CHAPTER 2

Love at First Sight: 1939–1945

The Office of Scientific Research and Development was organized to coordinate weapons development and medical care for the U.S. military as World War II approached.

The Office of Scientific Research and Development (OSRD) was the product of the leaders of the U.S. scientific community, among them Vannevar Bush, former vice president of engineering at the Massachusetts Institute of Technology, head of the Carnegie Institution of Washington, and director of the National Defense Research Committee (NDRC). Bush's principal colleagues were James B. Conant, a distinguished chemist and president of Harvard University; Frank B. Jewett, director of Bell Telephone Laboratories and president of the U.S. National Academy of Sciences; and Karl T. Compton, president of MIT. A. N. Richards, vice president for medical affairs of the University of Pennsylvania, was chairman of the OSRD's Committee on Medical Research. These individuals had earned the trust and respect of American scientists, but, most important, they had the support of the White House, from which the official and financial strength of the OSRD would eventually come. Together, they created a centralized, civilian research organization that would develop weapons and improved medical care for the war they believed that the United States would probably enter.

The NDRC represented the first attempt to put U.S. science and technology on a wartime footing. At the urging of Vannevar Bush in June 1940, President Roosevelt created the NDRC—his personal advisory committee for wartime science and technology—composed of civilian scientists who maintained a broader perspective than military advisers did. Although the NDRC could draw from its own funds to perform its assignments, and although Bush had direct access to the president, the NDRC was not comprehensive enough to translate its recommendations into action. In the summer of 1941, urged once again by Bush, Roosevelt created the OSRD and assigned Bush to coordinate all scientific and technological actions connected with the national preparation for defense in a world at war.

The OSRD was organized loosely on purpose: this encouraged initiative and innovation on the part of working scientists and engineers. Perhaps most significant was that the OSRD opted not to construct or operate laboratories of its own. Instead, it turned largely to universities, especially those that had previously demonstrated the capability to carry out broad-ranging assignments. The OSRD broke new ground by contracting universities on a cost basis that included expenses for universities' overhead. These contracts were drawn without the restriction to safeguard against profiteering ordinarily included in most contracts during WWII. The contracts were so successful—no mismanagement was found in later surveys—that they became the basis for federal funding of university scientific research after the war.

The flexible organization developed by the OSRD was able to merge young military personnel—often with battle experience—with civilian scientists and soon earned the respect of the senior officers responsible for weapons and weapon development in the armed services. Without the complete cooperation of those officers, advances in weapons and medicine emerging from the OSRD might have been delayed or even prevented from reaching the battle areas. At the same time, Bush and his colleagues knew the limits of civilian interference with the military and scrupulously stayed back from those limits. The smooth, productive way in which the largely civilian OSRD joined with and was accepted by the military in WWII was unprecedented. It has been a model for cooperation between civilian scientists and the military ever since.

Soon after the end of World War II, a series of books available to the general public under the title *Science in World War II* described the organization and accomplishments of the OSRD, which had been secret during the war. This series, consisting of seven parts contained in more than twenty volumes, explains in detail the areas in which the OSRD functioned and the breadth of its contributions to the science and technology of modern war. The titles of the seven parts of *Science in World War II* make clear that the work of the OSRD covered the entire allied war effort in science, technology, and medicine, excepting only the atomic bomb project: "New Weapons of Air Warfare," "Combat Scientists," "Advances in Military Medicine," "Rockets, Guns, and Targets," "Chemistry," "Applied Physics: Electronics; Optics; Metallurgy," and "Organizing Scientific Research for War." All were written by the people who did the work. There is also an official history of the OSRD—*Scientists Against Time*, by James Phinney Baxter III, with an introduction by Vannevar Bush—which was published in 1946.

The OSRD acted as stimulus, research agency, and mediator between civilian scientists and the military to bring about many important developments in weaponry.

Examples of the scope and variety of OSRD achievements are as compelling as they are significant. One of them, radar (radio detection and ranging) became a marvelously versatile instrument of warfare and transportation safety, revolutionizing both those areas. A radar unit broadcasts a radio beam focused by a parabolic reflector, like the light from an automobile headlight. A receiver in the unit picks up a portion of the broadcasted beam reflected back by the object or target it strikes. By measuring the total time required for the radio beam to travel to the target and return to the unit, the distance or range to the target is determined. The direction in which the beam is aimed locates the position of the target in space. The picture of an area scanned by radar, as described by one of the pioneers of radar development, Sir Robert Watson-Watt, "is a map-like outline in which seas, lakes and waterways remain black. . . . Coastlines with their cliffs, bays and inlets show up clearly as outline map features because they scatter radiation back to its source. . . . The inland landscape is a nondescript intermediate tone; and . . . 'the works of man'—camps, hangars and above all towns and cities—stand out brightly."[1] For locating the range and direction of distant aircraft, the efficiency of radar was unparalleled.

As early as 1925, two scientists at the Carnegie Institution of Washington, Gregory Breit and Merle A. Tuve, used pulses of radio waves to measure the height of the ionosphere, the layer of ionized air at high altitude that reflects radio waves back to Earth. This method of sending out a train of radio pulses and timing the echo became the standard for study of the ionosphere the world over. The idea of using the technique to detect aircraft and ships soon was taken up by scientists in the United States, England, France, and Germany. By the end of 1935, stimulated by fear of German air attack, the British constructed a chain of five stations for the radio location of aircraft on the east coast of England. The United States was not far behind and installed radio-locating units on its battleships *New York* and *Texas* in 1938 and on the carrier *Yorktown* in 1940. A radar unit developed by the U.S. Army detected Japanese aircraft approaching Pearl Harbor, but the observation was disregarded and the device turned off because it was thought to be malfunctioning.

The major advance in radar technology, however, came with the discovery in 1940 of a revolutionary radio wave generator, the resonant cavity magnetron, capable of producing extraordinarily large microwave power for high-resolution observation of very distant targets. The resonant cavity magnetron was the product of British physicists led by M. L. Oliphant, a professor at the University of Birmingham. The prototype, small enough to be carried in a briefcase, was brought to the United States by a British scientific mission, so the story goes, with the magnetron wrapped in newspaper and hand-delivered by Oliphant.

The advent of the magnetron made possible the design and construction of microwave radar units for ships, planes, and tanks—for all the armed services—units that provided enormous range and high resolution. The NDRC, already deeply immersed in radar research and development at the Radiation Lab of MIT and soon to come under the aegis of the OSRD, undertook and completed this task. This new superior radar used by the armed forces of Britain and the United States tipped the balance of the war on land, on sea, and in the air in their favor. By the end of the war, three billion dollars' worth of radar units designed and engineered in the MIT Radar Laboratory (Rad Lab) had been produced in industry and delivered to the armed services, as well as twenty-five million dollars' worth of radar gear supplied directly by the Rad Lab. This involved a hundred and fifty separate and distinct radar systems varying in size from lightweight compact sets for fighter planes and PT boats to the Microwave Early Warning system, housed in five trucks and manned by a company of soldiers. Apart from their use by armed services everywhere, the descendants of these systems are used today in every major airport and airliner in the world, and all but the smallest seagoing vessels rely on them for their safety.

A second example of an OSRD achievement, less widely known by the public then and now, was the radio proximity fuze. This development was a solution to the problem of how to damage or destroy a target that was not directly struck by a projectile—say, an antiaircraft shell—but where instead there was a near miss, that is, within the explosive pattern of the projectile fragments of the shell. The radio proximity fuze was a device closely related in concept to the idea at the heart of radar. Each device broadcast radio pulses, some of which would be reflected from a target to a receiver also in the device, and the received information would provoke action by the device itself. It would be displayed as an active, up-to-date map in a radar set or would trigger the explosion of the antiaircraft shell in which it was mounted, if the strength of signal reflected from the target indicated that the shell was within near-miss distance.

While the idea for the radio proximity fuze was simple and straightforward, implementation of the idea was not. The fuze had to be small enough to fit into a projectile, if possible a five-inch shell, leaving most of the room for explosive, and its components so ruggedly built that they would withstand the accelerations and shocks of being fired from a cannon. The requirements for miniaturization and resistance to mechanical shock had prevented earlier successful manufacture of a proximity fuze, although many patents had been issued in different countries. The Germans, for example, had at various times worked on more than thirty designs and were working on a dozen as late as 1944.

Problems with the design and manufacture of proximity fuzes had been recognized by the U.S. Navy by 1940 (and before that by the British Royal Navy). In that year, the NDRC got involved. At first, both the Americans and the British concentrated on proximity fuzes of a type that might be incorporated in bombs or rockets, because the space limitations in those projectiles were not as restrictive as in artillery shells. But a little later, the NDRC, by then a section within the OSRD, moved toward a radio proximity fuze for antiaircraft shells. Intensive research indicated that rugged, miniature electronic tubes and other components of a radio set capable of sending and receiving its own signal when reflected from a target aircraft were not as difficult to design and build as had been thought originally. Under pressure from the navy, development work at several laboratories—initially the Carnegie Institution of Washington and the National Bureau of Standards and later at the newly formed Applied Physics Laboratory of the Johns Hopkins University—went forward rapidly to test whether the components of the fuze would survive the firing of a shell and whether the necessary safety devices in the fuze to ensure against early misfirings were satisfactory. Finally, shells equipped with radio proximity fuzes had to demonstrate a satisfactory level of efficiency in shooting down aircraft.

Within two years, the fuze was extensively tested in the field in a variety of shells and demonstrated to be highly efficient against aircraft and safe for the personnel who used it. Soon after Pearl Harbor, the fuze was put into full-scale production. At the insistence of the U.S. Navy—a remarkable vote of confidence—the OSRD undertook arrangements for production and quality control. At the height of production there were three hundred companies and two thousand different plants at work on the radio proximity fuze, and nearly two million fuzes were manufactured each month.

Prior to WWII it was estimated that the antiaircraft fire from even the most efficient battery required more than two thousand rounds to bring down one of several attacking planes. The inaccuracy was more the result of shells' failure to explode at the correct range than of poor aim. The range at which a shell would burst was preset by hand in time-fuzed shells just before they were fired. A time-fuzed shell might explode anywhere along a thousand-foot length of its path as a result of the uncertainties inherent in the time-fuzed shells themselves, even if the range to the target had been estimated correctly (which was very hard to do for a rapidly moving airplane). The radio proximity fuze eliminated that defensive weakness just when the needs of the United States and Britain were most desperate. German dive bombers had demonstrated unequivocally in attacks on Belgium, Holland, and France that airpower was to be a dominant factor in WWII. The German campaign in Norway taught a lesson to the British about the ability of the airplane to neutralize seapower, as did the Japanese campaign in the Far East. The security of army ground forces as well as the mobility of fleets were threatened as never before.

The first large-scale use of the fuze was by the U.S. Navy in the Pacific. Improved gun directors—devices driven by a radar unit that automatically aimed and found the range for gun batteries—had somewhat increased antiaircraft battery efficiency but much remained to be done by the radio proximity fuze. Bush, a conservative engineer, estimated that the proximity fuze increased the effectiveness of naval five-inch gun batteries by a factor of seven. Put another way, this was the same as having seven times as many five-inch batteries on a ship.

Another defensive application of the fuze was in combating the first so-called flying bomb, the V-1. This is an extraordinary saga in its own right. In late 1943 secret intelligence indicated that the Germans were setting up to launch robot bombs, the V-1s, against London and southern England, where the Allied invasion force would be gathered in preparation for the invasion of France in mid-1944. It was absolutely imperative to find an effective countermeasure to that threat, and months before the first of the V-1 bombs were launched, intelligence services and the OSRD moved to do so.

The V-1 traveled at three hundred fifty miles per hour, about as fast as fighter planes of the time. The available defensive measures against it included fighter planes that would meet the robots at as great a distance from Britain as possible and, mostly as a last resort, antiaircraft fire at the coasts. When the bombs were first launched against London in June 1944, interceptor aircraft carried the burden of defense. A number of V-1s were shot down, but the toll of life and property destroyed by the bombs that penetrated the interceptor shield was large, and the implication for Allied support of the recently mounted Allied invasion of France was ominous. In the few months between the arrival of the first shipment of proximity fuzes in England and the most intense of the V-1 attacks, however, the British and Americans set up a number of defensive units on the coast of the English Channel that were ready by the second week of July. Each unit consisted of an advanced technology radar installation that fed a high-precision computerized electromechanical system that directed a battery of guns equipped with proximity-fuzed shells.

The V-1 attacks lasted eighty days. During the last four weeks of that period, destruction of V-1s by proximity-fuzed antiaircraft fire steadily grew. In the first week, 24 percent of the targets engaged were destroyed by ground fire using proximity-fuzed shells; in the second week, 46 percent; in the third, 67 percent; and in the last week, 79 percent. The V-1 ceased to be a serious threat.

The system of radar-computerized gun directors and radio proximity fuzes dealt a deadly blow to German forces in still another way. Authorization to use proximity fuzes over land was delayed by the U.S. Joint Chiefs of Staff's concern that an unexploded dud might be retrieved and copied by the enemy. The Joint Chiefs were ultimately persuaded that the time between capture of a dud and the availability of a manufactured supply of fuzes would be long, possibly two years, given the situation in Germany at end of October 1944. After the defeat of the V-1s, the proximity fuze was thus released for use over land, again mostly in conjunction with radar and automated gun directors. The fuze went into use against ground troops and armor at the time of the Battle of the Bulge, the last major German offensive of the war, which had been planned to take place in a period of bad weather when Allied planes could not perform effectively. Extensive studies of how to trigger radio proximity fuzes to detonate howitzer shells at varying heights above land targets had shown them to be more than five times as effective as contact fuzes in the same circumstances. The result was that German divisions, massed in the open and feeling secure against both Allied aircraft and the usual artillery fire, were decimated by proximity-fuzed artillery shells employed efficiently both day and night. The effect was summed up in a letter from General George Patton to General Levin Campbell, Chief of Ordnance, on December 29: "The new shell with the funny fuse is devastating. The other night we caught a German battalion, which was trying to get across the Sauer River, with a battalion concentration and killed by actual count 702. I think that when all armies get this skill we will have to devise some new method of warfare. I am glad that you all thought of it first."[2]

Today, artillery shells and bombs and rockets have evolved far beyond the technology of WWII, but the proximity fuze was a breakthrough in the same sense that radar was a breakthrough. Both revolutionized warfare during WWII and for the next half century. Begun somewhat earlier under the British and the NDRC and perfected and manufactured under the aegis of the OSRD, the work on radar was carried out at the Massachusetts Institute of Technology (MIT) Radiation Laboratory at about the same time that the proximity fuze was developed at the Johns Hopkins University Applied Physics Laboratory. These and other university laboratories, newly staffed with university scientists and engineers called to the war effort by the manpower commission of the time, reflected the coordination of civilian and military talent and resources imposed by the OSRD.

FIGURE 2.1. *Top*: National Defense Research Committee. *Front row, left to right*: F. B. Jewett, president of the National Academy of Sciences; Rear Admiral J. A. Furer, U.S. Navy, coordinator of research and development, Navy Department; J. B. Conant, president of Harvard University; R. C. Tolman, dean of the Graduate School, California Institute of Technology. *Rear row, left to right*: K. T. Compton, president of Massachusetts Institute of Technology; Roger Adams, head of the chemistry department, University of Illinois; C. P. Coe, U.S. commissioner of patents; Irvin Stewart, executive secretary of the Office of Scientific Research and Development.

Source: James Phinney Baxter III, *Scientists Against Time* (Boston: Little, Brown, 1946), p. 15.

Bottom: The Committee on Medical Research, Office of Scientific Research and Development. *Left to right*: Dr. R. E. Dyer, Public Health Service; Rear Admiral Harold W. Smith, U.S. Navy; Dr. A. Baird Hastings; Dr. Chester S. Keefer, medical administrative officer; Dr. A. N. Richards, chairman; Dr. Lewis H. Weed, vice-chairman; Brigadier General James S. Simmons, U.S. Army; Dr. A. R. Dochez; Dr. Irvin Stewart, executive secretary.

Source: James Phinney Baxter III, *Scientists Against Time* (Boston: Little, Brown, 1946), p. 124.

Another achievement of scientists in the OSRD, the result of medical research on blood, illustrates the variety of the agency's research and the wisdom of its organization.

Casualties involving hemorrhage, burns, and shock were known before WWII to require immediate treatment to restore blood volume to normal levels. Treatment of victims of auto accidents and other violence in peacetime had made this clear. Before WWII, however, restoring blood to a traumatized person meant having a donor present so that blood could be pumped directly from the donor to the recipient under sterile conditions. This was not possible on the battlefield, and the armed services encouraged the medical and chemical communities to find ways in which blood and blood derivatives might be stored for long periods and made available on demand. Today, the use of stored blood and blood plasma and its components in hospital operating and emergency rooms is commonplace, but in 1940 neither whole blood, nor plasma, nor its derivatives were available. Prompted by the navy, the Department of Physical Chemistry at Harvard University set out to find a remedy and soon was working in conjunction with other medical institutions and the American Red Cross, all coordinated by the Committee on Medical Research (CMR), a section of the OSRD.

It was not by chance that the physical chemists at Harvard were selected for this purpose. They had been studying the physical and chemical properties of proteins, including blood proteins, for more than twenty years and were well known for their accomplishments. It was quickly recognized that in certain circumstances components of blood other than red blood cells were especially valuable. For example, albumin, constituting 60 percent of blood plasma proteins and of small molecular size, was expected to draw fluid back into the blood vessels from the tissues and increase blood volume in a traumatized circulatory system. In extensive clinical testing done at CMR institutions during the winter of 1941–1942, this hypothesis was proved to be correct. Albumin was completely stable and nontoxic at all temperatures, and measurements made of plasma volume in patients before and after injection demonstrated its effectiveness. Human albumin, in concentrations of twenty-five grams of dissolved albumin in one-fifth of a pint of water—more than the amount of albumin in five times that volume of plasma—was formally approved for distribution to the military for transfusions in February 1942.

The attack on Pearl Harbor on December 7, 1941, came just before that formal recommendation. Only a small quantity of processed albumin remained at the time; most of it had been used in the successful clinical tests. But the navy was determined to do its best for the burned and wounded at Pearl Harbor. A telephone call from A. N. Richards, chairman of the CMR, to Edwin Cohn at Harvard set in motion the "as-soon-as-possible" shipment of the last of the albumin supply to the senior medical officer at Pearl Harbor. The results confirmed all the earlier clinical tests: burn victims and those suffering from loss of blood for myriad other reasons, many in deep shock, were rejuvenated and given at the least a temporary lease on life during which additional treatment could be provided.

There is much more to this story of how blood and blood derivatives were made available for immediate, on-the-spot transfusions. The American Red Cross supervised nationwide blood collection. Researchers discovered how to isolate and store other blood components, including whole blood itself, and how to manufacture—while scrupulously preserving sterility—enormous quantities of blood and blood plasma. Thirteen million pints of blood were collected, processed, and distributed to American armed forces everywhere by the end of WWII. And ever since, blood transfusions by the methods first developed during the war have been an invaluable weapon in the physician's arsenal.

Descriptions of these specific accomplishments of the Committee on Medical Research of the OSRD illustrate the magnitude of the challenges it accepted and successfully met. While the problem of blood was being solved, the CMR was also seeing to the production and distribution of sulfa drugs and penicillin on a worldwide scale. At the beginning of the war, there was not enough penicillin in the United States—or anywhere else—to treat a single patient. Imagine the labor and organization required to produce supplies adequate for the entire armed services. These medical products, antibiotics, blood derivatives, and whole blood furnished the life-sustaining support that made the extraordinary advances in WWII surgery possible. Two statistics sum it up: in the U.S. Army, including overseas forces in WWI, the death rate from all diseases was 14.1 per 1,000; in WWII, it was reduced to 0.6 per 1,000. Furthermore, despite the devastating antipersonnel weapons of WWII, the fatality rate among the wounded was lower than in any war in history.

The other major organization for science and technology in WWII was the Manhattan Project, the single purpose of which was to produce an atomic bomb.

"The Manhattan Project" was the popular name given later in the war to an organization very different from the OSRD, although its origins were similar. It seems likely that the term "Manhattan" was originally suggested because the earliest U.S. work on fission was at Columbia University, in Manhattan, New York. Later, when the army became involved, its first project office was also in Manhattan. In both cases, the OSRD and the Manhattan Project, scientists and educators brought to the government's attention scientific problems relating to the situation in Europe and urged the need for U.S. action to prepare to meet them. Indeed, the OSRD and the Manhattan Project were initially joined at the hip: the prospects leading to the Manhattan Project had been surveyed and assessed in studies by committees of scientists and engineers assembled by the OSRD. The OSRD, however, undertook and oversaw a multitude of diverse technical and medical problems, while the Manhattan Project was aimed at one vital goal: the production of an atomic bomb.

Before WWII, the heaviest stable element in the periodic table of the elements was uranium, which is found in ores deposited in several places on the planet. Experiments done in 1938 in Europe, mainly in Germany, indicated, however, that the uranium nucleus was much closer to the brink of instability than anyone had thought. These experiments, which took place a few years after the Nazis came to power but were unrelated to that political change, showed that the uranium nucleus could be induced to break into two lighter nuclei, in the process releasing a very large amount of energy. The reaction, which was given the name "fission" (breaking into two pieces), appeared to have been initiated when the uranium nucleus captured and absorbed a free neutron, the uncharged constituent of atomic nuclei. The early data came as a complete surprise but were soon confirmed and correctly interpreted during a period of great excitement among nuclear scientists in Europe, Britain, and the United States. The possibility of using the discovery to make a bomb of unparalleled destructive power was obvious and became a matter of grave concern within the scientific community. It led to the famous letter from Albert Einstein to President Roosevelt alerting him to the prospect some months after WWII had begun in Europe. Einstein's scientific reputation was unparalleled. A warning from him would not be ignored. He mentioned the work of Enrico Fermi and Leo Szilard in the United States and the more recent work of Frédéric Joliot in France as evidence that a nuclear chain reaction in uranium would be achieved in the immediate future. This new phenomenon, he said, could lead to extremely powerful bombs. A single bomb of the new type exploded in a port might very well destroy the whole port together with some of the surrounding territory. He suggested that an individual be chosen to maintain permanent contact between the administration and the group of physicists working on chain reactions in the United States. Finally, he noted that Germany had stopped the sale of uranium from the Czechoslovakian mines that it had taken over. He speculated that such early action might be explained by the fact that the son of the German under-secretary of state, von Weiszächer, was attached to the Kaiser-Wilhelm Institute in Berlin, where some of the American work on uranium was being repeated.

It was no easy task to convey to the president and other high-ranking government officials the nature of the threat posed by an atomic bomb, partly because it involved unfamiliar scientific ideas and partly because the scientists themselves did not know how real the threat was. The observation of fission in small samples of uranium in the laboratory was clear, and the release of a large amount of energy in each fission reaction was also clear. But whether it was at all possible to create a fission bomb and precisely how to do it were completely unanswered questions. One thing was certain, however: a bomb with the strength equivalent to tens of thousands of tons of TNT in the hands of Nazi Germany alone would be a catastrophe of the first magnitude for the United States and especially for Britain.

Einstein's letter was hand-delivered to President Roosevelt on October 11, 1939, in a meeting organized to brief the president and suggest action he might take. As a result, the president created an advisory committee—guilelessly named the Uranium Committee—to report to him; this represented the first action by the government toward construction of an atomic bomb. The advisory committee, chaired by Lyman J. Briggs, the director of the National Bureau of Standards, met soon after, on October 21, and Briggs reported to the president on November 1 that if the latent energy of fission could be developed, "it might supply power for submarines, and possibly provide . . . a source of bombs with destructiveness much greater than anything now known."[3] The committee report urged the government to support a thorough experimental study of those questions and to purchase several tons of pure graphite and fifty tons of uranium oxide immediately, just in case the preliminary experiments proved promising. It also urged the government to support and coordinate the work in different universities already engaged in fission-related studies and recommended that the Uranium Committee be enlarged to include individuals with a wider spectrum of skills and talents outside the government.

The next few months saw little progress in Washington, although the army and navy did transfer six thousand dollars to the Uranium Committee to purchase materials for experiments on the neutron absorption properties of graphite, a material thought to be useful as a container of uranium. The hiatus was due to the advisory nature of the Uranium Committee, which had no money of its own and no authority to take action on any of its recommendations. The situation changed dramatically in June 1940, however, when the president, responding to the German invasion of France, formed the National Defense Research Committee (NDRC), under the ongoing leadership of Vannevar Bush, who was given direct access to the president and an independent source of funds. The Uranium Committee was to report directly to Bush.

The NDRC mobilized the scientific resources—the scientists and laboratories—of the nation. At the urging of the army and navy, it excluded foreign-born scientists from formal membership in the Uranium Committee, but it continued to use them as important consultants. The NDRC made arrangements to block publication of reports on uranium research, an idea that originated with the scientists themselves. Most important, the newly strengthened Uranium Committee proposed a plan of research on two key questions that needed immediate answers.

One urgent question was whether a self-sustaining chain of fission reactions could be produced. This would require that at least two fission reactions be generated by each of the neutron products of a single fission reaction, that at least two fission reactions be generated by each of the neutron products of the subsequent fission reactions, and so on. This chain reaction—a nuclear physics term meaning exactly what it says—would be the heart of a self-sustaining nuclear reactor to power either a submarine or an atomic bomb. Multiplication of the number of fissioning nuclei by a factor of at least two in each link of the chain was the necessary condition to release the energy stored in a quantity of uranium by a self-sustaining chain of reactions.

It was not obvious that the multiplication factor of at least two could be achieved even if more than two neutrons were released in every fission. A

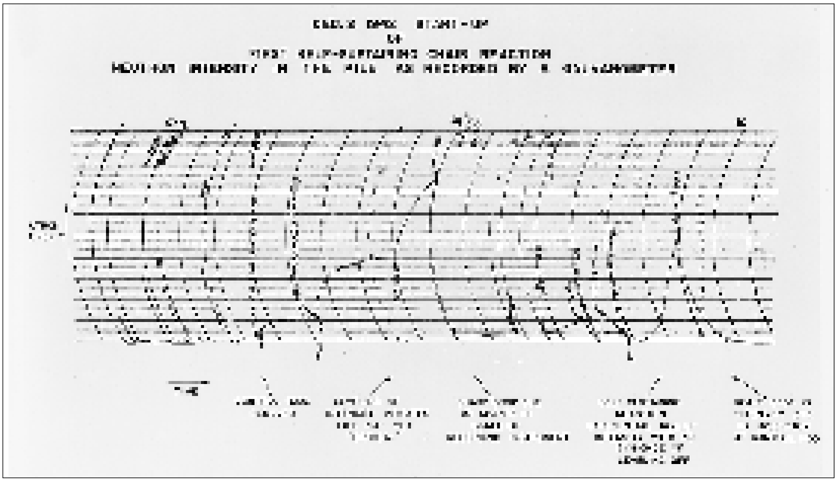

FIGURE 2.2. *Top*: The S-1 Executive Committee, September 1942. *Left to right*: H. C. Urey, E. O. Lawrence, J. B. Conant, L. J. Briggs, E. O. Murphree, A. H. Compton.

Source: James Phinney Baxter III, *Scientists Against Time* (Boston: Little, Brown, 1946), p. 436.

Bottom: Start-up of the first self-sustaining chain reaction. The figure shows the galvanometer recording of the neutron intensity in the "pile" (reactor) under the stands of the stadium at the University of Chicago on December 2, 1942. Insertion of the control rod after twenty-eight minutes ended the chain reaction.

Source: R. G. Hewlett and O. E. Anderson Jr., *The New World: A History of the U.S. Atomic Energy Commission*, vol. 1, *1939/1946* (Washington, D.C.: U.S. Atomic Energy Commission, 1972), p. 112.

neutron emanating from a fission could do other things besides generating a subsequent fission reaction: it could escape from the uranium-containing vessel, or produce a different nuclear reaction in the uranium, or be absorbed by the material holding the uranium (for example, graphite). Any appreciable loss of neutrons by these means would halt the chain reaction and result only in moderate heating of the uranium sample. Consequently, it was imperative to demonstrate that a self-sustaining chain reaction could be produced in a laboratory.

The second urgent question concerned the physical and chemical properties of uranium and their suitability for bomb production. Most elements occur in nature in the form of isotopes, nuclei with the same chemical properties (same number of protons) but different numbers of neutrons among their constituents. The total number of constituents is, for historical reasons, called the atomic mass of the nucleus and, in conjunction with the ratio of protons to neutrons in the nucleus, determines its stability against disruption by an outside force, for instance, the capture of a neutron from outside. Uranium has two isotopes; one, with an atomic mass of 235, is present in natural uranium at about 0.7 percent of the total, and the other, with an atomic mass of 238, is present in approximately 99.3 percent of the total. Early experiments done with very small quantities of each isotope showed that only the isotope of mass 235 fissioned readily, while the more abundant isotope 238 in the natural element was a limitation and certain to prevent an explosive chain reaction. Consequently, the Uranium Committee's second question addressed the methods of isotope separation that might yield substantial quantities of relatively pure isotope 235. Several methods were known to nuclear scientists at the time, but whether any of these, which had been tested only on minute quantities of material, could be applied to the separation of kilograms of isotope 235 from tons of natural uranium was a completely open question. Large-scale experimentation would be needed.

It was, of course, easier to formulate these questions than to answer them. Organizing the scientists and the laboratories in which the work was to be done, finding the money and supplies that were needed in increasing amounts, and coordinating all of it was more than the combined efforts of the Uranium Committee and the NDRC could accomplish. Both were too small and lacked the power to acquire the necessary resources. In addition, the NDRC had other urgent assignments, in particular, to develop radar and to stimulate research in military medicine. The way out of this impasse was the establishment of the Office of Scientific Research and Development

(OSRD), enacted by executive order on June 28, 1941, as an entity within the Office for Emergency Management of the executive office of the president. Again, Bush was to be its director and was personally responsible to the president. The NDRC would continue, but within the OSRD and with James Conant as its new head. The Uranium Committee became the OSRD Section on Uranium, designated as Section S-1.

There were many reasons to create the OSRD other than the consolidation of the uranium program, but the OSRD acted as the catalyst for the program in all respects. To produce a chain reaction, preparations to build a lattice of graphite and uranium metal and oxide, called a uranium pile, were in progress. Three methods of isotope separation were under test at the engineering level with an eye toward handling large quantities of uranium. The OSRD was also able to encourage study of the newly discovered element plutonium, with an atomic mass of 239: ninety-four protons in its nucleus, two more than in uranium. The significance of this discovery lay in the fact that plutonium was shown to fission under the action of neutrons just as uranium 235 did. Moreover, plutonium 239 and uranium 238, from which it was produced, were different chemical elements and could be separated from each other with far less difficulty than the two almost identical isotopes of uranium. The OSRD and its scientists began to contemplate the prospect of making bombs either of uranium 235 or of plutonium 239 or perhaps some of each kind.

Theoretical and experimental work on all these possibilities went on feverishly throughout the remainder of 1941 and all of 1942. The pressure to produce an atomic bomb before the Germans was immense. On December 2, 1942, to the overwhelming relief of everyone involved, the first controllable, self-sustaining chain reaction was produced in a graphite-uranium pile (a three-dimensional lattice of uranium and graphite rods) located under the stands of the University of Chicago football field. The radioactivity that emerged from the unshielded pile forced the scientists to terminate the chain reaction after a few minutes, but there was no doubting the importance of what had been achieved.

Even before the success in Chicago, the leaders of the Manhattan Project had concluded that construction of an atomic bomb was a feasible undertaking if sufficient funds and manpower were diverted to the effort. In addition to the evidence for a chain reaction, which they anticipated to be forthcoming, they achieved significant progress in uranium isotope separation and in the production and separation of plutonium to support such optimism. Nevertheless, they knew that they were far from manufacturing sufficient quantities of uranium or plutonium for a bomb and had no idea of how to build an actual bomb, much less one capable of a targeted explosion. They understood that a realistic plan would require diversion of resources from the continuing buildup of the U.S. arsenal for the war effort. Furthermore, they were not absolutely sure that a bomb could be produced before the end of the war or even at all, despite their confidence that they were on the right track. The fear that Nazi Germany might successfully do so, however, drove them to press forward and propose to President Roosevelt a tenfold expansion of the atomic bomb project from hundreds of millions to billions of dollars, a monumental sum. Their thinking was summed up in a statement attributed to Ernest Lawrence, a Nobel laureate in physics, head of one of the isotope separation programs, "It will not be a calamity if when we get the answers to the Uranium problem they turn out negative from the military point of view, but if the answers are fantastically positive and we fail to get them first, the results for our country may well be tragic disaster."[4]

The increase proposed in the plan would make the Manhattan Project too big and too costly to remain within the OSRD. Consequently, the plan recommended that an independent organization be formed to administer the project and special funds be provided for it. Complete exchange of atomic bomb information with the British was also recommended. President Roosevelt agreed and formed a new committee, named the Policy Committee, in which all policy relating to the Manhattan Project was to be confined; it consisted of the president; the vice president, Henry Wallace; the secretary of war, Henry Stimson; the army chief of staff, George Marshall; and the two leaders of the OSRD, Vannevar Bush and James Conant, who until then had been responsible for all decisions affecting the Manhattan Project. Rather than creating a new organization, the Policy Committee ordered the army to take control of the atomic bomb project when the uranium and plutonium isotope separation pilot plants—then still under design—were ready to operate, possibly in late 1942. At the same time, following a schedule of unprecedented speed, full-scale plant construction would be started without waiting for the guidance that might be obtained from the pilot plants. In addition, directions were given to construct a new laboratory to be devoted to the task of building an atomic bomb using the fissionable materials furnished by the isotope separation plants. In September 1942 Brigadier General L. R. Groves was placed in charge of all activities relating to the Manhattan Project, designated by the army as the "Manhattan District in the Corps of Engineers." In May 1943 the Manhattan District took over the research and development contracts, as well as the early construction contracts from the OSRD. This marked the end of the organizational connection of the OSRD with the Manhattan Project.

The Manhattan Project enlisted the aid of leading construction companies to build a network of isotope separation plants in isolated areas in sev-

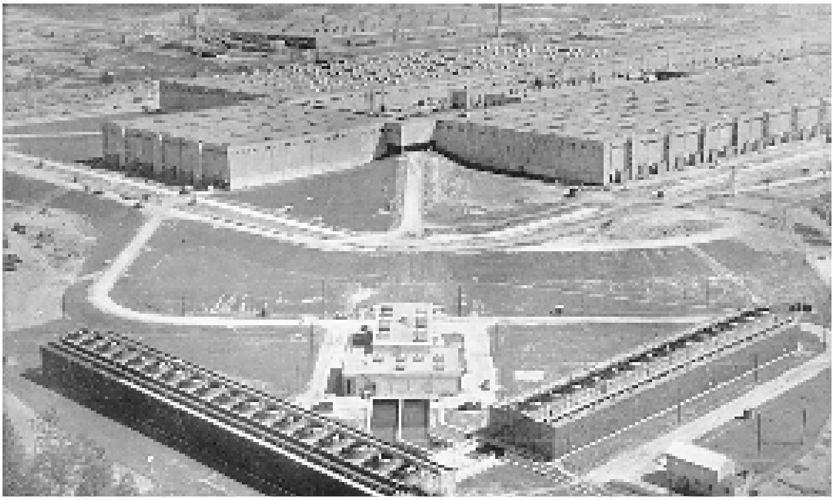

FIGURE 2.3. *Top*: One of the production plants at the Clinton Engineer Works at Oak Ridge, Tennessee.

Source: Henry D. Smyth, *Atomic Energy for Military Purposes: A General Account of the Scientific Research and Technical Development that Went into the Making of Atomic Bombs* (Princeton: Princeton University Press, 1945), plate 7.

Bottom: Leslie R. Groves (left) and J. Robert Oppenheimer.

Source: T. R. Fehner and Jack M. Holl, *Department of Energy, 1977–1994: A Summary History* (Oak Ridge, Tenn.: Office of Scientific and Technical Information, 1995), p. 10.

eral states. These were operated by industries whose peacetime business was large-scale chemical engineering. A full-scale gaseous diffusion plant for uranium isotope separation, operated by the Carbide and Carbon Chemicals Corporation, was built in a Tennessee valley on a 59,000-acre site designated the Clinton Engineer Works, near the Clinch and Tennessee Rivers, eighteen miles west of Knoxville. Two pilot plants, each in a separate valley, one for the production of plutonium and the other using the electromagnetic separation method for uranium, were also built on the same site. The original plan called for a full-scale plutonium plant, but fear that the several piles required for major plutonium production—each very much larger and more powerful than anything built before—might have an accident and endanger the population of Knoxville prompted a change in location to a more isolated area in Washington state. That plant, the Hanford Engineer Works, was located on 670 square miles near the Columbia River at Pasco and operated by the duPont Company. The isolation of these plants, dictated by the need for secrecy and safety, made it necessary to build them from the ground up. This included on-site cities to house as many as sixty thousand construction workers, plant operators, engineers, and scientists.

A laboratory built to learn how to build an atomic bomb—the famous Los Alamos Scientific Laboratory—began to take shape in New Mexico. Again, to preserve secrecy and stay far from populated areas, the laboratory was placed in a remote, relatively inaccessible location and had to be built with extensive housing for families, in addition to buildings for scientific and engineering work.

The nuclear separation plants in Tennessee and Washington began to produce sizable quantities of uranium 235 and plutonium 239 by the end of 1944. Significant progress toward an actual bomb was also made at Los Alamos, but the principal problem there was how to detonate the bomb. If done too slowly—too fast would not be a problem—neutrons would leak away, and the fissionable material would simply fizzle. Ultimate success in producing an exploding bomb seemed assured, but when it would be ready for use was still not very clear. Uncertainty also surrounded the war in Europe and the Pacific. Invasion forces in Europe were engaged in intense fighting in the Battle of the Bulge, and U.S. forces moving north in the Pacific encountered ever-increasing and costly resistance the closer they moved to Japan.

The situation changed dramatically in the spring of 1945. President

Roosevelt died on April 12 and was succeeded by Harry S. Truman. Too late for Roosevelt to witness it, Germany surrendered unconditionally a month later, on May 7. The U.S. Army and Navy were completing plans for their next major operation, the invasion of the island of Kyushu in Japan. At Los Alamos, scientists were in the last stages of preparing to test a uranium bomb at the Alamogordo, New Mexico, Bombing Range, one hundred miles south of Albuquerque. That test, code named "Trinity," went as planned on July 16. It was the first atomic bomb explosion, one with enough destructive power to amaze the scientists and officials who witnessed it.

At the time of the Alamogordo test, President Truman was in Potsdam, Germany, for a meeting with Stalin and Churchill. A major issue before them was how to end the war against Japan. The Soviets had massed an army on the border of Manchuria with the aim of driving the Japanese out of China. The Americans were hoping for Russian assistance against Japan but were unwilling to agree to Stalin's demands for major concessions in both Eastern Europe and China as the price for Russian participation. The success at Trinity changed that. No further persuasion of the Soviets to enter the war against Japan took place. The Potsdam Proclamation of July 26, a last warning to the rulers of Japan, signed by the United States, China, and Great Britain, called on Japan for "the unconditional surrender of all Japanese armed forces [and promised] a peacefully inclined and responsible government [to be established in accord with] the freely expressed will of the Japanese people." No reference was made to the fate of the emperor. The alternative was "prompt and utter destruction." As the conference concluded, Truman casually mentioned privately to Stalin that the United States had a new weapon of unusual destructive force, about which Stalin showed no special interest except to say that he was glad to hear it and hoped the Americans would make "good use of it against the Japanese."[5]

The Japanese government decided to ignore the warning in the Potsdam Proclamation and to "press forward resolutely to carry the war to a successful conclusion."[6] Radio Tokyo began broadcasting this message on July 29, Potsdam time. One week later, on Sunday, August 5, the first atomic bomb was dropped on Hiroshima. The magnitude of the destruction at Hiroshima was initially obscured by the thick layer of dark gray dust that covered the city after the explosion. Because of complete loss of communication with the city, the Japanese government had little idea of the devasta-

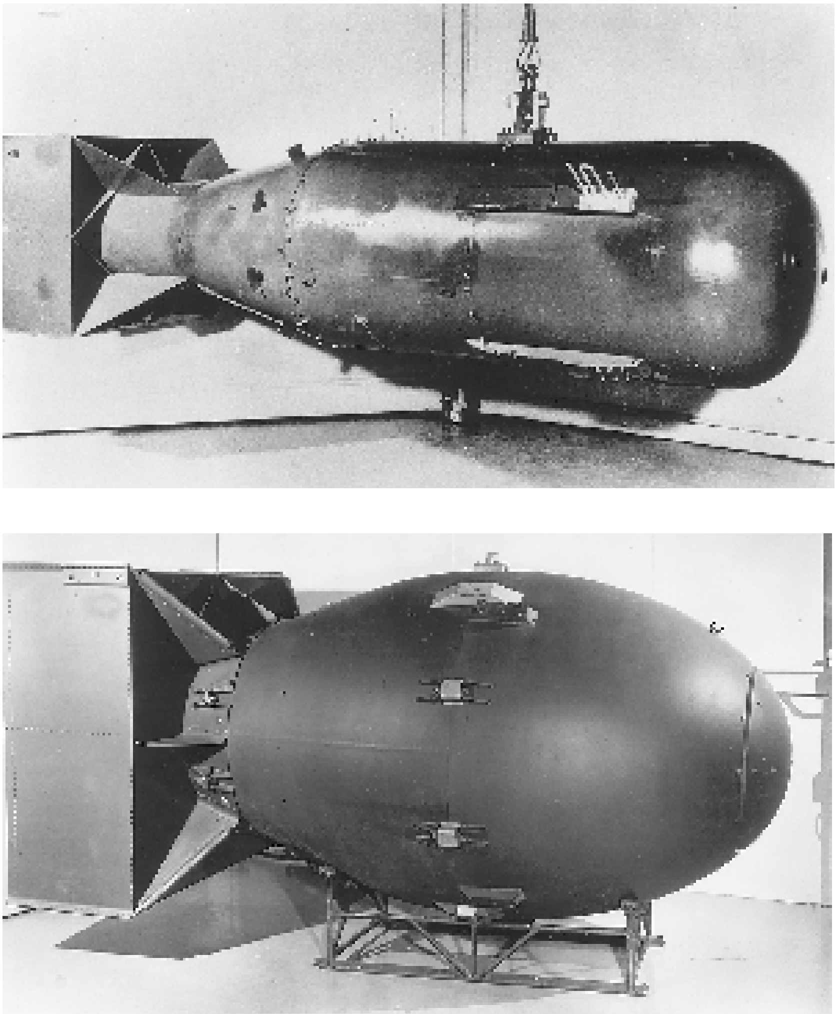

FIGURE 2.4. *Top*: Museum display of "Little Boy," the uranium bomb that was dropped above Hiroshima on August 6, 1945.

Source: R. G. Hewlett and O. E. Anderson Jr., *The New World: A History of the U.S. Atomic Energy Commission*, vol. 1, *1939/1946* (Washington, D.C.: U.S. Atomic Energy Commission, 1972), p. 400.

Bottom: Museum display of "Fat Man," the plutonium bomb dropped above Nagasaki on August 9, 1945.

Source: R. G. Hewlett and O. E. Anderson Jr., *The New World: A History of the U.S. Atomic Energy Commission*, vol. 1, *1939/1946* (Washington, D.C.: U.S. Atomic Energy Commission, 1972), p. 400.

tion. It was not until August 7 that the Japanese civilian leaders realized that a single bomb had destroyed the entire city. The Japanese military—believing that little had really occurred—would only agree to send an investigating team to Hiroshima. On August 9, discussions in Tokyo to surrender ended without a decision, despite word that a second atomic bomb attack had destroyed Nagasaki and that the Russians had at last entered the war against them. By morning of the next day, however, amid mass destruction and horror, Japan formally accepted the terms of the Potsdam Proclamation, with the proviso that it would not prejudice the emperor's position. The Japanese military managed to get the U.S. concession that, immediately upon surrender, the authority of the emperor would be subject only to the Supreme Commander of the Allied Powers. Negotiations continued as issues relating to disarmament and occupation were raised once more, but use of the third atomic bomb—the second available plutonium bomb—was expressly forbidden by the president without his consent. On August 10 the Japanese government accepted the Potsdam terms and surrendered.

President Truman briefly summarized for the American people the atomic bomb events in Japan. Ordinarily, he said, the government and the scientists would have made public all technical data, but he did not intend to do so "pending further examination of possible methods of protecting us and the rest of the world from the danger of sudden destruction."[7] There was, however, good reason to issue some kind of technical release if only to keep political pressure and speculation within bounds. A quasi-official report titled *Atomic Energy for Military Purposes* had been prepared earlier by Henry D. Smyth, a professor at Princeton University and a long-time member of the Manhattan Project. Smyth had been asked to write a description of the project from its beginning to its culmination with the aim of informing the public on a matter that, as he saw it, would be of vital concern to them for many years. The report was subtitled "A General Account of the Scientific Research and Technical Development that Went into the Making of Atomic Bombs" but had been carefully scrutinized to make sure it contained no information that might be of value to a foreign nation seeking to produce atomic bombs of its own. Nevertheless, the decision to publish the Smyth report was not easily made. Among the advisers of Secretary of War Stimson, General Groves and James Conant, for example, were in favor of publication because it was a lesser evil; James Chadwick, the British scientific counterpart to Conant, was opposed but

FIGURE 2.5. Henry Stimson, secretary of war during WWII, arrived in Berlin, July 15, 1945. Accompanying him was his aide, Colonel William H. Kyle. Stimson had been secretary of state from 1929 to 1933. He had the confidence of President Roosevelt and Vannevar Bush and was instrumental in the success of the OSRD.

Source: R. G. Hewlett and O. E. Anderson Jr., *The New World: A History of the U.S. Atomic Energy Commission*, vol. 1, *1939/1946* (Washington, D.C.: U.S. Atomic Energy Commission, 1972), p. 392.

pointed out that it was a U.S. matter and anyway would not be of much help to the Russians, and the assistant secretary of war, Robert A. Lovett, was also opposed. The final decision to publish was made by the president on August 12.

The rocky road to publication of the Smyth report was a sign of many fears: fear of the power of the atom if let loose in the world; fear of the absence at the time of a plan for the future of the Manhattan Project and atomic energy in general in the United States; and fear engendered by the emerging threatening nature of the Soviet Union.

FIGURE 2.6. Conference on the Smyth Report. Henry D. Smyth (left) and Ernest O. Lawrence confer at Berkeley, California, autumn 1944.

Source: R. G. Hewlett and O. E. Anderson Jr., *The New World: A History of the U.S. Atomic Energy Commission*, vol. 1, *1939/1946* (Washington, D.C.: U.S. Atomic Energy Commission, 1972), p. 376.

Atomic Energy for Military Purposes

The Official Report
on the Development of the Atomic Bomb
under the Auspices
of the United States Government,
1940–1945

By HENRY DeWOLF SMYTH
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Written at the request of
Maj. Gen. L. R. Groves, U.S.A.

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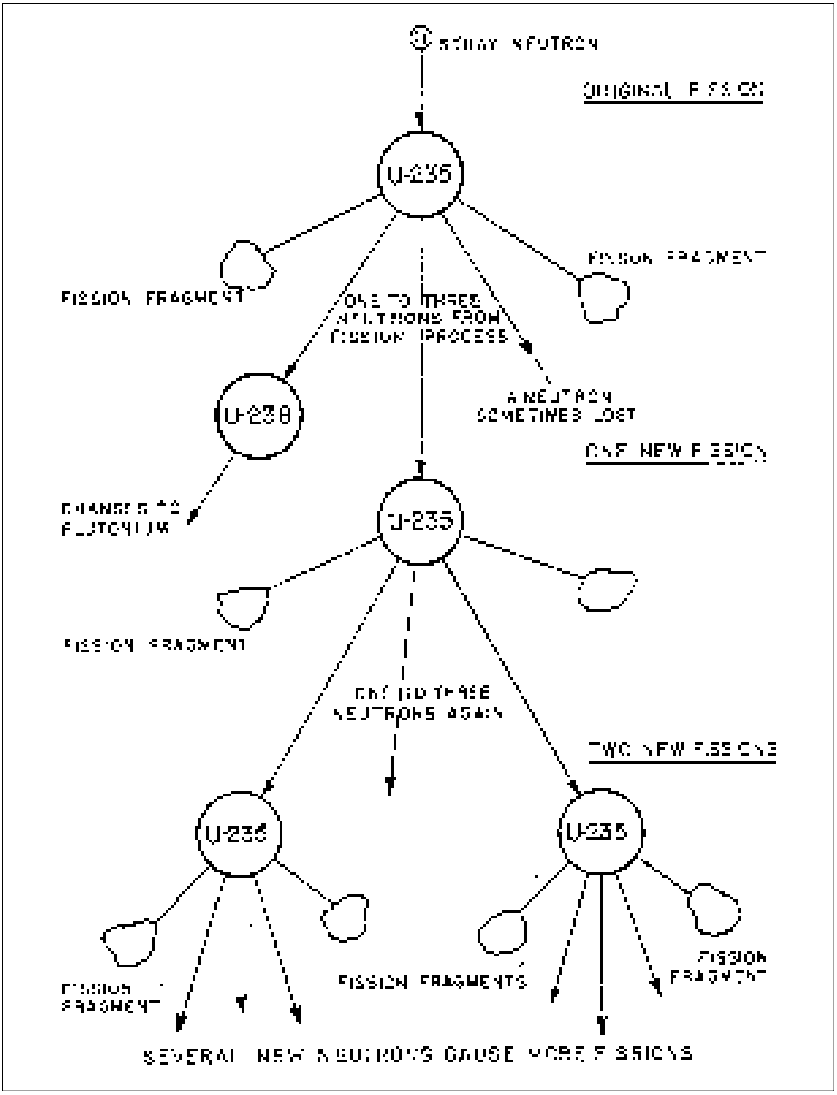


FIGURE 2.7. *Opposite page*: Title page of the Smyth report.

Source: Henry D. Smyth, *Atomic Energy for Military Purposes: A General Account of the Scientific Research and Technical Development that Went into the Making of Atomic Bombs* (Princeton: Princeton University Press, 1945), p. 35.

Above: Schematic diagram of a chain reaction, from the Smyth report.

Source: R. G. Hewlett and O. E. Anderson Jr., *The New World: A History of the U.S. Atomic Energy Commission*, vol. 1, *1939/1946* (Washington, D.C.: U.S. Atomic Energy Commission, 1972), p. 722.

Engineer and educator, Vannevar Bush was the first presidential science adviser.

Many of the events described here happened because of one man: Vannevar Bush. This is not to say that he did everything himself but that his character and ability were instrumental in giving both form and substance to the U.S. science and technology organizations of WWII.

First the NDRC, then the OSRD, and soon after the Manhattan Project bore the stamp of his influence from their earliest days to their termination. While he was director of the OSRD, he was also the senior administrator of the Manhattan Project until, on his own recommendation, it was placed under the direction of the army, although he continued as a member of the committee that set policy at the highest level for the project. In those capacities he served as the principal science adviser to President Roosevelt and, after Roosevelt's death, to President Truman until the end of the war. In effect, he was the architect of organized U.S. science and technology during WWII, just as General George Marshall was the architect of the modernized U.S. Army and its strategy.

Table 2.1. Cumulative Costs in the Manhattan Project Engineer District as of December 31, 1945 (in thousands of dollars)

	PLANT	OPERATIONS
Government overhead	22,567	14,688
Research and development	63,323	6,358
Electromagnetic plant (Y-12)	300,625	177,006
Gaseous-diffusion plant (K-25)	458,316	53,850
Thermal-diffusion plant (S-50)	10,605	5,067
Clinton Laboratories	11,939	14,993
Clinton Engineer Works (headquarters and central utilities)	101,193	54,758
Hanford Engineer Works	339,678	50,446
Heavy-water production plants	15,801	10,967
Los Alamos Project	37,176	36,879
Special operating materials	20,810	82,559
TOTALS	1,382,033	507,571

When WWII ended, Bush used his wartime experience to produce a blueprint, *Science: The Endless Frontier*, for organizing science and technology in the United States in peacetime, just as General Marshall produced the peacetime plan that bore his name to organize the recovery of Europe from the destruction of the war.

Long after WWII, Jerome B. Wiesner, who had been science adviser to presidents Kennedy and Johnson, began a biographical memoir of Bush with these paragraphs.

> No American has had greater influence in the growth of science and technology than Vannevar Bush, and the twentieth century may yet not produce his equal. He was an ingenious engineer and an imaginative educator, but above all he was a statesman of integrity and creative ability. He organized and led history's greatest research program during World War II and, with a profound understanding of implications for the future, charted the course of national policy during the years that followed.
>
> The grandson of two sea captains, "Van" Bush manifested his Cape Cod heritage in a salty, independent, forthright personality. He was a man of strong opinions, which he expressed and applied with vigor, yet he stood in awe of the mysteries of nature, had a warm tolerance for human frailty, and was open-minded to change and to new solutions to problems. He was pragmatic, yet had the imagination and sensitivity of a poet, and was steadily optimistic.[8]

Wiesner had a long, intimate association with MIT, where Bush began his career as an administrator of science and technology. Wiesner joined an OSRD laboratory, the MIT Radiation Laboratory, in 1942; almost thirty years later he became president of MIT. He was a friend and colleague of Vannevar Bush, with a close-up view of the man and his accomplishments. At the same time, he developed a perspective on American science from his experience as a presidential science adviser.

From Bush's own writing about how the OSRD and Manhattan Project were created and functioned, he emerges as a man with extraordinary good sense and superb organizational ability. He was able to develop and maintain good working relations with government agencies and Congress and to win and keep the respect and support of President Roosevelt and of the exceptionally influential secretary of war, Henry L. Stimson. And he retained the confidence of the leaders of the scientific community, themselves eminent spokesmen for science and engineering. Perhaps his distinctive features were a lack of pretension, selfless dedication to the cause at hand, and a good sense of humor. He included in his 1970 book *Pieces of the Action* a chapter on the critical need for proper organization to accomplish complex tasks. It begins, "When Eve joined Adam there was formed the first organization in history. It was a simple one, yet its essential relations and the regulations governing it have not even today been fully worked out."[9] It is an intriguing and effective way to begin a discussion of what could be a relatively dry subject.

Vannevar Bush grew up near Boston and graduated from Tufts College. He received a doctorate in engineering from a joint Harvard-MIT program in 1916. When the United States entered WWI in 1917, Bush worked on methods of submarine detection until the end of the war. He saw first hand how narrow the Allied victory over the submarine had been, and he learned about human relations problems in a research and development effort that involved both civilian scientists and military personnel.

Three years later, Bush joined the engineering faculty of MIT, where, in addition to teaching, he served as a consultant to a small firm from whose patents grew the successful electronics corporation Raytheon. At that time he also turned to the invention of electromechanical calculating machines that simulated complicated problems in physics and engineering, allowing quantitative solutions to be obtained. An important, relatively new problem of his time was how to optimize the efficiency of a network consisting of electrical power–generating stations, transmission lines, and the electric power loads on them. For this work, accomplished with a team of graduate students, Bush won a medal from the Franklin Institute of Philadelphia in 1928. He maintained a strong interest in calculating machines throughout his life. In the summer of 1945, as WWII was coming to an end, he published an article that described a machine called the "memex" that was remarkable as a forerunner in concept and detail of the ubiquitous personal computer of a half century later.

Bush was named dean and vice president of engineering of MIT in 1932 and might have become its president, but in 1938, foreseeing the coming war and U.S. involvement in it, he left to become president of the Carnegie Institution of Washington. This move opened the highest levels of national science policy making to him. Soon afterward, he was appointed to the

National Advisory Committee for Aeronautics (NACA) and a year later became its chairman. All these posts polished Bush's natural talent as an administrator of science and an adviser on science policy.

The experience with NACA fixed in Bush's mind the need for the chairman of a federal science advisory committee to report directly to the president and to receive support through emergency funds available to the president or by congressional legislation. The alternative would be an advisory committee without a strong sponsor and without federal funding, in short, without the capability to effect real change.

In June 1940 President Roosevelt established the National Defense Research Committee (NDRC) to coordinate the nation's science resources and supplement the weapons development programs of the army and navy. This was done in response to recommendations made by Bush, who was appointed chairman of the new committee. In this capacity he was the agent among many groups poised to face the challenges of wartime: the science community, the White House, Congress, and the armed services. The NDRC was supported by the president's emergency funds, and Bush reported directly to the president. In effect, Bush was the president's science adviser, the first of a long line of individuals to serve in that capacity in future administrations.

One year later, again in response to recommendations by Bush, the NDRC was incorporated in the newly created OSRD, which included the Uranium Committee then charged with evaluating the prospects for an atomic bomb and a section on medical research. The OSRD had the authority to promote the manufacture of the devices that emerged from its research, as it did in early nuclear fission experiments and with blood derivatives. The creation of the OSRD was a measure of Bush's vision and of his success in dealing directly with the president, managing a complex budget, and working with the Congress. The accomplishments of the OSRD were a testimonial to Bush's talent for bringing together civilian and military leaders in diverse areas of science, providing them with the organization and funds to enable them to work productively on joint projects, and stimulating them to do so harmoniously.

Bush tells a story in *Pieces of the Action* that reflects his view of what he did during the war. Some time after the National Science Foundation (NSF) had been established in 1950, there was a dinner at which Bush presided and President Truman spoke. They sat together at dinner, and in the course of their conversation the president asked Bush to serve as a member of the NSF

FIGURE 2.8. Roosevelt and Churchill at Quebec. The man in uniform is the earl of Athlone, then governor-general of Canada. In the background is Canadian prime minister Mackenzie King.

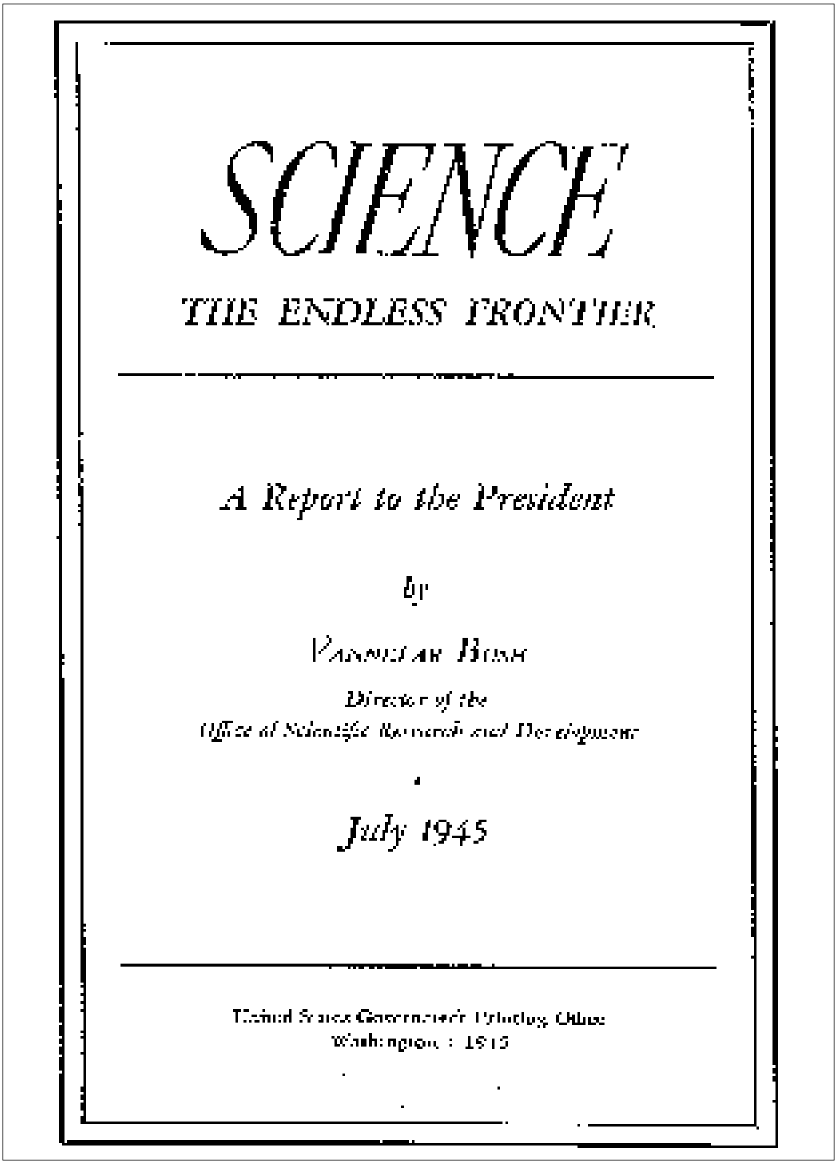
Source: R. G. Hewlett and O. E. Anderson Jr., *The New World: A History of the U.S. Atomic Energy Commission*, vol. 1, *1939/1946* (Washington, D.C.: U.S. Atomic Energy Commission, 1972), p. 272.

Science Board, which was then being formed. Bush demurred, probably because he and Truman did not mesh personally as he had with Roosevelt and because of their disagreement over the method of selection and duties of the members of the Science Board. Truman finally agreed to leave him off the board. Then he said, "Well, Van, you are not looking for a job, are you?" And Bush replied, "No, Mr. President, I am not looking for a job." The president added, "You cannot say I went looking for this job that I am in," and Bush commented, "No, Mr. President, not the first time," which obliquely referred to the 1948 presidential campaign in which, contrary to all predictions, Truman, the incumbent, defeated Dewey, the challenger. The president was tickled and, poking Bush in the ribs, said, "Van, you should be a politician. You have some of the instincts." To which Bush responded, "Mr. President, what the hell do you think I was doing around this town for five or six years?"[10]

Bush finished his report *Science: The Endless Frontier* in 1945. It had a profound impact on Washington politics even though the president had not requested it. Few disagreed with the need for a federal science agency or with the method proposed to provide one. The political climate of Washington was rapidly returning to the peacetime mode, however, and approval of an idea in principle no longer led to its quick realization in practice. Furthermore, Bush failed to recognize how seriously Truman regarded presidential control of the director and members of the governing board of any federal science agency. In fact the president vetoed a bill to establish a national science foundation that emerged from Congress in 1947 because of disagreement on that very issue. Three more years would pass before the foundation became a reality.

Bush was active in Washington until the foundation was established and for some time thereafter. True to his word, he "was not looking for a job," and in 1955 he resigned his position as head of the Carnegie Institution and returned to his home in Massachusetts. Nevertheless, he was regularly called on for testimony before congressional committees and for advice and recommendations as the postwar science agencies grew.

His intellectual drive did not abate. In the period between 1952 and 1959 he published articles on science in medicine, on an electric micromanipulator, on an automatic microtome, and on the surgical correction of calcification of the aorta in adults. And, of course, his interest in calculating machines remained. In addition, he published on the organization and administration of military research programs, on improving the



SCIENCE

THE ENDLESS FRONTIER

A Report to the President

by

Vannevar Bush

Director of the
Office of Scientific Research and Development

July 1945

United States Government Printing Office
Washington : 1945

FIGURE 2.9. Title page of the Bush report, *Science: The Endless Frontier*.

Source: Vannevar Bush, *Science: The Endless Frontier* (Washington, D.C.: U.S. Government Printing Office, 1945).

patent system, and on the relation of fundamental research to engineering. He wrote three books: *Science Is Not Enough*, *Modern Arms and Free Men*, and *Pieces of the Action*. In the last, he reminisced about his experiences in and out of the government. Bush died in June 1974, at age eighty-four.

FIGURE 2.10. Vannevar Bush, director of the Office of Scientific Research and Development and first presidential science adviser.

Source: Richard Mandel, *A Half Century of Peer Review (1946–1996)* (Alexandria, Va.: Division of Research Grants, National Institutes of Health, Logistic Applications, 1996), p. 8.