PART TWO
DAMAGE CRITERIA

SECTION V
INTRODUCTION

5.1 General
In part one, the phenomena associated with a nuclear explosion are described for various burst conditions. It remains to express the numerical values of these phenomena in terms of damage in varying degree to targets of military interest. Part two is a summary of the aggregate knowledge of nuclear weapons effects on personnel and materiel, and includes statistical and theoretical treatment of the large amount of data from tests of nuclear explosions, results of the bombs dropped on Japan, and laboratory work. Where check points are not available, some extrapolation of data is made where reasonable accuracy can be expected. An attempt is made to present the information in a form suitable for use by the atomic weapons staff officer. Graphical presentation is used in preference to tabular presentation wherever possible. Part two is divided into sections according to classes of targets which can be considered as a group because of similar response characteristics. Further subdivisions within the sections are generally by the phenomena causing the damage. The damage curves presented in part two are drawn for a probability of 50 percent of inflicting the degree of damage indicated, with curves of 90 percent and 10 percent probability included where the amount and quality of data available are sufficient to justify it.

5.2 Blast and Shock Damage
a. General. When a blast or shock wave strikes a target, the target may be damaged (distorted by an amount sufficient to impair usefulness) by the blast or shock wave itself, being translated by the blast wave and striking another object or the ground, or by being struck by another object translated by the blast wave. For example, the air blast wave itself can shatter windows, dish in walls, collapse roofs, deflect structural frames of buildings, and bend or rupture aircraft panels and frames. Vehicles, tanks, artillery pieces, and personnel can strike other objects or the ground while being hurled through the air or tumbled on the ground by the blast wave. Ship hulls may be split or crushed by the water shock wave. Buried structures or structural foundations can be displaced, collapsed or ruptured by the ground shock wave. Usually, the degree of damage sustained by a particular target cannot be specifically correlated to a single blast or shock parameter. The total damage received by the target may be dependent upon a combination of air blast and ground or water shock parameters, the manner in which the target is oriented with respect to the blast or shock wave, and the type of surface (the topography and/or the type of soil) associated with the target. In § and c below, the relationship between loading, response and damage of various targets is discussed briefly. In the introductory paragraphs of sections VI through XI, a detailed discussion of blast and shock damage criteria is given.

b. Loading. The blast loading on an object is a function not only of the blast characteristics of the incident wave (rise time, peak overpressure, peak dynamic pressure, decay and duration), but also of the size, shape, orientation, and response of the object. The manner in which the loading is influenced by the target characteristics is discussed below with emphasis on air blast loading.

(1) Air blast loading. The loading on an object exposed to air blast is a combination of the forces exerted by the overpressure and the dynamic pressure of the
incident blast wave. The loading at any point on a surface of an object can be described as the sum of the dynamic pressure, multiplied by a local drag coefficient, and the overpressure after any initial reflections have cleared the structure. Since the loading changes rapidly during the time the blast wave is reflecting from the front surfaces and diffracting around the object, loading generally comprises two distinct phases—first, loading during the initial diffraction phase, and second, loading after the diffraction is complete (i.e., the object is completely engulfed by the blast wave). This latter phase approaches a steady state and is usually referred to as the drag phase, because during this phase the drag forces (i.e., forces resulting from the dynamic pressures) predominate in producing a net translational force on the object. The generalized discussion of the loading process given below is based primarily on an ideal blast wave as described in section II. Where non-ideal blast waves (with slow rise time, irregular shapes and high dynamic pressures) introduce complications into the loading process, further explanation is given.

(a) Diffraction loading. As the shock front of an air blast wave strikes an object, the shock is reflected from the side facing the blast, creating overpressures on this face up to several times that of the incident overpressure. In the Mach reflection region the overpressure incident on the object is actually that of the original free air blast wave which has been reflected from the ground surface to a higher value; therefore, the reflection off the object constitutes a second reflection process. In the regular reflection region, the incident overpressure is that of the free air blast wave (see (e) below). The magnitude of this reflected overpressure depends principally on the angle between the shock front and the face of the object, the rise time of the incident blast wave, and the initial incident shock strength. The greatest reflected overpressures occur when the direction of propagation of the shock front is normal to the face of the object, when the rise to the peak overpressure is essentially instantaneous, and when the incident shock strength is very high. As the blast wave progresses, it bends or diffracts around the object, eventually exerting overpressures on all sides. Before the object is entirely engulfed in the pressure region, however, overpressure is exerted on the front side of the object, while only ambient air pressure exists on the back side. During the diffraction phase this pressure differential produces a translational force on the object in the direction of blast wave propagation. When the blast wave has completely surrounded a small object, the differential pressure is reduced essentially to zero, since the pressures on the front and on the back are almost equal. In the case of long objects or for short duration blast waves, the net force may actually reverse, since the overpressure on the front face may decay to a value lower than that on the rear face. The importance of this translational loading in the production of damage to the target depends on the duration of the loading or on the time required for the shock front to traverse the target, and therefore, on the size of the target. For the same overpressure, the effects of the translational load decrease as the duration of the load is decreased, until in certain cases such loading can be ignored. The overpressures continue on all sides of the object until the positive phase of the blast wave has passed. These pressures may be sufficient to crush an object (a 55-gallon drum may be so damaged in addition to damage incurred by translation). Thus the diffraction phase translational loading
depends primarily on the object size and on increases in differential overpressures resulting from reflection on the front face. Upon completion of the diffraction phase, crushing pressures continue on all sides due to the blast wave overpressures. Loading as a consequence of the negative phase is considered negligible.

(b) Drag loading. During the time of diffraction and until the blast wave has passed, dynamic pressures, caused by the high wind behind the shock front, are also exerted on the object. These pressures, except for high shock strengths, are much lower than the reflected overpressures but produce a translational force on a target component during the entire duration of the blast wave. For a given blast wave, the loading resulting from dynamic pressures depends principally on the shape and orientation of the object, ranging from less than four-tenths the dynamic pressures in the case of a cylinder (when normal to the cylindrical axis) to over twice the dynamic pressures for an irregular, sharp-edged object. This loading is called drag loading.

(c) Net loading. Figures 5–1A and 5–1B give representative net loadings on two structural elements or objects, one small and one large, for two weapon yields. The term "net loading" is used to denote the combined load on the element that tends to translate it in the direction of propagation of the blast wave. Thus the back face loading has been subtracted from the front face loading; the loads on the sides are of no effect. The terms "small element" and "large element" are relative, but the general sizes to keep in mind are—for "small", an object of about the size of a telephone pole or a jeep, and for "large", an object of the size of a house or larger. The loadings display an initial peak value, due to the overpressure being reflected up to more than twice the incident pressure on the front face of the element. The reflected pressure decays or clears the front face at a time dependent on the size of the element. The rapid decay for the small element may make the reflected pressure spike of no significance, whereas the slow decay for the large element creates a load which may entirely govern the response of the target. For the representative cases indicated, the diffraction phase is shown to terminate at time $t_{\text{diff}}$, the time at which the reflected pressure has decayed to the incident pressure. At this time the drag phase begins, and continues until the end of the positive phase of the incident blast wave. The load during the drag phase is shown as equal to the dynamic pressure (i.e., the drag coefficients of the elements are equal to 1.0). The characteristics of the target element determine whether the response of the element is governed primarily by the diffraction phase or the drag phase. Figures 5–1A and 5–1B show that for medium and high yield weapons and small elements, a much greater impulse (the area under the loading curve) occurs during the drag phase than during the diffraction phase. As the yield increases the drag phase impulse increases in predominance. For large elements and medium yield weapons, a much greater impulse occurs during the diffraction phase than during the drag phase. In this instance, as yield decreases the diffraction phase impulse increases in predominance. For large elements and large yield weapons, the diffraction phase and drag phase impulses are about equal. In this latter case the drag phase impulse may still be of no importance, since the significant target response may occur during the diffraction phase. Note that the diffraction phase impulses are not changed by the yield of the weapon (this remains true for all but very
large structures exposed to low yield weapons), while the drag phase impulses are directly related to the weapon yield (for the same peak dynamic pressures).

(d) Target motion. When air blast loading is considered, except for aircraft in flight, the movement of the target component during loading is assumed to have negligible effect on the loading itself. For the case of aircraft in flight, speed, orientation, and movement during loading assume increased importance. (See sec. IX.)

(e) Regular and Mach reflection. In computing the loading on a target, specific aspects of the blast wave propagation must be considered. The loading of a surface target in the regular reflection region is complicated by the vertical component of the incident blast wave, causing multiple reflections between the ground and the target and additional reflected pressures on horizontal surfaces. In the Mach reflection region the loading is simplified because the blast wave propagation is horizontal. Since near the surface of the ground the vertical component of the drag forces in the regular reflection region is quickly cancelled by the reflected wave, the brief vertical drag loading is ignored except when the target is very near the ground zero of an air burst. For aircraft in flight, the loading may be a single horizontal shock from a Mach stem or two separate shocks, the first from the free air wave and the second from the ground reflected wave. In establishing the damage curves for surface targets, the loadings on targets in the regular reflection region during the diffraction phase are considered separately from the loadings on similar targets in the Mach reflection region, and the surface conditions are assumed to be average unless otherwise indicated. Objects which are susceptible primarily to horizontal drag loading if in the Mach region may become primarily susceptible to crushing action if they are in the early regular reflection region.

(f) Non-ideal wave forms. As discussed in paragraphs 2.1c(3)c and (4)c, ideal wave forms are seldom found along the surface for overpressure levels above 6 psi. The description above of the diffraction and drag phases no longer holds true in regions of non-ideal wave forms. If the overpressure wave has a long rise time (30 or 40 msec) to a peak value, full reflection of the wave off the surface of a structure will not occur. At the same time, the relationship between dynamic pressure and overpressure is very much different from that described for the ideal blast wave, so that during the diffraction phase the drag forces due to high dynamic pressures may predominate as the damage producing criteria. Since many conventional surface structures sustain severe damage at low peak overpressure levels and since non-ideal wave forms occur only in the higher overpressure regions, such wave forms have not been considered in determining damage criteria for these structures. For protective shelters that are designed to withstand high pressures, however, careful consideration must be given to non-ideal wave forms and the dynamic pressures which are even higher than would be expected if the wave forms were ideal. Accurate prediction of blast loading in the high pressure regions is further complicated by inadequacy of data.

(2) Water shock loading. Water shock loading is not as well understood as air blast loading. As with an air blast shock front, when the water shock front strikes an object the pressure is reflected from the front face and, consequently, attains a higher pressure than in the incident shock front. The
\textbf{FIGURE 5-1}

\[ q = \text{Incident Dynamic Pressure} \]

\[ \Delta p = \text{Incident Overpressure} \]

\[ t_{\text{diff}} = \text{Time at Which Diffraction Phase Ends} \]

\( \text{A} \)

\text{Medium Yield Weapon}

\( \text{B} \)

\text{High Yield Weapon}

\text{NET BLAST LOADING ON REPRESENTATIVE STRUCTURES}
loading following the initial shock, however, is altered considerably by reflections from the surface of the water and by movement of the object.

(3) Ground shock loading. The loading of buried objects by ground shock is intimately tied to the response of the objects. Ground shock has to be so intense in order to cause serious damage to underground structures or foundations of aboveground structures that the damage area for these structures is confined closely to the crater area of a surface or underground burst. Therefore, the ground shock damage is given in terms of the crater radius and not in terms of the shock phenomena of stress (pressure), particle velocity, acceleration, or displacement. However, air blast induced ground shock, transmitted with little attenuation to a depth as great as 8 feet, may cause significant loading pressures on the roofs of shallow buried structures (with less than 15 feet cover) outside of the crater. Loading pressures are numerically equal to the ground stress normal to the structure. Such pressures do not produce detectable reflected pressures. The pressures exerted on the sides of such structures vary from 15 percent of the air blast pressures for dry soil up to nearly 100 percent for saturated soil. Internal equipment of a structure may be subjected to accelerations resulting from ground shock that will severely damage the equipment but may not damage the structure. For a discussion of accelerations resulting from ground shock see paragraph 2.26.

c. Response and Damage. Damage to a target is closely related to its response and is a direct derivative thereof. For targets anchored to the ground, damage is most often the result of displacement of one part of the target with respect to another part, resulting in permanent distortion, collapse or toppling. For movable targets, however, the target may be moved by the loading with or without damage resulting. In these cases the damage to the target is governed primarily by the manner in which the moving target comes to rest. Depending on the yield of the weapon, target characteristics and the damage level considered, either drag phase loading or diffraction phase loading assumes the greater importance.

For large targets such as buildings having small window areas and walls which either support the structure or are as strong as the structural frames, the reflected overpressure loading during the diffraction phase is predominant in causing failure of the structure. The failure occurs because the pressure differential between the front and rear face exists over a relatively long period of time. If the window area is large, the pressure on each wall is quickly equalized by the entry of the blast wave through the windows. The pressures exerted on the inside of the wall thus reduce the translational force on the wall. This translational force is also reduced because of a smaller wall area on which the pressures can act; however, the force exerted on interior partitions and rear walls tends to offset the reduction in front face loading in production of total damage. When the overpressures causing translational force on the structural component are quickly equalized because of the geometry or construction of the building, the primary damaging forces are those produced by the dynamic pressures or drag forces. Drag forces are the significant damaging forces when the structural components have fairly small cross sections, such as columns and beams. Structures normally damaged by drag forces are smoke stacks, telephone poles, truss bridges, and steel or reinforced concrete frame buildings with light walls. These buildings are drag sensitive because the light walls of corrugated steel, asbestos or cinder block fail at low reflected pressures, transmitting little load to the structure frame. Then only the frame itself is exposed to the blast and, being composed of small cross section structural elements, is distorted primarily by drag forces. These buildings are not considered severely damaged unless the structural frame has collapsed or is near the point of collapse. A tree is a good example of a drag sensitive target, since the duration of the diffraction phase is extremely short and there is considerable force applied by the high wind velocity drag loading. Most military field equipment is drag sensitive, because damage generally results from the tumbling or overturning caused by the drag forces.
If the target is shielded from the drag forces or lies within the early regular reflection region, high overpressures may become the damage-producing criteria. For blast resistant aboveground structures designed to resist more than 5 to 10 psi overpressure, the distinction between diffraction and drag sensitivity cannot be well defined primarily because full reflection from the surface of the structure does not occur and dynamic pressures greatly exceed those expected in the ideal wave form case. As a result, drag forces may predominate even during the diffraction phase in producing damage.

Aircraft may be damaged by the forces developed in the diffraction phase, in the drag loading phase, or in both. Parked aircraft can receive light, moderate, or often severe degrees of damage as a result of diffraction or crushing forces corresponding to low overpressures. For example, light skins and frames are easily dished and buckled at relatively low overpressures. At higher overpressure levels, drag loading (referred to as “gust loading” with respect to aircraft) adds to the damage. At these levels, much of the damage may result from translation and overturning of the aircraft. For aircraft in flight, the diffraction and drag forces combine with the existing aerodynamic forces to develop destructive loads on airfoils at low overpressure levels. The diffraction or crushing overpressure effects on the fuselage and other thin skinned components, however, are usually of secondary importance for the in-flight aircraft.

Severe water shock damage to ships or submarines results when the hull is split or crushed by the shock pulse. Generally, severe damage to surface ships is related to hull deformation, certain values of which are used empirically for damage criteria. For submarines, the damage to the hull is related to the impulse in the shock. Interior machinery damage is related to the bottom plate velocity for surface ships, and to the hull velocity for submarines. Water wave action produced by surface or subsurface bursts also may contribute to surface ship damage. In addition, waves striking shore installations may cause serious damage to the components of such installations.

5.3 Thermal Radiation Damage

a. General. The two most important effects of thermal radiation on ground targets are injury (burns) to personnel and the setting of fires in the target area. Depending upon the yield and detonation conditions of the weapon, and upon target characteristics, blast effects or nuclear radiation effects may override the thermal effects in importance. Predictions of thermal damage to targets are limited by the precision with which thermal energy may be scaled with yield, height of burst and slant range. The factors of target geometry, previous precipitation history, prevailing meteorology and seasonal effects introduce additional uncertainties. The criteria for thermal damage, set forth in part two in terms of specific radiant exposures required to produce the damage of interest, should be applied with the understanding that significant deviations from the mean values quoted may be experienced in individual cases because of variations in the factors mentioned above.

b. Energy and Rate Dependence. The damage produced by thermal radiation is dependent upon the energy per unit area incident on the target and the rate at which the energy is delivered. For convenience, the incident thermal energy per unit area (or radiant exposure) has been adopted as the damage criterion. Since the emission period for the thermal pulse increases with increasing yield of the detonation, the thermal radiation from the larger yield weapons is delivered over a longer period of time. For a given total amount of thermal energy received by each unit area of exposed material, the damage will be greater if the energy is delivered rapidly than if it were delivered slowly. For example, it takes 4 cal/cm² to produce a second degree burn on bare skin for the rapid pulse of a 1 KT detonation, whereas direct sunlight produces this amount of radiation in a little over 2 minutes with no effect. This means that, in order to produce the same thermal effect in a given material, the total amount of thermal energy received per unit area must be larger for a nuclear explosion of high yield than for one of lower yield, because the energy is delivered over a longer period of time, i.e., more slowly, in the former case. Therefore, thermal damage criteria in part two are given for specified
yields, or factors for scaling the criteria with yield are given.

c. Damage Mechanisms. Except for thin materials such as fabrics, newspaper, and leaves, thermal damage to materials is largely confined to changes at shallow depths in the exposed surface. Damage to materials results from raising the temperature of the surface, which, in the case of organic materials, brings about permanent chemical changes or induces ignition of the material. Only the portion of the energy which is absorbed (i.e., neither reflected nor transmitted) by the material is effective in producing thermal damage. Highly reflecting materials or transparent materials are relatively resistant to thermal damage. Light colored objects of a given thickness are more resistant than dark colored objects of the same material and thickness because they reflect more of the incident energy. However, color has little effect on the response of materials which blacken readily upon exposure early in the thermal pulse, since the energy delivered during the remainder of the pulse is largely absorbed by the blackened surface. The effect of absorptivity has been included in the derivation of damage criteria.

d. Effect of Thickness. Thick organic materials such as wood, plastics, and heavy fabrics do not support combustion, but only char as the result of exposure to thermal radiation. During the delivery of the pulse, the surfaces of these materials may flame, but the combustions are not sustained once the radiant pulse has died out. Materials such as light fabrics, newspaper, dried leaves and grass, and dry rotted wood may ignite at energies as low as 3 cal/cm² from a 1 KT detonation. The subsequent arrival of the blast wave at distances corresponding to these low ignition energies frequently fails to extinguish the ignitions and they become possible sources of primary fires. Charring and flaming or disintegration is typical of organic substances. Many of these substances emit jets of flame or smoke during exposure but do not actually ignite. Bare metals are unchanged unless structurally weakened or melted by heat action. The thicker the metal, the more resistant it is to thermal effects.

e. Effect of Orientation. Orientation of material is an important factor affecting the thermal damage produced by a weapon detonated in clear atmospheres, since the radiant exposure of a plane surface depends on the angle between the perpendicular to the surface and the direction of the burst. The maximum effect is produced when the incident radiation is perpendicular to the surface. Surfaces which do not receive direct radiation may be exposed to the lesser amounts of radiation reflected from the ground or from clouds or scattered by haze in the atmosphere. Under hazy conditions at slant ranges greater than half the visibility, much of the energy received is scattered by particles in the atmosphere and comes from all directions. References in table 12–2 to the exposures required to produce various types of damage are based on an alignment perpendicular to the incident beam. For other orientations of the target surface, greater exposures will be required to produce the same degree of damage.

f. Effect of Shielding. Except under hazy conditions at greater slant ranges, when the incident radiation is received from all angles, the geometry of the target of interest with respect to nearby objects is of importance, particularly within buildings or in complex target areas. Trees, buildings, foxholes, hills, etc., in a position to shield the target from the fireball, are effective as thermal shields. The shielding effect of deciduous trees, once the leaves have been shed, is greatly reduced. Reflection of thermal radiation from exposed walls of foxholes is about 5 percent.

g. Moisture Content. Thermal damage to materials which absorb moisture is dependent upon the percentage of water in such materials. Usually, the moisture content varies with the prevailing relative humidity. However, exposure to recent rain may greatly alter the moisture content. Scorching or charring of an organic surface by radiant energy is preceded by vaporization of the water. Because of this effect, more energy is required to produce a given damage effect to wet surfaces or to targets in highly humid atmospheres. Materials located within structures during the latter part of the heating season (late winter and early spring) are more readily damaged by thermal radiation, largely due to decreased interior humidities. On the other hand, materials exterior to structures are more readily damaged during the summer and
fall. Vegetation at the end of the growing season and fallen leaves are classed as ignition sources of greatest potential in the summer and fall. (See sec. XII.)

5.4 Nuclear Radiation

a. Relative Effects. With only a few exceptions, which are discussed in paragraph 12.2, significant radiation damage is limited to living organisms, so that for all practical purposes it is an antipersonnel effect. Basic nuclear radiation data are presented in previous sections, subdivided within burst types as to initial radiation and residual radiation. The penetrating radiations (neutrons and gamma rays) are the most dangerous, and the effect of these penetrating radiations in nearly every case exceeds that of the less penetrating residual alpha and beta radiations. The latter two may, however, become an internal hazard if taken into the lungs or digestive system, or an external hazard to skin in the case of beta rays. The ultimate effect of each of these radiations on living tissue is the same, and involves the damage of individual living cells. The modes of interaction with cellular matter differ, but these differences are not important in assessing the end result. The nature of the radiation determines whether the resultant injury is localized or diffuse. Thus beta rays, with their low penetrating power, are stopped within the first few hundredths of an inch of tissue, and may produce localized surface burns of varying degrees of severity; whereas gamma rays and neutrons can penetrate deeply (or may even pass completely through the body) before giving up some or all of their energy by interaction with body tissue.

b. Cumulative Effects. Ultimate body damage resulting from nuclear radiation is necessarily a summation of the several separate radiation effects involved. Thus, roentgens of initial gamma radiation received must be added to the roentgen equivalent dose for man (rem) of neutron radiation received, plus the roentgens of residual gamma radiation received, to obtain total dose. Beta radiation dose received must be evaluated separately, since it is a localized surface effect rather than a diffuse type of injury. If a significant portion of the total dose is received over an extended period of time, some biological recovery or repair occurs (see par. 6.3a).

c. Shielding. It is important to recognize that the basic nuclear radiation data presented in part one of this manual pertain to completely open and unshielded regions. Reductions in dosage actually received by an individual will occur from shielding afforded by surrounding structures and terrain elevations. Shielding factors and transmission curves by means of which actual doses behind certain shields can be estimated are given in paragraph 6.5.

5.5 Selection of Burst

a. General Considerations. Many factors enter into the selection of burst height or depth, and yield for a particular weapon. Among these factors are fuzing limitations, delivery systems available, the extent and vulnerability of the target, and the degree of damage which is desired. From an effects standpoint, the basic criteria which govern burst height or depth and yield selection are peak blast wave overpressure, peak dynamic pressure, duration of the positive phase, crater extent, initial nuclear radiation, residual fission product fallout and induced ground contamination, and thermal radiation. In the majority of cases, one of these criteria is present which, commensurate with troop safety, clearly indicates the type of burst to be employed, thus eliminating the time and effort necessary to make a detailed comparison of types of burst for a specific target. Some generalized statements on the relative importance of various effects for different burst conditions, which are useful in making such a decision, are as follows:

(1) Surface bursts. A surface burst will increase the range at which peak overpressures occur for pressures greater than about 12 psi; reduce thermal radiation received by ground targets compared to that received from an airburst at the same slant range; produce large areas of fallout contamination; and produce significant cratering and ground shock.

(2) Air bursts (depending on the applicable criterion). An airburst will increase the range on the ground at which overpressures of about 10 psi or less are obtained; maximize areas of thermal radiation received on the ground; elimi-
nate significant fallout contamination; and may increase the importance of neutron-induced activity.

(3) Subsurface bursts. Peak air overpressures, thermal radiation, and initial nuclear radiation will decrease as the depth of burst is increased. Cratering, ground or water shock, and fallout contamination will increase with depth of burst up to a maximum—the optimum depth depending on the effect being considered—and then decrease. Maximum water waves will be produced at certain critical depths of burst.

b. Estimation of Phenomena Extent. Figures 5–2A, B, and C show the horizontal range to which various physical phenomena extend as a function of yield for scaled heights of burst of 0 \( W^{1/2} \) feet (surface), 250 \( W^{1/3} \) feet (in the transition zone with respect to some phenomena), and 650 \( W^{1/3} \) feet (air burst), respectively. Figures 5–3A, B, and C are nomograms for the same scaled burst heights and conditions, from which the slant range of given levels of any phenomenon may be estimated with reasonable accuracy.

The curves and nomograms are presented to allow a rapid visual comparison of the extent of the various physical phenomena and to permit a rapid determination of the controlling damage mechanism at a particular distance for a given yield. The conditions for which the curves and nomograms are drawn are given on the figures. For other conditions, or to obtain maximum accuracy, the basic data curves of part one must be utilized.

The parameter values selected are not intended to imply equally damaging effects on a given target. Blast and thermal curves are not related directly to damage, since this depends on blast duration and rate of delivery of thermal energy, which in turn are related to yield. A discussion of this point is given in the facing page of figure 5–2. Areas of effect generated from this data would generally be circular, except in the case of fallout, the major portion of which is elliptical, and the horizontal component of the peak dynamic pressure, which may take the form of a hollow circle or annular ring (note fig. 5–2C).
Figures 5–2A, B, and C show the range from ground zero of various physical phenomena when a burst is on the surface, at a scaled height of 250 ft, and at a scaled height of 650 ft respectively. They are presented primarily for rapid visual comparison of the distance to which the various physical phenomena will extend, and secondarily for a rapid determination of the controlling mechanism of damage at any distance for any yield. From data presented in part one, a similar illustration could be prepared for any scaled or actual burst height.

The significance of the various phenomena curves presented varies with the target being considered. The initial and residual radiation curves are the most significant ones for human targets in the open or in shelters. The values chosen for plotting represent the following:

5 r—No obvious effect on personnel.
100 r—Non-lethal dose causing sickness in a few personnel, but permitting a unit to remain operationally effective.
450 r—Dose lethal within 30 days to 50 percent of personnel exposed.
10,000 r—Free field dose which will produce a dose of 100 r for personnel within a shelter having a dose transmission factor of 0.01.

The blast and thermal radiation curves cannot be related directly to damage, because of the increasing duration of blast and thermal phenomena with increasing yield and the dependence of the degree of damage sustained on the duration of the damage-producing effect. To assist in relating the curves presented to expected damage, the following table shows the variation with yield of the magnitude of weapon phenomena required to cause various degrees of damage to certain selected targets. (Refer to secs. VI through XII for a more detailed presentation of damage criteria.)

<table>
<thead>
<tr>
<th>Thermal effects:</th>
<th>1 KT</th>
<th>100 KT</th>
<th>10 MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second degree bare skin burn</td>
<td>4</td>
<td>5.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Newspaper ignition</td>
<td>2.9</td>
<td>5.1</td>
<td>9.1</td>
</tr>
<tr>
<td>White pine charring</td>
<td>10</td>
<td>18</td>
<td>32</td>
</tr>
</tbody>
</table>

Thermal effects—Continued

| Army khaki summer uniform destruction | 18 | 31 | 56 |
| Navy white uniform destruction | 34 | 60 | 109 |

Blast effects (in the Mach region):

Severe damage to overpressure sensitive structures:

| Blast-resistant designed buildings | 50 | 40 | 35 |
| Reinforced concrete buildings | 10.5 | 9.5 | 9 |
| Monumental wall bearing buildings | 20 | 15 | 15 |
| Wood frame housing | 3 | 3 | 3 |
| Window pane breakage | 0.5 | 0.5 | 0.5 |

Severe damage to dynamic pressure sensitive structures:

| Light steel frame single story buildings | 4.5 | 2 | 0.9 |
| Heavy steel frame single story buildings | 6 | 3 | 1.5 |
| Steel frame multistory buildings | 7.5 | 2.5 | 0.9 |
| 150°–250° span truss bridges | 50 | 8 | 5.5 |

Some curves are extrapolated beyond data presented in part one, since it is felt that the relationships between phenomena as shown will hold in those regions where there is little supporting knowledge, even though the actual values may be questionable. Since thermal curves are extended beyond one-half the visibility, their interpretation in that region must be approached with caution. In figures B and C, the relative air density would decrease as the actual height of burst is increased in a real case. However, it is held constant for illustrative purposes here. The conversion from slant range to ground range, plus the variation in enhancement of gamma radiation, causes the change in the shape of the radiation curves with change of burst height. Fallout contours are elliptical; only the downwind extent is shown.

Reliability. Varies with the phenomenon of interest. See part one.

Related material.

See paragraph 5.5.
PHENOMENA NOMOGRAMS FOR VARIOUS SCALED BURST HEIGHTS

Figures 5–3A, B, and C are nomograms which present various physical phenomena as a function of yield and slant range for a burst on the surface, at a scaled height of burst of 250 $W^{1/3}$ feet, and at a scaled height of burst of 650 $W^{1/3}$ feet, respectively. These nomograms afford a means of quick comparison of the slant ranges to which various phenomena extend under certain fixed conditions. It will rarely occur that all of these conditions are satisfied in a given situation. Thus, the answers to specific problems should normally be derived from the curves of part one. In addition, it is possible to generate some information from the nomograms which is outside the reliability criteria specified for the curves in part one from which the nomograms were derived. In these cases the reliability cannot be stated, but it may be assumed to be poor. Figure 5–3D is furnished to facilitate the conversion of slant range to horizontal distance for the specific heights of burst used in the phenomena nomograms.

Figures 5–3A, B, and C contain a range scale for each of the phenomena; a common scale on which is read initial gamma dose (roentgen), initial neutron dose (rem), or thermal exposure (cal/cm$^2$); peak pressure scales which give peak dynamic pressure and peak overpressure in psi; and scales of yield in KT. On figures 5–3A and 5–3C one yield scale is common to all phenomena except initial gamma radiation, while on figure 5–3B thermal exposure and initial gamma radiation both require separate yield scales.

To find the level of phenomena for a given yield, scaled height of burst, and slant range, select the appropriate nomogram for the height of burst, then connect the yield on the appropriate yield scale with the range on the appropriate range scale by a straight line. This line extended will intersect the appropriate phenomenon line at the level sought. The process is then repeated for all phenomena of interest. Conversely, a line connecting a particular level of any phenomenon with a yield on the yield scale for that phenomenon will intersect the range scale for that phenomenon at the range to which that particular level will extend.

In addition to the various scales described above, figure 5–3A contains two tick marks which may be used in conjunction with the yield and range scales for blast phenomena to determine crater dimensions (radius and depth) for a surface burst. A straight line connecting either of these marks with the proper yield on the blast phenomena yield scale will intersect the blast phenomena range scale at a point at which that particular dimension may be read.

Figure 5–3D contains a yield scale to be used for a scaled height of burst of 250 $W^{1/3}$ feet and one to be used for a scaled height of burst of 650 $W^{1/3}$ feet. It also contains a slant range scale, a horizontal distance scale, and two auxiliary scales. To obtain a horizontal distance corresponding to a given yield, scaled height of burst, and slant range, connect the yield on the appropriate yield scale and the slant range on the slant range scale with a straight line. Note the value at which this line, extended, crosses auxiliary scale number 1. Locate the value read from auxiliary scale number 1 on auxiliary scale number 2 and connect this point on auxiliary scale number 2 with the slant range on the slant range scale by a straight line. This line will cross the horizontal distance scale at the desired horizontal distance. If the line connecting yield and slant range goes off scale on the auxiliary scale number 1 in a direction such that the reading would be less than 1, the horizontal distance may be taken to be equal to the slant range. If the same line goes off scale such that the reading on auxiliary scale number 1 would be equal to or greater than 10, the height of burst is equal to or greater than the slant range being used and horizontal distance is zero or meaningless. It should be noted that figure 5–3D does not provide an easy method for obtaining a slant range for a given yield, height of burst and horizontal distance. This can be accomplished only through trial and error on figure 5–3D.

Example.

(1) Given: A 40 KT typical fission weapon is burst on an average surface. The visibility is 10 miles and relative air density is 0.9.

Find:

(a) The values of thermal exposure, initial gamma dose, initial neutron dose, peak overpressure, and peak dynamic pressure on the surface 2,000 yards from the burst.
(b) The radius and depth of the crater.

Solution: (a) From figure 5-3A, the desired values are—

<table>
<thead>
<tr>
<th>Thermal exposure</th>
<th>7.5 cal/cm²</th>
<th>Answer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial gamma</td>
<td>85 r</td>
<td>Answer.</td>
</tr>
<tr>
<td>Initial neutron</td>
<td>23 rem</td>
<td>Answer.</td>
</tr>
<tr>
<td>Peak overpressure</td>
<td>4 psi</td>
<td>Answer.</td>
</tr>
<tr>
<td>Peak dynamic</td>
<td>0.4 psi</td>
<td>Answer.</td>
</tr>
</tbody>
</table>

(b) Crater radius . . . 72 yd . . . Answer.
Crater depth . . . . 18 yds . . . Answer.

(2) Given: A 4 MT thermonuclear weapon is burst at a height of 250 W/h feet above an average surface. Visibility is 10 miles and relative air density is 0.9.

Find: The values of thermal exposure and initial nuclear radiation dose at a point where the peak overpressure is 15 psi.

Solution: From figure 5-3B the slant range at which this burst causes an overpressure of 15 psi is 3,600 yards. At this range the values of the other phenomena are—

<table>
<thead>
<tr>
<th>Thermal exposure</th>
<th>610 cal/cm²</th>
<th>Answer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial gamma</td>
<td>170 r</td>
<td>Answer.</td>
</tr>
</tbody>
</table>

Initial neutron 105 rem Answer.

(3) Given: A 100 KT fission weapon is burst at a height of 650 W/h² feet above an average surface.

Find: The horizontal distance to which 15 psi peak overpressure extends.

Solution: From figure 5-3C, the slant range at which this burst causes a peak overpressure of 15 psi is 1,500 yards.

On figure 5-3D, the line connecting 100 KT on the 650 W/h² height of burst yield scale with 1,500 yards on the slant range scale intersects the auxiliary scale number 1 at a value of 6.8. The line connecting the value of 6.8 on the auxiliary scale number 2 with 1,500 yards on the slant range scale intersects the horizontal distance scale at 1,100 yards. Answer.

Reliability. The same as for the various curves in part one from which these nomograms were derived, except where the limits of the reliability criteria for any curve are exceeded, in which case the reliability is unknown but may be assumed to be poorer than when the limits are not exceeded.

Related material.
See paragraph 5.5.
See also figures 5–2A, B, and C.
**Figure 5-3A**

**Phenomena Nomogram**

Surface Burst

Based Upon
1. Sea Level Homogeneous Atmosphere
2. Average Surface
3. Target on Surface
4. 10 Mile Visibility
5. Relative Air Density ≈ 0.9

**DOSE**
- Roentgens (Gamma)
- Rem (Neutrons)
- Calv/cm²

**SLANT RANGE (Yds)**
- For Gamma Radiation
- For Neutron Fusion Weapons
- For gamma Radiation Thermal Exposure
- For Neutron Radiation And Blast Phenomena

**YIELD (KT)**

**SLANT RANGE (Yds)**
- For Blast Phenomena

**Crater Depth**
- 1
- 2
- 4
- 8
- 10

**Crater Radius**
- 20
- 40
- 60
- 80
- 100

**Peak Pressure (Psi)**
- 200 Dynamic Pressure
- Overpressure

**For**
- 1,000
- 800
- 600
- 400
- 200

**Meters**
- 100
- 200
- 300
- 500
- 1,000

**Kilometers**
- 1
- 2
- 5
- 10
- 50
- 100
The image contains a nomogram for calculating dose, slant range, and yield based on neutron, gamma, and thermal exposure. The nomogram is titled "Phenomena Nomogram" and is based on several factors:

1. Sea Level Homogeneous Atmosphere
2. Average Surface
3. Target on Surface
4. 10 Mile Visibility
5. Relative Air Density = 0.9

The nomogram is used to calculate peak pressures in PSI, overpressures, and dynamic pressures. The values are shown along the vertical and horizontal axes, allowing for the calculation of various phenomena based on the input parameters.