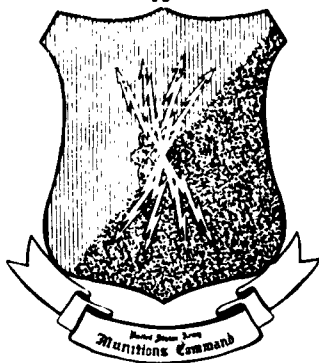


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TECHNICAL MEMORANDUM 1065



ESTABLISHMENT OF SAFETY DESIGN CRITERIA
FOR
HIGH ENERGY PROPELLANT MANUFACTURING
AND
STORAGE FACILITIES

LEON W. SAFFIAN

COPY NO. 27 OF 45

JANUARY 1963

PICATINNY ARSENAL
DOVER, NEW JERSEY

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**TECHNICAL MEMORANDUM 1065
AMMUNITION GROUP**

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FOR
HIGH ENERGY PROPELLANT MANUFACTURING
AND
STORAGE FACILITIES**

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JANUARY 1963

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FOREWORD

The material contained in this report was the subject of a presentation made to the Explosives Safety Seminar on High Energy Propellants at the Naval Propellant Plant, Indian Head, Maryland, 10-11 June 1959.

ESTABLISHMENT OF SAFETY DESIGN CRITERIA FOR HIGH-ENERGY PROPELLANT MANUFACTURING AND STORAGE FACILITIES

Picatinny Arsenal is engaged in a broad program aimed at establishment of more realistic safety design criteria for explosives manufacturing and storage facilities. We consider the term "explosive" to mean any material which, under certain conditions, will sustain a high order detonation and is therefore potentially capable of propagating detonation in adjacent systems in which it is contained; consequently we must consider including in this category many of the new high-energy propellants already developed, and those to be developed.

Test methods currently employed for determining sensitivity and detonability of high energy propellants used in our missile systems, and data obtained by these methods, are of value up to a point, but they do not give a complete quantitative picture of the potential large scale behavior of these materials in their actual environments. The usual laboratory tests on sensitivity to impact, heat, and electrostatic discharge are useful in indicating to the researcher the general nature of a propellant composition and giving him some idea as to the hazards involved in its handling. Other common methods of testing are based on attempting to detonate the material in question, either unconfined in a cardboard container or confined in a heavy wall pipe, by means of a booster charge or fragment impact. Results of tests of this type, which are conducted with larger quantities of material (roughly 1/4 of a pound to 100 pounds) and under more realistic conditions than laboratory tests, are significant in that they indicate the relative detonability of different propellants in terms of such parameters as minimum size of booster charge required to produce a stable detonation, and minimum charge diameter (critical diameter) required to sustain detonation. Tests have also been conducted with actual end items (motors with assembled warhead or other high explosive initiator) to determine such factors as order of detonation of the motor, contribution of propellant detonation to total blast produced, and general fragment effects.

Picatinny Arsenal recognizes the value of the aforementioned tests, which need not be detailed any further in this presentation. As a matter of fact a stepwise method for establishing hazard classifications of propellants recommended in one of our recent technical reports (Ref 1), is based on such tests. It is essential, however, to recognize, also, the limitations of these tests, particularly where the designer of propellant manufacturing or storage facilities is concerned. In order to fully appreciate these limitations, we must consider the objectives of the designer which are, broadly speaking, the prevention of propagation of explosions and prevention of structural damage in cases where such damage may cause injury to operating personnel and/or very costly equipment. In order to accomplish these objectives in a practical manner (i. e. without resorting to extensive large scale testing) and with confidence, the designer must have at his disposal a reliable basis for quantitatively

predicting the large scale behavior of the propellant under consideration in environments varying from early manufacturing states (e. g. a mixing vessel) to the end item (e. g. missiles stored at a launching site). This must be done in terms of such factors as propellant output, sensitivity to blast, and sensitivity to fragment impact, which in turn, determine quantity-distance relationships and barricade design criteria for a particular propellant or class of propellants. When considered in this light, it is clear that results of tests such as those previously mentioned cannot be used directly for design purposes, nor can they be used in a design equation. For example, if we establish that propellant X requires a minimum booster charge of 100 grams of tetryl to detonate high order and propellant Y requires a minimum of 200 grams of tetryl under the same conditions, we can say that propellant X is twice as sensitive as propellant Y under those particular conditions, when sensitivity is expressed as minimum size of booster required. If, however, we wish to express sensitivity in terms of minimum blast pressure or minimum kinetic energy required to cause high order detonation, which are major factors in defining quantity-distance relationships, about all we can say based on booster sensitivity is that under the same conditions the pressure and kinetic energy required will be higher for propellant Y than for propellant X; the booster sensitivity ratio of 2 has no quantitative meaning in this respect. In other words, the primary significance of the previously mentioned tests is that they permit gross classification of propellants into such categories as (1) not mass-detonating, (2) mass-detonating under certain very specific conditions only, and (3) mass-detonating over a wide range of conditions, as well as a qualitative ordering of the mass-detonating materials in terms of relative sensitivity. For the designer of facilities involving a propellant which has been shown to be mass-detonating, this is only the beginning.

In line with the previous discussion, the Picatinny safety design criteria program has been divided into three major phases which will now be discussed separately in terms of completed, current, and planned studies.

Phase 1 deals with establishment of realistic quantity-distance relationships for prevention of sympathetic detonation (i.e. propagation due to pure blast effects). The bulk of this work has been completed (Ref 2), and has resulted in the establishment of a method for deriving a quantity-distance relationship for any mass-detonating material, to be used for prevention of sympathetic detonation. The general equation proposed is shown in Figure 1, and is based on correlation of available data and relationships reported by various investigators. It has been found to hold fairly well for donor charges of various explosives ranging from 1 to 250,000 pounds in weight. This equation accounts for the various factors in addition to weight, (i.e. degree of confinement, ground reflection, explosive composition, and shape) which affect the peak pressure blast output of a donor charge. This is accomplished by means of the various coefficients indicated which refer to actual donor charge weights to a set of standard conditions. The factor K, therefore, is a constant for each explosive depending only on its sensitivity to blast (i.e. considering the explosive in the role of an acceptor charge). Each K value corresponds to a particular

peak pressure which is the minimum blast pressure required to cause sympathetic detonation. It should be noted at this point that the cube root law correlation and the method of donor weight adjustment employed are consistent with the assumption of peak pressure as the criterion of explosive blast output. The factor K for a particular material can be determined by a series of small scale tests in which different weights (e. g. 1-100 pounds) of bare spherical TNT charges held sufficiently high above the ground so that ground reflections may be considered negligible (i. e. F_c , F_s , F_e , and F_r each equal 1) are detonated at varying distances from an acceptor charge of the material in question. A logarithmic plot of the maximum distance at which sympathetic detonation occurs versus corresponding donor weight should give a straight line of $1/3$ slope, the intercept of which on the distance axis is equal to K. Concerning the donor weight adjustment factors, a considerable amount of information relative to these factors is available in the literature (Ref 3 & 4) which, although it is based on tests conducted with bursting charge explosives (e. g. TNT, Composition B, Composition C-3), should be largely applicable to mass-detonating propellants (with the obvious exception of the explosive composition coefficient). In cases where coefficients must be determined, or it is desired to check existing methods for calculating coefficients this can be accomplished by appropriate small scale tests. For example, the composition coefficient, F_e , for a new mass-detonating propellant X could be determined by the method outlined schematically in Figure 2.

Figure 3 illustrates what can be done with the proposed quantity-distance relationship for sympathetic detonation. First, it shows a logarithmic plot of the available test data relative to occurrence of sympathetic detonation. The effective donor weights ranging from 3 to 450,000 pounds were calculated by adjusting the actual donor weights (1 to 250,000 pounds) by the methods previously described. The plotted distance corresponding to any indicated charge weight approaches the maximum distance at which sympathetic detonation would occur with that charge; or, conversely the plotted donor charge weight corresponding to any indicated distance approaches the minimum weight necessary to produce sympathetic detonation at that distance. As would be expected, the plot shows a region in the weight-distance plane where sympathetic detonation has not occurred. A straight line drawn to separate the region of non-occurrence of sympathetic detonation from the region where sympathetic detonation does occur, (i. e. the lowest line) has a slope of approximately $1/3$ and corresponds to the equation $d_m = 3.1 W_e^{1/3}$ and a peak pressure of 100 psi. This is a gross separation based on the most sensitive explosive indicated, i. e. dynamite. Of course, the methods previously described could be used to establish a family of such lines, one for each mass-detonating propellant, depending on its sensitivity. The heavy line shown immediately above the sympathetic detonation boundary corresponds to a pressure of 30 psi and has the equation $d_s = 5 W_e^{1/3}$, where d_s denotes the proposed minimum safe distance for non-occurrence of sympathetic detonation. This line constitutes, in effect, the application of a safety factor of 1.6 to the maximum distances at which sympathetic detonation can be expected to occur (or a factor greater than 3 based on minimum peak pressure required). Also shown on Figure 3, are the two broken lines $d_s = 15 W_e^{1/3}$

(uppermost line) representing present intraline quantity-distance regulations for Class 9 and 10 explosives, and $d_g = 9W_e^{1/3}$ representing Class 9 and 10 magazine quantity-distances. A glance at the position of these two lines relative to the sympathetic detonation boundary and the line representing the proposed quantity-distance relationship, indicates the excessive conservatism inherent in the present regulations, with respect to prevention of sympathetic detonations. Figure 4 lists the equations of the lines just discussed and their corresponding peak pressures. This shows (Item 1) that, according to the data accumulated a minimum peak pressure of the order of 100 psi must be produced at an acceptor charge in order to produce sympathetic detonation (in fact individual values ranged as high as 2,000 psi). This is in contrast to present magazine and intraline regulations, which are apparently based on the premise that minimum pressures as low as 9 psi (Item 3) and 3.7 psi (Item 4), respectively, produce sympathetic detonation. On this basis the proposed quantity-distance relationship (Item 2) is considered to be entirely justified. A comparison of the various equation constants indicates that the proposed quantity-distances represent a 3-fold reduction in present intraline distances and an approximate 2-fold reduction in present magazine distances, even though they incorporate a safety factor of 1.6 as compared to maximum distances at which sympathetic detonation occurred. Furthermore, although present intraline and magazine distances are based on a cube root quantity-distance equation these relationships give no consideration to factors affecting the output of a donor charge other than weight. The significance of this is shown in Figure 5 which is a summary of calculations made by the method previously mentioned to arrive at effective weights of a 10,000 pound donor charge detonated under a wide range of conditions, and corresponding safe distances obtained from the proposed quantity-distance relationship. We have assumed a cylindrical shape for the charge, corresponding to a shape correction factor (F_s) of 1.25. As indicated at the left of the table, various explosive compositions were considered, corresponding to composition correction factors (F_e) ranging from 1.0 for TNT to 1.27 for H-6. Across the top of the table are assumed correction factors (F_r) ranging from 1.5 to 2.0, for various degrees of ground reflection, and for each of these reflection conditions, correction factors (F_c) ranging from 0.6 to 1.17 for various degrees of confinement are indicated. The calculated values of effective donor charge weights range from 12,500 pounds to 40,600 pounds with corresponding safe distances of 116 feet and 172 feet, respectively. According to present intraline regulations, the explosive weight would be taken as 10,000 pounds the corresponding safe distance as 400 feet, regardless of the widely varying conditions indicated.

Although our Phase 1 studies relating to sympathetic detonation are essentially completed, some additional refinements would be desirable and are planned for future study. For example, two factors which have yet to be taken into account are (1) effect of acceptor casing on sensitivity and (2) effect of types of ground upon ground reflection (the previously mentioned F_r accounts for weight of donor charge above ground but not for different types of ground).

Phase II of our program deals with the effects of fragment impact in causing high order detonation in an explosive charge, and related safety design criteria. A major portion of this work has been completed (Ref 5), and has resulted in the establishment of a method for predicting the vulnerability to high order detonation of an explosive system (or vulnerability to mass detonation of adjacent explosive systems) in terms of geometry of the system (e. g. explosive weight/casing ratio, casing thickness) and explosive properties (e. g. output and sensitivity). The method is based on correlation of various relationships developed by British and U. S. investigators as a result of theoretical studies, confirmatory tests, and actual experience. Although the actual tests and data relate to so-called conventional ammunition items containing standard explosive fillers (e. g. TNT, RDX/TNT), the relationships which will now be discussed are entirely applicable to the newer high-energy propellant systems for prediction of sensitivity and/or mass-detonability. These relationships, which are detailed in one of our forthcoming technical reports (Ref 5), are presented schematically on Figure 6. This shows the factors which must be considered for any explosive system in either a donor or acceptor role. As indicated by equation (1), an output constant (E') must be established for the donor material. Although values of this constant are available in the literature for the well-known explosives such as TNT and RDX/TNT (Ref 3 & 6), values for mass detonating propellants would have to be established experimentally. This could be readily accomplished by a series of small scale tests in which cased propellant samples of various (E/C) ratios are detonated and corresponding fragment velocities measured. The output constant is readily obtainable from a plot of (V_0) vs. (E/C) in accordance with relationship represented by equation (1). The other constant of interest with respect to the donor charge is (B) in equation (2). This equation as represented, is a special case of a general equation which can be used to calculate the number of fragments in any particular weight range produced by detonation of a cased charge. Values of (B) for TNT and various other well known explosives are available (Ref 6). For mass-detonating propellants this value could be determined by a series of small scale tests with cased charges of various geometries, in which fragment patterns are determined and a plot of the data made in accordance with the relationship schematically represented by equation (2). Considering, now, an explosive system which is a potential acceptor, equation (3) indicates that an explosive sensitivity constant (K_f) must be established for the acceptor explosive. As in the cases of the other constants previously discussed, values of this constant are available for some of the well known explosives such as TNT and RDX/TNT mixtures (Ref 7). For a mass-detonating propellant the (K_f) value could be established by a plot of (V_g) vs. $f(ta)$ (m) in accordance with equation (3). A simple method of obtaining the necessary data would be to fire individual fragments of known mass against propellant charges with various degrees of casing, and determining, for each charge, the minimum velocity of a given fragment required to produce high order detonation.

Some mention should be made at this point, of the critical diameter factor. For the bursting charge explosives (TNT, Composition B, HBX, etc.), this diameter is so small that it generally does not have to be considered in talking about mass-detonation relationships, i.e. any explosive system of practical interest (e.g. shell, warhead, reaction vessel) would have a diameter greater than critical, and therefore be potentially mass-detonating. A high energy propellant, on the other hand, may be capable of high order detonation only when charge diameters are relatively large. Of course, if the critical diameter is larger than anything that would be encountered in any in-process or end-item situation, the propellant can be considered to be non-mass-detonating for practical purposes. It may be, however, that the critical diameter of a material is less than diameters encountered in actual large-scale situations, but still large enough to present problems with respect to small scale testing. In most cases of this sort, use of large test charges could be avoided by using small charges which are, in effect, brought above the critical diameter by means of very heavy confinement. For example, in obtaining test data for determination of (K_f) in equation (3), Figure 6, the acceptor charges could be made up of small cylinders of the propellant in question with a thick metal casing (i.e. several inches) around the cylindrical portion but with ends exposed. Plates of various thickness would be butted flush against one end, and fragments fired against these plates in a direction parallel to the longitudinal axis of the charge. The plate thickness would be (t_a) in equation (3).

Once the various explosive constants have been established, and knowing the overall geometry and dimensions of an explosive system, it can be seen from Figure 6 that a reasonably reliable prediction as to its vulnerability to high order detonation by fragment impact (or its potential ability to contribute to propagation of an explosion when considered in relation to any specific environment of adjacent explosive systems) can be made by a straightforward series of calculations. Thus, for a particular donor-acceptor situation, (V_o) and (m) are first calculated. Since the equations are based on the assumption of cylindrical cased charges (i.e. constant cross-section) this will often require consideration of the donor in sections in such a way that equivalent cylinders can be constructed, having average wall thickness, average charge diameter, and the same (E/C) ratio as the actual section. After calculating (V_o) and (m) for each section the corresponding values of (V_s) are calculated, assuming impact at the thinnest portion of the acceptor casing (i.e. the most severe condition). It is also assumed that the acceptor is in very close proximity to the donor (again, the most severe condition) so that fragments strike the acceptor at their maximum velocity (V_o) , i.e. there are no velocity losses which would increase with increasing distance from the donor. As shown in Figure 6, therefore, we have established the ratio (V_o/V_s) as a criterion for predicting the gross mass-detonability characteristics of explosive systems, including those containing the newer high energy propellants which are of greatest current interest.

Figure 7 shows a comparison of the vulnerability to mass detonation of a number of standard shell, as predicted by the methods just described, and as stated in the Safety Manual (i.e. whether or not the item is in Class 10). It can be seen that the general agreement is quite good. Furthermore, in at least one of the cases of disagreement, the 240mm shell, it is probable that the predicted result is correct.

The primary objective of our current Phase II studies is very briefly expressed by equation (4), Figure 6, which represents a major refinement of the fragment impact relationships discussed thus far since it would permit calculation of safe distances for prevention of propagation by fragment impact. This work is also aimed at further refinements of the relationship represented by equation (4), such as probability factors (e.g. striking probability of fragments) which would permit reductions in design distances depending on the degree of risk, if any, that can be tolerated.

Phase III of our program, which will be initiated in the very near future, will relate to structural design criteria for barricades, substantial dividing walls, and other protective structures. Some of our thoughts along these lines may be of interest. It should be stated, first, that, as might be expected, our studies to date have conclusively indicated that fragment impact, rather than blast, is the major factor influencing the propagation of explosions, and has much more far-reaching effects in this respect. Secondly, blast and fragment effects should be considered separately with respect to their contribution to potential propagation. Correspondingly, the design of barricades, substantial dividing walls, and other protective structures should be based on individual consideration of these separate effects. In view of the relative importance of missiles in causing propagation, barricades should be designed primarily to protect explosives against the impact of missiles (although any resultant contribution of the barricade to blast protection may be incorporated as a further reduction in blast-propagation safe distance). Substantial dividing walls between operating bays should also be designed to protect against missiles but, in addition, should provide the required additional protection against propagation by blast in those cases where two bays must be separated by a distance less than that given by the proposed quantity-distance relationships. It should be noted that these quantity-distance relationships may have to be modified for application to cases where explosive material is distributed within a bay instead of being centrally located since the former explosive arrangement may not represent a true mass-detonating situation. It should be noted that severe structural damage to buildings and facilities may be expected in an installation separated from the origin of an explosion by a distance in accordance with the proposed blast-propagation safe distance, as is borne out by results of studies which indicate that peak detonation pressures of the order of 30 psi (basis for the proposed blast-propagation protection distances) will cause very destructive effects. The major factors to be considered in determining the need for designing to protect

against structural damage are economics, replacement lead time, and personnel exposure. With respect to economics, an installation which would withstand a blast pressure of 30 psi, would be excessively costly to build and might very likely be considerably more than twice the cost of a similar installation which is not designed to withstand such structural damage (i.e., even in the event of complete detonation of the latter installation, its original cost, plus replacement, would be less than the original cost of the installation designed to withstand 30psi). In extreme cases where very expensive equipment is to be installed in a particular building, the relative cost picture may conceivably change; however, this is unlikely. Of course, replacement lead time must also be considered; however, this should be done as part of establishing a safety factor for production capacity, which, in any case, must certainly be done in designing an installation for explosives manufacture, since it is completely unfeasible to design for protection against severe structural damage at the source of an initial detonation. Regarding personnel exposure, the trend in explosives manufacturing facilities is towards automation and minimization or complete elimination of exposure of operating people. Furthermore, there is every indication that this trend will continue, so that the possibility of injury to personnel will be very remote or virtually nonexistent. It may be concluded from the foregoing considerations that, in general, protection against structural damage should not be included in design of installations for explosive manufacture. In specific cases, however, where protection of personnel and/or costly specialized equipment is necessary, the required degree of protection against structural damage should of course be provided.

In conclusion, we at Picatinny strongly feel that an approach to each specific design case involving high-energy propellant facilities and/or operations, based on the methods discussed in this presentation will result in more meaningful safety design criteria, as well as minimization of requirements for costly large scale testing procedures.

REFERENCES

1. H. L. Partridge, Safety Hazards of Rocket Propellants, Picatinny Arsenal Technical Report DB-TR: 13-58, November 1958.
2. Richard M. Rindner, Establishment of Safety Design Criteria for Use In Engineering of Explosive Facilities and Operations, Report No. 1: Sympathetic Detonation, Picatinny Arsenal Technical Report DB-TR: 1-59, January 1959.
3. E. M. Fisher, Explosion Effects Data Sheets, U.S. Naval Ordnance Laboratory Report 2986, October 1955.
4. T. Sperazza, et al, Comparison of the Blast from Explosive Charges of Different Shapes, Ballistics Research Laboratories Report 681, January 1948.
5. Richard M. Rindner, Establishment of Safety Design Criteria for Use In Engineering of Explosive Facilities and Operation, Report No. 2: Detonation by Fragment Impact, Picatinny Arsenal Technical Report DB-TR: 6-59,
6. R. I. Mott, A Theory of Fragmentation, AOR Group Memo 113 (British).
7. The Sensitivity of High Explosives to Attack by Steel Fragments, ADE Technical Note T2/L9/AVF (British).

FIGURES

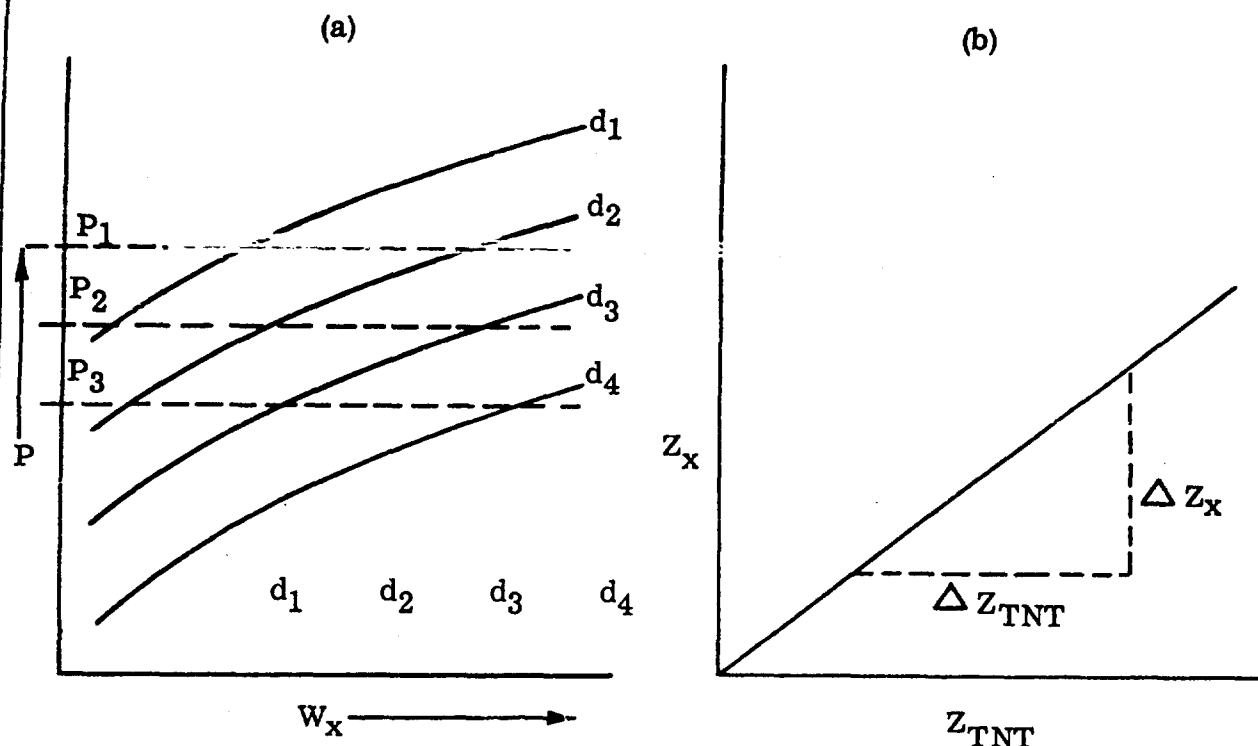
QUANTITY DISTANCE RELATIONSHIP FOR SYMPATHETIC DETONATION

$$d_m = KW_e^{1/3}, \text{ where } W_e = F_c F_r F_e F_s W$$

- d_m = Maximum distance between donor and acceptor charges, at which sympathetic detonation occurs (ft.)
- W_e = Weight of a bare, spherical, TNT charge, detonated in free air, which would produce a peak pressure blast output equivalent to that of the actual donor charge (lbs.)
- W = Weight of donor explosive charge (lbs.)
- K = Blast sensitivity constant (corresponding to minimum peak pressure required at acceptor charge to cause sympathetic detonation)
- F_c = Confinement coefficient-Ratio of equivalent bare explosive weight to actual weight of confined explosive (equivalent bare explosive weight is that weight of bare charge which would produce the same peak pressure blast output as the confined donor charge)
- F_r = Reflection coefficient-Ratio of equivalent free-air detonated bare explosive weight to equivalent bare explosive weight of the actual donor charges (equivalent free-air detonated bare explosive weight is that weight of bare explosive which, when detonated in free-air, would produce the same peak pressure blast output as a given donor charge)
- F_e = Composition coefficient-Ratio of equivalent free-air detonated bare TNT weight to equivalent free-air detonated bare explosive weight of actual donor charge (equivalent free-air detonated bare TNT weight is that weight of bare TNT which, when detonated in free-air, would produce the same blast output as a given donor charge)
- F_s = Shape coefficient-Ratio of peak pressure which would be produced by detonation of equivalent weight $F_c F_r F_e W$ of actual donor shape to peak pressure which would be produced by detonation of same equivalent weight having spherical shape.

Figure 1

DETERMINATION OF EXPLOSIVE COMPOSITION COEFFICIENT, F_e



1. Conduct a series of small scale tests in which different weights (W_x) of bare spherical charges of propellant X are detonated high enough from the ground so that ground reflections are negligible (i.e. F_c, F_g , and F_r each equal 1) and peak pressure (P) measurements are taken at various distances (d) from the detonation source. Plot the data as indicated in Fig. (a).

2. For lines of constant peak pressure obtain the corresponding values of d and W from Fig. (a). Calculate the reduced distance ($d/W_x^{1/3}$) for each point. This should be a constant value for each pressure.

3. For each of the above pressures, obtain the corresponding reduced distance from the Kirkwood-Brinkley relationship for bare, spherical TNT charges detonated in free air (Ref 5).

4. Plot propellant X reduced distance (Z_x) against TNT reduced distance (Z_{TNT}) for each pressure as shown in Fig. (b). These points should fall along a straight line passing through the origin. The slope of this line equals $F_e^{1/3}$, or

$$F_e = \left[\frac{\Delta Z_x}{\Delta Z_{TNT}} \right] = 3 \left[\frac{d/W_x^{1/3}}{d/W_{TNT}^{1/3}} \right] = \frac{W_{TNT}}{W_x}$$

Figure 2

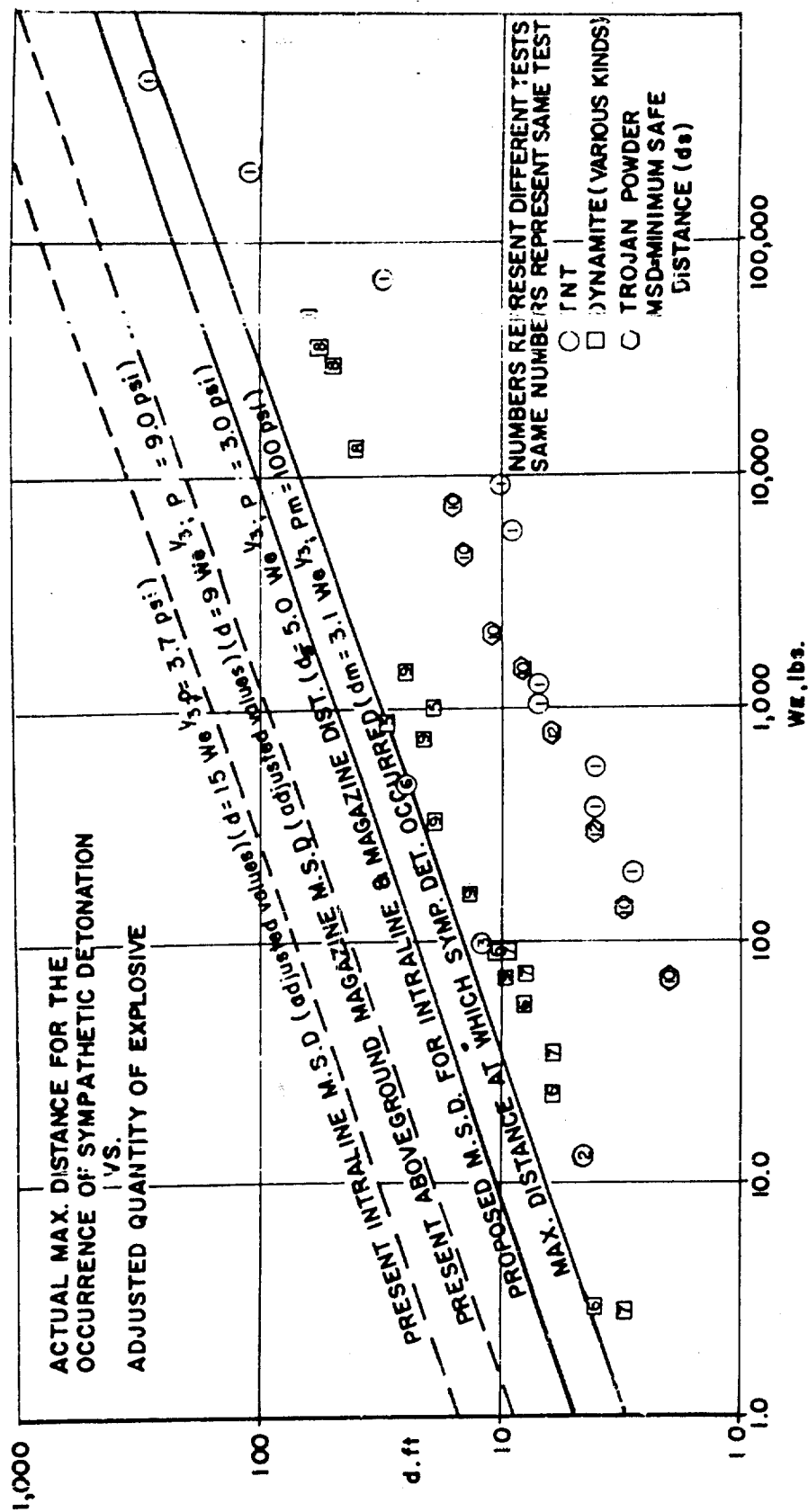


Figure 3

<u>COMPARISON OF PRESENT AND PROPOSED QUANTITY-DISTANCE RELATIONSHIPS</u>			
	d (ft.)	P (psi)	Remarks
1.	$3.1 W_e^{1/3}$	100	Maximum distance at which sympathetic detonation occurred
2.	$5.0 W_e^{1/3}$	30	Proposed M.S. D. for intraline and magazine distance
3.	$9W_e^{1/3}$	9	Present aboveground magazine M.S.D. (adjusted values)
4.	$15 W_e^{1/3}$	3.7	Present intraline M.S. D. (adjusted values)

Figure 4

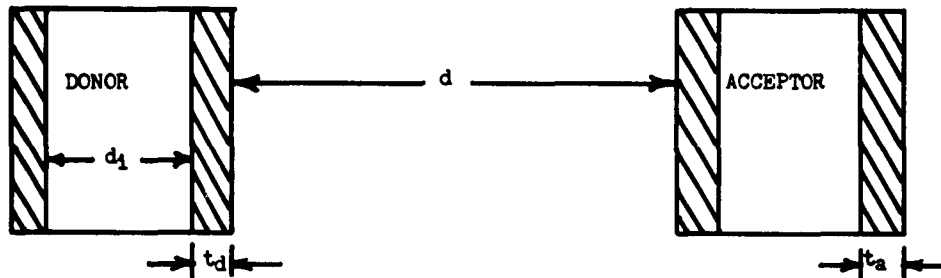
Effect of Various Explosive Weight Correction Factors on Minimum Safe Distance

Assume 10,000 lbs of donor explosive of cylindrical over all shape ($F_g=1.25$)

Reflection Factor		(Assumed $F_T=1.5$)				(Assumed $F_T=1.8$)				(Assumed $F_T=2.0$)			
Explosive/		Explosive/											
Total wt. ratio, C.		C=0.9	C=0.7	C=0.5	C=0.9	C=0.7	C=0.5	C=0.9	C=0.7	C=0.5	C=0.9	C=0.7	C=0.5
		$F_C=1.17$	$F_C=1.04$	$F_C=0.6$	$F_C=1.17$	$F_C=1.04$	$F_C=0.6$	$F_C=1.17$	$F_C=1.04$	$F_C=0.6$	$F_C=1.17$	$F_C=1.04$	$F_C=0.6$
TNT ($F_g=1.0$)	W_c	24,000	21,500	12,500	29,000	25,500	15,000	32,000	28,500	16,300	34,000	30,000	18,500
	d_g	144.0	139.0	116.0	153.0	146.0	122.0	158.0	153.0	129.0	165.0	158.0	132.0
Comp. B ($F_g=1.13$)	W_c	27,000	24,000	14,000	32,200	28,500	17,000	36,000	31,800	18,500	40,000	36,200	20,800
	d_g	150.0	144.0	120.0	158.0	153.0	129.0	165.0	158.0	132.0	172.0	165.0	138.0
Pentolite ($F_g=1.19$)	W_c	28,800	25,600	14,900	34,600	30,500	17,800	37,100	34,000	19,500	41,000	37,000	21,000
	d_g	153.0	147.0	123.0	163.0	157.0	131.0	169.0	162.0	134.0	174.0	167.0	140.0
H-6 ($F_g=1.27$)	W_c	30,500	27,500	16,000	37,000	32,500	19,100	40,600	36,200	20,800	42,000	38,000	22,000
	d_g	157.0	151.0	126.0	169.0	159.0	133.0	172.0	165.0	138.0	176.0	169.0	142.0

NOTE: According to present quantity-distance regulations, d_g for the assumed 10,000 pound donor explosive charge would be 400 feet, regardless of the widely varying conditions indicated above.

SCHEMATIC REPRESENTATION OF DONOR-ACCEPTOR RELATIONSHIPS GOVERNING
PROPAGATION BY FRAGMENT IMPACT



$$V_o = f(E')(E)/C \text{ - - - - - (1)}$$

V_o = initial fragment velocity
 E' = explosive output constant
 E/C = explosives/casing weight ratio

$$N_x = f(B)(C)(t_d)(d_1)(m) \text{ - - - - (2)}$$

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_1 = inside diameter of donor casing

$$m_{max} = f(B)(C)(t_d)(d_1) \text{ - - - - (2a)}$$

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

If $\frac{V_o}{V_{bmin}} < 1$; detonation by fragment impact will not occur.

If $\frac{V_o}{V_{bmin}} \geq 1$; possibility of detonation by fragment impact exists.

$$V_b = f(K_f)(t_a)(m) \text{ - - - - - (3)}$$

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

$$V_{bmin} = f(K_f)(t_a)(m_{max}) \text{ - - - - (3a)}$$

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

Figure 6

**COMPARISON OF CALCULATED RESULTS WITH SAFETY MANUAL
REQUIREMENTS**

Item	Explosive	Mass Detonation Characteristics	
		Calcul. Results	Safety Manual
76mm, M42A1	TNT	No	No
76mm	Comp B	No	No
90mm, M71	TNT	No	No
90mm	Comp B	Yes	No
105mm, M1	TNT	No	No
105mm	Comp B	Yes	No
155mm, M107	TNT	No	No
240mm, M114E1	TNT	Yes	No
280mm, T122E3	TNT	Yes	Yes
4.2 in. M329	TNT	Yes	Yes
Rocket head 3.5 in. M35A1	Comp B	Yes	Yes
Rocket head 4.5 in. M32	Comp B	Yes	Yes
81mm, M56	TNT	No	Yes
60mm, M49A2	TNT	No	No

Note: Yes - Possibility of mass detonation occurrence
No - Nonoccurrence of mass detonation.

Figure 7

ABSTRACT DATA

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FACILITIES**

Leon W. Saffian

Technical Memorandum 1065, January 1963
16 pp, figures.

Unclassified memorandum from the Process
Engineering Laboratory, Ammunition Group.

The data and discussion presented are based
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of acceptor charges were made. The effect
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