TECHNICAL MEMORANDUM 1066

# SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT

LEON W. SAFFIAN

COPY NO. 20 OF 43

APRIL 1963



PICATINNY ARSENAL
DOVER, NEW JERSEY

TECHNICAL MEMORANDUM 1066

AMMUNITION GROUP

# SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT

BY

LEON W. SAFFIAN

APRIL 1963

REVIEWED BY: D. Katz
D. KATZ
Chief, Process
Engineering Laboratory

APPROVED BY: S Fleischnick
J. J. MATT
Chief, Ammunition
Production & Maint.
Engineering Division

PICATINNY ARSENAL
DOVER, NEW JERSEY

# TABLE OF CONTENTS

## FOREWORD

The material in this report was the subject of a presentation made to the Explosive Safety Seminar on High Energy Propellants at Redstone Arsenal, Huntsville, Alabama on 12-14 July 1960.

## ABSTRACT

Relationships are outlined 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 relationship for a given situation is knowledge of properties of the explosives involved and geometries of the explosive systems. A simple method for graphically representing the relationships is presented.

## SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT

At last year's Explosives Safety Seminar, conducted at the Naval Propellant Plant, a paper was presented outlining the various phases of Picatinny Arsenal's Safety Design Criteria program. This work dealt with a consideration of propagation of detonation by blast effects and by fragment effects. It was possible on the basis of experimental and accidental data amassed over the years to establish a distance beyond which propagation would not occur, assuming no effective 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). In the large majority of the actual cases calculated, predictions as to mass-detonability coincided with recommendations for handling given in the Ordnance Safety Manual, 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 not to shielding other than that which the acceptor supplies by virtue of its own minimum casing thickness. Since the general relationships involved were outlined in some detail at the last Safety Seminar, I will review them only briefly at this time.

(Figure 1)

Equation 1 permits us to calculate the initial velocity of fragments as a function of explosive output and charge to casing weight ratio.

Equation 2 gives us the number of fragments larger than mass (m) as a function of (m), donor casing weight, thickness and inside diameter, and an explosive constant (B).

Equation 2a gives us the mass of the largest fragment produced by the donor detonation as a function of donor casing weight, thickness and inside diameter, and explosive constant.

Equation 3 gives us the boundary velocity, or striking velocity below which no detonation in the acceptor will occur, as a function of acceptor casing thickness, fragment mass and acceptor explosive sensitivity constant ($K_f$).

Finally equation 3a gives us the minimum boundary velocity required for detonation of given acceptor by fragment from a given donor as a function of explosive sensitivity constant ($K_f$), acceptor casing thickness and the mass of the largest fragment produced by the explosion of a given donor.

The ratio of $V_o/V_{b_{min}}$ (Figure 1) serves as a criterion for predicting the gross mass detonability characteristics of explosive systems. If this ratio is smaller than 1, then the detonation by fragment impact will not occur. On the other hand if this ratio of initial velocity to boundary velocity is equal to or larger than 1, then there is a possibility of detonation by fragment impact.

It is the intent of this presentation to go further into a primary objective of our studies, which is to develop relationships to permit the calculation of safe distances in terms of probability of high order detonation occurrence or risk of propagation of detonation by fragment impact at these distances. Having calculated such probability factors (e.g. striking probability of fragments) we could then establish design distances depending on the degree of risk, if any, that can be tolerated, as well as acceptor casing and/or supplementary shielding.

For the sake of simplicity and convenience of graphical representation of these relationships was set up, which is shown schematically on the next series of figures.

The plot presented on Figure 2 is based on equation 4. It relates fragment striking velocity ($V_s$) with fragment mass (m) at any distance from the detonation source (d) (constant distance lines - $d_m$ being limiting distance at which detonation will occur). Each plot is made for a single value of initial velocity of donor fragments ($V_o$). A series of plots like the one presented on Figure 2 can be prepared for different values of ($V_o$). The constant (k) is a function of the presented area to fragment mass ratio, density of air, and air drag coefficient.

Although it was found experimentally that the (k) value is somewhat higher for thin cased items than for heavier cased ones (the difference being about 20%) (Ref 1), the variations within each one of these general categories are comparatively small (Ref 2).

While Figure 2 indicates the velocity of the fragments at any particular distance from the donor, Figure 3 is a schematic representation of equation 3 which tells us what minimum velocity a fragment must have in order to detonate a given acceptor separated from the donor by that distance.

This plot relates the boundary velocity (minimum striking velocity at which a high order detonation will occur) with fragment mass (m) and acceptor casing thickness ($t_a$) and/or thickness of shielding in front of acceptor charge.

The graph is plotted for a single explosive sensitivity (expressed in terms of the sensitivity constant ($K_f$), discussed previously).

When we combine the plots from Figures 2 & 3 as shown on Figure 4 we obtain useful relationships. Figure 4 relates striking velocity (or boundary velocity) of a fragment with fragment mass at various distances (d) and acceptor casing thickness ($t_a$). If we now equate the boundary velocity of a fragment to its striking velocity, it becomes possible to find the minimum effective mass of a fragment produced by the donor explosive that will cause a high order detonation in the acceptor charge at any distance from the donor (d) and/or shielding of the acceptor (t). Therefore, according to equation 2 we can calculate the number of such effective fragments produced at any distance from the donor charge.

It is of interest to note the limiting case which is shown by equation 4a on Figure 4. This indicates the maximum distance ($d_m$) at which propagation by fragment impact can occur for a given donor - acceptor situation. This is the distance at which the largest fragment ($m_{max}$) produced by the donor strikes the acceptor at the minimum velocity ($V_{b_{min}}$) required for detonation. It should be noted further that in terms of probability of acceptor detonation this is a boundary situation representing minimum probability of acceptor detonation occurrence, i.e. maximum distance, minimum boundary velocity, and minimum number of effective fragments (the single largest donor fragment). At greater distances and/or lower velocities, the probability of acceptor detonation is therefore presumed to be zero.

We can now consider the general case of reducing design distances from the limiting distance value (as expressed by equation 4a) and/or shielding thickness by accepting a certain risk or probability of the possibility of high order detonation occurrence. The probable number of effective hits (i.e. hits which upon striking the acceptor charge will cause high order detonation) by impacting fragments may be expressed by equations 5 and 5a, Figure 5 (Ref 3). It is seen from this equation, the probability per unit area is dependent upon the number of effective fragments ($N_x$) (obtained from equation 2 previously discussed) and the distance between the donor and acceptor charges. Included in the equation is a constant (g), which depends on the spacial angular distribution of fragments. For most of our purposes a single value of (g) may be used without serious error. The plot shown on Figure 5 relates the distance between the donor and acceptor charges (d), shielding (t), and probability per unit area (P/A) of high order detonation occurrence for a single explosive system. A zero probability curve ($E_o$) indicates a relationship between the distance (d) and shielding (t) beyond which no high order detonation is possible. This line represents the limiting case mentioned earlier.

The higher the probability level that could be tolerated, the lower the distance-shielding combination necessary. This relationship permits us, with a fairly reasonable degree of accuracy, to predict the necessary separation and/or shielding between two explosive systems at any degree of probability of high order detonation occurrence. To compose such a relationship (as presented on Figure 5) all that would be necessary is knowledge of the geometry of the system and the previously discussed explosive properties relating to sensitivity and output.

The relationships which have been outlined permit one to predict the potential propagation characteristics of explosive systems, as well as to establish a design basis for prevention of propagation. A detailed presentation of the relationships involved and the calculation procedure, as well as illustrative examples are contained in a forthcoming technical report (Ref 4).

## REFERENCES

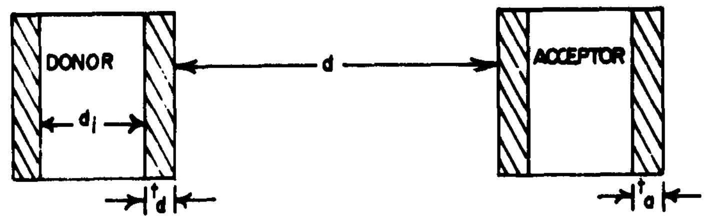
1. L.H. Thomas, Computing the Effect of Distance on Damage by Fragments, BRL Report No. 468

2. K.S. Jones, Vulnerability of Simulated Missile Warheads, BRL Report No. 472

3. R.I. Mott, A Theory of Fragmentation AOR Group Memo 113 (British)

4. R.M. Rindner and S. Wachtell, Establishment of Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations - Report No. 3. Safe Distances and Shielding for Prevention of Propagation of Detonation by Fragment Impact (DB-TR: 6-60)

# FIGURES




$V_0 = f\,(E')(E)/C)$ .................. (1)

$V_0$ = initial fragment velocity

$E'$ = explosive output constant

$E/C$ = explosives/casing weight ratio

$N_x = f\,(B)(C)(t_d)(d_i)(m)$ .............. (2)

$N_x$ = number of fragments greater than mass (m)

m = mass of fragment produced by donor detonation

B = constant depending on donor explosive and casing material

C = donor casing weight

$t_d$ = donor casing thickness

$d_i$ = inside diameter of donor casing

$m_{max} = f\,(B)(C)(t_d)(d_i)$ ............ (2a)

$m_{max}$ = mass of largest fragment produced by donor detonation.

$V_b = f\,(K_f)(t_a)(m)$ ............ (3)

$V_b$ = boundary velocity or fragment striking velocity of mass, m, below which high order detonation of the acceptor will not occur.

$K_f$ = explosive sensitivity constant

$t_a$ = acceptor casing thickness

$V_{b_{min}} = f\,(K_f)(t_a)(m_{max})$ ............ (3a)

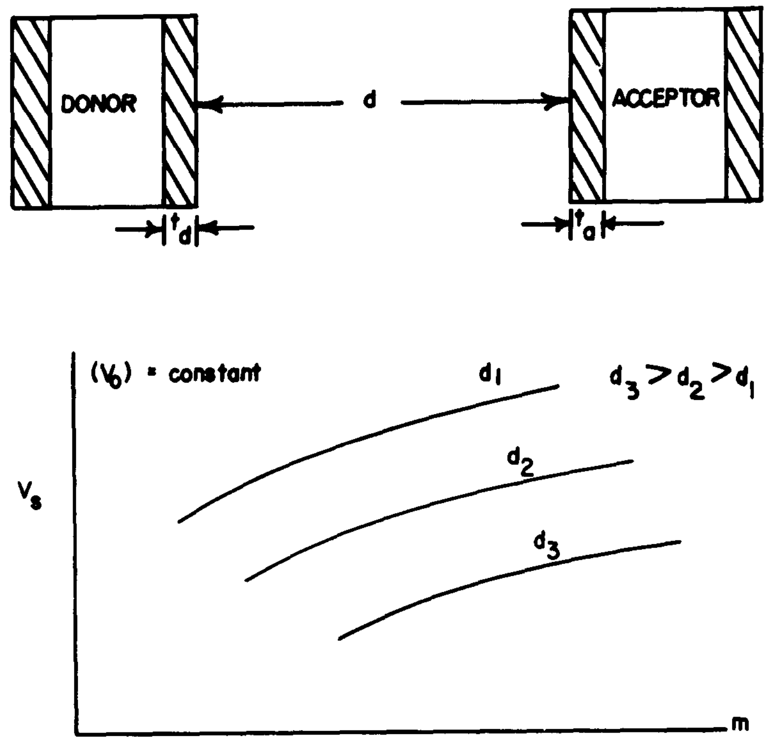
$V_{b_{min}}$ = minimum boundary velocity required for detonation of given acceptor by fragment from given donor.

CRITERION FOR POSSIBILITY OF DETONATION BY FRAGMENT IMPACT

IF $\dfrac{V_0}{V_{b\,min}} < 1$: detonation by fragment impact will not occur.

IF $\dfrac{V_0}{V_{b\,min}} \geq 1$: possibility of detonation by fragment impact exists.

Figure 1. Schematic Representation of Donor-Acceptor Relationships Governing Propagation by Fragment Impact.




$$d = f(k)(V_0/V_s)(m) \qquad (4)$$

d = distance from the donor charge.
k = constant depending on fragment size, shape, air density and drag coefficient.
$V_s$ = striking velocity of fragment at a distance. d

Figure 2. Striking Velocity of a Fragment as a Function at Fragment Mass and Distance

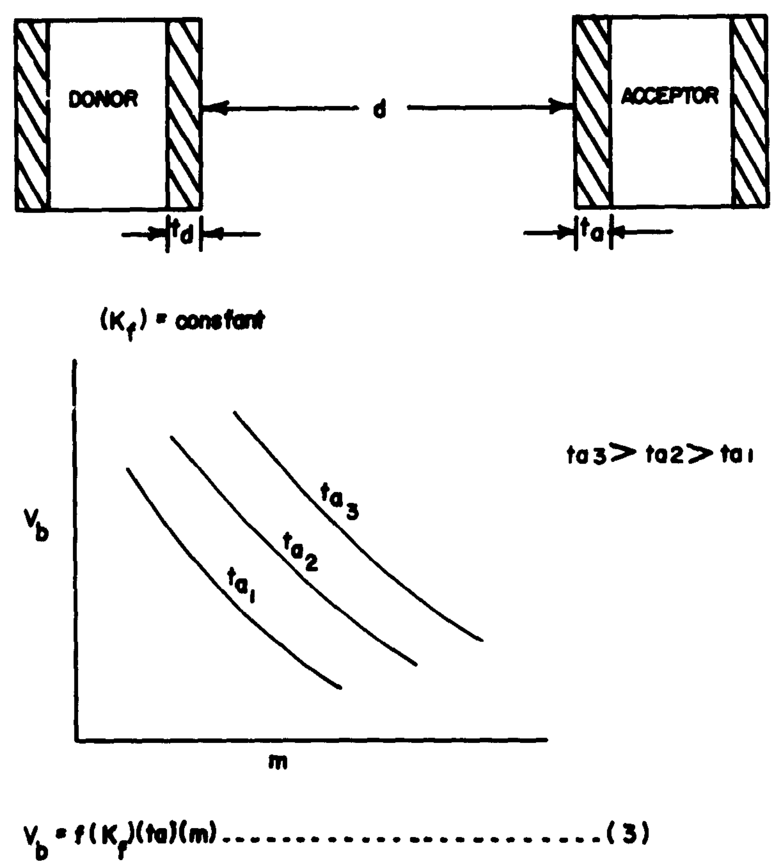
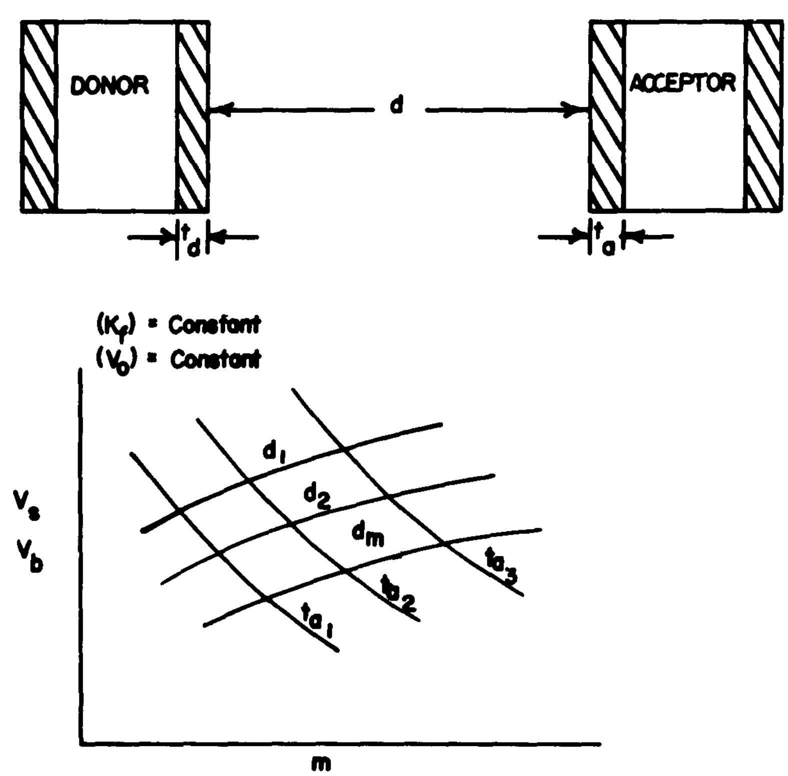


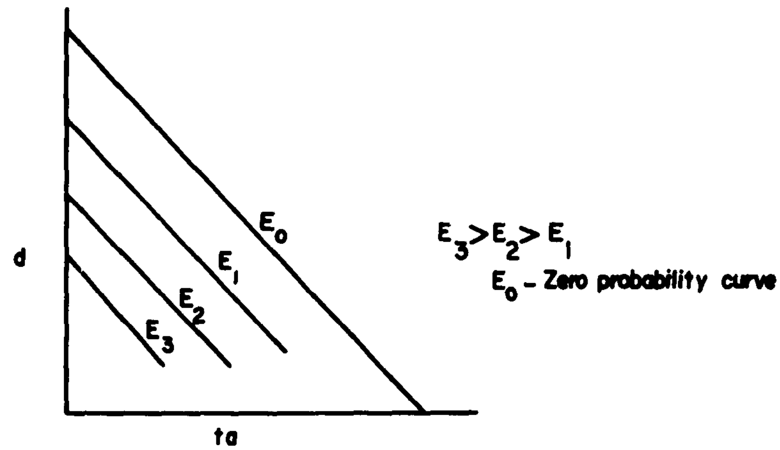

Figure 3. Boundary Velocity of a Fragment as a Function of Fragment Mass and Acceptor Shielding.




$$d_m = f(k)\,(V_o/V_b)_{min}\,(M_{max}) \quad \text{..........} (4_a)$$

WHERE $d_m$ = maximum distance from given donor charge at which detonation of given acceptor is possible.

Figure 4. Minimum Effective Fragment Mass and Corresponding Velocity as a Function of Distance and Shielding.




$$P/A = f(N_x)(d)(g) \text{ - - - - - - - - - - } (5)$$

$$E = f(P) \text{ - - - - - - - - - - - - - } (5a)$$

P/A = Probable number of effective hits per unit area.

$(N_x)$ = Total number of effective fragments.

(G) = Factor governing the distribution of fragments.

(D) = Distance between conor and acceptor charge.

(E) = Probability of high order detonation occurrence in the acceptor.

Figure 5. Probability of Detonation Occurrence as a Function of Distance and Shielding.

ABSTRACT DATA

ABSTRACT DATA

AD________ Accession No.________

Picatinny Arsenal, Dover, New Jersey

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

Leon W. Saffian

Technical Memorandum 1066, April 1963
21 pp, figures
Unclassified memorandum from the Process Engineering Laboratory, Ammunition Group.

Relationships are outlined 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 or separation distances for any other degree of tolerable risk.

All that is necessary to develop the specific relationship for a given situation is knowledge of properties of the explosives involved and geometries of the explosive systems.

A simple method for graphically representing the relationships is presented.

UNCLASSIFIED

1. Detonation by fragment impact -- Prevention

I. Saffian, Leon W.
II. Fragment impact

UNITERMS

Safe distances
Shielding
Propagation
Detonation
Fragment impact
Relationships
Saffian, L.W.

AD ______________ Accession No. ______________

Picatinny Arsenal, Dover, New Jersey

*SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT.*

*Leon W. Saffian*

Technical Memorandum 1066, April 1963, 21 pp, figures. Unclassified memorandum from the Process Engineering Laboratory, Ammunition Group.

Relationships are outlined 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 per-

(over)

UNCLASSIFIED

1. Detonation by fragment impact—Prevention

I. Saffian, Leon W.

II. Fragment impact

UNITERMS

Safe distances
Shielding
Propagation
Detonation
Fragment impact
Relationships
Saffian, L. W.

UNCLASSIFIED

AD ______________ Accession No. ______________

Picatinny Arsenal, Dover, New Jersey

*SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT.*

*Leon W. Saffian*

Technical Memorandum 1066, April 1963, 21 pp, figures. Unclassified memorandum from the Process Engineering Laboratory, Ammunition Group.

Relationships are outlined 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 per-

(over)

UNCLASSIFIED

1. Detonation by fragment impact—Prevention

I. Saffian, Leon W.

II. Fragment impact

UNITERMS

Safe distances
Shielding
Propagation
Detonation
Fragment impact
Relationships
Saffian, L. W.

UNCLASSIFIED

AD ______________ Accession No. ______________

Picatinny Arsenal, Dover, New Jersey

*SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT.*

*Leon W. Saffian*

Technical Memorandum 1066, April 1963, 21 pp, figures. Unclassified memorandum from the Process Engineering Laboratory, Ammunition Group.

Relationships are outlined 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 per-

(over)

UNCLASSIFIED

1. Detonation by fragment impact—Prevention

I. Saffian, Leon W.

II. Fragment impact

UNITERMS

Safe distances
Shielding
Propagation
Detonation
Fragment impact
Relationships
Saffian, L. W.

UNCLASSIFIED

AD ______________ Accession No. ______________

Picatinny Arsenal, Dover, New Jersey

*SAFE DISTANCES AND SHIELDING FOR PREVENTION OF PROPAGATION OF DETONATION BY FRAGMENT IMPACT.*

*Leon W. Saffian*

Technical Memorandum 1066, April 1963, 21 pp, figures. Unclassified memorandum from the Process Engineering Laboratory, Ammunition Group.

Relationships are outlined 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 per-

(over)

UNCLASSIFIED

1. Detonation by fragment impact—Prevention

I. Saffian, Leon W.

II. Fragment impact

UNITERMS

Safe distances
Shielding
Propagation
Detonation
Fragment impact
Relationships
Saffian, L. W.

UNCLASSIFIED

mit prediction of probability of propagation in an existing situation, as well as calculation of necessary changes in acceptor shielding or separation distances for any other degree of tolerable risk.

All that is necessary to develop the specific relationship for a given situation is knowledge of properties of the explosives involved and geometries of the explosive systems.

A simple method for graphically representing the relationships is presented.

UNCLASSIFIED

UNCLASSIFIED

mit prediction of probability of propagation in an existing situation, as well as calculation of necessary changes in acceptor shielding or separation distances for any other degree of tolerable risk.

All that is necessary to develop the specific relationship for a given situation is knowledge of properties of the explosives involved and geometries of the explosive systems.

A simple method for graphically representing the relationships is presented.

UNCLASSIFIED

UNCLASSIFIED

mit prediction of probability of propagation in an existing situation, as well as calculation of necessary changes in acceptor shielding or separation distances for any other degree of tolerable risk.

All that is necessary to develop the specific relationship for a given situation is knowledge of properties of the explosives involved and geometries of the explosive systems.

A simple method for graphically representing the relationships is presented.

UNCLASSIFIED

UNCLASSIFIED

mit prediction of probability of propagation in an existing situation, as well as calculation of necessary changes in acceptor shielding or separation distances for any other degree of tolerable risk.

All that is necessary to develop the specific relationship for a given situation is knowledge of properties of the explosives involved and geometries of the explosive systems.

A simple method for graphically representing the relationships is presented.

UNCLASSIFIED

UNCLASSIFIED

# TABLE OF DISTRIBUTION

## TABLE OF DISTRIBUTION

| | Copy Number |
|---|---|
| 1. Commanding Officer<br>Picatinny Arsenal<br>Dover, New Jersey<br>ATTN: SMUPA-VA6 | 1-5 |
| SMUPA-DP | 6 |
| SMUPA-DD | 7 |
| SMUPA-I | 8 |
| SMUPA-G | 9 |
| SMUPA-V | 10 |
| SMUPA-T | 11 |
| SMUPA-M | 12 |
| SMUPA-DX1 | 13-14 |
| 2. Commanding General<br>U.S. Army Munitions Command<br>Dover, New Jersey<br>ATTN: AMSMU-DP | 15 |
| AMSMU-AP | 16 |
| AMSMU-WP | 17 |
| AMSMU-E | 18 |
| 3. Commander<br>Armed Services Technical Information Agency<br>Arlington Hall Station<br>Arlington 12, Virginia | 19-28 |
| 4. Armed Services Explosives Safety Board<br>Dept. of Defense<br>Gravelly Point, Bldg. T-7<br>Washington 25, D.C.<br>ATTN: R.G. Perkins | 29 |
| 5. Bureau of Naval Weapons<br>Rm 2134, Munitions Bldg.<br>Washington 25, D.C.<br>ATTN: E.M. Fisher, RMMO-13 | 30 |
| 6. Office, Chief of Engineers<br>ENGMC-EM<br>Bldg. T-7, Gravelly Point<br>Washington 25, D.C.<br>ATTN: G.F. Wigger | 31 |

## TABLE OF DISTRIBUTION (CONT'D)

| | Copy Number |
|---|---|
| 7. Army Materiel Command<br>AMCAD-SA<br>Bldg. T-7, Gravelly Point<br>Washington 25, D.C.<br>ATTN: W.G. Queen | 32 |
| 8. Logistics Division<br>Defense Atomic Support Agency<br>The Pentagon<br>Washington, 25, D.C.<br>ATTN: E.L. Taton | 33 |
| 9. OOAMMA (OOYEG)<br>Hill Air Force Base, Utah<br>ATTN: N.W. Harbertson | 34 |
| 10. AFIDI (AFIAS-G2)<br>Norton Air Force Base, California<br>ATTN: D.E. Endsley | 35 |
| 11. Chief Safety Officer, ALOO<br>US Atomic Energy Commission<br>P.O. Box 5400<br>Albuquerque, New Mexico<br>ATTN: E.L. Brawley | 36 |
| 12. ED Division<br>US Naval Ordnance Laboratory<br>White Oak, Silver Spring, Maryland<br>ATTN: Wm. S. Filler | 37 |
| 13. Bureau of Yards & Docks<br>Code E-22.1<br>Department of the Navy<br>Washington 25, D.C.<br>ATTN: O.L. Hudson | 38 |
| 14. Hq USAF, AFOCE-EE<br>The Pentagon<br>Washington 25, D.C.<br>ATTN: J.R. Powers | 40 |

## TABLE OF DISTRIBUTION (CONT'D)

| | Copy Number |
|---|---|
| 15. US Naval Weapons Laboratory<br>Dahlgren, Va.<br>ATTN: Jas. Talley | 41 |
| 16. National Aeronautics & Space Admin. Hq.<br>Washington 25, D.C.<br>ATTN: G.D. McCauley, Code BY<br>R.A. Wasel, Code MLPS<br>Richard Schmidt, Code MLO | 42 |
| 17. Naval Ordnance Test Station<br>China Lake, California<br>ATTN: D.P. Ankeney, Code 3023 | 43 |