Chapter

11

Manhattan Project U^{235} production data, 1943-1945

During the summer and autumn of 1980 those former Manhattan Project Los Alamos scientists with whom I was acquainted in the programs of the New Mexico Energy Research and Development Institute had told me that to plausibly argue an atomic bomb had been detonated at the Port Chicago Naval Magazine I would need to show that the Manhattan Project had produced a sufficient quantity of fissionable material by 17 July 1944 to enable a nuclear fission bomb to be detonated on that date. Correlatively, I would need to know the quantity of fissionable material required to produce an atomic bomb of sufficient explosive efficiency to yield an energy of explosion equivalent to the energy of the Port Chicago explosion.

By December 1980 I had determined conclusively from the published Manhattan Project literature that production of plutonium in weapon quantity had not been feasible before the first plutonium producing reactor at Hanford, Washington, had commenced reliable operation at the end of December 1944. Therefore, if a nuclear fission weapon had been detonated 17 July 1944 at Port Chicago that weapon would necessarily have employed U^{235} as the fissionable material. What I required then to sustain my argument that a fission weapon had been detonated at Port Chicago was the U^{235} production data for the years 1943 and 1944, and then to ascertain if the quantity of U^{235} produced by 17 July 1944 had been sufficient to enable a nuclear fission weapon detonation equivalent to the energy of the Port Chicago explosion.

The available published Manhattan Project historical and narrative literature asserted that the Project had produced only sufficient U^{235} "to fill the belly of Little Boy"—Little Boy, the gun assembly Mark I weapon employed in combat at Hiroshima, which utilized U^{235} as the fissionable material. The literature asserted that the Project with great uncertainty of the outcome had barely produced sufficient U^{235} by 6 August 1945 to enable combat use of the one Little Boy bomb detonated at Hiroshima, but that claim of the literature was anecdotal and was not supported by factual U^{235} production data for the period prior to 6 August 1945. The Project's U^{235} production data for the years prior to 1950 were classified; even today U^{235} production data for the period prior to 1950 have not yet been administratively released by DOE.

The quantities of U^{235} and plutonium produced by the Manhattan Project during World War II were better kept secrets than the technology and design of atomic bombs. Circulation of general and specific information about the technology and design of the atomic bombs in development at Los Alamos was controlled by the most effective security policies and practices Gen. Groves could devise, with the purpose to restrict that information to persons in the Project "who had a need to know" that particular detail of the Project. But with several hundred people working on details of the program at Los Alamos, and in university-affiliated research laboratories, some details of the work inevitably did leak and were transmitted through the espionage network to the Russians. As Russian spymaster Anatoli Sudoplatov is reported to have told authors Leona and Gerald Schecter in 1994, the security of wartime secrets at Los Alamos would have been considerably more effective if Gen. Groves had ordered that the shirt pockets of all men leaving that facility were searched. Los Alamos photographic technician Paul Masters had removed a carefully folded copy of the document "History of 10,000 ton gadget" from Los Alamos in his shirt pocket.

Some details of the Project's work inevitably would leak and indeed some details of the work were transmitted to the Russians as the Project advanced during the war. The significance of those leaked details to the postwar development of Russia's first atomic bomb continues to be debated, but from the military point of view the leak of fragmentary details descriptive of the technology and design of U.S. atomic bombs was not as significant as a leak of information that would disclose the number of atomic bombs that the U.S. could employ in combat at any time during the war, or in later years as any military action might require. If a combatant can know the limit of an enemy's supply of arrows, bullets or atomic bombs, and thus know when that supply is significantly reduced or expended, that knowledge can be used in a variety of ways to achieve tactical and strategic advantage.

Given effective delivery systems, the number of atomic bombs that can be employed in combat at any time is dependent on the quantity of fissionable materials that has been produced. Therefore, the quantity of fissionable materials produced during the war was the most closely guarded secret of the Manhattan Project's weapons program. Only those few persons with some direct function or responsibility for U.S. military planning had a need to know the quantities of fissionable materials that had been produced.

Those persons were the Joint Chiefs of Staff and the Atomic Bomb Military Policy Committee, which committee provided that essential information to the Joint Chiefs. A spring 1943 secret memorandum issued by Gen. Groves ordered that within the Manhattan Project only the General himself, J. Robert Oppenheimer and Navy Capt. William Parsons would be informed of the quantity of fissionable materials as those materials were produced. However, it seems reasonable that Gen. Groves' deputy in the Project, Brigadier General Thomas F. Farrell, was informed and that the two civilians principally responsible for the Project's production of U^{235}, Philip H. Abelson at the Naval Research Laboratory and Earnest O. Lawrence at the Manhattan Project Oak Ridge site, could have calculated the quantity of production (Abelson) or would have been directly cognizant (Lawrence).

Before I contemplated a plan to locate and obtain the Project's U^{235} production data for the period prior to 1950 I decided I should ascertain the quantity of U^{235} that had been utilized by the Hiroshima Mark I bomb in order to know if the production data, when I obtained them, would show sufficient material by 17 July 1944 to enable a test of the

Mark I "Little Boy" bomb. In 1980 the quantity of U^{235} expended by the Mark I bomb at Hiroshima had not been published, but I had obtained important information about the design of that weapon that helped to calculate that quantity.

The Hiroshima Mark I weapon was a gun assembly design. One subcritical projectile of U^{235} was fired from the breech of a modified Navy 5" Navy anti-aircraft gun barrel (tube). At the muzzle end of the gun tube a fissionable "blind target" component of the Mark I weapon was composed of three or four discrete concentric rings of U^{235} partially sheathed in a depleted uranium tamper. The target rings and their tamper were contained within a very heavy steel encasement robustly thread-mounted to the muzzle end of the gun tube. The accelerated projectile entered the target case, which stripped the projectile's tamper; the projectile stripped of its tamper penetrated the concentric cavity of the target rings and was immediately stopped by the blind target case, which arrest assembled the projectile and target rings in a supercritical mass. By installation of one, two, three or perhaps four target rings the energy yield of the Mark I weapon could be varied. Neither the tampered projectile nor the tampered target assembly could exceed one tampered U^{235} critical mass for the particular geometries of those components.

The Classification Office at Los Alamos had told me the critical mass of U^{235} in a tampered sphere is 15.5 kg; a tampered U^{235} mass presenting non-spherical geometries, as were the geometries of the projectile and target rings, would permit a greater subcritical U^{235} accumulation than the spherical geometry. I knew that the fission of 1 kg U^{235} would yield about 22,000 tons TNT equivalent at 100 percent efficiency, but I did not know the efficiency achieved by the Mark I weapon.

The Mark I gun tube was manufactured at the Washington, DC, Navy Gun Factory and was modified from the standard 5" anti-aircraft gun tube in several ways. The tube was not rifled because the spin imparted to a projectile by the rifling of a gun barrel is advantageous to the stability of a projectile in exterior ballistic trajectory but was unnecessary to the Mark I projectile which did not enter an exterior ballistic trajectory and moved only within the interior of the gun tube, from the breech to the muzzle and target case.

The metal weight of the gun tube was significantly reduced because the Mark I gun would be fired only once and would not require the usual durability of an anti-aircraft gun barrel or gun tube subject to the strain and wear that result from multiple firing. The unidentified alloy of which the tube was forged was a lighter and stronger metal than the steel used in the conventional 5" anti-aircraft gun tube, but was sufficient with that lighter weight, with the enhancement of radial expansion (autofrettage) construction, to prevent rupture of the tube by the several tons per square inch gas pressure that resulted from the deflagration of the propellant charge.

I knew that the acceleration imparted to the Mark I U^{235} projectile within the gun tube had been accomplished by the same weight powder charge used to accelerate the standard 50-pound projectile for which the 5"/35 caliber Navy anti-aircraft gun was designed. I knew that the same powder charge weight imparted approximately the same rate of acceleration to the Mark I projectile as to the conventional 50-pound 5"/38 projectile. Therefore the weight of the Mark I U^{235} projectile would necessarily have been close to 50 pounds (22.68 kg). But I knew the Mark I U^{235} projectile had been partially sheathed in a depleted uranium tamper which represented some measure of the approximately 50-pound Mark I projectile.

Furthermore, I had learned that the Mark I U^{235} projectile was, for the 5" gun tube, a subcaliber projectile and was supported at rest in the tube and during acceleration by a sabot carrier. A subcaliber projectile of less weight than the gun's standard projectile, if fired with the same powder charge as that employed to propel the gun's standard projectile, achieves a significantly higher muzzle velocity (hypervelocity) than the muzzle velocity achieved by the gun's standard and heavier projectile. A hypervelocity plutonium projectile was contemplated for the Mark I weapon as a means to utilize plutonium in that weapon, but irreducible impurities in the plutonium produced by the Hanford reactors determined that even a hypervelocity plutonium projectile would not permit a rate of projectile acceleration sufficiently rapid to avoid partial detonation (predetonation) before the projectile and target components were fully assembled.

Although I have seen several documents in the Archives of Los Alamos National Laboratory that briefly discuss the application of sabot-carried projectile technology to the Mark I weapon the only published note, of which I am aware, that discusses that subject is found in the 1993 DOE publication *Critical Assembly* (Cambridge University Press) on page 84 and in the associated footnote:

"[Charles L.] Critchfield had worked on sabots before coming to Los Alamos. Because Oppenheimer believed that the projectile critical masses would need sabots, he considered Critchfield vital to the gun effort. Trained as a mathematical physicist, but also adept at ordnance experimentation, Critchfield was an ideal choice to translate gun concepts into experimental models. Born in Shreve, Ohio, Critchfield grew up in Washington, D.C., and attended George Washington University, where he became a protégé of Gamow and Teller. In 1943, while working for the Geophysical Laboratory on a project to perfect sabots, Critchfield was approached by both Oppenheimer and Teller and persuaded to join the project."

The diameter of a subcaliber projectile is smaller than the interior diameter (bore or caliber) of the gun tube or gun barrel from which the subcaliber projectile will be fired. A capability to utilize subcaliber ammunition in available guns in earlier military history was often useful or critical; the basic method of utilizing subcaliber projectiles was first devised by the French as early as 1848. Originally the capability to use subcaliber projectiles was important on the battlefield if, for example, the standard ammunition for a battery of 5" caliber guns was expended but a supply of 3" ammunition was available.

The wonderful but now difficult to find 1948 book *Rockets, Guns and Targets* provides a good summary of the sabot projectile research done by several contractors to the U.S. National Defense Research Committee (NDRC) and Office of Scientific Research and Development (OSRD) during World War II. The book is one volume of the series "Science in World War II" written and edited by OSRD staff and published by Little, Brown and Company, Boston. This

John E. Burchard, Damage Survey at Port Chicago, California, 29 July 1944 – 7 pages

volume of the series was edited by John E. Burchard. In the left margin the reader will find a link to Burchard's 7-page, 29 July 1944 report, "Damage survey at Port Chicago, California." Dr. Burchard's Port Chicago report was transmitted to Rear Admiral Julius A. Furer, Coordinator of Research and Development, U.S. Navy, via Vannevar Bush, Chairman, National Defense Research Committee. What appears to be a blind carbon copy of Burchard's report is held by Los Alamos National Laboratory Archives.

J. Robert Oppenheimer, 26 August 1944 comment on John E. Burchard's Damage Survey at Port Chicago

A 1-page manuscript note dated August 26, 1944 and signed "O." (Oppenheimer) provided by Los Alamos Archives in association with Burchard's Port Chicago report to Adm. Furer is also available as a link in the left hand margin. Oppenheimer's comment on Burchard's report states, "This seems a lot rougher than, but not inconsistent with, what our people reported & concluded." This note is the only certain evidence so far discovered that J. Robert Oppenheimer was personally involved in review and analysis of scientific reports descriptive of the Port Chicago explosion.

Twenty-two years of investigation into the Port Chicago explosion have produced tantalizing evidences of several as yet undiscovered Government reports and analyses that pertain to the explosion. One of those evidences is recognition that the copy of John Burchard's Port Chicago explosion report held by Los Alamos Archives was, at some later date, transmitted as "Enclosure (F)" of an undiscovered report. Demonstrably that undiscovered report to which Burchard's report was made enclosure "Enclosure (F)" originated at Los Alamos. The typescript notation "Enclosure (F)" which is added at the bottom of the first and last pages of the Los Alamos copy of Burchard's report was made on the same typewriter that produced Capt. Parsons' Port Chicago Disaster memoranda to Adm. Purnell. Similarly, the copy of Capt. Parsons' 31 August 1944 memorandum, "Port Chicago Disaster: Third Preliminary Report," as that copy was received from Los Alamos Archives, shows that memorandum was, after 31 August 1944, made "Enclosure (B)" of an undiscovered Port Chicago explosion report. Probably Capt. Parsons' 31 August 1944 Port Chicago memorandum to Adm. Purnell as “Enclosure (B)”, and John Burchard’s Port Chicago explosion report as “Enclosure (F)”, will be found to be parts of the same report, when that report is discovered.

I here transcribe John Burchard’s comment on page 319 of *Rockets, Guns and Targets* that reports the circumstances that prompted Burchard’s report on the Port Chicago explosion. References are made to the OSRD (OSRD divisions were identified by alphabetical designators) and the NDRC (NDRC divisions were identified by numerical designators). The NDRC was established during 1940 by Carnegie Institute President Vannevar Bush. In June 1941 Bush persuaded President Roosevelt to form the OSRD with Bush as director; Bush thereafter reported directly to President Roosevelt. Ongoing work conducted by the NDRC was folded into the OSRD in June 1941. Both organizations were established to mobilize civilian U.S. scientific personnel, their resources and competencies in support of the war effort.

“More often than not the apparent reluctance of the Services to seek the fullest co-operation [of NDRC and OSRD civilian scientists] was a matter of preoccupation or indifference rather than of veiled opposition. For example, when the great explosion occurred at Norfolk [Virginia] in September 1943, it did not occur to the Navy to request the admitted experts on damage working for [NDRC] Division 2 for assistance in evaluating the physical effects of the disaster. Yet such an evaluation was of great concern to the many [NDRC and OSRD] groups then interested in larger [atomic] bombs and far more powerful explosives [nuclear fission], who leaped for every piece of data however fragmentary which would or might bear on the question. When Burchard asked permission to send Bowman to make such an assessment, it was not only readily granted but Bowman was provided with every facility including observation aircraft, photographers, and guides. His report was distributed by the Navy. Yet, when the even greater explosion occurred some months later at Port Chicago (July 1944), again the matter had to be called to the attention of the Navy, which was again very co-operative, this time with Burchard, who made the survey en route home from the Pacific. The Navy was, of course, making extensive reports of both incidents but not from this [nuclear weapons] angle."

Because the scientific research that was contracted by the OSRD during the war to investigate sabot projectiles has not been generally reported, and because the Manhattan Project histories have, with one exception, failed to note that the Mark I weapon utilized a sabot projectile, and was the only World War II U.S. weapon to use a sabot projectile, we digress briefly from the principal topic of this chapter to reproduce text from *Rockets, Guns and Target* descriptive of the NDRC and OSRD sabot projectile research. The text is abstracted without the complete original continuity from Chapter XXXV, "The Quest for Hypervelocity," which reports the history of NDRC Division 1. Hypervelocity is the term which categorizes the velocity of projectiles that exceed the velocity of common military projectiles and has relevance to several applications including the greater armor-piercing capability of hypervelocity projectiles.

The principal contractor for NDRC sabot research was the University of New Mexico under the direction of Dr. E. J. Workman. Workman's progress and final reports have not been located nor can any Los Alamos archival records be discovered that substantially document the development of the Mark I sabot projectile. But because "By the end of December, 1942, Workman could report that various designs of sabot projectiles had already been developed and were adaptable to nearly all existing guns" the presumption is reasonable that Workman developed the projectile sabot carrier for the Mark I modified Navy 5" caliber gun tube in collaboration with Critchfield after Critchfield arrived at Los Alamos in 1943. It is of note that during World War II Germany did develop hypervelocity armor-piercing sabot-carried projectiles that disabled a great number of the Allied forces' combat tanks during the North African Campaign.

" 'Sabot' is the French for 'wooden shoe,' and in an ordnance context means the part used to fill the space between a small projectile and a larger gun bore; it is made detachable and is to be dropped as the projectile leaves the muzzle. Such devices were used as early as 1848 in order to adapt special projectiles for use in available guns; they were generally made of wood (hence sabot). In World War I the French used sabots to adapt 37-mm. ammunition for use in the 75-mm. gun. This gun had a low rifling pitch and the light projectiles were unstable in flight and none too accurate. American ordnance experts, mindful of this experience, and despite awareness of a reviving interest abroad, were not very interested in the sabot projectiles as practical ammunition. At the time when Division 1 took up the cudgels the sabot had a bad name in American military circles and the division and its contractors therefore faced an uphill fight against opposition which was not entirely made up of the technical difficulties inherent in the problem.

"The active interest of Division 1 in developing a sabot projectile was aroused by letters from [Vannevar] Bush to [Richard] Tolman on the 23rd of March, 1942. The Divisional staff was of course already familiar with the early history of the sabot but now it began to study its potentialities in earnest.

"In August, 1942, the University of New Mexico was awarded a contract for the design and development of subcaliber projectiles under the direction of Dr. E. J. Workman. Ultimately $230,000 [or, elsewhere, $208,000] was allocated for the work there. By the end of December, 1942, Workman could report that various designs of sabot projectiles had already been developed and were adaptable to nearly all existing guns as well as being suitable for mass production. The report stressed the advantages of the sabot projectile in its greater chance of scoring a hit on a moving target [because of a flatter trajectory] and its superior armor-penetration qualities."

To calculate the quantity of U^{235} expended by the detonation of the Mark I weapon at Hiroshima I worked four months with a four-function electronic calculator to determine, as I published my finding in 1982, that "the active nuclear component of the weapon detonated at Hiroshima could have been as much as 60 kilograms of U-235. More probably, however, the total U-235 component of that weapon was nearer to 45 kilograms." Seven years later, in summer 1989, I met with Stanford University Linear Accelerator Center (SLAC) physicist Pierre Noyes, a strange man then sympathetic with the styles of social improvement instituted by Chairman Mao Tse-tung in China and President Fidel Castro in Cuba.

In that meeting Professor Noyes told me that a Japanese physicist the previous year had undertaken to calculate the quantity of U^{235} employed in the Hiroshima bomb. The Japanese physicist's finding and mine were within 3 percent of the same range of weight, which difference arose because we started each with a slightly different degree of U^{235} enrichment in the material utilized by that weapon. In 1990 I found the very important Manhattan Project manuscript document written by Atomic Bomb Military Policy Committee alternate member Harvard University President James B. Conant, "Findings of Trip to L.A. [Los Alamos], July 4, 1944," which defines "50 '25' [U^{235}] kg" to be the active component of the Mark I weapon.

During the months that I had been occupied with those calculations, and with my duties in the Energy Research and Development Institute, I had made inquiries among my contacts in the Department of Energy, particularly in the Grand Junction, Colorado, offices, to learn which DOE offices, and who particularly in those offices, would have access to the U^{235} data for the years 1943-1949. As the Energy Information Coordinator for the State of New Mexico I said I wanted to put together a table of U^{235} production data that would demonstrate the state's historical contribution to that production. The several men I spoke with at DOE, Grand Junction, told me they had never seen that data and had frequently wondered what the numbers would be for those years.

By late November 1980 my DOE contacts had identified two men, one in each of two DOE offices, who my contacts had ascertained would have access to the U^{235} production data for the years 1943-1949: Don M. Cox in the DOE Enrichment Office Division at Oak Ridge, Tennessee, and Jim Staggs in the DOE Office of Uranium Resources Enrichment, Planning and Analysis Branch in Washington, DC. On 5 December 1980 I spoke by telephone with both those men and verbally obtained the U^{235} production data for the years 1943-1949. At that time both men believed those data had been declassified by the terms of a recent general declassification order that covered a wide range of Manhattan Project documents.

Peter Vogel to Don M. Cox, letter of 9 December 1980

On 9 December I transcribed the production data I had received verbally on 5 December from Cox and Staggs into a 2-page letter to Cox, which I transmitted on the letterhead of my office in the New Mexico Energy and Minerals Department, Energy Resource and Development Division. Because I considered that information and those data would be of significant historical importance as well as important historical significance I made a reporter's notes of all those inquiries that led to my 5 December request for those data and on 10 December I mailed those notes and a copy of my letter to Don Cox to David Weir, co-founder of the Oakland, California, Center for Investigative Reporting.

Don Cox, at Oak Ridge, provided the U^{235} production data for the years 1943 through 1949 in kilograms "equivalent top product" [ETP] which he explained is uranium enriched to 93.15 per cent U^{235}, and is uranium enriched in the U^{235} isotope to the degree requisite to the most efficient use in nuclear fission weapons. Kilograms ETP are approximately converted to kilograms U^{235} by multiplying units of ETP by 0.93. Therefore, the data provided by Cox show 74 kg U^{235} were separated during 1943, and 93 kg were separated during 1944.

Jim Staggs, in Washington, DC, provided the U^{235} production data for the years 1943-1949 in Separative Work Units (SWU), which he explained were approximately converted to kilograms U^{235} by dividing the number of SWU by the atomic weight of the U^{235} isotope, 235. Therefore, the 15,000 SWU accomplished during 1943 equates to 63.5 kg ETP which, multiplied by 0.93, gives 59 kg U^{235} separated during 1943. For 1944, 20,000 SWU equates to 85 kg ETP and 79 kg U^{235}.

The two sets of U^{235} Manhattan Project production data provided by Cox and Staggs document that either 74 kg or 59 kg were produced during 1943. Either quantity by the end of 1943 provided the requisite 50 kg U^{235} to permit the detonation of one Mark I weapon at Port Chicago the evening of 17 July 1944, which would have produced an explosive energy equivalent to 12,500 (12.5 kt) tons of TNT.

Although the requisite 50 kg U^{235} existed by 17 July 1944 to permit the detonation of a 12.5 kt energy yield Mark I weapon at Port Chicago the total energy yield of the Port Chicago explosion was equivalent only to 1,577 or 2,100 tons of TNT. The energy of the Port Chicago explosion was therefore grossly inconsistent with the detonation of a Mark I weapon, even if the weapon had been configured to the minimum energy option permitted by variation of the number of fissionable elements (rings) that could be installed into the Mark I's blind target component affixed to the muzzle end of the gun tube.

The gross inconsistency between the energy of the Port Chicago explosion and the minimum energy of the Mark I weapon was perplexing and seemed to defeat the thesis that an atomic bomb had been detonated at Port Chicago—until 1993 when I discovered the Manhattan Project's essentially unreported development of the Mark II weapon that required only 9 kg U^{235} to produce a nuclear fission explosion equivalent to 1,000 tons of TNT. On 4 July 1944 the Mark II with a nominal yield of 1 kt TNT equivalent was forecast to produce, from an optimal air burst, Class B damage within an area of 2-5 square miles and correspondingly less if the weapon were detonated in a surface burst, as was the circumstance of the Port Chicago explosion.

An optimal air burst occurs when a weapon is detonated at the correct height in air above a target to maximize structural damage beneath the exploded weapon by optimal distribution of the generated blast wave overpressure to the target area. At a height above optimal the radius of effective overpressure in the target area is reduced by blast wave energy dissipation in air. At a height below optimal the radius of effective overpressure in the target area is reduced by partial conversion of blast wave energy to earth shock and by above-horizontal angular reflection of the blast wave from the earth or water surface lying directly below the burst.

The detonation of a weapon essentially upon an earth surface produces the least efficient utilization of blast wave energy if the military objective is the destruction and damage of surrounding surface structures. This inefficiency arises, first, because a very considerable portion of the energy of an earth surface detonation is directly coupled to the earth and transmitted as earth shock, which may only slightly affect surrounding surface structures. The second reason a surface burst is ineffective in propagating an efficient blast wave that will affect local structures is that a large fraction of the energy generated by a surface burst is immediately reflected by the earth surface straight up from the point of the explosion.

In addition to that portion of the blast energy reflected straight up from the explosion, some of the blast energy of a surface burst is reflected at all angles intermediate between vertical and horizontal. Most of the blast energy that is reflected from the earth in a surface explosion is wasted to the purpose of causing destruction and damage to local structures—except tall buildings surrounding the point of a surface explosion will suffer the incident and earth-reflected blast wave from the bottom of the structure to the top. That effect of earth-reflected blast energy significantly contributed to the destruction and damage caused by the proximate surface detonation that occurred 19 April 1995 at the Murrah Building in Oklahoma City. For structures of lower height only that portion of the blast wave propagated essentially horizontally from a surface burst will be militarily effective.

If destruction of a large area is the military objective, as was the objective in the bombing of Hiroshima and Nagasaki, the burst must be made above the target at the correct height to optimally radiate an effective overpressure to the greatest radius given the energy yield of the weapon. Adjustment can be made to the height of the burst to induce an earth shock of sufficient magnitude to weaken the structural integrity of some particular class of structure, which weakened structures would then be collapsed by the pressure of the following blast wave.

On 4 July 1944 the optimal air burst of a 1 kt Mark II weapon was forecast to cause Class B damage within an area of 2-5 square miles depending on the surface terrain of the target area and the durability of target structures. The Port Chicago surface explosion of 1,577 to 2,100 tons TNT equivalent resulted in Class B damage to a radius of 2,500 feet, which calculates to an area of 0.7 square mile (Area = $3.14r^2$, where r [radius] equals 2,500 feet). Optimal military use of the atomic bombs in development by the Manhattan Project in 1944 would require airplane delivery and a fusing mechanism that would guarantee that a bomb released from a delivery aircraft would detonate at the optimal height above the intended target.

By the end of 1943 the Manhattan Project had produced either 74 or 59 kg U^{235}. The availability of 9 kg to permit the proof of a Mark II weapon at Port Chicago 17 July 1944 is thus established. But we can also interestingly examine the 1943, 1944 and 1945 production data to assess the validity of the anecdotal claim of the Manhattan Project historical literature that by 6 August 1945 only sufficient U^{235} was available to enable detonation of one Little Boy Mark I weapon, the weapon detonated at Hiroshima, which employed 50 kg.

During 1943 and 1944 a cumulative total of either 167 kg (Cox) or 138 kg (Staggs) U^{235} were separated. Those two totals, reduced by the 9 kg U^{235} expended in the proof of Mark II, allowed a remaining total of either 158 kg or 129 kg U^{235} at the end of 1944. Additional separation was accomplished during year 1945—either 289 kg (Cox) or 197 kg (Staggs) U^{235}.

However, the material form of the U^{235} produced by the Manhattan Project required conversion to metal and other fabrication processes before the material could be disposed in a weapon. I conclude that only the U^{235} produced during the first six months of 1945 should be added to that which was available at the end of 1944 in order to ascertain the quantity of U^{235} available for weapon use by 6 August 1945. The annual production data provided by Cox and Staggs are not broken down by month of production, so some estimate must be made of the fraction of 1945 production that was accomplished by the end of June 1945.

If one-half the 1945 production had been accomplished by the end of June, either 144.5 kg (Cox) or 98.5 kg (Staggs), were available from 1945 production for weapon use by 6 August 1945. Those amounts separated during the first six months of 1945, added to material remaining from 1943 and 1944 production, totaled either 302.5 kg (Cox) or 227.5 kg (Staggs)—sufficient material for either 6 or 4 of the Mark I bomb.

If one-third the 1945 production had been accomplished by the end of June, either 96 kg (Cox) or 98 kg (Staggs) were available from 1945 production by 6 August 1945. Those amounts separated during the first six months of 1945, added to the material remaining from 1943 and 1944 production, totaled either 254 kg (Cox) or 194 kg (Staggs)—sufficient material for either 5 or 3 of the Mark I bomb.

If one-fourth the 1945 production had been accomplished by the end of June, either 72 kg (Cox) or 49 kg (Staggs) were available from 1945 production by 6 August 1945. Those amounts separated during the first six months of 1945, added to the material remaining from 1943 and 1944 production, totaled either 230 kg (Cox) or 178 kg (Staggs)—sufficient material for either 4 or 3 of the Mark I bomb.

My sense of the matter is that one-fourth the total 1945 U^{235} production had been accomplished by the end of June, so that by 6 August 1945 the total available quantity of U^{235} was either 230 kg or 178 kg—equivalent to either 4 or 3 of the Mark I bomb. But I introduce one more variable into this assessment of the number of Mark I bombs that were available by 6 August 1945 for operational purposes.

There is archival documentary evidence and germane attestations in the historical literature which show that Chief of Staff General Marshall planned the use of 9 of the Mark II tactical weapons to prepare three beaches of the Japanese home islands for an Allied amphibious invasion if that invasion had been necessary to finally defeat the Empire. General Marshall planned the use of three of the Mark II to effect the destruction of beach obstructions and shore defenses on each of three invasion beaches; three of the Mark II were planned to effect the destruction of defensive installations and troops immediately behind the three invasion beaches; and three of the Mark II were planned to be employed against Japanese troops and military equipment that U.S. military planners anticipated would advance to meet the invasion from more distant locations.

Those 9 Mark II weapons would each require 9 kg U^{235}, for a total of 81 kg which quantity would have been reserved from the total available by 6 August 1945. Subtracting that 81 kg reserve from the totals of either 230 kg (Cox) or 178 kg (Staggs) U^{235} available by 6

August 1945, the U.S. had available either 149 kg or 97 kg U^{235} to provide the operational capability of either 2 or 1 of the Mark I strategic weapon and the reserve operational capability of 9 of the Mark II tactical weapon. The number of either 2 or 1 of the Mark I is accordant with the anecdotal claim of the Manhattan Project historical literature that by 6 August 1945 only sufficient U^{235} was available to enable the detonation of one Little Boy Mark I weapon, the weapon detonated at Hiroshima, which employed 50 kg U^{235}.

All the U^{235} produced during 1943 and that produced during 1944, prior to 17 July, was the conjunct result of two isotope separation processes: the liquid thermal isotope separation method developed by Philip Hague Abelson at the Naval Research Laboratory and the electromagnetic isotope separation process developed by Earnest Orlando Lawrence of the University of California, Berkeley, Radiation Laboratory. Chapter 12 provides review of those two technologies and how they operated in conjunction to produce the first U^{235} in weapon quantity during 1943, 1944 and the first six months of 1945.

Photographs and illustrations credits.

“John E. Burchard, Damage Survey at Port Chicago, California, 29 July 1944.” Source: Los Alamos National Laboratory Archives, Collection A-84-019, Series 5, 319.1 Port Chicago Disaster Reports, 7/17/44 - 11/16/44 & undated (Folder 29-1) [Formerly Folder 37-6].

“J. Robert Oppenheimer, 26 August 1944 comment on John E. Burchard’s Damage Survey at Port Chicago, California.” Source: Los Alamos National Laboratory Archives, Collection A-84-019, Series 5, 319.1 Port Chicago Disaster Reports, 7/17/44 - 11/16/44 & undated (Folder 29-1) [Formerly Folder 37-6]

“Peter Vogel to Don M. Cox, letter of 9 December 1980.” Source: Correspondence, Peter Vogel.