1.1 Shock Wave Propagation in Free Air

a. Rankine-Hugoniot Relationships. All of the peak values of the various blast wave characteristics are uniquely related at the shock front for ideal blast waves in free air by the Rankine-Hugoniot equations which are given below:

**Shock Velocity**

\[ U = C \left( 1 + \frac{6}{7} \frac{\Delta p}{p} \right)^{1/2}, \]

**Particle Velocity**

\[ u = \frac{5}{7} C \frac{\Delta p}{p} \left( 1 + \frac{6}{7} \frac{\Delta p}{p} \right)^{1/2}, \]

**Peak Density**

\[ \rho' = \rho \left( 1 + \frac{6}{7} \frac{\Delta p}{p} \right) \left( 1 + \frac{1}{7} \frac{\Delta p}{p} \right) \]

where \( \rho \) = ambient density (slugs/ft\(^3\)) ahead of the shock front (0.00238 slugs/ft\(^3\) at sea level),

\( p \) = ambient pressure (psi) ahead of the shock front (14.7 psi at sea level),

\( C \) = ambient sound velocity (ft/sec) ahead of the shock front (11,116 ft/second at sea level),

\( \rho' \) = peak density at the shock front (slugs/ft\(^3\)),

\( \Delta p \) = peak overpressure at the shock front (psi),

\( U \) = shock velocity (ft/sec), and

\( u \) = peak particle velocity (ft/sec) (wind velocity at the shock front).

Values of shock velocity as a function of distance in free air are given in figure I-1. It should be noted that the time of arrival curve, figure 2-2, may be derived from the shock velocity curve of figure I-1 by a successive integration procedure. Values of particle velocity as a function of distance are given in figure I-2.

The relationship between peak dynamic pressure and peak overpressure at the shock front is:

\[ q = \frac{5}{2} \left( \frac{\Delta p}{p} \right)^2, \]

where \( q \), the peak dynamic pressure (psi), is defined as

\[ q = \frac{1}{2} \left( \rho' u^2 \right) \]

The relationship between peak particle velocity and shock velocity is:

\[ \frac{5}{7} \frac{U}{C} \frac{\Delta p}{p} = \frac{1}{1 + \frac{6}{7} \frac{\Delta p}{p}} \]

where \( U \), \( u \), \( \Delta p \) and \( p \) are as previously defined.

The relationship between sound velocity, pressure and density in air is:

\[ C = 14.2 \left( \frac{p}{\rho} \right)^{1/2} = 49 T^{1/2}, \]

where \( C \) = sound velocity in feet/second,

\( p \) = pressure in pounds/sq. inch,

\( \rho \) = density in slugs/ft. cu., and

\( T \) = degrees Rankine (degrees \( F + 459 \)).

The relationship between the instantaneous value of the peak overpressure reflected from a surface and the peak overpressure incident upon that surface at a 90° angle is:

\[ \Delta p_r = 2 \Delta p \left( \frac{\frac{7p + 4\Delta p}{p + \Delta p}}{7p + \Delta p} \right) \]

where \( \Delta p_r \) = reflected peak overpressure, and \( \Delta p \) = incident overpressure.

A number of these relationships are shown in figure I-3 as a function of peak overpressure for a sea level atmosphere. Values for many of the variables are given in appendix II.

b. Overpressure Positive Phase Impulse and Wave Form in Free Air. The overpressure positive phase impulse \( (I_p) \) is the area under the positive portion of the pressure-time curve, or:

\[ I_p = \int_{t=0}^{t=T} \Delta p(t) \, dt, \]
where $\Delta p(t)$ is the overpressure as a function of time between $t=0$, the time of arrival of the blast wave at a given range, and $t_*=t^*$, the end of the positive phase. Values of overpressure positive phase impulse as a function of distance in free air are given in figure I-4. The positive phase pressure-time curve showing the exponential decay of overpressure at a given distance will vary, depending on the peak overpressure and time of duration for a given yield at that distance. A comparison of decay rates for various values of peak overpressure is shown in figure I-5 in terms of normalized coordinates; i.e., the values are expressed as fractions of the peak or maximum values. The use of normalized coordinates permits a comparison on a common basis of the variation of phenomena which differ in absolute magnitude. Where pressures are less than 25 psi, the variation of overpressure with time behind the shock front may be represented by the following semi-empirical equation:

$$\Delta p(t) = \Delta p(1-t/t^*) e^{-ut^*}$$

where $\Delta p(t)$ is the overpressure at any time $t$, $\Delta p$ is the peak overpressure, and $t^*$ is the positive phase duration of the blast wave. The wave form which this exponential equation describes is shown in figure I-6 in terms of normalized coordinates to permit comparison with the dynamic pressure wave form.

**c. Dynamic Pressure Impulse and Wave Form.**

The dynamic pressure impulse is the area under the dynamic pressure-time curve. It may be determined from the following expression:

$$I_e = \int_{t=0}^{t_*} q(t) dt.$$  

This expression is the integral of the curve representing the variation of dynamic pressure behind the shock front as a function of time between $t=0$, the time of arrival of the blast wave, and $t=t^*$, the end of the dynamic pressure positive phase. Assuming $t^*$ to be the same as $t^*$, the overpressure positive phase duration, will not introduce serious error. Values of dynamic pressure impulse as a function of distance in free air are given in figure I-7. The rate of decay varies in an exponential fashion, depending upon the peak dynamic pressure and time of duration.

A comparison of decay rates for various values of peak dynamic pressure is shown in figure I-8 in terms of normalized coordinates. Where dynamic pressures are less than 12 psi, the variation of dynamic pressure with time behind the shock front may be represented by the following approximate equation:

$$q(t) = q_0 (1-t/t^*) e^{-ut^*},$$

where $q(t)$ is the value of dynamic pressure at any time $t$, $q_0$ is the peak dynamic pressure at the shock front, and $t^*$ is the overpressure positive phase duration. This equation is derived from the expression given in $a$ above, with the shock relations given in $a$ above, and then simplifying the resulting expression. The positive phase duration of overpressure is used in the above equation instead of positive phase duration of dynamic pressure, since the difference is small and does not affect the total dynamic pressure impulse in a significant manner. The wave form described by the above equation is also shown in figure I-6.

**1.2 Blast Wave Perturbations**

**a. Overpressure Positive Phase Impulse and Wave Forms.**

The variation of overpressure positive phase impulse with range and height of burst is shown in figures I-9A and I-9B for 1 KT in a sea level homogeneous atmosphere. Figure I-9A applies to good surface conditions where thermal and mechanical effects are minimized, and near ideal wave forms may be expected. Figure I-9B applies to average surface conditions where non-ideal wave forms may be expected. It has been found convenient to divide the variations of wave forms into five major classifications, which are illustrated in figure I-10:

**Type I.** A relatively ideal wave form with a sharp rise to a peak value followed by a rapid exponential decay. Usually the peak pressure is rather high and the duration is rather short in comparison with later wave forms.

**Type II.** A wave form with two distinct peak values which becomes increasingly non-ideal with increasing range. Usually shock-type rises are evident at the closer ranges. However, as the distance from ground zero increases, the separation of the two peaks and the rise time for the main shock increase, while the first peak
attenuates more rapidly than the second. At midrange, the wave form is characterized by a shock-type rise to a first low peak followed either by a plateau or a slow decay, with a longer rise to a higher second peak preceding a more rapid decay. As the ground range continues to increase, the first peak becomes round and the second peak attenuates more rapidly than the first. This wave form is typical of the early stages of development in the precursor cycle. (A detailed discussion of the precursor is given in par. 2.1d(4).)

Type III. A wave form whose peaks and valleys become poorly defined with increasing range. At the closer ranges the wave form shows a first large rounded maximum followed by a slow decay, then a later and smaller second peak. As the distance from ground zero increases, the first peak attenuates more rapidly than the second, so that the two peaks become comparable in magnitude, while the rise times become longer. The second peak disappears at the farther ranges, resulting in a low, rounded, flat-topped wave form with a long initial rise and a rather slow decay marked by considerable turbulence. This wave form is typical of strong precursor action.

Type IV. A wave form which progressively loses its non-classical characteristics with increasing range. At the closer ranges, the wave form shows a compression-type rise to a rounded plateau followed by a slow rise to a second higher peak. As the distance from ground zero increases, the rise times decrease, so that the front of the wave form develops a step-like appearance, and the time separation between the two peaks becomes less. At the farther ranges, the second peak overtakes the first peak to form an almost classical form with a sharp rise to a more or less level plateau, followed by an essentially regular decay. This wave form is typical of the "clean-up" portion of the precursor cycle.

Type V. A classical or ideal wave form with a sharp rise to a peak value followed by an exponential decay. The duration is rather long in comparison with the type I wave form and the rate of decay is slower.

The overpressure wave form types to be expected at a given ground range as a function of height of burst are shown in figure I–11. Since types II, III, and IV are characteristic of precursor action, the figure also delineates the precursor zone.

b. Dynamic Pressure Wave Forms. A tentative classification of the various dynamic pressure wave forms has been made. It is not possible to make a direct correlation of these with the five general types of overpressure wave forms due to the lack of experimental data for dynamic pressure, particularly in the close-in region. The classifications illustrated in figure I–12 are as follows:

Type A. A relatively ideal wave form, with a sharp rise to a peak value followed by a very rapid decay. The duration is usually rather short in comparison with later wave forms.

Type B. A double-peaked wave form with a shock-type initial rise in most cases. The second peak is larger at the closer ranges but becomes comparable in magnitude with the first as the distance from ground zero increases.

Type C. A transitional double-peaked wave form with longer initial rise time. Actual record traces have a very turbulent appearance. The second peak is smaller than the first and becomes somewhat indefinite with increasing range.

Type D. An essentially single-peaked form characterized by a low amplitude plateau with a slow, smooth rise at the closer ranges. Actual traces have a very turbulent appearance. As the distance from ground zero increases, the turbulence becomes less and the plateau develops a shock rise with a flat top or a slow steady increase to a second shock rise followed by a smooth decay. The initial disturbance at the front of the wave form eventually dies out at the farther ranges, leaving a smooth, clean record with a slight rounding after an initial shock-type rise.

Type E. A classical or ideal wave form with a sharp rise to a peak value followed by an exponential decay. The duration is rather long in comparison with type A wave forms and the rate of decay is slower.

It is not possible to draw a wave form-height of burst chart for dynamic pressures at this time due to the lack of experimental data.
the air blast parameters at an altitude other than sea level. When this is the case, the air blast parameters must be converted to reflect the fact that the ambient conditions existing at a particular altitude differ from those existing at sea level. Table II–1 shows how the ambient temperature, sound velocity, density and pressure vary with altitude under standard conditions. The values of these ambient parameters determine the rate of propagation of the blast wave resulting from the detonation of a particular yield and the magnitude of the air blast parameters at a given distance from the point of detonation.

As mentioned in section II, when targets are at mean sea level altitudes of 5,000 feet or less, the differences resulting from conversion of air blast parameters to target altitude are small and are usually of no practical importance. For targets at altitudes in excess of 5,000 feet, conversion of the air blast parameters should be made.

b. Conversion Procedure. An approximate method for relating the air blast parameter values occurring at a point in space at a given altitude, as the result of a nuclear burst at the same or a different altitude, to the blast parameter values of a 1 KT burst occurring in a homogeneous sea level atmosphere, and one which shows good agreement with full scale tests, is a method based on the work of R. G. Sachs. This method assumes that the blast wave propagates in a homogeneous atmosphere of ambient conditions corresponding to those existing at the altitude of the point in space under consideration, regardless of the burst altitude, and that the total energy available for blast is independent of altitude. Therefore, in terms of a similarity transformation, the dependence of pressure and density of the air in the blast wave on distance and time for one set of homogeneous ambient conditions may be obtained from the dependence of pressure and density in the blast wave on distance and time for another set of homogeneous ambient conditions by relating the dimensional scales by which pressure, density, distance, and time in each atmosphere are measured.

The following modified Sachs relations combine both the necessary yield scaling and altitude conversion to compute distance, shock arrival time, peak overpressure, peak dynamic pressure, positive phase duration, peak particle velocity, and peak density at a point in space at a given altitude and specific distance from a burst of yield, W, from the properties of a 1 KT burst in a standard sea level atmosphere:

\[ d_s = d_o W^{1/3} S_d \]
\[ t_s = t_o W^{1/3} S_t \]
\[ \Delta p_s = \Delta p_o S_p \]
\[ q_s = q_o S_q \]
\[ t^*_p = t^*_o W^{1/3} S_t \]
\[ u_s = u_o \left( \frac{C_t}{C_s} \right) \]
\[ \rho_s' = \rho_o' \left( \frac{p_s}{p_o} \right) \]

where:

\[ S_d = \left( \frac{p_o}{p_s} \right)^{1/3} \], a factor used to convert distance as measured in a sea level atmosphere to distance measured from the burst to a point at altitude.

\[ S_t = \frac{C_t}{C_s} \left( \frac{p_o}{p_s} \right)^{1/3} \], a factor used to convert time of shock arrival and positive phase duration, as measured in a sea level atmosphere, to time of shock arrival and positive phase duration as measured at a point at altitude, at a distance from the burst computed with the factor \( S_d \).

\[ S_p = \left( \frac{p_s}{p_o} \right) \], a factor used to convert peak overpressure and peak dynamic pressure, as measured in a sea level atmosphere, to peak overpressure and peak dynamic pressure at a point at altitude and at a distance from the burst computed with the factor \( S_d \).

\[ p_o, C_o, \] and \( \rho_o \) = ambient pressure, speed of sound, and ambient density of the standard sea level atmosphere. (See appendix II.)

\[ p_s, C_s, \] and \( \rho_s \) = ambient pressure, speed of sound, and ambient density of the atmosphere at the altitude or elevation of the point where blast parameters are to be determined (app. II).

\[ d_s = \text{distance in a sea level atmosphere from a 1 KT burst to a point where the blast parameters are as follows:} \]

- time of shock arrival: \( t_s \)
- peak overpressure: \( \Delta p_s \)
- peak dynamic pressure: \( q_s \)
- positive phase duration: \( t^*_p \)
- peak particle velocity: \( u_s \)
- peak density: \( \rho_s \)
\( d_s = \text{distance from a burst of yield } W \text{ to a point at altitude where the blast parameters are as follows:}
\)

- time of shock arrival \( = t_s \)
- peak overpressure \( = \Delta p_0 \)
- peak dynamic pressure \( = \phi_0 \)
- positive phase duration \( = t^*_p \)
- peak particle velocity \( = u_s \)
- peak density \( = \rho_s \)

Figure I–13 presents values of the above altitude conversion factors \( S_p, S_u, S_r \).

For surface target situations at elevations above 5,000 feet, obtain \( \Delta p_0, t_s, t^*_p \) and \( \phi_0 \) from figures 2–2 through 2–5 or figures 2–8 through 2–13. Compute other 1 KT sea level values for use in the above relations from the relationships given in paragraph I.1a or obtain from figure I–3.

For airborne target situations obtain \( t_s \) and \( t^*_p \) from figures 2–2 and 2–4. Obtain \( \Delta p_0 \) from figure I–14. Using this value of \( \Delta p_0 \), compute other 1 KT sea level values from the relationships given in paragraph I.1a or obtain from figure I–14. Figure I–14 presents higher values of free air peak overpressure for ranges beyond 1,000 feet in a sea level atmosphere than does figure 2–3. The data of figure I–14, when converted to altitude by the above procedure, have correlated well with airborne measurements at weapon effects tests.

### 1.4 Blast Wave Reflection

As previously discussed in Section 2.1c, the reflection of the incident blast wave at the earth's surface produces higher peak overpressures than are obtained at the same range in free air. The characteristics of the blast wave after reflection are dependent upon the yield, height of burst, and the reflecting surface conditions. Under ideal conditions, the peak overpressure in the reflected wave may be determined from figure I–15 on page I–31 by knowing the peak overpressure in the incident wave and the angle at which the blast wave strikes the reflecting surface. This angle between the shock front and the surface is known as the angle of incidence. In the regular region of reflection, the incident and reflected shocks have not merged to form a Mach stem. The limit of regular reflection in the ideal situation is a function of incident pressure and angle of incidence. This limiting condition is shown as a dashed line on figure I–15 on page I–31.

### 1.5 Surface Burst

For nuclear weapons burst at the surface, reflection of the blast wave takes place immediately and a reinforced shock front is formed which propagates outward in a hemispherical manner. Propagation of the blast wave in free air above the surface after breakaway can be adequately described for military purposes by modified Sachs scaling up to altitudes of 50,000 feet assuming an equivalence of twice the yield in free air. Effects on airborne targets can thus be predicted by this procedure, using a 2W assumption with the curves presented in figure I–14 on page I–30.

In describing the propagation of the blast wave along the surface, an approximate equivalence of 1.6 times the yield in free air, or 1.6W, has been found to hold for the overpressure vs. distance relation over ranges of military interest. No such equivalence factor has been found for other blast wave parameters such as duration or impulse. Consequently, reference should be made to the height of burst curves, figures 2–8 through 2–11 inclusive, to obtain the best values of blast wave parameters at various ranges; however, for convenience an empirical curve of overpressure vs. distance has been prepared based on a large amount of data gathered from a number of nuclear surface bursts which is presented in figure I–16 on page I–32. Due to the limited nature of the precursor on surface bursts, this curve can be used for a variety of surface conditions. It is considered that use of the curve is more appropriate than scaling the free air pressure distance curve by modified Sachs scaling with the 1.6W assumption. There is, however, some uncertainty in the low pressure region (0.1 to 1.0 psi) due to the effect of meteorological conditions such as wind shears and temperature inversions which can cause focusing or degradation of the blast wave. This curve can also be used for predicting overpressures at long range for airbursts with low scaled heights of burst.
FREE AIR SHOCK AND PEAK PARTICLE VELOCITY VS. RANGE

Figures I-1 and I-2 show values of shock velocity and peak particle velocity, respectively. These values hold only at the shock front and are related to other blast parameters by the Rankine-Hugoniot equations discussed in the text.

Scaling. For scaling to other yields, use:

\[
\frac{d_1}{d_2} = \frac{W_1^{1/3}}{W_2^{1/3}}
\]

where yield \( W_1 \) will produce the same peak particle velocity and shock velocity at slant range \( d_1 \) as yield \( W_2 \) will produce at slant range \( d_2 \).

Example.

Given: A 20 KT free air burst in a homogeneous sea level atmosphere.

Find: Shock velocity and peak particle velocity at 3,000 feet.

Solution: Applying the scaling above to scale to 1 KT,

\[
d_1 = \frac{W_1^{1/3} \times d_2}{W_2^{1/3}} = \frac{1 \times 3,000}{20^{1/3}} = 1,100 \text{ feet.}
\]

From figure I-1, the shock velocity produced by 1 KT at 1,100 feet (and therefore by 20 KT at 3,000 feet) will be 1,300 feet/sec. Answer.

From figure I-2, the peak particle velocity produced by 1 KT at 1,100 feet (and therefore by 20 KT at 3,000 feet) will be 280 feet/sec. Answer.

Reliability. Free air shock velocity values are based on full-scale tests, while the peak particle velocity values are calculated using equations described in the text.

Related Material.

See paragraph I.1a.

See also figure 2-2, which may be derived from figure I-1 by successive integration; also figures I-3 and I-14.
FREE AIR PEAK PARTICLE VELOCITY VS SLANT RANGE FOR 1 KT BURST IN HOMOGENEOUS SEA LEVEL ATMOSPHERE
SHOCK FRONT PARAMETERS AS A FUNCTION OF PEAK OVERPRESSURE FOR SEA LEVEL ATMOSPHERE

PEAK OVERPRESSURE (PSI)

- REFLECTED PRESSURE SCALE (PSI)
- VELOCITY SCALE (FT/SEC)
- DYNAMIC PRESSURE SCALE (PSI)

SHOCK VELOCITY

PEAK PARTICLE VELOCITY

PEAK REFLECTED PRESSURE

NORMAL INCIDENCE

PEAK DYNAMIC PRESSURE

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FREE AIR OVERPRESSURE POSITIVE PHASE IMPULSE VS. SLANT RANGE

Figure I-4 gives values of free air overpressure impulse as a function of distance for a 1 KT burst. The overpressure positive phase impulse of the blast wave is derived from the overpressure-time curve as illustrated in figure 2-1. It is the integral of the curve representing the variation of overpressure as a function of time between the time of arrival of the blast wave at a given range and the end of the positive phase at that range.

**Scaling.** For scaling to other yields, use:

\[
\frac{I_1}{I_2} = \frac{d_1}{d_2} = \frac{W_1^{1.6}}{W_2^{1.6}},
\]

where yield \( W_1 \) will produce, at slant range \( d_1 \), an overpressure impulse \( I_1 \), and yield \( W_2 \) will produce an overpressure impulse \( I_2 \) at slant range \( d_2 \).

**Example.**

*Given:* A 20 KT free air burst in a homogenous sea level atmosphere.

*Find:* The overpressure impulse at 3,000 feet slant range.

**Solution:** Applying the scaling above to scale to 1 KT,

\[
d_1 = \frac{W_1^{1.6} \times d_2}{W_2^{1.6}} = \frac{1 \times 3,000}{20^{1.6}} = 1,100 \text{ ft}.
\]

From figure I-4, the overpressure impulse at 1,100 feet from a 1 KT burst would be 0.54 psi-second. Therefore, for a 20 KT burst at 3,000 feet the impulse will be

\[
I_2 = I_1 \times \frac{W_2^{1.6}}{W_1^{1.6}} = 0.54 \times 2.71 =
\]

\[
1.46 \text{ psi-seconds. Answer.}
\]

**Reliability.** Based largely on theoretical considerations with some full scale test data in the low pressure region.

**Related Material.**

See paragraph I.16.

See also figures 2-1 and I-5 through I-9.
FREE AIR OVERPRESSURE POSITIVE PHASE IMPULSE VS SLANT RANGE FOR 1 KT BURST IN A HOMOGENEOUS SEA LEVEL ATMOSPHERE

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FIGURE I-4

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FREE AIR OVERPRESSURE DECAY

At a given point in space, the rate of decay of overpressure after shock front passage depends upon the peak overpressure of the shock front. Figure I-5 shows the variation in overpressure with time for various free air peak overpressures in terms of normalized coordinates; i.e., the overpressure at a given time is expressed as a fraction of the peak overpressure \( \frac{\Delta p(t)}{\Delta p} \), and the time is expressed as a fraction of the positive phase duration \( \frac{t}{t^*} \), where \( \Delta p(t) \) is the overpressure at the point of interest at a time \( t \) after shock front passage.

\( \Delta p \) is the free air peak overpressure at the point of interest, obtained from figure 2-3.

\( t \) is the time after shock front passage.

\( t^* \) is the duration of the positive phase at the point of interest, obtained from figure 2-4.

Related Material.

See paragraph I.1b.

See also figures 2-1, I-6, and I-8.
Figure 1-5

Free Air Overpressure Decay

Values of Δp

- 3.0 psi
- 15 psi
- 30 psi
- 45 psi
- 75 psi
- 150 psi
- 750 psi
- 3000 psi

Normalized Overpressure

Normalized Time $\frac{t}{T}$ (Units of Positive Duration)
COMPARISON OF SIMPLIFIED WAVE FORMS FOR OVERPRESSURE AND DYNAMIC PRESSURE

\[ \frac{\Delta p(t)}{\Delta p} = (1 - \frac{t}{t^+})e^{-t/1^+} \]

\[ \frac{q(t)}{q} = (1 - \frac{t}{t^+})^2 e^{-2t/1^+} \]

NORMALIZED PRESSURE \( \frac{\Delta p(t)}{\Delta p} \) and \( q(t) \)

NORMALIZED TIME \( \frac{t}{t^+} \)
Figure I-7 gives values of free air dynamic pressure impulse as a function of distance for a 1 KT burst. The dynamic pressure positive phase impulse of the blast wave is derived from the dynamic pressure-time curve as illustrated in figure 2-1. It is the integral of the curve representing the variation of dynamic pressure as a function of time between the time of arrival of the blast wave at a given range and the end of the dynamic pressure phase.

Scaling. For scaling to other yields, use:

\[
\frac{I_1}{I_2} = \frac{d_1^{1/3}}{d_2^{1/3}} \frac{W_1^{1/3}}{W_2^{1/3}}
\]

where yield \( W_1 \) will produce at a slant range \( d_1 \) a dynamic pressure impulse \( I_1 \), and yield \( W_2 \) at slant range \( d_2 \) will produce a dynamic pressure impulse \( I_2 \).

Example.

Given: A 20 KT free air burst in a homogeneous sea level atmosphere.

Find: The dynamic pressure impulse at 3,000 feet slant range.

**Solution:** Applying the scaling above to scale to 1 KT,

\[
d_1 = \frac{W_1^{1/3} \times d_2^{1/3}}{W_2^{1/3}} = \frac{1 \times 3,000}{20^{1/3}} = 1,100 \text{ ft}.
\]

From figure I-7, the dynamic pressure impulse at 1,100 feet from a 1 KT burst would be 0.056 psi-sec.

Thus, the overpressure impulse at 3,000 feet from a 20 KT burst will be

\[
I_2 = \frac{I_1 \times W_1^{1/3}}{W_2^{1/3}} = 0.056 \times 2.71 = 0.152 \text{ psi-sec. Answer.}
\]

Reliability. Based entirely on theoretical considerations.

Related Material.

See paragraph I.1c.

See also figures 2-1, I-4 through I-6, I-8 and I-9.
FREE AIR DYNAMIC PRESSURE IMPULSE
VS.
SLANT RANGE
FOR A 1 KT BURST IN A HOMOGENEOUS
SEA LEVEL ATMOSPHERE

Dynamic Pressure Impulse (kPa·sec)

Slant Range (Feet)
FREE AIR DYNAMIC PRESSURE DECAY

At a given point in space, the rate of decay of dynamic pressure after shock front passage depends upon the peak dynamic pressure. Figure I-8 shows the variation in dynamic pressure with time for various free air peak dynamic pressures in terms of normalized coordinates; i.e., the dynamic pressure at a given time is expressed as a fraction of the peak dynamic pressure \( \left( \frac{q(t)}{q} \right) \) and the time is expressed as a fraction of the positive phase duration \( \left( \frac{t}{t^*} \right) \), where:

- \( q(t) \) is the dynamic pressure at the point of interest at a time \( t \) after shock front passage.

- \( q \) is the free air peak dynamic pressure at the point of interest, obtained from figure 2-5.

- \( t \) is the time after shock front passage.

- \( t^* \) is the duration of the positive phase at the point of interest, obtained from figure 2-4. The overpressure positive phase duration, \( t^* \), is used rather than the dynamic phase duration for reasons discussed in paragraphs 2.1b(4)(b) and I.1c.

**Related Material.**

- See paragraphs 2.1b(4)(b) and I.1c.
- See also figures 2-1, 1-5 and I-6.
OVERPRESSURE POSITIVE PHASE IMPULSE AT THE SURFACE

Figures 1–9A and 1–9B give overpressure positive phase impulse as a function of height of burst and ground range for a 1 KT burst in a sea level homogeneous atmosphere and represent the area under the positive phase of the overpressure-time curve at or near the reflecting surface. Figure 1–9A applies to good surface conditions where thermal and mechanical effects are minimized, i.e., near-ideal wave forms. Figure 1–9B applies to average surface conditions where the non-ideal wave forms discussed in paragraph I.2a may be expected. The curves in figures 1–9A are derived from figures 2–9 and 2–11. The curves in figure 1–9B are derived from figures 2–10 and 2–11.

Scaling. To scale to other yields, height of burst, ground range, and impulse scale as the cube root of the yield, or:

\[
\frac{I_1}{I_2} = \frac{h_1}{h_2} = \frac{d_1}{d_2} = \left(\frac{W_1^{1/3}}{W_2^{1/3}}\right)
\]

where \(I_1\), \(h_1\), and \(d_1\) are impulse, height of burst and ground distance for yield \(W_1\), and \(I_2\), \(h_2\) and \(d_2\) are the corresponding impulse, height of burst and ground range for yield \(W_2\).

Example:

Given: A 30 KT burst at a height of 1,000 feet over an average surface.

Find: The overpressure positive phase impulse on the surface at a ground range of 2,000 yards.

Solution: Using the above scaling to scale to the corresponding ground distance and height of burst for 1 KT,

\[
h_1 = \frac{W_1^{1/3} \times h_0}{W_2^{1/3}} = \frac{1 \times 1,000}{(30)^{1/3}} = 322 \text{ ft.}
\]

\[
d_1 = \frac{W_1^{1/3} \times d_2}{W_2^{1/3}} = \frac{1 \times 2,000}{(30)^{1/3}} = 644 \text{ yd.}
\]

From figure 1–9B for a height of burst of 322 feet and at a ground range of 644 yards the impulse is about 530 psi-msec. Therefore, for 30 KT at a height of burst of 1,000 feet, the overpressure impulse at a ground range of 2,000 yards will be:

\[
I_2 = \frac{I_1 \times W_2^{1/3}}{W_1^{1/3}} = 530 \times 3.11 = 1,650
\]

psi-milliseconds or 1.65 psi-seconds.

Answer.

Reliability. Based on full scale test data.

Related Material.

See paragraph I.2a.

See also figures 2–9 through 2–11, I–4 and I–7.
OVERPRESSURE POSITIVE PHASE IMPULSE AT THE SURFACE AS A FUNCTION OF HEIGHT OF BURST AND HORIZONTAL RANGE

1 KT AT SEA LEVEL FOR AVERAGE SURFACE CONDITIONS
Figure I-11 shows the overpressure wave form types to be expected for a 1 KT burst in a sea level homogeneous atmosphere as a function of height of burst and ground range for average surface conditions. In addition, the precursor zone is depicted.

Scaling. Height of burst and ground distance to which the precursor zone or a wave form type extend scale as the cube root of the yield:

\[ \frac{h_i}{d_i} = \frac{W_i^{1/3}}{W_1^{1/3}} = \frac{W_i^{1/3} \times d_i}{W_1^{1/3}} \]

where \( h_i \) and \( d_i \) are height of burst and ground distance from ground zero for yield \( W_i \), and \( h_i \) and \( d_i \) are the corresponding height of burst and ground distance from ground zero for yield \( W_1 \).

Example.

Given: A 100 KT burst at 600 feet over an average surface.

Find: (1) The ground range to which a precursor may be expected to extend; and (2), the wave form to be expected at the surface 660 yards from ground zero.

Solution: (1) Using the above scaling to obtain a corresponding height of burst for 1 KT,

\[ h_i = \frac{W_i^{1/3} \times d_i}{W_1^{1/3}} = \frac{1 \times 600}{100} = 129 \text{ ft.} \]

Entering figure I-11 at a height of burst of 129 feet, the precursor zone extends 368 yards for a 1 KT burst. To obtain the corresponding distance for 100 KT,

\[ d_i = \frac{W_i^{1/3} \times d_i}{W_1^{1/3}} = \frac{(100)^{1/3} \times 368}{1} = 1,710 \text{ yards. Answer.} \]

(2) The distance at the surface for 1 KT corresponding to 660 yards for 100 KT is:

\[ d_i = \frac{W_i^{1/3} \times d_i}{W_1^{1/3}} = \frac{1 \times 660}{100} = 142 \text{ yd.} \]

Entering figure I-11 at a height of burst of 129 feet and a ground distance of 142 yards, the intercept lies within the region of the precursor zone at which the overpressure wave form to be expected at the surface is type II. Answer.

Reliability. Boundary lines of precursor and wave form zones are derived primarily from full scale testing over desert surfaces.

Related Material.

See paragraphs 2.1c and d(4), and I.2a.
See also figures 2–16 and 2–17.
VARIATION OF OVERPRESSURE WAVE FORM WITH HEIGHT OF BURST AND GROUND RANGE FOR 1KT IN A SEA LEVEL HOMOGENEOUS ATMOSPHERE FOR AVERAGE SURFACE CONDITIONS.

- Wave Form Classical
- Wave Form Nearly Classical
- Some Thermal Effects
- Precursor Zone
- Type I
- Type II
- Type III
- Type IV
- Type V

Height of Burst (yards) vs. Ground Range (yards)
ALTITUDE CONVERSION

Example 1. (Surface Target Situation)

Given: A 1 MT detonation at 20,000 feet altitude above a ground surface at an elevation of 7,000 feet.

Find: (1) The time of shock arrival and free air peak overpressure incident at the surface directly below the burst.

(2) The reflected pressure at the surface.

Solution: (1) From figure I-13 the distance, time and pressure conversion factors for a target at an elevation of 7,000 feet are $S_x=1.09$, $S_y=1.11$, and $S_z=0.77$. The 13,000 foot range from burst to ground surface scaled to 1 KT and converted to sea level is:

$$d_s = \frac{d_t}{S_x (W)^{1/2} S_z} = \frac{13,000}{(1,000)^{1/2} 1.09} = 1,190 \text{ feet.}$$

From figures 2-2 and 2-3, the 1 KT sea level time of free air shock arrival and free air peak overpressure at a distance of 1,190 feet are 0.6 second and 5.2 psi. Therefore, at a surface at 7,000 feet altitude and 13,000 feet directly below a 1 MT burst, the time of shock arrival and free air peak overpressure incident at the surface are:

$$t_s = t_e W^{1/2} S_x = 0.6 (1,000)^{1/2} \times 1.11 = 6.6 \text{ seconds.}$$

$$\Delta p_s = \Delta p_x S_y = 5.2 \times 0.77 = 4.0 \text{ psi.}$$

Answers.

(2) From paragraph I.1a a free air peak overpressure of 4.0 psi at normal incidence to a surface produces a reflected pressure of about 9 psi. Answer.

Example 2. (Airborne Target Situation)

Given: At shock arrival time, an aircraft is flying at 25,000 feet altitude and at a horizontal range of 15,000 feet from a point directly above a 1 MT burst which is 5,000 feet above a sea level surface.

Find: The peak overpressure and peak particle velocity at the aircraft position.

Solution: The slant range

$$d_s = \frac{(15,000)^2 + (25,000 - 5,000)^2}{25,000 \text{ feet.}}$$

From figure I-13 for the 25,000 feet target altitude, the distance conversion factor $S_x=1.39$ and the pressure conversion factor $S_z=0.37$.

The range from target to burst scaled to 1 KT and converted to sea level is:

$$d_s = \frac{d_t}{S_x (W)^{1/2} S_z} = \frac{25,000}{1.39 \times (1,000)^{1/2} 0.37} = 1,800 \text{ feet.}$$

From figure I-14, the sea level peak overpressure $\Delta p_s$ and the peak particle velocity $u_p$ at a distance of 1,800 feet are 2.80 psi and 150 feet per second, respectively.

Therefore, at 25,000 feet altitude and a slant distance of 25,000 feet from a 1 MT burst, the peak overpressure $\Delta p_s$ is:

$$\Delta p_s = 2.80 \times 0.37 = 1.04 \text{ psi, and}$$

the peak particle velocity $u_p$ is:

$$u_p = u_s \left( \frac{C_p}{C_s} \right) = 150 \times \frac{1,016}{1,116} = 137 \text{ feet per second.}$$

Answers.

Reliability. The altitude conversion factors of figure I-13 introduce no significant additional error and do not change the reliability of the basic data to which they are applied. The sea level data from figure I-14 is considered reliable within ±20 percent when converted to altitudes up to 50,000 feet and scaled for yields up to 20 MT.

Related Material.

See paragraphs 2.1d(2)(c) and I.3.
ALTIMETER CONVERSION FACTORS

\[ S_d = \text{Distance Conversion Factor} = (P_0 / P_3)^{1/2} \]

\[ S_t = \text{Time Conversion Factor} = (C_a / C_i)(P_0 / P_3)^{1/2} \]

\[ S_p = \text{Pressure Conversion Factor} = P_0 / P_3 \]
FIGURE I-14

SEA LEVEL BLAST PARAMETERS FROM A 1KT BURST
FOR ALTITUDE CONVERSION FOR AIRBORNE TARGETS

Δp - FREE AIR PEAK OVERPRESSURE
q - PEAK DYNAMIC PRESSURE
u - PEAK PARTICLE VELOCITY
ρ' - PEAK DENSITY

SLANT RANGE (feet)
Figure I-16
CONFIDENTIAL

PEAK OVERPRESSURE VS. DISTANCE

HOMOGENEOUS ATMOSPHERE OF STANDARD SEA LEVEL CONDITIONS

1 KT SURFACE BURST

\[ \Delta p (\text{psi}) \]

\[ \text{RANGE (feet)} \]
APPENDIX II
USEFUL RELATIONSHIPS

II.1 General
Equivalents:
1 KT is equivalent to $10^{12}$ calories of energy.
1 MT = 1,000 KT = $10^{14}$ calories of energy.
(Ultimately all the energy from a nuclear weapon appears as heat.)
1 KT represents about $1.5 \times 10^{20}$ fissions.

Energy equivalents:
1 calorie = 4.184 joules
= 3.086 foot-pounds
= $2.61 \times 10^{13}$ Mev
= $3.966 \times 10^{-2}$ Btu.

Mass-energy conversion: 1 gram mass = $5.61 \times 10^{8}$ Mev.

The temperature associated with one electron-volt is 11,605.9 degrees Kelvin.
1 millibar = 1,000 dynes/cm$^2$ = 0.00145 psi.

Relative air density:
Given air pressures at detonation and target altitude,

$$ R = 25.8 \frac{p_1 - p_2}{\frac{h_1}{h_2}} $$

where $p_1 - p_2$ is pressure difference in millibars
$h_1 - h_2$ is the altitude difference in feet
Given detonation and target at same altitude,

$$ R = 0.27 \frac{\rho}{T} = 0.00129 \rho $$

where $\rho$ = pressure in millibars
$T$ = absolute temperature in degrees Kelvin
$\rho$ = air density in gm/cm$^3$

Given detonation and target altitude only, standard atmosphere assumed, see figure II-3.

Constants:
Velocity of light: $3 \times 10^8$ meters per second.
Avogadro's number: $6.023 \times 10^{23}$ molecules per mole.
Planck's constant: $6.624 \times 10^{-34}$ joule-second
Boltzmann constant: $1.38 \times 10^{-16}$ erg per degree.
Loschmidt number: $2.687 \times 10^{18}$ molecules per cubic centimeter at 0°C.

Mass of electron: $9.11 \times 10^{-28}$ gram.
Mass of proton: $1.67 \times 10^{-24}$ gram.
Mass of alpha particle: $6.64 \times 10^{-27}$ gram.
Classical electron particle: $2.82 \times 10^{-13}$ cm.

Standard sea-level atmosphere:
Pressure = 14.6960 lbs./square inch
= 29.92 in. of mercury (at 0°C)
= 76 cm of mercury (at 0°C)
= 33.9 ft. of water (at 4°C)
= 1,013.25 millibars
= 2,117 lbs./square foot
Temperature = 59.000 degrees Fahrenheit
= 15,000 degrees Centigrade
Density = 0.0023779 slug per cubic foot
Speed of sound = 1,116.215 ft/sec.

II.2 Thermal
Temperature scale conversions:

$^oK = ^oC + 273$; $^oC = 5/9 ($ $^oF - 32$)

$^oF = 9/5^oC + 32$; $R = ^oF - 459.4$

Thermal radiation from a nuclear weapon:
For air bursts under 50,000 feet,

$$ E = \frac{W}{3} KT = \frac{W}{3} \times 10^{12} \text{ calories (W in KT)} $$

For surface bursts viewed from the ground,

$$ E = \frac{W}{7} KT = \frac{W}{7} \times 10^{13} \text{ calories (W in KT)} $$

A radiant exposure of approximately 1 cal/sq cm will be received at a slant range of 1 mile from a 1 KT air burst on a clear day.
At a given slant range the radiant exposure for ground targets is proportional to weapon yield.

Time to radiant power minimum:

$$ t_{min} = \frac{W^{1/2}}{370} = 0.0027 W^{1/2} \text{ seconds (W in KT)} $$

Time to second radiant power maximum:

$$ t_{max} = \frac{W^{1/3}}{31.2} = 0.032 W^{1/3} \text{ seconds (W in KT)} $$
Second radiant power maximum:
For air bursts under 50,000 feet:

\[ P_{\text{max}} = 4 \ W^{1/2} \frac{KT}{\text{sec}} = 4 \ \frac{W^{1/2} \times 10^{12}}{\text{cal/sec}} \ (W \ in \ KT) \]

Less than 1 percent of the thermal radiation from a nuclear detonation near sea level is emitted before the radiant power minimum.

II.3. Nuclear

1 KT fission yield makes available 300 megacuries of radioactive fission product gamma activity at a time of one hour after a detonation.

1 curie is that quantity of radioactive material which undergoes \(3.7 \times 10^{10}\) disintegrations per second.

The roentgen is a measure of quantity of ionization, and is equivalent to:

83.8 ergs per gram of air; or

\(1.64 \times 10^{12}\) ion-pairs per gram of air; or

\(5.24 \times 10^7\) Mev per gram of air.

0.7 Mev is the approximate mean effective energy for the gamma rays from a residual fission product field.

To obtain the radiation intensity in roentgens per hour three feet above a plane residual fission product field, multiply the concentration of the contaminant in curies per square foot by 120, or in megacuries per square mile by 4.

Total dose in roentgens accumulated to infinite time from one hour after a burst is numerically equal to five times the dose rate in roentgens per hour at \(H+1\) hour. (Fission product activity.)

The radioactive decay of gross fission products is approximately exponential with time, so that—

\[ I = I_i \ e^{-t/\tau} \]

where \(I\) is the dose rate at any time \(t\), and \(I_i\) is the dose rate at unit time.

The velocity of a thermal neutron \((E=1/40 \text{ ev})\) is 2,200 meters per second.

Shielding thicknesses in inches required to cut incident gamma radiation by a factor of ten are:

<table>
<thead>
<tr>
<th>Material</th>
<th>Initial bomb gamma</th>
<th>Residual gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Iron</td>
<td>4.5</td>
<td>2.8</td>
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<tr>
<td>Concrete</td>
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<td>9.5</td>
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<tr>
<td>Soil</td>
<td>26</td>
<td>14</td>
</tr>
<tr>
<td>Water</td>
<td>41</td>
<td>21</td>
</tr>
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</table>

As a rough rule of thumb, the area of effect for a given degree of contamination resulting from a nuclear surface burst can be considered directly proportional to the fission yield of the weapon.

Greatest cloud diameter at 9 minutes after burst time (for kiloton yields) is approximately given by—

\[ d = 10,000 \ W^{1/2} \text{ feet} \]

The dose rate inside the bomb cloud is independent of yield (in the kiloton range) and is given by the formula,

\[ D = 1.31 \times 10^4 t^{-2.04} \text{ roentgens per hour} \]

where \(t\) is the time after detonation in minutes.
## Table 11-1. Standard Atmospheric Conditions

<table>
<thead>
<tr>
<th>Geometric Altitude</th>
<th>Temp. *°F</th>
<th>Pressure (psid)</th>
<th>Density (lb/ft³)</th>
<th>Sound Velocity (fps)</th>
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*Reference, U.S. Extension To The ICAO Standard Atmosphere—Tables and Data to 300 Standard Geopotential Kilometers.*
Table II-8. Average Atmosphere*

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<th>Geometric Altitude (feet)</th>
<th>Temperature *C. (°F.)</th>
<th>Pressure Millibars (psu)</th>
<th>Density kg/m³ (lbf/ft³)</th>
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FRACTIONAL POWERS AND DIMENSION SCALING NOMOGRAM

Figure II-1A presents several fractional powers of numbers between 1 and 100,000. The fractional powers presented are those which are necessary in the application of various scaling procedures presented elsewhere in the text.

Figure II-1B is a nomogram from which actual dimensions may be obtained from various scaled dimensions for yields from 0.1 KT to 100 MT. The scaling power for which the scaled dimensions are applicable is indicated at the top of the scale in each case. A straight line connecting a yield with any scaled dimension will cross the actual dimension scale at the proper value according to the scaling which is being used. The dimensions may be in any units for which scaling is given, but the scaled dimension and the actual dimension will always be in the same units.

Examples.

1. Given: A 500 KT weapon is to be burst at the minimum height of burst at which fallout is not expected.
   Find: The actual height of burst at which the weapon is to be detonated.
   Solution: From paragraph 4.3d the minimum burst height for a 500 KT weapon at which fallout is not expected is 180 \( W^{0.4} \) feet.
   a. From figure II-1A:
      \( (500)^{0.4} = 12 \)
      \( 180 \times 12 = 2,160 \) feet. Answer.
   b. From figure II-1B:
      A straight line connecting 500 on the yield scale with 180 on the 2/5 power scaled dimension scale crosses the actual dimension scale at 2,160. The desired height of burst is thus 2,160 feet. Answer.

(Note: Conversion from one scaling procedure to another is particularly easy with the nomogram. The line mentioned above crosses the cube root scaled dimension scale at 270. Thus 180 \( W^{0.4} \) feet corresponds to 270 \( W^{1/3} \) feet for 80 KT.)

2. Given: A ground range of 2,580 yards from an 80 KT surface burst.
   Find: The proper scaled range for determining overpressure from the 1 KT graphs.
   Solution: The applicable scaling is:
   \[ d_1 = \frac{W_1^{1/3}}{d_2} = \frac{W_1^{1/3}}{W_2^{1/3}} \]
   a. From figure II-1A:
      \( (80)^{1/3} = 4.3 \)
      \( d_1 = \frac{W_1^{1/3} \times d_2}{W_2^{1/3}} = \frac{1 \times 2,580}{4.3} = 600 \) yards.
   b. From figure II-1B:
      A straight line from 80 on the yield scale through 2,580 on the actual dimension scale intersects the cube root scaled dimension scale at 600. The scaled distance is thus 600 yards. Answer.
FIGURE II-2

CONFIDENTIAL

NOMOGRAM RELATING HEIGHT OF BURST
HORIZONTAL DISTANCE AND SLANT RANGE

Height of Burst (ft)

Slant Range (Yds.)

Horizontal Distance (Yds.)

0

1000

1500

2000

2500

3000

3500

4000

4500

0

1000

1500

2000

2500

3000

3500

4000

4500
RELATIVE AIR DENSITY
(STANDARD ATMOSPHERE)

Altitude of Detonation (Feet)

Altitude of Target (Feet)
ATMOSPHERIC WATER VAPOR DENSITY VS. RELATIVE HUMIDITY FOR VARIOUS AIR TEMPERATURES

Water Vapor Density (grams per cubic meter)

Relative Humidity (Percent)
APPENDIX III
GLOSSARY

Absorption coefficient—A number characterizing a given material with respect to its ability to absorb radiation. The linear absorption coefficient refers to the ability of a given material to absorb radiation per unit thickness; it is expressed in reciprocal units of thickness. The mass absorption coefficient refers to the ability of a given material to absorb radiation per unit mass; it is expressed in units of area per unit mass, and it is equal to the linear absorption coefficient divided by the density of the absorbing material.

Acceleration—Time rate of change of velocity. The acceleration due to gravity (g) is 32.2 ft/sec².

Activity—The rate of decay of radioactive material expressed as the number of nuclear disintegrations per second.

Air burst—See Burst types.

Albedo—The fraction of the incident radiation reflected in any manner by a material.

Alpha particle—A particle ejected spontaneously from the nuclei of some radioactive elements. It is identified with the helium nucleus, which has an atomic weight of four and an electric charge of plus two.

Amplitude—The maximum displacement of an oscillating particle from its position of equilibrium.

Angle of incidence—The angle between the perpendicular to a surface and the direction of propagation of a wave.

Apparent crater—See Crater. The visible crater remaining after a nuclear detonation.

Atmospheric transmissivity (T)—The fraction of the radiant exposure received at a given distance after passage through the atmosphere relative to that which would have been received at the same distance if no atmosphere were present.

Atomic cloud—An all-inclusive term, identified as the hot gases, the smoke and the vapors formed in the ball of fire produced by the burst of a nuclear weapon, which from large yield weapons may penetrate the tropopause and spread out because of temperature inversions and wind existing aloft. The cloud contains radioactive fission products. See Fireball.

Atomic weapon—See Nuclear weapon.

Attenuation—Reduction in intensity of radiation or blast by passage through any medium.

Ball of fire—See Fireball.

Base surge—A cloud which rolls out from the bottom of the column produced by a subsurface burst of a nuclear weapon. For underwater bursts, the surge is, in effect, a cloud of liquid droplets which has the property of flowing almost as if it were a homogeneous fluid. For subsurface land bursts, the surge is made up of small solid particles, but still behaves like a fluid.

Beta particle—A small particle ejected spontaneously from a nucleus of either natural or artificially radioactive elements. It carries a charge of one electronic unit and has an atomic weight of 1/1840. The charge may be either positive (positrons) or negative (electrons). The charge is thus one-half that of the alpha particle and the mass is 1/7360 of that of an alpha particle. The electron is much lighter than the hydrogen atom (atomic weight = 1), which is the lightest atom.

Blast wave—See Shock wave. The shock wave transmitted through the air as the result of an explosion, through usage, is referred to as a blast wave or air blast.

Blast yield—That portion of the total energy of a nuclear detonation which manifests itself as a blast or shock wave.

Bomb debris—See Weapon debris.

Breakaway—The onset of a condition in which the shock front moves away from the periphery of the expanding ball of fire.
Breaking wave—A wave of such steep slope that it is unable to maintain its shape and hence loses height by tumbling or falling over.

Burst geometry—The location of a nuclear detonation with respect to the ground surface, water surface, or bottom.

Burst types:
- **Air burst**—The explosion of a nuclear weapon at such a height that the weapon phenomenon of interest is not significantly modified by the earth’s surface. For example, these heights are such that for—
  - **Blast**—the reflected wave passing through the fireball does not overtake the incident wave above the fireball (~160 W^{1/3} ± 15 percent).
  - **Thermal radiation**—the apparent thermal yield viewed from the ground is not affected by heat transfer to the earth’s surface nor by distortion of the fireball by the reflected shock wave (~180 W^{0.4} ± 20 percent for 10 KT to 100 KT and ±30 percent for other yields).
  - **Fall-out**—militarily significant local fall-out of radioactive material will not occur. For W<100 KT, H_n=100 W^{1/2}; see Section 4.3 for reliability discussion; for W>100 KT, in the absence of data, H_n may be conservatively taken to equal 180 W^{1/3}. For certain other phenomena of interest, e.g., neutron induced activity, initial gamma or neutron flux, the height of burst at which an air burst occurs is difficult or impossible to distinguish.

- **Surface burst**—the explosion of a nuclear weapon at the earth’s surface (either ground or water surface).

- **Subsurface burst** (underground or underwater)—the explosion of a nuclear weapon in which the center of the detonation lies at any point beneath the earth’s surface (either ground or water surface).

- **Calorie**—The amount of heat required to raise the temperature of 1 gram of water from 15°C to 16°C at 760 mm Hg pressure.

- **Camouflage**—See Crater.

- **Casualty**—As used in this manual, an individual who, as a result of injury, requires medical attention.

Cavitation—The separation of the water particles and the forming of cavities, as a result of water’s inability to withstand the tensional wave reflected from the water surface.

Cloud chamber effect—See Condensation cloud.

Column—The visible column of particulate matter which may extend to the tropopause (the boundary between the troposphere and the stratosphere) subsequent to the explosion of a nuclear weapon. Also, the hollow cylinder of material thrown up from a subsurface nuclear detonation.

Combat ineffective—An individual whose injuries are of such nature that he is no longer capable of carrying out his assigned task.

Condensation cloud—A mist or fog which temporarily surrounds the ball of fire following a nuclear detonation in a comparatively humid atmosphere. As it is similar to the cloud observed by physicists in the Wilson cloud chamber, it is also called the “Wilson cloud.” Rapid cooling of the previously heated air surrounding the ball of fire during the negative pressure phase of the shock wave causes the moisture in the air to condense temporarily, forming a cloud. The cloud is dispersed within a second or so upon return of the air pressure to normal.

Contamination (radioactive)—The deposit of radioactive material on the surface of structures, areas, personnel, or objects. See Decontamination.

Contour method—The representation of the degree of contamination resulting from a nuclear burst by the use of contour lines to connect points of equal radiation dose or dose rate. See Isodose lines.

Coupling—The energy transfer of a shock wave traveling in one medium which produces a shock wave in a second medium at their common interface.

Crater—The pit, depression, or cavity formed in the surface of the earth by an explosion. May range from saucer shaped to conical, depending largely on the depth of burst. In the case of a deep underground burst no rupture of the surface may occur. The resulting cavity is termed a camouflet. See also True crater and Apparent crater.
Crater depth—The maximum depth of the crater measured from the deepest point of the pit to the original ground level.

Crater radius—The average radius of the crater measured at the level corresponding to the original surface of the ground.

Critical radiant exposure (Q)—The radiant exposure required for a particular effect on a material. The unit of critical radiant exposure is the cal/sq cm.

Curie—By definition, the quantity of any radioactive nuclide in which the number of disintegrations per second is $3.7 \times 10^{10}$.

Decontamination—The process of removal of contaminating radioactive material from an object, a structure, or an area. The problem of decontamination consists essentially of reduction of the level of radioactivity, and thus reduction of the hazard it imposes, to a reasonably safe limit. See Contamination.

Diffraction—The bending of waves around the edges of objects.

Diffraction loading—The forces exerted upon an object or structure by the blast wave overpressures as the shock front strikes and engulfs it.

Direct shock wave—A shock wave traveling through the medium in which the explosion occurred, without having encountered an interface, is referred to as the direct shock wave.

Dose (dosage)—The total amount of nuclear or ionizing radiation absorbed by an individual exposed to the radiating source, such as would be received from a nuclear explosion and resulting radioactive products. X-rays and gamma rays are measured in roentgens; alpha, beta, and neutron doses are measured in rem or rep. See Dose-rate.

Dose-rate—The amount of nuclear radiation received per unit of time. See Dose.

Dosimeter—An instrument for measuring the amount of radiation received. Dosimeters include film badges, pocket chambers, and pocket dosimeters; also glass, crystal, and liquid dosimeters.

Drag loading—The forces exerted upon an object or structure by the dynamic pressures from the blast wave of an explosion, influenced by certain characteristics (primarily the shape) of the object or structure.

Ductility—The ability of a material or object to undergo large permanent deformations without rupture.

Dynamic pressure ($q$)—$q = \frac{1}{2} \rho u^2$, where $\rho$ is the density of the medium and $u$ is the particle velocity behind the shock front. The drag force on an object is directly proportional to the dynamic pressure.

Dynamic pressure impulse—See Impulse.

Electromagnetic radiation—Radiation made up of oscillating electric and magnetic fields and propagated with the speed of light. Includes gamma radiation, X-rays, ultraviolet, visible and infrared radiation, and radar and radio waves.

Electromagnetic spectrum—The frequencies (or wave lengths) present in a given electromagnetic radiation. A particular spectrum could include a single frequency or a wide range of frequencies.

Energy partition—The distribution of the total energy released by a nuclear detonation among nuclear radiation, thermal radiation, and blast. The exact distribution is a function of time and of the weapon yield and the medium in which the weapon is detonated.

Factor—A multiplier, frequently used to indicate range of coverage. For example, "correct within a factor of two" means correct within a possible range of values between twice and one-half the stated value.

Fall-out—The process of the gradual settling out of small particles and the rapid fall of larger particles thrown up by the explosion. The local or militarily significant fall-out area may extend from the crater or immediate vicinity of the detonation out to distances of many miles, depending upon meteorological and surface conditions. Detectable amounts of fall-out may occur over distances of hundreds or thousands of miles for several months after an explosion.

Film badge—A photographic film packet in the form of a badge, carried by personnel, for obtaining a measure of gamma ray dosage. See Dosimeter.

Fireball—The visible luminous sphere of hot gases formed by a nuclear weapon.

Fire storm—A wind blowing toward a large burning area from all sides, reaching as much as 40 miles per hour and persisting for perhaps several
hours caused by the updraft of heated air over the burning area. This phenomenon may occur after a nuclear explosion over or in a city or other combustible area. The conditions required to initiate a fire storm are poorly understood at this time. The winds of a fire storm tend to limit the spread of the fire causing the storm.

Fission—The process of splitting an atom, usually into two major portions. This is the type of fission that occurs in materials used in nuclear weapons. The fission of U_{235} or Pu_{239} and certain other radionuclides releases large amounts of energy in extremely short intervals of time.

Fission products—The substances produced as a result of the fission of the nuclear material of nuclear weapons. The fission of uranium 235, for example, yields more than 60 direct products, sometimes called fission fragments, which are formed by the actual splitting of the uranium nuclei. These direct products, being radioactive, immediately begin to decay, forming additional daughter products.

Free air—A region of homogeneous air sufficiently remote from reflecting surfaces or other objects that the characteristics of the direct shock are not modified in any way by reflected shocks or other disturbances arising from scattering objects.

Free air overpressure (sometimes called free air pressure)—The unreflected pressure in excess of atmospheric or ambient pressure created in the air by the incident shock of any explosion.

Fusion—The process whereby the nuclei of light elements combine to form the nucleus of a heavier element; not to be confused with nuclear fission, which is the process whereby the nucleus of a heavy element splits into two nuclei of lighter elements.

Gamma rays—Electromagnetic radiations, similar to X-rays, originating from the atomic nucleus.

Ground zero (GZ)—The point on the surface of land or water vertically below or above the center of a burst of a nuclear weapon; also called surface zero.

Height of burst—The height above the earth's surface at which a weapon is detonated. Altitude, by contrast, is the height above mean sea level.

Hogging—The causing of tensile stresses above and compressive stresses below the longitudinal neutral axis of a ship by a wave crest passing amidships.

Hot spots—Regions in a contaminated area in which the level of radioactive contamination is considerably higher than in neighboring regions. See Contamination.

Impulse (I)—The product of the average force and the time during which it acts at a given point, or the integral of the curve representing variation of force with time, with integration over the time of interest. In considering the effectiveness of a shock wave in producing damage, it is generally more convenient to employ the concepts of overpressure impulse and dynamic pressure impulse. The overpressure impulse \( I_0 \) of the positive phase of a blast wave is the integral of the curve representing the variation of overpressure with time, the integration being performed from \( t=0 \), the time of arrival of the shock front at a given location, to \( t=t^* \), the end of the positive phase. The dynamic pressure impulse \( I_d \) is a similar integral of the dynamic pressure-time curve.

Induced radioactivity—Radioactivity resulting from certain nuclear reactions in which exposure to radiation results in the production of unstable nuclei. Many materials near a nuclear explosion enter into this type of reaction, notably as a result of neutron bombardment.

Induced shock wave—The shock wave induced in a medium when a shock wave traveling in another medium crosses the interface between the two media.

Infrared—That portion of the electromagnetic spectrum occurring between the wave lengths 0.7 and 12 microns.

Initial radiation—The nuclear radiation accompanying a nuclear explosion and emitted from the resultant ball of fire and atomic cloud. It includes the neutrons and gamma rays given off at the instant of the explosion, and the alpha, beta, and gamma rays emitted in the rising ball of fire and column. In contrast to residual radiation, its effect on persons and objects on the earth's surface is terminated about ninety seconds after the explosion, because of the removal of the final source (fission products in the atomic cloud) from
within radiation range of the earth at the end of that period of time. See Residual radiation.

*Intensity*—Energy incident per unit surface. See also Radiant exposure and Radiant power.

*Inversion (atmospheric temperature inversion)*—A region in the atmosphere in which the temperature rises with increasing altitude instead of dropping, as it does in the more general case.

*Ionization*—The production of charged particles (ions) by dislodging electrons from atoms or molecules.

*Irradiance (H)*—The incident radiant energy per unit time per unit area. The unit of irradiance is the cal/sq cm/sec.

*Isobaric*—Constant pressure condition.

*Isodose lines*—A term applied to imaginary contours in a radioactive field on which the total accumulated radiation dosage is the same.

*Kelvin scale*—The absolute temperature scale for which the zero is —273° C. Conversion from centigrade to Kelvin is made by adding 273° C. to the centigrade reading.

*KT (kiloton)*—Refers to the energy release of a thousand tons of TNT, where 1 ton equals 2,000 pounds and where the energy content of TNT is defined as 1,100 calories per gram.

*Lethal gust envelope*—The boundary of the area in any given plane within which the gust loading effects from a detonation inflict sufficient structural damage to destroy a given aircraft.

*Lip height*—The height above the original surface to which earth is piled around the crater formed by an explosion.

*Loading*—The forces imposed upon an object.

*Luminous*—See Visible.

*Mach stem*—The shock formed by the fusion of the incident and reflected shocks from an explosion. The term is usually used with reference to an air-propagated wave reflected from the surface of the earth, generally nearly vertical to the reflecting surface. See Shock front.

*Median lethal dose*—The amount of radiation received over the whole body which would be fatal to about 50 percent of human beings, animals, or organisms. It is usually accepted that a dose of 400 to 450 roentgens received over the whole body in the course of a few minutes represents the median lethal dose for human beings. The term is sometimes abbreviated as MLD or LD-50.

*Micron (μ)*—A unit of length equal to 10⁻⁶ meter, 10⁻³ millimeter, or 10⁵ Angstrom units.

*Millibar*—One thousand dynes per square centimeter, a unit of measure of atmospheric pressure.

*MT (megaton)*—Refers to the energy release of a million tons of TNT (10¹⁸ calories).

*Negative phase*—That portion of the blast wave in which pressures are below ambient atmospheric pressure.

*Neutron*—An electrically neutral particle which is one of the fundamental particles making up all atoms. It has nearly the same weight as the hydrogen nucleus (atomic weight 1). The neutron under appropriate conditions is capable of causing fission of U²³⁵ or Pu²³⁹ and certain other radionuclides. In the fission process other neutrons are produced, which can cause fission in additional U²³⁵ or Pu²³⁹ atoms. This multiplication process, triggered by neutrons, gives rise to the chain reaction which makes nuclear explosions possible.

*Nominal weapon*—A weapon with a 20 KT yield.

*Non-linear zone*—A wedge-shaped zone in water which increases in depth as the range from the burst point increases and within which anomalous reflections affect the underwater pressure history.

*Nuclear radiation*—Any or all of the radiations emitted as a result of the radioactive decay of a nucleus. The radiations include gamma radiation (of electromagnetic character) and particle radiation (alpha particles, positive and negative beta particles, and neutrons).

*Nuclear weapon*—A general name given to any weapon in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion or both. Also called Atomic weapon.

*Nuclide*—A general term referring to all nuclear species, both stable and unstable, of the chemical elements as distinguished from the two or more nuclear species of a single chemical element which are called isotopes.

*Overpressure*—The transient pressure, usually expressed in pounds per square inch, exceeding existing atmospheric pressure manifested in the blast wave from the explosion. During
some period of the passage of the wave past a
point, the overpressure is negative.

Overpressure impulse—See Impulse.

Period of vibration (period)—The time for one
complete cycle of oscillation or vibration.

Plastic deformation—That deformation from which
a deformed object does not recover upon removal
of the deforming forces.

Popcorning—The ejection of dust particles from
certain types of surface upon absorption of the
thermal radiation emitted by a nuclear detonation.

Positive phase—That portion of the blast wave
in which pressures are above ambient atmos-
pheric pressure.

Precursor—A pressure wave which precedes the
main blast wave of a nuclear explosion.

Radiant energy—See Thermal radiation.

Radiant exposure (Q)—The incident radiant energy
per unit area, expressed in cal/sq cm. Also
referred to as Intensity.

Radiant power (P)—Time rate of radiant energy
emission. Also sometimes referred to as Intensity. The units of radiant power are KT/sec.
or cal/sec.

Radioactive—Refers to the state of a material in
which the atoms decay spontaneously by the
emission of nuclear radiation.

Rarefaction wave—When a shock wave in a
medium strikes the interface between this
medium and a less dense medium, part of the
energy of the shock wave induces a shock wave
in the less dense medium. The remainder of
the energy forms a rarefaction or tensile wave
which travels back through the denser medium.

Reflected pressure—The pressure along a surface
of the instant a blast wave strikes the surface.

Reflected shock wave—When a shock wave traveling
in a medium strikes the interface between this
medium and a denser medium, part of the
energy of the shock wave induces a shock wave
in the denser medium and the remainder of
the energy results in the formation of a reflected
shock wave which travels back through the
less dense medium.

Relative air density—The ratio of the air density
under a given condition to the air density at
0° C. and 1,013 millibars.

Rem (roentgen equivalent mammal)—One rem is
the quantity of ionizing radiation of any type
which, when absorbed by man or other mammal,
produces a physiological effect equivalent to
that produced by the absorption of 1 roentgen
of X-ray or gamma radiation.

Rep (roentgen equivalent physical)—The quantity
of ionizing radiation which upon absorption in
the body tissue produces 93 ergs of energy per
gram of tissue.

Residual radiation—Nuclear radiation emitted by
the radioactive material after a nuclear burst.
Following a burst, the radioactive residue is in
the form of fission products, unshioned nuclear
material, and material such as earth and water
constituents, exposed equipment, etc., in which
radioactivity may have been induced by neutron
bombardment. It is sometimes referred to as
lingerér radiation. See Initial radiation.

Response—The action of an object under the
applied loading.

Rise time—The time interval from blast wave
arrival to the time of peak overpressure in the
blast wave.

Roentgen—A unit of X- or gamma-ray dose. The
exposure dose of X- or gamma-radiation such
that the associated corpuscular emission per
0.001293 gram of air produces, in air, ions
carrying one electrostatic unit of quantity of
electricity of either sign.

Scaling wind—An idealized representation of the
winds aloft in the atmosphere used to draw the
fall-out contours for contaminating bursts.

Scattering—Change in direction of propagation of
radiation caused by collision with particles.

Scavenging—That process by which fission prod-
ucts are removed from the radioactive cloud by
becoming attached to earth, rain, or other
particles.

Shielding—1. Material of suitable thickness and
physical characteristics used to protect personnel
from radiation during the manufacture, handling
and transportation of fissionable and radioactive
materials.

2. Obstructions which tend to protect per-
nsonnel or materials from the effects of a nuclear
explosion.

Shock front—The boundary at which the medium
being traversed by a shock or blast wave under-
goes abrupt changes in velocity, pressure, and
temperature.
Shock strength—The ratio of the peak blast wave overpressure plus ambient pressure to the ambient pressure.

Shock wave—The steep frontal compression or pressure discontinuity rapidly advancing through a medium as the consequence of a sudden application of pressure to the medium. Its form depends on the magnitude of the pressure and the displacement of the medium as the wave progresses. In soil the shock wave is commonly referred to as the ground shock; in water, the water shock; and in air, the air blast.

Slant range—The direct distance between an explosion and a point.

Slug—That mass to which a force of one pound imparts an acceleration of one foot per second per second.

Spectral distribution—Refers to the distribution of energy by wave length over the electromagnetic spectrum.

Subsurface burst—See Burst types.

Surface burst—See Burst types.

Tensile wave—See Rarefaction wave.

Thermal energy—See Thermal radiation.

Thermal pulse—The radiant power vs. time pulse from a nuclear weapon.

Thermal radiation—Electromagnetic radiation from a nuclear weapon which is emitted in the wavelength range from 0.2 micron in the ultraviolet, through the visible, to 12 microns in the infrared. Also called Thermal energy and Radiant energy.

Thermal yield—That part of the total yield of a nuclear weapon which appears as thermal radiation. See Thermal radiation.

Thermonuclear—An adjective referring to the process involving the fusion of light nuclei such as those of deuterium and tritium.

TNT effects equivalence—The expressing of the effect of a particular phenomenon of a nuclear detonation in terms of the amount of TNT which would produce the same effect.

TNT energy equivalence—Total energy of a nuclear detonation expressed in terms of the amount of TNT required to produce an equivalent energy.

Tolerance dose—The amount of radiation which may be received by an individual within a specified period with negligible effect.

Transition zone (region)—A zone extending above the earth’s surface in which the weapon phenomen-

enon of interest from a burst in the zone will be modified by the presence of the earth’s surface. See Burst types: Air burst for extent of this zone for various phenomena.

Transmissivity—See Atmospheric transmissivity.

Triple point—The intersection of the incident, reflected, and fused shock fronts produced by an explosion in the air. Because of the variation of the angle of incidence as the blast wave expands, and because the reflected wave, in a heated, denser medium, travels faster than the incident wave, the height of the triple point increases with the distance from the explosion. See Mach stem.

Tropopause—The boundary between the troposphere and the stratosphere.

True crater—See Crater. The crater excluding fall-back material.

Ultraviolet—That portion of the electromagnetic spectrum occurring between the wavelengths 0.2 and 0.4 micron.

Underground burst—See Burst types.

Underwater burst—See Burst types.

Visible—That portion of the electromagnetic spectrum occurring between 0.4 and 0.7 micron. The term luminous also is applied to radiation in this region.

Visibility—The horizontal distance at which a large, dark object can just be seen in daylight near the horizon.

Wave length—The distance between two similar and successive points on an alternating wave, as between maxima.

Wave train—A series of alternating crests and troughs of a wave system resulting from a surface disturbance.

Weapon debris—The residue of a nuclear weapon after it has exploded; that is, the materials used for the casing and other components of the weapon, plus unexposed plutonium or uranium, together with fission products.

Wilson cloud—See Condensation cloud.

Wind shear—A relatively abrupt change with altitude of wind direction or magnitude.

Yield (W)—The energy released in a nuclear explosion, usually measured by the estimated equivalent amount of TNT required to produce the same energy release. See TNT energy equivalence.
APPENDIX IV

BIBLIOGRAPHY

This bibliography contains many of the sources of data and information contained in this volume other than weapon test reports. It should not be considered inclusive, however, of all sources actually used. Many of the references listed herein contain extensive bibliographies on a particular subject. Further assistance in locating specific test data may be obtained from Cumulative Subject Guide to Weapons Test Information, TID 9004 (8th Rev.) (S) or the current Abstracts of Weapon-Test Reports, both published by Technical Information Service, Oak Ridge, Tennessee. Identification of Corporate Author Codes appears on the last page of this appendix.

GENERAL


BLAST AND SHOCK PHENOMENA

1. Airblast Peak Pressure Along the Water Surface from Shallow Underwater Explosions, NAVORD 2571, C. R. Niffenegger (NOL), 1 Aug 52 (C).
2. Behavior of Missiles from Underground Explosions at Dugway Covering Research from April to October 1931, SRI-317-TR-5, R. B. Vaile, Jr. (SRI), Nov 51 (S).
6. A Comparison of Altitude Corrections for Blast Overpressures, Haskell (AFCRC), Sep 54 (S).
10. Correlation of Experimental Peak Overpressures in the Fused Shock Region, (ARA) 236, David C. Knodel, Jan 57 (S–FRD).
13. Curves of Atomic Weapons Effects for Various Burst Altitudes (Sea level to 100,000 ft.), SC–3282 (TR), Cook and Broyles (SC), 9 Mar 54 (SRD).
14. The Effect of Earth Cover in Protecting Structures Against Blast, AFSPW–357, R. B. Vaile, Jr. (SRI), 30 Sep 54 (CRD).
15. Effects of the Explosion of 45 Tons of TNT Under Water at a Depth Scaled to Test BAKER, G. A. Young (NOL), 1 Dec 54 (S).

CONFIDENTIAL
17. The Effect of Rain or Fog on Air Blast, NAVORD-2944, G. K. Hartmann (NOL), 1 Aug 53 (S).
20. The Effects Produced by the Explosion of Charges in Shallow Water with Particular Reference to the
22. Height of Burst for Atomic Bombs, LA-1406, Francis B. Porzel (LASL), Mar 52 (SRD).
24. The Influence of Atmospheric Pressure and Temperature Variations on Shock-Wave Propagation,
   AFSWP-264, NAVORD-2707, Part I—Development of Theory and Calculation of Illustrative
   Examples, F. Theilheimer and L. Rudlin (NOL), 7 Oct 53 (S).
25. The Influence of Atmospheric Pressure and Temperature Variations on Shock-Wave Propagation,
   Part II, AFSWP-265, L. Rudlin (NOL), 1 Aug 54 (SRD).
26. The Interaction of Shock Waves with a Thermal Layer, Robert Varwig and Jay Zemel (NOL), 18 Jun
   55 (OUO).
27. Underwater Explosions, A Summary of Results, E. H. Kennard (DTMB), (C).
   (AFSWP), 10 Mar 55 (SRD).
30. On the Acoustical Theory of Transmission of a Spherical Blast Wave from Water to Air, A. B. Arons
   (Woods Hole), 1956 (C).
31. On the Oblique Reflection of Underwater Shock Waves from a Free Surface, Parts I-V, J. H. Rosen-
   baum (NOL), 1953-54 (C).
32. Operation TEAPOT—Underground Shot Base Surge Analysis, AFSWP-876, M. L. Milligan and
   G. A. Young (NOL), 31 Jan 56 (SRD).
   (AFSWP), 10 Apr 52 (SRD).
34. Phenomenology of a High Altitude Atomic Explosion, SC-3363, Shelton (SC), 28 Apr 54 (SRD).
35. The Precursor—Its Formation, Prediction and Effects, SC-2850 (TR), Frank H. Shelton (SC), 27
   Jul 53 (SRD).
36. Prediction of Dynamic Pressure, TM 121-54-51, R. J. Buehler (SC), 12 Jul 54 (SRD).
37. Predictions on the Effect of Refraction on Peak Pressure and Duration of Explosion Pressure Waves,
   R. R. Brockhurst (Woods Hole Oceanographic Institute), 1955 (S).
38. Prediction of Incident Pressure-Time Curves for Nuclear Explosions, SC-5112 (82), Luke J. Vortman
   (SC), Jan 54 (SRD).
39. A Preliminary Estimate of the Effect of Fog and Rain on the Peak Shock Pressure from an Atomic
   Bomb, AFCRD AFSG-16, H. P. Gauvin and J. H. Healy (AFCRC), Sep 52 (SRD).
40. The Preshock Sound Velocity Field over Inorganic and Organic Surfaces, AFSWP-420, F. M. Sauer
   (For. Serv.), Dec 54 (C).
41. Rain, Fog and Cloud Effects on Blast Damage from Atomic Weapons, SC-3008 (TR), Thomas B.
    Cook (SC), 22 Oct 53 (SRD).
42. Refraction and Diffraction of Explosion Pressure Pulses by Gradients in the Propagation Velocity,
    R. R. Brockhurst (Woods Hole), 1957 (C).
43. Response of Non-Linearly Supported Boundaries to Shock Waves, Case of the Spherical Cavity, M. L.
    Baron (Col. U.), Mar 56 (C).
44. A Scale Model Study of the Effects of Symmetric Ridges on Blast Overpressures, SC-3335 (TR), J.
    Todd (SC), 3 May 54 (C).
45. The Scaling of Base Surge Phenomena of Shallow Underwater Explosions, AFSWP-484, M. L. Milligan and G. A. Young (NOL), 1 May 54 (C).
46. Shock Wave Diffraction, N7oon-32104, Sachs and Sauer (SR1), (SRD).
49. Study of Blast Effects in the Regular Reflection Region, Task VI, Phase Report No. III of Ad Hoc Analytical Services, ARF-MO44-Phase II (ARF), 4 May 54 (S).
50. Study of Underwater Blast, F. B. Porzel (ARF), 1956 (CRD).
54. Water Waves Produced by Explosions, H. C. Kranzer and J. B. Keller (NYU), Sep 55 (U).

THERMAL RADIATION PHENOMENA

3. Atmospheric Attenuation of Thermal Radiation from a Nuclear Detonation, AFSWP-509, L. B. Streets and Harvey Marron (AFSWP), Dec 1, 54 (C).
4. Attenuation of Thermal Radiation by a Dispersion of Oil Particles, AFSWP-749, C. M. Sliepecevich et al. (ERI), May 54 (C).
7. Horizontal Attenuation of Ultraviolet and Visible Light by the Lower Atmosphere, NRL 4031, Lawrence Dunkelman (NRL), 10 Sep 52 (U).

NUCLEAR RADIATION PHENOMENA

2. The Effects of Soil, Yield, and Sealed Depth on Contamination from Atomic Bombs, R. D. Cadle (SRI), 29 Jun 53 (SRD).
3. An Estimate of the Relative Hazard of Beta and Gamma Radiation from Fission Products, AD–95 (H), R. I. Condit, J. P. Dyson, and W. A. S. Lamb (NRDL), Apr 49 (C).
8. Gamma Radiation in Air Due to Cloud or Ground Contamination, AFSWP–465, M. J. Berger and J. A. Doggett (NBS), 1 Jun 53 (U).
PERSONNEL CASUALTIES

3. The Biological Effects of Blast, TID–5251, C. S. White (AEC), 15 Sep 54 (SRD).
7. The Dose Received by Partially Shielded Gamma Ray Detectors, AFSWP–466, M. J. Berger (NBS), 8 Oct 54 (U).
11. The Effects of Total-Body Fast Neutron Irradiation in Dogs, AFSWP–760, V. P. Bond, et al. (NRDL), 10 Jan 55 (U).
17. Mechanical and Thermal Injury from the Atomic Bomb, E. H. Pearse and J. T. Payne (NEJM, CCXL1, 647), 1949 (U).
18. Ocular Lesions Following the Atomic Bombing of Hiroshima and Nagasaki, MDDC 936, J. J. Flick (AEC Oak Ridge, Tenn.), 13 May 47 (U).
20. Permissible Doses from External Sources of Ionizing Radiation, Handbook 59 (NBS), 24 Sep 54.

**DAMAGE TO STRUCTURES**

14. The Effect of Blast Loading Duration on Structural Damage, AFSPW–508 TAR, S. B. Smith, et al. (AFSPW), May 54 (S).
15. The Effect of Earth Cover in Protecting Structures Against Blast, AFSPW–357A, R. B. Vaile, Jr. (SR1), 30 Sep 54 (CRD).
19. Investigation of Shear Walls, Parts I and II (U), III through V (C), Williams and Benjamin (Stan. U.), 1952–53.
21. Loading Analysis of Five Story Reinforced Concrete Frame Structures (in the Regular Reflection Region, Two-Dimensional), (ARF), 16 Jul 56 (C).

**DAMAGE TO NAVAL EQUIPMENT**

3. Proceedings of Seventh Symposium on Underwater Explosion Research, Parts I (C) and II (DTMB), 1956 (SRD).

**DAMAGE TO AIRCRAFT**

1. The Effects of Atomic Explosions on Aircraft, 7 Volumes, WADC TR 52-244 (MIT), 1953 (SRD).
2. General Design Considerations for Aircraft Operating in the Vicinity of a Nuclear Burst, WADC TR-53-238, David J. Fink (WADC), Jul 53 (SRD).
4. Three-Dimensional Lethal Envelopes for the B-52 at 55,000-foot and 45,000-foot Altitudes Subjected to 2.0 KT and 0.5 KT Atomic Bursts (C), ARA-185, D. J. Fink, P. B. Athens, (ARA), 18 Aug 54 (SRD).
5. The Vulnerability of the MIG-17 (FRESCO) to Free-Air Nuclear Detonations, ARA-220, D. J. Fink, et al. (ARA), 10 Jun 55 (SRD).

**DAMAGE TO MILITARY FIELD EQUIPMENT**

1. The Effects of Atomic Weapons on Engineer Heavy Equipment, ERDL-1443 (ERDL), 25 Apr 56 (U).
4. Exercise Desert Rock IV (Hq Sixth Army), Apr-Jun 1956 (SRD).
5. Exercise Desert Rock V (Hq Camp Desert Rock), Jan-Jun 53 (SRD).
7. Damage to Field Military Equipment from Nuclear Detonations, AFSWP-511 TAR, R. J. Hesse (AFSWP), 1 Feb 56 (SRD).
8. The Influence of Atomic Weapons on Signal Communications in an Infantry Division (SigC Board Study No. 93A), 14 Jan 53 (S).
9. Influence of Atomic Weapons on Signal Communications in Corps and Army Areas (SigC Board Study No. 95), 2 Apr 52 (S).

FOREST STANDS

4. Thermal Conductivity of Some Common Forest Fuels, AFSWP–405, G. M. Byram, et al. (For. Serv.), 1 Dec 52 (U).

MISCELLANEOUS RADIATION DAMAGE CRITERIA

8. NML Reports on Critical Thermal Energies of Various Specific Materials as follows:
   Metallized rayon fabric, AFSWP–390; Doped fabrics, AFSWP–389, 388, 244, 393; Aluminized fabrics, 384; Protective coatings on wood, 382; Awning material, 381; Aluminized asbestos cloth, 380; Packaging materials, 379; Special fabrics (window shades, rugs, curtains, upholstery), 245; Plastics, 243; Flight clothing, 392; Rubber hose and gasket materials, 395; Canopy materials, 397; Plastic radome materials, 399; Curtain materials (aircraft), 400; Chemical warfare protective materials, 401; Ceramics, 402; Flame proofed cotton fabric, 403.


**IDENTIFICATION OF CORPORATE AUTHOR CODES**

AEC  Atomic Energy Commission
AFSWP  Armed Forces Special Weapons Project
ARA  Allied Research Associates
ARF  Armour Research Foundation, Illinois Inst. of Tech., Chicago, Ill.
BNL  Brookhaven National Laboratory
BRL  Ballistic Research Laboratories, Aberdeen Proving Ground, Md.
CFD  Committee on Fortification Design
DTMB  David Taylor Model Basin
ERA  Engineering Research Associates
ERDL  Engineer Research and Development Laboratory, Ft. Belvoir, Va.
ERI  Engineering Research Institute
For. Serv.  Forest Service, Dept. of Agriculture
LASL  Los Alamos Scientific Laboratory
MIT  Massachusetts Institute of Technology, Cambridge, Mass.
NAS  National Academy of Science
NBS  National Bureau of Standards
NDA  Nuclear Development Corporation of America
NML  Naval Material Laboratory, N. Y. Naval Shipyard
NOL  Naval Ordnance Laboratory, Silver Spring, Md.
NRC/DMS  National Research Council, Division of Medical Sciences
NRDL  Naval Radiological Defense Laboratory, San Francisco, Calif.
NRL  Naval Research Laboratory
ONR  Office of Naval Research
ORO/JHU  Operations Research Organization, Johns Hopkins Univ.
RAND  RAND Corp., Santa Monica, Calif.
SC  Sandia Corporation, Albuquerque, New Mexico
SRI  Stanford Research Institute, Menlo Park, Calif.
TOI  Technical Operations, Inc.
UERD  Underwater Explosions Research Division, Norfolk Naval Shipyard
WADC  Wright Air Development Center, Wright-Patterson AFB
WES  Waterways Experiment Station, Vicksburg, Miss.
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    Gravity dams: 7.5.
    Shielding properties: 6-5, 6-6.
    Walled structures: 5.2c; table 7-1, 7-1, 7-8.
  Condensation: 4.3c(2)(a).
  Conflagrations: 6.2g; table 11-4, 18-5, 18-5.
  Conifer forests: 11.2a, table 11-2, table 11-3.
  Constants: appendix II.
  Construction materials: table 12-2.
Contaminated area:

- Do not ingest.
- Do not inhale.
- A hazard to the environment.

- Blasted area: 4.8g, 4.3h, 4.3i(2), 4-85 through 4-93.
- Harbor area: 4-85.
- Land surface blast: 4.3c(1), 4-14.
- Underground blast: 4-10.
- Water surface blast: 4.3c(2).

- Contour: 4.3c(1)(b), 4.3c(1)(c), 4.3h, 4-15, 4-14 through 4-85, 4-87.
- Contour area: 4.3c(1)(c), 4.3c(2)(a), 4.3c(1), 4-14, 4-80, 4-85.

Copper alloys, induced activity in: 12.2a(3).
Coupling: 1.4c(3); 2.1d(4)(d), 2.3a(2)(e).
Cover, overhead: 7.4a(2).
Crane: 10.7, 10-7, 10-6.

Crater:

- Apparent: 2.2a(1), 3-20 through 3-23.
- Damage: 5.2b(3), 7.2b, 7.3b, 7.3c(2), 7.3c(3), 7.5c, table 7-3; 8.3b.
- Depth: 2.2a(1)(c), 2.3a(1)(g), 3-21, 3-23.
- Diameter (or radius): 2.2a(1)(e), 2.2a(1)(g), 3-20, 3-22; 7.3b.
- Lip: 2.2a(1)(d), 8-19; 7.5c.
- Parameters: 2.2a(1), 8-19.
- Surface burst: 1.4c(4), 1.4c(8); 2.2a(1), 7.5c.
- Transition zone, burst in: 1.4d(4).
- True: 2.2a(1), 3-20 through 3-23.
- Underground burst: 1.4e(6); 2.2a(1)(a), 2.2a(1)(d), 7.5c.
- Underwater: 2.2a(2), 3-21 through 3-26; 7.5c.

Critical radiant exposure: 6.2b, 6.2c, table 6-2, 6-2; 12.3, table 12-2.
Crosswind extent: 4-15, 4-82.
Crowning: 11.3f, table 11-4.
Cruisers: 8.2, table 8-1, 8-1 through 8-3.
Crushing: 5.2b(1)(a), 5.2b(1)(e); 9.1; 10.1a, 10.3a.
Crushing injuries: 6.1b(1), 6.1c.
Curie: 4.1c, 11.3.
Cutoff: 2.3a(2), 3-20.

Damage classification:

- Aircraft: 9-1 through 9-3.
- Foresters: table 11-1, 11-1 through 11-7.
- Military field equipment: 10.1b, 10.3a, 10-1 through 10-8.
- Naval equipment: 8.1.
- Structures: 7.2a(4)(c), table 7-1, table 7-2.

Damage criteria (see under phenomenon causing damage, specific type of damage, or item receiving damage).

- Dams: 7.1d, 7.5.
- Dark adaptation: 6.2f.

Decay rate:

- Dynamic pressure: 1.1c, 1-6, 1-8.
- Fission products: 4.3c(1)(d), 4-15; 11.3.
- Induced activity: 4.3l(2), 4-29.
- Overpressure: 1.1b, 1-5, 1-6.
- Decontamination: 6.3b(3)(c), 6.3c(3).
- Degree of burn (thermal): 6.2b.
- Delivery rate: 1.4b(2); 3.2c; 4.2c, 6.2b.

Density:

- Blast wave: 1.4b(3); 2.1b(4)(a), table 2-1: 1.1, 1.3, 1-14.
- Earth: 6-5, 6-6.
- Relative air: 4.2a, table 4-1; 11.1, 11-3.
- Various materials: 6-5, 6-6.
- Water vapor: 11-4.

Deposition pattern: 4.3c(1)(b).
- Destroyers: 8.2, table 8-1, 8-1 through 8-3.
- Diffraction loading: 5.2b(1)(a); 7.2a(2), 9.1, 9.2a.
- Digging-in: 10.9b.
- Direct blast injury: 6.1b.
- Direct ground shock: 2.2b(2).
- Displacement:
  - Soil particles: 2.2b(1), 2.2b(2)(d), 2.2b(3)(d).
  - Target: 5.2c.

Dose:

- Acute: 4.3g, 6.3a, 6.3b(1), 6.3d, table 6-4.
- Beta radiation: 6.3b(3).
- Cumulative effects: 5.4b.
- Delivery rate: 4.3c, 4-9, 6.3a.
- Free field: 4.3c; 6.3b(1).
- Initial gamma radiation: 4.2a; 6.3b(1), 6.5a.
- Neutron radiation: 4.1c, 4.2b, 4-10, 4-11; 6.3b(2).
- Personnel in aircraft: 4.2a(2), 4.2a(4), 4.3l, 4-1 through 4-7, 4-37; 6.3c(2).
- Residual gamma radiation: 4.3, 6.3b(1), 6.3c(2).
- Total: 4.3g, 4.3b(2), 4-26, 4-87, 4-30 through 4-85; 6.3b(1), 6.3b(2), table 6-4.
- Transmission factor: 6.5, table 6-5, 6-5, 6-6.
- Units: 4.1c; 6.3b(2).
- Whole body: 6.3a, 6.3b, table 6-4.

Dose contours: 4.3b, 4-87.

Dose rate:

- Decay factors: 4.3c(1)(d), 4.3i(2), 4-15, 4-29, 11.3.
- Free field: 4.3k.
- Induced radioactivity: 4.3i(2), 4-29.
- Units: 4.1c.

Dose rate contours (harbor burst):

- Areas: 4-85.
- Residual radiation: 4.3c(2)(b), 4-85.

Dose rate contours (land surface burst):

- Areas: 4.3c(1)(b), 4.3c(1)(e), 4.3c(1)(e), 4-14.
- Crosswind extent (distance): 4.3c(1)(e), 4-16.
- Decay factor: 4.3c(1)(d).
- Dimensions: 4.3c(1)(e).
- Downwind component: 4.3c(1)(c), 4-15.
- Downwind displacement GZ circle: 4.3c(1)(e), 4-18.
- Downwind extent (distance): 4.3c(1)(c), 4-15.
- Ground zero circle: 4.3c(1)(c), 4-17.
- Idealized: 4.3c(1)(c), 4-18.
- Parameters: 4.3c(1)(e), 4-18, 4-14 through 4-18.
- Residual radiation: 4.3c(1)(d), 4-14 through 4-18.
- Scaling: 4.3c(1)(e), 4-14 through 4-18.

Dose rate contours (burst in the transition zone): 4.3d, 4-14 through 4-18.
Dose rate contours (underground burst):
- Areas: 4.3e(1), 4-80.
- Crosswind extent: 4-22.
- Depth multiplicative factor: 4.3e(1), 4-24.
- Downwind extent: 4-21.
- Ground zero circle: 4-18, 4-83.
- Idealized: 4.3c(1)(c), 4-12.
- Parameters: 4.3e(1), 4-80 through 4-24.
- Scaling: 4-80 through 4-24.

Dose rate contours (underwater burst): 4.3e(2).

Dose rate contours (water surface burst): 4.3c(2), 4-14 through 4-18.

Dosimeter: 6.3b(2).

Drag:
- Forces: 2.1b(4)(a); 5.2b(1), 5.2c; 6.1b(2)(a); 7.5d(2); 10.1a.
- Loading: 5.2b(1)(b); 7.2a(3); 9.1.
- Shielding: 10.9.

Ductility: 7.2a(4)(a).

DUKW: 10.2, table 10-1, 10-1.

Duration:
- Blast wave: 2.1b(3)(b), 2.1b(4)(b).
- Diffraction loading: 5.2b(1)(a); 7.5a(2).
- Dynamic pressure: 2.1b(4)(b), 2.1c(4)(b), 2-11.
- Overpressure: 2.1c(3)(b).
- Positive phase: 2.1a, 2.1b(3)(b), 2.1c(3)(b), 2-4, 2-11; 1.3.
- Precursor effect: 2.1d(4)(c).
- Thermal pulse: 3.1, 3.2a.
- Water shock: 2.3a(2)(a), 2.3a(2)(c).
- Dust loading: 2.1c(4)(a), 2.1c(4)(c), 2.1d(4)(d).

Dynamic pressure:
- Atmospheric moisture effects: 2.1d(2)(a), 2-14.
- Burst selection: 5.5, 6-2, 6-3.
- Decay rate: 1.1c, I-8.
- Duration: 2.1b(4)(b), 2.1c(1), 2.1e(4)(b), 2-4, 2-11.
- Free air peak: 2.1b(4)(a), table 2-1, 2-5, 1.1, 1.3, 1-3.
- Horizontal component: 2.1e(4)(a), 2-12, 2-13.
- Impulse: 2.1b(4)(c), 2.1c(4)(c); 1.1c, I-7.
- Loading: 5.2b(1), 6-1; 7.2a(3).
- Mechanical influences: 2.1e(4)(a), 2.1e(4)(c), 2.1d(4).
- Precursor: 2.1e(4)(a), 2.1d(4)(c).
- Scaling: 2-5, 2-12, 2-13.
- Surface effects: 2.1b(4), 2.1d(4).
- Surface peak: 2.1c(1), 2.1c(4), 2-12, 2-13.
- Wave form: 2.1b(4)(c), 2.1e(4)(c), 1.1c, 1.2b, I-6, 1-8, I-10.

Ear drum rupture: 6.1b(1).

Earth: 6-5, 6-6.

Earth covered structures: 7.2a(4)(a), table 7-2, 7-14, 7-15.

Earth dams: 7.5c.

Earth moving equipment: 10.7, 10-7, 10-8.

Elastic deflection: 7.2a(4)(a).

Electromagnetic radiation: 1.4b(2); 12.2c.

Electronic equipment: 12.2a(2), 12.2c.

Electronic fire control equipment: 10.4, 10-4.

Emplacements: 7.3b, 7.4, table 7-4, 7-80 through 7-82.

Energy partition: 1.1b; 3.1, 3.2d.

Engineer equipment: 10.7, 10-7, 10-8.

Evasive action: 6.2e(2), 6-3.

Evergreen shrubs and trees: table 11-2.

Excess impulse: 8.3a(2).

Exposure (see Radiant exposure).

Explosion: 1.1a.

External radiation hazard: 6.3b.

Eye: 6.2d, 6.2f, table 6-3.

Fabrics: 5.3c, 5.3d; 6.2c; 9.1, 9.2b; 12.3, table 12-2.

Fallout:
- Air burst: 4.3b.
- Burst selection: 5.5, 6-2, 6-3.
- Decay factor: 4.3e(1)(d), 4-15; 11.3.
- Decontamination: 6.3b(3)(c), 6.3c(3).
- Ground contours: 4.3e(1)(b), 4.3e(1)(c), 4-12, 4-14 through 4-65, 4-27.
- Harbor burst: 4.3e(2)(b), 4-25.
- Land surface burst: 4.3e(1), 4-14 through 4-18.
- Radiation injury: 5.4; 6.3, table 6-4, 6-4.
- Residual:
  - Beta radiation: 4.3j; 6.3b(3).
  - Radiation: 4.3.
  - Scaling: 4.3c(1)(c), 4-14 through 4-27.
  - Time of arrival: 4.3c(1)(d).
  - Transition zone, burst in: 4.3d, 4-14 through 4-18.
  - Underground burst: 4.3e(1), 4-20 through 4-24.
  - Underwater burst: 4.3e(2), 4-25.
  - Water surface burst: 4.3c(2), 4-14 through 4-18.

Ferns: table 11-2.

Fibreboard: table 12-2.

Field:
- Equipment: 5.2c, section X.
- Fortifications (shelters): 7.4, table 7-4, 7-80 through 7-82.

Fir: 6-5, 6-6; 11.3f, table 11-2.

Fire:
- Forest: 11.3.
- General: 5.3a; 6.1c(1); 7.2c.
- Season: 11.3e, table 11-2; 12.1.
- Spread: 11.3f, table 11-4; 12.1d.
- Storm: 6.2g, 12-2, 18-3.
- Urban areas: 12.1, 18-2 through 18-3.

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- Air burst: 1.4b(2), 1.4b(6).
- Color temperature: 3.3a.
- Damage to materials: 12.3, 12-5.
- Distortion by reflected shock: 1.4d(3); 3.1.
- Energy loss to the surface: 3.1.
- Nuclear radiation: 4.1b.
- Radiating area: 3.2a.
- Radius: 3.2a, 3-1.
- Rise: 1.4b(6).
- Surface area: 3.2a.
- Surface burst: 1.4c(2).
- Temperature: 3.2a, 3-1.
- Transition zone, burst in: 1.4d(3).
- Underground burst: 1.4e(2); 3.1.
- Underwater burst: 1.4f(2); 3.1.
Firebrands: 11.3f.
Fire control equipment: 10.4, 10-4.
Fusion fragments (products): 1.4b(5); 4.1a, 4.1c, 4.3a, 4.3b; 6.3c(3); 11.3.
Fission process (reaction): 1.1a.
Flash blindness: 6.2f.
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Flood damage: 7.1d.
Fog: 2.1d(1), 2.1d(2)(a), 2-14; 3.4b; 4.3b; 6.2e(1).
Forests:
Air blast damage: 11.2, table 11-1, 11-1 through 11-6. 
Effect on blast wave: 2.1d(3)(d), 2.1d(4)(b).
Types of stands: 11.2a.
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Foundation damage: 5.2a, 5.2b(3).
Fuselages: 5.3f; 6.1b(2)(b), 6.1c(4), 6.2e(1), 6.5b, table 6-5, 7.4, table 7-4, 7-50 through 7-70.
Fractional powers: 7-1.
Fracture: 2.2a(1)(e); 6.1c(1).
Free air:
Neutron flux: 12.2a(1), 12-6.
Peak dynamic pressure: 2.1b(4)(a), table 2-1, 1-5, 1-5.
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Positive phase duration: 2.1b(3)(b), 8-4.
Time of arrival: 2.1b(2), 8-2.
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Initial gamma: 4-1 through 4-7; 6.3a, 6.3b(1).
Neutron: 4-10, 4-11; 6.3a.
Residual gamma: 4.3k; 6.3a.
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Fusion process (reaction): 1.1a.
Gamma radiation (gamma rays). (See also Initial gamma radiation and Nuclear chain reaction.)
Air burst: 1.4b(5); 4.2a(1), 4.2a(4), 4.3b.
Attenuation: 4.1a, 4.1b, 4.2a(1); 6.5, 6-5, 6-6.
Damage: 5.4; 12.2a.
Delivery rate: 4.2e, 4-6; 6.3b(1).
Initial: 4.2.
Injury: 5.4; 6.3, table 6-4, 6-4.
Land surface burst: 1.4c(6); 4.2a(2).
Neutron induced: 4.3i.
Residual: 4.3.
Shielding: 4.1a, 4.3k; 6.5, 6-6, 6-6.
Topographic and atmospheric effects: 4.2a(1).
Transition zone, burst in: 1.4d(3); 4.2a(1), 4.2a(3), 4.3d, 4.3i(2).
Underground burst: 1.4c(5); 4.2a(6), 4.3c(1).
Underwater burst: 1.4b(6); 4.2a(6), 4.3c(2).
Units: 4.1c; 6.5b(2).
Water surface burst: 1.4c(5); 4.2a(2), 4.3c(2).
Gamma radiation dose. (See also Initial gamma radiation dose.)
Acute: 4.3g; 6.3a, table 6-4.
Delivery rate: 4.2c, 4-9.
Initial: 4.2; 6.3b(1), 6.5.
Personnel in aircraft: 4.2a(2), 4.2a(4), 4.3i, 4-1 through 4-7, 4-70; 6.3c(2).
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Glass:
Breakage: 6.1c(2).
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Gondola cars: 10.6, 10-5.
Good surface conditions: 2.1c(1)(a), 2.1d(1).
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Air induced: 2.2b(1), 2.2b(3), 5-7; 5.2b(1)(f).
Damage: 2.2b(1); 7.1c, 7.2b, 7.3b, 7.3c(2), 7.4b, table 7-3.
Direct: 2.2b(1), 2.2b(2), 5-7.
General: 2.2b, 5-7.
Loading: 5.2b(3).
Reflection: 7.3a.
Surface burst: 1.4c(3).
Transition zone, burst in: 1.4d(4).
Underground burst: 1.4e(5).
Ground zero circle dose rate contours: 4.3e(1)(c), 4-17, 4-18, 4-25.
Ground zero dose rate: 4.3f.
Gun emplacements: 7.3b.
Gust loading: 5.2c; 9.1.
Hanks: 6.2d.
Harbor burst: 2.3a(2)(c); 4.3e(2)(b), 4-5.
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Humidity effects: 2.3c(4); 3.3b; 5.3g; 11.3d, 11.3e, table 11-4, 11-7; 12.1c, 12.3.
Hydrodynamic effects: 4.1a, 4.2a(1), 4.2a(3), 4.2a(4).
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Ignition:
   Points (sources): 5.3d, 5.3g; 7.2c; 10.3b; 11.3b; 12.1b, table 12-1.
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   Attenuation (transmission): 4.1b, 4.2a(1); 6.5, 6-5.
   Damage: 4.1b(3); 12.2b.
   Delivery rate: 4.2c, 4-9.
   Injury: 5.4; 6.3, table 6-4, 6-4.
   Land surface burst: 1.4c(0)(a); 4.2a(2).
   Shielding: 4.1a; 6.5b, 6-5.
   Transition zone, burst in: 1.4d(3); 4.2a(1), 4.2a(3).
   Underground burst: 1.4e(8)(a); 4.2a(6).
   Underwater burst: 1.4f(6); 4.2a(6).
   Units: 4.1c.
   Water surface burst: 1.4e(8).
Initial gamma radiation dose:
   Air burst: 4.2a(4), 4-5 through 4-7.
   Attenuation: 6.5b.
   Delivery rate: 4.2c, 4-9; 6.3b(1).
   Injury: 5.4; 6.3, table 6-4, 6-4.
   Land surface burst: 4.2a(2), 4-1 through 4-4; 4-7a through 4-7d.
   Sealing: 4-1 through 4-8.
   Shielding: 6.5b, 6-5.
   Transition zone, burst in: 4.2a(3), 4-1 through 4-4.
   Underground burst: 4.2a(6), 4-8.
   Underwater burst: 4.2a(6).
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Lethal:
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   Gust envelope: 9.3a, 9-4.
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   Thermal effects (aircraft): 9.3b, 9-4.
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   Lip (crater): 2.2a(1)(d), 8-19; 7.5c.
   Loading: 2.2b(3)(a); 5.2b, 5.2c, 8-1; 7.2a; 9.1.
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   Machinery damage: 5.2c, 7.3c(2)(d); 8.1c.
   Mach reflection: 2.1c(1), 2.1d(3)(b); 5.2b(1)(e); 10.1b(1).
   Mach stem: 2.1c(1), 2.1d(4)(d), 8-5, 8-7.
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   Metals: 5.3d, 12.2a(3), 12.3, 18-5.
   Military field equipment: 5.2c; section X.
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True crater: 2.2a(1)(a). |

Truss bridges: 5.2c; 7.2a(4)(a), table 7-2, 7-11, 7-12. |

Tunnels: 7.1e, 7.3b, 7.3c(2)(b), 7-19. |

Types of burst: 1.4. |

Ultraviolet: 3.3a. |

Underground burst, definition and description: 1.4e. |

Underground structures: 2.2b(1); 5.2b(3); 7.1c, 7.3, table 7-3, 7-14, 7-15. |

Underwater burst, definition and description: 1.4f. |

Underwater cratersing: 2.2a(2), 8-24 through 8-26. |

Underwater mines: 8.3b, 8-6 through 8-9. |

Uniforms: 6.2a, 6.3c, table 6-2, 12.3, table 12-2. |

Urban areas: 2.1d(4)(b); 12.1, 12-1 through 12-3. |

Utilities: 7.1c, 7.3c(3)(c). |

Vector average (wind): 4.3c(1)(c). |

Vehicles: 5.2a; 6.1c(3); 10.2, 10-1. |

Velocity of propagation: 1.4b(3), 2.1b(1), 2.2b(2)(a), 2.2b(3)(a). |

Venting: 1.4c(3), 1.4f(2), 2.3c; 4.3e(1). |

Visible range (visibility): 3.3b; 8-5. |

Wall bearing buildings: 5.2c; table 7-1, 7-3, 7-4.
Water:
- Decontamination: 6.3c(3).
- Loading: 2.1e(4)(c), 2.1d(4)(d).
- Pressure: 2.3a, 8-31.
- Shock: 1.4c(8), 1.4f(2), 1.4f(3), 2.3a, 8-31, 8-33, 5.2a.
- Shock damage: 5.2c, 7.1d, 7.5b, 8.2a, 8.3a(2), 8-1 through 8-5.
- Shock loading: 5.2b(2).
- Shock reflection: 5.2b(2), 8.2a, 8-3.
- Vapor density: 11-4.
- Wave damage: 7.5d; 8.2c.

Wave:
- Damage: 7.5d; 8.2c.
- Form (blast): 2.1b(3)(a), 2.1b(4)(c), 2.1c(3)(c), 2.1c(4)(a), 2.1c(4)(c), 2.1d(3)(b); 5.2b(1)(f); 1.1b, 1.1c, 1.2, 1-6, 1-10 through 1-14.
- Front: 8-35; 7.5d.
- Height: 2.3b, 8-35; 7.5d.
- Length: 7.5d.
- Train: 1.4c(8); 2.3b(1).
- Waves: 1.4c(8), 1.4f(5)(5), 2.3b, 8-34; 5.2c, 7.5d, 8.2c.
- Weapon ratings: 1.2.

Whirls: 11.3f.
- Wilson cloud: 1.4b(3), 1.4f(5); 3.4c.

Wind:
- Resultant: 4.3c(1)(c).
- Scaling: 4.3c(1)(c), 4-14 through 4-24.
- Shear: 4.3c(1)(b), 4.3c(1)(c).
- Vector: 1.4b(3), 4.3c(1)(c).
- Velocity: 2.1a, 2.1b(4), table 2-1, 4.3c(1)(c), 4.31.

Wire entanglements: 10.8b, 10-4.
- Wood: 5.3d; 6-5, 6-6, 11.3f, table 11-3; table 12-2.
- Wood frame structures: 5.2c; 7.2a(3), table 7-1, 7-5.
- Wooded areas: 2.1c(4)(c).

X-ray: 4.1c.

Yield:
- Blast: 1.1b, 2.1d(2)(c), 8-15.
- Fission: 4-14 through 4-24.
- Mass to yield ratio: 3.2c.
- Nuclear: 1.1b.
- Thermal: 1.1b, 3.2d, 3.3d, 3-4.
- Total: 1.1b, 1.2.
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