Introduction

This document is a companion document to the WW2 anti-tank gun penetration performance file, and I hope it will prove of equal or greater interest to WW2 wargamers. It differs from the ATk penetration file in its wider subject-matter and narrower range of sources. This is because, while information on anti-tank guns is frequently presented in popular works, data on the effectiveness of artillery or small arms is much rarer. All the sources currently cited here are documents from the PRO, Kew, in the series WO 291, which are reports and memoranda from operational research (OR) sections during and after WW2. The papers drawn on, in numerical order, are:

Introduction

WO 291/171, /180 and /741, which contain information on the accuracy and penetration of anti-tank guns, are summarised in the ATk penetration file.

This is an extensive series, and the material presented here has been chosen and points extracted to suit my personal taste and interest in limited available time. I have concentrated on papers that looked as if they might be informative on the effectiveness of artillery or small arms; it is not always obvious from the title exactly what a file contains.

Many of the papers concern field trials of fragmentation weapons. In these, wooden (I believe pine) board targets were set up, and the fragment impacts on them counted. Results are often expressed in "deep strikes and throughs". Using Professor Zuckerman's wounding criteria, penetration of one inch of wood was considered equivalent to incapacitating a man. "Throughs", obviously, are where fragments completely penetrate the target.

I have not been able to discover any difference in intended meaning between "vulnerable area" and "lethal area" when used in the context of fragmentation weapons. The two terms appear to be used interchangeably.

The usual common-sense cautions about the variability of results in real life apply, and in some cases the papers draw attention to the imperfect nature of their estimates. Wherever a passage appears in "quotation marks", it is copied verbatim from the original report.

Imperial units are used in all the source documents, and I have retained them here. In order to facilitate conversion to SI units, a note on conversion factors is included at the end of the document.

As ever, I would welcome comments, corrections or additions by e-mail to John.Salt@Brunel.ac.uk. If you can supply additional information on artillery or small-arms effectiveness, please be sure to include title, author, publisher and year of publication for any source you refer to.

John D Salt 16 December 1998

WW2 weapon effectiveness

WO 291/107 Comparison of the 7½lb and 10lb 3" mortar bomb.

The effectiveness of each is the same, as for some unknown reason the 7½lb bomb fragments more efficiently.

"For normal angles of descent (60º–70º) therefore the fragments sweep the ground all round the bomb with approximately uniform density."

Results of screen tests, deep strikes and throughs per square foot:

	7½lb bomb			10lb bomb	
Range (ft)	Calculated	Observed	Range (ft)	Calculated	Observed
20	0.318	0.135	15	0.511	0.333
40	0.063	0.066	30	0.116	0.444
60	0.25	0.022	45	0.061	0.062

"The chance per round of knocking out a point target is found to be approximately 1 in 16, so that after 20 rounds against an unprotected point target 70 per cent of the men present would have become casualties."

The results for the 10lb bomb are acknowledged to be anomalous.

The kill probability per round is given as 0.06.

It is stated that r.m.s. errors (whatever they are) are 80 × 20 yards.

WW2 weapon effectiveness

WO 291/113 Lethal effect of artillery fire.

The results presented in this paper are based on a trial conducted at the School of Artillery on 22 June 1943. 81 wooden targets were set out in a 9×9 grid 100 yards wide and 150 yards deep. Six series were shot as follows:

Series	Shell	Filling	Fuze	Action	Rounds fired	Effective rounds
1	25 pr HE Mk ID	TNT	222	Time airburst	100	85
2	105mm HE Mk 1	Amatol 50-50	M48 (delay)	Ricochet	100	95
3	75mm HE	TNT	M48 (delay)	Ricochet	38	29
4	25 pr HE Mk ID	TNT	231 Mk IV	Ricochet	100	82
5	25 pr HE Mk ID	TNT	118 Mk IV cap off	Instantaneous DA	200	159
6	25 pr HE Mk ID	TNT	118 Mk IV cap on	Short delay percussion	200	181

The effect on the targets was recorded as follows:

Series	Effective rounds	Strikes	Tgts incapacitated	Lethal area (sq ft)
1	85	12	9	340
2	95	65	65	3000
3	29	33	33	2500
4	82	26	26	720
5	159	61	61	2300
6	181	29	29	780

Ground was considered to shield one-third of the fragments that would otherwise hit standing men.

Airburst shells were considered to be no better than goundburst against targets in slit trenches, despite a theoretical prediction of a 2:1 improvement.

WW2 weapon effectiveness

WO 291/128 A theory of fragmentation.

The table below shows the "vulnerable areas" of various weapons, in square feet, making no allowance for ground effect. Protection levels shown are in thicknesses of mild steel in inches. Fragment velocities are in feet per second.

Weapon		Filling	Frag vel	No prot	¼ inch	½ inch	1 inch	2 inches
25 pdr		TNT	2200	3000	550			
		Amatol 50/50	1800	2650				
		Amatol 60/40	1800	2000	300			
	Ford steel	"	1800	3000	130			
95mm		TNT	3200	3270	780	140		
		Amatol 50/50	2800	3600				
5.5"	80lb shell	Amatol 50/50	2750	5400	1470	500		
	100lb shell	Amatol 70/30	2100	5600	1400	330		
3" 20cwt		TNT	1800	1950				
4.5-inch		"	1900	4200	800			
Bofors 40mm		"	2500	500				
Oerlikon 20mm		"	2650	220				
3" U.P.		"	4500	3450	600			
3" mortar	steel	Amatol 80/20	3000	8500	1100			
4.2" mortar		"	3000	9400	1900	300		
20lb "F" bomb		"	3500	9100	2100	400		
40lb GP bomb		Amatol 60/40	3500	12750	3900	1200		
250lb GP bomb		"	5000	38400	17400	9500	2500	
500lb GP bomb		"	"	45400	22900	14200	5100	350
1000lb GP bomb		"	"	68100	34600	21400	8400	440
250lb MC bomb		"	6500	35000	14300	7600	2000	
500lb MC bomb		"	"	40000	19500	11900	4600	400
1000lb MC bomb		"	"	62700	31600	20100	8400	1100

The vulnerable area for the 2-in mortar bomb (filled with baratol) is quoted as 2060 square feet by Professor Zuckerman, calculated as 1800–1900 square feet in theory. Figures for 3-in mortar including ground effect are 5,350 sq ft for the 7½ lb bomb, 5,700 sq ft for the 10lb bomb.

The expected difference in performance between GP and MC bombs was not shown.

WW2 weapon effectiveness

WO 291/129 Lethality of 3" mortar HE bomb.

The cast iron (Mark IV) bomb is about 70% better than the steel (Mark III) bomb, due to finer fragmentation.

Stick fuzes would probably add 65% to the effectiveness of the cast iron bomb, 25% to the steel.

Time-fuzed HE was considered "practically valueless" due to the zone of the fuze and the steep angle of descent.

"Jumping" mortar bombs might perhaps be up to ten times more effective against entrenched troops, whereas the stick fuze would be no more effective.

"Preliminary results obtained by AORS7 show that the reduction in overall lethality by small bumps may be as much as 6 times for men lying down."

Vulnerable areas are given as 3,200 square feet for the steel bomb, 5,500 the cast-iron.

Probability of incapacitation (%) for each type of bomb are given as:

Range (feet)	10	20	30	50	100
Cast iron	100	73	48.5	22	1.5
Steel	90	48	29	9.3	1.2

It is suggested that these can be usefully presented in two ways; either as percentage chances, or as odds.

As percentages at different ranges (yards):

Range (yds)	2	5	10	20	40
Cast iron	100	90	50	12	1
Steel	100	60	30	5	1

As ranges (yards) at which different odds apply:

Odds	10-1 on	Evens	3-1	10-1	100-1
Cast iron	5	10	15	20	40
Steel	3	5	10	15	40

WW2 weapon effectiveness

WO 291/138 Influence of ground cover on performance of HE projectiles.

Ground is considered to fall into one of five categories:

Cover rating		Description
I	Very poor	Sandy beaches
II	Poor	Bare heath, links, level grassland
III	Average	Most grassland, woods (ignoring trees)
IV	Good	Rough grass, old ploughland (3 weeks or more), land with strong undulations.
V	Very good	Ground with anthills, or strewn boulders; freshly ploughed land; old tank park.

Cover factors for each kind of ground are:

Rating	Ground cover factor		Lethal area	
	25 pdr	3" mor C.I.	25 pdr	3" mor C.I.
I	1–2	1–1.5	2000	8000
II	2–4	1.5–2	1000	6000
III	4–6.5	2–3	500	4000
IV	6.5–10	3–4	350	3000
V	>10	>4	<250	<2500

Effect of height of burst for 25pdr is given as:

Height (ft)	1	2	3	4	6
Cover factor	5.3	3.1	2.7	2.1	1.6

WO 291/146 Dispersion of M48 HE shell from 75mm M3 gun in Sherman M4A4.

90% zone of the shell, at the following ranges:

Range (yds)	Charge	Vertical (feet)	Horizontal (yards)
1000	Normal	3	35½
2000	"	8½	46½
3000	"	18	56
4000	"	39	83½
1000	Super	2½	59
2000	"	7	67
3000	"	13	66½
4000	"	27½	82½

WW2 weapon effectiveness

WO 291/150 WP as an anti-personnel weapon.

White phosphorous is considered especially effective against targets in slit trenches, as the burning lumps of phosphorous lose velocity quickly and fall vertically.

Soft ground decreases effectiveness; slit trenches halve the "incendiary area".

It is recommended that when WP smoke is used for screening, it should be placed directly on the enemy position to be screened. The advantages are both casualty effect and screening regardless of wind direction.

Infantry follow friendly artillery "perhaps as close as 70 yards".

"...battle experience has shown that flat trajectory support has not the same neutralising properties as 'crump', unless targets are accurately located, which is not often the case."

Four kinds of WP-filled projectile were available, with weights and fillings as follows:

Weapon	Overall weight	Weight of WP
77 grenade	12 oz	8 oz
2-in mortar	2¼ lb	5 oz
3-in mortar	10 lb	1½ lb
4.2-in mortar	20 lb	5 lb

The "incendiary area" (analogous to "lethal area" or "vulnerable area") of each, in square feet, is:

Weapon	Troops in the open			In slit trenches	
	Hard ground	Soft ground	Marshy ground	Hard ground	Soft ground
77 grenade	800				
2-in mortar	700				
3-in mortar	2700	1800	550	1500	
4.2-in mortar		5000			3000

The choking effect of WP smoke is mentioned. It is also mentioned that burns contaminated with phosphorous are extremely painful, but that the effects of WP are unlikely to be lethal.

If four 3-in mortars fire 100 HE bombs into an area 100 yards square occupied by a platoon (48 men) in slit trenches, it is considered that there is a 60% chance of destroying one trench (4% of the platoon). The same number of WP bombs is expected to result in 40% casualties. The same results could be achieved with about half the number of 4.2-in bombs.

WW2 weapon effectiveness

WO 291/157 Performance of 2-in mortar.

Results from trials performed in 1942. Use of the no. 2 sight is recommended to improve accuracy.

The 2-in smoke bomb was criticised for leaving smoke trails that were thought to give away the firing position; in fact the problem was with smoky propellant.

It is mentioned that the chance of hitting a target under 2-in mortar illumination at night is approximately one-third of the chance in daylight.

The following table gives the hit probabilities and number of rounds needed to secure a 50% chance of incapacitating the target, a standing man, at the ranges given:

Range (yds)	200 LA	400 LA	525	400 HA	200 HA
Hit probability	10%	3.8%	6.8%	4.9%	6.0%
No. bombs	7	18	10	14	12

WO 291/163 Smoke fog trials.

Trials were performed with lines of smoke generators up to 1000 yards long. The limiting wind-speeds for formation of an efficient smoke blanket, over flat ground with scattered belts of trees, were found to be 3 and 10 mph.

The optimum visibility for sub-units attacking, whether infantry on infantry or tanks on ATk guns, was, according to the trials participants, 15 to 25 yards.

"Even with so low a visibility as 20 yards, the infantry defender has an advantage of 7 seconds over the attacker as regards first sight. With greater visibilities, the advantage increases almost linearly."

The maximum useful visibility was 25 yards, which produced no difficulty in controlling a platoon provided that direction can be assured. Visibilities of 50 to 100 yards offer little protection against LMGs and small arms.

When tanks are attacking in visibility of 15 to 25 yards, "the interval of time between mutual sighting is so reduced that the tank has a very good chance of overrunning the gun before the latter can fire. In such densities of smoke the telescopic sight is useless, and the tank will depend on overrunning and its secondary armament.

The maximum range of the manpack flamethrower is given as 40 yards.

WW2 weapon effectiveness

WO 291/166 Accuracy and dispersion of fire from a 25-pdr troop.

This trial was conducted in 1943, consisting of six shoots with a troop of four guns.

The observed 50% zones, in yards, for each gun, for each shoot, were:

Shoot	1		2		3		4		5		6	
	Charge III		Charge III		Charge III		Charge III		Charge II		Charge III	
Gun	range	line	range	line	range	line	range	line	range	line	range	line
1	49	9	20	10	90	10	98	11	122	5	5	11
2	67	10	47	6	54	20	60	19	96	13	91	12
3	127	19	52	11	49	14	89	3	118	6	132	10
4	31	13	58	14	55	21	44	10	95	6	67	4

The number of ranging shots fired, for each shoot, were:

Shoot	1	2	3	4	5	6
Range, yds	6900	7150	7150	7000	6900	6900
Shots	9	8	14	7	13	13

For each shoot, the maximum errors in range and line, in yards, were:

Shoot	1	2	3	4	5	6
Range	+ 75	+143	+108	+62	+246	+187
Line	–106 (twice)	–35	–137	–179	–74	–100

WO 291/204 Japanese tank fighting methods.

"Until recently their heaviest ATk gun was the 37mm, which had approximately half the penetration of the 2-pdr firing APCBC shot."

"One Matilda at Finschhafen took 50 hits from a 37mm and a 75mm, and was only disabled eventually by a hit on the track and track adjuster. (Realising the 37mm will not penetrate the Matilda the Japanese are now shooting at the tank tracks)."

A 75mm hollow-charge round is estimated to have a penetrating performance of between 50 to 100mm of homogenous armour at normal, probably 80mm.

"One report mentions a 75mm AP round which just penetrated a Stuart turret at 50–80 yards."

The 75mm Model 88 AA gun has been used in the ATk role, on one occasion knocking out four light tanks, but it has a low velocity for an AA gun and penetration is only slightly better than the Model 90 field gun.

A hollow-charge ATk rifle grenade, similar to the German Gross Gewehr PanzerGranate 40, has a penetration performance of 50mm of mild steel.

A frangible Prussic acid gas grenade captured in Malaya contained 278 grams of HCN.

WW2 weapon effectiveness

WO 291/220 Dispersion and suggested bracketing drill for 95mm Tank Howitzer.

The following horizontal and vertical 90% zones and horizontal 50% zones are given for HE Mark IA from the 95mm Tank Howitzer:

Range	90% zones		50% zone
(yards)	Vertical (ft)	Horizontal (yds)	Horizontal (yds)
500	2.2	30.5	12.5
1000	8.5	54.0	22.0
1500	18.6	75.0	30.8
2000	32.2	94.0	38.5
2500	49.5	109.0	44.5
3000	69.5	119.0	49.0
3500	92.0	126.0	51.5
4000	118.0	131.0	53.5
4500	147.0	136.0	56.0
5000	177.0	141.5	58.0

WO 291/262 Study of casualties caused by bombardment.

"25 pdr equivalents" for two weapons, in nominal lbs:

Weapon	Warhead weight	HE weight	25-pdr equivalent
5-in rocket	29lb	7.0lb	50
105mm shell	33lb	4.9lb	40

Lethal areas for CB on gun targets, 5.5in 98½lb shell:

Target weapon	Lethal area, sq ft
150mm or 170mm gun	1300
75mm or 105mm gun	700
88mm gun	1000

No data were available on the lethal area for Nebelwerfer targets.

Some CB results reported in this document show German 88mm guns surviving, for example, a medium round in the gun pit, or 4 field rounds in the gun pit. Killing guns seems to need a direct hit or a medium round.

Results from a 500lb & 1000lb bomb drop on German tanks in an orchard showed much higher effectiveness than expected – 13.4 bombs per acre on 12 tanks resulted in 3 destroyed and 6 damaged by fire. No apparent relation was observable between fire damage and distance from the nearest crater.

WW2 weapon effectiveness

WO 291/300 VT fuzes.

In four trials, rates of accurate fuze function were observed as 66.7%, 77.8%, 77.5% and 71.0%.

"It should be noted that for angles of impact less than 50° these best heights of burst are very much lower than the mean height of burst obtained." In other words, VT tends to burst too high unless fired well into the upper register.

Some selected mean heights of burst:

Fuze	Shell	Mean height of burst (feet)
T97E6	25-pdr	105
T97E9A	25-pdr	195
T97E9C	25-pdr	73
T98E6	3.7" AA	225
T100E6	5.5" 80lb	142
T100E6B	5.5" 80lb	76
T100E9A	5.5" 80lb	125
T100E6	7.2"	173

WO 291/307 Effectiveness of the 'S' mine 35.

This report states that lethal area is not a good measure of effectiveness for mines.

Average chances of becoming a casualty at different distances from the mine are deduced from a casualty survey, and from a dummy trial.

From the casualty survey:

Range (feet)	Casualties	Exposed	Percentage
10	83	99	84
20	34	57	60
30	13	36	36
50	9	42	21
80	5	25	20

From the dummy trial:

Range (feet)	Casualties	Exposed	Percentage
5 to 10	2	3	67
15	6	8	75
20	3	7	43
30	5	13	38
40	5	32	16
60	10	72	14
80	4	97	4
100	1	98	1

WW2 weapon effectiveness

WO 291/308 Effect of flamethrowers on military personnel.

Users believe from experience in action that flamethrowers have a strong morale effect.

It is estimated that a gallon of burning fuel in contact with the victim will kill.

Information from flame actions showed an average of 270 gallons per death, 9 gallons per prisoner.

Discharge rates are 4.7 gallons/sec for the Crocodile, 1 gallon/sec for the manpack.

Thickened fuel gives a clean flame rod, with little or no obscuration, and the fuel continues to burn on the ground.

Unthickened fuel produces a sheet of billowing flame, much obscuration, and little burning on the ground.

This obscuration effect could be used to blind pillbox slits at 20 yards or over with a manpack flamethrower, then approach to 10 yards, close enough to shoot through the aperture.

WO 291/324 Accuracy of first round in ATk engagements.

This paper considers the various sources of error in the first shot for anti-tank shooting, and concludes that the dominating source of error is in range estimation. The following figures show the expected range error, in minutes, of different gun and ammo combinations:

Ammunition	Gun	Range (yds)	Range error (mins)
APCBC	6 pdr	400	± 2.9
	17 pdr	1000	± 6.3
APSV/DS	6 pdr	400	± 3.7
(zeroing with APCBC)	17 pdr	1000	± 5.2
APSV/DS	6 pdr	400	± 3.6
(zeroing with APSV/DS)	17 pdr	1000	± 5.1

1 minute of arc corresponds to an error of 4.2 inches at 400 yards, or 10.5 inches at 1000 yards.

WW2 weapon effectiveness

WO 291/383 Effectiveness of airburst HE.

This investigates the effectiveness of airburst HE using the 210 fuze. The 100% zone of the fuze is stated as 250 yards at 6000 yards. When combined with the "practical zone of the gun" for the 25-pdr of 160 yards, this gives (taking the square root of the sum of the squares of the two figures) a combined zone of 300 yards.

The difficulty of firing airburst is stressed, as the observer must adjust fire in three (range, line and fuze length), rather than two, dimensions. Adjustment is hard unless, as in dry dusty soil, the splinter pattern can be seen.

"The American SP 105mm with which one regiment is equipped, is provided with a proportion of time fuzes, and airburst HE was used against ATk gun detachments, and in the opinion of observing officers, its neutralising effect was far quicker and more effective than that of HE burst on the ground."

If a man is in cover such that he will only be hit by fragments coming down at angles over 45° to the horizontal, the lethal areas against targets in slit trenches vary with height of burst as follows:

Height (ft)	0	25	50	75	100	200	300	400	600
Lethal area (sq ft)	25 (direct hit)	400	800	900	800	500	350	250	180

WO 291/389 Weapon analysis memo.

This mentions that "...until quite recently, it was not known that very small fragments of shells, weighing less that 1/100 of an ounce, can easily kill a man."

WO 291/391 Night operations.

This 1943 paper suggest that night operations have so far been neglected. It offers various advice about preserving dark-adaptation and seeing at night, and the following table, giving ranges of visibility, in yards, of a man in khaki or field grey:

Lighting	Background		
	Snow or sky	Grass	Plough
Full moon	300	150	100
Half moon	150	75	50
Starlight	100	30	15

WW2 weapon effectiveness

WO 291/399 Casualties to Churchill tanks in 25-pdr concentrations.

A trial conducted in 1943 tested proposed new tactics, whereby Churchills would advance though concentrations of friendly 25-pdr fire, by twice driving a squadron of Churchills through live artillery fire. It is concluded that the worst that can happen to a Churchill in these circumstances is immobilisation. The effect of a 25-pdr round exploding on a Churchill is described thus:

"There is no adverse effect on the crew from a 25 pdr direct hit. Fragments cannot penetrate the tank, and the blast is not at all uncomfortable."

WO 291/410 A comparison of British and German mine detectors.

This paper concludes that there is "little to choose between them".

The average horizontal distance at which buried German ATk mines were found was 26 inches with the German detector, or the British one with the large search coil. With the British detector fitted with the small search coil the distance was 21 inches, "quite adequate for its purpose".

WW2 weapon effectiveness

WO 291/443 Ranging procedure adopted with the 3" mortar.

This paper is dated 28 May 1943.

The drill is:

1. Fire an HE round at the estimated range.
2. If it lands minus, add (typically 100 to 200 yards) so that the next shot falls plus, or vice-versa.
3. Continue until a "long bracket" is obtained, that is, two bombs straddling the target at ranges differing by 100 yards.
4. Confirm a "short bracket" by observing two bombs fired at the same range fall plus and two more at a range 50 yards less fall minus.
5. Fire for effect at a range midway between the two ends of the short bracket.

If a "contradiction" is obtained – two bombs fired at the same range, one falling minus, the other plus –
and if this is supported by having observed a minus at 50 yards less range and a plus at 50 yards more, there is no need to confirm the short bracket, and fire for effect can begin at once.

At ranges below 800 yards, the commander may go straight to a short bracket without obtaining a long bracket.

The mortar must be re-laid for range between shots, but not for line unless in very soft soil.

The table below shows results from 12 ranging shoots (13 shoots were made but no results recorded from the first), showing which shots fell plus and minus, the range in yards at which fire for effect was ordered, and the method of obtaining the range, whether by contradiction or confirmed short bracket. N/O means not observed, B means blind.

Shoot	1	2	3	4	5	6	7	8	9	10	Range	How obtained
2	–	+	+	–	–	+	FFE				950	Contradiction
3	–	–	–	+	+	+	–	FFE			1625	Conf. SB
4	+	–	–	–	+	FFE					1675	Conf. SB
5	N/O	–	+	–	–	+	FFE				1175	Conf. SB
6	–	+	–	+	–	–	–	+	FFE		1075	Conf. SB
7	N/O	+	–	+	+	–	FFE				2325	Conf. SB
8	–	+	–	+	+	–	–	–	+	FFE	2275	Conf SB
9	–	+	B	+	+	+	–	FFE			2200	Contradiction
10	+	–	–	–	+	FFE					2175	Conf. SB
11	–	+	–	–	+	FFE					2275	Conf. SB
12	–	+	–	+	FFE						2300	Contradiction
13	–	+	+	+	+	–	FFE				2200	Contradiction

WO 291/455 Cutting of wire obstacles by HE.

A single 25-pdr shell will cut a gap of about 10 × 1½ feet.

A single gun or a battery of 25-pdrs ranged accurately on the same point will require about 1000 shells to cut a gap through a wire obstacle. One cut per foot is considered sufficient for an effective gap.

Bangalore torpedoes cut gaps of 19ft in British wire, 15ft in German wire.

WW2 weapon effectiveness

WO 291/464 Measure of effect of an HE weapon.

"Radius of effect is defined as the radius of a semi-circle in front of the projectile on which the average density of throughs and deep strikes on vertical wooden targets is 1 per 10 square feet."

As the radius of effect of a projectile is proportional to the square root of the weight, so the area is directly proportional to the weight. "As a general rule the vulnerable areas of a projectile is rather less than proportional to its weight."

WO 291/469 Ranging mortars at night.

3" mortar star shell (parachute illuminating) has a 10-second delay and burns for 30 to 40 seconds. It will illuminate the position of the mortar from which it was fired unless the range is over 500 yards.

Stars can be fired to 650 yards with 3 secondary charges. Using more risks tearing the parachute off, but with 6 secondaries 850 yards is possible. It is considered that ranging can be done at 900 to 1000 yards, or to 1400 if a second tube is used to fire the stars. It is important to economise on star shell, as few are likely to be carried.

The ranging drill, whether firing stars from the same or a different tube, is:

1. Fire an HE round.
2. Wait 5 seconds.
3. Fire a star, which should light in time to show the HE burst.
4. Fire a second HE.
5. Fire 3 MPI rounds and a star.

If a long bracket is obtained with the first two HE bombs, only 2 stars may be needed to range.

At longer (6 secondaries) range, this won't work. Instead, fire 3 HE and one star in 8 seconds, or, probably better, fire 1 star, wait 10 seconds, then fire 3 HE and repeat as necessary. Firing the star first gives a slightly longer time to apply corrections to the sights.

WW2 weapon effectiveness

WO 291/471 Weight of small-arms fire needed for various targets.

"These figures are exceedingly tentative, and it should be realised that even if correct, they may have little value in the Infantry battle, where the weight of fire needed is in general decided more by what is available, and then corrected empirically."

Targets are considered to be in slit trenches, exposing an area of ½ sq ft to fire, or pillboxes, exposing an area of ¼ sq ft to fire from an embrasure.

Two levels of neutralisation are recognised.

"Light neutralisation" is defined as the minimum weight of fire to appreciably effect the accuracy of enemy fire. The enemy will suffer casualties at a rate of 2½% per minute, or one man per platoon per minute, if they stay in a firing position for more than a third of the time they are fired on.

"Heavy neutralisation" is defined as the weight of fire needed effectively to stop any retaliatory measures on the part of the enemy, with a casualty rate of 10% per minute, or one man per section per minute.

It is estimated that a bullet passing within 3 yards sounded near enough to be dangerous.

Sections are assumed to be at full strength, 1+9, with Bren, Sten and 8 rifles, although it is acknowledged that rarely in battle will section strength exceed 1+6. Brens are assumed to fire 120 rds/min, rifles 18 rds/min. The range of engagement is assumed to be 100 to 200 yards. The effect of 2-in mortars is neglected.

Rounds per minute required to achieve neutralisation on target frontages in yards are:

Cover		Slit trenches			Pillboxes	
Frontage	100	20	4	100	20	4
Light neut	250	50	10	500	100	20
Heavy neut	1000	200	40	2000	400	80

Force required to give covering fire:

Cover		Slit trenches			Pillboxes	
Frontage	100	20	4	100	20	4
Light neut	1 sec	1 Bren gp or rifle gp	1 rifleman	2 secs	Bren gp or rifle gp	Bren gp or 2 riflemen
Heavy neut	1 pl + 1 sec	1 sec	1 Bren gp or 3 riflemen	1 coy	2 sec	1 Bren gp or rifle gp

WW2 weapon effectiveness

WO 291/472 Performance and handling of HE grenades.

A trial of grenade-throwing accuracy was conducted using the 36 grenade (Mills bomb), taking the average of 18 throws (3 throws by 6 men). The average errors, in feet, at different ranges were:

		15 yds	20 yds	30 yds	40 yds
Guards	Range	13	11	14	12
	Line	5	4	10	10
Devons	Range	–	26	11	14
	Line	–	9	8	11

For stick grenades, "the stick does not seem to increase the maximum accurate throw, but it does prevent rolling". Average errors and length of roll, in feet, are given as:

	Range	Line	Roll
Mills 36	15	8	9
Time-fuzed stick	8	8	3

Chances of incapacitation, at different distances from different grenades, are given as:

Distance	36 grenade	USA grenade		German stick grenade	
(feet)		Normal filling	TNT filling	On base	As thrown
3				97%	83%
6				92%	75%
9				70%	45%
10	45%	20%	40%		
20	17%	7%	18%		
30	13%	2%	10%		
40	10%	0.5%	5%		
50	–				
60	3.0%				
70	1.4%				
80	0.7%				

The USA grenade was given an experimental TNT filling for these tests. Only one German grenade was available, so this was fragmented on its base and the results used to calculate the expected results "as thrown", the orientation of a thrown grenade being significant in affecting its burst pattern.

The 36 grenade, it is stated. "has a very irregular burst".

The lethal area of the 36 grenade is given as 1550 sq ft on meadow land, and that of the USA grenade 350 sq ft. The lethal area of the 36 grenade is calculated as 2000 sq ft on perfectly flat ground, which would correspond to 1500 sq ft on normal ground. On perfectly smooth ground, incapacitation probabilities are stated as being 84% at 10 feet, falling to 14% at 30 feet.

Maximum throws, in yards, for different types of British grenade:

Grenade	Standing	Lying
70	33	31
71	28	23
36	30	26

"The conclusions with regard to the 69 grenade were:–
(i) A direct hit would be lethal
(ii) Apart from the concussive effect and flying stones there seems to be little probability of injury beyond a radius of a few feet."

WW2 weapon effectiveness

Length of throw, in yards, for British and US grenades:

	Standing behind cover	In the open	Crouching behind cover	Lying in the open
British 36	31		21	
US fragmentation	31		21	
British 69		32		26
US offensive		28		26

Average length of throw, in yards, for different British grenades:

Grenade	Standing behind cover	Crouching behind cover	Lying
70	29	24	23
71	25	22	22
36	30	25	24
69 (segmented jacket)	26	23	24
69 (plain jacket)	28	23	22

Screen test results giving percentage chance of incapacitation at different ranges:

Grenade	4 feet	8 feet	12 feet
70	85	39	20
71	98	63	36
36	73	29	14
69 (segmented jacket)	96	56	31
69 (plain jacket)	91	44	23

Finally, the average percentage chances of incapacitation at 10 to 20 feet are given as 33% for the 36 grenade, 25% for the US rifle grenade M9A1, an anti-tank grenade, but with good anti-personnel characteristics.

WW2 weapon effectiveness

WO 291/473 Performance of bullet weapons.

On the matter of relative rate-of-fire of the Bren and MG-42, this paper says "...the advantages of the German gun over the Bren are due almost entirely to the belt feed rather than to the cyclic rate."

A trial was conducted to find out, for closely-spaced standing targets, whether "traversing fire" – traversing the gun over an arc without aiming at individual targets – was superior to "service bursts", that is, firing short aimed bursts at individual targets, with the Bren gun. The results tabulated here show the expected number of casualties per 30 seconds' firing:

Range (yds)	Spacing in feet	Service bursts	Traversing fire
100	4	9	16
100	8	5	8
200	4	8	12
200	8	5	7

Another trial concerned the relative accuracy of the Bren fired from the hip using ball and tracer ammunition. Firing at fixed targets at 35 yds and moving targets at 17 yds, an improvement averaging 24% was found firing tracer rather than ball.

Yet another trial involved comparing the Sten gun against the service pistol. At a range averaging 10 yards, the following average results were obtained on targets exposed for an average of 5 seconds and moving across the line of fire at 10 feet per second:

Type of fire	Hits per shot	Hits per engagement	Shots per engagement
Sten from the hip	0.12	1.86	16
Pistol from the hip	0.08	0.48	5
Pistol, aimed	0.14	0.71	5

WW2 weapon effectiveness

WO 291/474 Rate of fire of the LMG.

In trials held in 1944, the average time of Bren gunners needed to re-aim in between bursts was measured as 2.3 seconds; to change mag and re-aim, 3.8 seconds. These figures are not fast enough to maintain the official "rapid rate" of 112 rds/min, which would need 1.8 and 3.3 seconds respectively.

Four theoretical gun types were considered:

Gun	Cyclic rate of fire	Feed	rds/min burst fire	rds/min continuous fire
A	500	mag	112	218
B	1000	mag	120	285
C	500	belt	124	400
D	1000	belt	134	660

The above figures assume no time to change belts, but 9 seconds to change barrel after 280 rounds.

"It will be very exceptional for the LMG to be fired at a greater range than 600 yards by forward troops."

Trials were conducted on the time required to duck to cover on hearing a loud noise. They showed an average of 0.19 seconds to start ducking, and 0.56 seconds to get completely under cover. An average of about 20% improvement was expected for the belt-fed guns due to higher rate of fire. If being used to neutralise 8 targets over a frontage of 20 to 40 yards at a range of 100 to 200 yards, the relative neutralisation values of the guns in terms of targets neutralised were evaluated as 6 for gun A, 7 for gun B, and 8 for guns C and D.

Firing burst in defence, the relative advantages of the guns in casualty-causing potential were estimated at +7% for gun B, +11% for gun C and +20% for gun D, with even greater advantages for the faster guns if using traversing fire.

Expected casualties caused by each gun using traversing fire on 24 men spaced at 6 ft intervals:

Gun	A	B	C	D
½ minute	13	15	18	22
1 minute	19	21	23	24

Enfilade fire gives much bigger advantages to faster rates of fire; gun B +20%, gun C +100%, gun D +220%, though no allowance made for over-hitting.

WW2 weapon effectiveness

WO 291/476 Comparison of rifle, Bren and Sten.

This paper investigates four theories about small-arms effectiveness:

1. Rifle and Bren shooting is generally so poor that the real accuracy of these weapons is never used;
2. Rifles and Brens are rarely used at long ranges except by snipers;
3. For semi-skilled troops, automatic weapons are disproportionately better than single shot;
4. The advantage of automatic over single-shot is increased by battle conditions.

Trials conducted at the School of Infantry confirm 1, 2 and 4. "It is admitted that all the above trials have been on a small scale and that and that the sample of men was probably not representative of the Infantry as a whole; but it is expected that the trends shown will hold for all except possibly the first class shot."

The Bren and Sten were fired at 100, 200 and 300 yards, and the equivalent 90% zones, in inches, calculated at 25 yards.

	Single shot		Automatic	
	Bren	Sten	Bren	Sten
100 yds	2.4	4.3	3.8	4.6
200 yds	2.0	5.2	4.4	5.0
300 yds	2.0	5.4	3.8	5.6
Mean	2.2	5.0	4.1	5.0

Shooting was done lying with weapon rested; an improvised backsight was fitted to the Sten for shooting at 300 yards. An extra trial to confirm the lethality of Sten bullets at 300 yards was performed with ¾" deal targets covered in two thicknesses of webbing. All hits were "throughs".

Another set of trials, each of 20 rounds, was shot on a 30 yard range, and the following results obtained. It was noted that "the average firer has a higher overall chance of hitting an enemy at 200 yards with a Sten than with a rifle."

Weapon	Fire type	90% zone (inches at 25 yds)	% chance of a hit on a man at 200 yds	
			single shot	4-rd burst
Rifle (unrested)		3.1	57	
Bren	single	2.9	60	
	burst	4.0		90
Sten (unrested)	single	5.6	31	
	burst	10.4		40
Sten (rested)	single	4.6	40	
	burst	6.7		68

A trial was performed on moving targets at 17 yards. The targets were 4ft tall and 1ft wide, covering a 50 ft run, exposed for 5 seconds.

Weapon	Runs	Shots/run	Hits/run	Hits/shot
Rifle	6	2	1.3	0.67
Bren (single)	5	4	1.4	0.35
Bren (bursts)	6	6.8	1.2	0.17
Sten III (single)	10	5.6	2.0	0.36
Sten III (bursts)	35	12.1	4.4	0.38

"An analysis of the hits in each burst for 27 Sten runs showed that the most common number of hits per burst is about 1, thus disproving the suggestion that a high score in "bursts" is due to all the shots in one burst hitting."

WO 291/479 Optimum rate of aimed rifle fire.

"It has for some time been the practice at the School of Infantry and elsewhere to demonstrate a rifleman firing his rifle at a very high rate (up to 25 rounds per minute), and it has appeared to be questionable whether such a rate is worth while attempting."

A trial was conducted with 8 Guardsmen and 5 Canadians firing from the lying position at 25 yards. The average minimum and maximum rates of fire were 12.7 and 22.7 rds/min for the Guards, 13.2 and 19.5 rds/min for the Canadians.

The results were adjusted to give the following expected number of hits per minute on a 5ft × 1ft target at 200 yards:

Rate	10	12	14	16	18	20	22	24	26
Hits	3.8	4.5	5.1	5.7	6.2	6.7	7.1	7.5	7.9

WO 291/482 The indication of targets by infantry to tanks.

"It is realized that before the infantry can indicate targets to tanks, they must have located them themselves first. This is a major problem in itself and frequently the infantry will not be able to locate targets accurately."

It is pointed out that a proportion of tanks used to carry the 38 set for communication with infantry, but, since the withdrawal of 38 sets from infantry use, there has been no common set in tank and infantry use. Although when tanks and infantry had worked together before procedures arranged locally were thought satisfactory, it was felt desirable to have some standardised procedure.

The paper describes trials in which various methods of target indication were tried. Only tracer (preferably coloured) and flares from grenade launchers or 2-in mortar were considered satisfactory. WP smoke was too obscuring. Because of the inaccuracy and short range of flares (370 yards for the 2-in mortar, which is also stated as the range of its WP round) verbal communication was also required.

The average time for 3 gunners in the trial using all methods of target indication was 58 seconds. A commentary on the paper pointed out that tank telephones had been used with success on operations.

WO 291/486 The indication of targets within the infantry section.

This paper, dated 10 Mar 1945, report trials conducted at the School of Infantry at Barnard Castle. The use of tracer is recommended.

The average time taken for a section to fire for effect on a target for various methods of target indication are given as:

Method	Verbal	Tracer	Observe strike	Smoke tracer	Observing amn
Time (sec)	29	20	26	24	33

WW2 weapon effectiveness

WO 291/491 Notes on R & A trials of British 3-in and German 8cm mortars.

This paper was published in 1943.

Times of flight, on targets about 2600 yards away, are typically around 24 seconds.

"It is safe to conclude that the difference in maximum range using top service charge is small."

"It is safe to conclude that both German bombs are more accurate in range than our own, and that the m.d. in range of either German bomb is probably more than half the m.d. in range of our own."

Average mean deviations in range and line, in yards, for three types of bomb:

Bomb	Range	Line
British HE Mk IV	62	11
German HE WGr 34	41.3	9.5
German HE WGr 59	43.9	7.0

On one shoot, a 3-in mortar was fired using 16 secondaries, well over the "top service charge", achieving a range of 3874 yards.

WW2 weapon effectiveness

WO 291/496 Anti-personnel effect of small HE shell.

"It is frequently stated that the 75mm HE shell is the smallest that is likely to be useful. This is probably the case at long ranges where the angle of descent is large, because the small shell will be mainly below the surface at the moment of detonation, and small irregularities in the ground will have a large screening effect. The calculations of this paper suggest, however, that at short ranges with ricochets smaller shells will be effective."

The paper reproduces the table given for cover factors at different burst heights given in WO291/138, but mysteriously labels the heights as being in inches, instead of feet. It states that these factors are for men lying down, and that the effects are negligible on men standing.

The calculated vulnerable areas of a some HE rounds are given as:

Shell	Filling	Vulnerable area (sq ft)
2 pdr Bofors	TNT	500
6 pdr HE Mk I/T/L	TNT	1430
75mm	TNT	3000
25-pdr	Amatol 60/40	3000

It is stated that a Bofors, if correct for line and with a mean range error of 30 feet, fuzed to burst over a trench, will give the following chances per round of inflicting a casualty:

2ft wide trench	2.3%
4ft wide trench	4.5%

For a trench not more than 4ft wide, giving no protection against fragments descending at more than 30° from the horizontal, the following probabilities of inflicting a casualty per round are given:

	Chance per round		
Burst height	75mm	6-pdr	2-pdr
5 ft	5.4%	5.4%	5.4%
10 ft	10.7%	10.3%	7.9%
20 ft	20.2%	12.3%	5.6%

"A longer delay with the 75mm HE shell would, theoretically, give a considerable advantage; it is however doubtful whether this would compensate for the disadvantages in ranging."

WW2 weapon effectiveness

WO 291/502 German infantry in action.

This is a training pamphlet issued to familiarise readers with German minor infantry tactics, highlighting the places where these differ from British practice.

The rifle section is composed as follows:

Sec comd	LMG no. 1	LMG no. 2	LMG no. 3	6 riflemen
SMG	LMG, pistol	pistol, amn box	rifle, 2 amn boxes	rifle

The fact that the MG no.1 and no.2 carry pistols is contrasted with British practice.

Section formations are single file and extended line. Unlike British practice, file and arrowhead are not used.

Single file has the sec comd leading, followed by the gun group. The gun group is always positioned near the sec comd, with the senior private as "bringer-up".

It is stated that the German platoon consists of four sections.

The sec comd directs the fire of the LMG, and often uses it only. Riflemen, in contrast to British practice, usually fire independently. Sections advance in single file as long as possible to permit supporting MGs to fire past the section, an evolution not envisioned in British practice.

In defence against AFVs, men without ATk weapons take cover and remain hidden. This contrasts with British practice, which is to engage (1) accompanying infantry and (2) tank vision slits with small-arms. Again in contrast to British practice, German documents make no mention of ATk obstacles and tank-proof areas.

The Germans place more emphasis than the British on concealment in defence. Great stress is placed on direct observation of the battlefield, and quick local counter-attacks are stressed more. Written orders are regarded as exceptional.

WW2 weapon effectiveness

WO 291/538 A preliminary estimate of the destructiveness of various projectiles against MT and guns.

Projectile	Effect on MT	Field guns
25-pdr TNT	No trials; VA probably about 500 sq ft	Small
25-pdr 60/40 Amatol	VA about half TNT	Smaller than TNT
95mm TNT	Apparently better than 25-pdr TNT	Better than 25-pdr TNT
4.5"	VA about half 5.5"	Considerably smaller than 5.5"
5.5" 80lb shell	Roughly equal to 100lb	Better than 100lb
5.5" 100lb shell	VA perhaps about 1200 sq ft	
2" mortar	Small but unknown	Probably negligible
3" mortar steel bomb	About twice as good as 25-pdr TNT; VA perhaps 800 sq ft	Small
3" mortar cast-iron bomb	Small but unknown	Probably negligible
4.2" mortar steel bomb	3–4 times as good as 25-pdr TNT; VA prob. about 1500 sq ft	About equal to 5.5" 100lb shell
20lb 'F' bomb	VA probably about 2000 sq ft	VA probably about 150 sq ft
40lb GP bomb	VA probably about 3000 sq ft	Rather better than 20lb 'F'
250lb MC or GP bomb	MC bomb VA of the order of 15000 sq ft	VA 5000 sq ft
500lb MC or GP bomb	MC bomb "slightly better" than GP bomb	VA 7500 sq ft
1000lb MC bomb	VA probably 20–25000 sq ft	VA 12000 sq ft

The figures for 250lb and larger bombs are based partly on calculations and partly on Prof. Zuckerman's report on Pantelleria.

For guns in pits the VAs will be about half these figures.

WO 291/543 Note on an experiment with Grenades 36 on dummy targets at Birmingham.

"One of the main effects of a grenade 36, indoors, is blast. Our methods do not, however, allow us to assess this effect quantitatively."

"Personnel within 3 feet of the burst stand a very small chance of escaping incapacitation if not otherwise protected. Ordinary doors and planks afford little protection, ceiling and floor together are good, and even a thin brick wall gives absolute cover against this weapon."

"A man would seem to stand a more than even chance of escaping incapacitation if 5 feet or more away from the burst. A fuller trial in the open at the School of Infantry (by AORG 6) showed a risk rate falling from 45% ten feet from the grenade to 17% twenty feet from the grenade."

WW2 weapon effectiveness

WO 291/559 The visual location of enemy positions.

This paper is mostly about the selection of men with good eyesight. However, it lists the following "main essentials" when spotting camouflaged enemy positions:

1. Proper scanning routine.
2. Elementary appreciation of the factors which make an object visible, such as colour, tone, contrast and shape.
3. Study of common object in unusual positions. "A man may be thoroughly familiar with an ATk gun as normally seen in lateral view and yet have no idea of what a German ATk gun looks like with the gun pointing at him."
4. A study of German camouflage methods.

WO 291/579 Comparison of mortar bombs.

The fragment velocity of the American 60mm mortar bomb is estimated at 4000 feet per second, as against 3000 for the British 3-in mortar and 4500 for the 2-in mortar.

Vulnerable areas for each, allowing for a ground cover factor of 1.5, are given as:

Bomb	Vulnerable area (sq ft)
British 2"	1200
American 60mm	2500
British 3" steel	5000
British 3" cast iron	6500

WO 291/596 Observations on tank casualties.

This is a "how-to" guide on field reporting of tank casualties, published 11 Mar 1944. It goes into considerable detail on the "forensic" aspects of the behaviour of armour under different kinds of attack.

Four main types of armour plate are distinguished:

1. Rolled homogenous, machineable quality.
2. Cast.
3. Flame-hardened.
4. Rolled homogenous hard.

It is noted that (3) has been seen on Pz IV and Pz IV nose, tail and mantlet, but never yet on tank sides. (4) is used only on light vehicles such as armoured cars.

It is stated that face-hardened armour usually fails by "plugging" rather than "petalling".

WW2 weapon effectiveness

WO 291/602 The practicability of overhead cover.

Two types of overhead cover were considered. "Type A" uses raised overhead cover over the whole trench. "Type B" has a flat covered part, and so is harder to observe, but means that men must leave the overhead cover area to use their weapons.

On light soil (most soils, especially clays, give more protection for a given thickness), if 100 casualties would be caused by 25-pdr airburst on trenches without overhead cover, the following casualties are predicted:

Cover	Men manning weapons		Crouching in cover
	Type A	Type B	(either type)
6-inch logs with:			
No earth	12	100	10
1 ft earth	2	100	2
Corrugated iron or light timber, with:			
6" earth	65	100	60
1 ft earth	22	100	17
2 ft earth	12	100	10

"Both in Russia and Italy the Germans have used semi-mobile "pill-boxes" partly sunk in the ground and protected with 30 to 150mm armour plate. These accommodate 2 men and would be invulnerable to anything but a direct hit from a shell or bomb."

WO 291/620 The vulnerability of guns to attack by bombs and shell.

German guns are considered as the following equivalent target areas of ¼-inch mild steel:

88mm	4.8 sq ft
"IFH 18" 105mm howitzer	1.8 sq ft
"SFH 18" 150mm howitzer	5.5 sq ft

The vulnerable area of a 5.5" 100lb shell is "of the order of 1000 sq ft against a gun in the open".

"A sunken or sandbagged emplacement restricts effective rounds to those actually bursting in the emplacement except where part of the recoil system is above the barrel." The British 6-pdr, with its recoil system below the barrel, "is probably rather less vulnerable than the German 105mm".

Vulnerable areas, in square feet, for various weapons on 105mm and 150mm targets are given below. The 25-pdr, 20lb 'F' bomb and 40lb GP bomb are listed with no VAs, and so are assumed ineffective except for direct hits.

Weapon	150mm	105mm
5.5" shell	1300	600
250lb GP bomb	12500	5800
1000lb GP bomb	24300	11700

WW2 weapon effectiveness

WO 291/672 An investigation of the accuracy of aiming with the Wasp flamethrower Mark II.

This paper describes tests showing the improvement in aiming accuracy using a telescopic sight instead of the existing open sight. 50% zones in elevation and traverse, in minutes, are given as:

Range	Sight	Elevation	Traverse
20–30 yds	open sight	5.8	1.5
	telescopic sight	3.6	3.6
40–60 yds	open sight	18.2	4.7
	telescopic sight	5.9	1.9
70–90 yds	open sight	29.4	3.6
	telescopic sight	5.1	3.8

WO 291/716 The appearance of hull down tanks.

This paper contains photographs from field trials showing the appearance of hull down tanks.

The average areas visible, in square feet, of different types of tank:

Sherman	9.8
Crusader	10.3
Churchill	12.1
Cromwell	14.25

The use of periscopes is advised to minimise the exposed area of the turret.

Rounded turrets, as in the Sherman, are harder to spot than square, boxy turrets as in Churchill and Cromwell. Hatches sticking up are very noticeable.

WW2 weapon effectiveness

WO 291/741 Comparison of the performance of 75mm and 76mm tank gun ammunition.

The 75mm M48 is longer and heavier than the 76mm M42A1 and has greater capacity. 76mm M42A1 is assumed identical to the 3-inch M42A1. All three use the M48 fuze.

Vulnerable areas against men in the open, in square feet, are given as:

3" or 76mm M42A1	2200 sq ft
75mm M48	2900 sq ft

"Thickness of homogenous armour plate penetrated at 30°angle of attack by APCBC/HE shell." Ranges in yards.

Range	75mm	76mm
Point blank	79.5	108.2
200	75.3	104.2
400	72	100.2
600	68.5	96.7
800	65.5	93
1000	63	89.7
1200	60.3	86.3
1400	57.8	83.1
1600	55	80
1800	52.6	77
2000	50	74

The report concludes that, whereas lack of HE performance can be compensated for by using more of the less effective shell, lack of penetrating power cannot be made up for in this way.

WO 291/904 Morale effect of bombardment.

One case suggest that the casualty-producing value of an 81mm mortar may be nearer to 4 than 3 MGs.

The weighting factor for converting instantaneous nose-fused 250lb GP bombs to "25-pdr equivalents" seems to be about 1.0 – in other words, one such bomb is worth 10 25-pdr shells.

Two methods of assessing morale effect are described, based on the reduction to casualties among attacking troops by different levels of preparatory bombardment. It is stated that "...the effect on morale is several times as great as the material effect. "Several times" in the case of method A means about 6 times and in the case of method B about twice."

WW2 weapon effectiveness

WO 291/946 Effects of bombardment – present state of knowledge.

This summary was published in 1946.

Against men in slit trenches, 25-pdr groundburst must hit the trench or parapet to be effective.

If firing 1000 25-pdr shells into a 300 × 300 yard box with 100 men in it in slit trenches, the expected number of casualties would be nine.

Four kinds of effect from bombardment are distinguished:

Lethal: Killing or incapacitating personnel.
Material: Destroying weapons and equipment.
Neutralisation: Preventing the enemy from observing or using his weapons for the duration of the bombardment.
Morale effects: Reduction in effectiveness lasting after the bombardment has ceased.

Two possible morale effects are mentioned. "Sensitization" means that greater weights of bombardment have progressively more morale effect. The existence of this effect was supported by "abundant evidence". "Habituation" means the lowering of morale effect by men getting used to small bombardments. The occurrence of this was "more difficult to support by adequate evidence".

The "minimum effective density" of a bombardment is 0.3 lbs/sq yd for 25-pdr shell.

"If the enemy is in protected positions such as pillboxes or concrete gun casemates instead of in open positions the state of affairs is different. No projectile which cannot pierce the protection has any noticeable effect. The neutralising, morale and lethal effects do not exist until the material effect is achieved."

Experience on the Normandy beaches suggested that one 81mm mortar had the same casualty-causing effect as 1 MG. Casualties were weapon were one-and-a-half times more on Omaha than the British beaches, where they were in turn four times greater than on Utah. The difference is attributed to greater effectiveness of preliminary bombardment.

Morale effect (lasting after the bombardment ceases) "...can only be achieved against enemy in open positions, unless the duration is about 8 hours or more, in which case lightly protected positions may be affected especially if retaliation is impossible." On open positions a bombardment intensity of 0.1 lb/sq yd/hour in 25-pdr equivalents produces collapse in about 4 hours; 1.0 lb/sq yd/hour in about ¼ hour.

Neutralising effect, in NW Europe, on an enemy in open positions, was achieved with a bombardment intensity of 0.02–0.08 lb/sq yd/hr. in 25-pdr equivalents.

Lethal effect: A density of 0.1 lb/sq yd causes 2% casualties on targets in slit trenches, about 20% on targets in the open.

Material effect: A density of 0.1 lb/sq yd damages about 1½% of weapons or guns in pits, 20% of soft vehicles in the open.

Conversion factors

Imperial units used in this document are:

Imperial unit	Abbreviation	Conversion to SI
Weight (mass)		
1 pound = 16 ounces	lb	0.454 Kg
ounce	oz	28.4 g
Distance		
1 mile = 1760 yards	m or mi	1 609 m
1 yard = 3 feet	yd or ^{x}	0.914 m
1 foot = 12 inches	ft or '	0.305 m
inch	in or "	25.4 mm
Area		
1 acre = 4840 square yards		0.405 ha
1 square yard = 9 square feet	sq yd	0.835 m^2
square foot	sq ft	0.093 m^2
Volume		
1 gallon = 8 pints	gall	4.544 l

The conversion factors for yards, feet, acres, pounds and pints are taken from "SMP Elementary Tables", CUP, 1967, which are given only to 3 s.f.; the others have been calculated.

The pound shown here is the pound avoirdupois, used for weighing common materials; strictly, it is a measure of weight, whereas Kg is a measure of mass, but the distinction is elided in common usage. "Pound" is abbreviated "lb", as shown, but the poundage of guns (2-pounder, 6-pounder and so on), although it corresponds to the weight of their shot or shell in pounds, is always abbreviated as "pdr" or "pr", never as "lb" or "lber".

Note that the Imperial gallon is different from the U.S. gallon.

Note also that the Imperial system is far more baroque and illogical than this table may indicate, but I wish to spare the patient reader the full horrors of the troy ounce, the pottle and the ell.