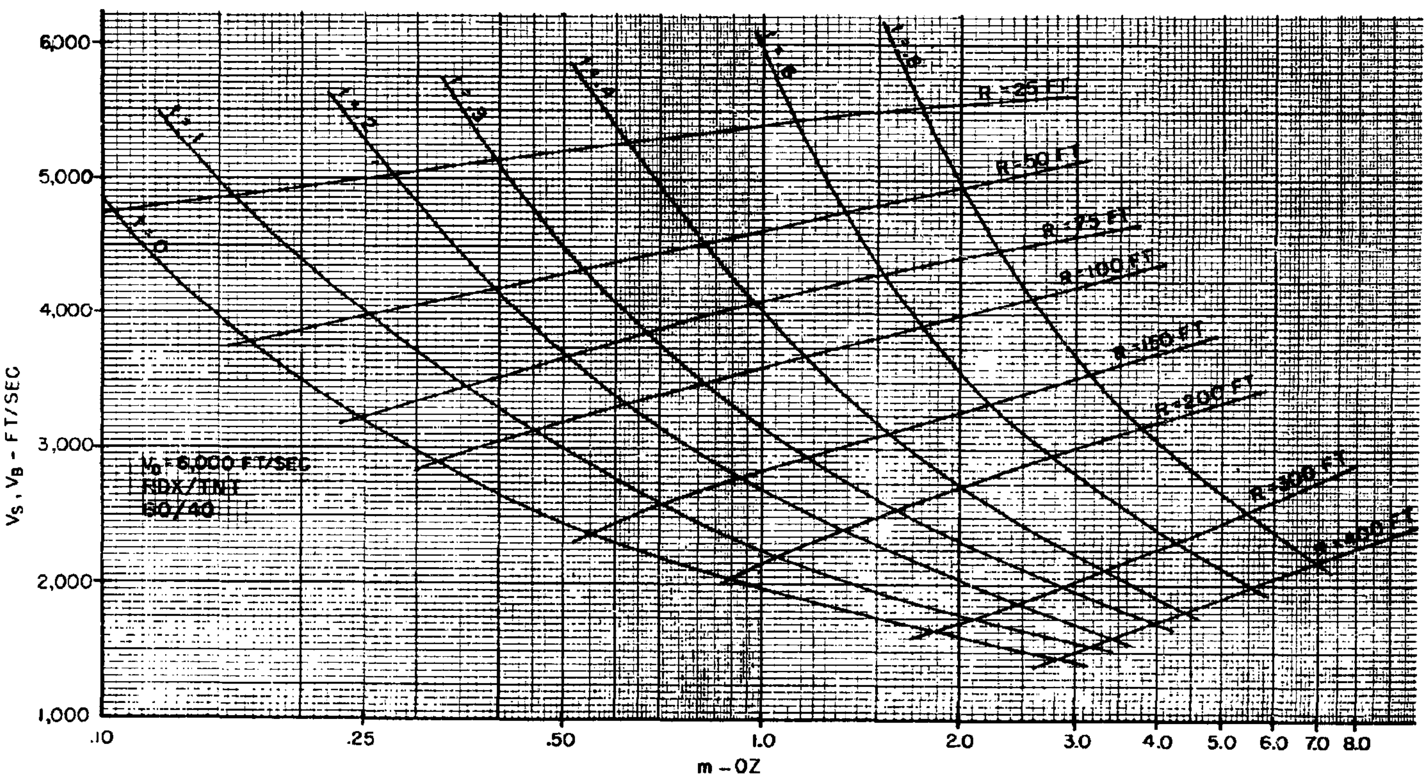


Figure 8. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

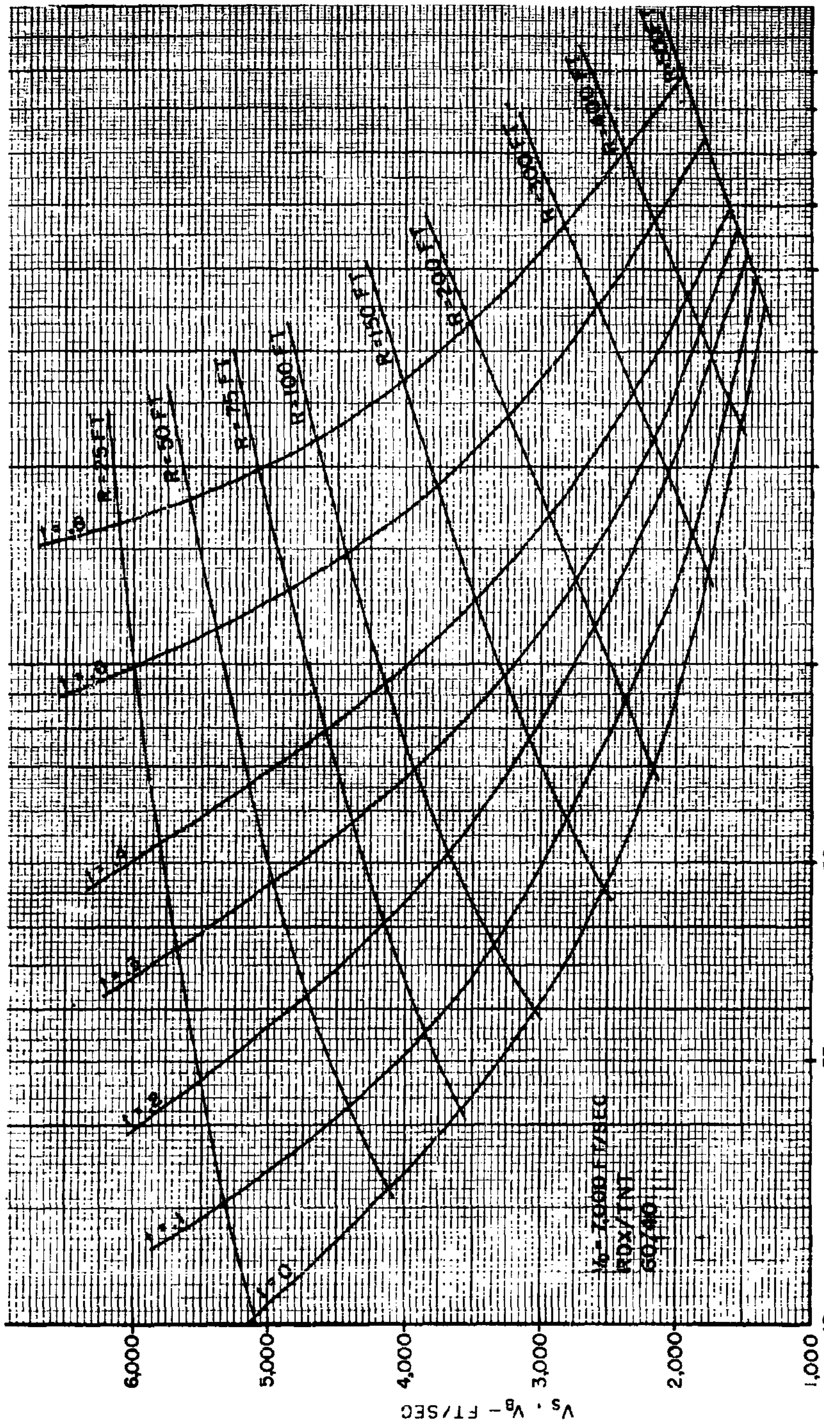


Figure 9. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

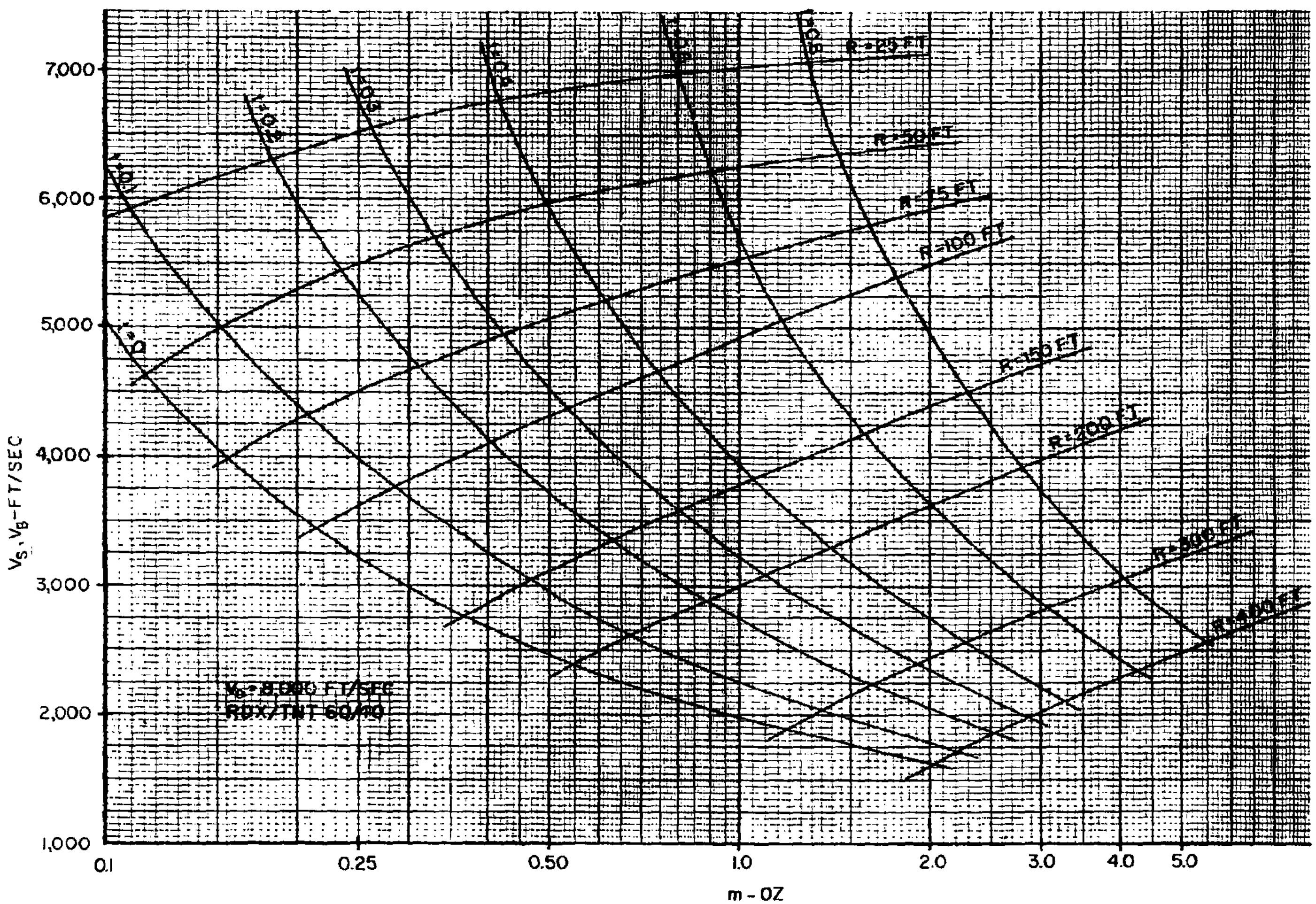


Figure 10. Fragment Mass (m) vs Striking or Boundary Velocity (V_S or V_B) at Various Distances (R) and Acceptor Shielding (t).

SECRET

APPENDIX D

TABLES 1-2

NUMBER OF EFFECTIVE
FRAGMENTS AND PROBABILITY

FIGURES 11-14

MASS OF FRAGMENT, SHIELDING
AND PROBABILITY RELATIONSHIPS

Table I

Number of Effective Fragments and Probability of Propagation of Detonation as a Function of Distance from the Donor and Acceptor Shielding.

Warhead Blast T2021 assumed to be filled with 60/40 Cyclotol

a. Number of Effective Fragments

R \ t	0	0.2	0.4	0.6
25	670	260	75	20
50	500	170	50	15
100	250	80	28	7
150	115	38	13	3
200	60	16	5	1
300	10	3	1	--

b. Probability of Propagation of Detonation

R \ t	0	0.2	0.4	0.6
25	.6	.32	.09	.026
50	.15	.05	.015	.0045
100	.018	.006	.002	.0005
150	.005	.0012	.0005	.0001
200	.001	.0003	.0001	---
300	.0008	---	---	---

Table II

Probability of Propagation of Detonation as a Function of Distance from the Donor and Supplementary Acceptor Shielding.

4.5 inch Rockethead

R \ t	0	.05	0.1	0.15	0.2	0.3
25	1.9×10^{-3}	1.4×10^{-3}	8×10^{-4}	4.5×10^{-4}	3×10^{-4}	0
50	2.5×10^{-4}	1.8×10^{-4}	10^{-4}	5×10^{-5}	10^{-5}	-
75	5×10^{-5}	3×10^{-5}	2×10^{-5}	8×10^{-6}	0	-
100	1.2×10^{-5}	8×10^{-6}	0	-	-	-
120	0	-	-	-	-	-

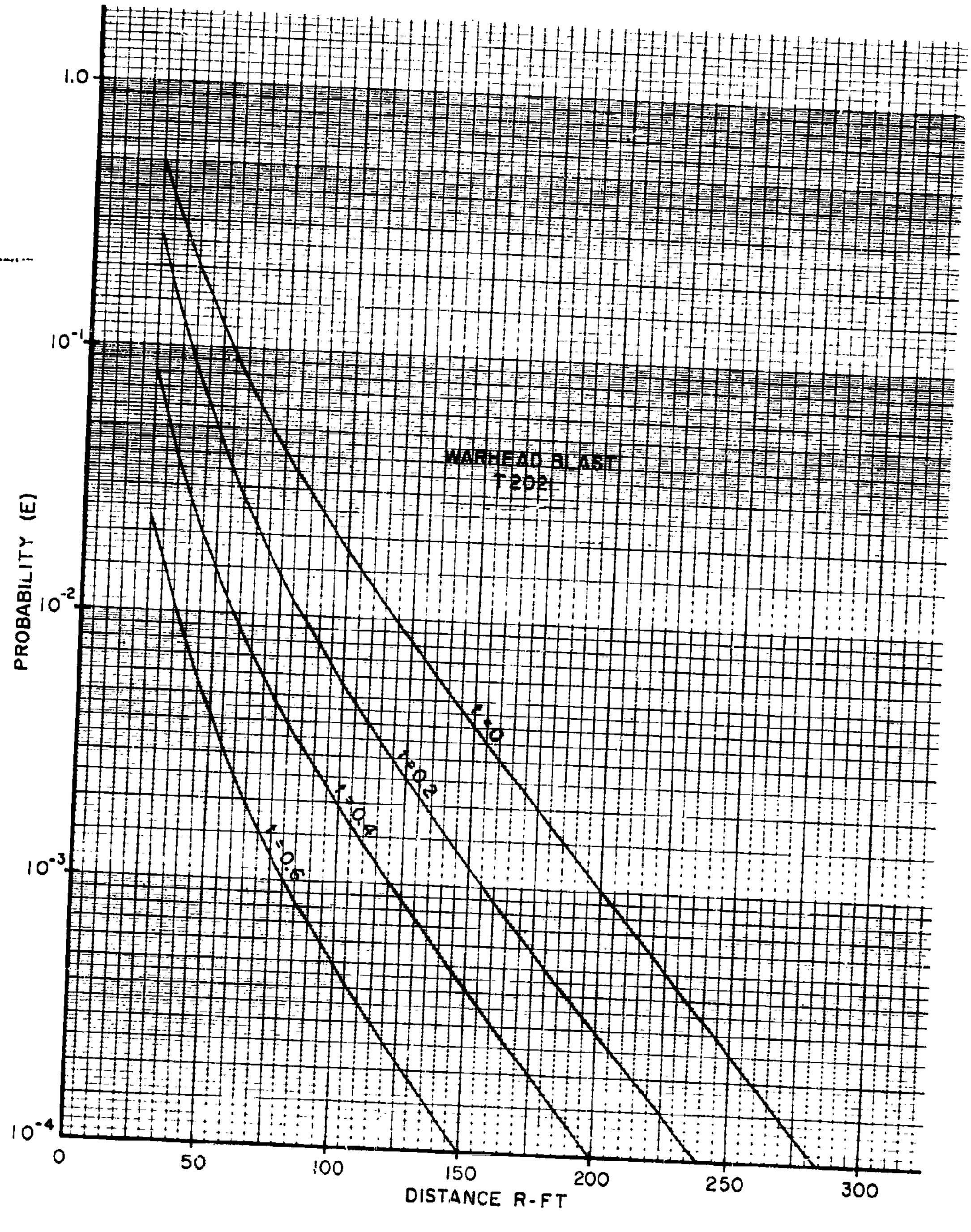


Figure 11. Probability of Propagation of Detonation vs Distance from the Donor at various Acceptor Shieldings.

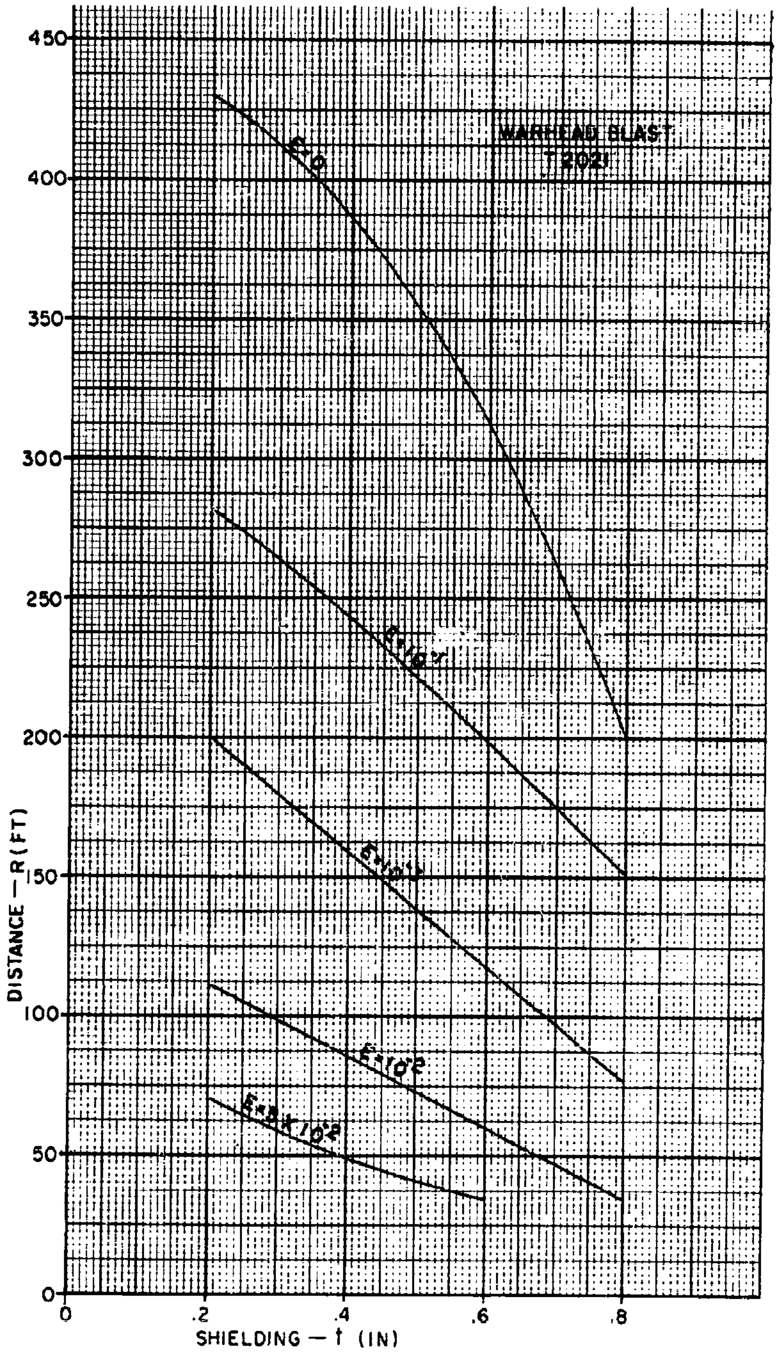


Figure 12. Supplementary Shielding vs Distance at Various Probabilities of Propagation of Detonation.

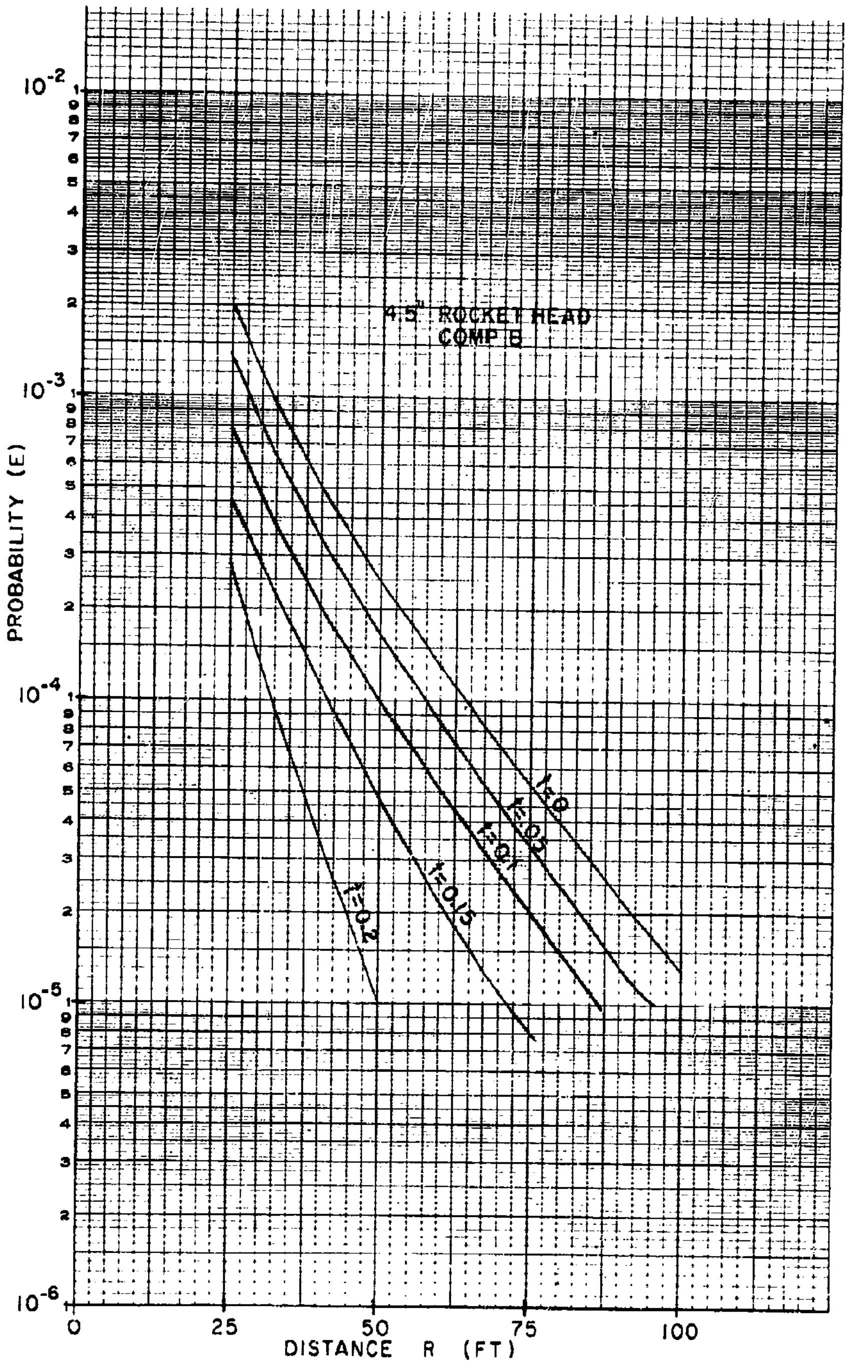


Figure 13. Probability of Propagation of Detonation vs Distance from the Donor at various Acceptor Shieldings.

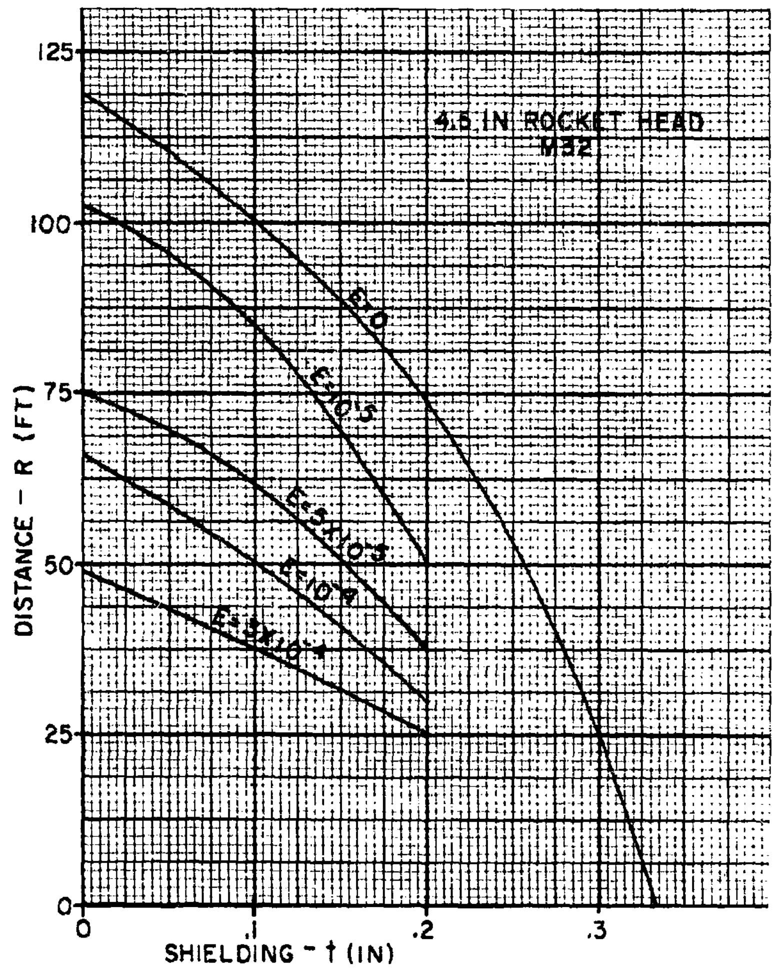


Figure 14. Supplementary Shielding vs Distance at Various Probabilities of Propagation of Detonation.

APPENDIX E

DERIVATION OF THE VALUE OF (G)

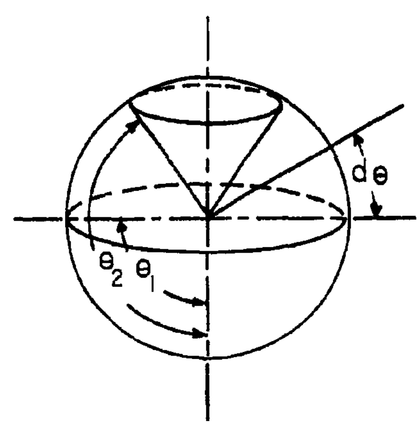
Derivation of value of (g)

The formula was derived in the following manner:

If it is assumed that the distribution of fragments from a source of explosion is equal in all directions, then the probable number of hits at the acceptor face at distance R from the donor is equal to:

$$\frac{P}{A} = \frac{N_x}{4\pi R^2} \qquad (3a)$$

In other words it is directly proportional to the number of effective fragments over the entire surface of a sphere at the distance of a radius R between the explosion source and the acceptor charge. This formula, as defined in the equation, assumes a uniform distribution of fragments in all directions. In this case the factor governing the distribution of fragments (g) is equal to $\frac{1}{4\pi}$. Actually this is not the case. The fragments lie in a spherical zone which is defined by the angles θ_1 and θ_2 where θ represents the angle between the longitudinal axis of the explosive system and the radial boundary of the fragment pattern (i. e. by the solid angle Ω).



This solid angle Ω corresponding to the angle θ can range in value from $0-4\pi$.

This solid angle Ω is equal to:

$$2\pi \int_{\theta_1}^{\theta_2} \sin\theta \, d\theta \quad \text{or} \quad 2\pi \left[\cos\theta_1 - \cos\theta_2\right]$$

The factor (g) is equal to: $\frac{1}{\Omega}$ or $\frac{1}{\left[2\pi \cos\theta\right]_{\theta_1}^{\theta_2}}$

Thus depending on the angle swept by fragments, (g) will vary depending on conditions such as type and shape of explosive confinement and whether the confined explosive is located on the ground or just above the ground. It was found experimentally (Reference 10) that the variations in the angle swept by fragments are not too great and that a constant value for (g) can be used. Reference 10 uses (g) = .16 for bombs exploded just above the ground and g = 0.1 for explosive detonated on the ground. Throughout this report the value of 0.1 is used for (g).

GLOSSARY OF TERMS

V_s - Striking Velocity of Fragment (ft./sec.)

R - Distance from Detonation (ft.)

m - Mass of Fragment (oz.)

k' - Constant Designating Air Drag and Fragments Presented Area

A - Presented Area of Fragment (in.^{2})

ρ_A - Air Density (oz./cu. in.)

C_D - Air Drag Coefficient

A' - Presented Area of the Acceptor (ft.^{2})

P - Probable Number of Effective Hits

N_x - Number of Effective Fragments

g - Factor Governing the Spacial Distribution of Fragments

E - Probability of at Least One Effective Hit

V_o - Initial Velocity of Fragments (ft./sec.)

V_B - Boundary Velocity of Fragments (ft./sec.)

B - Constant Designating an Explosive and Casing Material

C - Weight of Metal Casing (oz.)

d_1 - Inside Diameter of the Donor (in.)

d_o - Outside Diameter of the Donor (in.)

E_1 - Weight of Charge (oz.)

f - Factor Depending on $\frac{E_1}{C}$ ratio

GLOSSARY OF TERMS (Cont'd)

k - Constant Designating Explosive Output

K_f - Constant Designating Explosive Sensitivity

M_A - Fragment Distribution Parameter

t_{AV} - Average Thickness of the Metal Casing in the Do

t - Thickness of the Casing of the Acceptor (in)

C' - Constant in the Fragment Distribution Formula