Chapter

6

"History of 10,000 ton gadget": Critical explanation and analysis

The Document.

The complexities of the "History of 10,000 ton gadget" will present no obstacle to readers whose interest and study have been directed to mathematics and physics, but for those whose interests have inclined to other areas of accomplishment an introduction to the terms and relationships of which the "History" is constructed will be helpful. The first document term that requires definition appears in the legend entry for Step 6 of the document at the left margin: isothermal sphere.

Isothermal sphere.

Much of the vocabulary of the physical sciences consists of ancient Greek and Latin words that have very specific meaning handed down without change for two thousand years and longer. But if a descriptive word required in a modern scientific context is not available from the Greek or Latin an appropriately descriptive word may be invented for modern use, a word that can combine defined Greek or Latin words or word elements. *Isotherme* is a French word that means "having the same temperature," but the French is a combination of the Greek *isos*—meaning same or equal—and the Greek *therme,* which means heat; *therme* is itself derivative of the Greek word that means hot, *thermos.* An isothermal sphere, in the context of the "History of 10,000 ton gadget," refers to one of the earliest phenomena of a nuclear explosion noted in Step 6 of the "History." The isothermal sphere is a sphere of very hot gases of practically equal temperature throughout.

At the periphery of the isothermal sphere a very powerful initial shock wave is formed. The shock wave at the front of the isothermal sphere immediately propagates radially from the stable isothermal sphere and produces the intensely luminous ball of fire (fireball) that is typical of a nuclear explosion; from the periphery of the fireball a radially propagated energetic blast wave emerges. The isothermal sphere makes no significant contribution to the immediate military effects that result from the detonation of a 10 kt atomic bomb except that the isothermal sphere is so very hot that any material substance within 126 meters of the detonation will be converted to vapor.

Destruction of a military target by a nuclear fission weapon is comprehended mainly by the effects of a powerful blast wave in air but the more distant military consequences of a nuclear explosion can be significantly augmented by the thermal (heat) radiations emitted by the fireball that emerges from the isothermal sphere. Furthermore, accurate anticipation of the thermal characteristics and physical behavior of an isothermal sphere as it endures and rises above a nuclear explosion can be useful as a basis to predict the military and environmental effects of radioactive fallout since most of the dangerous fission byproducts of an atomic bomb detonation are concentrated in the isothermal sphere. The changing radius, pressure and temperature of the isothermal sphere permit calculation of the height the radioactive debris contained by the isothermal sphere will rise above the explosion, and thereby to predict how the radioactive debris will probably be precipitated locally and distantly according to the atmospheric conditions and winds prevailing at the maximum altitude to which the radioactive materials will be raised by the residuum of the very hot isothermal sphere.

Scientific abbreviations used in the document.

The scientific abbreviations written along the top line of the “History” identify the type of information that appears in the columns beneath those abbreviations; for most readers those abbreviations require explanation.

(t Millisec). The time (t) required to complete each of the 11 Steps identified in the legend is expressed in milliseconds (1 second is equal to 1,000 milliseconds). The ancient Greeks divided the day into 24 hours but why, in the obscure past, the hour was divided into 60 minutes and the minute divided into 60 seconds, is unknown. Speculation proposes that the number 60 was taken for those divisions because that number has the mathematical facility of "harmony and elegance"; 60 is divisible by a large number of small numbers without remainders: 1, 2, 4, 5, 6, 10, 12, 15, 20, 30. Time is not an absolute constant but is affected by motion and gravity. In an experiment conducted in 1971 atomic clocks were carried on two high-speed aircraft. One traveled eastward in the rotational direction of the Earth, and one westward. After the flight, the onboard clocks were found to have either lost or gained time (relative to a ground-based atomic clock) depending on their direction of travel, thus confirming a predicted effect of relativity.

(R Meters). R is the symbol that denotes radius, a line segment that joins the center of a circle or sphere with any point on the circumference. The diameter of a circle or sphere is twice the radius. The distance from the original position of the exploded bomb system to the unobstructed periphery of the effects of the explosion is defined as the radius (R) of the explosion and the unit of measure is the meter (m). The meter was redefined in 1960, after much dispute, as the length equal to 1,650,763.73 wavelengths of the orange-red radiation of the krypton 86 isotope in a vacuum. The customary U.S. measure of one foot is equal to 0.3084 meter and the U.S. measure of one yard, three feet, is thus slightly less than one meter. At the moment of detonation the bomb system is .70 meter radius. Completion of each Step in the progression of the explosion modeled by the "History" has increased the radius from the detonation point at which the expanding effects of the explosion are distinct.

($\overset{o}{R}$ ***m/sec).*** The small dot above the R symbol for radius denotes that the changes of radial distance entered in the previous column of data will be considered. In this column the speed at which the radius of the system changes will be calculated as the measure of radial change (meters) relative to the time (seconds) that comprehends that change expressed as meters per second (m/s). Radial change within the bomb system, measured in meters, is initially small. When the bomb is detonated the radius of the system is immediately decreased by implosion and compression from .70 meter to .23 meter; that change of radius is accomplished in .067 millisecond and is therefore a very rapid change, accomplished at the rate of 7 x 10^5 meters per second. Following the initial speed and reduction of the bomb system radius by implosion, the radius of the bomb system begins to expand in explosion, but the rate of expansion is slower than the initial rate of change that was accomplished by the originating implosion.

(P bars). P is the symbol employed by physicists to designate pressure. A barometer measures and displays atmospheric pressure; the unit of measure that expresses atmospheric pressure is the bar—derived from the Greek word *baros,* which means weight. One bar is the unit of pressure equal to the pressure of the weight of the atmosphere exerted upon the surface of the Earth at sea level, 14.7 pounds per square inch (psi). The figures in this column report the different air pressures that accompany the explosion at different times and corresponding distances. As the shock wave at the front of the isothermal sphere separates from the isothermal sphere and moves out from the center of the explosion as a blast wave in air, the pressure at the blast wave front diminishes. The initial energy of the blast wave is progressively distributed to a larger wave front area as the circumference of the (spherical) blast wave front expands from its origin; therefore the pressure at any point on the expanding blast wave front is diminished. The pressure, or energy, of the blast wave front at increasing distance is also diminished because energy of the blast wave is expended to overcome the resistance of the atmospheric gases and suspended particulate matter through which the blast wave expands.

(T). The temperature (T) of the explosion at various times is expressed in degrees Kelvin (°K), a temperature scale in which absolute 0 equals -273.16° on the Celsius (C) temperature scale. The Celsius temperature scale registers the freezing point of pure water as 0°C and the boiling point of pure water under normal atmospheric pressure as 100°C. The Celsius scale in popular use is still frequently called the Centigrade scale but in 1948 by international agreement the centigrade scale was officially designated by the name of the man who devised it, the Swedish astronomer Anders Celsius (1701-1744). The Fahrenheit scale, generally used in the United States to report weather temperatures, is named for its inventor Gabriel Daniel Fahrenheit (1686-1736), a German physicist who lived in Holland. For scientific purposes the Fahrenheit scale is cumbrous because it sets the freezing point of a salt-water mixture, rather than pure water, as 0°F and the boiling point of a salt-water mixture at 212°F under normal atmospheric conditions. For general weather reporting purposes when the temperature in Phoenix, Arizona, is 121°F most Americans know it's very hot in Phoenix; and when it's -60°F in Fargo, North Dakota, most Americans know it's really cold in Fargo. A temperature of 60°F converts to 15.555°C and 288.655°K.

The subscripts: s, i and o used in the document.

We notice that the first two data column headings, P bars and T (°K), that appear along the top line of the "History of 10,000 ton gadget," which we have reviewed, each carries the subscript, s: P_s bars and T_s (°K). To the right of those columns are four data column headings that carry the subscript, i: R_i Meters, P_i bars, T_i (°K), and the data column to the right of T_i (°K), which introduces the subscript, o: p_i/p_o.

The values presented in the columns identified with the subscript, s, are the pressure and temperature of the shock wave (s), through Step 6. At the beginning of Step 7 the shock wave has hydrodynamically separated from the isothermal sphere front and has become the expanding blast wave. For the purposes of this document the changing pressures and temperatures of the expanding blast wave, beginning in Step 7, are represented as extensions of the shock wave (s). The values calculated in the four columns identified with the subscript, i, represent the changing radius and pressure, and the estimated temperature and estimated gas density variations of the isothermal sphere (i) as it decays.

p_i/p_o.

The descriptive notation in the data column heading p_i/p_o seems to be the lower case letter p, but is the 17th letter of the Greek alphabet, rho, in the lower case, ρ. Rho, in the lower case, is the symbol used in physics to represent air density and is used to express the concept of the aggregate mass of molecules per volume of air, composed mostly of nitrogen (78 per cent) and oxygen (21 per cent). Estimations of the changing density of the gas present in the isothermal sphere were necessary to allow quantitative prediction of the characteristics of the shock wave that would develop from the isothermal sphere in the course of the explosion of a 10,000 ton gadget.

The variable properties of a gas are the gas pressure (P), temperature (T), mass (M), the volume (V) that contains the gas, and the gas density (p). These variables are related to one another, and the values of these properties determine the state of the gas and its thermodynamic characteristics.

Thermodynamics is the branch of physics which deals with the energy and work of a system and was born in the 19th century as scientists were first discovering how to build and operate steam engines. An atomic bomb is an engine that does work. The energy of a nuclear explosion is the product of nuclear fission, and the work of a nuclear bomb explosion is the application of that energy to military purposes, principally as the energy of the shock and blast wave in air. The changing density of the isothermal sphere gas significantly affects the characteristics of the shock wave that emerges from the isothermal sphere.

The characteristics and thermodynamic properties of air at sea level are often employed as a comparative standard for studies that describe the characteristics and thermodynamics of gas behavior in conditions that differ from sea level. The standard density of air at sea level is 1.229 kg/m^3 at 15°C and pressure 101.3 k-pascals (metric), or .00237 $slug/ft^3$ at 59°F and pressure 14.7 lbs/in^2 (English). The Greek letter rho in the lower case (and sometimes, r) is the symbol which specifically designates air density; when used with the subscript, o, the density of air at sea level is represented, p_o.

The data in this column estimate the changing density of the isothermal sphere gas. The isothermal sphere variables of pressure and radius, and therefore volume, were calculated with reasonable certainty as they would change during specific intervals of time. From those calculated values of pressure and volume, the temperature and density of the isothermal sphere gas could be generalized, but with a considerable factor of uncertainty because the necessary solving calculations were so complex. The data in the T_i (°K) column and the data in the p_i/p_o column, which are derived from the calculated pressure and volume of the isothermal sphere, "may be wrong by a factor of 2."

In their 18 July 1945 Los Alamos Report 296, "Opacity and thermodynamic properties of air at high temperatures," Joseph Hirschfelder and John L. Magee wrote, "It seems to us highly desirable that accurate tables of the thermodynamical properties of air be computed [for the high temperatures involved in a nuclear explosion]. This project would be easy to set up but the actual computations are sufficiently difficult that it would require approximately ten people for one year."

From Step 3 through Step 5 of the "History of 10,000 ton gadget" the density of the exploding bomb system declines from an initial density equal to the interior of the Sun to a value that, in Step 6, is usefully comparable to the density of air at sea level. In Step 6, when the radius of the isothermal sphere is 10.50 meters and the pressure is 16,160 bars, the density of the isothermal sphere gas, p_i, is estimated to have declined to 1.48 the density of air at sea level, p_o. Through the process of Step 7, as the radius of the isothermal sphere and fireball expand and their respective pressures decrease, the density of the isothermal sphere gas diminishes radically. In Step 8, when the fireball and isothermal sphere are fully expanded, and the pressure in each has declined to approximately 2 bars and 1 bar, the density of the isothermal sphere gas is extremely low: .0015 the standard density of air at sea level.

Illumination.

Representations in this column estimate the intensity of unobstructed light produced and perceptible at 10,000 yards consequent to the explosion of a 10 kt atomic bomb in the lower atmosphere. In Step 6 the first flash of brilliant light emitted by the isothermal sphere, perceived at 10,000 yards, is calculated to be 36 times the illumination of the Sun received directly on one square foot of Earth's surface at noon on a clear day in the middle northern latitudes at the summer solstice. All photometric concepts are based on the idea of a standard candle flame. Ordinary outdoor scenes in daylight have an average luminance of several hundred candles per square foot. More technically, when light falls upon a surface it produces illumination (illuminance); the usual measure of illuminance is the foot-candle, which is one lumen falling on each square foot of receiving surface. The lumen is defined as the amount of luminous flux radiated by a small point-source of one candle power into a cone having a solid angle of one steradian. The metric scale measure of illuminance is the lux; for conversion purposes 1 foot-candle is equal to 10.76 lux. A good discussion of steradians, or square radians, is found at:

http://www.physlink.com/ae174.cfm

Type of radiation.

Radiation, as that term is used in physics, denotes the emission or propagation of waves or particles including light, sound, radiant heat and the particles emitted by radioactivity either directly from unstable atomic nuclei or as a consequence of a nuclear reaction. A black body is an idealized radiation absorber and emitter that provides a useful concept to determine the non-radioactive radiation emissions of a nuclear fireball and isothermal sphere. Although in fact only a reasonable approximation, the assumption of black body behavior for the fireball and isothermal sphere provides an adequate model from which to calculate fireball and isothermal sphere thermal radiation and visible light characteristics. For a black body the distribution of radiant energy over the spectrum can be related to the surface temperature by Planck's radiation equation. From the Planck equation it is possible to calculate the rate of energy emission of a black body for a given wavelength. The Stefan-Boltzmann law dictates that the total amount of energy radiated per square centimeter per second by a black body in all directions in one hemisphere is related to the absolute temperature of the black body. The total radiant energy emitted by a fireball of any radius, and the total radiant energy emitted by an isothermal sphere of any radius can be readily calculated, as well as the spectral composition of that energy at any black body temperature.

Thermal radiation received at a distance from a nuclear explosion is fairly characteristic of a black body at a temperature of about 6,000 to 7,000°K, and at any distance is inversely proportional to the square of the distance from the blast point, but atmospheric scattering and absorption markedly decrease the ultraviolet with increasing distance. Assuming the black body characteristics of the fireball and isothermal sphere, the predicted temperature variations over time manifest by those radiant sources permit anticipation of the military effects resulting from thermal radiation; the intensity and spectral distribution of visible light emitted by a nuclear explosion in air can also be known.

One of the important differences between a nuclear and a conventional high explosive (HE) weapon is the large proportion of the energy of a nuclear explosion released in the form of thermal radiation that can cause fire damage and personal injury. The military consequences of thermal radiation can be important at greater distances than the destruction and damage caused by the blast wave. Ultraviolet, visible and infrared radiation from the fireball traveling with the velocity of light arrives at every distance from the explosion in advance of the blast wave. Local fires ignited by those prompt thermal radiations can become firestorms in forests, fields and through large urban areas when the blast wave wind arrives and creates the conditions of a blast furnace among those discrete fires, as occurred at Hiroshima (12.5 kt) and Nagasaki (22 kt). For those explosions, respectively 1,670 and 1,640 feet above the ground, solid materials on the ground immediately below the burst attainted surface temperatures of 3,000° to 4,000°C (5,400° to 7,200°F); solid materials at 3,200 feet (.61 mile) reached 1,800°C (3,270°F). Persons exposed to a flux of heat at those temperatures will not survive.

In development of the World War II nominal 10 kt atomic bomb the forecast of its military consequences included a general determination of the distances at which materials of different sear and combustion temperatures in a target area would be damaged or ignited by thermal radiations emitted by the fireball. Ignition or heat damage would depend on the spectrum and rate of thermal energy emission by the fireball, and the corresponding spectrum and rate of thermal energy absorption of materials at different distances. Some 35 per cent of the total energy of a nuclear fission air burst in the lower atmosphere is thermal radiation energy, of which the fireball is the principal source, with some contribution from the isothermal sphere from which the fireball emerges.

Calculation of the intensity of light that would be radiated by the detonation of the nominal 10 kt atomic bomb, and the spectral character of that light, was necessary to know the hazard of transient or permanent damage that direct or indirect observation of that light by observers positioned 10,000 yards from the explosion would experience; specifically, how the cornea, lens and retina of the eye might be damaged by the intensity and spectral character of that light. Scientific and military observers of the weapon test to be conducted at Trinity site were expected to be located 10,000 yards from ground zero. An additional important calculation was to know with certainty the distance from the explosion, and at what times, the crew of an aircraft that would deliver an atomic bomb in combat would require eye protection to preclude temporary or permanent blindness by exposure to that initial flash of light.

The spectrum and intensity of light received at 10,000 yards at .182 millisecond from the isothermal sphere behaving as a black body at 82,000°K surface temperature is estimated to be 36 suns—the initial flash of intense light. Formation of the fireball one-half millisecond later, at .628 millisecond, radiates as a black body of 30,300°K, which reduces the illumination received at 10,000 yards to 29 suns.

Following the initial one-half millisecond intense flash of light from the detonation of the 10,000 ton gadget described by the "History" the luminance of the explosion perceived at 10,000 yards immediately diminishes to 3.3 suns and then to 0.14 sun. However, at 38 milliseconds the luminance increases to 0.80 sun, and at approximately (~) 160 milliseconds the luminance increases to 1 sun. The luminance of 1 sun is sustained for 2 milliseconds before decreasing to 0.10 sun and finally declining to 0.001 sun at 200,000 milliseconds.

Timeline of a nuclear explosion described by the "History."

Step 1.

At the moment the detonation commences the time is 0 milliseconds. The radius of the gadget is .70 meter which includes the plutonium core, tamper, and mantle of molded HE blocks surrounding the tamper. The .70 meter radius does not include the bulky ballistic case that accommodated the gadget when adapted to combat delivery. The pressure of the system is the ambient atmospheric pressure at sea level, 1 bar.

Step 2.

Much less than one millisecond (.067 millisecond) is required for the detonation wave to propagate entirely through the HE blocks that enclose the tamper and core to reach the depleted uranium tamper interface. The radius has been reduced from .70 meter to .23 meter. The HE mantle was anticipated to be .47 meter thick. The explosive blocks of which the mantle was composed and which detonated the Trinity/Nagasaki weapon were not fabricated in their final and optimal form until late spring 1945, but the quantity of HE necessary to impart the needed energy of implosion was known by late 1944, so the indicated .47 meter thickness of the HE blocks is probably close to the actual thickness of the HE mantle of the gadget detonated at Trinity and the weapon detonated at Nagasaki. The change of radius was .47 meter, the lapsed time .067 millisecond, which gives an average speed for the detonation wave of 7×10^5 meters per second. The speed of radial change is constant through Step 3. The pressure of the system in Steps 2-4 is not calculated but would be equal to the interior pressure of the Sun.

Step 3.

At the end of .127 millisecond the imploding detonation wave has fully compressed the tamper and interior plutonium core (active), theoretically to 0 meter radius. The urchin has been vaporized and the neutrons produced by the urchin have provided a sufficiently large number of neutrons throughout the compressed plutonium core to efficiently initiate and sustain a comprehensive nuclear fission chain reaction. The temperature of the fully compressed system has reached 58,000,000°K.

Step 4.

At .128 milliseconds the heat and pressure of the fissioning plutonium core have expanded the core to .18 meter at an average rate of 2×10^5 meters per second. The highly compressed tamper, which has imparted its pressure to the core, has rebounded to a considerably less compressed state and for a brief moment resists and contains expansion of the core. During that moment of containment the multiplication of neutrons resulting from the fission process has induced fission as completely as will be achieved before the shock wave of the fissioning core impacts the tamper. The tamper under the influence of the shock wave is disintegrated and vaporized. The fissioning core expands beyond the radius at which the nuclear chain reaction will continue and is essentially complete. Much of the energy of the system has devolved to the energy of the shock wave and X radiations; the temperature has consequently dropped to 7,600,000°K.

Step 5.

At .132 milliseconds the shock wave has passed through the radial space occupied by the HE mantle prior to detonation and has disintegrated and vaporized the gadget's steel encasement. The radius of the exploding system has increased to .92 meter at an average speed of 2×10^5 meters per second. The pressure of the system is now calculated to be 29,000,000 bars. The temperature of the system has dropped to 760,000°K which accounts the conversion of thermal energy to the kinetic energy of the shock wave and energy radiated as X rays.

Step 6.

At .182 millisecond the isothermal sphere is formed with a radius of 10.50 meters; the speed of radial expansion has diminished to 3.6 x 10^4 meters per second. The shock wave has hydrodynamically separated from the isothermal sphere to become the blast wave. The legend entry for Step 6 reports that "Radiation squirts out," which is a picturesque but not scientifically precise description of the massive emission of visible, thermal, X ray, gamma and neutron radiation from the isothermal sphere. The pressure of the isothermal sphere is 16,160 bars and the temperature that of a black body at 82,000°F, cut off at 10,000 yards in the ultraviolet by atmospheric absorption. The momentary luminance of the isothermal sphere received at 10,000 yards is estimated to be 36 suns.

Step 7.

Summary.

During the approximately 38 milliseconds of the explosion described in Step 7 the blast wave, which has propagated and separated from the isothermal sphere, expands into the atmosphere and the fireball forms. The radius of the fireball increases; its pressure and temperature diminish. The radius of the isothermal sphere increases; its temperature and pressure diminish. The pressure of the blast wave at the fireball front is greater than the pressure of the isothermal sphere throughout Step 7; the temperature of the fireball front is much less than the temperature of the isothermal sphere throughout Step 7. However, the temperature of the fireball is sufficiently high that all the radiations of the isothermal sphere, which is enclosed within the fireball, are confined and blocked from emission and view by the thermal opacity of the fireball during most of the period described by Step 7.

Blast wave and fireball during Step 7.

The radius of the blast wave front, which is still coincident with the fireball front, increases from 21 meters to 126 meters, a factor of 6. The rate of expansion rapidly diminishes from 1.7 x 10^4 to 1,300 meters per second. The pressure decreases from 3,360 bars to 20 bars, a factor of 168. The fireball surface temperature decreases from 30,300° to 500°K, a factor of 60.5.

At the beginning of Step 7 the fireball radiates as a black body of 30,300°K and is sufficiently hot to be essentially opaque to all radiations of the interior isothermal sphere. The initial luminance of the explosion perceived at 10,000 yards in Step 7 is produced from the surface of the fireball and decreases as the fireball cools and the luminance decreases from 29 suns to 0.14 sun at 14.280 milliseconds. However, at 14.280 milliseconds the temperature of the fireball (1,500°K) has cooled sufficiently to become transparent to most of the isothermal sphere radiations; in consequence, at the end of Step 7 the luminance of the much hotter isothermal sphere has increased the perceived luminance from 0.14 sun at 14.280 milliseconds to 0.80 sun.

Isothermal sphere during Step 7.

The radius of the isothermal sphere increases from 15.70 to 94.60 meters, a factor of 6; the radius of the fireball has also increased by a factor of 6. The initial pressure of the isothermal sphere in Step 7 is 2,020 bars, which is one-third less than the initial Step 7 fireball pressure of 3,360 bars. By the end of Step 7 the pressure of the isothermal sphere is reduced to 9.4 bars, a factor of 215, and compares to the final Step 7 pressure of the fireball of 20 bars. The initial temperature of the isothermal sphere in Step 7 is 67,000°K. By the end of Step 7 the temperature of the isothermal sphere has been halved to 33,000°K. The initial Step 7 temperature of the fireball, in comparison, has been reduced from 30,300°K to 500°K, a reduction factor of 61. The isothermal sphere at the end of Step 7 is 66 times hotter than the fireball surface because the opaque fireball had briefly blocked most energy-reducing radiations from the isothermal sphere; the heat and temperature of the isothermal sphere are correspondingly maintained.

Black body radiation during Step 7.

At the commencement of Step 7 the isothermal sphere radiations have been cut off by the fireball which is sufficiently hot at 30,300°K to have become opaque to the intensely hotter central isothermal sphere. The radiations of the explosion at .628 millisecond are essentially those of the 30,300°K fireball, a black body of 30,000°K. When the fireball temperature is diminished to 8,300°K at 2.774 milliseconds the radiations of the explosion continue to be essentially those of the fireball, a black body of 8,000°K. However, at 14.280 milliseconds the temperature of the fireball has declined to 1,500°K and is now partially transparent to the 39,000°K black body isothermal sphere radiations. In consequence, the radiations of the explosion are of a black body of approximately 4,500°K, hotter than the 1,500°K fireball but cooler than the 39,000°K isothermal sphere. As the fireball continues to cool and becomes progressively more transparent to the isothermal sphere radiations the black body temperature of the explosion increases to 6,000°K at the end of Step 7.

Step 8.

At approximately 160 milliseconds the fireball is fully expanded to approximately 220 meters radius. The rate of radial change is slowed to 500 meters per second; the pressure at the fireball front is now only approximately 2 bars. The energy of the fireball has been dissipated by radiation emissions and cooling by expansion, and immediately the 20,000°K isothermal sphere becomes the dominant radiating body and is perceived at 10,000 yards with the luminance of 1 sun and radiating as a black body of approximately 10,000°K. The maximum radius of the isothermal sphere, 155 meters, is formed coincidentally with the maximum radius of the fireball, approximately 220 meters. The isothermal sphere then visually appears as an intensely hot, brilliant spherical core within the larger fireball which has cooled sufficiently to become transparent to the intense light of the isothermal sphere.

Step 9.

At approximately 2,200 milliseconds (2.2 seconds) the blast wave has traveled 1,200 meters from the locus of the explosion to arrive at the "damage area." The blast wave is advancing at 332 meters per second, less than the 440 meters per second (1,150 feet per second) speed of sound at sea level—the blast wave at the damage area is subsonic. The luminance perceived at 10,000 yards has diminished to 0.10 sun and the isothermal sphere radiates as a black body of less than (<) 5,000°K. The pressure at the blast wave front in Step 9 is defined to be 5 psi "overpressure." Overpressure is that pressure, expressed in pounds or fractions of a pound per square inch, which exceeds the ambient atmospheric pressure: 1 bar, or 14.7 psi, at sea level. Overpressure, as will be discussed later, is a measure that permits prediction of blast wave-induced structural damage. A peak overpressure of 5 psi, which is an impulse pressure of 5 pounds per square inch in excess of ambient pressure, will destroy most structures; an overpressure of 2.5 psi will induce sufficient damage that most structures affected by that overpressure will be rendered useless. In the Port Chicago explosion the limiting radius of 2.5 psi overpressure was 2,500 feet (771 meters), or one-half mile.

Step 10.

At 28 seconds the blast wave has traveled 10,000 meters (10,000 yards) from the detonation point. The speed of the blast wave is 332 meters per second; the overpressure at 10,000 yards is .18 psi, which is not sufficient to rupture the human ear drum. The diminishing luminance of the explosion is 0.01 sun. The temperature at the blast wave front has cooled nearly to the ambient atmospheric temperature. At Trinity site observers in the open who were positioned 10,000 yards from ground zero experienced the blast wave as a gentle gust of warm wind. The fireball has reached a height of 2,000 feet and has begun to disintegrate to flame-hot turbulent gasses radiating as a black body much less than 5,000°K and rising above the detonation point, no longer a discrete ball of fire but a lengthening column of flame that at the top will form a mushroom cap as the top cools and is obstructed in greater ascent by the atmosphere.

In the Port Chicago explosion the initial, discrete ball of fire reached a height of 2,000 feet and was completely disintegrated into turbulent convection currents that resolved to a column of flame which expanded and billowed at the top as it rose. The top of the column of flame from the Port Chicago explosion reached an altitude of 7,000-10,000 feet. The column of flame was red at the top and brightened from orange to yellow at the base.

Step 11.

Finally, at 200,000 milliseconds (200 seconds; 3 minutes and 33 seconds) the hot, turbulent and luminous gasses produced by the detonation of the 10,000 ton gadget at Trinity would rise and cool by expansion and convection. The ball of fire and supervening column of flame at Trinity was expected to resolve to a dark mushroom-capped smoke cloud that would ascend to 18,000 feet in “typical Port Chicago fashion.” At Port Chicago on that moonless night of 17 July 1944 the dark smoke cloud above the explosion was invisible against the dark night sky and we have no account of the final height achieved by the top of the smoke cloud top that arose from the Port Chicago explosion.

[Note. The “History of 10,000 ton gadget” does not account one militarily significant artifact that results from the detonation of a 10 kt weapon, but which is an artifact that also occurs in consequence of any explosion and is proportional to the energy yield of an explosion. In the wake of a radially expanding blast wave the pressure of the atmosphere in the area behind the blast wave front does decrease below the ambient, pre-explosion pressure of the atmosphere. In the area behind a blast wave a negative pressure phase results and a wind, proportional to the energy of the explosion, will blow in toward the locus of the explosion. The wind produced by that negative or suction phase of a large explosion can amplify the destruction caused by the blast wave when structures weakened by the blast wave are demolished by the negative phase wind. Personal casualties will also increase among those who survived the blast wave when the negative phase wind translates the wreckage left by the blast wave into a barrage of missiles.

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