Chapter

5

“History of 10,000 Ton Gadget”: The Authors and the Bomb it describes

The “History of 10,000 ton gadget” is the most comprehensive mathematical description of the progression of the explosion of a World War II atomic bomb that the public will ever see. The larger portion of the document is manuscript; the document’s legend that runs from top to bottom on the left margin is typescript. The original document consists of two sheets of paper put together with transparent “Scotch” tape. The mathematical data in manuscript notation were written across the 14 inch dimension of one 8.5 x 14 inch sheet of “legal” size paper; the legend was typed down the 8.5 inch margin of one 8.5 x 11 inch sheet of “letter” size typing paper. The two sheets of paper were trimmed and taped together, first on back of the document. With the two sheets of paper taped together on the back, the horizontal and vertical lines that divide the data and legend entries were drawn, and a strip of tape was applied to the face of the document along the vertical line that divides the typescript and manuscript portions of the document. An outline of the tape that joins the two sheets on the face of the document can be seen along the length of that vertical line.

In my first article on Port Chicago, published in the Spring 1982 issue of *The Black Scholar*, the document was reproduced and carried a copyright in my name. I claimed ownership of the document by right of possession, but clearly Paul Masters had thieved the document from Los Alamos. The right of ownership by possession is usually contravened if the licit owner of stolen property can be determined and I had determined that Los Alamos was the licit owner of the document. I held the document in a bank safety deposit box a few months less than five years. In late 1984 in the first basement of the J. Robert Oppenheimer Library at Los Alamos National Laboratory I met with Los Alamos Archivist Roger A. Meade and put the document into his hands as a voluntary gift, a donation made to the laboratory Archives. The following year I listed the gift as a charitable donation for federal tax purposes and claimed a deduction equal to the cash expenses I had made to establish authenticity of the document and to determine its licit owner, plus the $0.25 I had paid to acquire the document at the Christ Evangelical Lutheran church rummage sale in spring 1980; the donation and deduction were approved without dispute by the Internal Revenue Service.

The authors of the "History of 10,000 ton gadget."

The "History" carries no information that permits identification of its authors. In January 1981 I began a study of the Manhattan Project historical literature to determine who were the authors of the "History." The public information office at Los Alamos lab suggested I start a general study of the Project history with David Hawkins' *Manhattan District History, Project Y, The Los Alamos Project,* Volume I, LAMS-2532 (Los Alamos, 1961). I found that paragraph numbered 11.20 of Hawkins' Los Alamos history describes a part of the work accomplished at Los Alamos immediately following 1 August 1944; the description of that work provided by paragraph 11.20 is a point-by-point recapitulation of the information presented in the "History of 10,000 ton gadget":

"11.20. Much more extensive investigation of the behavior and effects of a nuclear explosion were made during this period than had been possible before, tracing the history of the process from the initial expansion of the active material and tamper through the final stages. These investigations included the formation of the shock wave in the air, the radiation history of the early stages of the explosion, the formation of the 'ball of fire,' the attenuation of the blast wave in air at greater distances, and the effects of blast and radiations of [sic] human beings and structures . . . General responsibility for this work was given to Group T-7, with the advice and assistance of W.G. Penney."

Paragraph 11.20 of Hawkins' history reported that after 1 August 1944 general responsibility for investigation of the behavior and effects of a nuclear explosion had been given to Los Alamos Group T-7, with the advice and assistance of W.G. Penney. Further close reading of Hawkins' history showed that Los Alamos Laboratories Theoretical Division Group T-7 (Damage) had been formed in November 1944 by a change of name. Theoretical Division Group T-7 had been the former Group O-5 (Calculations) of the Ordnance Division. Both O-5 and T-7 were reported to have been led by Joseph O. Hirschfelder.


Joseph Oakland Hirschfelder (1911-1990)

It seemed to me probable that Joseph Hirschfelder in his work with Groups O-5 (Calculations) and T-7 (Damage) would have been linked with the preparation of the "History of 10,000 ton gadget" and therefore acquainted with the Port Chicago explosion and the Port Chicago explosion fireball. Joseph Oakland Hirschfelder in 1981 was a mathematician and theoretical chemist at the University of Wisconsin, Madison. He had, I also learned, been chairman of the editorial board that produced the first comprehensive, publicly available technical account of the way nuclear fission weapons work and their effects: the 1950 U.S. Atomic Energy Commission text, *The Effects of Atomic Weapons.*

Hirschfelder had taken a double Ph.D. in theoretical physics and chemistry at Princeton University in 1936 under Eugene P. Wigner, later a prominent Manhattan Project physicist. After receiving his Ph.D., Hirschfelder spent an additional year as a postdoctoral fellow with John von Neumann at the Princeton Institute for Advanced Study. In 1937 he went to the University of Wisconsin as a Wisconsin Alumni Research Foundation research associate. At the beginning of the war for about two years Hirschfelder was with the National Defense Research Committee (NDRC) in Washington, DC, where he worked as head of the Interior Ballistics Group on a wide variety of problems including the thermodynamics of propellant gases and the fluid dynamics and combustion in the barrels of guns, mortars, and rockets. John von Neumann arranged Hirschfelder's transfer to Los Alamos in early 1944 where Hirschfelder was a group leader through the end of the war. During his time as a group leader at Los Alamos, Hirschfelder worked with Hans Bethe and John Magee on the dynamics of nuclear explosions including, specifically, the formation of the fireball and shock wave. In 1945-46 Dr. Hirschfelder was head of theoretical physics at the Naval Ordinance Test Station at Inyokern, California (China Lake), and in 1946 he was chief phenomenologist at the U.S. atomic bomb tests at Bikini Atoll in the South Pacific.

In 1946 Hirschfelder returned to Madison to become a full professor in the Department of Chemistry. He then established the University of Wisconsin Naval Research Laboratory which he directed until 1959 when it was reorganized as the University of Wisconsin Theoretical Chemistry Institute. Joseph Hirschfelder died 30 March 1990. The prestigious Joseph O. Hirschfelder Prize in Theoretical Chemistry with its $10,000 stipend is awarded annually by the University of Wisconsin Institute of Theoretical Chemistry. The Hirschfelder Prize, established in 1991, was made possible by a gift from the chemist's widow, the mathematician Elizabeth Hirschfelder.

Hirschfelder, I was confident in 1981, would certainly have known in 1944-45 how to distinguish the distinctive spherical fireball typical of a nuclear fission explosion from the amorphous turbulent mass of hot luminous gases characteristic of the explosion of conventional TNT-based munitions. The roiling cloud of hot, luminous gases that results from a chemical explosion, of which TNT and dynamite explosions are examples, is of fundamentally different appearance from the initial discrete spherical fireball of a nuclear fission explosion because of the enormous temperature and heat differences that distinguish a nuclear fission explosion from a relatively cold chemical explosion. A principal area of Joseph Hirschfelder’s work at Los Alamos was to calculate and predict the behavior of the distinctive fireball of a nuclear explosion and his work in that study was made with the thermodynamicist Hans Bethe, who first predicted the distinctive fireball characteristic of a nuclear explosion.

In 1981, I spoke with Hirschfelder at the University of Wisconsin at Madison, provided to him a copy of the “History of 10,000 ton gadget,” and asked him what his role had been in the preparation of that document and what signified that document’s reference to the Port Chicago ball of fire as having been typical of a nuclear explosion.

Professor Hirschfelder, I had been told, ever refused to discuss his wartime activities at Los Alamos as he did when I spoke with him. He declined to discuss the document or to explain the document's reference to Port Chicago.


William George Penney
(1909-1991)

Paragraph 11.20 of David Hawkins' history reported that W.G. Penney had provided advice and assistance to Hirschfelder's Group T-7 (Damage) after 1 August 1944 in that group's investigation of the behavior and effects of a nuclear explosion. William George Penney was born at Gibraltar 24 June 1909; his death came 3 March 1991 in East Hendred, England. During the early 1930s Penney spent two years at the University of Wisconsin, Madison, before he received a doctorate from the University of Cambridge in 1935. In spring 1944 William George Penney was Professor of Applied Mathematics, Imperial College of Science and Technology, University of London.

Later knighted for his service to the Commonwealth in the development and successful test of Britain's first atomic bomb, 3 October 1952, Penney often is designated the "Oppenheimer of Britain." Prior to World War II Penney's area of scientific specialty was the physics of hydrodynamic waves, both shock waves and the more familiar ocean waves, known as "gravity" waves. During 1943 and early 1944 Penney designed and supervised development of the mobile breakwaters that would be emplaced by the Allies off the Normandy beaches during the opening phases of the D-Day invasion to degrade the potentially treacherous interaction of energetic Atlantic ocean waves and the personnel and water craft that would invade the Normandy beaches through the hazards of the Atlantic rollers.

Geoffrey Ingram (G.I.) Taylor was an extraordinary British physicist one generation older than William Penney. During World War II, as he had during World War I, Taylor applied his scientific expertise to military problems including the propagation of blast waves in both air and underwater explosions. Almost from the beginning of the Manhattan Project Geoffrey Taylor was a consultant to the Manhattan Project program at Los Alamos; he was, in the final account, a major theoretical and practical scientific contributor to the intricate design of the atomic bomb tested at Trinity site in New Mexico and detonated in combat at Nagasaki. Early in 1944 Taylor had arranged that William Penney should join the atomic bomb development program at Los Alamos. Penney departed London for Los Alamos shortly before D-Day and arrived at Los Alamos in the third week of June 1944.

Penney's principal assignment at Los Alamos was to develop theoretical predictions of damage effects from the blast wave of an atomic bomb. But his expertise in the hydrodynamics of ocean waves was enlisted to theoretically investigate the effects of underwater atomic bomb detonations; theoretical investigation was augmented by an experimental program of very small explosions conducted in the Anchor Ranch explosion pond at Los Alamos. On 17 July 1944 theory supported by the minuscule explosions made in the Anchor Ranch pond yielded to analysis of the water waves that resulted from the Port Chicago explosion; seventy-five per cent of the weight of explosive detonated at Port Chicago was submerged, below the water line, in the lower cargo holds of the exploded ship *E.A. Bryan.*

There is no doubt in my mind that, in addition to Penney's participation in analysis of the water waves that resulted from the Port Chicago explosion, Penney also participated in review of the various Los Alamos analyses of the Port Chicago explosion blast wave in the air, analyses made in the days, weeks and months following the explosion. Prediction of the damage effects from the blast wave of an atomic bomb was William Penney's principal assignment at Los Alamos.


William Sterling Parsons, USN (1901-1953)

William Penney's significant contributions to the wartime work at Los Alamos can be broadly comprehended with recognition that within a few weeks of his arrival he was added to the core group of scientists there who made all key decisions in the direction of the program. The others with whom he shared that duty and responsibility were Los Alamos Laboratories Director J. Robert Oppenheimer; Los Alamos Laboratories Associate Director Captain William Sterling Parsons, USN; the physicist, theoretician and mathematician John von Neumann; and the brilliant physicist and operational planner Norman Ramsey.

Penney was an observer at the 16 July 1945 bomb test at Trinity site in New Mexico; on 9 August 1945 he witnessed the bombing of Nagasaki

J. Robert Oppenheimer
(1904 – 1967)

from one of the observation planes that accompanied the Nagasaki mission bomber *Bock's Car;* he was a member of the U.S. team of scientists and military analysts who entered the rubble of Hiroshima to assess the effects of the atomic bomb that was detonated there 6 August 1945. At Bikini Atoll in July 1946 he joined Joseph O. Hirschfelder and other scientists from Los Alamos who had responsibility for the program to test two U.S. atomic bombs at Bikini in Operation Crossroads. After completion of the analyses of the Bikini tests Penney returned to England to undertake development of the first British atomic bomb.

I had no opportunity to speak with Lord Penney until the summer of 1990 when I provided to him a copy of the "History of 10,000 ton gadget" and asked him what his role had been in authorship of that document and what he had known of the Port Chicago explosion. Sir William told me he had had no knowledge of the Port Chicago explosion, and had not been acquainted with the "History of 10,000 ton gadget" until he received a copy of that document from me. The Port Chicago explosion, he said, had not been discussed within the scope of his associations during the time he was with the Manhattan Project at Los Alamos. Specifically, Penney said neither Los Alamos Laboratories Director J. Robert Oppenheimer nor Los Alamos Laboratories Associate Director Captain William Parsons had ever mentioned the Port Chicago explosion in his hearing.

August 1945, Tinian Island, South Pacific. Left to right: Captain William Sterling Parsons, USN, 1901-1953, Associate Director Manhattan Project Los Alamos Laboratories; bomb commander, Hiroshima combat bombing mission. Rear Admiral William R. Purnell, USN, Navy member Atomic Bomb Military Policy Committee. Brigadier General Thomas Farrell, USA, Administrative Deputy Director Manhattan Project. Source: U.S. National Archives.

That assertion was either an error of memory or a deliberate misrepresentation of fact. I did not have the impression in telephone conversations with Sir William, nor from the text of his letters to me, that his recollection of events related to his participation in the development of the first nuclear fission weapons at Los Alamos was clouded.

Paragraph 11.20 of Hawkins' official Manhattan Project history attests that William Penney provided advice and assistance to the work of Joseph Hirschfelder's Los Alamos Group T-7

(Damage). The work of Group T-7 in defining the phenomenology of nuclear weapons explosions is shown to have been summarized by the "History of 10,000 ton gadget," in which the Port Chicago explosion fireball is characterized to have been typical of a nuclear explosion.

Dr. Maurice Mandel Shapiro, Chief Scientist Emeritus, Laboratory for Cosmic Physics, U.S. Naval Research Laboratory (1915-2008)

There is documentary evidence which conclusively shows that William Penney was cognizant of the Port Chicago explosion prior to 31 August 1944 and that he contributed to scientific analyses of the effects of the explosion. The 16-page report, "Effects of the tidal wave in the Port Chicago explosion of July 17, 1944," was researched and written by the civilian Los Alamos physicist Maurice Mandel Shapiro. Ph.D., and transmitted 31 August 1944 by Capt. Parsons to his superior officer Rear Admiral William R. Purnell in Washington, DC. Admiral Purnell was the Navy member of President Roosevelt's three-man Atomic Bomb Military Policy Committee. In paragraph H, page 11, of his report on the Port Chicago tidal wave Dr. Shapiro wrote:

"Another consideration which throws some light on the probable wave height has been suggested by Dr. W. G. Penney. If the initial wave behaved as a solitary wave, then it would have tended to instability as its height approached a value equal to the depth of the water. Since the depth at the point in question [the southern tip of Roe Island] was about 5 feet, the wave would probably have attained no greater height than this."

On page 15 of this undated report on the effects of the Port Chicago tidal wave, but which was transmitted 31 August 1944, Dr. Shapiro wrote, "It is interesting to compare the wave effects in the Port Chicago explosion with those observed in our model experiments in the explosion pond at Anchor Ranch. We shall apply similitude relations deduced by W. G. Penney in his hydrodynamic theory of surface explosions. In this theory it is assumed that a known impulse is delivered to a water surface over a finite circular area. . . ."

This Port Chicago explosion tidal wave analysis concludes on page 16 with Dr. Shapiro's remark, "Considering the large error involved in these estimates, the presence of shelving at the Roe Island bank, and the fact that the mean depth of water in the channel was much less than

200 feet, the agreement between the Port Chicago wave amplitudes and those predicted by Penney's theory is good."

The Anchor Ranch technical area at Los Alamos and the experimental explosion pond constructed there actually took that name from the name of the privately owned Anchor Ranch adjacent to Los Alamos Ranch School for Boys; both properties had been taken by the Government in late 1942 to establish the site of Los Alamos Laboratories.

William Penney had mathematically formulated his hydrodynamic theory of surface explosions before his arrival at Los Alamos in late June 1944; but experiments in which he participated that were conducted at the Anchor Ranch explosion pond with explosions of two ounces of pentolite at the surface of water two feet deep provided small scale demonstrations of Penney's theory, and the Port Chicago explosion provided field-scale confirmation of that theory. In fact, all the physical phenomena of the Port Chicago explosion would later provide comparative examples and effects data important in analysis of the first British nuclear bomb test, Operation Hurricane conducted 3 October 1952 off the west coast of Australia in the Monte Bello Islands. Operation Hurricane was organized and directed by William Penney and proved a bomb his team of British scientists had designed and built; that bomb was fundamentally the same device described by the "History of 10,000 ton gadget."

The circumstances of the first British atomic bomb proof made in Operation Hurricane in several important ways were remarkably correspondent to the circumstances of the Port Chicago explosion, in which the first U.S. atomic bomb was proven. The 25 kilotons TNT equivalent energy yield of the weapon detonated in Operation Hurricane was 25 times greater than the nominal 1 kiloton TNT equivalent energy of the first U.S. nuclear fission weapon proven at Port Chicago, but the similarities of the two explosions begin with recognition that both explosions originated and were "barricaded" within the confines of a blue water ship.

The British weapon detonated in Operation Hurricane was located within the hull of the aging 1944 River-class frigate HMS *Plym. Plym* was a relatively small, fast, shallow-draft gunboat which displaced

1,370 tons and was 301 feet overall length. *Plym* was anchored 400 yards off Trimouille Island beach in water 40 feet deep; the center of gravity of the explosion was 10 feet below the water line. At Port Chicago, the exploded Liberty ship *E.A. Bryan* was a deep draft, wide beam cargo ship that displaced 14,245 tons and was 441 feet overall length. The *E.A. Bryan* was moored to a pier 300 yards off the shoreline of the Port Chicago Naval Magazine and the center of gravity of the main munitions explosion within the ship's cargo holds was 10 feet below the water line, in water depth a little less than 40 feet. Those circumstances are typical of merchant ships either dockside or at anchor in the majority of the world's maritime harbors and ports.

Operation Hurricane and the weapon proof conducted at Port Chicago were both intended to ascertain the military effects of a nuclear weapon carried by ship into a port facility or harbor and detonated. The Port Chicago explosion had provided baseline data for a 1 kiloton tactical atomic bomb detonated in a port, and those Port Chicago data were augmented by data obtained from the Bikini atomic bomb tests that involved a variety of ships, large and small. The principal objective of Operation Hurricane, beyond a proof of the first prototype British nuclear weapon, was to ascertain the immediate and long-term radiation effects of an atomic bomb that might be smuggled by ship into a British port and detonated. In the early 1950s the threat of an atomic bomb carried into a port cached among the cargo of an innocent-looking merchant vessel, and then detonated, was of great concern to the maritime British with their many ports and harbors. That same threat to the port or harbor of any of the world's maritime nations is no way diminished today, and the miniaturization of nuclear fission weapons greatly facilitates concealment of an atomic bomb among a ship's containerized merchant cargo.

Destruction of a maritime port was the first suggested military application for a U.S. atomic bomb. Albert Einstein's letter of 2 August 1939 to President Franklin Delano Roosevelt proposed the delivery of an atomic bomb to a port by boat, considering that the weapon would likely be too heavy to be transported and delivered in combat by aircraft. In that letter Einstein informed the President that nuclear fission was on the threshold of development and that atomic bombs would be the first practical consequence. Einstein explained:

“This new phenomenon would also lead to the construction of bombs, and it is conceivable—though much less certain—that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.”

In the spring 1982 publication of my first article on the Port Chicago explosion I attributed authorship of the “History of 10,000 ton gadget” to Joseph Hirschfelder with the assistance of William Penney. I made that attribution despite Joseph Hirschfelder’s 1981 refusal to confirm or deny his contribution to the “History,” and eight years before my 1990 discussions and correspondence with William Penney. More than 10 years after I published that attribution of authorship, the Manhattan Project history *Critical Assembly*, prepared by the U.S. Department of Energy and published by the Cambridge University Press in late December 1993, confirmed that attribution on pages 343-344:

“By January 1945, Hirschfelder and British physicist William J. [sic] Penney had gathered a great deal of data from Britain on the structural damage caused by German high-explosive bombs. These data proved extremely useful in the group’s further calculations, and by the next month it had developed a hypothetical ‘history’ of the explosion of a nuclear weapon with the explosive power of 10,000 tons of TNT.”

Although Paul Masters recalled in conversation with me in 1980 that he had removed the “History” from Los Alamos in autumn 1944, the information provided by *Critical Assembly* sets January or February 1945 as the date that document was prepared. The date that document was prepared, a minor detail, remains uncertain. Hirschfelder and Penney by January 1945 had gathered a great deal of information on structural damage caused by German high-explosive bombs that fell on England; but the phrase “by the next month” is vague. Interpretation of that phrase could mean the “History” had been prepared by the beginning of February 1945 or by the end of that month.

The type of bomb described by the "History of 10,000 ton gadget."

The "History of 10,000 ton gadget" is a technical document that provides a complex mathematical model of the detonation and anticipated physical effects of the atomic bomb proof-fired at Trinity site in New Mexico 16 July 1945. That bomb design, with combat modifications, was detonated at Nagasaki 9 August 1945. The energy of the weapon described by the "History" is equivalent to 10,000 tons of TNT (10 kilotons, or abbreviated as 10 kt). The document mathematically models a "nominal" 10 kt atomic bomb explosion.

During the theoretical period of the atomic bomb program a 10 kt TNT equivalent atomic bomb was calculated as the minimum energy of explosion that would fulfill the Manhattan Project's specific mandate to produce a militarily-decisive atomic bomb for use during the war. A bomb of nominal 10 kt TNT equivalent energy yield was therefore established as the practical objective of the Project.

As represented by the "History," a nominal 10 kt atomic bomb was used as the basis for general theoretical descriptions of an atomic bomb explosion, but the effects of atomic bombs of greater and lesser energy could be computed easily from the benchmark description of a 10 kt explosion. A bomb of 10 kt yield, or greater than 10 kt, would constitute a strategic, militarily-decisive weapon. Bombs of energy less than 10 kt would be applicable to tactical military uses, but one or several tactical nuclear bombs would not necessarily be militarily decisive. The contemplated strategic weapons of 10 kt, and greater energy yield, would destroy the major part of a city, as occurred at Hiroshima and Nagasaki; tactical weapons would destroy lesser, limited targets as, for example, a military or commercial maritime port as occurred at Port Chicago.

The prototype weapon design that was proof fired at Port Chicago was a nominal 1 kt tactical device, but the realized energy yield of the prototype detonated at Port Chicago was much less than the nominal 1 kt combat potential of that weapon. The explosive energy of the Port Chicago device, in order to conserve the very limited supply of fissionable uranium available by July 1944, was intentionally limited to the minimum that was calculated to be necessary to sustain a productively efficient, recognizable nuclear fission chain reaction explosion; reduction of the amount of fissionable uranium available in the device to that minimum constrained the energy yield of the Port Chicago device to about 300 tons TNT equivalent. That minimal nuclear fission explosion, however, sympathetically detonated all the conventional military munitions loaded in the exploded ship and those that were emplaced next to the ship on the Port Chicago Magazine ship loading pier. Those conventional munitions exploded with an energy equal to the high order detonation of 1.5 to 2.1 kt of TNT. The combined explosive result was equivalent, as an order of magnitude, to the 1 kt energy yield that prototype tactical weapon was forecast to produce when it would be optimized for combat use. The fireball and succeeding column of flame that instantly rocketed to 10,000 feet above the primary nuclear explosion at Port Chicago was easily recognized by those who had predicted that typical characteristic of a nuclear explosion.

The Trinity/Nagasaki weapon described by the "History of 10,000 ton gadget" was a spherical implosion design. Within a heavily armored exterior steel ballistic case, an inner spherical steel encasement contained the spherical, functional bomb components. The fissionable component of the Trinity/Nagasaki bomb was a ball of essentially pure plutonium-239 located as the central core of the weapon; that active component of the weapon has been reported by some accounts to have been the size of a grapefruit, reported by other accounts to have been the size of a chicken egg, and suggested by some writers to have been the size of the human eyeball. The 21 kt energy yield of the Trinity device, however, reasonably suggests the plutonium core was more grapefruit-sized than less.

The plutonium core contained within it a small manufactured mechanism called the urchin, so called because it physically resembled the common spiny sea urchin that, in death, leaves a bulbous, bumpy five sided penta-radial, thin calcareous shell up to four inches across seen washed onto ocean beaches. In life the sea urchin protrudes a dense array of brittle spines that are the animal's principal defense against being eaten and the means by which it can gather food and carve a protective niche for itself in soft rock. The urchin within the plutonium core of the Trinity/Nagasaki bomb physically resembled the live sea urchin: spine-like projections from the centrally located urchin extended into the plutonium core. When the bomb was detonated, which is to say imploded by a surrounding mantle of conventional high explosives, the plutonium core was radically compressed; urchin and urchin spines were crushed and disrupted. Seven grams of beryllium and 50 curies of a polonium^{210} alpha source, segregated in the urchin spines, were instantaneously mixed. When exposed to alpha particles, beryllium emits neutrons. The resulting beryllium-polonium nuclear reaction released vast numbers of neutrons within the plutonium core and thereby pervasively initiated the explosive neutron-induced plutonium nuclear fission chain reaction.

The abundance of neutrons produced by the urchin promoted initiation of the nuclear fission chain reaction and greatly increased the efficiency of the chain reaction, but as the detonation progressed only a few percent of the plutonium core atoms of the Trinity/Nagasaki weapon were subject to fission before the heated core began to expand and plutonium atoms within the core that had not fissioned became more widely separated than in the compressed state. As the core expanded, and the distance between plutonium atoms increased, the likelihood that a fission-inducing neutron would collide with any Plutonium nucleus and induce fission was diminished. Misses rather than hits became more probable in the expanding fissile core. To partly overcome the tendency of the bomb to blow itself apart before the chain fission reaction was as complete as possible the plutonium core was enclosed within a heavy shell of depleted uranium, the tamper. Depleted uranium (DU) is highly refined uranium from which most of the atoms susceptible to fission have been removed. The tamper also served to reflect neutrons that reached the periphery of the core; those neutrons, without reflection into the core, would have been lost to the continuing chain reaction.

Depleted uranium, like lead and gold, is a material of very great density. Depleted uranium has a very high mass density compared to cotton. The energy required to move a material body of very high mass density is much greater than the energy required to move a material body of very low mass density of the same size: a puff of breath will move and rapidly accelerate a 1-inch cotton ball, but a puff of breath will not disturb a 1-inch ball of uranium. The tendency of a body at rest to remain at rest or of a body in motion to stay in motion in a straight line unless disturbed by an external force is defined in physics as the inertia of that body. The inertia of uranium is very great compared to cotton. The inertia of depleted uranium in motion, its momentum, recommends its use as the material of which armor piercing anti-tank rockets and gun projectiles are manufactured because an accelerated uranium projectile is very difficult to stop; a projectile of depleted uranium traveling at 3,000 feet per second will pass through several inches of military armor steel plate; higher velocities increase the penetrating power of the projectile.

Difficult to stop, a mass of depleted uranium is also difficult to move. The plutonium core of the Trinity/Nagasaki weapon was enclosed by a depleted uranium tamper that significantly resisted the expansion of the heated core and contained the fissioning material very briefly, but for the sufficient small fraction of a second necessary to permit the fission chain reaction to proceed more completely through the core material than would have been realized without the confining effect of the tamper. However, the rapidly increasing pressure of the expanding plutonium core very quickly overcame the inertia of the depleted uranium tamper and the tamper was disintegrated and vaporized.

Surrounding the core and tamper of the Trinity/Nagasaki bomb design was a spherical mantle of molded high-explosive blocks, tightly fitted together and each shaped in design so that when detonated simultaneously the combination achieved the effect of a focusing optical lens. When the explosive blocks were detonated most of the released energy was focused inward toward the core of the weapon; predominantly an *implosion* rather than an *explosion*. When the explosive blocks were simultaneously detonated they produced a powerful, inward moving, focused spherical pressure wave, the detonation wave; the detonation wave progressed rapidly through the detonating explosive to the interface of the explosive with the depleted uranium tamper. The detonation wave at the tamper interface produced a pressure of several million pounds per square inch uniformly on the surface of the tamper. The tamper under that influence became radically compressed and transferred the energy of the detonation wave against the plutonium core. In motion, the momentum of the now exceedingly dense, compressed tamper moved inward against the core, against the resisting mass of the plutonium core, which was of essentially the same mass density as the tamper before compression.

The millions of pounds per square inch pressure exerted by the tamper compressed the core plutonium to about the size of a mote. During compression of the core the urchin spines were ruptured, which released swarms of neutrons to effectively initiate the nuclear fission chain reaction. As the full power of the fission chain reaction exploded, the tamper was disintegrated and vaporized by the shock wave of energy released by the fission reaction. The expanding shock wave disintegrated and vaporized the inner spherical steel encasement and immediately disintegrated and vaporized what remained of the bomb's armor-plate exterior case. The shock wave then emerged into the surrounding atmosphere where it expanded with great speed and tremendously destructive force as a very hot, high-pressure blast wave in air.

How a nuclear explosion proceeds.

The sudden liberation of energy by an explosion, chemical or nuclear, causes a sudden increase of temperature and pressure surrounding the explosion; materials present in the explosion are converted to very hot, luminous gases that expand rapidly and create a pressure or shock wave in the surrounding environment. The characteristic of a shock wave is a sudden increase of pressure at the wave front expanding into the surrounding medium—air, water or earth—with a gradual decrease of pressure behind the front. A shock wave in air is generally called a blast wave because it resembles and is accompanied by a very strong wind. In water or in the ground, shock wave, rather than blast wave, is the proper term because in water and ground the effect is like that of a sudden impact.

At very early times in the development of a nuclear explosion, beginning in less than a microsecond, the explosive shock wave is formed and driven by the energy of the expanding bomb debris; the temperature at that moment is several tens of millions of degrees. Because of that intense heat, all the fission products, bomb casing and other weapons parts are converted to the gaseous form. Within less than a millionth of a second of the detonation of a nuclear fission weapon, the extremely hot weapon residues radiate large amounts of energy, mainly as X rays. Approximately 85 percent of the energy of the explosion during this early stage is the kinetic energy of nuclear fission fragments present in the form of "soft" X rays. Within the X-ray portion of the electromagnetic spectrum soft X rays have relatively longer wavelengths and relatively lower energies than "hard" X rays. The initial energy of the explosion is distributed between soft X rays and shock wave energy. The proportions are determined by the nature of the medium in which the bomb explodes.

When an explosion takes place in a medium of high density—like water or earth—a larger percentage of the X-ray energy of the fission fragments is immediately converted to heat energy than is the case when an explosion takes place in the less dense medium of air. In a water or earth medium the emitted X rays are quickly stopped and their energy converted to intense local heat, which reduces the energy available to the shock wave; in the less dense medium of air, X rays travel a relatively greater distance before an interaction with the more widely separated atoms and molecules of the atmosphere. Consequently, in air a greater portion of the energy of explosion is available to blast wave. The X-ray energy imparted to the atoms and molecules of the atmosphere is so great and the temperature generated so high that an instantaneous brilliant flash of visible white light is emitted by those superheated gasses. In a nuclear explosion in air, where the air density does not differ greatly from sea level, most of the X rays, which constitute the primary thermal radiations, will be absorbed within a few feet of the explosion. It is in this manner that the initial fireball is formed in an air or surface burst.

The characteristic white flash of light generated by a nuclear explosion immediately precedes formation of the explosion fireball; the fireball follows the luminous flash and remains luminous for several seconds or minutes, depending on the energy yield of the weapon. The surface temperature of the fireball, upon which the brightness, or luminance, depends, does not vary greatly with the total energy yield of the weapon. The observed brightness of the fireball in an air burst close to sea level is roughly the same, regardless of the energy yield of the weapon.

As an explosion in air proceeds, the blast wave expands into the surrounding atmosphere until the energy of the blast wave has been dissipated by the resistance of the air that the wave front encounters and moves through. The blast wave finally ceases to exist as a manifestation of the explosion when the pressure at the wave front is equal to the ambient air pressure, which at sea level is 14.7 pounds per square inch.

Photographs and illustrations credits.

Joseph Oakland Hirschfelder (1911-1990), Professor of Chemistry, University of Wisconsin, Madison. Source: University of Wisconsin, Madison. Used with permission.

William George Penney (1909-1991), postwar Director of Atomic Weapons Research and Development at Aldermaston, England; Chairman, Board of the Atomic Energy Authority, U.K. Source: School of Mathematics and Statistics, University of St Andrews, St Andrews, Fife, Scotland. Used with permission.

J. Robert Oppenheimer (1904-1967), Director Manhattan Project Los Alamos Laboratories. Source: Los Alamos National Laboratory.

August 1945, Tinian Island, South Pacific. Left to right: Captain William Sterling Parsons, USN (1901-1953), Associate Director Manhattan Project Los Alamos Laboratories; bomb commander, Hiroshima combat bombing mission. Rear Admiral William R. Purnell, USN, Navy member Atomic Bomb Military Policy Committee. Brigadier General Thomas Farrell, USA, Administrative Deputy Director Manhattan Project. Source: U.S. National Archives.

Maurice Mandel Shapiro, Ph.D. (1915-2008), Chief Scientist Emeritus, Laboratory for Cosmic Physics, U.S. Naval Research Laboratory. Source: Photo by Dr. Arthur E. Smith. Copyright by Dr. Arthur E. Smith. Used with permission. Photo available at:

http://home.hiwaay.net/~smithae/shapiro.html.