The Effects of Nuclear Weapons

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PREFACE

When "The Effects of Atomic Weapons" was published in 1950, the explosive energy yields of the fission bombs available at that time were equivalent to some thousands of tons (i.e., kilotons) of TNT. With the development of thermonuclear (fusion) weapons, having energy yields in the range of millions of tons (i.e., megatons) of TNT, a new presentation, entitled "The Effects of Nuclear Weapons," was issued in 1957. A completely revised edition was published in 1962 and this was reprinted with a few changes early in 1964.

Since the last version of "The Effects of Nuclear Weapons" was prepared, much new information has become available concerning nuclear weapons effects. This has come in part from the series of atmospheric tests, including several at very high altitudes, conducted in the Pacific Ocean area in 1962. In addition, laboratory studies, theoretical calculations, and computer simulations have provided a better understanding of the various effects. Within the limits imposed by security requirements, the new information has been incorporated in the present edition. In particular, attention may be called to a new chapter on the electromagnetic pulse.

We should emphasize, as has been done in the earlier editions, that numerical values given in this book are not—and cannot be—exact. They must inevitably include a substantial margin of error. Apart from the difficulties in making measurements of weapons effects, the results are often dependent upon circumstances which could not be predicted in the event of a nuclear attack. Furthermore, two weapons of different design may have the same explosive energy yield, but the effects could be markedly different. Where such possibilities exist, attention is called in the text to the limitations of the data presented; these limitations should not be overlooked.

The material is arranged in a manner that should permit the general reader to obtain a good understanding of the various topics without having to cope with the more technical details. Most chapters are thus in two parts: the first part is written at a fairly low technical level whereas the second treats some of the more technical and mathematical aspects. The presentation allows the reader to omit any or all of the latter sections without loss of continuity.

The choice of units for expressing numerical data presented us with a dilemma. The exclusive use of international (SI) or metric units would have placed a burden on many readers not familiar with these units, whereas the inclusion of both SI and common units would have complicated many figures, especially those with logarithmic scales. As a compromise, we have retained the older units and added an explanation of the SI system and a table of appropriate conversion factors.

Preface

Many organizations and individuals contributed in one way or another to this revision of "The Effects of Nuclear Weapons," and their cooperation is gratefully acknowledged. In particular, we wish to express our appreciation of the help given us by L. J. Deal and W. W. Schroebel of the Energy Research and Development Administration and by Cmdr. H. L. Hoppe of the Department of Defense.

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GLOSSARY

A-Bomb: An abbreviation for atomic bomb. See *Nuclear weapon.*

Absorbed Dose: The amount of energy imparted by nuclear (or ionizing) radiation to unit mass of absorbing material. The unit is the rad. See *Dose, Rad.*

Absorption: The irreversible conversion of the energy of an electromagnetic wave into another form of energy as a result of its interaction with matter. As applied to gamma (or X) rays it is the process (or processes) resulting in the transfer of energy by the radiation to an absorbing material through which it passes. In this sense, absorption involves the photoelectric effect and pair production, but only part of the Compton effect. See *Attenuation, Compton effect, Pair production, Photoelectric effect.*

Absorption Coefficient: A number characterizing the extent to which specified gamma (or X) rays transfer their energy to a material through which they pass. The *linear energy absorption coefficient* is a measure of the energy transfer (or absorption) per unit thickness of material and is stated in units of reciprocal length (or thickness). The *mass energy absorption coefficient* is equal to the linear absorption coefficient divided by the density of the absorbing material; it is a measure of the energy absorption per unit mass. See *Attenuation coefficient.*

Afterwinds: Wind currents set up in the vicinity of a nuclear explosion directed toward the burst center, resulting from the updraft accompanying the rise of the fireball.

Air Burst: The explosion of a nuclear weapon at such a height that the expanding fireball does not touch the earth's surface when the luminosity is a maximum (in the second pulse).

Alpha particle: A particle emitted spontaneously from the nuclei of some radioactive elements. It is identical with a helium nucleus, having a mass of four units and an electric charge of two positive units. See *Radioactivity.*

Angstrom: A unit of length, represented by A, equal to 10^{-8} centimeter. It is commonly used to express the wavelengths of electromagnetic radiations in the visible, ultraviolet, and X-ray regions.

Apparent Crater: See *Crater.*

Arching: In the case of a buried structure, it is the tendency for the soil particles to lock together in the form of an arch, with the result that part of the stress is transmitted around the structure instead of through it.

Atom: The smallest (or ultimate) particle of an element that still retains the characteristics of that element. Every atom consists of a positively charged central nucleus, which carries nearly all the mass of the atom, surrounded by a number of negatively charged electrons, so that the whole system is electrically neutral. See *Electron, Element, Nucleus.*

Atomic Bomb (or Weapon): A term sometimes applied to a nuclear weapon utilizing fission energy only. See *Fission, Nuclear weapon.*

Atomic Cloud: See *Radioactive cloud.*

Atomic Number: See *Nucleus.*

Atomic Weight: The relative mass of an atom of the given element. As a basis of reference, the atomic weight of the common isotope of carbon (carbon-12) is taken to be exactly 12; the atomic weight of hydrogen (the lightest element) is then 1.008. Hence, the atomic weight of any element is *approximately* the mass of an atom of that element relative to the mass of a hydrogen atom.

Attenuation: Decrease in intensity of a signal, beam, or wave as a result of absorption and scattering out of the path of a detector, but not including the reduction due to geometric spreading (i.e., the inverse square of distance effect). As applied to gamma (and X) rays, attenuation refers to the loss of photons (by the Compton, photoelectric, and pair-production effects) in the passage of the radiation through a material. See *Absorption, Inverse square law, Photon, Scattering.*

Attenuation Coefficient: A number characterizing the extent of interaction of photons of specified gamma (or X) rays in their passage through a material. The *linear attenuation coefficient* is a measure of the photon interaction per unit thickness of material and is stated in units of reciprocal length (or thickness). The *mass attenuation coefficient* is equal to the linear attenuation

coefficient divided by the density of the material; it is a measure of the attenuation per unit mass. See *Absorption coefficient.*

Background Radiation: Nuclear (or ionizing) radiations arising from within the body and from the surroundings to which individuals are always exposed. The main sources of the natural background radiation are potassium-40 in the body, potassium-40 and thorium, uranium, and their decay products (including radium) present in rocks and soil, and cosmic rays.

Base Surge: A cloud which rolls outward from the bottom of the column produced by a subsurface explosion. For underwater bursts the visible surge is, in effect, a cloud of liquid (water) droplets with the property of flowing almost as if it were a homogeneous fluid. After the water evaporates, an invisible base surge of small radioactive particles may persist. For subsurface land bursts the surge is made up of small solid particles but it still behaves like a fluid. A soft earth medium favors base surge formation in an underground burst.

Bearing Wall: A wall which supports (or bears) part of the mass of a structure such as the floor and roof systems.

Beta Particle: A charged particle of very small mass emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit (negative) beta particles. Physically, the beta particle is identical with an electron moving at high velocity. See *Electron, Fission products, Radioactivity.*

Beta Patch: A region of air fluorescence formed by absorption of beta particles from the fission products in the debris from a nuclear explosion above about 40 miles altitude.

Biological Half-Life: The time required for the amount of a specified element which has entered the body (or a particular organ) to be decreased to half of its initial value as a result of natural, biological elimination processes. See *Half-life.*

Black Body: An ideal body which would absorb all (and reflect none) of the radiation falling upon it. The spectral energy distribution of a black body is described by Planck's equation; the total rate of emission of radiant energy is proportional to the fourth power of the absolute temperature (Stefan-Boltzmann law).

Blast Loading: The loading (or force) on an object caused by the air blast from an explosion striking and flowing around the object. It is a combination of overpressure (or diffraction) and dynamic pressure (or drag) loading. See *Diffraction, Drag loading, Dynamic pressure, Overpressure.*

Blast Scaling Laws: Formulas which permit the calculation of the properties, e.g., overpressure, dynamic pressure, time of arrival, duration, etc., of a blast wave at any distance from an explosion of specified energy from the known variation with distance of these properties for a reference explosion of known energy (e.g., of 1 kiloton). See *Cube root law.*

Blast Wave: A pulse of air in which the pressure increases sharply at the front, accompanied by winds, propagated from an explosion. See *Shock wave.*

Blast Yield: That portion of the total energy of a nuclear explosion that manifests itself as a blast (or shock) wave.

Bomb Debris: See *Weapon debris.*

Boosted Fission Weapon: A weapon in which neutrons produced by thermonuclear reactions serve to enhance the fission process. The thermonuclear energy represents only a small fraction of the total explosion energy. See *Fission, Thermonuclear.*

Breakway: The onset of a condition in which the shock front (in the air), moves away from the exterior of the expanding fireball produced by the explosion of a nuclear (or atomic) weapon. See *Fireball, Shock front.*

Bremsstrahlung: Literally "braking radiation." Radiations covering a range of wave lengths (and energies) in the X-ray region resulting from the electrical interaction of fast (high-energy) electrons with atomic nuclei. Bremsstrahlung are produced by the interaction of beta particles with matter. See *X rays.*

Burst: Explosion or detonation. See *Air burst, High-altitude burst, Surface burst, Underground burst, Underwater burst.*

Clean Weapon: One in which measures have been taken to reduce the amount of residual radioactivity relative to a "normal" weapon of the same energy yield.

Cloud Chamber Effect: See *Condensation cloud.*

Cloud Column: The visible column of weapon debris (and possibly dust and water droplets) extending upward from the point of burst of a nuclear (or atomic) weapon. See *Radioactive cloud.*

Cloud Phenomena: See *Base surge, Cloud column, Fallout, Fireball, Radioactive cloud.*

Colum (or Plume): A hollow cylinder of water and spray thrown up from an underwater burst of a nuclear (or atomic) weapon, through which the hot, high-pressure gases formed in the explosion

are vented to the atmosphere. A somewhat similar column of dirt is formed in an underground explosion.

Compton Current: Electron current generated as a result of Compton processes. See *Compton effect, Compton electron.*

Compton Effect: The scattering of photons (of gamma or X rays) by the orbital electrons of atoms. In a collision between a (primary) photon and an electron, some of the energy of the photon is transferred to the electron which is generally ejected from the atom. Another (secondary) photon, with less energy, then moves off in a new direction at an angle to the direction of motion of the primary photon. See *Scattering.*

Compton Electron: An electron of increased energy ejected from an atom as a result of a Compton interaction with a photon. See *Compton effect.*

Condensation Cloud: A mist or fog of minute water droplets which temporarily surrounds the fireball following a nuclear (or atomic) detonation in a comparatively humid atmosphere. The expansion of the air in the negative phase of the blast wave from the explosion results in a lowering of the temperature, so that condensation of water vapor present in the air occurs and a cloud forms. The cloud is soon dispelled when the pressure returns to normal and the air warms up again. The phenomenon is similar to that used by physicists in the Wilson cloud chamber and is sometimes called the cloud chamber effect.

Contact Surface Burst: See *Surface burst.*

Contained Underground Burst: An underground detonation at such a depth that none of the radioactive residues escape through the surface of the ground.

Contamination: The deposit of radioactive material on the surfaces of structures, areas, objects, or personnel, following a nuclear (or atomic) explosion. This material generally consists of fallout in which fission products and other weapon debris have become incorporated with particles of dirt, etc. Contamination can also arise from the radioactivity induced in certain substances by the action of neutrons from a nuclear explosion. See *Decontamination, Fallout, Induced radioactivity, Weapon debris.*

Crack: The light-colored region which follows closely behind the dark slick in an underwater burst. It is probably caused by the reflection of the water shock wave at the surface. See *Slick.*

Crater: The pit, depression, or cavity formed in the surface of the earth by a surface or underground explosion. Crater formation can occur by vaporization of the surface material, by the scouring effect of air blast, by throwout of disturbed material, or by subsidence. In general, the major mechanism changes from one to the next with increasing depth of burst. The apparent crater is the depression which is seen after the burst; it is smaller than the true crater (i.e., the cavity actually formed by the explosion), because it is covered with a layer of loose earth, rock, etc.

Critical Mass: The minimum mass of a fissionable material that will just maintain a fission chain reaction under precisely specified condition, such as the nature of the material and its purity, the nature and thickness of the tamper (or neutron reflector), the density (or compression), and the physical shape (or geometry). For an explosion to occur, the system must be supercritical (i.e., the mass of material must exceed the critical mass under the existing conditions). See *Supercritical.*

Cube Root Law: A scaling law applicable to many blast phenomena. It relates the time and distance at which a given blast effect is observed to the cube root of the energy yield of the explosion.

Curie: A unit of radioactivity; it is the activity of a quantity of any radioactive species in which 3.700×10^{10} nuclear disintegrations occur per second. The *gamma curie* is sometimes defined correspondingly as the activity of material in which this number of gamma-ray photons are emitted per second.

Damage Criteria: Standards or measures used in estimating specific levels of damage.

Debris: See *Weapon debris*

Decay (or Radioactive Decay): The decrease in activity of any radioactive material with the passage of time due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, sometimes accompanied by gamma radiation. See *Half-life, Radioactivity.*

Decay Curve: The representation by means of a graph of the decrease of radioactivity with respect to time.

Decontamination: The reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface so as to remove or decrease the contamination; (2) letting the material stand so that the radioactivity is decreased as a result of natural decay; and (3) covering the contamination so as to attenuate the radiation emitted. Radioactive material removed in process (1) must be disposed of

by burial on land or at sea, or in other suitable way.

Delayed Fallout: See *Fallout.*

Deuterium: An isotope of hydrogen of mass 2 units; it is sometimes referred to as heavy hydrogen. It can be used in thermonuclear fusion reactions for the release of energy. Deuterium is extracted from water which always contains 1 atom of deuterium to about 6,500 atoms of ordinary (light) hydrogen. See *Fusion, Isotope, Thermonuclear.*

Diffraction: The bending of waves around the edges of objects. In connection with a blast wave impinging on a structure, diffraction refers to the passage around and envelopment of the structure by the blast wave. *Diffraction loading* is the force (or loading) on the structure during the envelopment process.

Dome: The mound of water spray thrown up into the air when the shock wave from an underwater detonation of a nuclear (or atomic) weapon reaches the surface.

Dosage: See *Dose.*

Dose: A (total or accumulated) quantity of ionizing (or nuclear) radiation. The *absorbed dose* in rads represents the amount of energy absorbed from the radiation per gram of specified absorbing material. In soft body tissue the absorbed dose in rads is essentially equal to the exposure in roentgens. The biological dose (also called the *RBE dose*) in rems is a measure of biological effectiveness of the absorbed radiation. See *Exposure, Rad, RBE, Rem, Roentgen.*

Dose Equivalent: In radiation protection associated with peacetime nuclear activities, the dose equivalent in rems is a measure of the biological effectiveness of absorbed ionizing radiation. It is similar to the biological dose which is used in connection with the large radiation exposures that might accompany a nuclear explosion. See *Dose, Rem.*

Dose Rate: As a general rule, the amount of ionizing (or nuclear) radiation which an individual or material would receive per unit of time. It is usually expressed as rads (or rems) per hour or in multiples or submultiples of these units, such as millirads per hour. The dose rate is commonly used to indicate the level of radioactivity in a contaminated area. See *Survey meter.*

Dosimeter: An instrument for measuring and registering the total accumulated dose of (or exposure to) ionizing radiations. Instruments worn or carried by individuals are called *personnel dosimeters.*

Dosimetry: The theory and application of the principles and techniques involved in the measurement and recording of radiation doses and dose rates. Its practical aspect is concerned with the use of various types of radiation instruments with which measurements are made. See *Dosimeter, Survey meter.*

Drag Loading: The force on an object or structure due to the transient winds accompanying the passage of a blast wave. The *drag pressure* is the product of the dynamic pressure and the drag coefficient which is dependent upon the shape (or geometry) of the structure or object. See *Dynamic pressure.*

Dynamic Pressure: The air pressure which results from the mass air flow (or wind) behind the shock front of a blast wave. It is equal to the product of half the density of the air through which the blast wave passes and the square of the particle (or wind) velocity behind the shock front as it impinges on the object or structure.

Early Fallout: See *Fallout.*

Effective Half-Life: See *Half-life.*

Elastic Range: The stress range in which a material will recover its original form when the force (or loading) is removed. *Elastic deformation* refers to dimensional changes occurring within the elastic range. See *Plastic range.*

Elastic Zone: The zone beyond the plastic zone in crater formation in which the ground is disturbed by the explosion but returns to its original condition.

Electromagnetic Pulse: A sharp pulse of radio-frequency (long wavelength) electromagnetic radiation produced when an explosion occurs in an unsymmetrical environment, especially at or near the earth's surface or at high altitudes. The intense electric and magnetic fields can damage unprotected electrical and electronic equipment over a large area. See *Electromagnetic radiation, High-altitude burst.*

Electromagnetic Radiation: A traveling wave motion resulting from oscillating magnetic and electric fields. Familiar electromagnetic radiations range from X rays (and gamma rays) of short wavelength (high frequency), through the ultraviolet, visible, and infrared regions, to radar and radio waves of relatively long wavelength (low frequency). All electromagnetic radiations travel in a vacuum with the velocity of light. See *Photon.*

Electron: A particle of very small mass, carrying a unit negative or positive charge. Negative electrons, surrounding the nucleus, (i.e., orbital

electrons), are present in all atoms; their number is equal to the number of positive charges (or protons) in the particular nucleus. The term electron, where used alone, commonly refers to negative electrons. A positive electron is usually called a positron, and a negative electron is sometimes called a negatron. See *Beta particle.*

Electron Volt (EV): The energy imparted to an electron when it is moved through a potential difference of 1 volt. It is equivalent to 1.6×10^{-12} erg.

Element: One of the distinct, basic varieties of matter occurring in nature which, individually or in combination, compose substances of all kinds. Approximately ninety different elements are known to exist in nature and several others, including plutonium, have been obtained as a result of nuclear reactions with these elements.

EMP: See *Electromagnetic Pulse.*

Energy Absorption: See *Absorption.*

Energy Partition: The distribution of the total energy released by a nuclear explosion among the various phenomena (e.g., nuclear radiation, thermal radiation, and blast). The exact distribution is a function of time, explosion yield, and the medium in which the explosion occurs.

Exposure: A measure expressed in roentgens of the ionization produced by gamma (or X) rays in air. The *exposure rate* is the exposure per unit time (e.g., roentgens per hour). See *Dose, Dose rate, Roentgen.*

Fallout: The process or phenomenon of the descent to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The *early (or local) fallout* is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The *delayed (or worldwide) fallout* consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by winds to all parts of the earth. The delayed fallout is brought to earth, mainly by rain and snow, over extended periods ranging from months to years.

Fireball: The luminous sphere of hot gases which forms a few millionths of a second after a nuclear (or atomic) explosion as the result of the absorption by the surrounding medium of the thermal X rays emitted by the extremely hot (several tens of million degrees) weapon residues. The exterior of the fireball in air is initially sharply defined by the luminous shock front and later by the limits of the hot gases themselves (radiation front). See *Breakaway, Thermal X-rays.*

Fire Storm: Stationary mass fire, generally in builtup urban areas, causing strong, inrushing winds from all sides; the winds keep the fires from spreading while adding fresh oxygen to increase their intensity.

Fission: The process whereby the nucleus of a particular heavy element splits into (generally) two nuclei of lighter elements, with the release of substantial amounts of energy. The most important *fissionable materials* are uranium-235 and plutonium 239; fission is caused by the absorption of neutrons.

Fission Fraction: The fraction (or percentage) of the total yield of a nuclear weapon which is due to fission. For thermonuclear weapons the average value of the fission fraction is about 50 percent.

Fission Products: A general term for the complex mixture of substances produced as a result of nuclear fission. A distinction should be made between these and the *direct fission products* or *fission fragments* which are formed by the actual splitting of the heavy-element nuclei. Something like 80 different fission fragments result from roughly 40 different modes of fission of a given nuclear species (e.g., uranium-235 or plutonium-239). The fission fragments, being radioactive, immediately begin to decay, forming additional (daughter) products, with the result that the complex mixture of fission products so formed contains over 300 different isotopes of 36 elements.

Flash Burn: A burn caused by excessive exposure (of bare skin) to thermal radiation. See *Thermal radiation.*

Fluence (or Integrated Flux): The product (or integral) of particle (neutron or photon) flux and time, expressed in units of particles per square centimeter. The absorbed dose of radiation (in rads) is related to the fluence. See *Flux.*

Flux (or Flux Density): The product of the particle (neutron or photon) density (i.e., number per cubic centimeter) and the particle velocity. The flux is expressed as particles per square centimeter per second and is related to the absorbed dose rate. It is numerically equal to the total number of particles passing in all directions through a sphere of 1 square centimeter cross-sectional area per second.

Fractionation: Any one of several processes, apart from radioactive decay, which results in change in the composition of the radioactive weapon debris. As a result of fractionation, the

delayed fallout generally contains relatively more of strontium-90 and cesium-137, which have gaseous precursors, than does the early fallout from a surface burst.

Free Air Overpressure (or Free Field Overpressure): The unreflected pressure, in excess of the ambient atmospheric pressure, created in the air by the blast wave from an explosion. See *Overpressure.*

Fusion: The process whereby the nuclei of light elements, especially those of the isotopes of hydrogen, namely, deuterium and tritium, combine to form the nucleus of a heavier element with the release of substantial amounts of energy. See *Thermonuclear.*

Gamma Rays (or Radiations): Electromagnetic radiations of high photon energy orginating in atomic nuclei and accompanying many nuclear reactions (e.g., fission, radioactivity, and neutron capture). Physically, gamma rays are identical with X rays of high energy, the only essential difference being that X rays do not originate from atomic nuclei, but are produced in other ways (e.g., by slowing down (fast) electrons of high energy). See *Electromagnetic radiation, Photon, X rays.*

Genetic Effect: The effect of various agents (including nuclear radiation) in producing changes (mutations) in the hereditary components (genes) of the germ cells present in the reproductive organs (gonads). A mutant gene causes changes in the next generation which may or may not be apparent.

Ground Zero: The point on the surface of land vertically below or above the center of a burst of a nuclear (or atomic) weapon; frequently abbreviated to GZ. For a burst over or under water the corresponding term is *surface zero* (SZ). Surface zero is also commonly used for ground surface and underground bursts.

Gun-Type Weapon: A device in which two or more pieces of fissionable material, each less than a critical mass, are brought together very rapidly so as to form a supercritical mass which can explode as the result of a rapidly expanding fission chain. See *Critical mass, Supercritical.*

Half-Life: The time required for the activity of a given radioactive species to decrease to half of its initial value due to radioactive decay. The half-life is a characteristic property of each radioactive species and is independent of its amount or condition. The *effective half-life* of a given isotope is the time in which the quantity in the body (or an organ) will decrease to half as a result of both radioactive decay and biological elimination. See *Biological half-life.*

Half-Residence Time: As applied to delayed fallout, it is the time required for the amount of weapon debris deposited in a particular part of the atmosphere (e.g., stratosphere or troposphere) to decrease to half of its initial value.

Half-Value Thickness: The thickness of a given material which will absorb half the gamma radiation incident upon it. This thickness depends on the nature of the material—it is roughly inversely proportional to its density—and also on the energy of the gamma rays.

H-Bomb: An abbreviation for hydrogen bomb. See *Hydrogen bomb.*

Height of Burst: The height above the earth's surface at which a bomb is detonated in the air. The *optimum height* of burst for a particular target (or area) is that at which it is estimated a weapon of a specified energy yield will produce a certain desired effect over the maximum possible area.

High-Altitude Burst: This is defined, somewhat arbitrarily, as a detonation at an altitude over 100,000 feet. Above this level the distribution of the energy of the explosion between blast and thermal radiation changes appreciably with increasing altitude due to changes in the fireball phenomena.

Hot Spot: Region in a contaminated area in which the level of radioactive contamination is somewhat greater than in neighboring regions in the area. See *Contamination.*

Hydrogen Bomb (or Weapon: A term sometimes applied to nuclear weapons in which part of the explosive energy is obtained from nuclear fusion (or thermonuclear) reactions. See *Fusion, Nuclear weapon, Thermonuclear.*

Hypocenter: A term sometimes used for ground zero. See *Ground zero.*

Implosion Weapon: A device in which a quantity of fissionable material, less than a critical mass, has its volume suddenly decreased by compression, so that it becomes supercritical and an explosion can take place. The compression is achieved by means of a spherical arrangement of specially fabricated shapes of ordinary high explosive which produce an inwardly-directed implosion wave, the fissionable material being at the center of the sphere. See *Critical mass, Supercritical.*

Impulse (Per Unit Area): The product of the overpressure (or dynamic pressure) from the blast wave of an explosion and the time during which it acts at a given point. More specifically, it is the integral, with respect to time of overpressure (or dynamic pressure), the integration

being between the time of arrival of the blast wave and that at which the overpressure (or dynamic pressure) returns to zero at the given point.

Induced Radioactivity: Radioactivity produced in certain materials as a result of nuclear reactions, particularly the capture of neutrons, which are accompanied by the formation of unstable (radioactive) nuclei. In a nuclear explosion, neutrons can induce radioactivity in the weapon materials, as well as in the surroundings (e.g., by interaction with nitrogen in the air and with sodium, manganese, aluminum, and silicon in soil and sea water).

Infrared: Electromagnetic radiations of wavelength between the longest visible red (7,000 Angstroms or 7×10^{-4} millimeter) and about 1 millimeter. See *Electromagnetic radiation.*

Initial Nuclear Radiation: Nuclear radiation (essentially neutrons and gamma rays) emitted from the fireball and the cloud column during the first minute after a nuclear (or atomic) explosion. The time limit of one minute is set, somewhat arbitrarily, as that required for the source of part of the radiations (fission products, etc., in the radioactive cloud) to attain such a height that only insignificant amounts of radiation reach the earth's surface. See *Residual nuclear radiation.*

Integrated Neutron Flux: See *Fluence.*

Intensity: The amount or energy of any radiation incident upon (or flowing through) unit area, perpendicular to the radiation beam, in unit time. The intensity of thermal radiation is generally expressed in calories per square centimeter per second falling on a given surface at any specified instant. As applied to nuclear radiation, the term intensity is sometimes used, rather loosely, to express the exposure (or dose) rate at a given location.

Internal Radiation: Nuclear radiation (alpha and beta particles and gamma radiation) resulting from radioactive substances in the body. Important sources are iodine-131 in the thyroid gland, and strontium-90 and plutonium-239 in bone.

Inverse Square Law: The law which states that when radiation (thermal or nuclear) from a point source is emitted uniformly in all directions, the amount received per unit area at any given distance from the source, assuming no absorption, is inversely proportional to the square of that distance.

Ionization: The separation of a normally electrically neutral atom or molecule into electrically charged components. The term is also employed to describe the degree or extent to which this separation occurs. In the sense used in this book, ionization refers especially to the removal of an electron (negative charge) from the atom or molecule, either directly or indirectly, leaving a positively charged ion. The separated electron and ion are referred to as an *ion pair.* See *Ionizing radiation.*

Ionizing Radiation: Electromagnetic radiation (gamma rays or X rays) or particulate radiation (alpha particles, beta particles, neutrons, etc.) capable of producing ions, i.e., electrically charged particles, directly or indirectly, in its passage through matter. See *Nuclear radiation.*

Ionosphere: The region of the atmosphere, extending from roughly 40 to 250 miles altitude, in which there is appreciable ionization. The presence of charged particles in this region profoundly affects the propagation of long-wavelength electromagnetic radiations (radio and radar waves).

Ion Pair: See *Ionization.*

Isomer (or Isomeric Nuclide): See *Nuclide.*

Isotopes: Forms of the same element having identical chemical properties but differing in their atomic masses (due to different numbers of neutrons in their respective nuclei) and in their nuclear properties (e.g., radioactivity, fission, etc.). For example, hydrogen has three isotopes, with masses of 1 (hydrogen), 2 (deuterim), and 3 (tritium) units, respectively. The first two of these are stable (nonradioactive), but the third (tritium) is a radioactive isotope. Both of the common isotopes of uranium, with masses of 235 and 238 units, respectively, are radioactive, emitting alpha particles, but their half-lives are different. Furthermore, uranium-235 is fissionable by neutrons of all energies, but uranium-238 will undergo fission only with neutrons of high energy. See *Nucleus.*

Kilo-Electron Volt (or KEV): An amount of energy equal to 1,000 electron volts. See *Electron Volt.*

Kiloton Energy: Defined strictly as 10^{12} calories (or 4.2×10^{19} ergs). This is approximately the amount of energy that would be released by the explosion of 1 kiloton (1,000 tons) of TNT. See *TNT equivalent.*

Linear Attenuation Coefficient: See *Attenuation.*

Linear Energy Absorption Coefficient: See *Absorption.*

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

Loading: The force on an object or structure or element of a structure. The loading due to blast is equal to the net pressure in excess of the ambient value multiplied by the area of the loaded object, etc. See *Diffraction, Drag loading.*

Mach Front: See *Mach stem.*

Mach Region: The region on the surface at which the Mach stem has formed as the result of a particular explosion in the air.

Mach Stem: The shock front formed by the merging of the incident and reflected shock fronts from an explosion. The term is generally used with reference to a blast wave, propagated in the air, reflected at the surface of the earth. The Mach stem is nearly perpendicular to the reflecting surface and presents a slightly convex (forward) front. The Mach stem is also called the Mach front. See *Shock front, Shock wave.*

Mass Attenuation Coefficient: See *Attenuation.*

Mass Energy Absorption Coefficient: See *Absorption.*

Mass Number: See *Nucleus.*

Mean Free Path: The average path distance a particle (neutron or photon) travels before undergoing a specified reaction (with a nucleus or electron) in matter.

Megacurie: One million curies. See *Curie.*

Megaton Energy: Defined strictly as 10^{15} calories (or 4.2×10^{22} ergs). This is approximately the amount of energy that would be released by the explosion of 1,000 kilotons (1,000,000 tons) of TNT. See *TNT equivalent.*

MEV (or Million Electron Volt): A unit of energy commonly used in nuclear physics. It is equivalent to 1.6×10^{-6} erg. Approximately 200 MeV of energy are produced for every nucleus that undergoes fission. See *Electron volt.*

Microcurie: A one-millionth part of a curie. See *Curie.*

Micrometer: See *Micron.*

Micron: A one-millionth part of a meter (i.e., 10^{-6} meter or 10^{-4} centimeter); it is roughly four one-hundred-thousandths (4×10^{-5}) of an inch.

Microsecond: A one-millionth part of a second.

Million Electron Volt: See *MeV.*

Millirad: A one-thousandth part of a rad. See *Rad.*

Millirem: A one-thousandth part of a rem. See *Rem.*

Milliroentgen: A one-thousandth part of a roentgen. See *Roentgen.*

Millisecond: A one-thousandth part of a second.

Mirror Point: A point at which a charged particle, moving (in a spiral path) along the lines of a magnetic field, is reflected back as it enters a stronger magnetic field region. The actual location of the mirror point depends on the direction and energy of motion of the charged particle and the ratio of the magnetic field strengths. As a result, only those particles satisfying the requirements of the existing situation are reflected.

Monitoring: The procedure or operation of locating and measuring radioactive contamination by means of survey instruments which can detect and measure (as dose rates) ionizing radiations. The individual performing the operation is called a *monitor.*

Negative Phase: See *Shock wave.*

Neutron: A neutral particle (i.e., with no electrical charge) of approximately unit mass, present in all atomic nuclei, except those of ordinary (light) hydrogen. Neutrons are required to initiate the fission process, and large numbers of neutrons are produced by both fission and fusion reactions in nuclear (or atomic) explosions.

Neutron Flux: See *Flux.*

Nominal Atomic Bomb: A term, now becoming obsolete, used to describe an atomic weapon with an energy release equivalent to 20 kilotons (i.e., 20,000 tons) of TNT. This is very approximately the energy yield of the bombs exploded over Japan and in the Bikini test of 1946.

Nuclear Cloud: See *Radioactive cloud.*

Nuclear Radiation: Particulate and electromagnetic radiation emitted from atomic nuclei in various nuclear processes. The important nuclear radiations, from the weapons standpoint, are alpha and beta particles, gamma rays, and neutrons. All nuclear radiations are ionizing radiations, but the reverse is not true; X rays, for example, are included among ionizing radiations, but they are not nuclear radiations since they do not originate from atomic nuclei. See *Ionizing radiation, X-rays.*

Nuclear (or Atomic) Tests: Test carried out to supply information required for the design and improvement of nuclear (or atomic) weapons and to study the phenomena and effects associated with nuclear (or atomic) explosions. Many of the data presented in this book are based on measurements and observations made at such tests.

Nuclear Weapon (or Bomb): 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. Thus, the A- (or atomic) bomb and the H- (or hydrogen) bomb are both nuclear weapons. It would be equally true to call them atomic weapons, since it is the energy of atomic nuclei that is involved in each case. However, it has become more-or-less customary, although it is not strictly accurate, to refer to weapons in which all the energy results from fission as A-bombs or atomic bombs. In order to make a distinction, those weapons in which part, at least, of the energy results from thermonuclear (fusion) reactions of the isotopes of hydrogen have been called H-bombs or hydrogen bombs.

Nucleus (or Atomic Nucleus): The small, central, positively charged region of an atom which carries essentially all the mass. Except for the nucleus of ordinary (light) hydrogen, which is a single proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge, or *atomic number*; this is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons, called the *mass number*, is closely related to the mass (or weight) of the atom. The nuclei of *isotopes* of a given element contain the same number of protons, but different numbers of neutrons. They thus have the same atomic number, and so are the same element, but they have different mass numbers (and masses). The nuclear properties (e.g., radioactivity, fission, neutron capture, etc.) of an isotope of a given element are determined by both the number of neutrons and the number of protons. See *Atom, Element, Isotope, Neutron, Proton.*

Nuclide: An atomic species distinguished by the composition of its nucleus (i.e., by the number of protons and the number of neutrons). In *isomeric nuclides* the nuclei have the same composition but are in different energy states. See *Atom, Neutron, Nucleus, Proton.*

Overpressure: The transient pressure, usually expressed in pounds per square inch, exceeding the ambient pressure, manifested in the shock (or blast) wave from an explosion. The variation of the overpressure with time depends on the energy yield of the explosion, the distance from the point of burst, and the medium in which the weapon is detonated. The peak overpressure is the maximum value of the overpressure at a given location and is generally experienced at the instant the shock (or blast) wave reaches that location. See *Shock wave.*

Pair Production: The process whereby a gamma-ray (or X-ray) photon, with energy in excess of 1.02 MeV in passing near the nucleus of an atom is converted into a positive electron and a negative electron. As a result, the photon ceases to exist. See *Photon.*

Photoelectric Effect: The process whereby a gamma-ray (or X-ray) photon, with energy somewhat greater than that of the binding energy of an electron in an atom, transfers all its energy to the electron which is consequently removed from the atom. Since it has lost all its energy, the photon ceases to exist. See *Photon.*

Photon: A unit or "particle" of electromagnetic radiation, carrying a quantum of energy which is characteristic of the particular radiation. If ν is the frequency of the radiation in cycles per second and λ is the wavelength in centimeters, the energy quantum of the photon in ergs is $h\nu$ or hc/λ, where h is Planck's constant, 6.62×10^{-27} erg-second and c is the velocity of light (3.00×10^{10} centimeters per second). For gamma rays, the photon energy is usually expressed in million electron volt (MeV) units (i.e., $1.24\times10^{-10}/\lambda$ where λ is in centimeters or $1.24\times10^{-2}/\lambda$ if λ is in angstroms).

Plastic Range: The stress range in which a material will not fail when subjected to the action of a force, but will not recover completely, so that a permanent deformation results when the force is removed. *Plastic deformation* refers to dimensional changes occurring within the plastic range. See *Elastic range.*

Plastic Zone: The region beyond the rupture zone associated with crater formation in which there is no visible rupture but in which the ground is permanently deformed and compressed to a higher density. See *Crater, Elastic Zone, Rupture zone.*

Plume: See *Column.*

Positive Phase: See *Shock wave.*

Precursor: An air pressure wave which moves ahead of the main blast wave for some distance as a result of a nuclear (or atomic) explosion of appropriate yield and low burst height over a heat-absorbing (or dusty) surface. The pressure at the precursor front increases more gradually than in a true (or ideal) shock wave, so that the behavior in the precursor region is said to be nonideal. See *Blast wave, Shock front, Shock wave.*

Proton: A particle of mass (approximately) unity carrying a unit positive charge; it is identical physically with the nucleus of the ordinary (light) hydrogen atom. All atomic nuclei contain protons. See *Nucleus.*

Quantum: See *Photon.*

Rad: A unit of absorbed dose of radiation; it represents the absorption of 100 ergs of nuclear (or ionizing) radiation per gram of absorbing material, such as body tissue.

Radiant Exposure: The total amount of thermal radiation energy received per unit area of exposed surface; it is usually expressed in calories per square centimeter.

Radiation: See *Ionizing Radiation, Nuclear radiation, Thermal radiation.*

Radiation Injury (or Syndrome): See *Syndrome (Radiation).*

Radioactive (or Nuclear) Cloud: An All-inclusive term for the cloud of hot gases, smoke, dust, and other particulate matter from the weapon itself and from the environment, which is carried aloft in conjunction with the rising fireball produced by the detonation of a nuclear (or atomic) weapon.

Radioactivity: The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nuclei of an (unstable) isotope. As a result of this emission the radioactive isotope is converted (or decays) into the isotope of a different (daughter) element which may (or may not) also be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (nonradioactive) end product is formed. See *Isotope.*

Radio Blackout: The complete disruption of radio (or radar) signals over large areas caused by the ionization accompanying a high-altitude nuclear explosion, especially above about 40 miles.

Radioisotope: A radioactive isotope. See *Isotope, Radioactivity.*

Radionuclide: A radioactive nuclide (or radioactive atomic species). See *Nuclide.*

Rainout: The removal of radioactive particles from a nuclear cloud by precipitation when this cloud is within a rain cloud. See *Washout.*

RBE (or Relative Biological Effectiveness): The ratio of the number of rads of gamma (or X) radiation of a certain energy which will produce a specified biological effect to the number of rads of another radiation required to produce the same effect is the RBE of the latter radiation.

Reflected Pressure: The total pressure which results instantaneously at the surface when a shock (or blast) wave traveling in one medium strikes another medium (e.g., at the instant when the front of a blast wave in air strikes the ground or a structure). If the medium struck (e.g., the ground or a structure) is more dense than that in which the shock wave is traveling (e.g., air), the reflected pressure is positive (compression). If the reverse is true (e.g., when a shock wave in the ground or water strikes the air surface) the reflected pressure is negative (rarefaction or tension).

Reflection Factor: The ratio of the total (reflected) pressure to the incident pressure when a shock (or blast) wave traveling in one medium strikes another.

Rem: A unit of biological dose of radiation; the name is derived from the initial letters of the term "roentgen equivalent man (or mammal)." The number of rems of radiation is equal to the number of rads absorbed multiplied by the RBE of the given radiation (for a specified effect). The rem is also the unit of dose equivalent, which is equal to the product of the number of rads absorbed and the "quality factor" of the radiation. See *Dose, Dose equivalent, Rad, RBE.*

Residual Nuclear Radiation: Nuclear radiation, chiefly beta particles and gamma rays, which persists for some time following a nuclear (or atomic) explosion. The radiation is emitted mainly by the fission products and other bomb residues in the fallout, and to some extent by earth and water constitutents, and other materials, in which radioactivity has been induced by the capture of neutrons. See *Fallout, Induced radioactivity, Initial nuclear radiation.*

Roentgen: A unit of exposure to gamma (or X) radiation. It is defined precisely as the quantity of gamma (or X) rays that will produce electrons (in ion pairs) with a total charge of 2.58×10^{-4} coulomb in 1 kilogram of dry air. An exposure of 1 roentgen results in the deposition of about 94 ergs of energy in 1 gram of soft body tissue. Hence, an exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue. See *Dose, Rad.*

Rupture Zone: The region immediately adjacent to the crater boundary in which the stresses produced by the explosion have exceeded the ultimate strength of the ground medium. It is characterized by the appearance of numerous radial (and other) cracks of various sizes. See *Crater, Plastic zone.*

Scaling Law: A mathematical relationship which permits the effects of a nuclear (or atomic) explosion of given energy yield to be determined as a function of distance from the explosion (or from ground zero), provided the corresponding effect is known as a function of distance for a reference explosion (e.g., of 1-kilton energy yield). See *Blast scaling law, Cube root law.*

Scattering: The diversion of radiation, includ-

ing radio, radar, thermal, and nuclear, from its orginal path as a result of interactions (or collisions) with atoms, molecules, or larger particles in the atmosphere or other medium between the source of the radiations (e.g., a nuclear explosion) and a point at some distance away. As a result of scattering, radiations (especially gamma rays and neutrons) will be received at such a point from many directions instead of only from the direction of the source.

Scavenging: The selective removal of material from the radioactive cloud from a nuclear explosion by inert substances, such as earth or water, introduced into the fireball. The term is also applied to the process of removal of fallout particles from the atmosphere by precipitation. See *Rainout, Snowout, Washout.*

Shear (Wind): Unless the term "velocity shear" is used, wind shear refers to differences in direction (directional shear) of the wind at different altitudes.

Shear Wall: A wall (or partition) designed to take a load in the direction of the plane of the wall, as distinct from lateral loads perpendicular to the wall. Shear walls may be designed to take lateral loads as well. See *Bearing wall.*

Shielding: Any material or obstruction which absorbs (or attentuates) radiation and thus tends to protect personnel or materials from the effects of a nuclear (or atomic) explosion. A moderately thick layer of any opaque material will provide satisfactory shielding from thermal radiation, but a considerable thickness of material of high density may be needed for nuclear radiation shielding. Electrically continuous housing for a facility, area, or component, attenuates impinging electric and magnetic fields.

Shock Front (or Pressure Front): The fairly sharp boundary between the pressure disturbance created by an explosion (in air, water, or earth) and the ambient atmosphere, water, or earth, respectively. It constitutes the front of the shock (or blast) wave. See *Shock wave.*

Shock Wave: A continuously propagated pressure pulse (or wave) in the surrounding medium which may be air, water, or earth, initiated by the expansion of the hot gases produced in an explosion. A shock wave in air is generally referred to as a *blast wave,* because it resembles and is accompanied by strong, but transient, winds. The duration of a shock (or blast) wave is distinguished by two phases. First there is the *positive (compression) phase* during which the pressure rises very sharply to a value that is higher than ambient and then decreases rapidly to the ambient pressure. The positive phase for the dynamic pressure is somewhat longer than for overpressure, due to the momentum of the moving air behind the shock front. The duration of the positive phase increases and the maximum (peak) pressure decreases with increasing distance from an explosion of given energy yield. In the second phase, the *negative (suction, rarefaction, or tension) phase,* the pressure falls below ambient and then returns to the ambient value. The duration of the negative phase may be several times the duration of the positive phase. Deviations from the ambient pressure during the negative phase are never large and they decrease with increasing distance from the explosion. See *Dynamic pressure, Overpressure.*

Skyshine: Radiation, particularly gamma rays from a nuclear explosion, reaching a target from many directions as a result of scattering by the oxygen and nitrogen in the intervening atmosphere.

Slant Range: The distance from a given location, usually on the earth's surface, to the point at which the explosion occurred.

Slick: The trace of an advancing shock wave seen on the surface of reasonably calm water as a circle of rapidly increasing size apparently darker than the surrounding water. It is observed, in particular, following an underwater explosion. See *Crack.*

Snowout: The removal of radioactive particles from a nuclear cloud by precipitation when this cloud is within a snow cloud. See *Rainout.*

Spray Dome: See *Dome.*

Stopping Altitude: The altitude in the vicinity of which a specified ionizing radiation coming from above (e.g., from a high-altitude nuclear explosion) deposits most of its energy by absorption in the atmosphere. The stopping altitude varies with the nature of the ionizing radiation.

Stratosphere: A relatively stable layer of the atmosphere between the tropopause and a height of about 30 miles in which temperature changes very little (in polar and temperate zones) or increases (in the tropics) with increasing altitude. In the stratosphere clouds of water never form and there is practically no convection. See *Tropopause, Troposphere.*

Subsurface Burst: See *Underground burst, Underwater burst.*

Supercritical: A term used to describe the state of a given fission system when the quantity of fissionable material is greater than the critical mass under the existing conditions. A highly supercritical system is essential for the produc-

tion of energy at a very rapid rate so that an explosion may occur. See *Critical mass.*

Surface Burst: The explosion of a nuclear (or atomic) weapon at the surface of the land or water at a height above the surface less than the radius of the fireball at maximum luminosity (in the second thermal pulse). An explosion in which the weapon is detonated actually on the surface (or within $5W^{0.3}$ feet, where W is the explosion yield in kilotons, above or below the surface) is called a *contact surface burst* or a *true surface burst.* See *Air burst.*

Surface Zero: See *Ground zero.*

Surge (or Surge Phenomena): See *Base surge.*

Survey Meter: A portable instrument, such as a Geiger counter or ionization chamber, used to detect nuclear radiation and to measure the dose rate. See *Monitoring.*

Syndrome, Radiation: The complex of symptoms characterizing the disease known as *radiation injury,* resulting from excessive exposure of the whole (or a large part) of the body to ionizing radiation. The earliest of these symptoms are nausea, vomiting, and diarrhea, which may be followed by loss of hair (epilation), hemorrhage, inflammation of the mouth and throat, and general loss of energy. In severe cases, where the radiation exposure has been relatively large, death may occur within 2 to 4 weeks. Those who survive 6 weeks after the receipt of a single dose of radiation may generally be expected to recover.

Tenth-Value Thickness: The thickness of a given material which will decrease the intensity (or dose) of gamma radiation to one-tenth of the amount incident upon it. Two tenth-value thicknesses will reduce the dose received by a factor of 10×10, i.e., 100, and so on. The tenth-value thickness of a given material depends on the gamma-ray energy, but for radiation of a particular energy it is roughly inversely proportional to the density of the material.

Tests: See *Nuclear tests.*

Thermal Energy: The energy emitted from the fireball (or other heated region) as thermal radiation. The total amount of thermal energy received per unit area at a specified distance from a nuclear (or atomic) explosion is generally expressed in terms of calories per square centimeter. See *Radiant exposure, Thermal radiation, Transmittance, X-ray pancake.*

Thermal Energy Yield (or Thermal Yield): The part of the total energy yield of the nuclear (or atomic) explosion which is received as thermal energy usually within a minute or less. In an air burst, the *thermal partition* (i.e., the fraction of the total explosion energy emitted as thermal radiation) ranges from about 0.35 to 0.45. The trend is toward the smaller fraction for low yields or low burst heights and toward the higher fraction at high yields or high bursts. Above 100,000 feet burst height, the fraction increases from about 0.45 to 0.6, and then decreases to about 0.25 at burst altitudes of 160,000 to 260,000 feet. At still greater burst heights, the fraction decreases rapidly with increasing altitude.

Thermal Radiation: Electromagnetic radiation emitted (in two pulses from an air burst) from the fireball as a consequence of its very high temperature; it consists essentially of ultraviolet, visible, and infrared radiations. In the early stages (first pulse of an air burst), when the temperature of the fireball is extremely high, the ultraviolet radiation predominates; in the second pulse, the temperatures are lower and most of the thermal radiation lies in the visible and infrared regions of the spectrum. For high-altitude bursts (above 100,000 feet), the thermal radiation is emitted as a single pulse, which is of short duration below about 270,000 feet but increases at greater burst heights.

Thermal X-Rays: The electromagnetic radiation, mainly in the soft (low-energy) X-ray region, emitted by the extremely hot weapon residue in virtue of its extremely high temperature; it is also referred to as the *primary thermal radiation.* It is the absorption of this radiation by the ambient medium, accompanied by an increase in temperature, which results in the formation of the fireball (or other heated region) which then emits thermal radiation. See *Weapon residue, X-ray pancake, X-rays.*

Thermonuclear: An adjective referring to the process (or processes) in which very high temperatures are used to bring about the fusion of light nuclei, such as those of the hydrogen isotopes (deuterium and tritium), with the accompanying liberation of energy. A *thermonuclear bomb* is a weapon in which part of the explosion energy results from thermonuclear fusion reactions. The high temperatures required are obtained by means of a fission explosion. See *Fusion.*

TNT Equivalent: A measure of the energy released in the detonation of a nuclear (or atomic) weapon, or in the explosion of a given quantity of fissionable material, expressed in terms of the mass of TNT which would release the same amount of energy when exploded. The TNT equivalent is usually stated in kilotons or megatons. The basis of the TNT equivalence is that the

explosion of 1 ton of TNT is assumed to release 10^9 calories of energy. See *Kiloton, Megaton, Yield.*

Transmittance (Atmospheric): The fraction (or percentage) of the thermal energy received at a given location after passage through the atmosphere relative to that which would have been received at the same location if no atmosphere were present.

Triple Point: The intersection of the incident, reflected, and merged (or Mach) shock fronts accompanying an air burst. The height of the triple point above the surface (i.e., the height of the Mach stem) increases with increasing distance from a given explosion. See *Mach stem.*

Tritium: A radioactive isotope of hydrogen, having a mass of 3 units; it is produced in nuclear reactors by the action of neutrons on lithium nuclei.

Tropopause: The imaginary boundary layer dividing the stratosphere from the lower part of the atmosphere, the troposphere. The tropopause normally occurs at an altitude of about 25,000 to 45,000 feet in polar and temperate zones, and at 55,000 feet in the tropics. See *Stratosphere, Troposphere.*

Troposphere: The region of the atmosphere, immediately above the earth's surface and up to the tropopause, in which the temperature falls fairly regularly with increasing altitude, clouds form, convection is active, and mixing is continuous and more or less complete.

True Surface Burst: See *Surface Burst.*

2 *W* Concept: The concept that the explosion of a weapon of energy yield W on the earth's surface produces (as a result of reflection) blast phenomena identical to those produced by a weapon of twice the yield (i.e., $2W$) burst in free air (i.e., away from any reflecting surface).

Ultraviolet: Electromagnetic radiation of wave length between the shortest visible violet (about 3,850 Angstroms) and soft X-rays (about 100 Angstroms).

Underground Burst: The explosion of a nuclear (or atomic) weapon with its center more than $5W^{0.3}$ feet, where W is the explosion yield in kilotons, beneath the surface of the ground. See also *Contained underground burst.*

Underwater Burst: The explosion of a nuclear (or atomic) weapon with its center beneath the surface of the water.

Visibility Range (or Visibility): The horizontal distance (in kilometers or miles) at which a large dark object can just be seen against the horizon sky in daylight. The visibility is related to the clarity of the atmosphere ranging from 170 miles (280 kilometers) for an exceptionally clear atmosphere to 0.6 mile (1.0 kilometer) or less for dense haze or fog. The visibility on an average clear day is taken to be 12 miles (19 kilometers).

Washout: The removal of radioactive particles from a nuclear cloud by precipitation when this cloud is below a rain (or snow) cloud. See *Rainout, Snowout.*

Weapon, Atomic (or Nuclear): See *Nuclear weapon.*

Weapon Debris: The highly radioactive material, consisting of fission products, various products of neutron capture, and uranium and plutonium that have escaped fission, remaining after the explosion.

Weapon Residue: The extremely hot, compressed gaseous residues formed at the instant of the explosion of a nuclear weapon. The temperature is several tens of million degrees (Kelvin) and the pressure is many millions of atmospheres.

Wilson Cloud Chamber: See *Condensation cloud.*

Worldwide Fallout: See *Fallout.*

X-Ray Pancake: A layer of air, about 30,000 feet thick at a mean altitude of roughly 270,000 feet, which becomes incandescent by absorption of the thermal X rays from explosions above 270,000 feet altitude. The heated air emits thermal radiation (of longer wavelengths) in a single pulse of several seconds duration. See *Thermal radiation, Thermal X rays.*

X Rays: Electromagnetic radiations of high energy having wavelengths shorter than those in the ultraviolet region, i.e., less than 10^{-6} cm or 100 Angstroms. Materials at very high temperatures (millions of degrees) emit such radiations; they are then called thermal X rays. As generally produced by X-ray machines, they are bremsstrahlung resulting from the interaction of electrons of 1 kilo-electron volt or more energy with a metallic target. See *Bremsstrahlung, Electromagnetic radiation, Thermal X-rays.*

Yield (or Energy Yield): The total effective energy released in a nuclear (or atomic) explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion. The total energy yield is manifested as nuclear radiation, thermal radiation, and shock (and blast) energy, the actual distribution being dependent upon the medium in which the explosion occurs (primarily) and also upon the type of weapon and the time after detonation. See *TNT equivalent.*

Guide to SI Units

The International System of Units (SI) has been adopted in the publications of several scientific and technical societies in the United States and other countries. It is expected that in due course that these units will come into general use. The SI units and conversion factors applicable to this book are given below. For further information, see "The International System of Units (SI)," National Bureau of Standards Special Publication 330, U.S. Government Printing Office, Washington, D.C. 20402.

Base Units

Quanity	SI Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature*	kelvin	K

*(Temperatures may also be expressed in °C)

Derived Units

Quantity	Unit	Symbol	Formula
Force	newton	N	$kg \cdot m/s^2$
Pressure	pascal	Pa	N/m^2
Energy, heat, etc.	joule	J	N•m
Power	watt	W	J/s
Frequency	hertz	Hz	1 (cycle)/s
Radioactivity	becquerel	Bq	1 (decay)/s
Absorbed dose	gray	Gy	J/kg

Conversion Factors

To convert from:	to:	multiply by:
Length, Area, Volume		
inch	meter (m)	2.540×10^{-2}
foot	meter (m)	0.3048
yard	meter (m)	0.9144
mile	kilometer (km)	1.609
centimeter	meter (m)	10^{-2}
angstrom	meter (m)	10^{-10}
square inch	$meter^2$ (m^2)	6.452×10^{-4}
square foot	$meter^2$	9.290×10^{-2}
square mile	$kilometer^2$ (km^2)	2.590
cubic foot	$meter^3$ (m^3)	2.832×10^{-2}

Mass

pound	kilogram (kg)	0.4536
ounce	kilogram (kg)	2.835×10^{-2}

Energy

calorie	joule (J)	4.187
erg	joule (J)	1.00×10^{-7}
MeV	joule (J)	1.602×10^{-13}
ton (TNT equivalent)	joule (J)	4.2×10^{9}

Miscellaneous

density (lb/ft^3)	kg/m^3	1.602×10
pressure (psi)	pascal (Pa)	6.895×10^{3}
radiant exposure (cal/cm^2)	J/m^2	4.187×10^{4}
speed (ft/sec)	m/s	0.3048
speed (miles/hour)	m/s	0.4470
dose (rads)	gray (Gy)	1.00×10^{-2}
dose rate (rads/hour)	Gy/s	2.778×10^{-6}
curie	becquerel (Bq)	3.700×10^{10}

The only multiples or submultiples of SI to which appropriate prefixes may be applied are those represented by factors of 10^n or 10^{-n} where n is divisible by 3. Thus, kilometer (10^3m or 1 km), millimeter (10^{-3}m or 1 mm), and micrometer (10^{-6}m or 1 μm). The centimeter and gram are not used in the SI system, but they are included in the metric system proposed for adoption in the United States.

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