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ARMY OPERATIONAL RESEARCH GROUP

REPORT No. 272

**FC**  
**BAC**

A Theoretical Determination of the  
Best Height of Burst for V.T. Fuzed  
Mortar Bombs

91300

*Communicated by Superintendent. A.O.R.G.*

*Report requested by S.A./A.C.*

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Army Operational Research Group Report No. 272A Theoretical Determination of the Best Height of  
Burst for V.T. Fuzed Mortar BombsABSTRACT

A theoretical estimate of the areas of effect of airburst mortar bombs against various targets has been made. The improvement which could be secured (a) by tail initiation, (b) by a specially designed bomb, has also been investigated. The results are:-

	Best Set Height of burst (ft.)	Corresponding Mean Area of Effect (sq. ft.)
<u>Nose Initiation</u>		
(a) Men crouching in trenches	17	800
(b) Men lying on rough ground	19	2950
(c) Men running in the open	8	8400
<u>Tail Initiation</u>		
(a) Men crouching in trenches	21	1200
(b) Men lying on rough ground	24	3400
(c) Men running in the open	15	6800

The best set height for general use is 17 feet with nose or 22 feet with tail initiation; in each case it gives very nearly the maximum effectiveness against targets (a) and (b) and 90% of the maximum possible effectiveness against target (c). The improvement secured by the V.T. fuze over a D.A. fuze is

Target	Performance of V.T. Nose Fuzed Bomb relative to D.A. Fuzed Bomb = 1
(a) Men crouching in trenches	7
(b) Men lying on rough ground	3.5
(c) Men running in the open	1.5

The relative performance of tail and nose initiation in the 3" Mk. IV bomb at the best all round heights of 22 and 17 feet respectively is target (a) 1.5 to 1, target (b) 1.2 to 1, target (c) 0.8 to 1.

Against men crouching in trenches the maximum effectiveness of a specially designed bomb of weight 10 lbs. is probably not more than 3 times that of the nose initiated 3" Mk. IV bomb (or twice that of the tail initiated bomb). To attain maximum effectiveness a forward fragment zone of semiangle  $50^{\circ}$  to  $65^{\circ}$  is required.

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A Theoretical Determination of the Best Height of  
Burst for V.T. Fuzed Mortar Bombs

Part I - General

1. Object

The object of this investigation is to determine:-

- (a) The best height of burst for the existing 3" mortar bomb (Mk. IV cast iron) with V.T. Fuze.
- (b) The improvement which could be secured by tail initiation of the existing bomb.
- (c) The order of the improvement to be expected from a specially designed bomb.

2. Basis of Comparison

The performance of the burst at various heights has been compared on the basis of area of effect against various targets. The term "area of effect" replaces "vulnerable area" which was the description of the same measure of effectiveness used in earlier A.O.R.G. Reports. It may be defined briefly as follows:-

If E is the area of effect of a shell which bursts in an unlimited area containing targets at a density of  $t$  per square foot, the number of casualties produced by that shell is expected to be  $tE$ .

The targets considered are

- (a) Men crouching in slit trenches
- (b) Men lying on rough ground (in hollows)
- (c) Men running in the open.

The presented areas of a man in positions (a) and (c) are taken from A.O.R.G. Report No. 153. In position (b) the presented area is taken as 4.5 square feet from directly above and as  $4.5 \cos B$  square feet when seen from an angle of  $B$  to the vertical.\*

Part II - Effectiveness of the 3" Mortar Bomb Mk. IV

3. Fragmentation

The fragment weight distribution has been taken from a report of the Safety in Mines Research Station (A.C. 7323). This was a collection in sawdust and therefore the amount of secondary break up on collection is as small as can be obtained at present. No attempt has been made to estimate the extent of secondary break up in sawdust, and the weight distribution has been used as it stands (see Table I). The resultant fragment velocity for the cast iron bomb in flight is taken as 2000 ft/sec., the initial velocity from a static burst being 1910 ft/sec. (O.B. Proc. 27982) and the residual velocity of the bomb 600 ft/sec.

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\* This is not exactly equivalent to the American "O.P. Foxhole" in which the area of a man exposed to fragments descending at an angle  $B$  to the vertical is  $1-B/90$  (see TDBS Report No. 14). This expression falls off more rapidly with increasing  $B$  than  $B \cos \theta$ , as would be expected when a man is crouching in a foxhole instead of being prone on the ground. The results given by the two expressions should not, however, differ very widely.

Table I

Weight Group (1 oz.)	No. of Fragments	Weight		
		lb.	oz.	gr.
1/1200	Not recorded	-	10	14
1/1200 - 1/330	7743	-	12	6
1/330 - 1/200	1585	-	6	-
1/200 - 1/100	1705	-	11	15
1/100 - 1/50	1177	1	-	5
1/50 - 1/25	739	1	4	4
1/25 - 1/8	415	1	10	3
1/8 - 1/4	43	-	6	14
1/4 - 1/2	3	-	1	1

4. Fragment Zones in Flight

The fragment zones in flight are devised from the static fragment zones reported in A.O.R.G. Report No. 139 by making suitable allowance for the residual velocity of the bomb and the point of initiation. The present design of V.T. fuze for the mortar does not require a much greater intrusion than the normal D.A. fuze and therefore the point of initiation is not altered, and the fragmentation does not need modifying to allow for displaced filling. The fragment zones for a nose initiated burst in flight can be partially checked by reference to O.B. Proc. 26706 "Fragmentation of Mortar Bombs in Flight" which indicates that the main zone which has been used here is correct. For a tail initiated burst the estimation of zones in flight is more difficult, since the normal design of bomb would have to be modified and the new point of initiation is not definite. In addition there would probably be some form of nose plug which would modify forward fragmentation. The zones which have been used must therefore be regarded more as a reasonable example than as a definite forecast of what may be achieved with tail initiation. The static trials indicate that the small zones can be amalgamated into large ones of fairly uniform density and it is reasonable to suppose that this broad grouping will persist in flight. A considerable saving of work can be made by using a few broad zones instead of a large number of narrow zones and in this case there is little loss of accuracy in using the broad classification. The zones are shown in Table II. The angle of descent of the bomb has been taken as 70° throughout. It was thought that the angle of descent would not vary sufficiently widely from this figure to modify the results quoted to any great extent. In support of this view some results for angle of descent 45°, which may be regarded as a minimum, are given in Appendix B.

Table II

Fragment Zones

Static Trial		In Flight (Theoretical)			
		Nose Initiation		Tail Initiation	
Angle	Density	Angle	Density	Angle	Density
0 - 25	0.075	0- 40	0.20	0- 40	1.84
25 - 50	0.126	40- 60	1.74	40- 80	3.93
50 - 75	1.019	60- 90	4.36	80-110	0.35
75 - 87½	3.24	90-120	0.50	110-140	0.03
87½-100	3.83	120-155	0.03	140-180	0.04
100 -112½	3.83	155-180	0.10		
112½-125	0.583				
125 -137½	0.427				
137½-162½	0.051				
162½-180	0.187				

The "Angle" is measured from the nose of the bomb.

The "Density" is the number of strikes per square foot at 15 feet from the burst.

5. Method of Calculation

The ground surface is divided up into elements of area bounded by the conic sections produced by the intersection of the fragment zone boundaries with the ground, and by circles drawn with the point vertically below the point of burst as centre. Each point on any one of these circles is equidistant from the burst, the distances being  $h \sec B$  where  $h$  is the height of burst and  $B$  the angle to the vertical made by the line joining the point of burst to any point on the circle. The area of each element can be expressed as  $h^2 f(B, \delta)$  where  $\delta$  is the semivertical angle of a fragment zone boundary cone, and  $f(B, \delta)$  is independent of  $h$ . The chance  $P$  of causing a casualty is assumed uniform over each element of area, equal to the chance at the mid-point of the area.  $P$  is defined by the equations.

$$P = 1 - e^{-P} \quad (3.1)$$

$$P = kN.A(B) \omega r^2 \quad (3.2)$$

where  $N$  is the number of effective fragments from the whole bomb at a distance  $r$  from the burst, effectiveness being determined by the criterion of Burns and Zuckerman (R.C.350),  $k$  is the proportion of all fragments projected between the two consecutive boundary zones in question and  $\omega$  the solid angle included between them.  $A(B)$  is the presented target area for a fragment descending at an angle  $B$  to the vertical. The area of effect is  $h^2 \int (P f(B, \delta))$ . This method of calculation of areas of effect will be described in greater detail in a later report.

6. Results

The areas of effect for various exact heights of burst are given in Table III. Aiming errors have not been taken into account since they are believed to be of the same order for V.T. and D.A. fuzing. The areas of effect are, therefore, strictly for an unlimited target area but the best heights will not be modified if the area to be attacked is reasonably large, say as large as a company area. This is confirmed by calculations for the 25 pr. which will be included in a later report.

Table III

Height of Burst in ft. (Exact)	Men crouching in trenches		Men lying on rough ground		Men running in the open	
	Nose Initiation	Tail Initiation	Nose Initiation	Tail Initiation	Nose Initiation	Tail Initiation
1	200	250	1670	1150	9890	6830
10	890	1100	3280	3030	10,660	8410
15	1040	-	3720	-	10,220	-
20	1010	1590	3880	4330	9040	8580
30	800	1400	3012	4140	6560	7000
40	660	1180	-	-	-	-

These results are plotted in figures 1, 2 and 3 from which it will be seen that the best results are as follows:-

Table IV

(Exact Height)

	Best Height of Burst (feet)	Best area of effect (sq. ft.)	Limits (feet)
<u>Nose Initiation</u>			
(a) Men crouching in trenches	16	1,050	11 - 23
(b) Men lying on rough ground	19	3,900	12 - 25
(c) Men running in the open	7	10,800	1 - 17
<u>Tail Initiation</u>			
(a) Men crouching in trenches	20	1,600	15 - 28
(b) Men lying on rough ground	23	4,500	17 - 31
(c) Men running in the open	16	8,700	4 - 27

The limits in the final column give the height range in which the area of effect is within 10% of the best value. It is, however, impossible to obtain an exact height in practice and for a given set height  $h$  the standard deviation is of the order of  $1/3 h$ . In addition some allowance for a percentage of failures must be allowed; we have taken 20%. Although the percentage of failures at the present stage of development is much higher than this, less than 20% of failures occur with the T97 shell fuze and it is expected that the mortar fuze will eventually reach a similar standard of efficiency. Allowing for variations in the set height and 20% failures, the best set height and the corresponding mean areas of effect are shown in Table V.

Table V  
(Set Height)

	Best Set Height of burst (ft.)	Corresponding Mean Area of Effect (sq.ft.)
<u>Nose Initiation</u>		
(a) Men crouching in trenches	17	800
(b) Men lying on rough ground	19	2,950
(c) Men running in the open	8	8,400
<u>Tail Initiation</u>		
(a) Men crouching in trenches	21	1,200
(b) Men lying on rough ground	24	3,400
(c) Men running in the open	15	6,800

7. Discussion

We take the mortar bomb with nose initiation as standard since this is available without modifying the bomb design. It will be seen that the best height depends on the target to be attacked. If the attack of men in the open is considered the best height is fairly low (8 feet), but if there is reasonable protection (deep trenches or hollows in rough ground) the best height rises to 17 to 19 feet. The best all-round height depends on the relative importance of the different targets, but if the attack of protected personnel is at least as important as the attack of men in the open the best height is undoubtedly around 17 feet. This height gives very nearly the maximum possible effectiveness against targets (a) and (b) and 90% of the maximum possible effectiveness against target (c). The advantage of the V.T. fuze set at 17 feet compared with D.A. fuzeing is shown in Table VI.

Table VI  
Relative Areas of Effect

Target	V.T. Fuze (nose initiation)	D.A. Fuze
(a) Men crouching in trenches	7	1
(b) Men lying on rough ground	3.5	1
(c) Men running in the open	1.5	1

If tail initiation is practicable it will secure an improvement in the performance of the bomb against targets (a) and (b), but will be less effective against target (c). The relative figures, if the best set height is chosen for each method of initiation, are as follows:-

Table VII

Relative Performance of Tail and Nose  
Initiated Bombs

Target	Nose Initiated (set height 17 ft.)	Tail Initiated (set height 22 ft.)
(a) Men crouching in trenches	1	1.5
(b) Men lying on rough ground	1	1.2
(c) Men running in the open	1	0.8

The degree of improvement secured by tail initiation is probably too small to be worth while. This may be compared with the case of aircraft bomb where the increase produced by tail initiation in the area of effect against men crouching in slit trenches is expected to be 100 to 200, (see A.R.D. Explosives Report 19/44, A.C.5783).

The reasons why tail initiation in the 3" Mk. IV mortar bomb may be expected to produce a smaller gain are as follows:-

- (i) The fragment velocity of the mortar is low (1900 ft/sec.) compared to the aircraft bomb (5000 - 10,000 ft/sec.), and the residual velocities of both are roughly the same. In the aircraft bomb the forward throw of fragments due to the residual velocity is just about sufficient to compensate for the backward throw to nose initiation; in the mortar bomb there is an appreciable forward throw of fragments even in the nose initiated bomb.
- (ii) The mortar bomb has practically no parallel wall so that its main fragment zone is wider, and contains a smaller proportion of the total weight of available metal, than the main zone of an aircraft bomb.
- (iii) This mortar bomb is of cast iron and has a very fine fragmentation. The secondary fragment zones, although produced by only a small weight of metal, nevertheless contain a large number of effective fragments.

8. Comparison with American Mortar Shell

The following results were obtained for 81 mm mortar shell in T.D.B.S. Report No. 60.

81 mm Mortar Shell	M43A1	M56
Total weight of shell fuze T.132	7.05 lbs.	10.77 lbs.
Weight of Explosive	1.23 lbs.	4.30 lbs.
Initial Fragment Velocity	3930 f.s.	6180 f.s.
<u>Attack of 10<sup>0</sup> Foxholes (Angle of Descent 64<sup>0</sup>)</u>		
Best Height	10.5 ft.	11.5 ft.
Casualties (Target Density 1 per 100 sq.ft.)	4.8	9.8
Area of Effect	480 sq.ft.	980 sq.ft.

These areas of effect are not directly comparable to the ones calculated for the 3" Mk. IV mortar bomb in this report, as the target used in T.D.B.S. Report No. 60 is intermediate between our targets (a) and (b), and the basis of calculation is different. We may conclude, however, that

- (i) The best height for the 3" Mk. IV mortar bomb is higher than that of either of the 81 mm shell.
- (ii) The 3" Mk. IV mortar is probably more effective than either of the 81 mm shell against slit trenches, foxholes, and prone men.

The reasons for this are as follows:-

- (i) In T.D.B.S. Report No. 60 the criterion of effectiveness of fragments is 58 ft.lbs. energy which underestimates the effectiveness of small fragments when compared with the Zuckerman criterion. Part of the apparent superiority of the 3" Mk. IV bomb is, therefore, due to the use of different criteria and not to a real difference in effectiveness. The more stringent criterion used in T.D.B.S. Report No. 60 will also lower the best height relative to the present calculations.
- (ii) The high fragment velocity and low terminal velocity of the 81 mm shell give very little forward throw of fragments, whereas the low fragment velocity of the 3" Mk. IV bomb allows a considerable forward throw to take place even when the residual bomb velocity is low. Part III of this paper shows that this forward throw will increase both the best height and the effectiveness.
- (iii) The fine fragmentation of the 3" Mk. IV bomb due to its cast iron case, and the greater weight of metal available for fragmentation due to its lower capacity, more than compensate for its low fragment velocity, and lead to greater effectiveness.

The British 3" Mk. III (Steel) mortar bomb would be more similar in effect to the American bombs than the 3" Mk. IV.

### Part III - Effectiveness of a Forward Fragmenting Bomb

#### 9. Type of Bomb

It is desired to find what increase in effectiveness might be expected from a specially designed forward fragmenting mortar bomb with V.T. fuze. In order to simplify the calculations the following mortar assumptions have been made:-

- (a) The weight of metal available for forward fragmentation is 6 lbs. If the 3" mortar bomb is to retain its normal weight of approximately 10 lbs. the weight of metal available could hardly exceed this figure.
- (b) The metal splits up into equal fragments of weight 1/64 oz. Preliminary calculations (see Appendix A) indicated that this was a slightly more effective size than 1/125 oz. or 1/37 oz. fragments, although variation in best area of effect is small, and that it is near the best fragment size for this purpose. Uniform fragment size gives larger areas of effect than normal fragmentation, provided that a sufficiently small size can be produced; the areas of effect calculated on this assumption are therefore believed to be near the maximum attainable.
- (c) The fragments are uniformly distributed over a forward cone.
- (d) The initial fragment velocity is 3000 ft/sec.

The methods by which this type of fragmentation could be secured are not discussed here, but a bomb employing the domed head principle might be suitable.

#### 10. Method of Calculation

The method of calculation is the same as in Part II, simplified by the assumptions of equal fragments and a uniform fragment zone. The only target considered is men crouching in trenches since it is against this type of target that the greatest improvement is expected.

#### 11. Results

The best height of burst has been calculated for fragment zones of various sizes, and the results are given in Table VIII and shown graphically in Figs. 4 - 6. No allowance for variation in set height or for failures has been made.

Table VIII

Variation of Best Height of Burst and Area of Effect with Fragment Zone

<u>Semi-angle of Forward Fragmentation Zone (degrees)</u>	<u>Best Exact Height of Burst in feet</u>	<u>Corresponding Area of Effect in square feet.</u>
10	114	1200
20	82	2100
30	64	2900
40	52	3650
50	44	4000
60	38	4080
70	35	3900
80	32	3560
90	30	3180

If allowance is made for 20% failures and a variation in height of standard deviation  $1/3 h$ , the best area of effect, which is that for a semi-angle of  $50^\circ$  to  $65^\circ$  at a set height of about 40 ft., is approximately 3000 square feet.

## 12. Discussion

Fig.4 shows how the best height of burst decreases as the fragment zone becomes wider. Fig.5 shows how the area of effect at the best height of burst varies with width of fragment zone; the curve has a fairly flat maximum such that any width between  $45^\circ$  and  $70^\circ$  semi-angle gives a value within 5% of the optimum. Fig.6 shows the variation in area of effect when height of burst and width of fragment zone vary independently.

Against men crouching in slit trenches the best area of effect for the 3" Mk.IV mortar bomb, and the specially designed bomb are respectively 800 and 3000 square feet, showing a possible improvement of rather less than 4 times. Since we have, if anything, overestimated the possibilities of the specially designed bomb it would be unwise to expect a practical improvement of more than 3 to 1 if the mortar bomb is to be limited to a weight of 10 lbs. In addition to this improvement against men crouching in trenches, some increase in effectiveness against men lying on rough ground and a considerable decrease in effectiveness against men standing or running in the open might be expected.

Prepared by G. D. Kaye for A.O.R.S.7.  
(O. i/c. F. R. N. Nebarro)

*H. A. Sargeant*

Superintendent, A.O.R.G.

APPENDIX A

Best Fragment Size for a Forward Fragmenting Bomb

The following table shows the number of incapacitating fragments at various distances from the burst produced by 6 lbs. of metal breaking up into fragments of equal size travelling with a velocity of 3000 ft/sec.

Fragment Weight (m)	1/37 oz.	1/64 oz.	1/125 oz.
$\frac{1}{m^3}$	0.3	0.25	0.2
Number of Fragments	3556	6144	12,000
Number of Incapacitating Fragments at			
20 feet	3556	5837	9600
40 "	3414	5222	6120
60 "	3165	3809	3000
80 "	2560	2580	2160
100 "	2169	1905	1440

It will be seen that the 1/37 oz. size is best over 80 feet, the 1/64 oz. size best in the range 50 - 80 feet, and the 1/125 oz. size best up to 50 feet against men crouching in slit trenches. Calculations of the areas of effect show that the range 50 to 80 feet is the most important, for example if we take a fragment zone of semi-angle 60° we obtain the following results.

Fragment Size	Best Exact Height of Burst	Corresponding Area of Effect
1/37 oz.	44	3530
1/64 oz.	38	4080
1/125 oz.	36	4030

It is obvious that over the range from 1/37 to 1/125 oz. the fragment size has very little effect on the best height or best area of effect and that the size we have chosen is representative of the whole range.

APPENDIX B

If the angle of descent is taken as 45° instead of 70° the results are modified as shown below:-

Fuzing and Target	Angle of Descent 45°		Angle of Descent 70°	
	Best Set Height of Burst (feet)	Corresponding Mean Area of Effect(sq.ft)	Best Set Height of Burst (feet)	Corresponding Mean Area of Effect(sq.ft)
<u>Nose Initiation</u>				
(a) Men Crouching in trenches	22	800	17	800
(b) Men lying on rough ground	24	2150	19	2950
<u>Tail Initiation</u>				
(a) Men crouching in trenches	23	950	21	1200
(b) Men lying on rough ground	26	2500	24	3400

Target	Performance of V.T.Nose Fuzed Bomb relative to D.A. Fuzed Bomb = 1		Performance of Tail Fuzed Bomb relative to Nose Fuzed Bomb = 1	
	Angle of Descent 45°	Angle of Descent 70°	Angle of Descent 45°	Angle of Descent 70°
(a) Men crouching in Trenches	7	7	1.2	1.5
(b) Men lying on rough ground	3	3.5	1.2	1.2

It will be noted that for 45° descent compared to 70° descent

- (a) The best height of burst is higher, the increase being greater for nose initiation.
- (b) The advantage of the V.T. fuzed bomb over the D.A. fuzed bomb is decreased against men lying on rough ground.
- (c) The advantage of tail initiation over nose initiation is decreased against men crouching in trenches.
- (d) These differences are small, and the result for 70° descent may reasonably be considered to apply for all angles of descent above 45°.

FIG.1

3" MORTAR MK. IX.  
AREA OF EFFECT OF BOMB AGAINST MEN CROUCHING IN SLIT TRENCHES

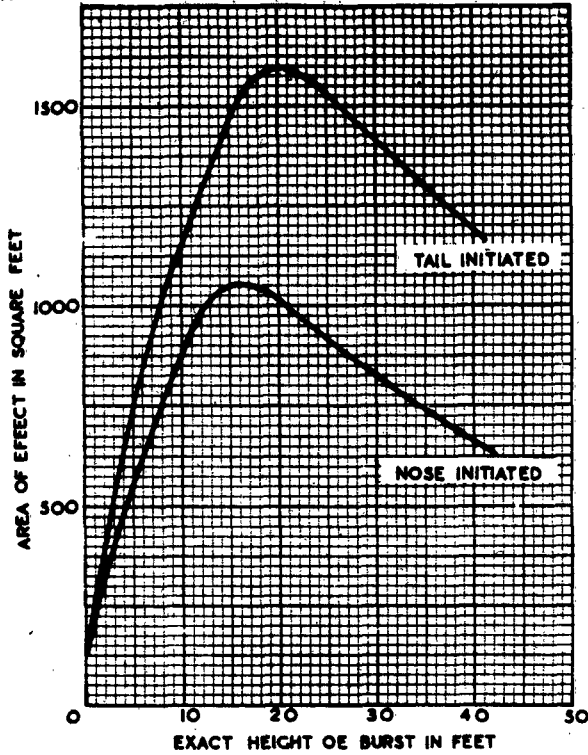


FIG.2

3" MORTAR MK. IX.  
AREA OF EFFECT AGAINST MEN LYING ON ROUGH GROUND

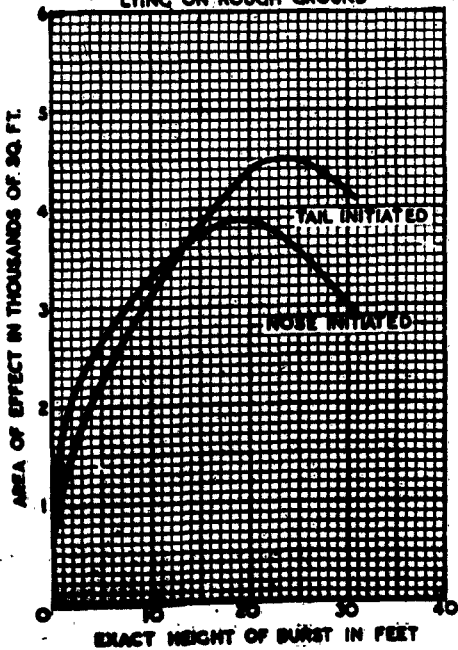


FIG.3

3" MORTAR MK. IX.  
AREA OF EFFECT AGAINST MEN RUNNING IN THE OPEN

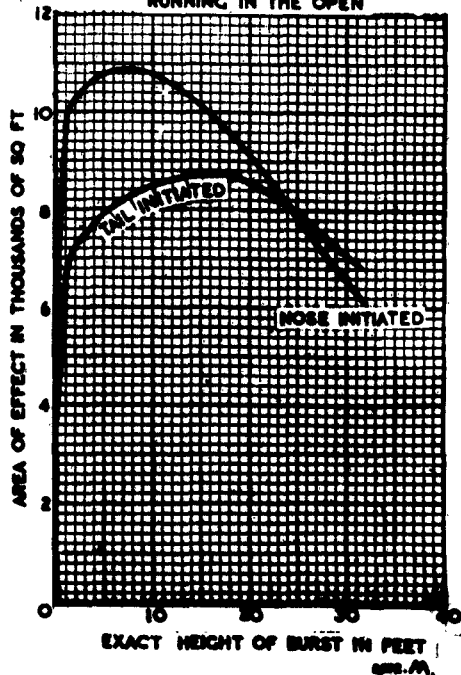


FIG.4

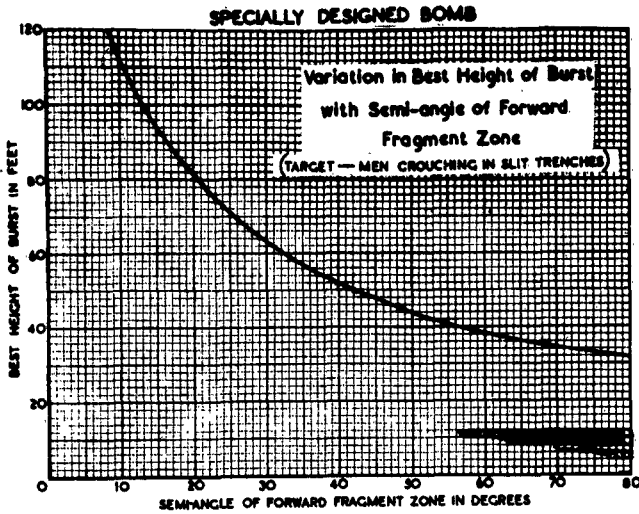


FIG.5

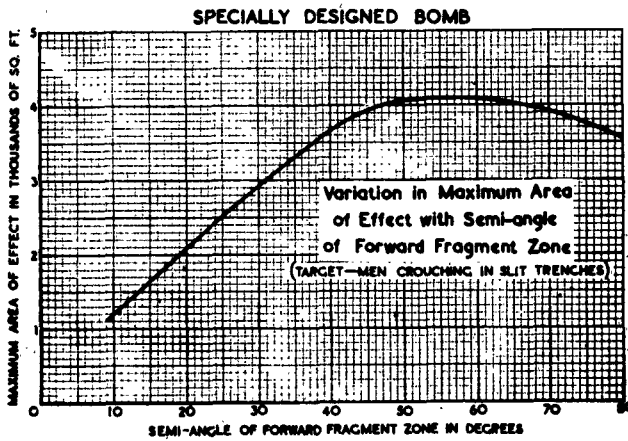
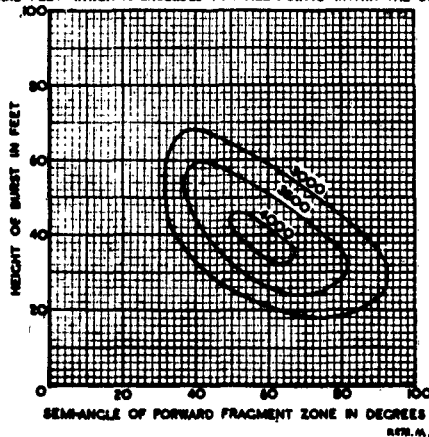


FIG.6

Contours showing Area of Effect of a Specially Designed Bomb against Men Crouching in Slit Trenches as a function of Height of Burst and Semi-angle of Forward Fragment Zone  
THE FIGURE ADJACENT TO EACH CONTOUR SHOWS THE AREA OF EFFECT IN SQUARE FEET WHICH IS EXCEEDED FOR ALL POINTS WITHIN THE CONTOUR





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