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HISTORICAL GENESIS OF HANFORD SITE WASTES

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ABSTRACT

This paper acquaints the audience with historical waste practices and policies as they changed over the years at the Hanford Site, and with the generation of the major waste streams of concern in Hanford Site clean-up today. The paper also describes the founding and basic operating history of the Hanford Site, including World War II construction and operations, three major postwar expansions (1947-55), the peak years of production (1956-63), production phase downs (1964-the present), and some past suggestions and efforts to chemically treat, "fractionate," and/or immobilize Hanford's wastes.

Recent events, including the designation of the Hanford Site as the "flagship" of Department of Energy (DOE) waste remediation efforts and the signing of the landmark Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement), have generated new interest in Hanford's history. Clean-up milestones dictated in this agreement demand information about how, when, in what quantities and mixtures, and under what conditions, Hanford Site wastes were generated and released.

This paper presents original, primary-source research into the waste history of the Hanford Site. The earliest, 1940s knowledge base, assumptions and calculations about radioactive and chemical discharges, as discussed in the memos, correspondence and reports of the original Hanford Site (then Hanford Engineer Works) builders and operators, are reviewed. The growth of knowledge, research efforts, and subsequent changes in Site waste disposal policies and practices are traced. Finally, the paper places the current Hanford Site waste remediation endeavors in the broad context of American and world history.

IMPORTANCE OF HANFORD SITE HISTORY

On August 6, 1945, an atomic bomb was dropped on Hiroshima, Japan, and President Harry Truman released the story of the special wartime weapons project that had produced it. Although the material in the Hiroshima bomb came from the Clinton Engineer Works (now the Oak Ridge Site) in Tennessee, the President told the world about the entire Manhattan Engineer District (MED), the landlord of the Hanford Engineer Works (HEW - predecessor to the current Hanford Site). Three days later, an atomic bomb consisting of material manufactured at HEW exploded over Nagasaki, Japan, and produced an Allied victory in World War II just five days later. Then as now, the public was hungry for information about HEW. Then as now, it is important that we understand the history and the workings of these vast plants, their genesis, their operating history, and the wastes they produced.

Recent events, including the designation of the Hanford Site as the "flagship" of Department of Energy (DOE) waste remediation efforts and the signing of the historic Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement), have generated new interest in Hanford's history. Clean-up milestones dictated in this agreement demand information about how, when, in what quantities and mixtures, and under what conditions, Hanford Site wastes were generated and released. The attention of the national media is on the Hanford Site, especially since it has been learned that two-thirds of all the nuclear waste in the DOE complex lies in the lovely Columbia Basin (home to the Hanford Site). The bill for the 30-year clean-up projected in the Tri-Party Agreement is staggering, and must compete with other worthy public projects for funding. For all of these reasons, and also because of the very human desire to know our roots, and to own whatever problems and challenges are attached to them, Hanford Site history has become very important.

As the Environmental Division historian, I study Site history intensively everyday, and I speak and present to audiences who demonstrate the same hunger for knowledge about our past and our activities as was shown in 1945. Our history is rich - with glory as well as with nuclear waste and with difficult challenges - but all of it is ours, and we want to learn it and know it. It binds us together, and arms us to go out and solve the unique riddles in our pioneering waste clean-up program. Today, I would like to share with you some of the understandings that have been gained through the study of Hanford's history.

PRE-SITE HISTORY AND CHARACTERISTICS OF THE COLUMBIA BASIN

Non-Indian settlement of the Yakima Valley and the Columbia Basin began with sparse cattle ranches in the late 1850s. The first towns, Pasco and Kennewick, were founded in 1882, as the Northern Pacific Railroad brought development to the arid region. A small real estate boom between 1905 and 1910 founded the towns of White Bluffs, Hanford and Richland. From that time until 1943, the region stabilized into a network of farms and small supply and grain shipment towns. When MED officer Col. Franklin T. Matthias and two DuPont Corporation engineers came to look at the Columbia Basin in late December 1942, they found a region not highly developed nor populated. About 19,000 people lived in Benton and Franklin counties, nearly a fourth of them in the railroad town of Pasco. Kennewick held 1,800 people, and White Bluffs, Richland and Hanford combined had 1,500. The rest lived on regional farms.

However, the stark and lovely Basin met the criteria defined by General Leslie R. Groves, head of the Manhattan Project, and by leading DuPont and MED scientists. It provided a large and remote tract of land, served by abundant power and rail lines and by the huge, clean water supply of the Columbia River. Its soil could bear heavy loads and yield a virtually endless supply of aggregate for making concrete. Matthias and the two DuPont scouts quickly realized that here they could establish a "hazardous manufacturing area" of at least 12 by 16 miles, far removed from main highways or populous towns. They reported to General Groves that the place was "far more favorable in virtually all respects than any other."[1] Groves agreed, and land acquisition proceedings began.

WORLD WAR II CONSTRUCTION AND OPERATIONS

Once the land was procured, construction proceeded at a nearly unbelievable pace. Between groundbreaking in March 1943, and the end of the war in August 1945, the MED built 554 permanent structures, among the most prominent of which were B,D and F reactors, T, B, and U processing plants, 64 underground, high-level waste storage tanks and many buildings dedicated to fuel fabrication in the 300 Area. The Hanford Project also constructed the new "government city" of Richland, capable of housing 17,500 people. It accomplished all this at a cost of $230 million.

Secrecy and the unique factor of radioactivity most defined wartime operations at Hanford. In the graphite reactor cores, tolerances for error were held in the range of five ten-thousandths of an inch, in order to compensate for the stresses that irradiation would produce. Newly designed ventilation systems sucked air inward, in an attempt to prevent the spread of airborne activity. 200-foot high stacks were erected to vent the separations plants off-gases (particularly Iodine-131) and to provide for safe dispersal through local air currents. Special fans and blowers added diluting air to the stack gases because, according to DuPont: "From the inception of the work under this program, it was realized...that the extraction of the plutonium from the uranium and fission products...would be accompanied by the removal and liberation of gases either highly toxic in nature or extremely radioactive." MED builders were determined to provide "for the safety of plant employees from the effects of these gases [and]...for the safety of all inhabitants and living creatures within a large radius of the project."[2] However, incomplete knowledge of the exponential generation of the off-gases and of the necessary "cooling" (decay) periods for irradiated metal, resulted in the release of 345,000 curies (Ci) of I-131 during 1945, and of 76,000 Ci during 1946.

MED leaders knew that HEW would need a team of on-Site experts in the new science of health physics. An umbrella organization known as the Health Instruments (HI) Section was established. (This section later expanded to become a division, and consumed 4 percent of Hanford's budget and personnel by 1950.) It defined and measured radiological hazards, established procedures to make jobs in plutonium production safe for workers, and developed and calibrated a number of new and unique environmental-monitoring instruments. Victoreen integrons (air monitors placed at 29 locations on and off the project), gas and liquid sampling vessels, and Geiger-Mueller counters and other devices for personnel monitoring all were used at Hanford. Film badges and two small, thin ionization chambers ("pencils") were worn by every employee on every shift. Finger rings, alpha monitors ("poppies"), and urine checks also were used to survey employees who worked directly in "danger zones."

In June 1945, in response to unexpectedly high levels of I-131 evolution, routine thyroid checks were begun among workers in the 200 Area. At that time, surveys of vegetation were expanded far afield of the Hanford Site, and routine monitoring of Columbia River water and aquatic life, and project groundwater, were established.

POSTWAR PRODUCTION LULL

After the victory celebrations of WWII, President Harry S. Truman offered a phased-in control of atomic energy and weapons to the United Nations. However, the Soviet Union, racing to develop its own bomb, vetoed the plan. The U.S. then sought to formulate legislation to place its atomic facilities under civilian control. Delays and Congressional wrangling characterized these efforts throughout 1946.

Throughout late 1945 and most of 1946, the MED adopted essentially a caretaker position. In fact, it instituted cost-savings measures that, at HEW, resulted in the closure of B Reactor in December 1945, and in the decrease of power levels at D and F Reactors. The number of contractor personnel at the eastern Washington site fell by half, from 10,000 in September 1945 to 5,000 in December 1946.

During the same period, many government officials and members of the public began to worry about the confused state of U.S. atomic policy and about slowed defense production. Finally, on January 1, 1947, the new civilian Atomic Energy Commission (AEC), formulated in the McMahon Atomic Energy Act of 1946, took control of the U.S. atomic complex, including Hanford Works. (The word Engineer was dropped to symbolize the separation of the plants from war-time control by the Army Corps of Engineers).

FIRST POSTWAR EXPANSION

Meeting early in the year, the AEC's General Advisory Committee assigned its highest priority to weapons research and production. Improvement and expansion of the plutonium-production units at Hanford topped the list. In a series of spring directives, the General Electric Company (prime site contractor since September 1946) was directed to build two new production reactors, and to develop the new REDOX (reduction-oxidation) separations process, as quickly as possible.

In August 1947, the upcoming expansion was announced in Richland. Residents expressed relief and joy and Tri-City businesses, which had been slumping, revived. The expansion of the Hanford plants and the city of Richland that occurred from 1947-49 was the largest peacetime construction project in American history up to that point, and cost more than the original building of HEW ($350 million).

During this expansion, H and DR reactors were constructed, going critical in October of 1949 and 1950, respectively. Z Plant, or the Plutonium Finishing Plant, also was built, making possible the conversion of Pu nitrate paste to hockey-puck-shaped plutonium metal, known as "buttons." Forty-two additional high-level waste storage tanks were also constructed, and Hanford Works became unionized. The Hanford Atomic Metal Trades Council was formed in 1948, and was certified officially by the National Labor Relations Board in February 1949.

Work also went forward on the development of the REDOX process, in order to save scarce uranium that was wasted in the first precipitation cycle of the old bismuth-phosphate processing. In 1949, Hanford Works built C-Plant in 200-E Area as a "hot semi-works" (pilot plant) for the REDOX process. Also during the 1947-49, the AEC built new housing on the west side of Richland, and the city grew to about 23,000. Richland "village," as it was known in the 1947-49 expansion period, was a busy and energetic place. By 1948, it had the highest birth rate in the nation, and it became the first city in the U.S. to adopt a "sister city" in Europe on an ongoing charitable basis. Visitors were enchanted by the optimism and vigor of Richland. In 1949, Time magazine termed it a "model residential city...an atomic utopia."[3]

During this same two-year period North Richland was founded five miles north of the then-current border of Richland. Barracks and small trailers there housed construction workers and their families. By the summer of 1948, just one year after its establishment, North Richland housed about 12,000 construction workers and about 13,000 of their family members.

Nevertheless, there were problems in the booming Richland area. There were frequent power outages as electrical transmission lines underwent constant expansion and there was an acute housing shortage. Billowing construction dust was constantly present. According to AEC records, radioactive particulates, Iodine-131 and nitrous-oxide fumes sometimes burdened the dust, and local officials undertook a vigorous tree-and-grass-planting effort to anchor down the powdery amalgam. Additionally, what the community newspaper described as a "mosquito plague" beset Richland every spring and summer beginning in 1945. For several years, large amounts of DDT were sprayed throughout the town and along the Columbia river to control these pests.

Meanwhile, as Richland and the Hanford plants grew, the Cold War worsened. The Soviet Union precipitated a communist coup in Czechoslovakia, and initiated a blockade of the city of Berlin in 1948. The U.S. responded with the Marshall Plan to aid economically unstable areas of Europe, and with the Berlin airlift (an 11 month ordeal). In 1949, communist and noncommunist nations each formed mutual assistance pacts -- the North Atlantic Treaty Organization (NATO) in the case of the U.S. and its allies, and the Warsaw Pact in the case of the Soviet Union and its satellites.

SECOND POSTWAR EXPANSION

Later that year however, the defense equation was altered by an astonishing new development. In September 1949, the Soviet Union detonated its first atomic bomb, and Hanford Works was plunged into another major growth surge. This expansion, lasting from 1950-52, received added impetus from the victory of Mao Tse-tung's Communist forces over Nationalist forces in China. Quickly, Mao signed a mutual assistance pact with Soviet dictator Josef Stalin. On June 25, 1950, Communist North Korean forces crossed south of the 38th parallel and ignited the Korean conflict. During the same period, some of the most well-known spy cases in American history surfaced, including those of Klaus Fuchs, Julius and Ethel Rosenberg, David Greenglass and Alger Hiss.

These events initiated the greatest era of expansion in U.S. atomic/nuclear history. Between late 1949 and 1952, the Nevada Test Site was established and began trials with atomic weapons, and the Pacific Proving Ground (Bikini and Enewetak - formerly spelled Eniwetok - Atolls) was expanded and refurbished. The same period saw the founding of the Reactor Testing Station (now Idaho National Engineering Laboratory), the Paducah Gaseous Diffusion Plant (KY), the Savannah River Plant (SC), the Rocky Flats Plant (CO), the Pantex Plant (TX), the Fernald Feed Materials Production Plant (OH), and the Sandia Laboratory (as a separate entity from Los Alamos). In January 1950, Truman approved development of the hydrogen (fusion) bomb, known at that time as the "Super."

At Hanford, the REDOX plant was completed and began operations in January 1952. REDOX utilized a methyl isobutyl ketone (known as hexone) solvent extraction chemistry, with prolific use of aluminum nitrate, nitric acid, sodium dichromate, and solutions containing ferrous ions. All of these corrosive chemicals, contaminated with radionuclides, reached the environment through spills, overflows, and ground disposal practices. Additionally, significant particulate releases of ruthenium 103/106 from the REDOX stacks occurred during the first three years of operations.

Other facilities built during the 1950-52 expansion at Hanford Works included C-Reactor, which went critical in November 1952, a large Experimental Animal Farm and Aquatic Biology Laboratory in 100-F Area, and 18 more single-shell storage tanks for high-level waste. The chronic shortage of tank space led to the decision to build two evaporators, 242-B and 242-T. Beginning in 1951, they functioned to boil off low-level wastes for cribbing and to concentrate and reduce the volume of high-level wastes. GE also reorganized the site as the Hanford Atomic Products Operation (HAPO).

In the 300 Area, five large buildings, along with ancillary service structures, opened. The 325 Radiochemistry Building, complete with eight "hot" cells, assumed many of the developmental missions of the WWII Technical (3706) Building. The 325 Building, along with three other new structures, was connected to a Radioactive Liquid Waste Sewer (RLWS) that led to the new 340 Retention and Neutralization Complex for holding radioactive wastes for transport and disposal in the 200 Areas. The 326 Physics and Metallurgy Building conducted approach-to-critical, lattice design experiments that led to safer, more efficient lattice configurations in the KE, KW, and N reactors. The 327 Radiometallurgy Building also opened in 1953, conducting both destructive and non-destructive examination (DE and NDE) of fuel rods and reactor process tubes. The 328 Building, a large machine and fabrication shop that replaced four WWII shops, also was completed. The 329 Biophysics Laboratory opened to develop and utilize state-of-the-art radiation detection instruments for the pioneering Hanford Works environmental monitoring and bioassay program.

Soon after these buildings were completed, continuing defense production expansions brought major additions to many of them. Also, the projected coming of N Reactor led to construction of the 306 Metal Fabrication Development Laboratory in 1956, and the 333N Fuels Manufacturing Building in 1960.

In 1952, U-Plant in 200 W Area, built during WWII but not needed as a processing canyon, was retrofitted as the Metal Recovery Plant. It's mission was to utilize a new tri-butyl phosphate/saturated kerosene (TBP-NPH) extraction technique, pioneered by Hanford chemists, to recover uranium from the waste stored in Hanford's tank farms. Due to this unique process, the U facility also became known as the "TBP Plant." The scarcity of high-grade uranium supplies made this mission crucial. Much of the U.S. supply of uranium was housed in Hanford's tanks! Unfortunately, this mission also generated unexpectedly large amounts of chemically complex waste. Ferrocyanide salts were added to the waste stream in order to precipitate the cesium-137 component, thereby making the remaining wastes available for evaporation and ground discharge. The problems that have resulted from the ferrocyanide additions now constitute some of the most challenging ones in the Hanford Site clean-up program, and the ground discharges have added radionuclide and chemical burdens to subsurface soils and water.

THIRD POSTWAR EXPANSION

Just as the first Korean War expansion was reaching completion, the election of President Dwight D. Eisenhower initiated yet another huge augmentation at HAPO. The new President, alarmed that the defense budget had tripled in the past three years, believed that a spending slowdown could be achieved by concentrating resources on atomic weapons rather than conventional forces. He called this policy the "New Look" in armaments. His beliefs, in combination with the threat perceived by the explosion of the first Soviet hydrogen bomb in 1953, and with the need for plutonium for the embryonic American intercontinental ballistic missile (ICBM) development program, brought more rapid growth to Hanford.

This second Korean War expansion, sometimes known as the Eisenhower expansion, saw the construction of KE and KW reactors, the PUREX plant, 21 more single-shell waste tanks, and the Recuplex plant. The coming to power of the K reactors, known as the "jumbos," in 1955 brought the total number of reactors operating in the Hanford Reach of the Columbia River to eight. The cumulative effects of their effluent, released into the Columbia after only a few hours in retention basins, attracted the attention of the AEC. Scientists and physicians from the Division of Biology and Medicine conferred repeatedly with Hanford officials regarding potential threats to river life and safety.

The PUREX plant, like the U-Plant, used a basic TBP/NPH chemistry. Despite many advantages such as built-in concentrators and the utilization of nitric acid that could be distilled and reused many times, it produced copious volumes of liquid wastes, and increased groundwater mounds and radionuclide values in groundwater beneath 200-E Area. The Recuplex process, a Pu scrap recycling mission, produced relatively small, but highly concentrated, wastes. Carbon tetrachloride and many acidic wastes, all contaminated with Pu, were disposed to soils around the Recuplex plant from 1955-62.

ADDITIONAL EXPANSION BASED ON THE "PEACEFUL ATOM"

The 1950s also was a time of expansive plans and dreams for the future of the "peaceful atom." President Eisenhower's "Atoms for Peace" program, announced in December 1953, and the passage of the new Atomic Energy Act of 1954, designed to allow for more private, commercial atomic applications, brought innovative, non-defense programs to HAPO. Because U fuel sources were scarce worldwide, it was important to experiment with alternate fuel mixtures and types. In response, HAPO built the 308 Plutonium Fuels Pilot Plant (PFPP) and the 309 Plutonium Recycle Test Reactor (PRTR), both completed in 1960 in the 300 Area. From 1968-72, the 318 High Temperature Lattice Test Reactor (HTLTR) operated to test powdered, pelletized and other experimental fuels at high temperatures. The new 324 Chemical Engineering Laboratory adopted new waste vitrification work, and became heavily involved in fuels examination and in the processing of many Materials Open Test Assemblies (MOTAs) for the Fast Flux Test Facility (FFTF).

PEAK PRODUCTION YEARS AT THE HANFORD SITE

The years 1956-64 witnessed the most intense defense production period at the Hanford Site. Tensions of the Cold War, intensified by the coming to power of Nikita Khrushchev in the Soviet Union, drove the production of special nuclear materials. An confrontational Cold Warrior, Khrushchev told Americans in a 1959 visit: "Your grandchildren will live under communism!" He launched Sputnik I, the world's first, man-made vehicle to orbit the earth, on October 4, 1957. Within seven months, he had launched Sputniks II and III. These achievements combined with a dazzling string of other Soviet "firsts" in space to create a sense of national urgency in the United States. President John F. Kennedy pledged that he would close the "missile gap" with the U.S.S.R., and "get America moving again." Policies that he initiated tripled the U.S. nuclear destructive capability by 1964. In the Cuban "missile crisis" of October 1962, he successfully challenged the Soviet attempt to place ICBMs in the western hemisphere. Hanford's weapons production, as it had done with President Eisenhower before him, gave Kennedy's words the backbone and the teeth to face down the determined U.S.S.R. Without that production, the course of history might have been quite different.

During the peak production years of 1956-64, N-Reactor was built at HAPO, along with the Federal Building and the last four single-shell, high-level waste storage tanks. A larger and more sophisticated plutonium recycling plant, known as PRF (Plutonium Reclamation Facility), opened in 1964. Hanford chemists also pioneered a number of "isotope campaigns," producing megacuries of cerium, strontium, cesium, promethium and other rare earths elements for special military and NASA applications. During that period, Hanford was the world's only source for promethium, a rare earth element not found in nature, but used by Donald W. Douglas in the development of the artificial heart. From 1968-78, B-Plant, the old wartime bismuth-phosphate separations plant, operated to extract strontium (Sr-90) and cesium (Cs-137) from high-level waste.

WASTE MANAGEMENT PROBLEMS GROW IN 1950s AND 1960s

As the years of peak production went forward at HAPO, volumes of wastes produced by the eight single-pass reactors, N-Reactor, and the REDOX, PUREX, Z-Plant and B-Plant separations facilities, increased sharply. A 1956 "feasibility study" (prototype for modern Environmental Impact Statements required by the National Environmental Policy Act) resulted in the voluntary decision by Hanford managers not to construct additional single-pass reactors at the complex. However, power and exposure levels at the existing reactors were raised many times, to the point where each of the eight older reactors operated at power levels nearly ten times those of World War II. Such levels brought thermal increases and added chemical and radionuclide burdens to the Columbia River. The river was cooled by huge controlled spills of cold water from the bottom levels of Lake Roosevelt, behind Grand Coulee Dam, each summer from 1958-64. By 1960, reactor effluent (wastewater) discharges to the Columbia averaged 14,500 curies per day, after a four-hour decay period in reactor retention basins. Hanford and AEC leaders discussed rising levels of contamination in fish tissues in the river and in shellfish in coastal waters near the river's mouth. Chemists and operators at the Site sought new practices that would reduce radionuclide formation in reactor effluent, or would bind or transmute the isotopes in different disposal practices. Much time, effort and money was applied, but workable, large-scale solutions remained elusive. During the same period, volumes of low-level wastes discharged to the ground also increased. Mounds in the water table beneath 200-E and 200-W grew larger, as did activity values in portions of the groundwater. In the mid-1950s, suspected and sometimes confirmed leaks from single-shell, high-level waste storage tanks began.

In 1958, the first comprehensive Hanford waste management plan was completed, calling for the immobilization of high-level tank wastes. However, the requirements for radioisotopes for the burgeoning U.S. space program and for new medical applications were among the reasons that the plan was not implemented. Many Site and other officials believed that Hanford's wastes could be a source of valuable isotopes.

PRODUCTION PHASE-DOWNS AT THE HANFORD SITE

On January 7, 1964, President Lyndon Johnson surprised the nation with his announcement of a decreased need for special nuclear materials. "Hanford To Cut Back In 1965," proclaimed the local newspaper the following day. Thus, the era of peak production at the eastern Washington desert complex slowed. Between December 1964 and January 1971, all eight single-pass reactors shut down. Production continued at N Reactor for another 17 years, driven by national programs to improve and expand guided missile systems, anti-ballistic missile systems, and other U.S. weapons programs. During these years, 28 double-shell tanks for the storage of high-level nuclear waste were constructed. The Site also engaged in new missions involving chemical extractions of special radioisotopes, and experiments with waste solidification methods. Development and construction of the FFTF brought new growth in many Hanford areas.

MODERN WASTE CLEAN-UP ENDEAVORS AT THE HANFORD SITE

In the late 1980s, the DOE began the large-scale release of thousands of historical reports known as the Hanford Historical Documents. Through these, the public, officials of the U.S. Environmental Protection Agency (EPA) and other agencies learned of the volume and extent of nuclear wastes at the Hanford Site. In consensus with the DOE, the decision was reached to pursue waste remediation at weapons production and testing sites throughout the nation. The pioneering Tri-Party Agreement, signed at the Hanford Site in May 1989 now serves as a national model for clean-up agreements. Historical research plays an important role in Hanford Site clean-up programs. By understanding the technical workings of the old chemical and atomic processes, we can identify and characterize the wastes logically produced by these operations. Further, we can identify and verify waste sites and their contents, always searching for another level of detail in terms of quantities, chemical components, times of discharge, methods of storage and disposal, and many other factors. Historical investigations can locate new waste sites and, in some cases, save the high costs of invasive physical characterization efforts when they are not needed. In the broadest sense, history can help us to piece together pioneering and seminal developments in the emerging discipline of American nuclear history -- to help our nation understand how and why certain events unfolded as they did, when they did, and thus to provide the raw materials for open, democratic discourse about our national history, goals and common identity.

1. Franklin T. Matthias, "Hanford Engineering Works: Manhattan Engineer District, Early History," Address delivered at the Technical Exchange Program, U.S. Department of Energy, Richland Washington, January 14, 1987, p. 10.

2. DuPont Corporation, "Design and Procurement History of Hanford Engineer Works and Clinton Semi-Works," IN-6263 (Wilmington, DE: E.I. DuPont de Nemours and Co., 1945), Vol. II, pp. 195-196.

3. "The Atomic Model City," Time, Vol. 54, #24 (December 12, 1949), p. 21.