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TECHNICAL REPORT
NATICK/TR-95/003

BLAST OVERPRESSURE AND SURVIVABILITY CALCULATIONS FOR VARIOUS SIZES OF EXPLOSIVE CHARGES

By
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Blast overpressures and durations were calculated for several different explosive charge sizes. The charge sizes range from 1 ounce of TNT to 32 ounces of TNT. The distance from the charge ranged from 1 to 3 feet. When the blast calculations were compared to human blast tolerance limits, it was found that the blast exposures mostly fell in between the 1% survival limit and the threshold of lung damage. This probably means that a heavily-protected explosive ordnance disposal technician, supplied with a rigid enclosed thoraco-abdominal protector, may be able to survive the air blast effects at these distances. Note that these calculations only pertain to direct air blast effects and ignore fragments and thermal effects entirely.

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PREFACE

This report was written for the purpose of calculating the potential for air blast lung injuries due to various sizes of explosive charges that soldiers engaged in clearing mines or explosive ordnance might be exposed to.

Several reviewers provided comments and suggestions which were incorporated into the report. They include Andreas Blanas, Janet Ward, and Thomas Tassinari of the Textile Research and Engineering Division, Survivability Directorate; Denise Tolliver and Stanley Waclawik of the Soldier Integrated Systems Division, Survivability Directorate; and Heidi Schreuder-Gibson of the Fiber and Polymer Science Division, Science and Technology Directorate.

Blast Overpressure and Survivability Calculations for Various Sizes of Explosive Charges

1. Introduction

The purpose of this report is to present blast overpressures and durations for several small explosive charge sizes and compare them to human blast tolerance limits. The calculations look only at the properties of the air shock wave, and their potential for causing lung damage. Other sources of injury are not considered, such as fragments, burns due to the fireball, or injuries due to being thrown down or away from the blast. It should be noted that these other sources of injury are usually more important for small charge sizes than lung injuries due to the air shock wave.

The motivation was to determine the possible vulnerability to lung damage of soldiers who must perform tasks such as clearing mines and disposing of explosive ordnance. For smaller antipersonnel mines, these soldiers are quite well protected from fragments, by virtue of their ballistic armor. However, the soldiers who are wearing soft body armor without a rigid chest protector may still be vulnerable to the effects of the blast wave even if they are protected from fragments.

2. Approach

For the purpose of these estimates, explosive properties were calculated in terms of the peak overpressure and positive phase durations of the air shock wave resulting from the detonation of a given bare explosive charge. Therefore, these are very rough estimates of what might occur for soldiers exposed to a blast on the battlefield, since the confinement of the charge by a metal case, which is important for mines and mortar shells, will change both the peak overpressure and the duration of the resulting air shock wave.

The explosive charge was assumed to be composed of TNT. Charge weights of 1 ounce up to 32 ounces were used for the calculations. The calculations could also easily be performed for Composition C-4 (90% RDX), which has a TNT equivalency of about 1.3. Other assumption were: 1) a standard atmosphere (14.7 psi), 2) the explosive charge was located on the ground surface, 3) the ground reflection factor was equal to 2.0 (a hard surface). These are worst case conditions.

Handbook values are available for estimating human blast tolerances. Most of these were derived from extensive animal testing.[1] Examples of these plots are shown in Figures 1 and 2. Unfortunately, these plots do not extend down to the lower charge weights and distances from the charge that are of interest in this report. However, these plots *suggest* that a person can get very close to charge weights of around 1 lb and still survive.

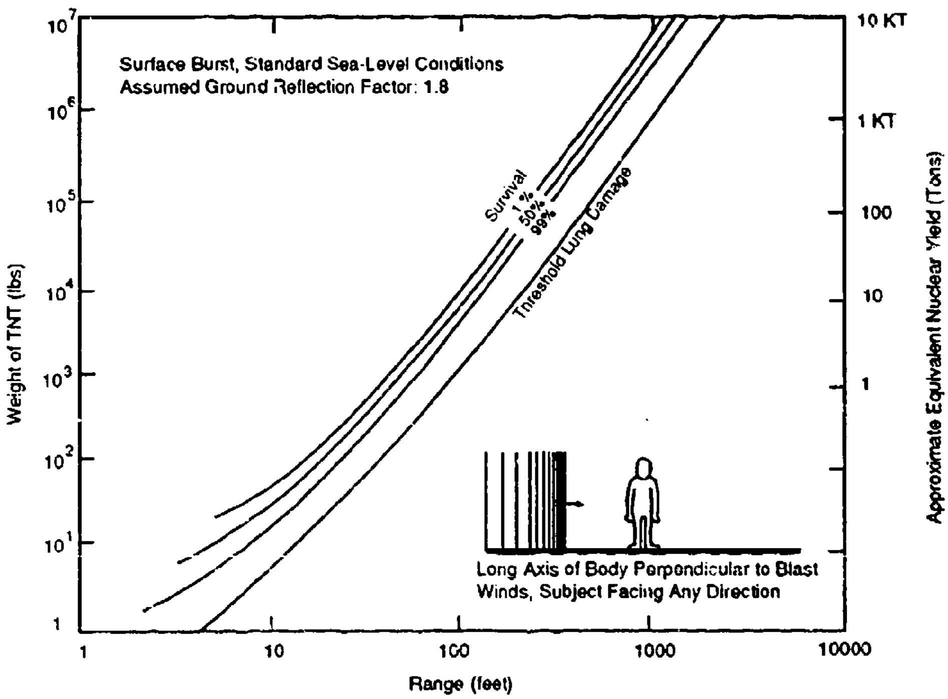

Figure 1. Predicted survival curves for man exposed in the free stream to surface bursts of TNT where the long axis of the body is perpendicular to the blast winds (from Reference 1).

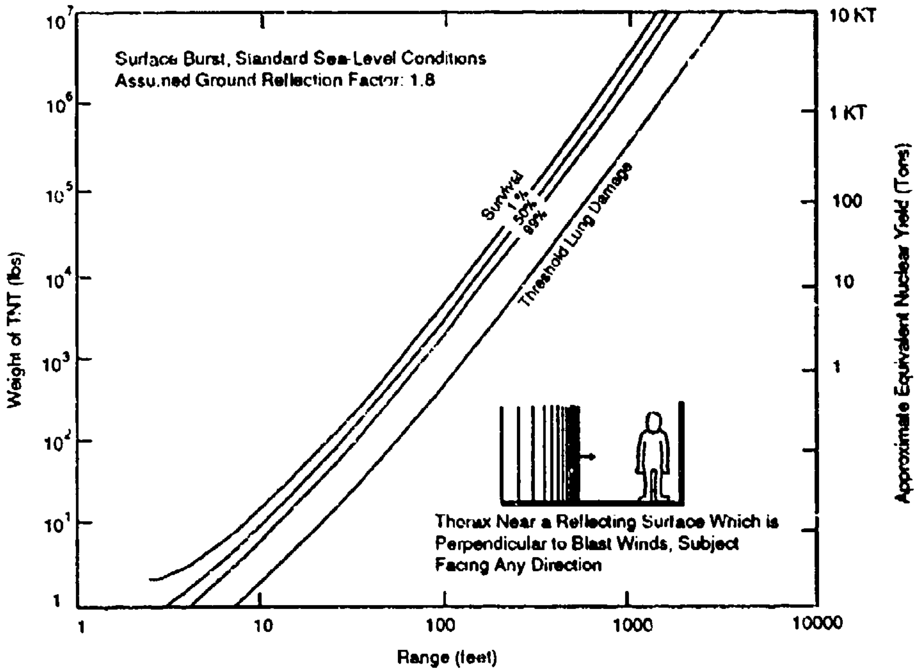

Figure 2. Predicted survival curves for man exposed in the free stream to surface bursts of TNT where the thorax is near a flat rigid surface reflecting the blast wave at normal incidence (from Reference 1).

There are critical factors that contribute to the potential of lung damage from small explosive charges: 1) the large dimensions of the human body relative to the radius of curvature of the shock wave, and 2) the rapid change in shock properties as a shock wave travels away from the explosion source. Both would have an influence on the possible lung damage to a human. Figures 1 and 2 assume that the shock wave is essentially planar in nature, since those plots were developed to assess possible injuries from air shock waves due to nuclear weapons. For the purposes of this report, the blast wave will be assumed to be planar in nature, and the influence of the human body size will be ignored.

To get a better estimate of blast effects down in this lower range, the blast wave properties were calculated based on Hopkinson-Sachs blast wave scaling laws which have been established for chemical explosives.[2] The blast parameters of most use in establishing the potential of human casualties from air shock waves are side-on blast overpressure (p_0) and the duration of the positive overpressure phase (t_d). The charge weights were 1 oz, 2 oz, 4 oz, 8 oz, 16 oz, 24 oz, and 32 oz. Calculations of p_0 and t_d were done for each charge size at ranges of one to three feet, and at intervals of 0.1 foot. Rather than use scaled blast tables and look up each value, empirical equations developed at the Naval Weapons Center were used.[3]

Overpressure p_0 (psi) was calculated using the equations shown below where W= TNT equivalency (kg), and Z (scaled distance)= actual distance(meters)/$W^{1/3}$. The appropriate constants for converting from metric to English units are included in these two equations.

$$p_0(\text{psi}) = \frac{(797)(14.7\text{ psi})\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{1+\left(\frac{Z}{0.048}\right)^2}\sqrt{1+\left(\frac{Z}{0.32}\right)^2}\sqrt{1+\left(\frac{Z}{1.35}\right)^2}}$$

Positive phase duration t_d (msec) was calculated from:

$$t_d(\text{msec}) = \frac{980\left(W^{1/3}\right)\left[1+\left(\frac{Z}{0.54}\right)^{10}\right]}{\left[1+\left(\frac{Z}{0.2}\right)^3\right]\left[1+\left(\frac{Z}{0.74}\right)^6\right]\sqrt{1+\left(\frac{Z}{6.9}\right)^2}}$$

The tables of calculated values using these equations are given in the Appendix, along with a simple computer program to generate the values.

3. Results

The peak overpressure (psi) is plotted versus distance (feet) from the explosive charge in Figure 3.

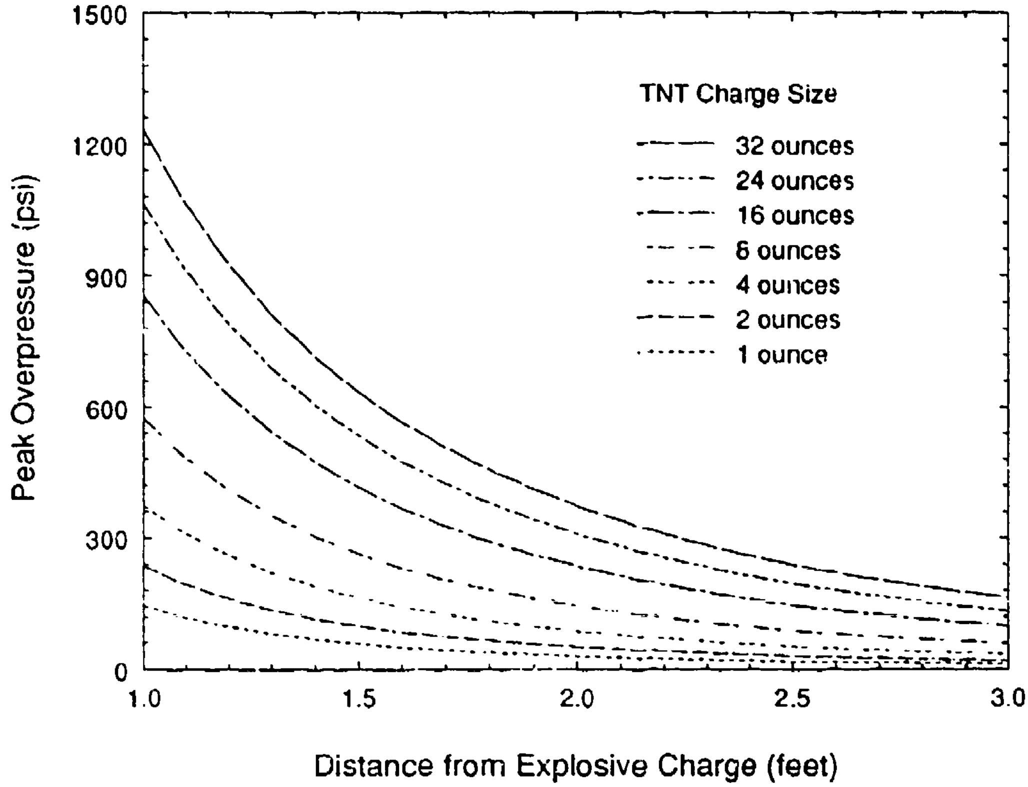

Figure 3. Peak side-on overpressure versus distance from the charge for several different charge weights of TNT. Surface burst assumed with a ground reflection factor of 2.0.

The two situations of most interest are: 1) when a soldier is standing out in the open (free-stream situation), and 2) when the soldier is standing next to a rigid surface which reflects the shock wave and essentially doubles its strength. Human tolerance curves[4] for the two situations are shown in Figures 4 and 5.

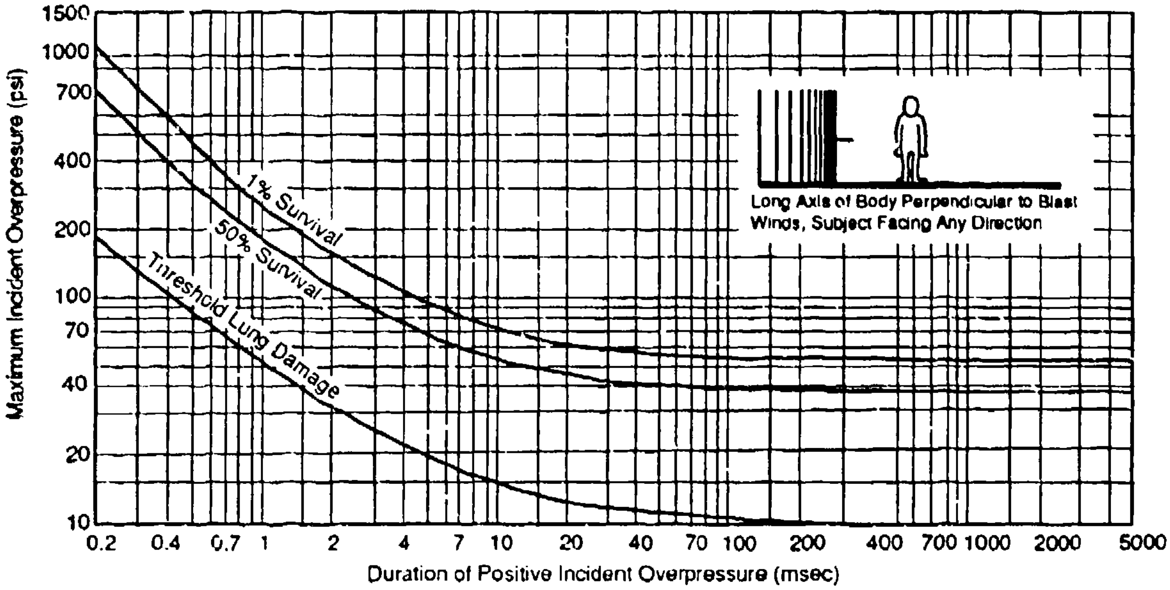

Figure 4. Survival curves predicted for a 70 kg man, applicable to free-stream situations where the long axis of the body is perpendicular to the direction of propagation of the blast wave (from Reference 4).

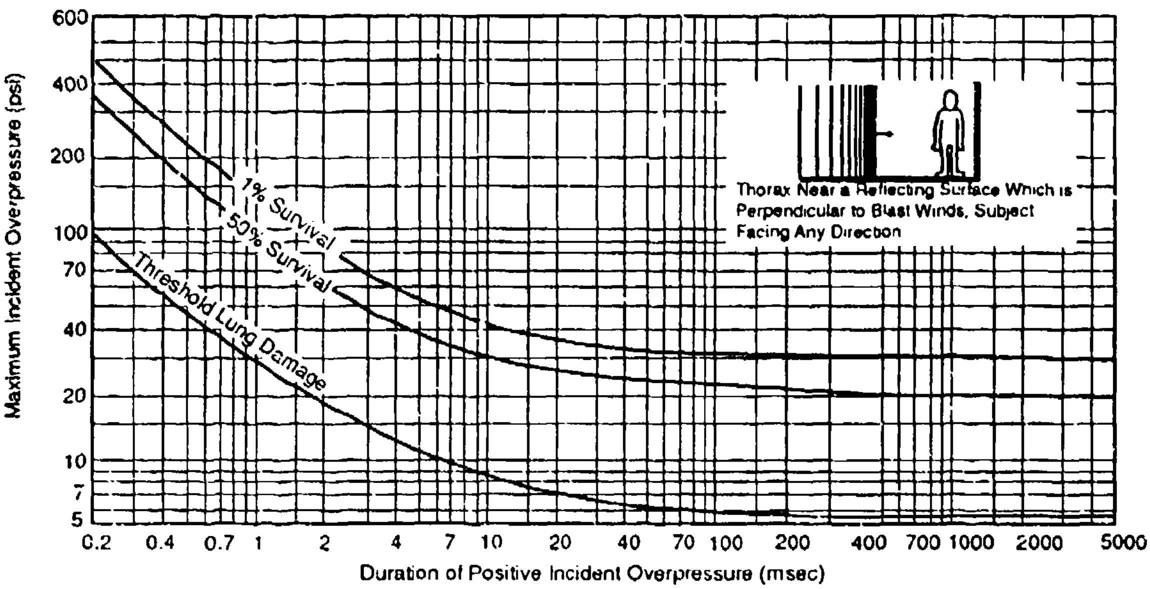

Figure 5. Survival curves predicted for a 70 kg man, applicable to situations where the thorax is near a surface against which a blast wave reflects at normal incidence (from Reference 4).

We can take the calculated overpressure-distance data for the various charge weights and combine them with the survival curves shown in Figures 4 and 5. This is complicated by the fact that both the peak blast overpressure and the positive phase duration are required to determine the injury potential of a given air shock wave.

This is done in Figures 6 and 7. Figure 6 covers the free-stream situation and Figure 7 covers the reflected shock situation. Each individual curve is for a different charge weight. Each curve is a composite of different distances from the explosive charge. The points corresponding to a 1 foot, 2 feet, and 3 feet distance away from the charge are indicated on each curve. The actual values are also shown in the tables in the Appendix. The doubling back of the curves for the higher charge weights is due to the proximity to the blast origin. The minimum in positive phase duration is due to inertial effects and the initial resistance of the air to expansion. This minimum in t_d is physically real, and is seen in all explosions close to the fireball.

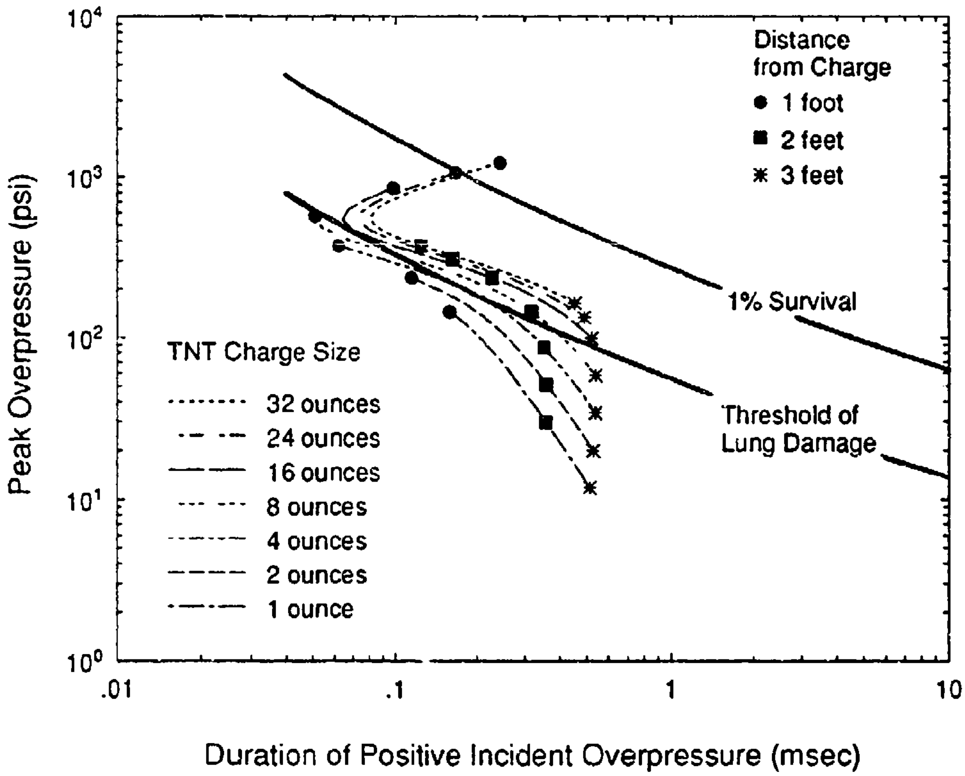

Figure 6. Calculated TNT blast curves superimposed on human blast tolerance limit plot for the free-stream situation.

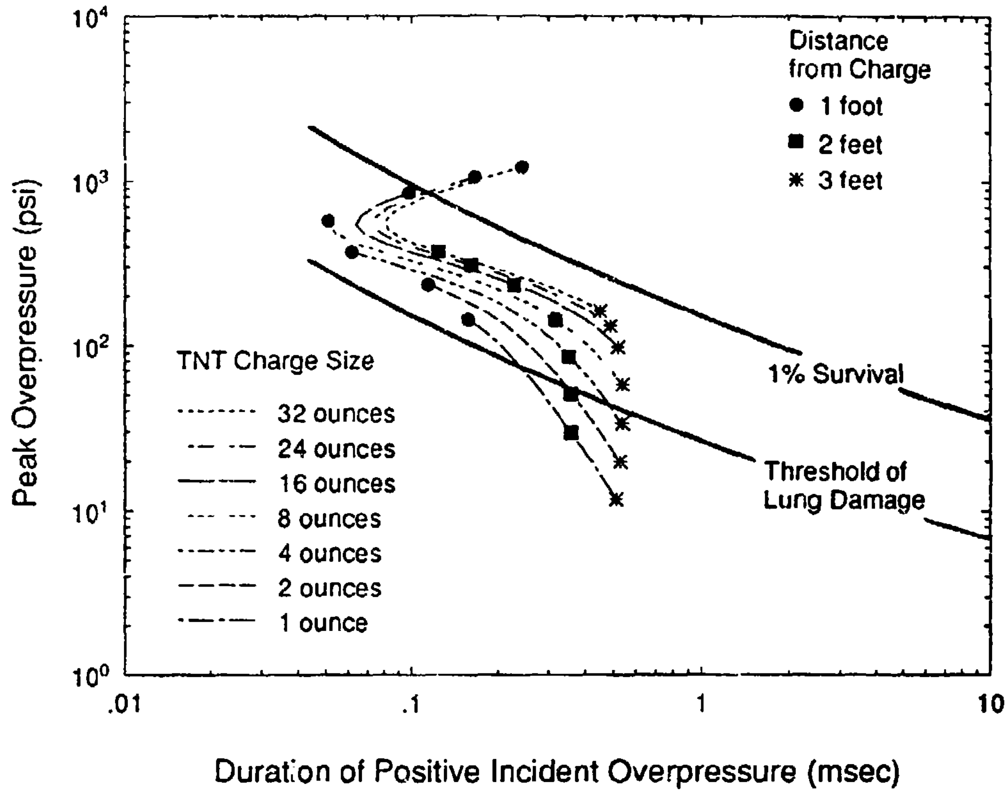

Figure 7. Calculated TNT blast curves superimposed on human blast tolerance limit plot for the reflected shock situation.

Above the 1% survival curves shown on the plots, death would be likely within 24 hours. For those points below the threshold of lung damage, significant injury from the air shock wave is unlikely, but unprotected eardrums would likely be damaged. In addition, the person may be knocked down or thrown, and various injuries may occur due to fragments or burns.

4. Conclusions

When the blast calculations for explosive charge sizes from 1 to 32 ounces, at ranges of one to three feet, were compared to human blast tolerance limits, it was found that the blast exposures mostly fell in between the 1% survival limit and the threshold of lung damage. This probably means that a heavily-protected explosive ordnance disposal technician, supplied with a rigid enclosed thoraco-abdominal protector, might survive a blast of this magnitude. Those individuals who only have soft body armor, although they may be adequately protected against fragments, may be vulnerable to lung damage from the air shock wave. Again, note that these calculations only pertain to direct air blast effects and ignore fragments entirely.

This document reports research undertaken at the U.S. Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-95/003 in the series of reports approved for publication.

5. References

1. Bowen, I., Fletcher, E., Richmond, D., "Estimate of Man's Tolerance to the Direct Effects of Air Blast," Technical Progress Report, DASA-2113, Defense Atomic Support Agency, Oc.ober 1968.

2. Kinney, G.F., and Graham, K.J., *Explosive Shocks in Air*, 2nd Edition, Springer-Verlag, New York, 1985.

3. Sewell, R.G.S., Zulkosi, T.R., and Kinney, G.F., "Blast Parameter Characterization", Naval Weapons Center Technical Report TP 5920, Part 1, Volume 2, China Lake, CA, 1979.

4. White, C.S., et. al., "The Biodynamics of Airblast", Defense Nuclear Agency Report DNA 2738T, July 1971.

APPENDIX

Tables of Blast Overpressure and Positive Phase Duration as Function of Distance for Small Explosive Charges and Computer Program to Generate the Values

1 ounce charge

Distance feet	Overpressure p_o (psi)	Duration t_d(msec)
1.000	144.520	.158
1.100	117.342	.185
1.200	96.700	.209
1.300	80.733	.230
1.400	68.182	.250
1.500	58.179	.269
1.600	50.107	.287
1.700	43.521	.305
1.800	38.092	.323
1.900	33.577	.340
2.000	29.790	.357
2.100	26.590	.373
2.200	23.866	.390
2.300	21.532	.406
2.400	19.520	.422
2.500	17.776	.437
2.600	16.256	.453
2.700	14.924	.468
2.800	13.752	.483
2.900	12.717	.497
3.000	11.797	.512

2 ounce charge

Distance feet	Overpressure p_o (psi)	Duration t_d(msec)
1.000	235.302	.114
1.100	193.044	.149
1.200	160.502	.182
1.300	135.011	.211
1.400	114.745	.237
1.500	98.422	.260
1.600	85.123	.282
1.700	74.177	.302
1.800	65.082	.322
1.900	57.463	.341
2.000	51.032	.359
2.100	45.564	.377
2.200	40.886	.395
2.300	36.860	.412
2.400	33.375	.429
2.500	30.343	.446
2.600	27.692	.463
2.700	25.364	.479
2.800	23.311	.495
2.900	21.493	.511
3.000	19.877	.527

4 ounce charge

Distance feet	Overpressure p_o (psi)	Duration t_d(msec)
1.000	372.799	.062
1.100	309.409	.089
1.200	259.885	.122
1.300	220.586	.158
1.400	188.972	.193
1.500	163.233	.225
1.600	142.051	.255
1.700	124.452	.282
1.800	109.704	.307
1.900	97.248	.330
2.000	86.653	.352
2.100	77.583	.372
2.200	69.772	.392
2.300	63.008	.412
2.400	57.121	.430
2.500	51.973	.449
2.600	47.451	.467
2.700	43.463	.485
2.800	39.931	.502
2.900	36.793	.519
3.000	33.994	.537

8 ounce charge

Distance feet	Overpressure p_o (psi)	Duration t_d(msec)
1.000	573.383	.051
1.100	481.870	.054
1.200	409.255	.066
1.300	350.832	.088
1.400	303.248	.116
1.500	264.067	.150
1.600	231.488	.185
1.700	204.159	.221
1.800	181.051	.255
1.900	161.370	.287
2.000	144.498	.317
2.100	129.945	.345
2.200	117.324	.370
2.300	106.322	.394
2.400	96.685	.417
2.500	88.208	.439
2.600	80.720	.460
2.700	74.080	.480
2.800	68.171	.500
2.900	62.896	.519
3.000	58.170	.538

16 ounce charge

Distance feet	Overpressure p_o (psi)	Duration t_d(msec)
1.000	854.393	.098
1.100	727.636	.078
1.200	625.363	.067
1.300	541.840	.064
1.400	472.894	.069
1.500	415.429	.082
1.600	367.117	.101
1.700	326.177	.127
1.800	291.235	.158
1.900	261.215	.192
2.000	235.268	.228
2.100	212.717	.264
2.200	193.016	.299
2.300	175.723	.332
2.400	160.478	.364
2.500	146.983	.394
2.600	134.990	.422
2.700	124.296	.448
2.800	114.727	.473
2.900	106.139	.497
3.000	98.407	.520

24 ounce charge

Distance feet	Overpressure p_o (psi)	Duration t_d(msec)
1.000	1062.529	.166
1.100	912.178	.126
1.200	789.657	.100
1.300	688.684	.083
1.400	604.639	.075
1.500	534.060	.074
1.600	474.310	.079
1.700	423.358	.091
1.800	379.617	.109
1.900	341.834	.133
2.000	309.015	.162
2.100	280.356	.194
2.200	255.210	.229
2.300	233.046	.264
2.400	213.430	.300
2.500	195 999	.335
2.600	180.456	.369
2.700	166.547	.402
2.800	154.061	.432
2.900	142.819	.462
3.000	132.668	.489

32 ounce charge

Distance feet	Overpressure p_o (psi)	Duration t_d(msec)
1.000	1231.714	.243
1.100	1063.488	.183
1.200	925.449	.142
1.300	810.952	.114
1.400	715.079	.096
1.500	634.123	.085
1.600	565.241	.081
1.700	506.226	.083
1.800	455.345	.091
1.900	411.220	.104
2.000	372.749	.124
2.100	339.040	.149
2.200	309.366	.177
2.300	283.133	.210
2.400	259.848	.244
2.500	239.103	.280
2.600	220.554	.316
2.700	203.915	.351
2.800	188.945	.386
2.900	175.434	.419
3.000	163.209	.451

```
c*****  program tntblast in fortran
c*****  uses hopkinson scaling laws to calculate yields
c*****  phil gibson
        write(*,*)'input charge weight in ounces'
c*****  w1=charge weight, ounces
c*****  w=charge weight, tnt equivalent (kg)
c*****  d=distance from charge in meters
c*****  z=scaled distance
c*****  po=peak overpressure
c*****  td=posive phase duration, milliseconds
        read(*,*)w1
        w=w1*.02835
        feet=1.0
        d=feet*.3048
        open(21,file='tntblast.dat')
        write(21,*)'      feet        po        td(msec) '
        do 1000 k=1,21
        z=d/w**.3333
        po=((14.7)*(797)*(1.0+(z/4.5)**2))/((sqrt(1.+(z/0.048)**2))*
     &(sqrt(1.+(z/0.32)**2))*(sqrt(1+(z/1.35)**2)))
        td=((w**.3333)*980.*(1.+(z/0.54)**10))/((1.+(z/0.02)**3)*(1+(z/
     &0.74)**6)*(sqrt(1.+(z/6.9)**2)))
        write(*,*)feet, po,td
        write(21,900)feet,po,td
        feet=feet+.1
        d=feet*.3048
1000    continue
 900    format(3f15.3)
        close(21)
        stop
        end
```