Constant Change in the Early Years

Hanford's Historic Reactors

By Michele S. Gerber

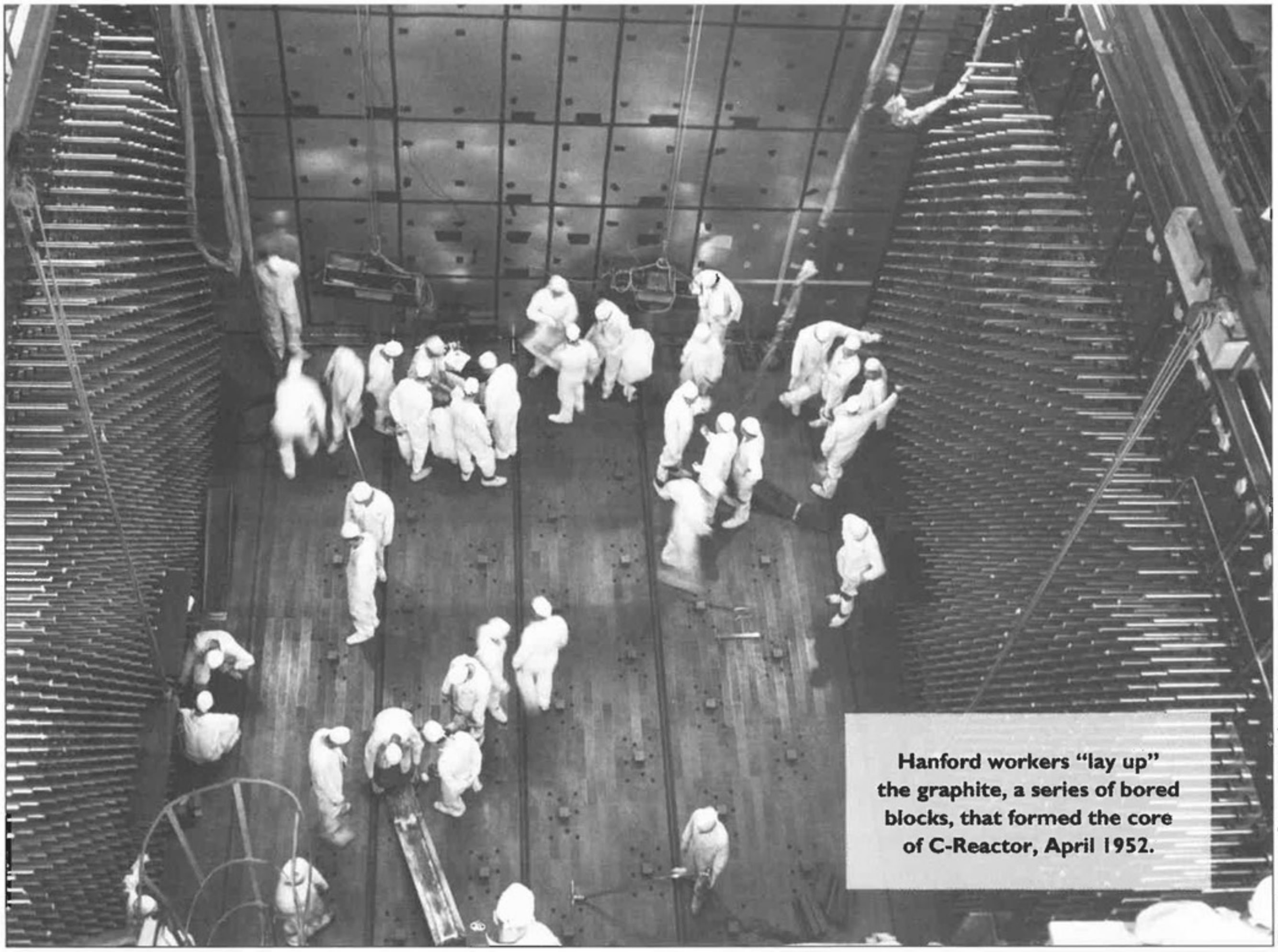
Nine plutonium production reactors, now closed and silent, hug a 14-mile stretch of the Columbia River's Hanford Reach in the southeastern corner of Washington. Built as the core of America's atomic defense arsenal during World War II and the Cold War, this grouping forms the largest collection of full-size reactors in the world. More defense activity took place here than anywhere else, particularly during the first 25 years of operations (1944-1969), as the Hanford site raced to produce over half of the nation's supply of plutonium and nearly a quarter of the world's supply.

Hanford's B Reactor was the first full-scale nuclear reactor to operate in world history. Built by the Army Corps of Engineers and the DuPont Corporation in just 11 months, between October 1943 and September 1944, the structure is now listed in the National Register of Historic Places. B Reactor also has received special awards from the American Society of Mechanical Engineers and the American Society of Civil Engineers.

The next seven reactors, D, F, H, DR, C, KE, and KW (in order of construction) were similar in most features. Built between 1943 and 1955, and shut down between 1964 and 1971, they had an average life span of just 20 years, yet they will present cleanup and waste management challenges for hundreds to thousands of years. The ninth and last defense

C Reactor, Hanford's sixth defense production nuclear reactor, under construction in 1951.

Courtesy of the U.S. Department of Energy



Hanford workers "lay up" the graphite, a series of bored blocks, that formed the core of C-Reactor, April 1952.

Courtesy of the U.S. Department of Energy

production facility, N Reactor, operated from 1963 to 1987. There were major differences between N and the older reactors. In particular, N's cooling system recirculated and reused water many times before returning it to the Columbia River, thus contributing less overall contamination to the river than did the older reactors.

The story of the first eight of Hanford's reactors is one of constant learning, experimentation and change. Tied in umbilical fashion to the Columbia River, these machines drew cooling water from the river, and pumped it through a series of filtration, chemical treatment, and storage buildings and tanks. The water then was passed directly through long, horizontal tubes in the reactors, where aluminum-jacketed uranium fuel rods were undergoing active neutron bombardment. From there the water was pumped out the back of the reactors, left for a brief time (30 minutes to 6 hours) in retention basins to allow for short-term radioactive decay, and then returned to the Columbia River. This cycle earned these reactors the nickname "single-pass" reactors.

The construction and general specifications of B Reactor were similar to those of most of Hanford's other single-pass reactors, although C, KE and KW were slightly larger and contained some special features. B Reactor rested on a thick concrete foundation topped with cast-iron blocks inside the 105-B Building, a reinforced concrete structure shaped like a tiered wedding cake.

Surrounded by thick shields, the reactor core itself consisted of a graphite "core" measuring 28 feet from front to rear and 36 feet from side to side and top to bottom. The entire reactor block was enclosed in a welded steel box that functioned to confine a gas atmosphere. The atmosphere of the earliest reactors was composed of helium, an inert gas selected for its heat removal capacity. Heat removal was considered important because original calculations estimated that the formation of one gram of plutonium 239 (Pu-239) liberated some 80-million BTUs (British thermal units) of energy, the equivalent of 1,000 kilowatt days.

The early Hanford reactors also were equipped with various safety and control instruments that measured temperature, pressure, moisture, neutron flux and radioactivity levels. Because no one instrument had enough range to measure neutron flux all the way from shutdown levels to the approximately one trillion times shutdown levels experienced during operations, the reactor was fitted with sub-critical, midrange and full power flux instrumentation.

Many questions about reactor operations puzzled early Hanford scientists. For example, they worried about the possibility of "slug failures," that is, the accidental penetration by cooling water of the aluminum jackets surrounding the fuel elements. They knew that such penetration would cause the uranium to swell, thus blocking the coolant flow within the process tube. This condition would necessitate tube removal and replacement and could melt the fuel elements in that tube. Also, fuel ruptures would allow the escape of radioactive fission products. The desire to avoid the problems associated with fuel ruptures initiated intensive study of fuel fabrication methods, corrosion principles and water treatment methods soon after World War II.

Temperature and neutron flux distribution were other topics that intrigued the early operators of Hanford's reactors. At first, "poisons" (neutron absorbing materials) were distributed in a uniform pattern throughout the reactor core during operation. This method of control produced a flux pattern that resembled a bell curve, front to rear within the reactor. Such a curve meant that while uranium elements in the center of the reactor achieved maximum or optimum irradiation, many of the fuel elements located in the rest of the reactor achieved sub-optimal irradiation, due to lower neutron flux. This situation not only was inefficient in terms of utilization of the uranium supply, it also contributed to temperature gradients that caused expansion of the graphite in the central portions of the reactor.

Shortly after World War II Hanford scientists, working under key Manhattan Project physicist C. W. J. Wende, tested several new poison patterns, with the goal of "flattening" the pronounced curve, thus evening out the distribution of neutron activity and enlarging the area of maximum flux and temperature within the reactor. They quickly learned that many alterations in poison distribution (control rod positions) would achieve higher and lower temperatures and exposures in various reactor zones. They dubbed all of these manipulations "dimpling" the reactor.

Of all the operational questions and issues that were pioneered in the Hanford reactors, almost none proved more compelling than those involving graphite. Swelling of the graphite, along with embrittlement, was a side-effect of irradiation. By late 1945 graphite expansion was causing the process tubes to bow, "binding" them too tightly with their fittings and other components, and straining the seals at the top and side corners of the reactor shields.

As a result, a graphite expansion committee was formed at Hanford in early 1946. Ultimately, concern over the graphite expansion problem and its intrinsic threat to reactor "life" led to a decision on March 15, 1946, to shut down B Reactor. However, in mid 1947, convinced by positive developments in graphite study, site managers decided to restart the reactor the following year.

By 1950 further experiments had made it clear that the addition of carbon dioxide (CO_2) to the helium in reactor atmospheres could alleviate graphite swelling. Because it had a lower heat removal capacity than helium, CO_2 allowed the carbon atoms in the graphite crystal, displaced by irradiation, to heat up, become active, and thus realign themselves. By 1954 the CO_2 additions were working so well that the oldest reactors operated with a gas atmosphere composed of 40 percent helium and 60 percent CO_2.

No early or ongoing operational issue (including the graphite puzzle) was more important to the Hanford Works than that of increasing power levels. B Reactor, along with D, F and DR, was designed to operate at 250 megawatts while H, built five years later, was designed for 400 megawatts. C Reactor, built during 1951-52, was designed for 650 megawatts. The learning curve in operations then took such a leap that the twin K Reactors, built during 1953-55, were designed for 1,800 megawatts each.

Questions concerning how to achieve higher power levels, with consequent increases in plutonium production, had intrigued Hanford scientists since World War II. In April 1949 an incremental test program that would take D Reactor to 330 megawatts was undertaken. By January 1950 this experiment was so successful that DR Reactor was being operated at 400 megawatts. With the explosion of the first Soviet atomic weapon in August 1949, the victory of the communist forces of Mao Tse-Tung in China, and the discovery of the famous Klaus Fuchs spy case, increased power levels in the Hanford reactors became even more important to perceived national defense needs. From the late 1940s through the closure of the last single-pass reactor in 1971, the Hanford story is dominated by a constant effort to achieve increased power levels.

By late 1956, under President Eisenhower's policy of "massive retaliation" and the boisterous challenges of Soviet Premier Kruschchev, the World War II power levels at the three oldest reactors had more than tripled, to stand at 800 megawatts. At that time, a set of modifications, designed to allow increased coolant flow, was completed at these reactors. Similar modifications were made at the other single-pass reactors through the early 1960s, spurred by the threat of Soviet technical superiority as demonstrated by Sputnik.

These changes and the fuel and tube design improvements resulted in power level increases in the World War II reactors that reached the 2,200-2,400 megawatts range by the mid 1960s, just after the Cuban "missile crisis" had once again boosted American desire for a strong nuclear defense. The mid-1960s operating figures in the oldest HW reactors were nearly ten times the original design levels. At the KE and KW reactors, final operating levels in 1970 and 1971 stood at approximately 4,100 megawatts each.

Higher power levels were easily achieved by adding enriched uranium fuel elements (containing higher percentages of U-235). However, increased power levels presented many puzzling operational challenges in the effects they caused in reactor systems and components. By mid 1951 Hanford scientists knew that the higher temperatures associated with increased power levels could produce substantially higher fuel jacketing and tube corrosion and failure rates. But their main concerns centered around how to get additional cooling water to, through and out of the reactors in order to offset "boiling disease," a situation wherein steam might form in a process tube. If this happened at higher power levels, greater water pressures would be needed to sweep the steam from the tube and thus prevent a localized meltdown.

By mid 1953 effluent removal piping at the oldest reactors, already operating at 20 to 50 percent above design capacity, was under intense study. At the same time, operators realized that the filtration capacity for intake water would have to be increased well beyond the original capacity of approximately 35,000 gallons per minute (gpm) per reactor. More important, however, was the need to increase the intake pumping capacity.

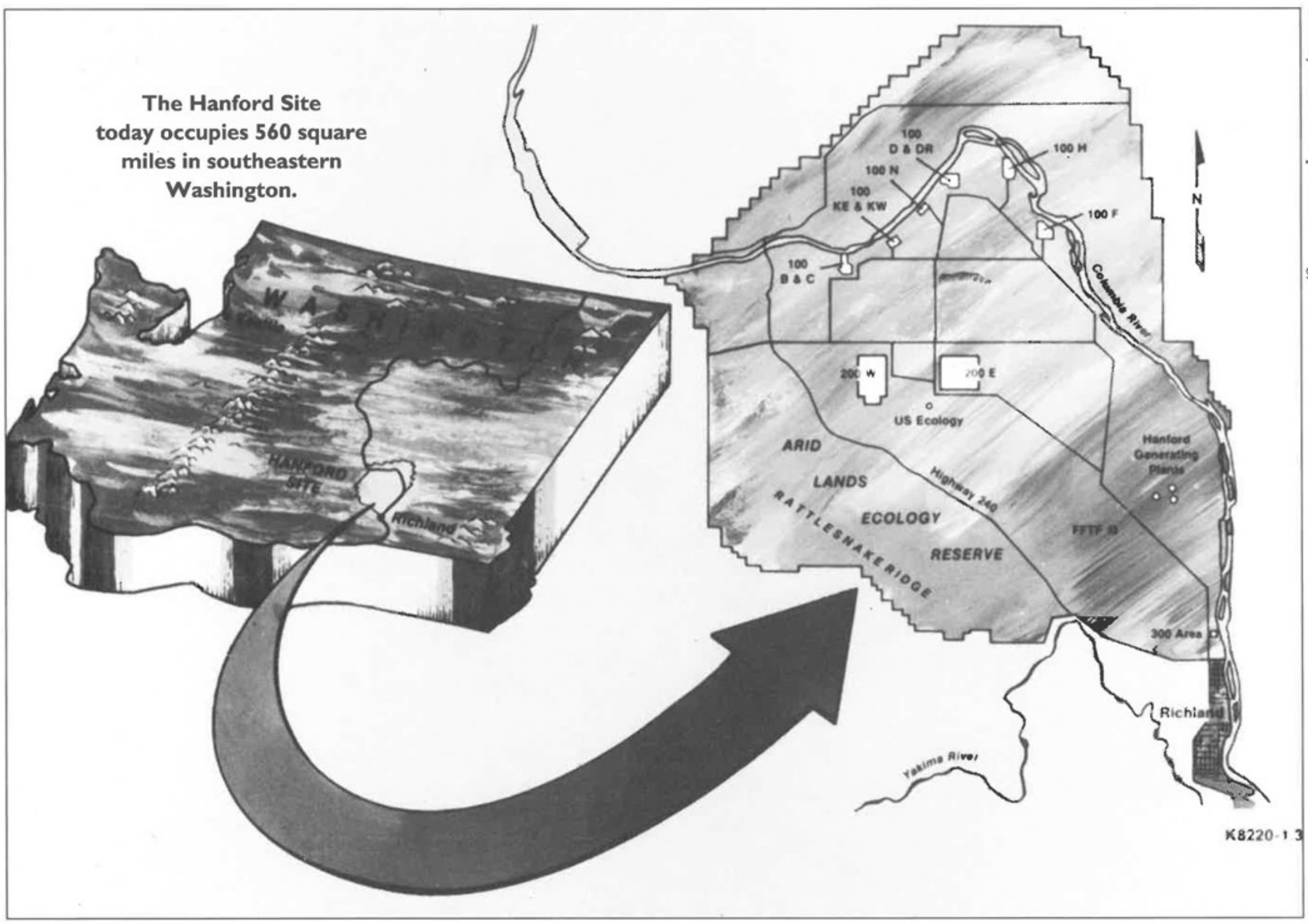
Meanwhile, as power levels crept upward in the oldest reactors during the late 1940s and early 1950s, fuel element ruptures became a reality. The first rupture occurred at F Reactor in May 1948, and two others occurred later that year at B Reactor. The number of fuel element ruptures increased slowly during 1949-50, but expanded dramatically in 1951 when Hanford Works experienced 115 fuel failures. This number continued to climb throughout the early 1950s, bringing further focus to fuel fabrication improvement studies.

Along with fuel element failures, higher power levels and higher temperatures brought increasing levels of corrosion and failure of process tubes. By 1953 each Hanford reactor needed an average of 200 tube replacements per year. In order to reduce the ruinous corrosion, a special "Flow Laboratory" was built in late 1951 in a modified World War II refrigeration building. It functioned to study corrosion and heat transfer within process tube simulations.

At the same time, the Hanford Works began an intense review of intake water treatments. Sodium dichromate, a key corrosion inhibitor that had been added to reactor water since World War II, was evaluated closely. Because sodium dichromate was known to have detrimental effects on the fish of the Columbia River, much experimentation with other corrosion blockers was undertaken. However, due to dramatic rises in tube and fuel element corrosion when the sodium dichromate was withdrawn, site scientists decided to continue using it.

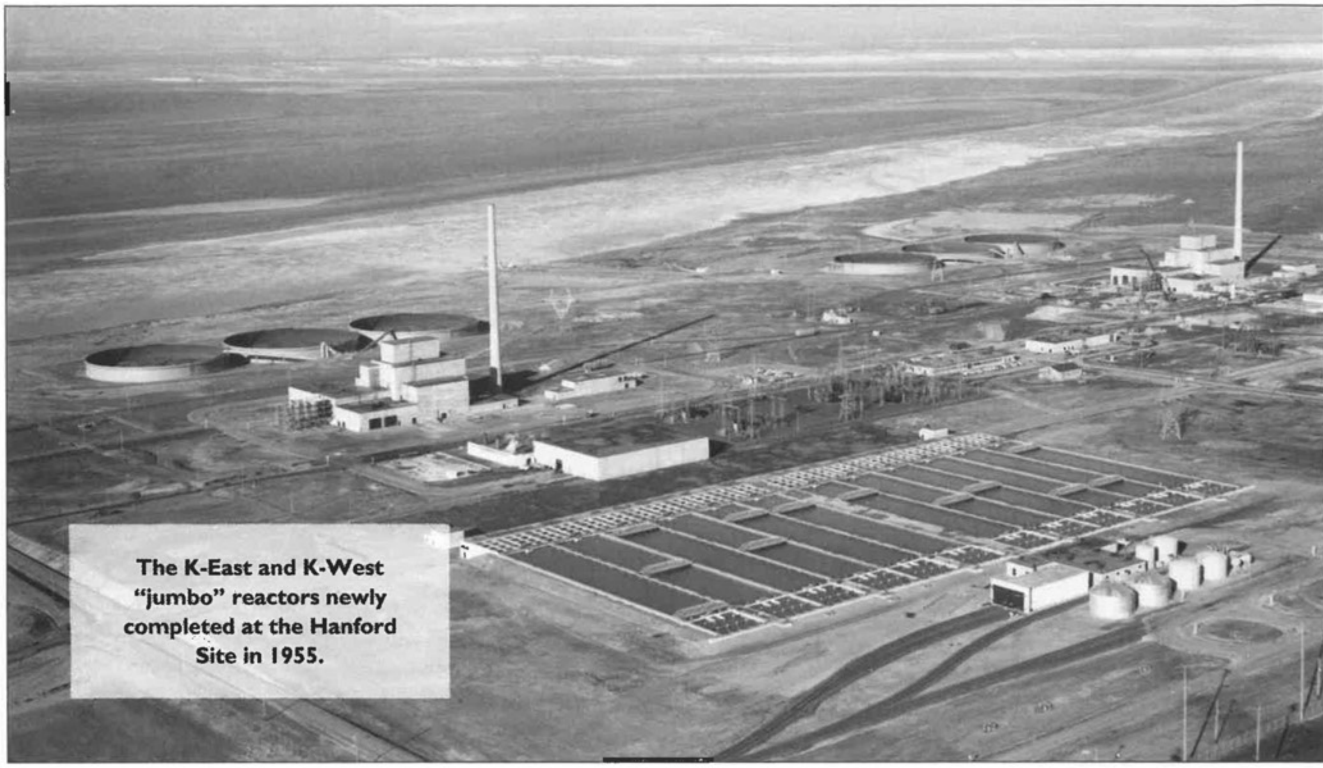
The drive to higher and higher power levels in Hanford's reactors throughout the late 1940s and mid 1950s was accompanied by the need for several changes to enhance operating safety. The "last ditch" safety system in the five oldest reactors was replaced with tiny, neutron-absorbing, nickel-plated carbon steel balls. These balls were poised in hoppers at the top of the reactors, ready to pour in and tamp down the fission reaction if necessary. Physical braces and supports and many additional instruments also were added.

Other changes in reactor operations shortened the time required to perform routine operating chores. Since World War II loading and unloading the fuel elements from a reactor had been performed while a reactor was shut down. However, by 1950 experiments were underway to perform charge-discharge operations while a reactor was running. During the



The Hanford Site today occupies 560 square miles in southeastern Washington.

Courtesy of the U.S. Department of Energy



The K-East and K-West "jumbo" reactors newly completed at the Hanford Site in 1955.

early and mid 1950s such a system was tested successfully. It operated remotely and worked by flushing fuel elements down the process tubes via high pressure water. Due to cost, this system was not installed at the five oldest reactors, but it was emplaced in the newer reactors.

Another change aimed at saving shutdown time concerned "purging" or cleansing the process tubes. Minerals, elements and suspended solids in the Columbia River's water routinely built up a film on the process tube surfaces. This situation caused heat build-up within the reactors. Since the mid 1940s operators had "purged" the film from the tubes on a monthly basis, while the reactors were shut down. However, by the early 1950s the Hanford Works was trying to conduct "hot" purges—so called because they occurred while the reactors were running. Such operations were very effective in removing reactor films, but greatly increased the levels of pollution entering the Columbia River.

To help ameliorate high levels of radioactivity, restrictions were placed on the frequency of purges that could be conducted during periods of low river flow. Also, a series of experiments was initiated to find ways to protect the river. Beginning in 1954 and continuing into the early 1960s, a series of modifications were made to the eight single-pass reactors. Intake pumping, filtration, chemical treatment and storage capacities all were increased substantially. Effluent systems likewise were strengthened and greatly enlarged.

Ironically, just as these projects were getting under way, a series of significant changes in fuel elements and process tube designs and materials took place at the Hanford Works. These developments allowed dramatic increases in reactor power levels, once again straining the newly upgraded support systems. Much of the increase in power level was made possible by the use of internally and externally cooled fuel elements, which were first tested on a production basis in 1958. These fuel elements had a full, end-to-end coolant channel down their center, in contrast to the solid configuration of the fuel elements previously used. As such, they had a vastly augmented cooling capacity.

Other operating efficiencies that came quickly in the late 1950s and early 1960s resulted from the gradual replacement of aluminum process tubes with tubes made primarily of stronger, more tensile zirconium. Also, self-supported ("projection," "bumper" or "ribbed") fuel elements were developed at Hanford. Such fuel elements allowed greater passage of cooling water, again allowing higher power levels to be sought within a margin of safety.

The higher power levels permitted by development of internally and externally cooled fuel elements, ribbed fuel elements, and new process tubes, brought multiple operating challenges to the support systems of the Hanford reactors. Strained pumps and pipes developed leaks, while electrical capacities proved inadequate. Much of the reactor instrumentation was rendered obsolete. Even the graphite swelling problem increased as neutron flux and bombardment levels rose exponentially. Safety reviews called for a mounting list of improvements.

From that time forward the primary challenge for the operators of the Hanford single-pass reactors became how to design and fund all of the support systems upgrades that were needed. One project accomplished at all of these reactors during 1960-62 was the construction of a large exhaust gas confinement system. It was comprised of a below-ground filter building, sampling equipment and duct work that routed gases from the reactor through these filters and then back into the exhaust stack. Based on safety and control considerations, several instrumentation improvements and replacements also were approved for many of the reactors.

In January 1964 President Lyndon Johnson announced that, due to a decreased need for special nuclear material, Hanford's reactors would be shut down in a phased sequence beginning in December 1964. After that time it became even harder to gain approval for improvement projects.

Additionally, Columbia River pollution from reactor effluent was becoming an increasingly important factor in regional and national considerations. Hanford scientists as well as health officials in Washington, Oregon and the United States Public Health Service became more and more concerned with the effects of reactor effluent in the huge river. By 1960 the total volume flow from the Hanford reactors had increased approximately ten-fold over that of the World War II period, shortening the practical retention time to only about 30 minutes and making diversion of unusual effluents to "cribs" (percolating areas dug into the earth) or other holding areas virtually impossible. Furthermore, the total amount of radioactivity reaching the Columbia River stood at nearly 14,000 curies per day.

Within this effluent flow the main isotopes of concern were phosphorus 32 (P-32), zinc 65 (Zn-65), chromium 51 (Cr-51), iron 59 (Fe-59), and arsenic 76 (As-76). Scientists had known since the late 1940s that these isotopes concentrated within aquatic plants and animals at vastly higher levels than were found in the river water itself. Multiple studies by Hanford's chief aquatic biologist, R. F. Foster, and others pointed to the fact that the Columbia's water could be at or below permissible levels for various radionuclides and still present a hazard to consumers of river fish, ducks and other wildlife. The majority of the studies that reported these findings were classified as secret and were not accessible by the public until years after the HW reactors had closed.

Throughout the late 1950s and early 1960s virtually every aspect of the bioaquatic and potential downstream health consequences of reactor effluent was examined, including the effects of temperature, operating purges, various purge agents and filtration aids, fuel element ruptures, sodium dichromate, and the radionuclides themselves. Various solutions were proposed and tested. Among these was the concept of passing reactor effluent through beds of aluminum shavings in order to trap various radionuclides. Laboratory tests seemed promising, but a production-size bed installed in 1960 at the D Reactor retention basin demonstrated so many shortcomings that the idea was soon abandoned.

Another concept that was explored thoroughly at Hanford was that of varying the intake water treatments. However, mixed results, combined with undesirable side effects, resulted in very little practical improvement. In the early 1960s an idea that had been explored in the 1950s for reducing radionuclide releases to the Columbia River was revived. This "inland lake" concept proposed routing reactor effluent through trenches to artificial inland lakes dug in the center of the site where the distance between land surface and the underground water table was significantly greater than it was near the reactor retention basins. Proponents of the idea pointed to the longer time period for radioactive decay and thermal cooling of effluent before the wastes finally would reach the river. However, studies conducted in the 1950s had demonstrated undesirable effects, including the wind entrainment of radioactive mists that could spread contamination over wide areas extending even to offsite. Furthermore, problematic underground mounds in the water table, caused by disposal of low-level liquid wastes from chemical processing plants near the center of the site would be worsened by the addition of reactor effluent.

As the reactor shutdowns began at Hanford in the mid 1960s, operators and scientists struggled to extend the viability of those remaining by developing environmentally acceptable means of effluent disposal. In the spring of 1967, with five single-pass reactors operating, a Hanford summary report on alternate methods of reactor effluent treatment and disposal listed several options. Conversion to recirculating cooling systems was listed as economically prohibitive. Along with related equipment changes, a total conversion cost of $32 million per reactor was estimated. Other potential solutions were also expensive and posed awkward siting problems between the reactors and the Columbia River.

It is clear that Hanford's single-pass reactors closed for a combination of reasons, encompassing changing national defense needs and newer environmental standards and concerns. Over the years since closure, all reactor fuel has been removed and several of the support buildings have been taken down. In 1993 Hanford officials, citing deterioration and safety issues associated with the remaining ancillary buildings, committed to an accelerated program to decontaminate and decommission these structures.

At nearly the same time, a "Record of Decision" was announced with regard to the reactors themselves. After a period of "safe storage" in place, to allow for further radioactive decay, their cores will be lifted in one-piece fashion onto huge trailers and transported to the 200 Areas (central portions of the Hanford site designated for long-term waste management activities). A study to determine the feasibility of upgrading the B Reactor building itself for use as a public museum or interpretive center is now under way.

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FRONT COVER: ***"Perspective View of the Proposed Capitol Group for the State of Washington," watercolor by architects Walter Wilder and Harry White, 1912. (Washington State Capital Museum)*** ***See related story starting on page 20.***