Hanford's 100-HX Pump and Treat Project – a Successful Blend of Science, Technology, Construction, and Project Management - 12412

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ABSTRACT

CH2M HILL Plateau Remediation Company (CHPRC) recently completed construction and start-up of the $25 million 100-HX Groundwater Pump and Treat Project for the Department of Energy (DOE) at its Hanford Reservation site in Washington State. From the onset, the 100-HX Project Leadership Team was able to successfully blend the science and technology of a state-of-the-art groundwater pump and treat system with the principles, tools, and techniques of traditional industrial-type construction and project management.

From the 1940s through most of the 1980s, the United States used the Hanford Site to produce nuclear material for national defense at reactor sites located along the Columbia River. While the reactors were operational, large volumes of river water were treated with sodium dichromate (to inhibit corrosion of the reactor piping) and used as a coolant for the reactors. After a single pass through the reactor and before being discharged back to the river, the coolant water was sent to unlined retention basins to cool and to allow the short-lived radioactive contaminants to decay. As a result of these operations, hexavalent chromium was introduced to the vadose zone, and ultimately into the groundwater aquifer and the adjacent Columbia River. In addition, numerous leaks and spills of concentrated sodium dichromate stock solution over the lifetime of reactor operations led to higher concentrations of chromate in the vadose zone and groundwater in localized areas. As a result, the 100 Area was included in the National Priorities List sites under the Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA).

The mission of the 100-HX Project is to significantly reduce the concentration of hexavalent chromium in the groundwater by treating up to 3.8 billion gallons (14,300 megaliters) of contaminated water over its first nine years of operations.

In order to accomplish this mission, groundwater scientists and geologists using sophisticated scientific modeling optimized the 100-HX's approximately 0.7 square mile (181 hectometers) extraction and injection well field to support continuous operation of a maximum of 800 gallons (3,028 liters) per minute, 24 hours per day, and 7 days per week. The use of traditional resin technology for the plant's ion exchange system required a change out of the resin every 12 weeks and shipment to an offsite facility 1,500 miles (2,414 kilometers) away for regeneration. Instead, the project leadership pursued newer technology with a disposable resin that could be disposed of on-site and would require less frequent change outs, reducing the project's life cycle costs by more than $16 million.

Constructing the facility had its own challenges. The well field location overlapped ecologically sensitive lands where bald eagles and native wildlife use the land for their mating habitat for nearly half of the year.

Building locations had to be planned around historically and culturally sensitive areas, and around another contractor's remediation work zones. Also, the size of the well field required a transfer (pumping) facility and installation of more than 60 miles (97 kilometers) of high-density polypropylene pipe, 23 miles (38 kilometers) of power cable, and 28 miles (46 kilometers) of control cable.

Along with schedule and budget constraints typical of any fast-track project, the project team dealt with severe resource constraints due to competing projects across the Hanford Site caused by the influx of American Recovery and Reinvestment Act stimulus funding. In addition, the project team itself was stretched between completing another $25 million dollar construction project while designing and constructing this project. In order to save money, the project schedule was compressed by three months from the original baseline schedule. This was made possible by the strong use of project management principles throughout the design, construction, and testing phases, as well as implementation of many lessons learned from a similar construction project. In summary, the 100-HX Project truly was a unique blend of science, technology, construction and project management.

INTRODUCTION

The Hanford Site in Washington State served as the primary plutonium production facility in the United States. The 100-D and 100-H Areas at the Hanford Site contain three of the nine plutonium production reactors constructed at Hanford. These are the D reactor, one of the original three reactors constructed during World War II, and the DR and H reactors, which were the first reactors constructed following the initiation of the Cold War in 1947 [1,2,3]. These reactors used sodium dichromate in their cooling water to prevent corrosion of the tubes within the reactor pile. Cladded fuel slugs were loaded into the front side of the reactor and discharged on the back side of the reactor into a water-filled fuel storage basin that allowed the fuel time to cool thermally and radioactively. Approximately 25,000 gal/min (94.6 kiloliter/min) of water containing 2 mg/L of sodium dichromate was sent through the tubes during the early years of operations[1] for cooling [4]. Releases of large volumes of cooling water from basins and trenches, in combination with point sources of stock solution from rail car unloading facilities and leaks in distribution piping, resulted in contamination of a large portion of the groundwater and the vadose zone in the 100-D and 100-H Areas with hexavalent chromium.

Consequently, the 100-D and 100-H Areas were designated for cleanup under the CERCLA program. The 100-HR-3 Operable Unit (OU) includes both the 100-D and the 100-H Areas. The OU includes the northern-most portion of the Hanford Site and includes the tip or Horn of the Hanford Site (Fig. 1). A remedial process optimization (RPO) was initiated in October of 2008. The RPO efforts have focused on the expansion of the remedial systems to achieve the Remedial Action Objectives (RAOs) within specified timeframes. The primary objectives for the RPO designs are (a) to prevent the discharge of hexavalent chromium to the Columbia River at concentrations exceeding those considered protective of aquatic life in the river and riverbed sediments by the year 2012; and (b) aquifer restoration inland by attaining the Washington State Standard of 48 µg/L by the year 2020. The objectives related to achieving river protection by 2012 and target cleanup levels by 2020 will be met, at a minimum, by pumping groundwater from existing and proposed extraction wells located within and around the contaminated areas and removing hexavalent chromium from the groundwater by treatment at ex-situ facilities.

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[1] D Reactor operated from December 17, 1944 to June 26, 1967. DR Reactor operated from October 3, 1950, to December 30, 1964. H Reactor operated from October 29, 1949, to April 21, 1965.

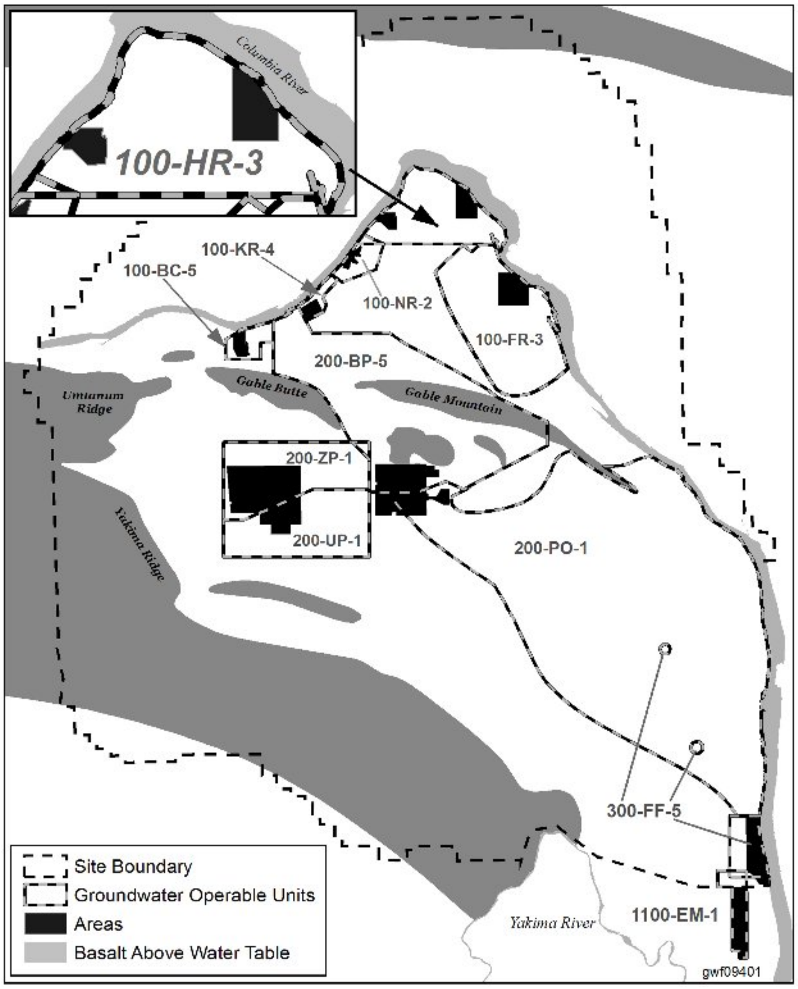

Fig.1. Location of the 100-HR-3 OU [6]

NATURE AND EXTENT OF CONTAMINATION

Contamination in the 100-HR-3 OU consists primarily of hexavalent chromium with lesser amounts of nitrate and localized strontium-90 in the 100-H Area. Hexavalent chromium is found in groundwater from the 100-D Area across the Horn to 100-H Area (Fig. 2). Concentrations range from 70,000 µg/L in a local area at 100-D in the vicinity of the old sodium dichromate rail transfer station to broad areas less than 100 µg/L across the Horn into 100-H [7]. There is a zone of relatively clean water that divides the plume in the 100-D Area in the vicinity of the 182-D Reservoir, a water supply structure that provides emergency fire suppression and special process water to the Hanford Site as a secondary supply to the 182-B Reservoir.

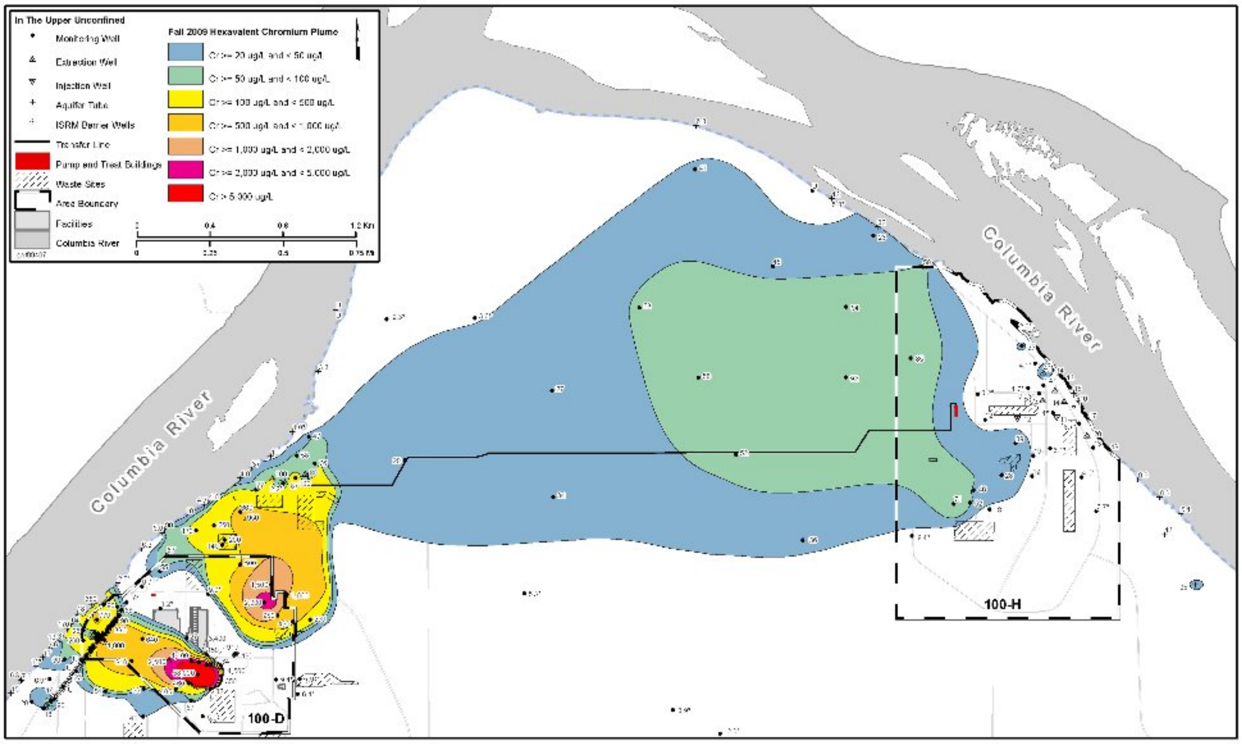

Fig. 2. Hexavalent Chromium Concentrations in Groundwater at the 100-HR-3 OU

The hexavalent chromium groundwater contamination is divided geographically into four regions: 1) the D South plume, 2) the D North plume, 3) the Horn plume, and 4) the H plume. The present-day expression of these plumes represents the culmination of anthropogenic and natural processes over a period of 65 years at the 100-D Area and approximately 55 years at the 100-H Area; the area is characterized by hexavalent chromium entering the environment at or near land surface and subsequently migrating through the vadose zone and groundwater to the Columbia River. Additional amounts of hexavalent chromium were discharged directly to the Columbia River via large outfall pipes following passage through the reactors and a period of time in cooling ponds. Of the remnants of hexavalent chromium that are observed in the field today, the highest concentrations are observed in a groundwater "hotspot" area at the D South plume where concentrations have approached 70,000 µg/L.

There are several different source terms for the hexavalent chromium that must be integrated to understand its present-day distribution in the environment. During the early years of operation (1944-53), the sodium dichromate was delivered to the site in dry form in bags and mixed on site to form 2 mg/L solution in the cooling water for the reactors. Given the high level of throughput, large groundwater mounds formed in the areas adjacent to the reactors. Beginning in 1953, concentrated sodium dichromate stock solution was utilized for several years. By the time operations began at H reactor in 1956, operational experience indicated that 700 µg/L provided sufficient chromium protection and less concentrated solutions were used. Consequently, groundwater contamination at lower concentrations is observed at 100-H. In addition, there have been leaks and spills related to the sodium dichromate stock solution and the dichromate distribution piping system. Finally, there are a number of other sites in the vicinity of the reactors where sodium dichromate was released to the environment through either planned or unplanned releases.

REMEDIATION

In 1996, a ROD was issued for the 100-HR-3 OU [8], which provided for the application of a pump-and-treat remedy to treat the hexavalent chromium plume for the purposes of protecting the river and providing information that would lead to the final remedy. In response, a relatively small system called the HR-3 pump-and-treat system was designed to treat the known extent of the plume at that time [9, 10]. A pair of 100 gal/min trains containing ion exchange resin were placed in an old warehouse building at 100-H, which pumped from 10 extraction wells at 100-H and 100-D. After treatment, the clean water was injected back into the ground in the 100-H area. A regenerable ion exchange resin was utilized at this plant, which was shipped off site, cleaned and returned. This system was reconfigured several times and did a reasonable job of remediating the far eastern extent of the contamination in the OU.

Further characterization and monitoring of the 100-D portion of the OU revealed high concentrations in the southwest portion of the 100-D Area [6]. Two actions occurred in response to these findings: 1) a ROD Amendment was issued in 2000 [11] that authorized the use of an in-situ redox manipulation (ISRM) barrier in the D South plume, and 2) a second pump-and-treat system was constructed. The DR-5 pump-and-treat system was established in 2002 to treat these high-concentration zones. The system is small, consisting of 4 extraction wells and 1 injection well.

The Ambient Water Quality Standard for hexavalent chromium in Washington State is 10 μg/L. A dilution attenuation factor (DAF) of 1:1 is allowed for compliance in the Interim ROD; consequently, 20 μg/L is the prescribed compliance level in the aquifer.

In 2007, Ecology published a paper that described the state of the Hanford Site groundwater remediation strategy, the lessons learned, and the path forward [13]. In this paper, Ecology concluded that pump-and-treat systems such as those in 100-HR-3 "…provided a meaningful approach to address certain contaminants" with the caveat that the deployment "…was too small in scale" and that efforts to deploy innovative technologies and scale-up approved remedies was hampered by budget constraints.

Shortly thereafter, several events occurred that enabled more aggressive remediation at the Hanford Site. CH2M HILL Plateau Remediation Corporation (CHPRC) was awarded the contract that includes groundwater cleanup at the Hanford Site, target milestones to protect the Columbia River by 2012 and cleanup the contamination plumes by 2020, along with the passage of the American Recovery and Reinvestment Act (ARRA) of 2009 [14]. An RPO was initiated in October of 2008 following award of the contract to CHPRC.

The RPO efforts have focused on the expansion of the remedial systems to achieve the RAOs within specified timeframes. The primary objectives for the RPO designs are (a) to prevent the discharge of hexavalent chromium to the Columbia River at concentrations exceeding those considered protective of aquatic life in the river and riverbed sediments by the year 2012; and (b) aquifer restoration inland by attaining the Washington State Standard of 48 μg/L by the year 2020. The objectives related to achieving river protection by 2012 and target cleanup levels by 2020 will be met, at a minimum, by pumping groundwater from existing and proposed extraction wells located within and around the contaminated areas and removing hexavalent chromium from the groundwater by treatment at ex situ facilities.

Groundwater flow and contaminant transport modeling was performed to calculate pump and treat capacity needs and appropriate pumping rates for injection and extraction wells to achieve the RPO objectives. A groundwater flow model was developed that encompasses 100-K, 100-N, 100-D, and 100-H Areas to support design of pump-and-treat interim remedies and to evaluate the performance of the pump-and-treat systems.

The groundwater flow model was constructed using the U.S. Geological Survey three-dimensional modular groundwater flow model, MODFLOW, to simulate the operations of the pump-and-treat systems at the OUs. Model development was based on various sources of information including the Model Data Package [15] developed for that reason by CHPRC for each OU. The modeling is documented in a technical memorandum [16]. The model was calibrated using continuous water level data from monitoring wells in the 100-K, 100-D, and 100-H Areas from January 2006 through June 2009. Particle tracking was implemented to develop “capture efficiency” maps to depict likely system performance by estimating hydraulic containment extent under transient conditions. A contaminant transport model was then developed to simulate the migration of hexavalent chromium in the 100 Areas, using a dual-domain approach that describes advective transport in the mobile domain and mass-transfer between the immobile and mobile domains. The model timeframe was extended to facilitate comparative predictive simulations of various remedial alternatives for each OU.

During the initial stages of the RPO effort, an expanded pump-and-treat system at 100-HR-3 was developed that included 47 injection and extraction wells, focused primarily on meeting the 2012 river protection milestone. However, this initial stage modeling clearly showed additional system expansion was required to meet the 2020 aquifer cleanup milestone. The extraction/injection well configuration was expanded and additional modeling was conducted to optimize the well field and to develop a design that has a reasonable likelihood of meeting both the river protection and aquifer restoration goals based on our best available understanding of the hydrogeology of the system.

The resulting pump-and-treat system design consists of 70 “new” and 33 existing extraction and injection wells for a total capacity of 1,400 gal/min. Under this well configuration, most extraction wells are designed to operate at 15 to 20 gal/min with most injection wells operating at 40 to 60 gal/min. The contaminated water is being treated at two new plants, the DX plant in the 100-D Area with a capacity of 600 gal/min, and the HX plant in the 100-H Area with a capacity of 800 gal/min. These plants are designed to provide hydraulic gradient control for plume containment and expedited mass removal.

The expected remediation based on these modeling design studies is shown in Fig. 4 for 2012 and 2020. The remediated plume configurations suggest that the pump-and-treat system design at DX and HX will be able to achieve the target milestones.

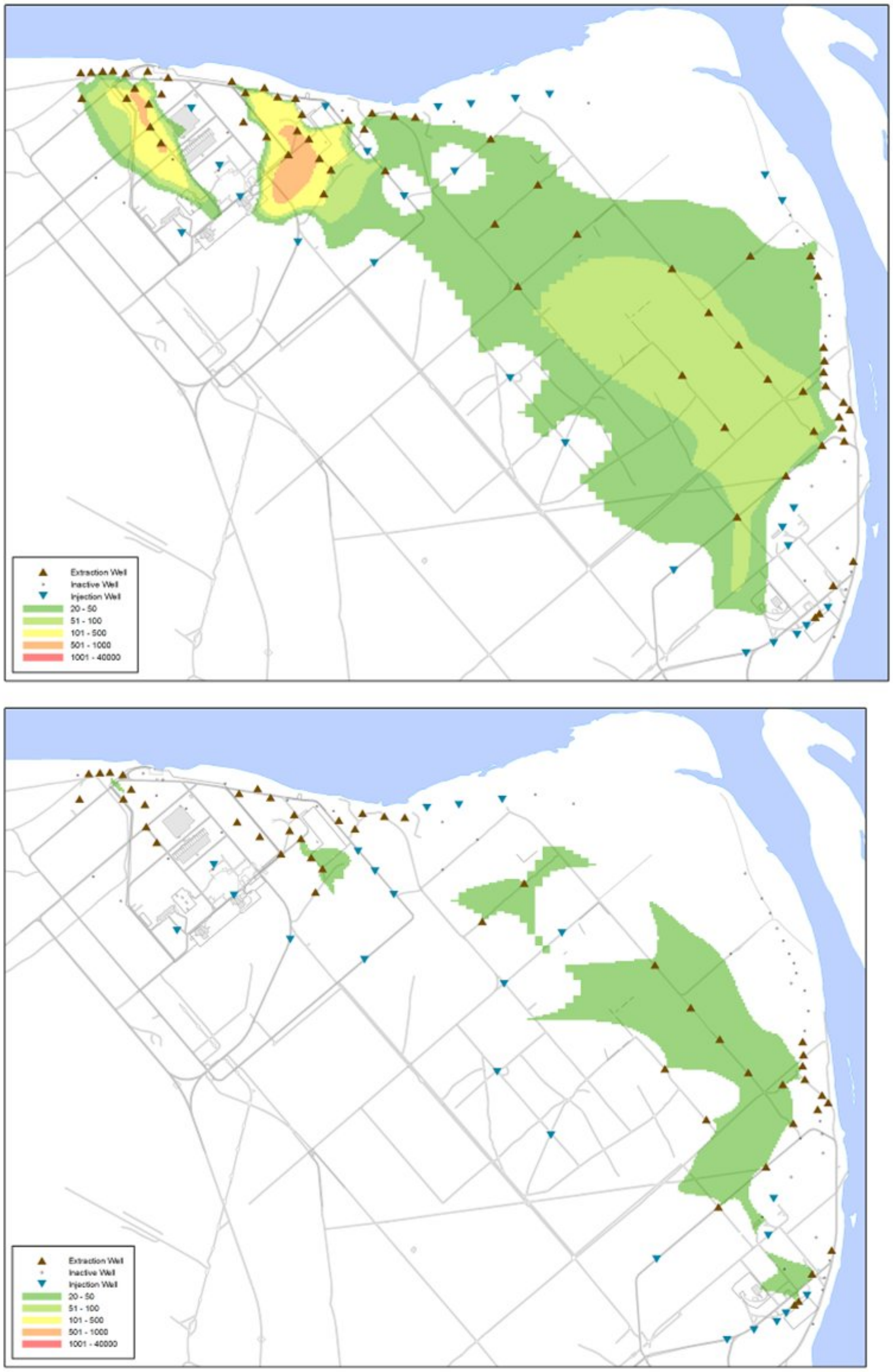

Fig. 4. Projected Remediation in Groundwater, 2012 (top) and 2020 at the 100-HR-3 OU

ION-EXCHANGE RESIN AND REGENERATION PROCESS OPTIMIZATION

The ion-exchange (IX) process is a key element to the HX plant's effectiveness in removing the hexavalent chromium from the influent groundwater. The initial design for the HX system was based on the 2,271 L/min (600-gpm) 100-KX IX system (hereafter referred to as KX) that began operating in the 100-K Area in 2008.

The KX system used a strong-base resin Dowex®821K16-20 (hereafter referred to as Dowex) to remove hexavalent chromium from influent groundwater. After the resin is spent, it is sent offsite for regeneration. Although the designs of the ion exchange components of the KX plant and the HX plants are virtually identical, additional options for the type of resin and the resin regeneration approach to be used for the HX plant was investigated.

Resin performance is an important source of uncertainty in determining operations and maintenance costs for the HX IX systems. Consequently, six candidate resins were used in pilot testing that began during March 2009 to evaluate their performance under site-specific conditions and to produce site-specific resin capacity data. Results from March through July 2009, as well as vendor information and site operational data, were used in this document to evaluate and compare the performance and cost effectiveness of candidate resins. Purolite® A500 resin was deemed the most cost effective resin tested when considering any of the resin regeneration options (offsite, onsite, and in vessel).

A weak-base resin, ResinTech® SIR-700, was the only single-use resin tested and, therefore, was the resin used where regeneration of the spent resin would not be employed.

The following four options were considered for the IX process for the HX plant:

1. Offsite regeneration: IX using Purolite® A500 resin, which is sluiced into totes for offsite regeneration. This process generates a small, solid waste stream consisting primarily of resin fines generated during backwashing that would be disposed of at the Hanford Site's Environmental Restoration Disposal Facility (ERDF).
2. Onsite regeneration: IX using Purolite® A500 resin, which is sluiced into totes for onsite regeneration at a central regeneration facility (CRF) which would need to be constructed.
3. In-vessel regeneration: IX using Purolite® A500 resin, which is treated sequentially in the IX vessels with sodium chloride, sodium dithionite, and dilute hydrochloric acid. This process generates wastewater containing significant quantities of chloride and sulfate and waste solids (principally resin fines and precipitates of trivalent chromium as chromium phosphate hexahydrate) . Treated regenerant solutions are metered into and co-mingled with the treated effluent groundwater stream for reinjection into the aquifer. The co-injection of treated regenerant solutions raises several potential regulatory issues. The waste solids would be disposed of at ERDF.

4. Single-use resin: This IX process uses ResinTech® SIR-700, a weak-base resin that is disposed of when it is exhausted. The SIR-700 resin has a much higher capacity to remove hexavalent chromium from acidic (pH less than 6.0) groundwater than an equivalent amount of the strong-base resin. As a

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result, extracted 100-H Area groundwater influent would require acidification before treatment and neutralization after treatment and before reinjection into the aquifer.

Three resin evaluation tests were conducted [17]. The relative performance of the resins was compared based on their breakthrough times and breakthrough curves. "Breakthrough" is defined as two consecutive effluent hexavalent chromium readings above 10 µ/L, signifying that hexavalent chromium has started to exit the column. Continued testing beyond this point defined the shape of the breakthrough curve, which provided information on the rate at which the contaminant approaches equilibrium in the column; for example, when inlet and outlet concentrations are equal. Changes in the slope of the breakthrough curves were used to estimate the approximate breakthrough for the small volumes of resin used. This is due to the sensitivity of these columns to fluctuations of process conditions resulting from short resin to water contact times.

The results of these tests revealed performance differences that were not predictable from vendor-supplied information. The first series of tests showed that the Dowex performed as expected, but Purolite® A500 performed two to four times better and ResinTech® SIR-700 performed greater than 10 times better than Dowex in terms of capacity and breakthrough time as discussed below.

- Purolite® A500 had the longest breakthrough time and highest capacity of the regenerable resins tested. The ion exchange vessels were initially designed with in-vessel regeneration capabilities in the event co-injection became viable (the most cost-effective option). Since this option is not currently technically viable, the preferred regeneration option is for ex-vessel regeneration (initially offsite, but could later be near-site or onsite to mitigate the DOE offsite regeneration risk.
- ResinTech® SIR-700 has a Cr (VI) retention capacity projected to be an order of magnitude greater than that of Purolite A500. The high capacity observed in these tests is consistent with operational experience obtained by the U.S. Environmental Protection Agency. Once exhausted, this resin would be disposed of at the onsite ERDF.

In addition, a life-cycle cost analysis was performed based on the physical testing results [18]. It was determined that using the single-use ResinTech® SIR-700 resin would yield a savings of more than $16 million over the proposed 11-year lifetime of the HX facility. Therefore, the HX facility design basis was modified to incorporate ResinTech® SIR-700 resin into the IX process design.

CONSTRUCTION CONSTRAINTS AND PROJECT MANAGEMENT

There were a considerable number of cultural, ecological, and fiscal constraints involved in building the HX project.

The HX Construction Project involved constructing a 17,500 square foot (1,626 square meters) treatment building, a 2,400 square foot (223 square meters) transfer building, along with installation of more than 60 miles (97 kilometers) of high-density polypropylene pipe, 23 miles (38 kilometers) of power cable, and 28 miles (46 kilometers) of control cable. The building locations are in an area of undeveloped land with no existing electrical or water utilities. The project required upgrading or providing site infrastructure, including road improvements to allow safe access for workers to the building sites, and installation of electrical utilities via 15 new power poles to the new buildings.

The northern portion of the Hanford Site has a number of culturally sensitive sites predominantly relating to historical Native American usage of the land. The 100-D and 100-H Areas contain a number of sites that were historically inhabited by the local tribes. These include fishing grounds, villages, burial sites, and spiritual sites. Many of these places are in close proximity to the Columbia River; consequently, placement of wells and extraction/injection piping very close to the river was difficult. Each activity had to be cleared through a time and labor intensive cultural review process that required review by the tribal stakeholders, the DOE cultural resource review office, and the Washington State Historical Preservation Office.

The area is also marked by a number of bald eagle roosting areas, particularly in the zone north of the 100-H Area. During the eagle roosting season from November to March each year, access to this area is severely limited to approximately 4 hours in the middle of the day. In addition, much of the 100-H Area is used as mating habitat by the native wildlife (other birds, deer, etc.) during the other half of the year. Therefore, rates of progress during this time were limited. An ecological review process was used to minimize disturbances to the native wildlife.

In addition, planned pipe routings and road crossings had to be closely coordinated with another Hanford contractor that was performing soil remediation activities in the same area. Weekly interface meetings between representatives of the HX project and the other contractor were necessary to discuss planned pipe routings, building locations, and future remediation dig sites. In some instances, the HX project had to re-plan building locations, re-reroute pipe, and install new road crossings to accommodate the other contractor’s work scope. However, close interface throughout the project duration was beneficial to both contractors and allowed work to continue for both parties with no delays.

Much of the pipe bonding occurred during the hot and dry summer months, which restricted working hours due to severe fire danger. Heat stress prevention was also a significant consideration during much of the construction period because the work required the construction trades to work in the sun in the open desert to lay the pipe, power, and signal cable.

A change in procurement strategy occurred mid-way through the construction period. The HX project team piloted the new procurement process, which required converting a large majority of the in-process orders for construction material to the new system. Some long lead items were delayed as a result of this conversion process, which required construction management to re-plan how the equipment was to be installed in order to minimize down time for the construction crews and keep progress moving forward. In spite of this, construction and testing of the facility was completed three months ahead of the baseline schedule.

Maintaining work force continuity was a key element in achieving construction of the HX plant in less than 12 months. It was fortuitous that the HX facility came on the heels of completing construction and testing of another similar facility, enabling the majority of the skilled craft workers to shift over as a team to build HX. This provided considerable cohesion to the team and ensured that CHPRC’s strong industrial safety culture could be maintained without hiring a significant number of new personal requiring upfront training and familiarization with the Hanford safety culture. The HX project team used its daily construction pre-job briefings to solicit worker feedback on how planned activities for the day could be performed in a safer manner, including mitigating potential hazards and identifying different methods/means for achieving the day's objectives. As a result, there were no recordable injuries or days away from work cases experienced during HX's construction.

Applying Lessons Learned also expedited the construction effort. Listed below are the major Lessons Learned that were applied to the HX Project:

- Permanent lighting fixtures (on temporary power) were used during construction and yielded multiple benefits – consistent, adequate lighting throughout the inside of the buildings; eliminated the need for change out of temporary overhead and task lighting to complete mechanical installation and plant startup; reduced tripping hazards associated with temporary lighting cords on the floor; and improved workforce morale.
- The building footprint was enlarged to allow for safer movement of equipment and materials during construction and plant operations.
- To mitigate tripping hazards, workers developed and implemented the use of scrap unistrut for construction of temporary power cord hangers. This accommodated safe storage of cords for construction tools and eliminated inherent tripping hazards from using floor-based extension cords.
- Building floors were epoxy coated early during construction to eliminate potential chemical vapor hazards and restrict access during final equipment installation.
- The area between the (construction tool and installation supply) connex boxes was covered, creating a cost-effective and efficient sheltered material storage area.
- Acid system design was changed from polyvinylidene fluoride to stainless steel to eliminate any chemical incompatibility hazards based on plant operator feedback.
- A canopy was installed above the permanent outside safety showers to keep them cooler during hot summer months.
- The caustic storage tank was procured with insulation already installed, eliminating the need for the equipment installation contractor to build scaffolding around the tank to install the insulation.
- Energization of the buildings was delayed until immediately before testing began to minimize lock and tag controls required during equipment installation.

CONCLUSION

In summary, Hanford's 100-HX Pump and Treat Project was a successful blend of science, technology, construction, and project management.

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