State Significance of Property, and Justify Criteria, Criteria Considerations, and Areas and Periods of Significance Noted Above.

SUMMARY STATEMENT OF SIGNIFICANCE:

The B Reactor qualifies as a National Historic Landmark under Criterion 1 as the first production nuclear reactor in history. Constructed between 1943 and 1944, B Reactor (along with D Reactor and F Reactor) provided the plutonium 239 used in the first atomic device ever exploded, near Alamogordo, New Mexico, on July 16, 1945 (designated an NHL in 1965 as Trinity Site), and in the first and only plutonium weapon and the most powerful nuclear device ever used in warfare – the bomb dropped on Nagasaki on August 9, 1945. While D Reactor and F Reactor were also built as part of the Manhattan Project, they do not merit NHL status, since they have been "cocooned" and lack integrity and because B Reactor was the first of the Hanford reactors to become operational (see Figures 1, 5, 7, 9 & 10). Although B Reactor is predated by the experimental plutonium reactors Chicago Pile I (operational on December 2, 1942; designated an NHL in 1965 as "Site of First Self-Sustaining Nuclear Reaction") and the X-10 Reactor at Oak Ridge (operational on November 4, 1943; designated an NHL in 1965), the B Reactor was the first nuclear reactor ever designed to operate on a production (industrial) scale -- 500 million times more powerful than Chicago Pile I and 62 times more powerful than the X-10 – the only scale capable of providing enough material to create a nuclear bomb. The B Reactor necessitated not merely a scaling up from the experimental reactors, but a radically different design with new reactor materials, cooling system, shielding, and instrumentation to deal with the unprecedented radiation levels. The Manhattan Project was both a scientific and a technological effort. B Reactor provides an essential place to understand the technological side of this story. The fissionable material produced there helped end World War II – a cataclysmic worldwide event that killed millions and marked the definitive arrival of the United States as a world superpower.

The B Reactor also qualifies as a National Historic Landmark under Criterion 4 as the model for World War II and Cold War reactors. As an engineering structure, B Reactor provided the basic design used in two Hanford reactors (D and F) built during the war and five Hanford reactors (DR, H, C, KW, and KE) built from 1947 to 1955 -- all water-cooled, graphite-moderated reactors. These reactors produced all the plutonium that fueled U.S. nuclear weapons, until the Savannah River, S.C., plant came on line in 1952. They demonstrate the significant technological role of B Reactor in shaping the Cold War arms race. B Reactor served as the design model of the nuclear facilities that fueled the United States' early nuclear arsenal. Plutonium from these facilities was a critical component of the events that ushered in the Cold War that would dominate world diplomacy and U.S. society and politics during the second half of the twentieth century, as well as the Nuclear Age -- with its fears of nuclear annihilation, nuclear proliferation, radioactive pollution, and nuclear terrorism -- that continues to shape world events.

The B Reactor's period of significance spans from 1943 to 1952. The beginning date corresponds to the year when construction of the reactor began, and the ending date reflects the year that the Savannah River nuclear facility came on line, signifying a distinct departure from the B Reactor's design. This time period encompasses the reactor's key years of productive life, its role in national and world events during World War II and the Cold War, and its influence on the design of subsequent reactors at Hanford and the role Hanford played as the sole producer of plutonium in the United States.

HISTORIC CONTEXT

Beginnings

On the early morning of July 16, 1945 the first atomic device ever detonated, codenamed "Trinity," was exploded in the desert of New Mexico near Alamogordo. The plutonium that fueled this explosion came from the B, D, and F Reactors at Hanford. Three weeks later, on August 6, 1945, in an effort to force Japan to surrender and avoid a costly Allied invasion of the Japanese home islands, the U.S. Air Force dropped an atomic bomb on the Japanese city of Hiroshima – a nuclear device powered by uranium from the Oak Ridge, Tennessee, facility. Three days later, on August 9, a second bomb was dropped on Nagasaki. Like the first device exploded in the New Mexico desert, this bomb was fueled by plutonium from Hanford's B, D, and F Reactors. After some equivocation, Japanese leaders announced their surrender and the end of World War II. While historians and the public at large have focused more on the scientists who participated in the Manhattan Project and successfully created a device capable of destruction on an unprecedented scale, the Manhattan Project also required impressive feats of engineering and industrial management. The B Reactor at Hanford represents the best place to understand this side of these historic events that transformed the course of World War II and the shape of diplomacy and society in the postwar world. The creation of plutonium at B Reactor was both an ending and a beginning. It represented the first practical application of Manhattan scientists' research to a production-scale nuclear reactor and produced one of the weapons that helped end World War II. It also stood at the beginning of the Cold War. In proving the viability of production-scale nuclear reactors, it led to the construction of seven other reactors at Hanford closely modeled on the form of the B Reactor – reactors that produced all the plutonium for the U.S. nuclear arsenal until 1952, when the Savannah River facility came on line.

The events that led to this technological structure that would shape world history date back to October 1939. In that month, President Franklin D. Roosevelt listened to a briefing by several eminent scientists about the possibility of producing an explosive device of unprecedented power using uranium. Nazi Germany had launched World War II a month earlier and the scientists explained their concerns that Germany was working on a similar weapon. In the aftermath of the briefing, Roosevelt commented to an aide, "this requires action." The President set in motion a cooperative effort by physicists and military personnel to research the possibilities of producing an atomic weapon, which would end with the use of atomic bombs against the Japanese cities of Hiroshima and Nagasaki in August 1945, leading to the surrender of Japan. In addition to breaking new scientific ground, the Manhattan Project was also an industrial effort on a huge and unparalleled scale. In 1939, the Danish physicist Niels Bohr argued that in order to produce enough fissionable material for an atom bomb the United States would have to turn itself into a huge factory. On visiting the U.S. and its atomic complex after World War II Bohr remarked that that was exactly what the nation had done. The B Reactor at Hanford in central Washington

State was an essential component of this immense new industrial complex that was built with unprecedented speed and which was designed to produce an atomic weapon.[1]

To produce the fissionable material for the atomic bombs required the construction of huge new industrial complexes of a kind never seen before. The B Reactor and its fellow piles were unprecedented in their size and capacity to produce plutonium in large quantities. This industrial nature of the project has received less recognition than its scientific advances, yet without this capacity to produce plutonium in quantity, the atomic bombs would not have been developed as quickly as they were. Hanford's B Reactor was an essential element of the Manhattan Project, and made a central contribution to the development of the first atomic bombs.

After Roosevelt's briefing in October 1939, scientific research into nuclear physics progressed over the following two years. It took until October 1941, however, for the White House to approve a full-scale program to investigate the feasibility of producing an atomic bomb. Despite this delay Roosevelt's decision would lead to the eventual establishment of the Hanford Engineer Works and the construction of the B Reactor at that facility as part of the effort to build the first atomic bombs. Until mid-1942, however, the U.S. did relatively little to prepare for the enormous task of building the facilities to produce a workable atomic weapon and the atomic program remained a matter of experimentation and theoretical innovation. The program to this point focused around academic research, led by scientists.

Physicists believed that either uranium 235 or plutonium 239 was capable of forming the explosive core of an atomic weapon, but neither had been produced in substantial quantities and it was uncertain whether their production and incorporation into a bomb were actually feasible. Reflecting growing concerns about the possibility that Germany was further along in its atom bomb development program than the U.S. and in an effort not to put all their "eggs in one basket," leaders of the American project made the decision to pursue both uranium 235 and plutonium 239 as the fissionable core of the weapon. Producing these elements in the quantities necessary for a bomb posed a daunting and unprecedented challenge. Scientists working on the project faced several possible methods of producing the fissionable material central to building the bomb, all of them theoretical rather than proven. Eventually, reflecting the increasing urgency surrounding the project, James Conant, one of its key leaders, decided that all the production methods should be pursued simultaneously, in the hope that one or more of them would prove to be successful. The decision had been made to move from theoretical research toward production.[2] Ultimately, both approaches would prove successful. Uranium 235 fueled the weapon dropped on Hiroshima; plutonium 239 fueled the bomb dropped on Nagasaki.

The intensification of the effort to develop an atomic bomb took another important step in June 1942 with a huge increase in its budget and transfer of responsibility for managing the project to the Army Corps of Engineers. The Corps would be responsible for building the facilities necessary to produce the fissionable material for a bomb, and ensuring the timely completion of

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[1] Quoted in Richard G. Hewlett and Oscar E. Anderson, Jr., *A History of the United States Atomic Energy Commission*, Volume I: *The New World, 1939/1946* (University Park, PA.: Pennsylvania State University Press, 1962), 17, 52; Edward Teller, *The Legacy of Hiroshima* (New York: Doubleday, 1962), 211.

[2] Thomas E. Marceau, "Historic Overview," in *Hanford Site Historic District: History of the Plutonium Production Facilities, 1943-1990* (Columbus, OH.: Battelle Press, 2003), 1.9.

the effort. Under the Corps of Engineers, the project was designated the Manhattan Project. Despite these rapid developments the project seemed to be adrift, with little progress on the development of the production facilities. It took the appointment of General Leslie Groves as commanding officer of the Manhattan Project in September 1942 to accelerate the whole program, and in particular to initiate the construction of the vast industrial complex that the project required, of which the B Reactor would be a central component.[3]

Constructing the World's First Production-Scale Nuclear Reactor

As one of the largest construction projects of World War II, the Hanford Engineer Works required a hard-charging, decisive leader. Under Groves, who took a ruthless approach to managing large-scale projects, the industrial nature of the Manhattan Project rapidly took shape. Extremely cognizant of the pressure to build a bomb before the Germans, the general moved quickly to acquire land for the project's two main production sites – at Oak Ridge, Tennessee, and at Hanford in central Washington State. For Groves, time was a more critical factor than the cost of developing the facilities necessary to build a working atomic weapon and he would spend money liberally in efforts to speed up the development process of the bomb and the construction of facilities necessary for the weapon's manufacture. The general was keenly aware of the need to build plants on an industrial scale to extract the radioactive materials necessary to fuel an atomic bomb and of the need for professional industrial management of those plants. Historians John M. Findlay and Bruce Hevly have argued, "The Manhattan Project was at bottom an effort to build and operate an immense industrial complex – one that, by war's end, would rival in size and cost the entire U.S. automobile industry."[4]

Realizing the industrial nature of the undertaking, Groves successfully worked to convince E. I. du Pont de Nemours and Company (DuPont), a major force in the chemical industry, to become the main contractor on the project. Utilizing its industrial experience, DuPont assumed responsibility for constructing and operating the plants. Despite its extensive experience in building and managing huge chemical production factories, the plutonium facility at Hanford, of which the B Reactor was an essential part, was the largest plant the company had ever built or operated. It would become one of the largest construction projects of the wartime home front, reflecting the total mobilization of America's society and economy for the war effort.[5]

Scientists believed that the atomic bomb could be built using either uranium 235 or plutonium 239 as fissionable material. Groves decided that the project should pursue the production of both elements simultaneously in order to increase the chances of successfully producing a workable weapon as quickly as possible. This decision would lead directly to the building and operation of the B Reactor at Hanford. The process of producing plutonium in sizable quantities required a chain reaction created in large-scale reactors to transform uranium 238 to plutonium. These reactors, of which B Reactor was to be the first, would be 500 million times more powerful than

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[3] Marceau, "Historic Overview," 1.10-1.11.

[4] Hewlett and Anderson, *The New World*, 181; John M. Findlay and Bruce Hevly, "'P.S. Your Bombs Are Certainly Wonderful': Hanford and the American West" (Unpublished manuscript, copy in author's possession), chapter 1.

[5] Stephane Groueff, *Manhattan Project: The Untold Story of the Making of the Atomic Bomb* (Boston: Little, Brown & Company, 1967), 55-62; Richard Rhodes, *The Making of the Atomic Bomb* (New York: Simon & Schuster, 1986), 603.

the first experimental reactor built by Enrico Fermi at the University of Chicago and operated successfully for the first time in December 1942. As the emphasis shifted toward producing both plutonium and uranium powered bombs, project managers planned to build the plant to produce the highly radioactive plutonium near Chicago. However, the Chicago site was soon ruled out due to the hazards of locating the facility close to a major population center. The initial main industrial site of the Manhattan Project was at Oak Ridge in Tennessee, which was built to produce uranium 235. After some consideration, Oak Ridge also seemed increasingly unsuitable for the plutonium production facilities. The Tennessee site lacked sufficient power, did not have enough space, and was too close to population centers for considerations of both security and safety.[6]

In response, Groves and his subordinates began a search for another location to build the plutonium production plant. The ideal site would have a large supply of cool water of at least 25,000 gallons per minute and be easily connected to 100,000 kilowatts of electric power. In addition, security and safety requirements called for at least several hundred square miles of land, which needed to be some distance from towns, railroads or highways. At the same time the site needed to be close enough to railroad lines to facilitate the transport of construction supplies and equipment. Groves ordered Colonel Franklin T. Matthias to investigate potential sites on the West Coast. Matthias and representatives of DuPont visited several sites in the region in December 1942 but were most impressed with a site close to the small central Washington community of Hanford. This "sagebrush and sand" property was on the western side of the Columbia River, and in a sparsely populated part of Washington State. At nearly 700 square miles in area, the location met the project's requirements in terms of isolation and security. The newly completed Grand Coulee Dam, upriver from the site, could meet the project's projected power requirements. The presence of large quantities of gravel nearby would facilitate the huge construction undertaking that the project would require. In addition, the area's arid climate allowed construction work to proceed year round. As historians Findlay and Hevly have argued, "The Pacific Northwest seemed ready to meet every need that the government's atomic-weapons program had for it."[7]

After examining other sites in Oregon and California, Colonel Matthias returned to Washington, D.C., where he strongly recommended the Hanford Site to Groves. The general visited the area in January 1943 to confirm Matthias's recommendation. Describing the area as "sagebrush suitable only for…sheep," Groves regarded it as ideal for Manhattan Project purposes and

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[6] Henry DeWolf Smyth, Atomic Energy for Military Purposes: The Official Report of the Atomic Bomb under the Auspices of the United States Government, 1940-1945 (Princeton: Princeton University Press, 1945), 112; D.W. Harvey, "Construction History," in Hanford Site Historic District, 2-1.1; Findlay and Hevly, "P.S. Your Bombs Are Certainly Wonderful," chapter 1; Hewlett and Anderson, The New World, 188-189; Rhodes, The Making of the Atomic Bomb, 407, 487, 496.

[7] Leslie R. Groves, *Now It Can Be Told: The Story of the Manhattan Project* (New York: Harper & Brothers, 1962), 68-74; Colonel F.T. Matthias, "Building the Hanford Plutonium Plant," *Engineering News-Record*, 13 December 1945, 118-119 (qtn); Harry Thayer, *Management of the Hanford Engineer Works in World War II* (New York: ASCE Press, 1996), 162-167; Hewlett and Anderson, *The New World*, 189-190; Smyth, *Atomic Energy for Military Purposes*, 112; Anthony Cave Brown and Charles B. MacDonald, *The Secret History of the Atomic Bomb* (New York: The Dial Press, 1977), 317-319; Michele Stenehjem Gerber, *On the Home Front: The Cold War Legacy of the Hanford Nuclear Site* (Lincoln, NE.: University of Nebraska Press, 1992), 12, 25-26; Findlay and Hevly, "P.S. Your Bombs Are Certainly Wonderful," chapter 1 (qtn); Rhodes, *The Making of the Atomic Bomb*, 497.

ordered its acquisition by the government. The Army acquired the land through sometimes-contested condemnation proceedings for $5.1 million, one of the largest land acquisitions in the United States during the war. The first construction workers arrived in the spring of 1943 in the remote Hanford area. They began the incredible task of transforming the desert landscape into a massive industrial plant for what was still a theoretical process of separating plutonium from irradiated uranium. Reflecting the industrial nature of the facility, the site became known as the Hanford Engineer Works. Hanford's B Reactor, the first to be built and operated at the complex, would be a vital component of what Matthias called "the world's greatest atom making factory."[8]

Before work could proceed very far on construction at the Hanford Site, however, Groves and other key figures in the Manhattan Project were faced with fundamental decisions. Until early 1943, no one was quite sure of the exact type of facilities that would have to be built at Hanford, or of key features of the reactors' design. Of major concern was the type of cooling system that would be used in the production reactors at the site. The first reactor to ever achieve critical mass was that built at the University of Chicago. While this was a tremendous breakthrough, the reactor was experimental and small in scale and required little in the way of sophisticated cooling systems. The plutonium production reactors intended for Hanford, however, would be much larger and generate immense amounts of heat when operating at full capacity. This heat needed to be dissipated for effective and safe operation of the pile. Initial plans for the plutonium production reactors called for them to be cooled by helium gas, but that process provided numerous technical obstacles that could only be overcome at great difficulty and expense. Eventually, in early 1943, scientists at the Manhattan Project in Chicago proved the utility of water as a coolant for reactors. This development vindicated the decision to locate the plutonium production reactors at Hanford, adjacent to the water of the Columbia River. Project leaders decided that the reactors at Hanford should be water-cooled. As a result, DuPont proceeded with construction of water-cooled reactors and other facilities there. B Reactor – the world's third nuclear reactor -- was the first reactor ever to be built that used water for a cooling system. Water-cooled reactors, such as the B pile, would become the standard in reactor construction.[9]

The construction of the B Reactor and the Hanford complex was one of the largest construction projects in the United States during World War II, reflecting the importance assigned to the plant as part of the home front mobilization of the U.S. economy. Building the plant at Hanford and all of the housing and facilities for construction workers and plant operatives was a mammoth undertaking that cost $350 million. The cost of the project, its huge size, and the commitment of large quantities of scarce labor and materials reflected the vital nature of the Hanford plant and the importance assigned it by the top levels of government. Construction of the plutonium production plant and support facilities lasted from March 1943 to February 1945. Completing a

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[8] Groves, *Now It Can Be Told*, 75-77 (qtn); Findlay and Hevly, "P.S. Your Bombs Are Certainly Wonderful," chapter 1; S.L. Sanger, *Working on the Bomb: An Oral History of WWII Hanford* (Portland, OR.: Continuing Education Press, Portland State University, 1995), 19-20; Rhodes, *The Making of the Atomic Bomb*, 497; Ted Van Arsdol, *Hanford…The Big Secret* (Richland, WA: Columbia Basin News, 1958), 2-3, 11-17; Harvey, "Construction History," 2-1.2; Matthias, "Building the Hanford Plutonium Plant," 118 (qtn).

[9] Groves, *Now It Can Be Told*, 78-81; Smyth, *Atomic Energy for Military Purposes*, 98, 113-114; Hewlett and Anderson, *The New World*, 179-182, 193, 197-198; Brown and MacDonald, *The Secret History of the Atomic Bomb*, 321; Rhodes, *The Making of the Atomic Bomb*, 497-498; D.C. Stapp, "Reactor Operations," in *Hanford Site Historic District*, 2-3.2—2-3.3.

plant of the size and complexity of Hanford in that short a period of time was an unprecedented achievement. As one historian has described, the military "transformed an open agrarian landscape into a closed military-industrial complex." Hanford was a powerful example of the mobilization of the American economy and society as part of the war effort on the home front. Despite its importance during the war, Hanford and its role in producing plutonium has been ignored or forgotten about compared to other sites of the wartime home front mobilization.[10]

Matthias and DuPont officials at Hanford were under pressure to get plutonium production up and running as quickly as possible to forestall the possibility of German success with their atom bomb program. Building the plant, however, posed huge and seemingly insoluble problems. Many aspects of its designs were unclear and would not be solidified until experiments at other Manhattan Project facilities confirmed their utility.

The Hanford area was remote – workers had to be brought in from other places and housing had to be provided for them before construction of the actual plant could begin. When construction did start, crews excavated 25 million cubic yards of earth, enough to build housing for 400,000 people. Two aggregate production plants were built on the site to supply aggregate and sand for the project. In addition, the site had five concrete mixing plants, which supplied a total of 780,000 cubic yards of concrete during the construction phase of the project. The 40,000 tons of scarce structural steel used in its construction reflected the top wartime priority assigned to the plant. General Groves had to fight doggedly to ensure that the project got the highest priorities in terms of its allocation of labor and for scarce materials such as steel, copper, aluminum, etc. Despite some problems and interruptions due to labor shortages, construction at Hanford went ahead at a blistering pace.[11]

Building the B Reactor and the rest of the plutonium production complex required a huge workforce. At its peak, 45,000 workers were employed in building the plant. Recruiting these workers presented DuPont with a major problem. By the middle of 1943, labor was in very scarce supply throughout the nation as wartime industry created an almost insatiable demand for workers. This was particularly the case in the Pacific Northwest. The Boeing Airplane Company and shipbuilding plants in Seattle, Tacoma, Bremerton, and the Portland-Vancouver area had high priorities for wartime labor and recruited workers from all over the country. In response to this labor shortage, Du Pont developed a sophisticated recruiting operation, with representatives sent all over the U.S. to seek potential workers. Reflecting the top priority assigned to building the B Reactor and the rest of the plant by the Manhattan Project, the War Manpower Commission provided essential assistance, giving preference to Hanford in assigning workers. In addition to trying to recruit more workers, project managers tried to increase the productivity of the existing workforce. Workers in the early stages of the project worked eight hours a day, six days a week. In September 1943, management increased the workday to nine hours, and later installed floodlights to allow work to proceed around the clock.[12]

[10] Marceau, "Historic Overview," 1.15 (qtn).

[11] Van Arsdol, *Hanford…The Big Secret*, 27; Matthias, "Building the Hanford Plutonium Plant," 120; Hewlett and Anderson, *The New World*, 214-215.

[12] Marceau, "Historic Overview," 1.20; Van Arsdol, *Hanford…The Big Secret*, 18-23; Groueff, *Manhattan Project*, 141-142; Thayer, *Management of the Hanford Engineer Works in World War II*, 93; Hewlett and Anderson, *The New World*, 215-216.

The size of the construction workforce required the building of extensive housing, dining and recreational facilities. Due to the lack of housing in the surrounding areas, DuPont built a huge camp consisting of dormitory buildings to accommodate workers. A large trailer park provided facilities for those workers who brought their own trailers with them to the area. The camp area housed enough people that at one point it was the fifth largest community in Washington State. While most of the workers were white, there were also contingents of African American and Hispanic American workers, who were segregated in their housing and recreational facilities.[13]

Labor turnover was a major cause of concern in building the plutonium plant. Approximately 132,000 workers were employed at various times over the course of the construction project. Turnover ranged from 10 percent in the early stages of the project to over 20 percent by the middle of 1944. One cause of labor turnover was the secret nature of the project. Until atomic bombs were used at the very end of the war few of the workers who built or operated the reactors or any of the other plutonium production facilities knew what they were building or what its purpose was. The secrecy surrounding the project sometimes made it difficult to motivate workers about the importance of their work, despite the urgent priority assigned to the B Reactor and the other plutonium facilities by the highest levels of the government. Believing that they were not making a significant contribution to the war effort some workers on the project grew frustrated and left the area to seek what they saw as more meaningful employment elsewhere. Conditions on the construction site also encouraged high labor turnover. The work involved in building the huge plutonium production plant was difficult and the climate of the area exacerbated workers' discomfort with blisteringly hot summers and regular dust storms. As a consequence of these conditions and the isolation of the area, many workers abandoned their jobs. In an effort to encourage workers to come to the area and stay, plant authorities tried to ensure that conditions were as comfortable as possible for the workforce. Management provided, for example, entertainment and good food at low cost, and in particular supplied workers in the plant's cafeterias daily with meat at a time when it was in scarce supply. Due to the labor shortage, workers arrested for drunkenness in the sprawling camp were not usually charged but held overnight in jail to make certain they were available for work the next day. Given these problems of labor supply, the construction of the B Reactor in approximately one year was a major accomplishment.[14]

The Manhattan Project's Metallurgical Laboratory (MetLab) in Chicago developed the design for the production reactors at Hanford. While the design was based on the original pile built by Enrico Fermi at the University of Chicago, which had achieved the first ever self-sustaining chain reaction in December 1942, the industrial scale of the operation require radical innovations involving new reactor materials, cooling system, shielding, and instrumentation. The Hanford

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[13] Hewlett and Anderson, *The New World*, 216; Findlay and Hevly, *"P.S. Your Bombs Are Certainly Wonderful,"* chapter 1.

[14] Groueff, *Manhattan Project*, 142-143, 288-291; Rhodes, *The Making of the Atomic Bomb*, 499; Matthias, "Building the Hanford Plutonium Plant," 119-120; Hewlett and Anderson, *The New World*, 215-216; Thayer, *Management of the Hanford Engineer Works in World War II*, 171-172; Marceau, "Historic Overview," 1.18. For the construction of housing for workers at the plant see Carl Abbott, "Building the Atomic Cities: Richland, Los Alamos, and the American Planning Language," in Bruce Hevly and John M. Findlay, eds., *The Atomic West* (Seattle: University of Washington Press, 1998), 90-99; Van Arsdol, *Hanford…The Big Secret*, 31, 40, 45, 50; Findlay and Hevly, *"P.S. Your Bombs Are Certainly Wonderful,"* chapter 1.

reactors, like Fermi's, were comprised of a core of graphite blocks but the plutonium production piles were to be much larger. In February 1943, project leaders decided that the new reactors should be cooled by water rather than by helium. The water would flow through tubes in the graphite core, dispersing the heat created by the reactor (see Figure 6). The fuel elements for the piles were uranium slugs, measuring 1.5 inches by 8 inches, clad in aluminum "jackets," a process referred to as "canning." The slugs were inserted into the tubes in the pile's graphite core. They would then be bombarded with neutrons, which would create a chain reaction. This chain reaction caused the uranium to convert some of its isotopes into plutonium. Reactor operators would then push the slugs, made up of uranium and plutonium, out of the back of the pile where they would fall into tanks of water. Ideally, the slugs remained in the water for thirty days while their radioactivity declined. Still highly radioactive, they were then transported by rail to the separation plant (or 200 area) for the separation of the plutonium from the uranium fuel slugs.[15]

The plutonium production facilities built at wartime Hanford included three production reactors (designated B, D, and F), chemical separation plants for separating plutonium from irradiated uranium, and a fuel fabrication facility. Construction of support facilities for the first of the piles, the B Reactor, such as the water systems designed to cool it, began at the end of August 1943. Held up by the wait for design drawings of the actual reactor, DuPont began work on constructing the actual building that was to house the B pile in October 1943. The three piles were built six miles apart, on the south side of the Columbia, and close to the river to facilitate the use of its water for cooling purposes. All of the reactors were located as far as possible from the towns of Pasco and Richland for safety purposes. The reactor areas were designated the 100 area, thus the B pile was in the 100-B area. Designers designated the actual reactor building as the 105 building, and so the B pile building was known as 105-B. The pile building used 390 tons of structural steel, 17,400 cubic yards of concrete, and 50,000 concrete blocks. On May 20, 1944, work began on installing the graphite blocks that were the core of B Reactor. By June 11 the graphite installation was complete and workers began to finish the concrete shielding over the pile.[16]

Enclosed in large concrete buildings for safety purposes, the core of the reactor was made of 100,000 graphite blocks, which, when stacked, measured thirty-six feet wide by thirty-six feet high. Some of the graphite blocks of the reactor core featured tubes that were to be loaded with uranium slugs once the pile was completed. Scientists at the Metallurgical Laboratory (Met Lab) in Chicago, who were responsible for reactor design, believed that 1,500 fuel tubes would be sufficient in the pile. Physicist John Wheeler, along with some DuPont officials, argued for extra fuel tubes and, despite the significant extra cost, eventually prevailed in having the number increased to 2,004. Like B Reactor, five of the later reactors built at Hanford would also accept 2,004 fuel tubes (D, F, H, DR, and C). The decision to enlarge the pile was a fortuitous one, as became clear shortly after the reactor achieved a self-sustaining reaction for the first time at the end of September 1944 (see Figure 8).[17]

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[15] Stapp, "Reactor Operations," 2-3.2—2-3.3; Findlay and Hevly, "P.S. Your Bombs Are Certainly Wonderful," chapter 1.

[16] Marceau, "Historic Overview," 1.16; Sanger, *Working on the Bomb*, 70; Hewlett and Anderson, *The New World*, 216-217.

[17] Thayer, *Management of the Hanford Engineer Works in World War II,* 5, 10, 52-53.

Shortages of skilled workers served to slow progress on the completion of the B Reactor. Building the piles involved developing solutions to problems that had never been encountered before. The construction required extremely fine tolerances, particularly in cutting and laying the graphite blocks that were the heart of the reactor. The graphite also had to be kept extremely clean, requiring special procedures from the workers involved in working on the reactor core. Tolerances on the welds on the pipes going into the reactor and all steel in its construction were also extremely tight, with only the most skilled workers employed on this aspect of the project, factors which also contributed to slowing the job down.[18]

Welders presented a particular problem. There were over 50,000 linear feet of welded joints in B Reactor, and all had to seal perfectly, provide structural support, and could not warp or shrink. Construction of the reactor consumed more than 100 tons of welding rods. Welding for B Reactor involved unique new issues and quality standards, and there was an acute shortage of qualified welders. DuPont explained: "The procurement of a sufficient number of welders for work on the [B] Pile was particularly difficult for two reasons: (1) the welding technique required was extremely complicated and (2) the welding was of such a nature that the welder himself was more or less responsible for seeing that the work was done according to specifications. It was not possible, in other words, to inspect the welds other than by visual examination. Any weld failures encountered would, in many cases, have been extremely serious and perhaps even impossible to rectify."[19]

The issues associated with welding to the needs required in B Reactor were so critical that DuPont Corp. called a special meeting of welding specialists, including personnel from other companies, to study and make recommendations in February 1944. Even the experiences in building the X-10 reactor at the Clinton Engineer Works were not viewed as sufficient to solve the problems associated with maintaining the integrity, huge size and thickness, and close tolerances of the welds needed in B Reactor.

As a result of the February 1944 meeting, a special team was formed, and new requirements for welders and for welds, were developed that then served as the "gold standard" for the nuclear industry. New techniques were developed through experimentation and practice at one of the companies on the team – the Combustion Engineering Corp. of Chattanooga, Tennessee. In the end, states DuPont, "the basic method by which the problem of warpage and shrinkage was met was by 'peening' the welds. The weld was deposited in small amounts which was [sic] then peened, or hammered, before cooling. Thus the contraction normally taking place during cooling was prevented."[20]

A shortage of qualified welders was deemed by both DuPont and Mathias to be the most severe problem experienced during the construction of B Reactor.[21] Experienced journeymen welders at the top of their craft were carefully selected and tested to perform work on B Reactor. Each candidate welder's work record was examined going back 10-15 years, his security profile was

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[18] Thayer, *Management of the Hanford Engineer Works in World War II*, 70, 72, 98-99; Hewlett and Anderson, *The New World*, 217; B Reactor Museum Association, *Historic American Engineering Record, B Reactor (105-B Building), HAER No. WA-164* (Richland, WA: U.S. Department of Energy, 2001), 27-29.

[19] DuPont, *Construction*, Vol. III, p. 792.

[20] DuPont, *Construction*, Vol. III, p. 797.

[21] DuPont, *Construction,* Vol. III, p. 792; and Matthias, "Diary and Notes," March 25, 1944.

checked, and then he was given a "rigid welding test in the field….This test was so difficult that only approximately 18% of the welders, all of which had previously passed [other welding tests]…qualified. When the welders realized that, due to the critical shortage of men in their craft, they would be employed on the [Hanford] Project even if they failed the 105 [B Reactor] test, they were reluctant to work in the 105 Area due to the additional work, skill and responsibility which it entailed." Consequently, after intense negotiations involving the highest levels of the Manhattan Engineering District, DuPont, and labor representatives,[22] a special, higher wage rate was established for welders working the "105 job."

In requesting the higher wage rate – a very unusual step in wartime – DuPont wrote to the Manhattan Engineering District: "The high degree of skill required in this operation (welding) is peculiar to the [Reactor] Project and, to our knowledge, has not been required in any other operation. Because of this condition, factual data [from other projects] to support the request is not available." [23]

In addition to experiencing unusual difficulties with welders, B Reactor's construction was affected by unique problems with pipefitters. In July 1944, Matthias wrote that "the 105 [B] Building…[has been] somewhat delayed principally due to difficulty with the pipefitters. At the present time, the shortage of pipefitters is the one thing that is holding up work more than any other item [24] There was both a shortage of expert pipefitters, and some unrest among the pipefitters over hours, lack of local representation, and other job-related matters. The shortage was alleviated in mid-September 1944 by a special arrangement in which some expert pipefitters on active duty in the military were discharged to the Army Reserve and sent to Hanford. However, grievances resulted in a brief walk-out of pipefitters already at Hanford in early September, 1944.

In addition to the technical and engineering problems created by the venture into a new world of reactor construction, the project also faced the challenge of pressure to complete the pile as soon as possible so as to build an atomic weapon. While most workers on the project did not know what the pile was for, management did stress that it was vital to the war effort and this helped to motivate employees to push on with the construction of the reactor as quickly as possible. Despite the problems faced in the reactor's construction, its completion in just over a year was an incredible accomplishment given the hurdles that had to be overcome, especially that of working with unproven technology and the labor shortages at the Hanford Site. Construction of the B Reactor in such a short period was one of the most impressive achievements of the wartime home front.[25]

B Reactor's importance in the wider Manhattan Project was reflected in the arrival of top physicists such as Enrico Fermi as the pile neared completion. The scientists were there to supervise the reactor's start-up. Fermi began loading the first of the fuel elements into the B pile on September 13, 1944. This was less than two years after he had overseen the first ever nuclear

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[22] The labor representatives participated as invited guests who were not officially recognized as bargaining authorities since HEW was not unionized.

[23] DuPont, *Construction*, Vol. III, pp. 792-793.

[24] Matthias, "Diary and Notes," July 19, 1944.

[25] Findlay and Hevly, *"P.S. Your Bombs Are Certainly Wonderful,"* chapter 1; Hewlett and Anderson, *The New World*, 218; Thayer, *Management of the Hanford Engineer Works in World War II*, 70, 98-99.

reactor to achieve a chain reaction at the University of Chicago. After the frantic and unprecedented construction of the huge Hanford complex, the heart of the plutonium production plant was almost ready to begin the work it had been designed for. Within two weeks the fuel tubes had been loaded and B Reactor was ready to begin its historic role as the first plutonium production reactor ever built and central part of the Manhattan Project.[26]

Producing the Plutonium for the World's First Nuclear Explosion

The unprecedented nature of the engineering work at Hanford required ongoing innovation and problem-solving to assure the project's success. On the early morning of September 27, 1944, the B Reactor went critical for the first time and was operating at "a higher level of power than any previous chain reaction." Despite this initial success, after less than a day's operation, the reactor experienced a significant problem due to by-products of the fission process, which caused it to lose power and shut itself down. The shut down initially baffled the plant's personnel, who were under pressure to produce plutonium for the atomic bomb as quickly as possible, as well as to prove that the millions of dollars spent on the reactor and the plutonium plant had not been in vain. Eventually the scientists and engineers discovered that the problem was created by the production of xenon as a by-product of the fission process. Scientists figured out that the solution to the problem was to increase the power output of the pile. Luckily, DuPont engineers, in conjunction with John Wheeler, a Manhattan Project physicist, had insisted on building extra capacity in the form of additional fuel tubes into the graphite core of the reactor during its construction, despite the opposition of scientists from the Met Lab. This stubborn conservatism of DuPont's engineers, born of their experience in building and running other industrial plants, proved to be vital in solving the xenon problem. The extra capacity in the pile allowed it to run at higher power, which proved to be essential in overcoming the xenon issue. Had the extra fuel tubes not been available, there would have been few options other than building a completely new reactor with the required capacity, which would have set the entire plutonium production project back by months. This could have had an affect on the way and time that the war against Japan ended.[27]

Loading the extra fuel tubes and connecting them to the cooling system took two months. During this time, the pile was not idle. Operators ran it at increasing power levels and produced the first irradiated plutonium-bearing uranium slugs in November and more in December. This marked the beginning of the industrial scale production of plutonium that was such a vital part of the Manhattan Project's mission to build atomic weapons before the end of the war. After storage in the water tanks behind the reactor face to reduce their radioactivity, the irradiated slugs were transported to the 200 area to be processed for plutonium. After allowing the fuel elements to "cool down" further in terms of their radioactivity, operators began the processing that would produce plutonium on December 26.[28]

B Reactor was operating at full power by December 28, 1944. In the meantime, the second

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[26] Hewlett and Anderson, *The New World*, 304-305; Rhodes, *The Making of the Atomic Bomb*, 557.

[27] Marceau, "Historic Overview," 1.26; Groueff, *Manhattan Project*, 303-309; Thayer, *Management of the Hanford Engineer Works in World War II*, 53, 172; Rhodes, *The Making of the Atomic Bomb*, 557-560 (qtn); Hewlett and Anderson, *The New World*, 305-308; Sanger, *Working on the Bomb*, 147, 152.

[28] Marceau, "Historic Overview," 1.26; Hewlett and Anderson, *The New World*, 308; Rhodes, *The Making of the Atomic Bomb*, 560; Sanger, *Working on the Bomb*, 147-148.

completed pile, the D reactor, had achieved critical mass eleven days earlier, the second Hanford reactor to do so. The F pile became operational early in 1945. The successful start up of these two reactors was a direct result of the experience operators and scientists gained from starting the B Reactor. The D and F piles were almost identical in design and construction to the B pile. The main difference between them was that D and F had refrigeration units that were intended to allow them to lower the temperature of the river water used to cool the reactors, especially during the hot summers of central Washington State. Thus, by the beginning of 1945, all three of Hanford's plutonium production reactors were operating at an industrial scale of production and "humming like a factory assembly line" in producing plutonium in much greater quantities than any previous reactors. While previously produced plutonium was largely used for research purposes, that produced in B Reactor and its counterparts was destined for use in the first atomic weapons. Early in 1945, officials at Hanford began to ship plutonium produced at the plant's reactors to Los Alamos, New Mexico, where the first atomic devices would be assembled. By the spring of 1945, Hanford was sending shipments of plutonium to Los Alamos every five days. The gamble taken by Manhattan Project leaders and the effort expended by construction crews, scientists, engineers, and plant operatives in building the huge Hanford complex had paid off. The B Reactor and its fellow piles worked as planned.[29]

DuPont came under pressure to produce more plutonium from General Groves and from the scientists at Los Alamos who eagerly awaited as much of the material as they could get to assemble the first atomic device. During the construction phase Colonel Matthias summed up the objectives of the Hanford plant succinctly: "our first requirement is the early production of some material, and…our second requirement is a large quantity of material." The emphasis on quantity intensified even as the war in Europe drew to a close in the spring of 1945. Groves and senior government officials wanted to have a bomb for use against Japan before the war in the Pacific ended. That meant more plutonium was urgently needed. In response, the company ran B Reactor and its counterparts at levels higher than they were rated for. Under pressure to produce, the company reduced the time for irradiated fuel to "cool" in terms of its radioactivity and made releases of radioactive wastes to the atmosphere, even when winds were not favorable for the dispersion of this pollution without jeopardizing populated areas. DuPont took these risks in order to produce plutonium as quickly as possible to meet the demands of Groves and the scientists at Los Alamos.[30]

On the early morning of July 16, 1945 the first atomic device, codenamed "Trinity," was detonated in the desert of New Mexico, marking the beginning of a new era in human history. Three weeks later, in an effort to force Japan to surrender and avoid a costly Allied invasion of the Japanese home islands, the U.S. Air Force dropped an atomic bomb on the Japanese city of Hiroshima. Several days after the Hiroshima attack, a second bomb was dropped on Nagasaki. After some equivocation, Japanese leaders announced their surrender and the end of World War II.

Using plutonium from Hanford's reactors, the Trinity test device and Nagasaki bomb were the

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[29] Sanger, *Working on the Bomb*, 70, 148 (qtn); Rhodes, *The Making of the Atomic Bomb*, 557-560, 604; Groueff, *Manhattan Project*, 309-311; Hewlett and Anderson, *The New World*, 308-310.

[30] Marceau, "Historic Overview," 1.27; Findlay and Hevly, *"P.S. Your Bombs Are Certainly Wonderful,"* chapter 1 (qtn).

culmination of the huge effort that had gone into building and running the plutonium production plant at Hanford in the previous two and a half years. The B Reactor and its counterparts at Hanford, through their production of plutonium, had played an essential role in ending World War II. The United States had managed to meet its goal of producing atomic weapons before Germany could do so. General Groves would later praise the tremendous achievement of those who worked to produce plutonium as fissionable material for the atomic weapons, describing the need to:

> …keep in mind the truly pioneering nature of the plutonium development as well as the short time available for research, to appreciate the gigantic steps taken by both scientists and engineers in moving as rapidly as they did from the idea stage to an operating plant of commercial size. It was a phenomenal achievement; an even greater venture into the unknown than the first voyage of Columbus.[31]

The general argued that the most difficult aspect of the Manhattan Project had been the production of uranium 235 and plutonium as fissionable material for the bombs. Hanford's B Reactor was a critical part of that achievement.[32]

Continued Mission in the Cold War

In producing plutonium for U.S. nuclear weapons B Reactor was an essential part of the national security complex during the Cold War. It also served as the basic model for the other reactors at Hanford that produced the fissionable material for the formidable nuclear arsenal that U.S. policy-makers saw as vital to containing the power and influence of the Soviet Union in the context of the Cold War.[33]

Until the use of the atomic bombs against Japan, the vast majority of Hanford's workforce had little idea about what the plant produced. In the aftermath of the Hiroshima and Nagasaki attacks, the veil of secrecy surrounding the facility was partially pulled back and Hanford workers celebrated their role in the development of the new weapons and in hastening the end of the war. With the end of the war, operators reduced the power levels of the reactors, but continued to make plutonium. The graphite cores of the Hanford piles seemed to be expanding, raising concerns about the future availability of the reactors for plutonium production. General Groves ordered the shut down of the B pile at the end of 1946. The reactor was to be held in reserve in case graphite expansion seriously damaged the production capability of the D and F piles. If that were to happen, B Reactor would be available to produce plutonium.

Hanford's mission did not disappear at the end of World War II. With tensions growing between the United States and the Soviet Union, Hanford's reactors greatly increased their plutonium production during the Cold War. By early 1947, the newly formed Atomic Energy Commission (AEC) had ordered an expansion of Hanford's plutonium production facilities. Despite their age and some operational problems, the existing reactors (B, D and F) remained vital to the

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[31] Groves, *Now It Can Be Told*, 38.

[32] Quoted in Ferenc Morton Szasz, *The Day the Sun Rose Twice: The Story of the Trinity Site Nuclear Explosion, July 16, 1945* (Albuquerque, NM: University of New Mexico Press, 1984), 15.

[33] Hanford Cultural and Historic Resources Program, "The Hanford Site Historic District" 2002, p. 2.3-4 to 2.3-10.

production of plutonium for the nation's nuclear arsenal. Reactors D and F built during the war were modeled closely on B Reactor. Like B Reactor, they were graphite moderated and light-water cooled (in other words, cooled by ordinary water rather than deuterium oxide, known as "heavy water"). Like B Reactor, they had graphite stacks measuring 36 feet wide, 36 feet tall, and 28 feet front-to-back and accepting 2,004 process rods.[34] In mid 1948, Hanford operators restarted B Reactor and raised power levels on D and F. Operators overcame the graphite creep problem by running the piles at higher levels. For several years the original three reactors were the sole source of plutonium for the U.S. nuclear arsenal. Several new reactors (designated H, DR, C, KW and KE) were constructed between 1947 and 1955. The first three of these postwar reactors constructed – H in 1949, DR in 1950, and C in 1952 – again replicated the exact dimensions of the B Reactor stack and accepted the same number of process tubes. The last two reactors built on the B Reactor model – KW in 1954, and KE in 1955 – had slightly larger stacks than the B Reactor and accepted 3,220 process tubes.[35] While these new piles were larger and were capable of operating at higher levels than the original World War II-era reactors, they followed the same basic design initiated by the B Reactor which, while crude, was proven and effective. Experience gained on building and operating the B, D, and F reactors during World War II also proved invaluable in constructing the newer piles.[36]

Demand for plutonium grew as the U.S. nuclear arsenal expanded rapidly in response to the National Security Council's document issued in 1950, NSC 68, which called for vastly increased defense spending by the U.S. to counteract the growing strength of the Soviet Union. The power and size of nuclear arms grew dramatically when President Harry Truman ordered the development of thermonuclear weapons (the hydrogen bomb or "super") in the early 1950s. With this development, B Reactor gained a new mission in producing tritium, an essential element of the new weapons, in addition to its traditional role of plutonium production. President Dwight Eisenhower's administration adopted a policy of "massive retaliation," placed even greater emphasis on nuclear weapons as part of the nation's national security strategy, and created an even greater need for plutonium produced by Hanford's reactors. In response to these developments operating levels on the B Reactor and the other piles at Hanford were continually pushed higher and higher to meet increased demands for plutonium. The reactor continued and expanded its wartime mission of industrial scale production. B Reactor eventually operated at almost ten times its original design level, a remarkable achievement for a reactor built in just over a year, with few precedents, to meet a wartime need.[37]

The growing demands that policy-makers made for more nuclear weapons and new types of nuclear weapons required Hanford manager to make a number of changes to B Reactor and the other Hanford reactors in order to achieve higher operating levels. These changes reflected the rapid expansion of the U.S. stockpile in the 1950s and 1960s, as the U.S. arsenal went 369 nuclear warheads in 1950 to 20,434 in 1960 and peaked at 31,642 in 1965.[38] At B Reactor, increasing power levels required better safety systems and led managers in 1952 to replace the

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[34] Hanford Cultural and Historic Resources Program, "The Hanford Site Historic District" 2002, p. 2.3-4.

[35] Hanford Cultural and Historic Resources Program, "The Hanford Site Historic District" 2002, p. 2.3-4.

[36] Marceau, "Historic Overview," 1.40, 1.43-1.48; Hewlett and Anderson, *The New World*, 625, 630; Stapp, "Reactor Operations," 2-3.6-2-3.7; Findlay and Hevly, "P.S. Your Bombs Are Certainly Wonderful," chapter 1.

[37] Marceau, "Historic Overview," 1.49, 1.53-1.54, 1.56, 1.59.

[38] Natural Resources Defense Council. "Table of Global Nuclear Weapons Stockpiles, 1945-2002." 2002 [http://www.nrdc.org/nuclear/nudb/datab19.asp, accessed December 2006].

existing liquid boron system with the “Ball-3X” system that could funnel nickel-plated carbon steel balls down into the VSR (vertical safety rod) channels, in order to quickly shut down the reactor in the event of an emergency or a test. Beginning in 1954 and continuing into November 1956, B Reactor received a series of modifications under Project CG-558. These modifications expanded the piping and pumping systems, allowing more cooling water to flow through the reactor, so that the system could operate at higher power levels. In 1959 and 1960, Hanford managers initiated another project, CGI-791, known as the Reactor Confinement Project, which was necessitated by the greatly increased power level achieved under Project CG-558. CGI-791 served to reduce emissions from Reactor B by routing reactor gases through a new filtration system and back out the existing ventilation stack. In the early 1960s, Hanford managers created a more robust effluence management system to deal with increased power levels. While most of these modifications were made outside of the B Reactor building itself and involved improvements to the 107-B Basin, the project also upgraded the downcomer pipe within the 105-B building. A detailed discussion of these modifications appears in the “Analysis of Historical Modifications to Plant Operations” section below.

The Hanford reactors – all modeled on B Reactor – produced all the plutonium that fueled the U.S. nuclear arsenal until 1952. In that year the Savannah River, S.C., site came online with a reactor built on a very different design. According to noted historian of Hanford and of nuclear power, Michele S. Gerber, the Savannah River Site reactors used heavy water (deuterium oxide) for both cooling and for moderation of neutrons, while the Hanford reactors had used light water for cooling and graphite for moderation. Fuel and target assemblies were loaded into the reactor tanks (one large tank for each reactor), with 600 target and fuel assemblies per tank, plus cadmium safety rods and control rods. When the safety and control rods were lifted, the nuclear reaction began. Lithium targets were loaded in to produce tritium; uranium fuel was loaded in to produce plutonium 239. Over the years, the Savannah River reactors produced curium 244, californium 252, plutonium 238, cobalt 60 of high specific activity, polonium 210, uranium 233, and other specialty isotopes. Once the Savannah River facility came on line in 1952, Hanford lost its status as the sole producer of plutonium for the U.S. arsenal.[39]

By the 1960s, the nation’s plutonium industrial complex had become a victim of its own success and productivity. As a result of the output of plutonium at Hanford and other locations, the U.S. had extensive stockpiles of plutonium, reducing the need for the production reactors. In 1968, the AEC shut the B Reactor down, ending its quarter-century mission as an essential production facility for the nation’s national security needs.

Pollution

Beyond the role of B Reactor in World War II and the Cold War, it and the other Hanford reactors had major, detrimental effects on the environment. The environmental hazards emanating from B Reactor and the other Hanford reactors led to the formation of citizens’ groups to address pollution and health concerns. This public reaction represents an important chapter in the development of environmentalism in the United States.

Environmental concerns led to a number of the modifications of B Reactor during the Cold War and environmental clean-up is now the major activity at Hanford. Almost as soon as the

[39] Michele S. Gerber, personal communication, November 13, 2006.

dramatic power level augmentations began at B Reactor after Project CG-558, the effects of reactor effluent in the Columbia River became an increasing concern. Throughout 1957, 1958, and 1959, Hanford managers launched studies of virtually every aspect of the bioaquatic and potential downstream health consequences of reactor effluent, including the effects of temperature, operating purges, various purge agents and filtration aids, fuel element ruptures, sodium dichromate, and radionuclides. Hanford's aquatic biology staff reported in 1957 that the sodium dichromate could cause "significant retardation in growth and a measurable increase in mortality...[in] important species of fish" such as salmon and trout.[40]

Various purging agents and frequencies were scrutinized to counter film buildup on process tubes and these purging agents, including standard diatomaceous earth slurry Super-Cel and Turco 4306-B, also raised concerns about pollution.[41] Despite the negative bioaquatic consequences, the exposure reduction value of chemically decontaminating reactor piping was considered to be so great that facilities for such decontamination were installed at each Hanford reactor for major tube replacement programs that took place in 1962 and 1963.[42]

The reactors raised environmental concerns, not only because of contaminants released into the environment, but also due to the increased water temperature they created in the Columbia River. In 1958, the site's chief aquatic biologist wrote that "valuable species of Columbia River fish, and especially the fall run of Chinook salmon, are definitely vulnerable to further temperature increases [caused by increased amounts of hot effluent in the river]." At the same time, unpublished Hanford laboratory data demonstrated that temperature increases of only two-to-three degrees Celsius above normal "significantly increased" the mortality of both the eggs and young of whitefish. By November 1960, the river temperature at the old Hanford townsite (just downstream of all of the reactors) was measured at two degrees Celsius higher than the water temperature upstream of B Reactor (the reactor furthest upstream).[43]

Not surprisingly, increases in reactor power levels and throughput brought about by the escalating nuclear arms race dramatically augmented the radionuclides released to the Columbia. Site scientists listed the radionuclides of concern as phosphorus 32, due to its "extreme concentration in aquatic organisms and white fish," arsenic 76, which was thought to contribute "approximately 50% of the exposure to the G.I. tract at Pasco;" neptunium 239, another nuclide that delivered its dose directly from drinking river water; strontium-89/90, due to its bone and gastrointestinal tract effects; and zinc 65, due to accumulations in bones and in shellfish at the mouth of the Columbia River. Chromium 51 was the nuclide "released in greatest quantity" downstream of the reactors, but its contribution to dose in living creatures was thought to be small. Sodium 24, nitrogen 16, and manganese 56 were released in even greater quantities, but decayed in such short half-lives that they almost did not factor into dose calculations.

During 1957, the Hanford reactors downstream of 100 B/C Area began to detect higher and higher concentrations of radioactivity in their raw water intakes. The activity accumulated in

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[40] Foster, HW-49713; and Gerber, *On the Home Front*, Chapter 5.

[41] Turco 4306-B was a trademark product of the Turco Purex Industrial Corporation of Westminster, California.

[42] Koop, HW-50601; and Nielson and Perkins, HW-52908; and Chemical Effluents Technology Operation, HW-53225; and Miller and Hall, HW-58153; and Koop, HW-53372; and Hauff, Jensen, and Smith, HW-78039.

[43] Foster, HW-54858; and Junkins, HW-68096.

particulate solids in the 183 Building filters, the settling basins, at the riverbank around the 181 Buildings, and in corrosion product in the raw water lines. Slug ruptures increased the total radioactivity levels both at these points, and in river water and on sanitary supply intakes at Pasco, Washington, a point considered to be 24 hours of water travel time downstream from the reactors. A 1959 Hanford study estimated that fuel element ruptures contributed 20 percent of the total strontium 89/90 content of the Columbia's water at Pasco, and four percent of the gross (total) fission product activity there. Furthermore, this study calculated, the curies released to the river annually by slug ruptures had increased from about 16,500 in 1954 to 45,000 in 1958.[44]

A 1959, Health Instruments (H.I.) Division study stated that, due to human dose exposure, "provision to reduce the output of...[phosphorus-32] must be included in any [reactor] expansion program." The study continued to say that "provision to reduce the output of other radioisotopes will be required for most cases...[and] it may be necessary to reduce sodium dichromate concentrations." The deleterious effects of temperature increases on Columbia River fish also were emphasized.[45]

By 1960, the total volume flow from the Hanford reactors had increased approximately ten-fold over that of the World War II period, shortening the practical retention time to only about thirty minutes and making diversion of unusual effluents to cribs or other holding areas virtually impossible. Furthermore, the total amount of radioactivity (in radionuclides with half-lives fourteen days or longer) reaching the Columbia River stood at nearly 14,000 cubic inches per day![46]

As the worrisome findings about the effects of reactor effluent in the Columbia River mounted in the late 1950s, various solutions were proposed and tested at Hanford. One key idea, tested from 1959 to 1961, was to pass reactor effluent through beds of various metals, metal oxides, and ion exchange resins, to entrap radionuclides; this proved impracticable due to algae build-up and corrosion in the test beds.[47]

As Hanford scientists searched intensively in the 1960s for ways to reduce radionuclide releases to the Columbia River, they revived the mid-1950s idea of disposing reactor effluent through inland lakes, or directly to the river through trenches. At that time, seepage from the trenches into groundwater forced managers to abandon this project. However, a trench with a different orientation was placed into service in the 100 B Area on October 30, 1967. This trench was 500-foot long, 40 feet wide at the bottom and 200 feet wide at the top, and was tied into the 1904-B outfall line that led to the Columbia River. Within two weeks, the effluent flow rate from B Reactor to this trench was increased from 5,000 gpm to 50,000 gpm. By early 1968, according to Hanford scientists, an "increase in the level of the water table in the vicinity of B Area [was] apparent...[and] extensive new seepage areas...formed along the riverbank." B

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[44] McCormack and Schwendiman, HW-61325.

[45] Hall, HW-65733; and Hall and Jerman, HW-64517; and Hall and Jerman, HW-63653.

[46] Hall and Jerman, HW-63653; and Silker, HW-56366; and McCormack and Schwendiman, HW-61325; and Foster and Junkins, HW-63654; and Healy, HW-60529; and Geier, DUN-1906; and Gerber, On the Home Front, Chapter 5.

[47] Rieck, HW-72215; and Hanford Laboratories Operation and Irradiation Processing Department, HW-70526; and Ballowe, DUN-2231.

Reactor's closure that February ended the trenching test.[48]

Clearly, by the end of B Reactor's operating lifetime, effluent disposal problems in the Columbia River had not been solved and were essentially intractable. The effluent disposal issues played a large role in the federal decision to close Hanford's single pass reactors in sequence between December 1964 and early 1971. Today however, groundwater contaminated with plumes of Chromium^{+6} is a serious problem in the 100 Areas of the Hanford Site, and is the subject of extensive and expensive remediation work. Chromium^{+6} is a carcinogen, and is readily soluble in water, and therefore it enters and binds to the tissues of living organisms (fish, man, and others). Most of the cleanup efforts in Hanford's 100 Areas today center on extracting groundwater contaminated with Chromium^{+6} and treating it to change it into Chromium$^{+3.}$

Public Response

As concerns about the health effects of pollution from Hanford grew, a number of citizen groups formed to gather more information and lobby for government action. The Hanford Education Action League (HEAL) was formed in 1985 in Spokane. In February of 1986, the U.S. Department of Energy (DOE) released thousands of pages of documents on the history of the Hanford Site.[49] Citizens learned that contaminants had been released into the environment in amounts far in excess of previously known levels. Those concerned about the health effects of living downwind from Hanford took the name "Downwinders." A Hanford Downwinders chapter of the National Association of Radiation Survivors was formed in 1988. A Seattle-based group called the Downwinders Information and Support Group (DISG) formed in mid-1989. That same year, portions of Hanford, including that area containing B Reactor, were declared Superfund sites.

In May of 1989, the Department of Energy, the Environmental Protection Agency, and the State of Washington signed the Hanford Federal Facility Agreement and Consent Order (known as the Tri-Party Agreement) to effect the cleanup of the Hanford Site by 2018. By the early 1990s, only one nuclear reactor was operating at Hanford: the Fast Flux Test Facility, which was permanently deactivated in 2000. The business of the Hanford Site had shifted from the operation of nuclear reactors to cleanup of nuclear waste – a monumental task with no clear end in sight.

Comparative Study

The Manhattan Project involved the coordination of facilities across the United States, including Hanford, Washington; Oak Ridge, Tennessee; Los Alamos, New Mexico; Dayton, Ohio; and Chicago, Illinois. Facilities at the University of Chicago were most important in the earlier experimental stages of the project, which culminated in the Chicago Pile I becoming the first reactor to sustain a nuclear reaction on December 2, 1942. The largest facilities were at Hanford and Oak Ridge, which operated on an industrial scale to produce the fissionable material needed to create nuclear devices. Oak Ridge produced small amounts of plutonium 239 and produced the uranium 235 used in the bomb dropped on Hiroshima. Hanford produced the plutonium 239

[48] Healy, HW-60529; and Geier, HW-75949; and Ballowe, DUN-2231; and Geier, DUN-3935.
[49] Gerber, *On the Home Front*, 201-218.

used in the device detonated in the Trinity test and in the bomb dropped on Nagasaki. The Dayton site researched trigger devices and produced the polonium needed for these devices. The primary goals of the Los Alamos laboratory were to determine the chemical and metallurgical properties of uranium 235 and plutonium 239 and then design and assemble atomic devices. To date, four sites associated with the Manhattan Project have been designated as NHLs: the Los Alamos Scientific Laboratory, the X-10 Graphite Reactor at Oak Ridge, the Trinity Site, and the Chicago Pile I.

As the first industrial-scale nuclear reactor in history, as the nuclear reactor which produced the fuel for two of the first three nuclear devices detonated, and as a model for Cold War-era nuclear reactors, B Reactor deserves designation as a National Historic Landmark. The facilities built at Hanford to produce plutonium were without precedent anywhere in the world. Manhattan Project scientists and DuPont Company engineers had to build an entirely new type of plant with only a very vague knowledge of how it would work. There were experimental reactors at Oak Ridge and at the project's facilities in Chicago, but the piles built at Hanford were of a scale and sophistication never before attempted. While the experimental air-cooled pile at Oak Ridge (designated X-10) did produce plutonium before the reactors at Hanford, it did so in small quantities. The plutonium produced at Oak Ridge was used merely as a means of learning about the plutonium separation process and for experimental purposes before the production-scale Hanford reactors were completed. The Chicago pile and the X-10 did not seem to provide models for the plutonium production reactors except in the most general sense and the Hanford reactors would be significantly different. As one historian of the Manhattan Project has written "the scale at Hanford would be so gigantic in comparison with the X-10 pilot plants, that it looked as if all the problems would have to be solved anew."[50]

One significant difference between the B Reactor and the earlier reactors was in their cooling systems. The Chicago pile's power output was too small to require any cooling system. The X-10 had an air-cooling system that used atmospheric air drawn into the reactor via fans in its cooling process, which meant that it could only reach its highest power levels on cooler days. An air-cooled system would not be sufficient to cool the much larger B pile and so it and its counterparts were built to utilize water from the Columbia River for cooling purposes. As a result of its innovative and unique water-cooling system, and in contrast to the X-10, the B Reactor could operate independent of climatic conditions.[51]

B Reactor was unique in other important ways. The maximum power level of the X-10 reactor at Oak Ridge was four million watts-thermal, in sharp contrast to the 250 million watts-thermal of the B Reactor. Hanford's B pile and its counterparts were designed to produce plutonium in far greater quantities than any previous reactors in order to have enough of the element to build several atomic weapons before the war ended. B Reactor was a production reactor in that it was designed to produce enough fuel to achieve a specific industrial task – in this case the building of atomic bombs. By contrast, the Chicago pile and the X-10 were experimental reactors that only produced plutonium in small quantities. Enrico Fermi, one of the leading physicists on the Manhattan Project, was quoted as describing Hanford's three production reactors as "different

[50] Groueff, *Manhattan Project*, 294 (qtn).

[51] Groves, *Now It Can Be Told*, 78-79; Rhodes, *The Making of the Atomic Bomb*, 547; National Register of Historic Places Nomination, *X-10 Reactor, Oak Ridge National Laboratory*.

animals" compared to any of the previous, smaller-scale experimental piles. The significant differences between the B type piles and previous reactors meant that engineers had limited experience that they could draw on in developing and operating the Hanford reactors. There was no pilot plant or prototype of the B type reactors that plant operators could learn from. Given these constraints, the success of the engineers, construction workers, operatives and scientists in building a working plutonium production plant at Hanford, all in less than two years, was an remarkable accomplishment. B Reactor stands as a reminder of that achievement.[52]

	B Reactor	**X-10**	**Chicago Pile**
Mission	Large-scale production of plutonium for the first atomic weapons	Production of plutonium for experimental purposes	Experimental
Cooling System	Water cooled	Air Cooled	None
Maximum power level	250 million watts thermal[53]	Four million watts thermal	
Scale of reactor's graphite core	36 feet wide x 36 feet tall, and 28 feet front to rear	24 feet x 24 feet	25 x 20 feet
Design Status	The first of several wartime piles of the same design and a model for reactors built after World War II	Once-off design	Once-off design

Table 2: Comparative analysis of World War II era reactors – B Reactor, X-10 reactor and Chicago Pile.

[52] Patricia Nelson Limerick, "The Significance of Hanford in American History," in David H. Stratton, ed., *Washington Comes of Age: The State in the National Experience* (Pullman, WA: Washington State University Press, 1992), 166; Rhodes, *The Making of the Atomic Bomb*, 500 (qtn).

[53] This was the initial World War II design operational level. After the war, B Reactor was operated at levels up to 2,000 megawatts. See B Reactor Museum Association, *Historic American Engineering Record, B Reactor*, 22.

ANALYSIS OF HISTORICAL MODIFICATIONS TO PLANT OPERATIONS

Since the historic significance of B Reactor derives from its operations that produced plutonium for the first nuclear device and served as a model for Cold War-era nuclear reactors, it is important to understand the facility, not only as a static artifact; it is also important to understand the historical operations of the plant, including the subtle modifications that accompanied the expanding power levels that the plant achieved during its period of operation.

B Reactor Modifications

The B Reactor underwent a series of modifications after the period of significance (1943-52). None of these, however, changed the fundamental design and character of the reactor. The reactor retains a high degree of integrity that evokes both the momentous events of World War II associated with it and the design established during the war which would serve as the model for many of the early Cold War reactors. Several projects, as mentioned above, were Project CG-558, which modified the reactor plant to increase production, and Project CGI-791, which improved reactor confinement. The reactor also received modifications relating to the following issues: cooling water flow and supply; safety and control instrumentation and electrical systems; and reactor shutdown.

Modifications to Boost Power Levels: Project CG-558

Beginning in 1954 and continuing into November 1956, B Reactor received modifications under Project CG-558. The higher power levels associated with Project CG-558 necessitated changes to the reactor's cooling systems. During this two year period, B Reactor received a series of modifications that expanded the piping and pumping systems, allowing more cooling water to flow through the reactor, so that the system could operate at higher power levels. These modifications did not alter markedly the interior or exterior appearance of the B Reactor building, as most of the changes occurred in other buildings outside the NHL boundary, such as the 181-B/C River Pump House (still extant) and the 183-B Filter Plant (since demolished). Changes within the 105-B building itself were: 1) Upgrading the pipes from the 190-B building (pump house, since demolished) to the 105-B building from 12-inch to 18-inch pipes. 2) Replacing the four existing, 20-inch stainless steel lines connecting the main valve pit headers to the risers with two, 36-inch carbon steel lines, with all necessary valves and fittings. A 36-inch venturi tube was installed in each line to provide flow measurement for the automatic power calculator. 3) Replacing the two existing, 20-inch carbon steel main headers within the 105-B building with a single, 36-inch carbon steel header. The four extant, 20-inch stainless steel risers were superseded by two, 36-inch carbon steel risers. 4) Installing new instrumentation in the 105-B building to monitor flows and temperatures in this expanded piping system. As a comparison of recent photographs with photographs from 1954 demonstrates, while some new instrumentation was added after the period of significance, these minor changes did not compromise the integrity of the control panel and its ability to convey its historic character.[54]

[54] G. E. Hanford Company, HW-33389; and Trumble, HW-44708, Vols. 1 and 2; and Russ, HW-30401, Vol. 1; and Young, HW-56230-RD; and IPD, HW-74094, Vol. 3; and Stainken, HW-35589.

Reactor Confinement: Project CGI-791

A modification project implemented in 1959 and 1960 at B Reactor was necessitated by the higher power levels achieved as a result of Project CG-558. Project CGI-791 -- known as Reactor Confinement -- greatly reduced emissions from the reactor. During 1958, the Atomic Energy Commission (AEC) was being pressured by agricultural interests in Washington state to open land to farming on the Wahluke (North) Slope across the Columbia River from the Hanford reactors. For many years, secret studies by Hanford scientists had shown that, in the event of any airborne (radioactive) fission product release from one or more reactors, the release would "exercise its effect mainly over the Wahluke Slope" due to proximity and "meteorological conditions."[55]

As a compromise, the AEC in December 1958, announced the release of secondary (non-central) zones of the Wahluke Slope to the U.S. Department of the Interior, Bureau of Reclamation, for development as farmland. As a compromise, at the same time, it authorized Project CGI-791, the phased-in installation of rear reactor area fog sprays and exhaust filtration systems that would entrap a small percentage of the reactor's noble gases (krypton 85, argon 39, 41, and 42, and xenon 135), 70-95 percent of the halogens (iodine 131 and bromine 82), and most of the remainder of the particulates and aerosols in reactor gases (including cesium 137, tellurium 129, selenium 79, ruthenium 103/106, and others). In addition, the AEC mandated that front face fog sprays be installed in the Hanford reactors that still were operating between 1966 and 1968. Project CGI-791 -- the exhaust confinement system -- was adopted in lieu of placing a full steel containment dome over each Hanford reactor.[56]

Project CGI-791 began at B Reactor in late 1959, and the rear face fog spray system (Phase I) was manually operable by September 1960. A below-grade filter building (117-B) was constructed, housing a series of horizontal "absolute" (i.e., extremely effective) filters for fine particulate removal, and activated charcoal filters for halogen removal. This building was subsequently demolished in 1989. A 119-B sampling building (since demolished) was also constructed to house instrumentation to indicate water flow and high/low pressure through the fog spray system, pressure drop across the filters, air pressure differentials, and to detect I-131. In addition, tie-ins, exhaust fan modifications, and other changes routed reactor gases through the new system and back out the existing ventilation stack. Once the new system was operational, the entire air flow was maintained at a slight negative (internal building) pressure, and steam-driven emergency power systems were installed. A crib was constructed to receive liquid effluents generated within the filter system.[57] The primary effect of this project was that the effluent gasses were being passed through filtration through modifications to buildings outside of the proposed NHL.

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[55] Dickeman, Healy, and Tomlinson, HW-55756; and MacCready, "Hanford Confinement Study Program," March 17, 1958.

[56] Trumble, HW-67131; and Rogers and Heacock, HW-57185; and McFeron, HW-61839 Rev.; and Gerber, WHC-SD-EN-RPT-004.

[57] Trumble, HW-67131; and Heacock and Jones, HW-SA-2287; and Irradiation Processing Department, "Acceptance of Completed Project...," November 8, 1961; and Jessen, "Physical Completion Notice...," December 15, 1961.

Modifications: Cooling Water Flow and Supply

Throughout B Reactor operations, the water coolant delivery system presented innumerable challenges and puzzles. Efforts to increase the output of the reactor led to modifications of the coolant delivery system. B Reactor originally was constructed with a 0.240-inch orifice in the inlet nozzle of every process tube. However, operators learned very early that higher neutron flux levels, requiring greater cooling capacity, existed in the center of the pile. Therefore, in late 1944, about half (998) of B Reactor's inlet nozzles were re-orificed. A concentric circle of 428 tubes around the central zone was retrofitted with 0.175-inch orifices, and the outermost ring of 570 tubes was retrofitted 0.140-inch orifices. With this configuration the water flow was adjusted to give an inlet nozzle pressure of 350 pounds per square inch, thus providing the desired supply of approximately 20 gpm per reactive tube. The temperature of the exit cooling water (water that had left the process tubes) was held at 65 degrees Celsius, because Hanford scientists believed that excessive process tube and fuel element corrosion would occur above this level.[58]

Almost immediately after startup, reactor operators expressed a desire for instrumentation to indicate whether or not the coolant was flowing smoothly and uniformly through the reactor. As a result, a Panellit[59] gauge, which measured coolant pressure by sensing the amount of flow passing through an orifice, was installed at the inlet of each of the 2,004 process tubes. Each sensor was attached via a single hydraulic line to a pressure monitoring gauge in the control room, and was set at both a high and low trip point. Use of the Panellit gauges began in early 1945.

As higher power levels became a reality in the 1950s with the implementation of CG-558, B Reactor experienced increasing levels of process tube corrosion and failure. In 1953, internal tube corrosion came under intense scrutiny. After Project CG-558, the vastly increased coolant flow through B Reactor corroded more and more process tubes strained the rear face piping systems and fittings, stressed the downcomer, and wore large and destabilizing leaks in the effluent disposal system. Between 1955 and 1957, most of the original process tubes in B Reactor were replaced with new aluminum tubes, but a 1960 Hanford study found that even the "average" second generation process tube had lost about 25 percent of its thickness to internal corrosion. During 1959 and 1960, such corrosion led to the complete failure of 35 process tubes in B Reactor, causing worrisome wetting of the graphite and the loss of over 275 hours of production time. In the late 1950s and early 1960s, B Reactor aluminum process tubes that failed were gradually replaced (on an as-needed basis) with zircalloy-2 tubes. The more tensile strength of zirconium allowed tubes that were thinner and that consequently had a greater cooling annulus. Also, the melting point of zirconium is approximately 1200 degrees Celsius higher than that of aluminum, making the zircalloy-2 tubes safer in events involving the loss of coolant. In total nearly one-third of B Reactor’s aluminum process tubes were replaced by zircalloy-2 tubes between the late 1950s and the reactor’s closure in 1968.

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[58] DuPont, *Operation*, Book 11, p. 74; and DuPont, HW-10475-B, p. 1110; Gerber, WHC-SD-EN-RPT-004.

[59] Panellit was a trademark of Ametek, Inc., New York, New York.

Modifications: Safety and Control Instrumentation and Electrical Systems

The drive to higher power levels in B Reactor throughout the late 1940s and mid-1950s was accompanied by the need for several safety modifications. One component of the World War II reactor design that was especially vulnerable to increased power levels was the third or "last ditch" safety system. The original arrangement, tanks of boric acid solution held at the top of the reactor ready to pour into the VSRs to shut down operations through neutron absorption in case of an accident that interrupted both the primary and secondary coolant flow, would not work at the augmented power levels. By 1950, Hanford operators expressed concern that, at higher operating temperatures, the boron liquid would "flash" to steam at initial contact with the hot aluminum thimbles that lined the VSRs. If this happened the solution could boil and there might not be enough liquid left to shut down the pile. Furthermore, the vapor formed from the boron solution might rupture the thimbles, thus wetting the graphite. This risk was considered so severe that operators did not dare to test the third safety system at all after the summer of 1950.

As a result, the liquid boron was replaced with 29 "ball hoppers" (one at the top of each VSR channel) that contained 3/8-inch to 7/16-inch nickel-plated carbon steel balls. These balls, which also acted to shut down the pile through neutron absorption, could funnel down into the VSR channels via a step-plug assembly, in the event of an emergency or a test. The ball could then be removed by a vacuum system. In January 1952, B Reactor became the first to be fitted with the new "Ball-3X" system.[60] It is important to note that, while the Ball 3X system was the first actual modification to the reactor, it did not fundamentally alter B Reactor's character, operations, or functions. Rather it modified one of the peripheral systems that sat above the graphite stack, without modifying the reactor's basic appearance or character as a water-cooled, graphite-moderated nuclear reactor.

As B Reactor's power level increased continually throughout the years after 1948, many new instruments and safety devices were added. Among these were reactor shield restrainers in 1950, and thermocouples for the VSR thimbles (which were approaching their melting temperature) in 1951. Also in 1951, crossheader pressure monitoring equipment was added, downcomer repairs were made, and additional health monitoring equipment for the radiometallurgical examination facilities in the 111-B Building was installed. In 1952, outlet temperature monitoring thermocouples were attached at the downstream ends of the process tubes in B Reactor, and earthquake detectors (called seismoscopes) also were installed.[61]

In 1954, the "rod tip length" (control portion) of the horizontal control rods (HCRs) at B Reactor were increased by ten and ½-inches. The following year, continuous effluent water temperature monitoring equipment was added to the reactor. The equipment consisted of resistance bulbs located in specially modified pigtails in each reactor zone, and was used in addition to the existing reactor temperature monitors (thermocouples).[62] Again, none of these modifications changed the essential operations, character, or structure of B Reactor. Rather, additional monitoring instruments were implaced along with the existing Manhattan Project-era instruments.

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[60] Wahlen, WHC-EP-0273, p. 20; and DeNeal, DUN-6888, p. 9.
[61] Woods, HW-15121; and Roesch, HW-19499; and McClaine and Bupp, HW-22109.
[62] Paul and Stephens, HW-34467; and Greager, HW-37033; and Call and Rector, HW-30863.

In 1955, as a part of Project CG-558, several instrument changes were installed in B Reactor. Improved Panellit gauges and calibration equipment were necessary because, with the higher operating power levels, water pressure was consistently higher and the high and low "trip" points on the gauges were set much closer together. Water pressure surges in the 75-foot line that led from each process tube to its Panellit gauge often caused swings that brought about instrument scrams. The number of such incidents at B Reactor rose from 20 in 1951 to 42 in 1954. Consequently, accurate calibration became even more important, and the gauges needed much attention.

Installation of the new calibration equipment involved replacing 2,004 pairs of needle valves (a pair for each process tube) with 2,004 three-way toggle valve/needle valve assemblies. These new valves had the same space requirements as the older valves, so adjacent equipment did not need replacement. However, a pump, piping and valving, and pressure regulators independent of the normal reactor cooling system had to be installed to supply regulated water pressure to the test manifolds.[63]

Due to the higher heat levels experienced with the power level increase made possible by Project CG-558, the aluminum thimbles that lined the HCR, vertical safety rod (VSR) and test hole channels at B Reactor had become hazards. They were constantly in danger of melting, and, as a result, all thimbles that did not contain self-cooling tubes were removed in Project CG-558. Additionally, new HCR inner tip control sections were installed, using the existing rack sections. The new rod sections consisted of one-piece aluminum extrusions that slid through silicon sleeves mounted on the exterior of the left side shield. The new tips had similar neutron absorption capabilities to those of the earlier HCRs, but with greater flexibility and heat transfer capacity. Also, the existing shield gates over the HCR openings were removed, and the shield gate control lines were used as suction lines for a rod seal leak detection system. After Project CG-558, shield plugs were used when a rod was removed, and a shield was installed over the withdrawn parts of the rods.

The higher power levels made possible by Project CG-558 strained the material tolerances in B Reactor's biological and thermal shields, and made accurate temperature monitoring more crucial than ever before. New temperature monitoring devices were installed in the biological shield, consisting of thermocouples within each layer of steel at three points in the far side shield and at one point in each steel layer of the top shield. Additionally, operators began inserting neutron-absorbing poisons in the reactor fringe channels nearest the biological shields, in order to reduce heat stress in the shields. They compensated for this reactivity loss by enriching other areas of the reactor. Also, a rotating vane, sight-glass flow indicator was seated between the thermal loop and each thermal shield cooling tube, to indicate the coolant flow in each tube.

In addition, new iron/constantan and chromel/alumel wire thermocouples to monitor graphite temperatures were placed on stringers in process channels located in various zones of the reactor. An automatic power calculating system was installed, and all existing instruments whose ranges would be exceeded by the new flow, temperature or power levels were re-worked or replaced to fit the new conditions. Automatic outlet water temperature monitors were installed on about five percent of the process tubes, and the beta activity monitors that sampled each rear crossheader

[63] Greager, HW-37033; and Talbott, HW-37304; and Gerber, WHC-SD-EN-RPT-004.

and riser were replaced with scintillation-type gamma monitors to permit earlier and more definite detection of slug ruptures. These new gamma detectors required a periodic oxalic acid and water flushing (cleaning).[64] In addition, an instrument known as a "probolog" was developed at Hanford in about 1956 to check for process tube leaks and corrosion using tritium as a radioactive tracer.

In 1958, attempting to reduce spurious reactor scrams caused by power surges and/or minor variations in the flux meters and controllers, a new flux monitor "dual trip" system was installed at B Reactor. New controllers and circuitry modifications were emplaced, along with bypass switches, relays, and control board upgrades. Under the "dual trip" system, two concurrent "trips" above or below pre-set flux limits, as registered on the flux monitors, were needed to initiate an automatic reactor scram.

The following year, sub-critical neutron flux monitors were installed in test holes A and D of B Reactor. This new instrumentation could more precisely monitor the rate-of-rise during startups, or during the "high sub-critical" periods, when rapidly changing power levels could cause spurious scrams, localized hot spots, and other operating abnormalities. The previous equipment was not able to calculate neutron flux levels accurately during times of low but quickly shifting power conditions. The new instrumentation consisted of neutron sensitive chambers, log rate meters, recorders, amplifiers, and an alarm relay system. Additional rate-of-rise metering equipment was installed in late 1960 and early 1961.[65]

In April 1960, automatic gas make-up equipment was installed at the 100 B Area, with components in both the 105-B and 115-B Buildings. The system consisted of an electronic analyzer to measure the gas mixture and the pressure/flow rate, as well as valving to preclude fluctuations and maintain constant gas pressure and flow. Soon after the installation however, it became apparent that the control valves were not sized in proportion to the flow characteristics of the gas, and many system malfunctions occurred. In 1962, to correct these conditions, new prototype gas control instrumentation was installed in the 115-B Building to serve B Reactor.[66]

In 1963, pressure monitoring system improvements were emplaced at B Reactor, in order to reduce false reactor scrams caused by component failure in the Panellit gauges and their related circuitry.[67]

During 1962 and 1963, improvements were made to the gamma monitoring, rupture detection equipment at B Reactor. Rear face sample lines from the crossheaders to the sample rooms were replaced, gamma monitoring equipment in the X, Y, and Z sample rooms at B Reactor were consolidated into the X room, where sample room piping was replaced and pulse height signal

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[64] Trumble, HW-44708, Vol. 2, pp. 8, 9, 12; and Janos, HW-30083; and Greenfield, HW-38541.

[65] Irradiation Processing Department, "Project Proposal...Project CG-786," December 2, 1957; and Murray, "Construction Completion and Cost Closing Statement," February 13, 1959; and G. E. Hanford Company, "Project Proposal, Revision 1...Project CG-707," June 21, 1957; and Irradiation Processing Department, "Semi-Monthly Project Report," November 1958; and Irradiation Processing Department, "Project No. CGI-806...," June 15, 1961.

[66] Knirck, "Outage Report - Project CG-706 - 105-B," April 12, 1960; and Amy, "Gas Make-Up Control...," April 15, 1960; and Clement, "CG-706 Improvements...," April 10, 1961; and Steach, "Evaluation of Proportional Gas Controller," July 23, 1962; and Hamilton, "Evaluation of Project Gas Control System," July 31, 1962.

[67] Ferguson, "Proposed Program...," February 4, 1960.

generators and oscilloscopes were seated. In addition, heat exchangers, automatic flow regulators and shutoff valves were installed on all sample lines. Combined isokinetic flow probes and shutoff valves were placed on sample tops, and new cooling water supply and drain lines were provided to the affected areas. In addition, range-change kits were installed in all count rate meters and gamma system recorders, and portable rupture confirmation instrumentation was provided. [68]

Additional safety and instrumentation improvements installed in the 105-B building in the latter half of the 1960s included resistance thermal detectors (RTDs) emplaced on the rear face piping in 1965 and 1966 to measure the rate at which effluent temperatures changed. This information was translated by Hanford operators into an indication of power rate-of-rise, and was considered to be an improvement over rate of rise instrumentation installed in 1958 and 1960.[69]

In Project CG-558, electrical systems were also strengthened. New circuit breakers and underground cables were installed at the 151-B Electrical Substation, to transmit 13,800-volt power directly to the process pump motors in the 190-B Building. Also, a new, 13.8/2.3 kilovolt (kV), 5,000-kilovolt-ampere substation was installed at the 181-B River Pump House. Switchgear equipment was relocated from the 190-B Building to the 181-B and 183-B structures to supply the pumps of those facilities. Still, the immediate post-CG-558 power needs were such that all three, 151-B transformers needed to be in constant service, using forced air cooling systems (fans to cool radiator oil) "for a substantial portion of the time." The forced air cooling allowed the transformers to routinely carry loads that exceeded their self-cooled rating. However, if one transformer broke down, the added burdens on the other two transformers increased to the point where even the fan-cooled ratings were exceeded.[70]

The astonishing new power levels B Reactor’s electrical system strained even the improved electrical systems. One 1960 study of the safety and reliability of the reactor electrical power supply system concluded that equipment was approaching its "maximum capability," and that "operation of the present loop under critical power conditions is unsatisfactory." This document recommended immediate increase in transformer capacity at the 100 B/C Area.[71]

In 1960, the Ball-3X electrical system at B Reactor was upgraded. Dual and independent Ball-3X power and control systems were installed, along with continuous monitoring equipment and some changes in the layout of system controls and components. In 1965, a four-inch discharge chute was installed to carry irradiated balls from the top of B Reactor to a storage pad outside of the building. The following year, baffles were installed in this chute and it was connected to a ball holding tank with one-foot-thick concrete block shielding all around it.[72]

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[68] Irradiation Processing Department, “Acceptance of Completed….,” May 1, 1963; Astley, “Project CGI-904….,” July 24, 1964.

[69] Simsen, IP64-15; and Hermann, HW-78840; and Lyons, DUN-812; and Douglas United Nuclear, "Acceptance of Completed Project CGI-143 (105-B)," September 30, 1966.

[70] Trumble, HW-44708, Vols. 1 and 2; and Baker and McLenegan, HW-43937.

[71] Deichman, HW-67741-Del; and Dickeman, HW-65580; and Bainard, HW-49777; and Travis and Bloch, HAN-71403; and Upson, HW-63562.

[72] Irradiation Processing Department, "IPD Radiation Exposure Reduction Program," October 20, 1958; and Walker, HW-50351-Del; and Faught, "Reevaluation of the Justification...," February 13, 1958; and Porter, "Request for Mechanical Development...," November 17, 1958; and DeNeal, DUN-6888.

During 1966 and 1967, high resistance neutral grounding and ground detection equipment was installed in the existing 2,400-volt power systems in the 100 B Area. A three-phase grounding transformer was emplaced to supply ground current, along with a secondary circuit to limit fault current valves. Also, a current pulse generator and ground detection instrument to locate ground faults and an annunciator alarm were installed. The new equipment provided sufficient ground current to suppress transient over-voltage, and served to locate ground faults without shutting down the power system.[73] B Reactor's instrumentation and electrical improvements following Project CG-558 provided capacity to more closely monitor and control the reactor at higher power levels.

Modifications Associated with B Reactor Shutdown

On January 29, 1968, the U.S. Atomic Energy Commission issued a shutdown order for B Reactor, to take effect on February 12 provided there were no serious water leaks prior to that time. If such a leak into the graphite occurred before that time, shutdown was to occur immediately after the stack underwent sufficient drying. Since no water leak occurred, final shutdown took place on February 12. As of that date, the reactor was reclassified from Plant and Equipment In-Service to Plant and Equipment for Future Use.

Hanford managers implemented a shutdown procedure generally involving draining systems of fluids, disconnecting machinery from power sources, and decontaminating surfaces. Some components were locked or sealed. Access to certain areas was sealed off. For instance, all entrances to the inner rod room were locked and sealed. The access areas to the rear face were locked and tagged. However, vital systems remained in the building after the shutdown process. All dummies, inserts, and poison pieces were removed from the 105-B building, being either offered to other reactor areas or buried. Trash, graphite samples, and other materials were also removed from the building.

Gradually, the support buildings for B Reactor were removed or demolished (see Figures 7, 9 & 10 and Photographs 4-6). During 1969-1970, in connection with the shutdown of C Reactor, some additional deactivation was conducted at B Reactor. Those systems that had remained operational to support C Reactor were drained, disconnected, and sealed. In 1975, the 1736-B Building was moved to Hanford's 400 Area to support the Fast Flux Test Facility and the 1704-B Building was moved to the 200 Area. In 1977, the 107-B Retention Basin was graded along the outside walls and the contaminated soil was covered with four feet of clean earth. Clean fill to a depth of 18-20 inches was added to the inside of the basin, to stabilize contamination. Two years later, the vertical walls of the 1904-B Outfall Overflow Flume were broken down, and the walls and bottom of the flume were covered with earth. At the same time, all electrical and underground water services were removed from the 184-B Power House. Also in 1979, several surplus buildings and associated equipment were sold as excess and removed. Among these facilities were the 187-B High Tanks, the 190-B Annex, the 190-B Tank Room and four large tanks, the 1902-B Power House Water Tank, the 1707-B Building and Annex, the 1715-B Building, the 1716-B Building, and the 1719-B Building.

In 1983, the two smoke stacks serving the 184-B Power House were demolished and buried in

[73] Lyons, DUN-589; and Lyons, RL-REA-676; and Jessen, "Physical Completion Notice...," April 10, 1967.

place, and the ventilation stack for the 108-B Building was demolished and buried in a trench that had been excavated at the base. The 184-B Power House itself then was dismantled and removed. The concrete pad and foundation were removed and buried in 1988. In 1984, the contaminated equipment in the 111-B Test Building was removed, packaged, and buried in 200 Area burial grounds. The building itself then was decontaminated, dismantled, and disposed as clean waste. The floor, foundation, and concrete waste tanks were left in place at the site. Additionally that year, the two-year site preparation process for the removal of the 108-B Building began. Asbestos, mercury, radioactive, and hazardous waste were retrieved and disposed. Equipment was taken out and clean waste was buried in the 184-B coal pit. In 1985, the structure itself was decontaminated and demolished. Also in 1984-1985, a two-year deactivation and decommissioning (D&D) process was carried out to place the 105-B fuel storage basin in a stable mode. The 8-to-10-foot heel of contaminated water, fuel buckets, and other miscellaneous radioactive materials were removed. The solid materials were buried within the 100 B/C area, but outside the proposed NHL, and the residual water was processed and released according to criteria of that period. Next, the contaminated sludge was removed and stored under protective conditions in the transfer area. Finally, a fixative was applied to the contamination remaining on the basin surfaces.

In 1985, D&D began on the 117-B Filter Building. All filters and fixtures were removed and buried in place and the inside surfaces of the structure were washed with decontaminating rinses. In 1989, the building was demolished and the debris was buried in place. In 1986, equipment and fixtures from the blower-dryer rooms of the 115-B Building were packaged and buried in the 200-W Area burial grounds. In 1989, the structure itself was demolished. The aboveground debris was used as fill for the 184-B coal pit, but the floor, basement, and pipe tunnel walls were buried at the 115-B Building site. During 1987-1988, the 183-B Chemical Treatment and Filter Building was demolished. The clearwells were left in place to hold clean decommissioning waste.[74] All of these structures were outside the proposed NHL.

In 1991, the Department of Energy (DOE – a successor agency to the AEC) issued a Record of Decision defining the future end state of the eight SPR facilities, including B Reactor, at the Hanford Site. The path forward was to be demolition of the reactor buildings and all ancillary buildings and facilities in the 100 Areas (excluding the 100 N Area).[75] The reactor cores were to be carried by heavy crawler vehicles to the 200 Areas (central, reprocessing areas) of the site and buried as waste.[76] However, in view of the huge costs and the potential radiation exposure to D&D workers dismantling the reactor cores, the DOE adopted a revised plan in 1995. Known as Interim Safe Storage, the new plan was quickly nicknamed the "cocooning project" by Hanford workers.

In 1996, work began on the first cocooning project at C Reactor, in the 100 B Area (see Photo 6). The large project, completed in September 1998, removed 85 percent of the C Reactor structure, including filters and tunneling, and water piping, and left only the reactor's core and front face work area. These areas were capped and wrapped with a steeply slanted steel roof that extended down the building's sides approximately one-third of their distance from the roof. All

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[74] Wahlen, WHC-EP-0478.
[75] Note: A similar Record of Decision was later issued for the 100 N Area, including the N Reactor.
[76] U.S. Department of Energy, DOE/EIS-0119F.

penetrations in the remaining concrete were filled with back-pours of concrete, effectively sealing or “cocooning” the reactor. All ancillary buildings that had supported C Reactor were demolished, except the B/C pumphouse at the Columbia River’s edge.[77]

Meanwhile, between 1989 and 2006, the following additional structures were demolished in the 100 B Area: 185-B Water Laboratory and Instrument Shop, 190-B Main Process Pump House, 190-BA Pump House Annex, 1701-BA Patrol Headquarters and Badge House, 103-B Fuel Element Storage Building, 104-B-1 Oil Storage Building, 104-B-2 Tritium Storage Vault. During 2004-2006, the solid waste burial grounds in the 100 B/C Area were exhumed, and contaminated solid waste was moved out of the area. Throughout 2003-2006, contaminated soil from the area between B Reactor and the Columbia River was exhumed, moved out of the area, and replaced with clean fill soil.

Conclusion

By the time it shut down, B Reactor, constructed in a little over a year, with few precedents for its builders to draw on, had produced large amounts of plutonium for U.S. national security purposes over its twenty-four year career. Most importantly, it had made an indispensable contribution toward the Manhattan Project’s production of the first atomic weapons by its facilitation of the production and deployment of the first atomic device tested at the Trinity site, near Alamogordo, New Mexico, and the bomb dropped on Nagasaki that helped to end World War II. In addition, the construction and operation of the reactor during World War II was one of the most important construction and industrial projects of the wartime home front and had marked the shift in plutonium production from an experimental to an industrial process capable of producing large quantities of the fissionable material. The reactor has also been recognized as a National Historic Mechanical Engineering Landmark by the American Society of Mechanical Engineers (1976), as a Nuclear Historic Landmark by the American Nuclear Society (1993), and as a National Civil Engineering Landmark by the American Society of Civil Engineers (1994). The B Reactor has been listed on the National Register of Historic Places (1992) and recorded by the Historic American Engineering Record (2000). For its role in the events that ended World War II, its contribution to the industrialization of plutonium production, and its status as a symbol of the World War II home front, the B Reactor holds a powerful historic significance. Likewise, as the reactor that served as the model for all the early nuclear reactors built at Hanford – the reactors that served as the sole suppliers of plutonium for the U.S. nuclear arsenal in the early years of the Cold War until 1952 – B Reactor has unique historical significance and deserves designation as a National Historic Landmark

[77] Palmquist, BHI-01231, Rev. 0.