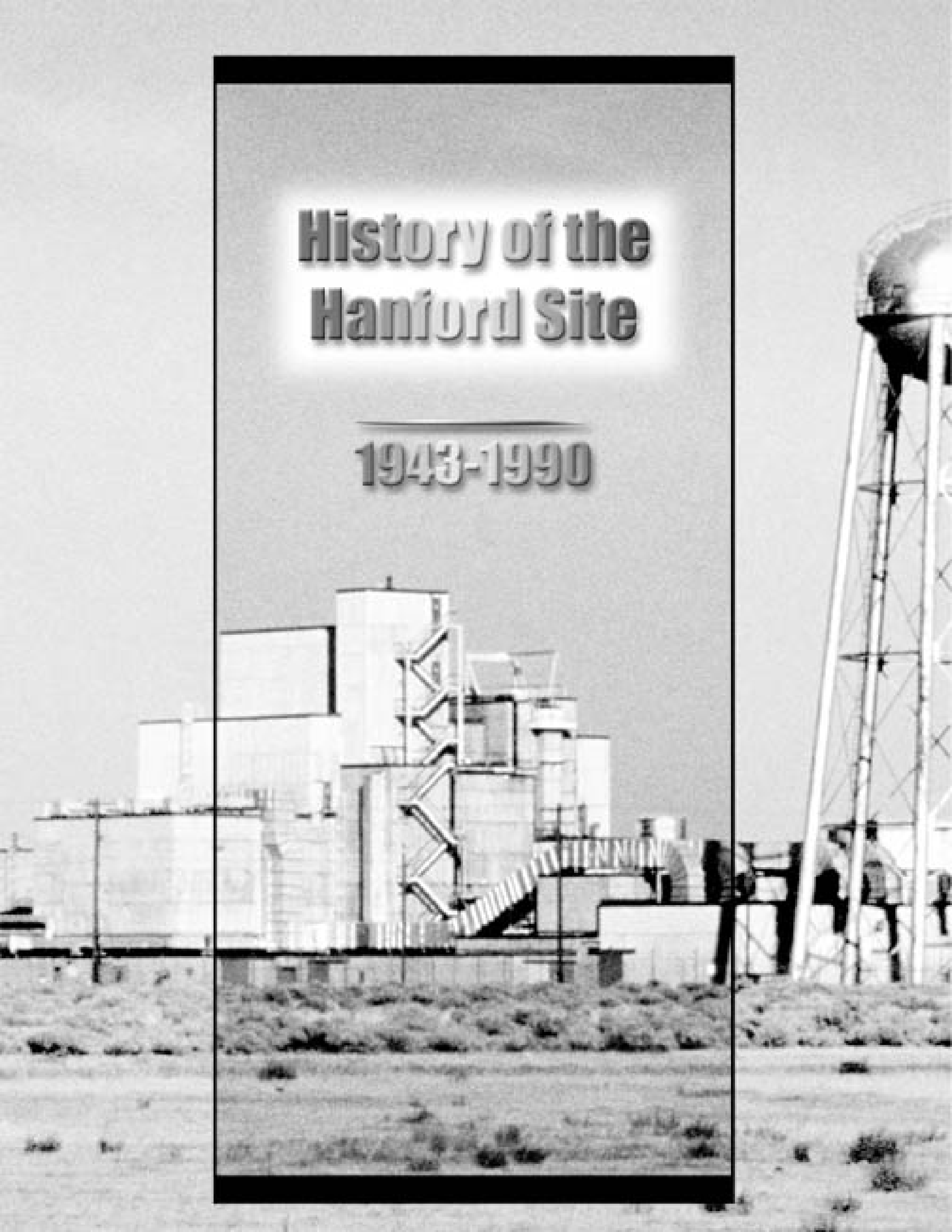
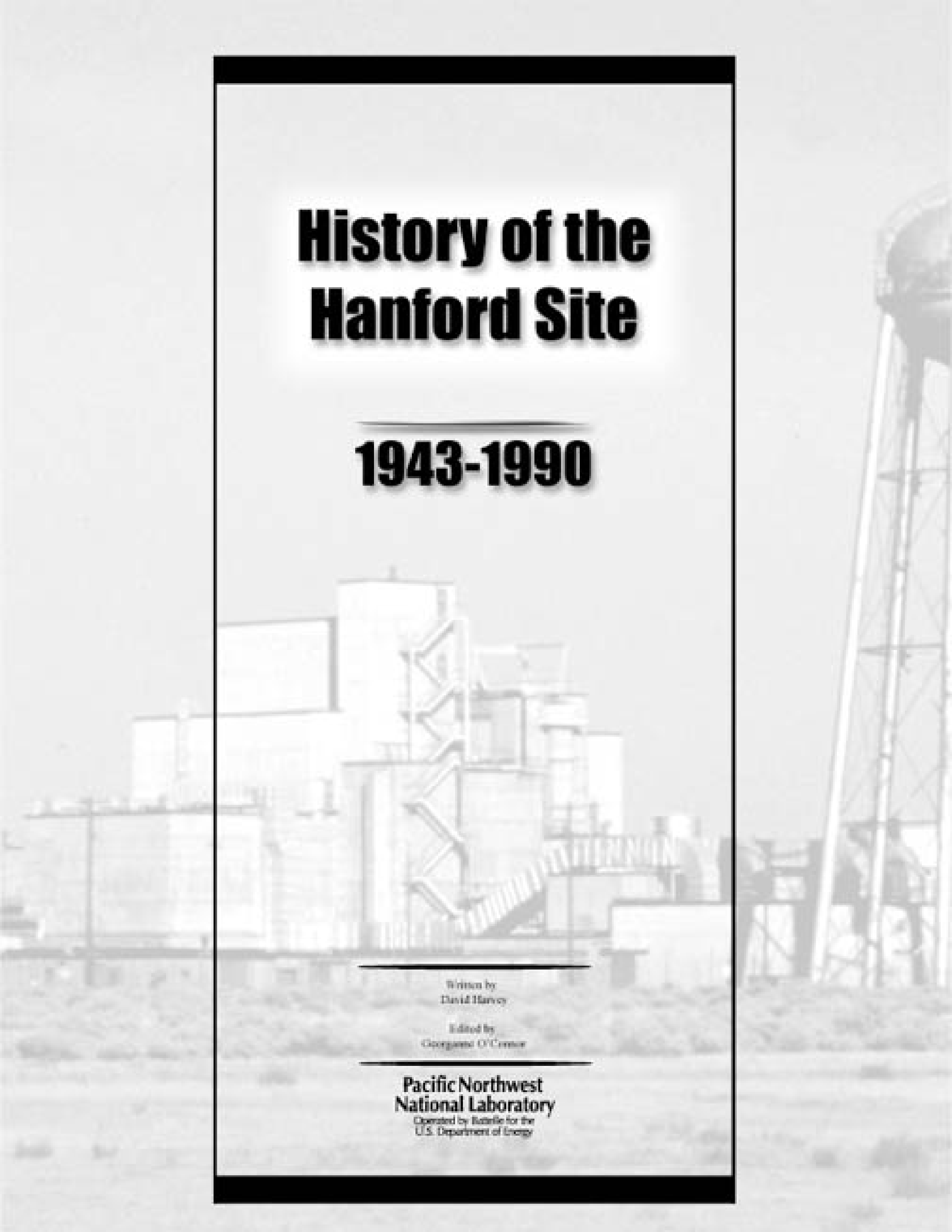
History of the Hanford Site

1943-1990





History of the Hanford Site

1943-1990

Written by
David Harvey

Edited by
Georganne O'Connor

Pacific Northwest
National Laboratory
Operated by Battelle for the
U.S. Department of Energy

Preface

This booklet was developed to highlight the national and international historical events that occurred in association with the development of the Hanford Site. The purpose of the booklet is to increase the awareness Hanford Site employees have of the historical significance of the Site's contributions and missions during the Manhattan Project (1943-1946) and Cold War era (1946-1990). By increasing knowledge and understanding of the Site's unique heritage, it is hoped this publication will help generate an appreciation of the Site's historic buildings and structures, and, thus, instill a sense of "ownership" in these buildings. One cannot appreciate the historic significance of a place or building without first knowing its story.

The booklet also is meant to facilitate improved cooperative compliance by staff with the National Historic Preservation Act of 1966. To carry out its responsibilities under the National Historic Preservation Act, the Department of Energy established a Manhattan Project and Cold War Historic District at Hanford as the most efficient way to determine what buildings were important and have contributed to the historical significance of the Hanford Site. The project was funded through the Pacific Northwest National Laboratory (PNNL) Environmental Management Services Department by the U.S. Department of Energy under contract DE-AC06-76RLO-1830.

Project Lead: *Regan Weeks, PNNL*
Writer: *David Harvey, PNNL*
Editor: *Georganne O'Connor, PNNL*
Designer: *Jane Winslow, WinSome Design, Inc.*

Pacific Northwest
National Laboratory
Operated by Battelle for the
U.S. Department of Energy

Contents

Preface iii

Establishment of the Hanford Site 1
- Inception of the Manhattan Project 2
- Selection of Plutonium Production Site 3
- Selection Criteria 3
- Hanford Selected 3
- Hanford Engineer Works Village—Richland 4
- Wartime Emergency 4

Construction of the Hanford Engineer Works 5
- Acquisition, Design, and Layout 6
- Hanford Workforce 6
  - Finding Construction Personnel 6
  - Retaining Construction Workers 7
  - Organized Labor 8
- Construction Styles and Materials 8
- Development of Major Process Areas 10
- 300 Area 10
- 100 Areas 11
- 200 Areas 12
- 600 Area 12

Site Security 14
- Declaration of Secrecy 15
- Compartmentalization 15
- Critics of Secrecy 16
- Movement of Classified Material 16
- Conversation Monitoring 16
- Measures Related to Richland Village 17

Cold War Expansion of the Hanford Site 18
- Building Expansion at the Hanford Site 19

First Postwar Expansion (1947-1949) 19
Korean War Expansion (1950-1952) 19
Eisenhower Expansion (1953-1955) 21
Major Defense Production (1956-1964) 21

Fuel Element Research and Manufacturing During the Cold War 23
Increased Power Levels—In Pursuit of the Perfect Fuel Element 24

Military Operations During the Cold War 25
Anti-Aircraft Artillery Sites 26
Nike Missile Installations 26

Cold War Security 28

Cold War Research and Development 30
300 Area 31
Research and Development Facilities 31

Waste Management 32
100 Areas 33
200 Areas 33
300 Area 33
Management of Fuel Manufacturing Waste 33

Changing Missions and Environmental Restoration 34
Industrial Landscape 35
Buildings Mitigation Efforts 35
Compliance with the National Historic Preservation Act 36
Conclusion 36

References 38

Establishment of the Hanford Site

December 7, 1941. August 6, 1945. While numerous dates mark significant events during the twentieth century, these two dates mark dramatic watersheds for the United States and the entire world. On December 7, 1941, Japan's surprise military attack on Pearl Harbor forced the United States onto the world stage as a major participant in the Second World War. United States entry into the War accelerated its rise to superpower status and hastened the development of the atomic bomb. August 6, 1945, is the date the (Little Boy) atomic bomb was dropped on Hiroshima, which, along with the dropping of the (Fat Man) atomic bomb on Nagasaki on August 9, ended the Second World War and ushered in the nuclear age.

The Little Boy bomb included uranium-235, produced from gaseous diffusion at the Oak Ridge Reservation in Tennessee. The Fat Man bomb was made with plutonium from the graphite reactors at the Hanford Engineer Works.

During the 3 1/2 years between these two events, monumental social and economic changes occurred in the United States. The nation was put on a war footing, which produced dramatic demographic shifts with the establishment of war industries across the country. The Mid-Columbia Basin in south-central Washington State was one area that experienced dramatic population shifts as it became the setting for the nation's first plutonium production facility, the Hanford Engineer Works, later known as the Hanford Site.

Inception of the Manhattan Project

The Manhattan Project had its inception in the Advisory Committee on Uranium that was established by President Franklin Roosevelt in October 1939 to pursue scientific uranium research. Roosevelt's approval of the committee was based on his belief that the United States could not take the risk of allowing Hitler and Nazi Germany to unilaterally gain possession of atomic bombs. While over the next couple of years considerable research on the feasibility of the production of a uranium or plutonium bomb took place, experiments were restricted to laboratory studies until the United States entered the Second World War. Soon after Pearl Harbor, the Advisory Committee on Uranium decided to sponsor an intensive

> research program on plutonium. The research contract was placed with the Metallurgical Laboratory (Met Lab) of the University of Chicago . . . the purpose of this research project was to develop the knowledge to design, build, and operate a plant for the conversion of uranium into plutonium . . . [and] recommended that the Army Corps of Engineers carry out the construction work for such a plant (DOE 1997b, p. 5.5).

Responding to the concerns that Nazi Germany might be in the lead to develop an atomic bomb, and that a plutonium bomb apparently could be built and influence the outcome of the war, the United States accelerated its research program to develop technology capable of producing nuclear weapons under the Army Corps of Engineers (Corps) newly formed Manhattan Engineer District. The program was named the Manhattan Project because a key Corps official was located in Manhattan, New York City, and the name did not draw attention to the project's atomic bomb mission.

In September 1942, General Leslie R. Groves was appointed to head the Manhattan Engineer District and manage the Manhattan Project. Soon after his appointment, Groves moved quickly to persuade the E. I. Du Pont de Nemours and Company (Du Pont) to construct and manage the project's plutonium production facilities.

The Manhattan Project drew on virtually every available resource from the nation's academic community to the country's industrial giants. The center of the project, however, lay with the creation of three top-secret "atomic cities": Los Alamos (Site Y), Clinton Engineer Works at Oak Ridge (Site X), and Hanford Engineer Works at Richland, Washington (Site W). The scientists at Los Alamos were assigned the task to design and fabricate the world's first atomic bombs. Oak Ridge's assignment was to separate sufficient amounts of the fissionable uranium isotope U-235 from the more common U-238 to serve as fuel for the bomb. Du Pont's Hanford mission was to construct several nuclear reactors, fuel management facilities, and chemical separation facilities, which would produce sufficient amounts of the fissionable element plutonium for the nation's nuclear weapons.

Selection of Plutonium Production Site

The plutonium production plant was originally to be located at the Clinton Engineer Works at Oak Ridge, Tennessee. By late fall 1942, however, "discussions with key bomb development scientists such as J. Robert Oppenheimer and others pointed out to Manhattan Engineer District officials the hazardous nature of the plutonium production process" (DOE 1997a, p. 5.5). The possibilities of a nuclear accident that could contaminate nearby Knoxville and strategic war industries in the region around the Tennessee Valley Authority prompted the government to search for a more remote site in one of the western states.

The government officials selecting Manhattan Project sites decided early on to locate production facilities in remote areas, partly for secrecy and military security and partly out of concern for public safety in the event of a catastrophic accident. An isolated area, however was not to be artificially created by the evacuation of large numbers of people from the site.

The siting criteria narrowed the choice of a location to a few isolated places in the far West, with the Pacific Northwest at the top of the list. Because of safety and security considerations, and the need for considerable amount of water and electricity, Manhattan Engineer District officials scouted secluded areas in the arid regions of Colorado, California, Oregon, and Washington. An important requirement was that the site had to have access to electricity generated by one of the newly constructed hydroelectric dams in the West: Boulder, Shasta, Grand Coulee, or Bonneville.

Selection Criteria

Because of the hazards inherent in the production and separation of plutonium and the handling and disposal of large quantities of radioactive materials and waste, the design and layout of the world's first plutonium production facility had to satisfy the Corps' safety, location, and natural resource requirements. The site had to have (Corps 1947, Vol. 3):

- Area of at least 12 miles by 16 miles
- Remote setting with no population greater than 1,000 within 20 miles
- Abundant water supply of at least 25,000 gallons per minute to cool the reactors
- Dependable hydroelectric power source to supply at least 100,000 kilowatts of electricity
- Convenient access to railroad and highway facilities
- Relatively flat landscape
- Available fuel and concrete aggregate

Wartime economic considerations influenced selection criteria. The site had to have regional suppliers of coal, oil, and gravel to reduce transportation costs and conserve precious wartime fuel. Aggregate had to be available locally to provide concrete for construction needs. Because of the wartime scarcity of metal, the chosen site had to be close to a source of power so that it would not be necessary to build long transmission lines.

In the Pacific Northwest, the Bonneville Power Administration's excess quantities of electrical power were available year-round without the need to install additional generating equipment. The discovery that a high-voltage power line from Grand Coulee Dam (1941) to the Bonneville Dam (1937) ran through the future Hanford Site made the area even more attractive.

Hanford Selected

Colonel Franklin T. Matthias, future officer-in-charge at Hanford, and two Du Pont representatives scouted the Hanford Site in late December 1942. Matthias said:

> I thought the Hanford site was perfect the first time I saw it. We flew over the Rattlesnake Hills up to the river, so I saw the whole site on that flight. We were sure we had it. I called General Groves from Portland, and told him I thought we had found the only place in the country that could match the requirements for a desirable site (Sanger 1995, p. 19).

Shortly thereafter, Hanford was chosen as the site of the Manhattan Project's plutonium production facility. Hanford's flat, arid environment was perfectly suited to the project's needs. Like other desert environments in the West used by the federal government, the Hanford Site was viewed as an isolated wasteland, remote from population centers, that could be used indiscriminately for national defense or natural resource extraction purposes. The resources of the desert landscape were seen as inexhaustible, like the abundant water supply from the Columbia River, and the area's glacial sediment provided sand and aggregate for constructing large concrete structures. Additionally, the Hanford Site was far enough inland to satisfy War Department officials' concerns about exposure of the site to enemy attack if it was located near coastal areas.

In choosing isolated areas like Hanford, the Manhattan Engineer District officers dispensed with the usual practice of locating a large industrial facility near adequate housing, services, construction labor, and skilled work force. Instead, the Manhattan Project had to build and administer whole new communities and draw masses of people from other places to work at the sites.

Hanford Engineer Works Village - Richland

The Manhattan Engineer District selected Richland as the site of the Hanford Engineer Works Village because of its close proximity to the major production areas at the northern end of the nuclear reservation, and because it was considered to be sufficiently distant from the production facilities for security and safety purposes.

Spokane architect Albin Pehrson contracted with Du Pont to provide plans and specifications for housing types, commercial buildings and central business district, dormitories, and infrastructure for a new Richland Village. Because of the wartime emergency, Pehrson was pressured by Du Pont to provide quality housing for employees and by the military for an economic approach that would provide only the basic and minimal forms of housing. The emergency nature of the project was evident by the fact that Pehrson had to provide plans for the initial duplex house type within his first week on the job. The first housing units, designated by a letter of the alphabet, were completed in July 1943. Du Pont continually had to increase the number of homes needed to accommodate an initial Richland Village population of 6,500 to a population of 16,000 at the war's end. A total of eight housing units were designed and used during the Manhattan Project for a total of 2,500 housing units. But a shortage of housing for construction personnel during the war altered Pehrson's community design as 1,800 prefabricated housing units were imported to provide additional living accommodations.

Wartime Emergency

The need for the Manhattan Project to proceed with haste despite the reliance on untested technologies was expressed years later by General Groves:

> ...I had decided...that we would have to abandon completely all-normal, orderly procedures in the development of the production plants. We would go ahead with their design and construction as fast as possible, even though we would have to base our work on the most meager laboratory data. Nothing like this had ever been attempted before, but...we could not afford to wait.... (Groves 1983, p. 72).

Wartime urgencies necessitated the construction of a plutonium production facility in a short time span to keep to the tight schedule mandated by the U.S. Army for the Manhattan Project's effort to build an atomic bomb. "Two of Groves' initial motivations for getting the atomic bomb built speedily were a fear that the Germans might be developing their own bomb and a desire to win the war as quickly as possible" (Findlay and Hevly 1998, p. 71). The Manhattan Project required an immense amount of expertise, labor, and building materials, at a time when all these commodities were in short supply.

Construction of the Hanford Engineer Works

In February 1943, the federal government, under the authority of the War Powers Act, acquired 625 square miles of the mid-Columbia basin for the Hanford site, known as the Hanford Engineer Works during the Manhattan Project, and offered residents compensation. Approximately 1,500 people living in towns and on farms from Priest Rapids to Richland were ordered to leave their homes and property. In some cases, landowners had only 30 days to pack up and move.

"Land acquisition became, in some instances, a matter of bitter controversy between evicted owners and the government. Some compensation cases were not settled until after the war" (Sanger 1995, p. 17). The Manhattan Engineer District may have found the ideal location to construct the plutonium production plant, but for local residents like Annette Heriford and her family, it was a devastating decision. She recalls:

> In March, 1943, . . . we received a letter from the government saying that we would have to move in 30 days. It was a terrible shock . . . The only thing that made it credible to us was because of the war . . . We were so patriotic . . . [but] it was still a terrible blow (Sanger 1989, p. 8).

Acquisition, Design, and Layout

Hanford was one of the largest procurements of land (approximately 400,000 acres) handled during the war. Within a year after the federal government acquired it, they transformed the site from a sparsely populated, arid desert into a major military and manufacturing complex that entailed construction of a permanent set of facilities, establishment of a construction camp at the former Hanford townsite, and a new town in Richland.

For safety and security reasons, the planners of the Hanford Engineer Works separated production process areas by relatively large distances because of "the possibility of explosions of catastrophic proportions and the possibility of releasing to the atmosphere of intensely radioactive gases would dictate the selection of a site of sufficient area to permit the several manufacturing areas to be separated by distances of several miles . . ." (Corps 1947, Vol. 3, p. 2.1). The plutonium production reactors, B, D, and F, were separated from each other by at least 1 mile. The three initial separations plants, T, U, and B, were separated from each other by at least one mile and from the reactors by at least 4 miles. This decision was made to ensure that accidents in any one area would not affect the operation of the remaining units. Furthermore, because of the dangers inherent in the irradiation of uranium fuel elements, Du Pont situated the reactors as far as possible from the nearest populated area.

The construction of the site presented a number of unprecedented problems, that stemmed both from the project's wartime emergency mission and its immense magnitude. The secret nature of the project caused coordination difficulties because of inflexible military security requirements. The most difficult element, however, was the isolated location of the site.

> The isolation of the site from any existing centers of population presented serious problems with respect to many phases of construction. These problems were related primarily to the procurement, transportation, housing, feeding, health, morale, and retention of a maximum total construction force of about 45,000 persons which number was reached in June 1944 . . . (DOW n.d., pp. 4-5).

Hanford Workforce

The successful completion of the Hanford Engineer Works was amazing considering that 1) the design decisions that had to be made for untried technologies, 2) workers were brought to an area with no housing or infrastructure to support them, and 3) operating facilities had to be constructed in an atmosphere of utmost secrecy and tight security.

Finding Construction Personnel

Finding skilled labor and even unskilled laborers for the construction of the Hanford Engineer Works in the numbers needed during wartime was a challenge. The military had already taken a large portion of the labor pool, and the War Department's demand for weapons

and general supplies further reduced the available labor supply. The remote location of the site made recruiting even more difficult.

A severe labor shortage (up to 50 percent) existed for the first 14 months of construction. Between 1943 and 1945, it took 262,040 interviews by Du Pont recruiters to find 94,307 people to hire, with approximately 45,000 workers representing the peak workforce in May 1944.

> Even after the initial labor shortage subsided, the Hanford Engineer Works still experienced shortages of certain types of construction workers such as pipefitters. To obtain the needed skills, various creative strategies were used by Du Pont and the Corps to obtain qualified workers (Findlay and Hevly 1995, pp. 16-17).

Advertisements for construction workers, like the one below, were circulated nationwide. (Van Arsdol 1992, p. 18).

War Workers
Needed on
Southeastern Washington
Construction Project

Transportation Advanced
Attractive Scale of Wages

54-59 Hours Per Week
Immediate Living
Facilities for Employed
Persons Only

One strategy cited for drawing workers to the Hanford Engineer Works was the high rate of pay. Rates at the Hanford Site averaged $8 per day for unskilled laborers, where $3 to $4 per day was more typical for laborers in other parts of the nation. Skilled labor, pipefitters, and electricians earned $15 per day, compared to the typical $10 per day.

> Another strategy for dealing with the labor shortage was to increase the workweek, with the reward of large paychecks enhanced by overtime pay. Ten-hour days were the norm, and employees worked 5-1/2 to 6 days per week, and sometimes on Sunday (Findlay and Hevly 1995, p. 19).

Retaining Construction Workers

Once Du Pont obtained the workers to build the Hanford Engineer Works, the challenge became retaining them. Four reasons commonly cited for the high turnover were 1) the isolation of the site, 2) the miserable living conditions and housing shortages, 3) the requirement to maintain secrecy, and 4) the sense that the Hanford Site was not vital to the war effort since workers did not know what they were building because of tight security over the nature of the project.

> Recruiting workers often proved easier than retaining them . . . officials could not tell anyone what Hanford was producing, only that it was ‘something to help end the war.’ Patriotic appeals sufficed for a time, but nagging security restrictions, dismal housing conditions, lack of a family support system, and the often bleak surroundings sent hundreds back home or on to West Coast industries (Sanger 1995, p. 4).

At the beginning of the Manhattan Project, little available housing existed in the surrounding communities for the workers needed to construct the plant. Most construction workers were housed in the Hanford Construction Camp that was hastily established at the Hanford townsite. The workers initially lived in tents until the barracks were constructed. At its peak occupancy in 1944, it was reportedly the fourth largest city in the state of Washington, housing approximately 45,000 workers in accommodations that consisted of “131 barracks for nearly 25,000 men, 64 barracks for 4,350 women, 880 hutment’s for 10,000 men, and 3,600 trailer lots” (Findlay and Hevly 1995, pp. 24-25). The camp had stores, schools, churches, and medical facilities. During the life of the camp, a total of 1,200 buildings and 9 service facilities were constructed.

The presence of a few thousand single women in a construction camp of over 40,000 men, mostly single, presented its own problems. The women’s barracks were fenced and patrolled, thereby affording security and protection. General Groves noted that the women in the Hanford construction camp suffered from their own morale problems, as any group would “in an isolated area under rugged conditions, with few of the amenities of normal life” (Groves 1983, p. 90).

More than one story exists about the conditions created by the large construction project. Winds were especially notable, made worse by the loose sand so prevalent in a construction area located in a desert environment that led to horrific sandstorms. "Residents nicknamed the winds 'termination winds.' The morning after a storm of high winds and blowing dust, there would be a long line of workers at the employment office seeking to draw their termination pay and leave the area" (Kubik 1994, p. 44).

New recruits, just off the bus from the train station in Pasco, many veterans of the Dust Bowl, turned around and left at the first sight of a dust storm, not even bothering to spend the night. The following song lyrics commemorated the dust and wind (Hales 1997, p. 103):

Blow ye winds of Richland,
Blow ye winds high-o,
Blow ye winds of Richland,
Blow, blow, blow.
That fearful termination wind,
Can't stand it anymore;
Each time I sweep
the dust so deep
blows underneath my door.

Finding ways to keep the "troops" entertained was thought to be key to keeping them working at the Site. Dances, movies, and baseball games all became important, authorized activities. Bars in the construction camp were well patronized, and unauthorized activities such as gambling and prostitution existed and thrived.

Organized Labor

Labor unions were an important source of workers in building the Hanford Engineer Works. Union leaders had difficulty, though, pushing too hard on Hanford management for better wages and working conditions for two main reasons: first, was the appeal from the Corps and Du Pont to support the war effort, and second, that unions could not supply the numbers of skilled labor because of labor shortages. Still, about one-quarter of Colonel Matthias' construction journal entries were union-related, indicating that union matters required constant attention.

Construction Styles and Materials

Du Pont began construction of the Hanford Engineer Works in March 1943 and essentially completed it by April 1945. The constructed buildings reflected industrial and utilitarian functions over aesthetic concerns, not only in the design and layout of the site's production areas but also in the design of individual buildings and construction materials used. Functional, unadorned concrete and steel were the most commonly used materials at Hanford.

The amount of concrete used was substantial. It was the most extensively used material in the construction of the site. More than 780,000 cubic yards of concrete were applied, an amount equal to approximately 390 miles of concrete highway 20 feet wide by 6 inches thick. About 1,500,000 concrete blocks and 750,000 cement bricks were used in plant construction, enough to build a 1-foot by 6-foot wall over 30 miles long.

Other notable construction accomplishments included 386 miles of highways, 158 miles of track, and housing erected for 5,000 women and 24,000 men. "Excavation crews moved 25 million cubic yards of earth in the process . . . Building Hanford has been compared to the simultaneous construction of seven major industrial plants" (Sanger 1995, p. 3).

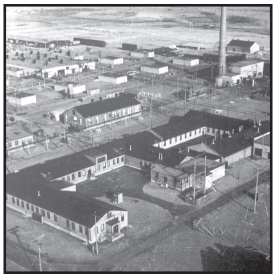
The Hanford crafts [unions] were solidly patriotic. On their own initiative they asked everyone for a day's pay and raised $162,000 in seven weeks, enough to buy a four-engine B-17 bomber for the Air Corps. The bomber, named the "Day's Pay," flew in from Boeing Field in Seattle to the Hanford air strip in July 1944 for a memorable ceremony to present the bomber to the Fourth Air Force. Concerning the overall effect of buying the B-17, Matthias said, "This activity, conceived by the workmen and handled by them, . . . was the most effective single morale builder during the job and did much to develop an attitude of teamwork and desire to help the war than any other thing" (Thayer 1996, p. 99).

The urgent nature of the Manhattan Project at the Hanford Site dictated an emphasis on speed and functionalism, which translated into a preference for flat roof, concrete, box-like structures over more traditional architectural forms. Exterior walls exhibited minimal non-functional ornamentation. Their steel skeletons allowed the construction of non-loadbearing exterior walls made predominantly of concrete. Cladding consisted of various types of concrete applications, horizontal wood, asphalt shingles, corrugated metal, and galvanized steel panels.

The layout and construction of the site was also reflective of the federal government's desire for cost-effective, wartime mobilization. As with other World War II military installations, speed of design and construction was of the utmost necessity. Stabilizing construction design was difficult, however, because no previous experience or precedent was available from which to draw upon. Because of the wartime emergency situation, however, only slight design variations were permitted at Hanford. Nevertheless, the production process areas were constructed without major design flaws and were completed on schedule.

Development of Major Process Areas

The buildings constructed during the Manhattan Project housed the following plutonium production processes or steps: "uranium fuel elements were fabricated and jacketed in the 300 area, irradiated in the 100 Areas (reactors), and chemically dissolved and separated into plutonium, unconverted uranium, and various fission byproducts in the 200 Areas" (DOE 1997a, p. 5.6).



300 Areas

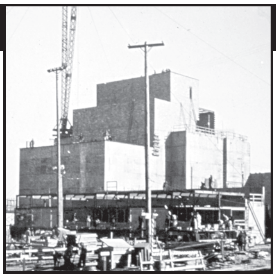
The 300 Area housed the first step in the plutonium production process where the uranium fuel was manufactured before it was sent for irradiation to the 100 Area reactors. 300 Area personnel fabricated nuclear fuel in the form of pipe-like cylinders (referred to as fuel slugs or elements) from metallic uranium obtained from offsite production facilities. The metallic uranium was extruded into rods and encapsulated in aluminum or zirconium cladding.

The rods were extruded, outgassed, and straightened in the 314 Metal Extrusion Building. The rods were transferred to the 313 Metal Fuels Fabrication Building for machining into cores and canning the cores into fuel elements. The fuel elements were trimmed to a specified diameter and cut to the required length. Then they were subjected to a final testing in the 305 Test Reactor before being sent to the 100 Area reactors.

The fuel manufacturing process in the 300 Area went through numerous changes during World War II, especially in the 313 Building. The 313 Building experienced eight additions during its first year (1943-1944) because of process improvements and changes in uranium fuel manufacturing activities.

The high power level of the production reactors called for the uranium fuel elements to be bonded to aluminum cans to improve heat conduction from the fuel element to the cooling water. Uranium fuel had to be canned to prevent the release of highly radioactive fission products into the coolant and corrosion of the uranium by the coolant.

During the early years of the Manhattan Project, however, Du Pont and the Corps were deeply concerned over the lack of progress in solving the problems of fuel manufacturing. In retrospect, it is hard to imagine how tens of thousands of fuel elements needed for the first loading of the reactor were ever completed on time. Walter Simon, Hanford Engineer Works, chemist, and the site's first operations manager, described the situation:



> One of the most difficult problems . . . was the making of uranium fuel slugs (or elements). The uranium was held in an aluminum can, a slug (fuel element), about eight inches long and (an) inch and five-eighths in diameter. The can had to fit very tightly with no air space or bubbles. They couldn't leak because if water got into the uranium it destroyed the ability to react (Sanger 1995, pp. 153-154).

The entire Manhattan Project was jeopardized by the delay because

> . . . nothing less than an absolute perfect fit was acceptable: the slightest leak or air pocket in even one of the thousands of slugs (fuel elements) could have the disastrous effect of contaminating the whole area and shutting down the pile (reactor) as well. The canning technique called for uniform heating of the entire surface of the uranium slug (core), then slipping it into an aluminum can, which likewise had to be heated uniformly, (inserting an aluminum cap) and then welding the two (cap and can) together. The bond between the uranium and the aluminum casing had to be perfect; even fuel elements showing 90 or 95 percent quality at the test inspection were rejected (Groueff 1967, pp. 297-298).

Du Pont scientists ultimately accomplished uniform bonding of the fuel elements. They

> . . . submerged the slug (core) in one of the four-foot-deep, round tanks and tried to can it beneath the surface . . . using long tongs . . . obtained perfectly good, uniform heat transfer. But then [they] discovered they had burned a hole through the aluminum can. Apparently the temperature of the liquid in the bath was so high that it melted the aluminum . . . the canning operation would have to be done more swiftly . . . After several more tests and experiments, a canning technique had been found . . . (Groueff 1967, p. 300).

Once the problem of canning the cores was solved, the production line for canned fuel elements made a round-the-clock effort and produced thousands of fuel elements needed for the startup of B Reactor. As the yields of acceptable fuel elements went up and the number of failures declined, an adequate number of bonded fuel elements were ready for the first reactor charge at B Reactor.

The first steps in the fuel manufacturing process occurred in the 313 Building and the 314 Building where the fuel cores were manufactured and jacketed.

Completed in autumn 1943, the 313 Building was the site's original fuel manufacturing facility and produced fuel for Hanford's eight single-pass reactors from 1944-1971. Its primary mission originally was to extrude and machine uranium rods to specific dimensions required for the cores, jacket or can the cores, and test the jackets for proper bonding and sealing. Until the 314 Building was completed and the press for extruding billets into rods installed in it, the first uranium billets were extruded into rods offsite and the rods sent to the Hanford Engineer Works for completion of the process.

The 314 Building was completed in 1944, with the installation of the 1,000-ton extrusion press occurring the following year. The press allowed the site to process raw uranium billets into extruded rods that were suitable for manufacturing into fuel cores. The uranium billets were taken to the 314 Building to be extruded into rods, then outgassed and straightened. The rods were then transferred to the 313 Building for machining the rods into cores.

100 Areas

Fabricated fuel cylinders were shipped by rail from the 300 Area to the reactors in the 100 Areas for irradiation, the second step in the plutonium production process. The nine plutonium production reactors and their ancillary/support facilities were situated along the south shore of the Columbia River. The reactor areas had to be situated close to the river because large quantities of water were required to dissipate the heat generated during reactor operations.

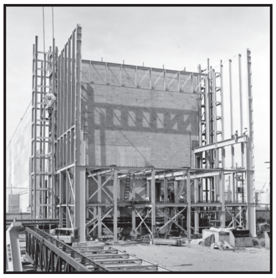
Construction of the first three Hanford reactors (B, D, and F) began in March 1943 and was completed in 1944-45. The B Reactor was the world's first production-scale nuclear reactor. In spite of the unproven technology and wartime constraints, the reactor was constructed and taken to criticality (in September 1944) with complete success, all within a single year. In the first nine months of operation, it produced fissionable material (plutonium) for the world's first atomic bomb, the Trinity test in July 1945. The reactor also produced plutonium for the atomic bomb that was dropped on Nagasaki, Japan, contributing to the end of the Second World War. From 1945 to the end of the Cold War, B Reactor and the other eight Hanford reactors produced the majority of the nation's weapons-grade plutonium.

200 Areas

The 200 Areas, with their chemical separations (processing) plants, functioned as the site of the third step in the plutonium production process at the Hanford Site. The purpose of chemical separations at Hanford was to extract and purify plutonium from fuel elements irradiated in the 100 Area reactors. The 200 Areas contained all the facilities used to separate, isolate, store, and ship the plutonium. To separate the plutonium from the uranium and fission by-products formed in the irradiation process, the chemical separations plants dissolved irradiated fuel cylinders and then chemically manipulated the resulting plutonium-bearing solution.

At each separation plant, operators dissolved the irradiated uranium fuel rods in nitric acid, first to remove the protective outer jacketing, and then to reduce the uranium metal to a liquid state. Then they extracted plutonium from the uranium nitrate solution and sent it to the Plutonium Finishing Plant to be purified into plutonium metal.

T, B, and U Canyon Plants were built during the Manhattan Project to chemically process irradiated fuel from the 100 Area reactors. U Plant, however, was never used for its original purpose. The building was retrofitted in 1952 as the Metal Recovery Plant to recover uranium from waste stored in Hanford's tank farms.



600 Area

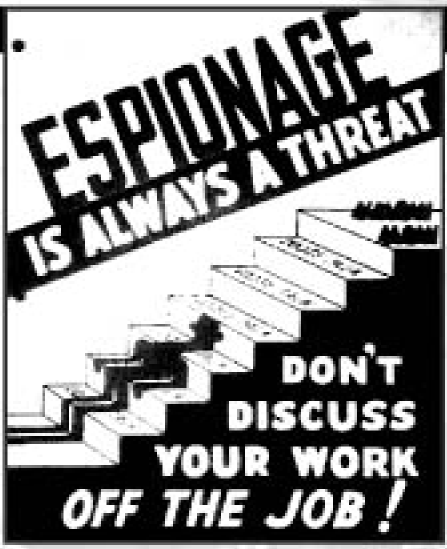
The 600 Area consists of facilities that serve more than one specific area, " . . . and in cases, such as roads and railroads, serve the entire Project . . ." (DuPont 1945, Vol. 4, p. 1085). The isolation of the Site and the distances separating the various manufacturing areas, and the volume and types of construction materials involved, made the establishment of a complete transportation network a necessity.

> An extensive system of roads and railroads was designed and constructed to expedite transfer of the enormous quantities of construction equipment and materials to the various areas as well as to provide adequate transportation facilities in case of an emergency in one or more of the areas during plant operations.... (Corps 1947, Vol. 3, p. 7.4).

Built in 1913 as the Priest Rapids branch of the Chicago, Milwaukee, St. Paul and Pacific Railroad between Beverly Junction and the towns of White Bluffs and Hanford, the section of railroad from Riverland (Vernita) to Hanford Townsite was acquired by the federal government in April 1943 and used to transport materials to assist in construction of the Hanford Engineer Works. The railroad was improved and extended to support site needs such as delivery of fuel elements between production areas, and transportation of waste byproducts, construction materials, and infrastructure materials.

To start the chain reaction at Manhattan Project reactors, control operators withdrew the horizontal, neutron-absorbing control rods from the reactor block. To slow the chain reaction or stop it if necessary, control operators moved the control rods back into the reactor block. To stop a reactor quickly, they tripped the vertical safety rods, enabling them to penetrate the reactor block from the top of the reactor.

Fuel operators loaded uranium fuel elements into the process channels located in the front face of the reactor block, a process called charging. As they loaded new fuel elements, the irradiated fuel elements already in the reactor were pushed out of the rear face, falling into a pool of water, a process referred to as discharging. From here they were placed by remote means into a cart to facilitate transport in the fuel basin. Once the fuel elements had cooled for a sufficient time, about 30 days, the carts were pulled out of the basin and the elements placed in railroad cars for transport to the cooling basin where they stayed until ready for shipment to the 200 Areas.



Site Security

The importance of security at the Hanford Site during the Manhattan Project could not be overstated. A letter from President Franklin D. Roosevelt to General Leslie Groves, June 29, 1943, acknowledged the need for tight security: "I am writing to you as the one who has charge of all the development and manufacturing aspects of this work. The fact that the outcome . . . is of such great significance to the nation requires that this project be even more drastically guarded than other highly secret war development(s). As you know, I have therefore given directions that every precaution be taken to insure the security of your project (UPOA 1977, bk. 1, vol. 14, pp. A-1)."

Most importantly, the Manhattan Project demanded tremendous secrecy to disguise its real mission. The immense size of the site area and the number of people involved in the project made secrecy a difficult task.

The purpose of security at the Hanford Site during the Manhattan Project was to prevent others from learning how to create an atomic bomb by "provid[ing] the secrecy and protection necessary to prevent all possible espionage, sabotage, damage, interference or other harmful effects which might endanger the successful completion of the Program" (UPOA 1977, bk. 1, vol. 14, p.1.2).

Security measures undertaken were numerous: background investigations of new employees, security education and information programs, classified areas and documents, security safeguards, and emergency preparedness.

Secrecy played a major role in the daily lives of employees on the Hanford site. They were told little to nothing about the project on which they were working, only that their work was going to help the United States win the war. Thus, secrecy and efficiency in their work was essential. Even the Selective Service, which deferred those working at Hanford, only knew the Manhattan Project was related to a wartime effort.

> All rumors regarding the purpose of the (Manhattan) Project, health hazards, or other rumors which might create unrest among the personnel were promptly traced to their source and disciplinary action was taken in the form of termination or reprimand (UPOA 1977, bk. 4, vol. 1, p. 6.2).

Few of the construction workers at the Hanford Site knew they were building a plant to produce materials for a new type of weapon. They were told that the work was related to the war effort but were required to avoid any discussions about their work. Stories abound about workers who talked about their work being discharged immediately.

Although prohibited from doing so, employees and Richland Village residents speculated about what was being produced at the Hanford Site. Some humorous theories included: Pepsi-Cola, Kleenex, clothes pins, or fourth-term Roosevelt campaign buttons.

Declaration of Secrecy

To keep people from talking, each employee received a security orientation in which they signed a Declaration of Secrecy form. In signing the form, the employee took a pledge of faith and allegiance to the United States, agreed not to disclose any classified information or materials to unauthorized individuals or to misuse the material, and understood that violation of the National Espionage Act or the Federal Sabotage Act was punishable by up to 10 years in prison or up to $10,000 in fines.

Compartmentalization

The main way to stop information leaks at the Hanford Site was to limit the knowledge of each employee. This was called "compartmentalization of knowledge." General Leslie Groves' philosophy on compartmentalization is stated below:

> Compartmentalization of knowledge, to me, was the very heart of security. My rule was simple and not capable of misinterpretation - each man should know everything he needed to know to do his job and nothing else. Adherence to this rule not only provided an adequate measure of security, but it greatly improved over-all efficiency by making our people stick to their knitting . . . (Groves 1983, p. 140).

Furthermore, "to minimize risk or compromise, employees of the (Manhattan) Project shall be organized into small working groups or teams, each working on its own phase of the job and not being permitted to inspect or discuss the work being done by others" (Loeb 1982, p. 26).

Employees were directed to focus only on their specific task and refrain from asking questions and unnecessarily discussing their jobs with fellow employees and even spouses or friends. Only a select group of employees knew the true mission of the Manhattan Project.

Critics of Secrecy

The strict security regulations were found by some, particularly scientists, to be oppressive and excessive during the Manhattan Project. Because background investigations had to be so comprehensive they "result[ed] in delays in employment and hindering the already overworked recruitment drive" (Hageman 1944, p. 73).

Compartmentalization was particularly a nuisance to scientists. Many felt that the restriction prohibiting them from exchanging data and discussing the Manhattan Project kept the technology from developing faster, thus causing extended delays in achievement of scientific and technical objectives of the program. This was the view of Leo Szilard, a Manhattan Project scientist. He stated in 1946,

> compartmentalization of information was the cause for failure to realize that light uranium (U-235) might be produced in quantities sufficient to make atomic bombs. We could have had it eighteen months earlier. We did not put two and two together because the two two's (sic) were in a different compartment (Jones 1985, p. 270).

Others commented that compartmentalization

> resulted in bearing the seeds of unfortunate mistakes, duplication of research and ridiculous exaggerations. Inevitably, in some cases, scientists might waste time and effort solving a problem that had already been solved in another laboratory. They did not know it, however, because they had not been permitted to exchange information (Groueff 1967, p. 43).

Du Pont remarked that compartmentalization "resulted in a general loss of efficiency, required more supervision to obtain proper coordination, and, despite all attempts to counteract it, lowered morale and caused delays" (Du Pont 1945, p. 38).

Movement of Classified Material

Armed Hanford Site patrol officers and military guards were assigned to escort classified material being moved at Hanford. A former site worker explained the method of transferring plutonium from the 231-Z Plutonium Metallurgy Facility to the 213 Final Storage Magazine vaults in the side of Gable Mountain.

> We would make up a little caravan of one car with the plutonium, one car ahead of us and one car behind us, with Army personnel with .45s and I think machine guns. The vault doors at the storage building required two combinations to open. As I recall, nobody was supposed to know both combinations (Sanger 1995, p. 193).

Conversation Monitoring

In 1943, agents from the Corps counter-intelligence organization began undercover work to identify any security breaches within the workforce or the local community. The agents "occupied strategically located positions in the project offices, laboratories, and plants, set up listening posts, checked intensively into personal and other records of individuals under suspicion, and took other measures designed to solve espionage cases" (Jones 1985, p. 262).

Undercover agents would pose as regular members of the work force or community, such as painters, contractors, hotel clerks, tourists, electricians and even gamblers (Jones 1985). One agent had regular informants who would frequently eavesdrop on employees and residents. An agent recalls: "One story they picked up was that we (the Hanford Site) were making rockets, anti-personnel rockets. They told me who had said it. I told my

office this person was starting rumors and they took care of it. The guy was young, and unmarried, and he got drafted real quick" (Sanger 1995, p. 140).

The counter-intelligence agents investigated unauthorized releases of classified information and in most cases

> found that the information leaks . . . were the result of carelessness or ignorance on the part of the employee or individual with knowledge of the project. But because it was always possible such leaks were surface ramifications of much more dangerous espionage activity, all cases of careless handling of classified data received prompt and rigorous corrective action (Jones 1985, p. 260).

This sensitivity to careless talk led to this former employee's recollection of a specific instance.

> When they spoke of radiation during that time they referred to it as 'activity'. I made the mistake in the hearing of one of our managers, I used the word radioactive, because I knew what I was talking about. But, oh my, I was taken into an office and security people told me that word is a No-No, NEVER say that again (Sanger 1995, p. 176).

Measures Related to Richland Village

No security fence was installed around Richland Village though its residents were closely watched by counter-intelligence agents and the village police kept a copy of a key to every house in town. Colonel Matthias asked Du Pont to keep the town clean and presentable because it would be open to outsiders and possibly be a reflection on the entire operation.

Although attempts may have been made to make Richland Village appear to be a normal town, the necessity for strict security still played a role in the life of this government town. The Richland Village phone book was stamped as a classified or restricted piece of information. Richland residents' mail was examined to ensure no sensitive information was being communicated out of town through the mail. Phones were tapped to listen for a breach of security or loose talk. Photographs could not be commercially sold or published without approval of the area manager.

No one was allowed to live in the village unless they were Hanford Engineer Works employees or family members. Background investigations were conducted to some degree on all residents of the village.

The daily lives of employees at Hanford Engineer Works were surrounded in one way or another by factors relating to security. This was the environment employees accepted as part of life while living in a government town and working at Hanford.

The Villager

EXTRA

IT'S ATOMIC BOMBS

President Truman Releases Secret of Hanford Product

Information Is Made Public This Morning

News Spreads Slowly, Surprises Everyone Here

Cold War Expansion of the Hanford Site

The dropping of atomic bombs on Hiroshima and Nagasaki, which hastened the ending of the Second World War, saw the beginning of the nuclear age and development and stockpiling of nuclear weapons and delivery systems. The United States and the Soviet Union, wartime allies, soon became adversaries. The deterioration of relations between the two superpowers led to a dramatic increase in weapons research and production, and subsequent expansion of plutonium production facilities at Hanford.

The escalating intensification of the Cold War during the late 1940s to early 1950s increased congressional allocations to national defense and expanded America's nuclear weapons program. This translated into a dramatic expansion of facilities at all nuclear weapons sites under the control of the Atomic Energy Commission. Athe time, there was a substantial increase in plutonium production and constructionmodification

of plutonium production structures at the Hanford Site. Postwar expansion at Hanford resulted in the largest federal peacetime construction project to that date.

The effort to expand the Hanford Site's production capabilities looked and felt somewhat like the wartime production years. Much of the burden of plutonium production fell directly upon Hanford, which was the sole supplier of fissionable plutonium for atomic bombs until the completion of the first reactors at the Savannah River Site in 1953.

Between 1947 and 1955, the Atomic Energy Commission added five new reactors (C, H, DR, KE, KW) at the Hanford Site, while concurrently boosting the output of the three Manhattan Project reactors (B, D, F). Incremental improvements in the basic components of the World War II reactors and a construction program to build reactors that incorporated these changes accounted for doubling the plutonium output in 1952-1953.

Building Expansion at the Hanford Site

Historian Michelle Gerber characterized the postwar expansion of the Hanford Site's production facilities between 1947-1964 into four primary periods: 1) First Postwar Expansion (1947-49), 2) Korean War Expansion (1950-52), 3) Eisenhower Expansion (1953-55), and 4) Major Defense Production (1956-1964).

First Postwar Expansion (1947-1949)

In 1949, the Hanford Site began running its production reactors at higher neutron flux, and thus, higher temperatures, which led to more plutonium production and less graphite swelling. When the announcement came in September 1949 that the Soviets had exploded their first nuclear weapon years earlier than most had predicted, the order came to complete DR Reactor. The General Electric Company, who took over the operation of the Hanford site from Dupont in 1947, constructed DR and H reactors during this period. General Electric also constructed the Plutonium Finishing Plant in 1949. This plant made it possible to convert plutonium-nitrate paste to hockey puck-shaped plutonium metal, known as buttons. At the end of the chemical separation process, the plutonium was in the form of plutonium nitrate. The plant converted the nitrate solution into plutonium metal and then formed it into appropriate shapes for use in nuclear weapons, until the plant closed in 1989.

Plutonium finishing initially took place in the 231-Z Isolation Building in the 200 West Area. Until the Plutonium Finishing Plant became operational, the plutonium finishing process at 231-Z consisted of drying the plutonium and shipping it in containers to the weapons assembly facilities at Los Alamos, where it was made into metallic plutonium and formed for use in nuclear weapons.

But a safer and more stable form for shipment over the long distances to Los Alamos was the impetus in the design and construction of the Plutonium Finishing Plant.

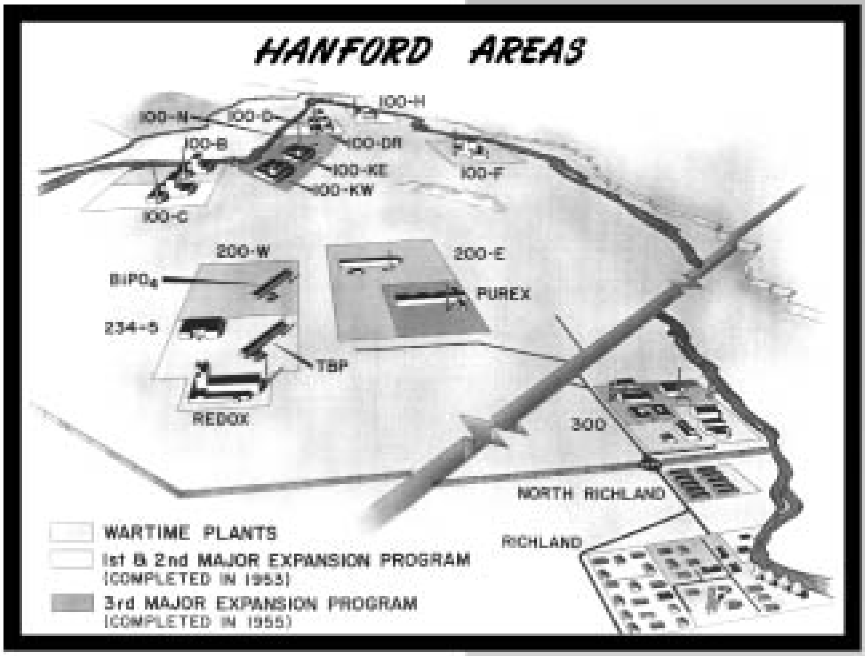
The first postwar expansion led to a dramatic increase in the construction of research and development laboratories, maintenance and craft shops, and administrative facilities in the 300 Area to handle the increase in defense and energy research, waste management activities, and biological and environmental sciences research.

Postwar expansion of Hanford Site facilities prompted the need for additional housing in Richland Village to accommodate the increase in site personnel and their families. More spacious housing units were designed to accommodate the larger postwar families. The postwars increase in village population prompted the expansion of Richland's residential and commercial boundaries.

Korean War Expansion (1950-1952)

This expansion was the result of the Soviet Union's detonation of its first atomic bomb and the North Korean invasion of South Korea. In response, the Atomic Energy Commission completed its sixth Hanford reactor, C Reactor, in November 1952.

During the early 1950s, General Electric constructed many buildings and facilities in the 300 Area under the Hanford Laboratories Operation Program for



The Hanford Site's first postwar expansion occurred, in part, as a result of America's commitment to nuclear weapons as a central part of its postwar defense doctrine.

Tensions between the Soviet Union and the United States escalated soon after the end of the Second World War, and reached a threshold in spring 1948 when the Berlin blockade began. One response from the Atomic Energy Commission was to authorize the restart of Hanford's B Reactor, which had been shut down since 1946 because of concerns about graphite expansion. When it appeared that a solution to the graphite expansion problem might be at hand, the Atomic Energy Commission authorized one replacement reactor at D area, called DR for D Replacement, and one new reactor at a new area, H, located between the F and D areas.

research and development activities associated with national defense initiatives. The most prominent developmental laboratories and shops included the 324 Chemical Materials Engineering Laboratory, 325 Radiochemistry Building, 326 Pile Technology Building, 327 Radiometallurgy Building, and the 329 Biophysics Laboratory.

In the 200 West Area, the Reduction-Oxidation (REDOX) chemical separation plant was constructed in 1952 with an improved separation process. The REDOX plant was the first full-scale solvent extraction plant built in the United States for recovery of plutonium and uranium that used an advanced organic solvent extraction process to replace the bismuth phosphate process employed in B and T plants.

Eisenhower Expansion (1953-1955)

This expansion was the result of President Dwight D. Eisenhower's massive retaliation policy and the first Soviet hydrogen bomb detonated in 1953. In 1952, President Harry Truman decided to increase the ratio of plutonium over enriched uranium supplies, which in turn resulted in authorization and construction of the jumbo KE and KW reactors at Hanford. Construction of the 100-K Area reactors began in September 1953 as part of Project X, the next large Cold War expansion effort at Hanford. The construction of the 1,850-megawatt reactors, the largest reactors built as of that date, was completed in 1955.

The K reactors represented a second-generation reactor. Although still using the same basic graphite-moderated, water-cooled design, the K reactors differed from the earlier reactors in several significant ways, mainly in the number, size, and type of process tubes, the size of the moderator stack, and the type of shielding used. They generated an enormous increase in power output than the other single-pass reactors. The K reactors were designed for 1,800 megawatt-thermal while the first Hanford reactors were designed for 250 megawatt-thermal. The operating limits of the K reactors were gradually increased to a limit of 4,400 megawatts by 1961. KW Reactor operated until 1970 and KE until 1971.

The Plutonium-Uranium Extraction (PUREX) Plant, a chemical separation facility, became operational in 1955 as Hanford's final and most advanced separation plant. PUREX used a continuous flow extraction process that was designed to separate plutonium and uranium from irradiated reactor fuel. The plutonium was sent in a liquid form to the Plutonium Finishing Plant, while the uranium was sent in liquid form to the 224 Uranium Trioxide (UO3) Plant.

The 300 Area's original function as a process improvement and fuel fabrication area remained relatively unchanged through the duration of the Cold War era. During this expansion period, though, the 300 Area became the locale for numerous research and development efforts to improve the fuel manufacturing process and to reuse fuel manufacturing materials through various recycling programs. Some changes were meant to improve the process, some to improve plutonium production, and others to use the fuel manufacturing materials more economically. Numerous buildings and structures in the 300 Area had to be retrofitted to accommodate new technologies and changing missions.

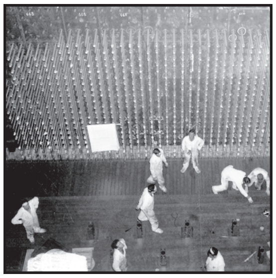
Expansion of the Hanford Site facilities during the 1950s also included programs dedicated to the peaceful uses of the atom. Eisenhower's "Atoms for Peace" program in 1953 and the passage of the Atomic Energy Act of 1954 allowed for private, commercial atomic applications, which brought innovative, non-defense programs to Hanford. These programs led to the construction of the 308 Plutonium Fuels Pilot Plant and the 309 Plutonium Recycle Test Reactor, both used to test developmental fuels for use in commercial reactors.

Major Defense Production (1956-1964)

This was the period of the most intense defense production at Hanford, which included the construction of N Reactor. N Reactor was "an unique plant that combined plutonium production with the steam generation of commercial electric power . . . . Producing over 65 billion kilowatts in 24 years, N Reactor was the largest electric power producer in the nation in its early years . . . ." (Gerber 1992, pp. 31-32).

Several factors led to a proposal in 1957 for the new production reactor at Hanford. These included increasing interest in President Eisenhower's Atoms for Peace initiative, an increasing concern for human and environmental safety, and the drive to reduce plutonium production costs. In response, General Electric proposed a dual-purpose reactor for the Hanford Site that had the capability to generate electricity and produce plutonium. Several features distinguished N Reactor from the other Hanford reactors: a closed-loop, primary cooling system to eliminate cooling water discharges to the Columbia River, a cause of extensive contamination; heat exchangers to generate steam that could power electricity-generating turbines; and a confinement system to limit the spread of radioactivity in the event of an accident.

A new fuel manufacturing method was developed in the 1960s to accommodate N Reactor fuel needs. Called coextrusion, the N Reactor fuel fabrication process differed from the other eight reactors that had used aluminum clad fuel elements. N Reactor fuel elements, made of zirconium alloy, lasted longer and, thus, enhanced reactor operations. The coextrusion process was developed in the 306 Fuel Element Pilot Plant and implemented in the 333 Fuel Cladding Facility. The pilot plant was completed in 1956 initially to assist 313 Building operations and to pilot process improvements in single-pass reactor fuel fabrication methods. The facility was expanded in 1960 to develop the coextrusion fabrication process for N Reactor fuel elements. The addition became known as the 306-E Building, and the older section became the 306-W Building. The 333 Building was constructed at the same time to manufacture fuel elements using the newly developed coextrusion process. This new method provided a more uniform bond than the earlier process of jacketing or cladding single-pass reactor fuel elements.



Coextrusion provided a more complete bond, which was superior to previous canned fuel elements that were subject to bubbles and other flaws between the layers. Coextrusion provided an outer layer superior to the previously used aluminum because it could tolerate greater temperatures inside the pressurized system of the new reactor with a lower rate of corrosion. N Reactor's light-water recirculation design configuration required a fuel element with a tougher exterior resistant to the higher pressure necessary to operate its cooling system.

Design of N Reactor began in 1958 with construction beginning the following year. The reactor was completed in 1963, and dedicated by President John F. Kennedy in September 1963.

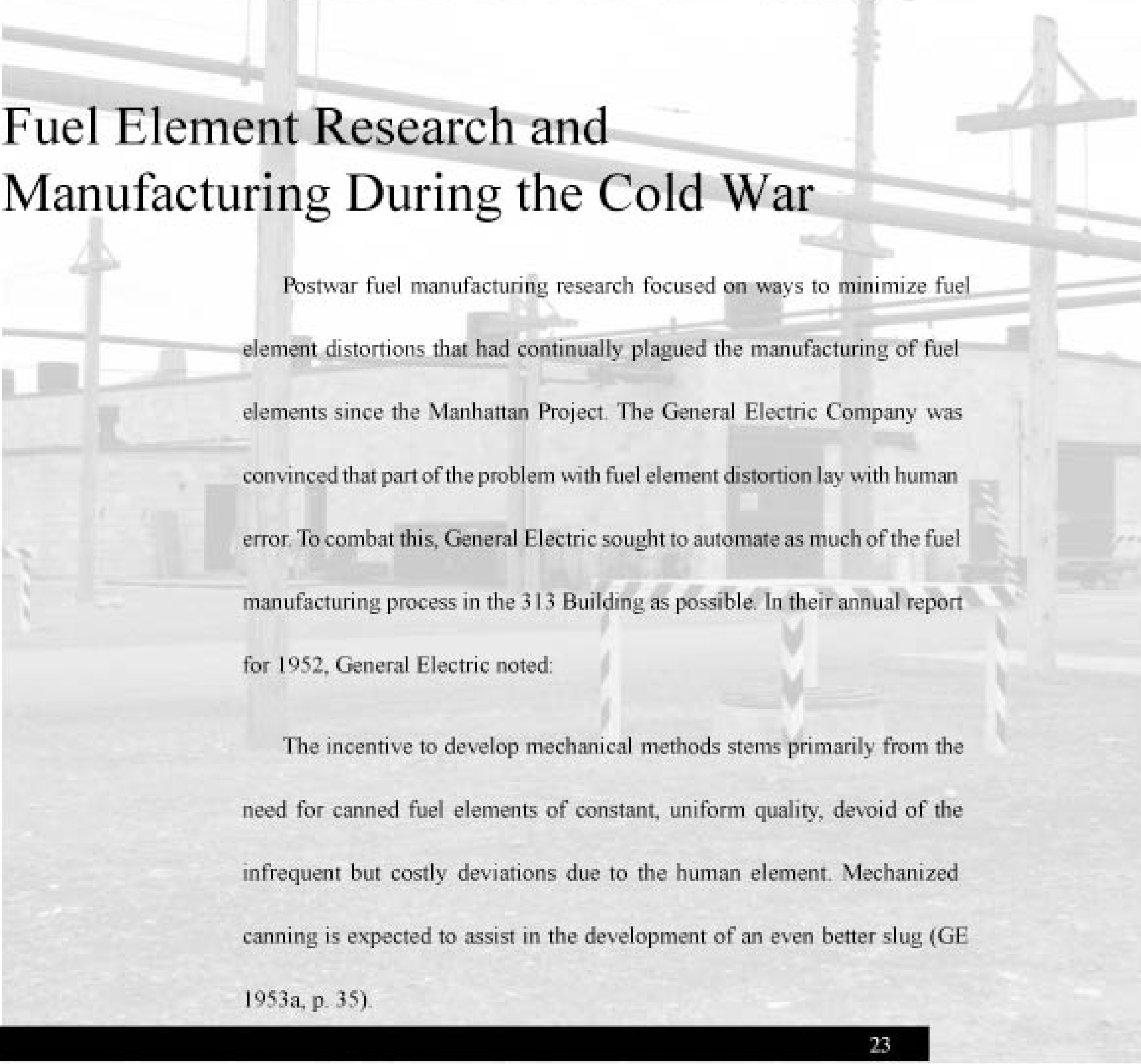
N Reactor began producing plutonium in 1964. The (Hanford Generating) steam plant began producing electricity in 1966, and for many years it was the largest nuclear power plant in the world. Producing 800 megawatts of electricity, it roughly equaled the total output of all nuclear power producing reactors in America at the time.

By the 1960s, the nation's plutonium stockpile was much greater than deemed necessary. Thus, plutonium production decreased. In 1964, President Lyndon B. Johnson announced that some Hanford reactors would be shut down. The Atomic Energy Commission closed H, DR, and F reactors based on their age and condition. In 1967, the Atomic Energy Commission closed D Reactor, and in 1968, the Atomic Energy Commission announced that B Reactor was to close.

In 1969, all the remaining production reactors (C, KE, KW), except N, were shut down. Fuel manufacturing and the separations plants also closed as the need for their services ended.

In the 1970s, relations between the United States and the Soviet Union deteriorated again with the Soviet Union's invasion of Afghanistan. By 1982, the federal government decided to produce weapons-grade plutonium again at N Reactor, though little, if any, was ever processed. The Chernobyl explosion in 1986 led to a shutdown of N Reactor and national assessments of its ability to operate safely. When the Cold War ended in 1989, there was no need to continue production. With N Reactor's transition to cold standby, the Hanford Site's production mission ended, and the cleanup mission began.

Fuel Element Research and Manufacturing During the Cold War



Postwar fuel manufacturing research focused on ways to minimize fuel element distortions that had continually plagued the manufacturing of fuel elements since the Manhattan Project. The General Electric Company was convinced that part of the problem with fuel element distortion lay with human error. To combat this, General Electric sought to automate as much of the fuel manufacturing process in the 313 Building as possible. In their annual report for 1952, General Electric noted:

> The incentive to develop mechanical methods stems primarily from the need for canned fuel elements of constant, uniform quality, devoid of the infrequent but costly deviations due to the human element. Mechanized canning is expected to assist in the development of an even better slug (GE 1953a, p. 35).

Increased Power Levels - In Pursuit of the Perfect Fuel Element

Ideally, the perfect fuel element would produce record amounts of power in the reactor without warping, swelling, or blistering. Increased power levels allowed more plutonium to be produced per hour, which achieved greater economic efficiency as well as increased production, but entailed a greater risk of fuel element distortion or failure.

During the late 1940s, the power levels of the Hanford Site reactors were increased to generate additional production. Although the subsequent increase in temperatures kept the graphite from swelling further, and in some cases, even shrank it to its original size, the hotter conditions limited the already short time in which fuel elements could remain in the reactors. The higher heat also caused blistering or distortion of fuel elements and sometimes ruptured the cans.

Fuel elements

> needed constant redevelopment in order to withstand the intense heat to which they were subjected . . . Improved inspection techniques, new watering treatment processing, and enhanced instrumentation also extended fuel slug lifetime and increased overall production levels (Carlisle and Zenzen 1996, p. 64).

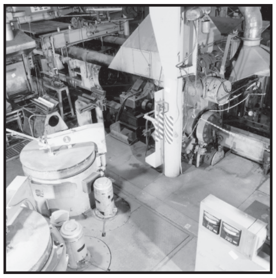
In an attempt to reduce the chances of fuel element distortions, the Hanford Site switched to a new, lead-dip process for canning the fuel in 1954.

> The process consisted of immersing the uranium fuel cores (elements) in a bath of molten lead covered with molten aluminum, followed by a molten aluminum-silicon bath. Between 1955 and 1964, about 30,000 single-pass reactor fuel elements were canned each week [using this new process] (DOE 1997b, p. 157).

To produce the perfect fuel element, scientists in the mid-1960s

> began to experiment with a new canning procedure called the Hot Die Size process . . . to replace the Al-Si (aluminum-silicon) fuel fabrication process . . . the new process was more economical and more productive, . . . Overall, the bonding between the uranium core and the aluminum can would be better and the cladding more uniform (Kubik 1997, pp. 43-44).

Valuable production time was lost each time a uranium fuel element failed in a reactor because the reactor had to be completely shut down to remove the damaged fuel element. It was not unusual for a reactor to be shut down at least once a month because of fuel element failures.



Military Operations During the Cold War

The increasing strategic military importance of the Hanford Site during the early post-World War II period and the growing number of site personnel brought about a call for a permanent military installation in the area. The need for substantial military protection of the Hanford Site was recognized because of the increase in Cold War era tensions between the United States and the Soviet Union, and the concurrent increase in plutonium production and expansion of Hanford Site facilities. In response, the Army in 1951 established Camp Hanford and used anti-aircraft artillery and Nike missiles to protect the site.

Anti-Aircraft Artillery Sites

Camp Hanford initially consisted of a military compound in North Richland and 16 anti-aircraft artillery positions that encircled the 100 and 200 Areas to protect the reactors and chemical separation plants from airplane attack. The first Army contingents assigned to Hanford, the Sixth Army's 5th Anti-Aircraft Artillery Group and four attached gun battalions (83rd, 501st, 518th, and 519th), each had four batteries to operate the air defense systems.

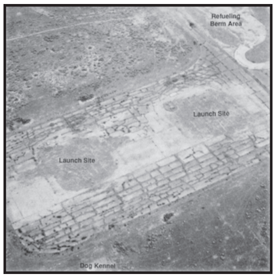
The internal layout of the anti-aircraft artillery sites reflected a standard military arrangement of facilities separated by function. They were roughly 20 acres in size and contained any number of buildings consisting of wooden structures, prefabricated metal buildings, and, later, permanent, concrete block structures. Each site contained four gun emplacements situated within semi-circular revetments made of sandbags and wood planking. The four revetments were arranged in a square or rectangular plan separate from the residential and administrative facilities.

The more permanent, concrete structures were situated in a rectangular grid that included barracks, latrines, mess halls, recreation halls, motor pools, administrative, and radar facilities. Each anti-aircraft artillery site typically had a small arms range, a water storage cistern, and sanitary/sewage waste facilities.

Nike Missile Installations

The Nike Ajax and Nike Hercules missile defense systems were developed in response to heightened Cold War tensions and the escalating international arms race. Nike missile systems had the capability of intercepting high speed aerial targets at greater ranges than conventional anti-aircraft artillery. From the early 1950s to the mid-1970s, the Army deployed Nike, Ajax, and Hercules missiles throughout the continental United States to protect major metropolitan areas and strategic military installations from enemy aerial attack.

Four Nike missile installations supplanted the 16 anti-aircraft artillery sites at the Hanford Site during the mid- and late 1950s. Nike Ajax and Hercules missiles were deployed at three locations on the Wahluke Slope and one on what is now the Fitzner-Eberhardt Arid Lands Ecology Reserve. All four Nike sites were of similar construction and layout, consisting of a battery control center, launch area, and associated barracks and administration buildings.



The battery control areas were normally placed on the highest possible point. They contained all the radar, guidance, electronic, and communications equipment needed to identify incoming targets, launch missiles, and direct and guide missiles in flight to intercept enemy aircraft.

The launch areas contained underground missile storage magazines and launch equipment, including buildings and structures used for testing and servicing the missiles. These included generator buildings; missile fueling and warheading facilities; missile assembly and maintenance buildings; pump houses and other utilities; and administrative, housing, and recreation buildings.

The main function of the launch areas was to maintain the missiles in a combat-ready posture that required the assembly, storage, handling, and disposal not only of missile components and propellants but also of solvents, fluids, fuels, and other support materials. Each launch area at Hanford had two underground missile storage magazines, 20 Ajax missiles, and eight launchers.

By the late 1950s, the development of intercontinental ballistic missiles had rendered Nike missiles obsolete. In October 1960, the camp and its missile battalion and batteries were deactivated. Camp Hanford officially closed on March 31, 1961.

Conditions in the forward positions during the early years at Camp Hanford were described as primitive. "Initially we lived in tents, hauled our water, dug latrines, ate food liberally sprinkled with sand, bathed in helmets and under home-made cold showers . . . . The equipment and vehicles were frequently obliterated by sand storms. The rutted roads scratched out of the desert made traveling slow, uncomfortable and caused maintenance to become a great problem" (Army 1955, p. 9). Frank Trent ". . . remembers burning shoe polish inside the tents and sleeping back-to-back during frigid winter nights just to keep warm . . . soldiers also heated their squad tents by stealing heaters from railroad sheds . . ." (Mulick 1998, p. C3).

By the end of the camp's first 2 years, however, living conditions for the soldiers in the field had improved considerably. New latrines, mess halls, barracks, and sewage facilities were built, and water and power supplies were upgraded.

Cold War Security

The concept of compartmentalization, or "the need to know," continued into the Cold War era. However, during the Cold War, compartmentalization was not focused on the creation of the bomb (which was by then a known fact), but on general national security and business sensitive information and activities. Secrecy was no longer as important as protecting classified information and nuclear materials.

During the Cold War, Site security measures required elasticity, stretching to support increased security needs and contracting when those needs no longer existed. Increased security needs that stretched the system were mainly caused by unexpected events or changes in the Hanford Site mission, funding, and international affairs

The elasticity of site security was especially flexed when the Korean War started in 1950, with the increase in air patrols to 24 hours per day, and the establishment of Camp Hanford for protection against the threat of attack on the facilities.

With the end of the Korean War, some security measures were relaxed (although some remained in place into the 1960s). For example, the use of M-8 light-armored cars, vehicle rovers, and manned fence towers was discontinued by the 1960s, and routine air patrolling ended in 1964.

The threat of international terrorism during the late 1970s and into the 1980s led to an increase in security measures and upgrades. Extra security fences with detection and alarm systems were installed at the PUREX Plant and other 200 Areas facilities. At N Reactor, several structures were added, such as rooftop guardhouses, river guard towers, and pill boxes or guard stations in the hallways of the reactor building that armed security guards would use to watch for suspicious activity.

Other security measures were relaxed in the 1970s and 1980s. For example, the stretch of the Columbia River through the Hanford Site was officially opened to the public in 1979. The number of protected areas requiring high security was reduced, with the placement on cold standby status of N Reactor in 1988 and PUREX in 1990.

Dealing with site security's all-encompassing regulations continued to be part of the Hanford cultural environment throughout the Cold War. With the end of the Cold War, and the subsequent change in mission in the late 1980s, decreased regulations resulted in security becoming a less restrictive aspect of working at the Hanford Site.

Cold War Research and Development

Following World War II, the Hanford Site played an increasing role in research and development activities in response to demands from the government for greater and more efficient (and reducing costs of) plutonium production, improving health and safety for the workers and public, and demands from private industry to commercialize nuclear energy.

Thus, the nature of research and development activities at the Hanford Site changed over the years in response to national and international events, such as the rise of civilian nuclear power, the environmental movement, the energy crisis, and the information revolution.

300 Area

The 300 Area is the area most associated with the Site's research and development activities. During the Cold War period, several test reactors and fuel fabrication pilot facilities in the 300 Area were used for non-defense purposes. With the worldwide uranium supplies limited, research efforts were undertaken to develop and test alternate fuels.

Knowing that worldwide supplies of uranium were finite, the United States embarked on a large research effort to find alternate supplies of reactor fuels. Research was undertaken to find methods to stretch or diversify the uranium fuel supply for commercial nuclear reactors by creating oxide fuel blends. This was the result of President Eisenhower's Atoms for Peace program that envisioned use of nuclear technology to fuel civilian and industrial power needs. In response, the Atomic Energy Commission pursued a program of developing nuclear fuels for industrial and commercial uses.

The 300 Area was also the locale of an extensive research effort to demonstrate the effectiveness of fuels blended from the combinations of plutonium oxide, uranium oxide, and other mixed oxide materials. The following facilities were constructed to develop and test alternate reactor fuels: the Physical Constants Test Reactor and Thermal Test Reactor in the 305-B Building, the Plutonium Fabrication Pilot Plant in Building 308, the Plutonium Recycle Test Reactor in the 309 Building, and the High Temperature Lattice Test Reactor in the 318 Building.

Research and Development Facilities

During the period of considerable growth of the 300 Area beginning in the early to mid-1950s, many buildings and facilities were constructed for research and development activities. The most prominent developmental laboratories and shops included the following:

305 Test Pilot/Hot Cell Verification Building
325 Radiochemistry Laboratory/Cerium Recovery Building
329 Biophysics Laboratory
320 Low Level Radiochemistry Building
326 Physics and Metallurgy Laboratory
327 Post Irradiation Test Laboratory
324 Chemical Engineering Laboratory
337 Technical Management Facility
337-B High Temperature Sodium Facility
328 Mechanical Development Building

Waste Management

Numerous industrial, chemical, and radiological processes were required to produce weapons grade plutonium at the Hanford Site. Each process generated hazardous and/or radioactive waste.

Each step of the plutonium extraction process produced high-level radioactive waste that was transferred through underground lines to large underground storage tanks located in tank farms near each separations plant. Much of this high-level radioactive waste continues to be in storage today.

100 Areas

Reactor operations generated several waste streams, including solid waste that was disposed of in burial grounds, low-level liquid waste that was disposed of in the soil, and reactor cooling water, another form of low-level liquid waste. The cooling water (reactor effluent) from the reactors without closed loop systems was allowed to cool and then was released to the Columbia River.

200 Areas

Five chemical separation plants, T, B, U, Redox and Purex Plants were Hanford's primary sources of high-level radioactive waste, though small additional quantities came from the Plutonium Finishing Plant and elsewhere. All plants used complex, toxic, and corrosive chemicals in their separation processes.

Originally the plutonium was extracted from the uranium in the bismuth phosphate process, and the uranium was sent to underground waste tanks. In the 1950s, with the Cold War, however, the demand for uranium increased. In response, officials at the Atomic Energy Commission and the Hanford Site made three major modifications to the chemical separations process during the Cold War. Their first modification, in 1952, altered U Plant to enable it to reprocess uranium that was previously stored in underground waste tanks. A second modification allowed the Uranium Trioxide Plant to convert uranyl nitrate hexahydrate to a dry form of uranium trioxide for shipment offsite. In the third case, the B Plant was modified to reprocess and encapsulate fission products from underground waste tanks and the waste streams of the PUREX Plant.

300 Area

In the 300 Area laboratories, scientists conducted extensive research and development in support of the plutonium production technologies that generated low-level liquid and solid waste that was disposed of in the 300 Area ponds, trenches, burial grounds, and at waste disposal facilities in other areas.

The 300 Area differed from the other areas in that the management and disposal of low-level radioactive liquid waste was centralized. From their construction in 1944, the many 300 Area laboratories and fuel manufacturing facilities were connected to a common process sewer that collected low-level radioactive liquid waste and disposed of it in a single process pond located east of the area near the river.

Management of Fuel Manufacturing Waste

For four decades, fuel manufacturing activities, especially in the 313 and 314 buildings, generated acidic liquid (chemical) waste from canning, capping, sleeve cleaning and testing, and uranium scrap processing. The liquid chemical waste from the 313 and 314 buildings that did not contain recoverable uranium was discharged to the process sewer until the shut down of the single-pass reactors.

By 1970, the Atomic Energy Commission had instituted an accelerated program to reduce radioactive discharges in every operation to the lowest practicable levels. The program was later expanded to cover all hazardous waste. One of the results of this program was the installation, beginning in 1973, of the Waste Acids Treatment System. This system processed waste acids and chemical waste from various 300 Area laboratories and fuel manufacturing facilities and disposed of it in tanks for treatment and storage rather than into settling ponds from which the materials could leach into the Columbia River. Developed in the 333 Building, the Waste Acids Treatment System specifically caught and neutralized waste acids from the 333 Building's fuel manufacturing activities. Waste acids were collected in the Acid Pump House (334-A Building) and then pumped to tanks in the south end of the 313 Building for neutralization.

Changing Missions and Environmental Restoration

During the Manhattan Project and Cold War, the Hanford Site managed to construct the world's first full-scale plutonium production reactors and manufacture enough plutonium to significantly impact the ending of World War II. In all, over 67,000 kilograms of plutonium were produced at the Hanford Site of which 13,000 kilograms were fuel-grade plutonium. The Hanford Site produced 100 percent of the nation's nuclear arsenal plutonium between 1945 and 1953 and over 65 percent of the plutonium during the history of United States plutonium production.

By the mid-1960s, decreased national demand for special nuclear materials precipitated a downsizing of the Hanford Site's plutonium production mission. By 1971, all but one reactor were closed. Plutonium production for national defense use came to a halt between 1972 and 1983 when the site's only fuel processing facility was shut down. Fuel production at the Hanford Site stopped when the N Reactor shut down in 1987 while numerous improvements were made. By 1988, improved relations with the Soviet Union, symbolized by Strategic Arms Reduction Treaty talks, seemingly reduced the need for special nuclear materials, and N Reactor was put in standby mode, never to operate again. The closure of N Reactor brought to an end nearly 45 years of plutonium production at the Hanford Site.

Since 1987, when the last of the nine reactors was shut down, operational activities have shifted toward cleanup of areas contaminated by radioactive and/or chemical wastes. The mission change to environmental restoration/remediation has had a significant impact on the historic industrial landscape. Decommissioning and decontamination activities have led to extensive alteration and demolition of many of the remaining Manhattan Project/Cold War era buildings and structures. The site's military landscape also has been dramatically altered with demolition of most of the Nike and anti-aircraft artillery sites. Of all the production areas, the 100-B, C, D, DR, F, and H areas have been the focus of the most extensive demolition activities. Numerous facilities in the 300 and 200 Areas have also been subjected to extensive modification, the result of accommodating changing technologies over the years, or demolition.

Industrial Landscape

Although the industrial landscape at the Hanford Site has been significantly affected by cleanup activities through the demolition of numerous buildings and structures, the basic design and configuration of site production areas has remained relatively intact.

Soon after the end of World War II, many of the wartime mobilization structures or temporary construction facilities were removed. For example, the Hanford Construction Camp located at the former Hanford Townsite was removed within a year after the end of the war.

Other similar modifications to the Manhattan Project and Cold War period landscape are evident throughout the Hanford Site. The former Central Shops facility (a major maintenance and servicing area for Manhattan Project construction activities located north of 200 West and removed shortly after the end of World War II) left a landscape dotted with concrete slabs, foundations, and pits. Similarly, the concrete slabs, foundations, walkways, roads, and grids of former military facilities are still evident in stark contrast to the surrounding desert landscape.

Other distinctive Manhattan Project and Cold War landmarks that still exist include reactors, separation buildings, fuel manufacturing facilities, water towers and stacks, and miscellaneous infrastructure facilities, such as the site railroad and roads. Numerous ancillary buildings and structures in the production process areas have been demolished and removed.

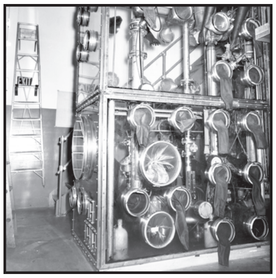
Buildings Mitigation Efforts

The mission change from production to cleanup and disposal of what are now U. S. Department of Energy owned lands created a critical need for development and implementation of new and different strategies to manage historic and cultural resources on the Hanford Site. As a federal agency, the Department of Energy is directed by Congress and the President to provide leadership to identify, evaluate, and protect prehistoric, historic and traditional cultural places on lands it administers. This includes the responsibility to manage and protect properties on the Hanford Site listed in, or determined eligible for, the National Register of Historic Places under the National Historic Preservation Act of 1966.

To carry out its responsibilities under the National Historic Preservation Act, the Department of Energy has undertaken an innovative preservation planning effort of the Hanford Site's Manhattan Project and Cold War buildings and structures. These presentation efforts are based on the stipulations and mitigation efforts identified in a programmatic agreement for the management of the built environment (DOE/RL-96-77).

The establishment of a Manhattan Project and Cold War Historic District offered the best opportunity to identify, evaluate and mitigate important buildings and structures at Hanford. The Department of Energy established a Historic Buildings Task Group to define the historic district, evaluate the Manhattan Project/Cold War buildings as contributing or noncontributing properties within that district, and identify a representative sample of the National Register-eligible contributing properties for documentation (or mitigation).

A selected list of buildings, structures, and complexes, representative of the major property types and themes of the Manhattan Project and Cold War era at Hanford, were identified as contributing properties within the District that should be documented or mitigated through written and photographic records.



In addition to written and photographic documentation, mitigation of historic buildings also requires the Department of Energy to assess the contents of Hanford's historic buildings and structures before structural modification, deactivation, decontamination, decommissioning, or demolition activities. The purpose of these assessments is to locate and record (and identify with a Hanford artifact tag) historic artifacts or records associated with the Manhattan Project and/or Cold War that may have research, interpretive or educational value as exhibits within local, state or national museums. Criteria developed to guide the identification and preservation of important Manhattan Project/Cold War artifacts include 1) artifacts associated with historically significant figures, 2) artifacts associated with historically important events, 3) artifacts representing a significant leap in technology, and 4) artifacts that reflect social historical impact on twentieth century American life. Items made at the site, or made offsite specifically for Hanford, are considered a high priority for collection since Hanford is probably the only place they exist. These artifacts are one-of-a-kind technological items that once they disappear cannot be replaced.

Compliance with the National Historic Preservation Act

Hanford Site staff who work in (or are responsible for) historic Manhattan Project/Cold War era buildings have a special responsibility to ensure that the historical aspects and physical integrity of the buildings are maintained. The staff of the Hanford Cultural Resources Laboratory of the Pacific Northwest National Laboratory are available to the Hanford Site workforce to coordinate compliance with the National Historic Preservation Act requirements.

Conclusion

The Cold War era at Hanford was a different time and mission. The end of the Cold War spelled the end to Hanford's plutonium production mission. The public's growing disfavor with the peaceful uses of the atom, specifically commercial nuclear power, terminated that mission. During this time the public was kept deliberately in the dark on what was going on behind the fences. For national security reasons, the role of many of the facilities was classified. But the end of the Cold War has led to the lifting of the veil of secrecy. As public interest in the Manhattan Project and Cold War continues to grow, attention to the Hanford Site's contribution to national security and historic development of the atomic bomb and nuclear power has increased. Because of this fact and the recognition of the international significance of the site, the documentation and preservation of the history of Hanford and its contributions to this important era in American history is recognized, and is ongoing, by the Department of Energy.

The Manhattan Project, because of its secret mission and ultimate contributions to ending World War II, held a sense of high adventure for those who participated in its scientific endeavors at Hanford. John Wheeler, a leading Manhattan Project physicist, saw the romance of the times and place. He saw Hanford "[as] a song that hasn't been sung properly," and said Hanford was far from simply a production facility insofar as that term implies a factory. "I never thought of Hanford in terms of being a factory. There was a sense of adventure about it. I associate it with pioneering. I would think it was like the first steamship that must have been exciting. The first airplane was exciting, the first locomotive was exciting. I feel these comparisons are the right comparisons" (Sanger 1995, p. 157).

References

Army - U. S. Department of the Army, Military History Institute. 1955. *83rd Antiaircraft Artillery Missile Battalion, Camp Hanford, Washington: Information for personnel assigned to the 83rd AAA Missile Battalion*. Carlisle, Pennsylvania.

Carlisle, R. P. and J. Zenzen. 1996. *Supplying the Nuclear Arsenal: American Production Reactors, 1942 - 1992.* The John Hopkins University Press, Baltimore, Maryland.

Corps - United States Army Corps of Engineers. 1947. *Manhattan District History, Book IV - Pile Project.* In Manhattan Project, Official History and Documents (1977 Microfilm), University Publications of America, Washington, D. C.

DOE - United States Department of Energy. 1996. *Programmatic Agreement Among the U.S. Department of Energy, Richland Operations Office, the Advisory Council on Historic Preservation, and the Washington State Historic Preservation Office for the Maintenance, Deactivation, Alteration and Demolition of the Built Environment on the Hanford Site, Washington*. DOE/RL-96-77, Rev. 0, Richland, Washington.

DOE - United States Department of Energy. 1997a. *National Register of Historic Places Multiple Property Documentation Form - Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington*. DOE/RL-97-02, Rev. 0, Richland, Washington.

DOE - United States Department of Energy. 1997b. *Linking Legacies: Connecting the Cold War Nuclear Weapons Production Processes to their Environmental Consequences.* DOE/EM-0319, Washington, D. C.

DOW - United States Department of War. n. d. *Background Information on the Hanford Engineer Works*. Washington, D. C.

Du Pont - E. I. Du Pont de Nemours and Company. 1945. *Construction of the Hanford Engineer Works: History of the Project.* HAN-10970, Vol. 4, Wilmington, Delaware.

Findlay, J. M. and B. Hevly. 1995. *Nuclear Technologies and Nuclear Communities: A History of Hanford and the Tri-Cities, 1943 - 1993.* The Hanford History Project, Center for the Study of the Pacific Northwest, University of Washington, Seattle, Washington.

Findlay, J. M. and B. Hevly, eds. 1998. *The Atomic West.* The Center for the Study of the Pacific Northwest in association with the University of Washington Press, Seattle, Washington.

GE - General Electric Company. 1953. *1952 at Hanford Works*. HW-26705, Richland, Washington.

Gerber, M. S. 1992. *Legend and Legacy: 50 years of Defense Production at the Hanford Site.* WHC-MR-0293, Westinghouse Hanford Company, Richland, Washington.

Groueff, S. 1967. *Manhattan Project: The Untold Story of Making the Atomic Bomb.* Little, Brown and Company, Boston, Massachusetts.

Groves, L. R. 1983. *Now It Can Be Told: The Story of the Manhattan Project.* DaCapo Press, Inc., New York.

Hales, P. S. 1997. *Atomic Spaces - - Living on the Manhattan Project*. University of Illinois Press, Urbana, Illinois.

Hageman, R. C. 1944. *Threshold of an Era.* Manuscript at U. S. Department of Energy Public Reading Room, Richland, Washington.

Jones, V. C. 1985. *Manhattan: the Army and the Atomic Bomb.* Center for Military History, U. S. Army, Washington, D. C.

Kubik, B. J. 1994. *Richland - - Celebrating Its Heritage*. City of Richland, Washington.

Loeb, P. 1982. *Nuclear Culture.* Coward, McCann and Georghegan, Inc., New York.

Mulick, C. 1998. "Camp Hanford - Site Wasn't Easy for Young Soldiers Who Served as the Last Line of Defense." *Tri-City Herald*. March 8, 1998, Kennewick, Washington.

Sanger, S. L. 1989. *Hanford and the Bomb: An Oral History of World War II*. Living History Press, Seattle, Washington.

Sanger, S. L. 1995. *Working on the Bomb: An Oral History of World War II Hanford.* Continuing Education Press, Portland State University, Portland, Oregon.

Thayer, H. 1996. *Management of Hanford Engineer Works in World War II*. American Society of Civil Engineers Press, New York.

UPOA - University Publications of America. 1977. *A Guide to Manhattan Project: Official History and Documents.* Book 4, Instrument Department; Book 10, Production Department, Part I - II; Washington, D. C.

Van Arsdol, T. 1992. *Hanford: The Big Secret*. Privately Published, Vancouver, Washington.